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Flow and aquifer parameter evaluation using groundwater age-dating geochemical tools and numerical modeling : Missoula aquifer western Montana

Karl A. Pracht
The University of Montana

Flow and Aquifer Parameter Evaluation Using Groundwater Age-dating, Geochemical Tools and Numerical Modeling; Missoula Aquifer, Western Montana

by

Karl A. Pracht

B.S. University of Minnesota-Duluth

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Flow and Aquifer Parameter Evaluation Using Groundwater Age-Dating, Geochemical Tools and Numerical Modeling; Missoula Aquifer, Western Montana
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The sole-source, unconfined, coarse-grained Missoula Aquifer underlies an urban, intermontane valley and supplies potable water for the City of Missoula. This study's goal was to refine estimates of groundwater flow rates and aquifer hydraulic properties. In addition, investigation of vertical gradients and Tertiary recharge to the aquifer were accomplished. Specific conductance, chlorofluorocarbons (CFCs) and tritium/helium-3 ($^3H/^3He$) sampling of the groundwater was completed. In addition, historic head and chemical data from two well nests were analyzed and with the aid of a well packer, head differences were measured to determine presence of vertical gradients and distinct flowpaths. Finally, a numerical profile model was constructed to refine hydraulic properties and interpret the geochemical results. The results from the CFC analyses show that most of the groundwater samples have concentrations in excess of air-water solubility rendering them unsuitable for age-dating. The losing river had a CFC-12 concentration of 345.8 pg/kg; the groundwater concentrations ranged from 345.8 to 9,392.3 pg/kg. The highest CFC concentrations were detected immediately downgradient of areas containing 512 to >5,120 septic systems/mile^2, suggesting that septic effluent and releases from improper disposal of CFCs may be potential sources of the excess CFCs. Tritium concentrations ranged from 8.67 to 13.13 tritium units (TU) indicating modern water. Preliminary age-dates range from –1.5 to 4.6 years. Noble gas results show elevated concentrations of terrigenic He, hindering $^3H/^3He$ age-dating analysis. The source of the excess of He is unclear and the terrigenic $^3He/^4He$ ratio needs to be resolved to refine $^3H/^3He$ ages. Preliminary analyses of weak, specific-conductance changes in the Clark Fork River and nearby wells suggest that observation of river recharge pulses may be useful as an environmental tracer. However, resolution of river recharge pulses at nearby wells was poor due to a low spring runoff event and paired river-groundwater data sets showing clear significant differences were not observed. Hydraulic conductivity estimates from modeling ranged from 4,900 to 36,000 ft/d. The calculated minimum velocity was 90 ft/d. Large discrepancies exist between model-simulated ages and $^3H/^3He$ age-dates at some sites. The upward leakage of Tertiary recharge into the overlying Missoula Aquifer may explain such discrepancies.

ACKNOWLEDGMENTS

Many people were involved in making this research and thesis successful. My committee chairman, Dr. Bill Woessner provided invaluable advice, knowledge, resources and support. Without him I would have floundered. Bill, I cannot thank you enough.

Mr. John LaFave of the Montana Bureau of Mines and Geology provided assistance with sampling and understanding the concepts of age-dating with CFCs and $^3H/^3He$. It was through his efforts that funding existed for sampling and analyses of the CFC and $^3H/^3He$ samples. He is also credited with obtaining the digital landscape map of Missoula that is used in so many of my figures.

Thanks to my remaining committee members Dr. Nancy Hinman and Dr. Garon Smith for their insightful reviews and criticisms.

Funding for this study was provided by the Montana University System Water Center through the Montana Bureau of Mines and Geology. Technical advice on age-dating with CFCs and $^3H/^3He$ was given by Dr. D. Kip Solomon of the University of Utah. Sampling assistance was provided by personnel at the Montana Bureau of Mines and Geology. Historic water level and inorganic ion data were provided by the Missoula Water Quality District.

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Chapter 1: Introduction

Statement of Problem

Nationwide there is a growing reliance upon groundwater resources for safe drinking water (Driscoll, 1986; Keeley, 1985; Postel, 1997; Speidel et al., 1988; Simon, 1998). The Missoula Aquifer, in western Montana, has been designated a Sole Source Aquifer for the City of Missoula by the Environmental Protection Agency (EPA) (MCCHD, 1987). It is highly prolific, unconfined and vulnerable to contamination, lacking a continuous overlying protective unit. Effective management and care of this groundwater resource requires the use of reliable values of the aquifer parameters and identification and quantification of the aquifer recharge sources (Driscoll, 1986; Woessner, 1988). Initial work by Miller (1991), forms the framework upon which this effort is based. He derived zones of hydraulic conductivity and estimates of rates of recharge by the Clark Fork River.

Goals and Objectives

The goal of this research was to assess if the environmental tracers $^{3}H/^{3}He$ and CFCs, and conservative inorganic tracers could be used to refine estimates of the magnitude and distribution of hydraulic conductivity and velocities currently used in groundwater management models for the Missoula Aquifer (Miller, 1991; Land and Water, 1991). The specific objectives of this research were to:

- Evaluate groundwater velocities, the hydraulic conductivity distribution and the presence of vertical gradients within the Missoula Aquifer, and
- Evaluate whether the underlying Tertiary sediments are an important recharge source to the Missoula Aquifer.

Thesis Organization

This thesis is broken into six additional chapters. Chapter 2 defines the study area and describes the topography, climate, geology and hydrogeology. Chapter 3 describes the concepts of age-dating groundwater using CFCs and $^{3}H/^{3}He$. Chapter 4 presents the data collection methods. Chapter 5 describes the results. Chapter 6 contains the discussion. Chapter 7 states the conclusions and recommendations for further study.

Chapter 2: Site Location and Conditions

Study Area

The 19 mile^2 study area is within the Missoula Valley of northwestern Montana (Figure 1). The northern and southern boundaries are the Clark Fork River and the Sapphire Mountains, respectively. The eastern and western boundaries are the Sapphire Mountains and the Bitterroot River, respectively. The valley floor slopes gently to the west and southwest at approximately 12.5 ft/mile (2.4 m/km) (Woessner, 1988).

The Missoula Valley has a semi-arid climate. Winter weather is dominated by Pacific maritime air, with occasional cold continental air. The Missoula Valley, on average, receives 13.4 inches of rain and 48 inches of snow. The highest amounts of precipitation occur in May and June; the lowest amounts occur in February and March. Occasional storms in July and August may contribute significant amounts of precipitation (Woessner, 1988).

The Missoula Valley lies in a northwest-southeast trending intermontane depression that is believed to have formed from horizontal extension after Laramide thrusting during the middle Eocene time, 52 million years ago (Fields and others, 1985). The mountains surrounding the Missoula Valley range from 6,000 to 8,000 feet above sea level and are composed mostly of Precambrian siltstones, sandstones and mudstones from the metasedimentary Belt Supergroup. On the southern boundary are low foothills composed mostly of fine-grained sediments shed from the surrounding mountains during the Tertiary Period, 43 to 5.3 million years ago. The grain sizes range from clay to coarse gravel (Woessner, 1988).

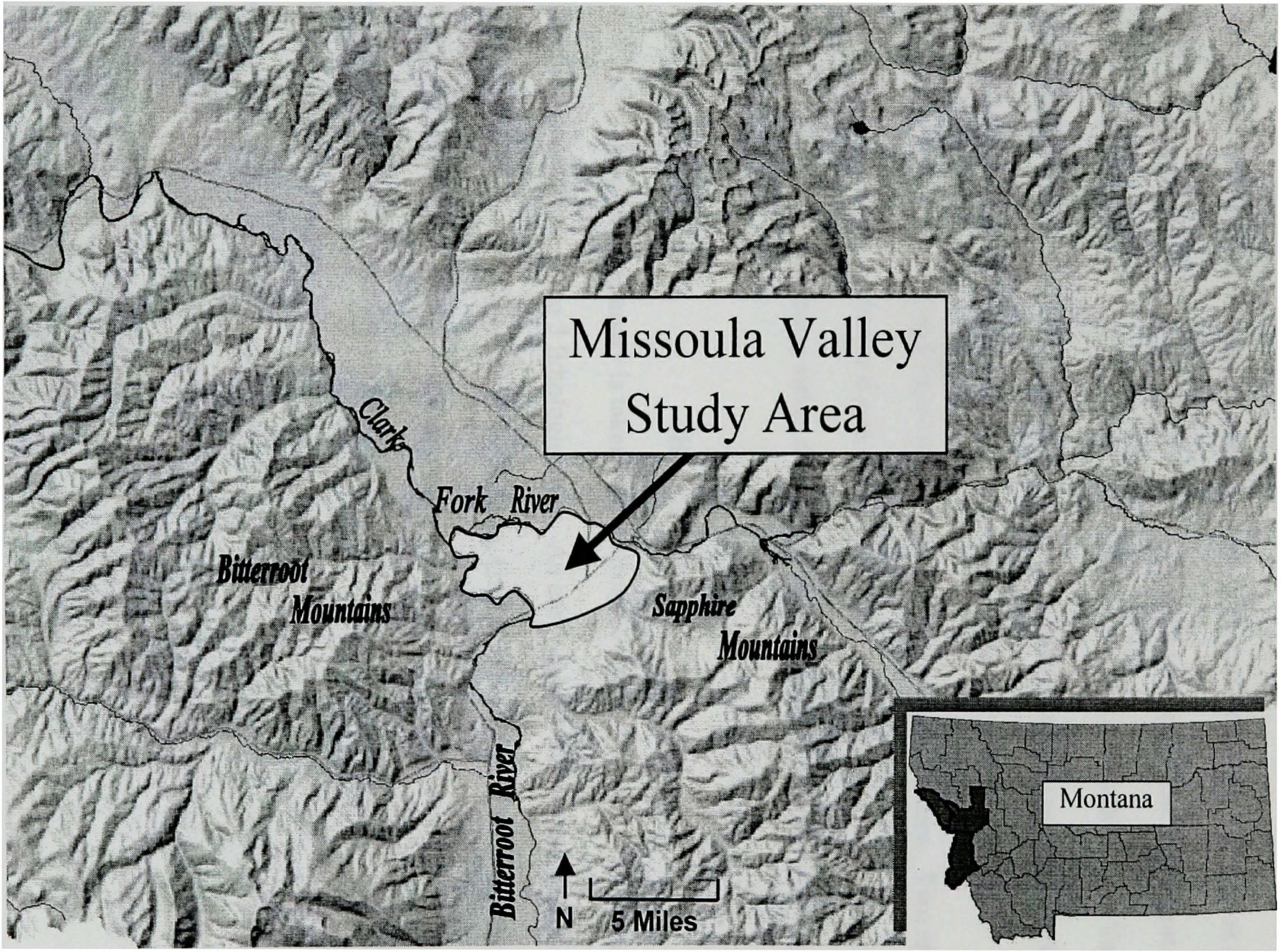


Figure 1: Missoula Valley Location. Modified from LaFave (2000).

Two rivers, the Clark Fork and Bitterroot, are located within the study area. The Clark Fork River flows east out of Hellgate Canyon for approximately 12.7 miles meeting the Bitterroot River at Kelly Island 4 miles west of Missoula. The Clark Fork River has an average flow of 8,130 ft^3/s (http://montana.usgs.gov/) and a gradient of 7.9 ft/mile in the study area. The Bitterroot River flows north out of the Bitterroot Valley and flows for 7.75 miles from the Buckhouse Bridge before joining the Clark Fork River at Kelly Island. The Bitterroot River has an average flow of 2,950 ft^3/s (http://montana.usgs.gov/) and a gradient of 0.65 ft/mile in the study area. Two streams drain into the study area. Pattee Creek from the southeast is ephemeral, disappearing into the valley floor before meeting either river. Rattlesnake Creek from the north flows into the Clark Fork River.

Hydrogeology

The following summary is taken mostly from Woessner (1988). The Missoula Aquifer can be divided into 3 lithologic units. An east – west trending cross-section and location are shown in Figures 2 and 3. The top, Unit 1, is bouldery with sand and gravel, 10-30 feet thick and located above the watertable. It is thought to have formed by aggrading glacial meltwater rivers during the late Pleistocene. The middle, Unit 2, is composed of silty, sandy clay with sand and gravel lenses; it is about 40 feet thick and discontinuous in places. It is thought to have formed from recurrent draining and filling of Glacial Lake Missoula in the Pleistocene. The bottom, Unit 3, is 50-100 feet thick and composed of coarse-grained sediments that further coarsen at the base of the aquifer. It is the most prolific layer of the aquifer. It is thought to have formed from channel lag, point bar and floodplain deposits of a large fluvial system during the Pleistocene or late

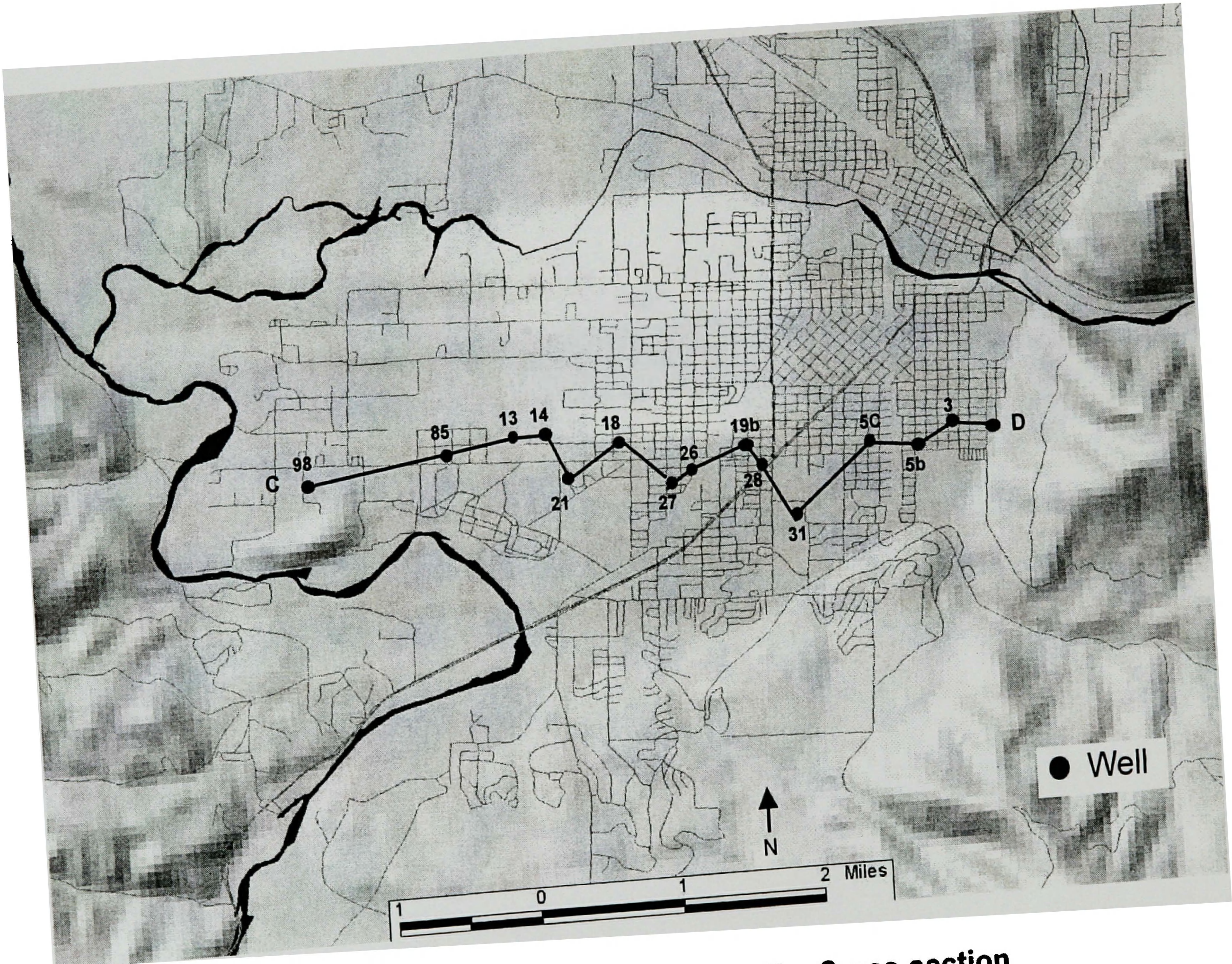


Figure 2: Location of Missoula Aquifer Cross-section

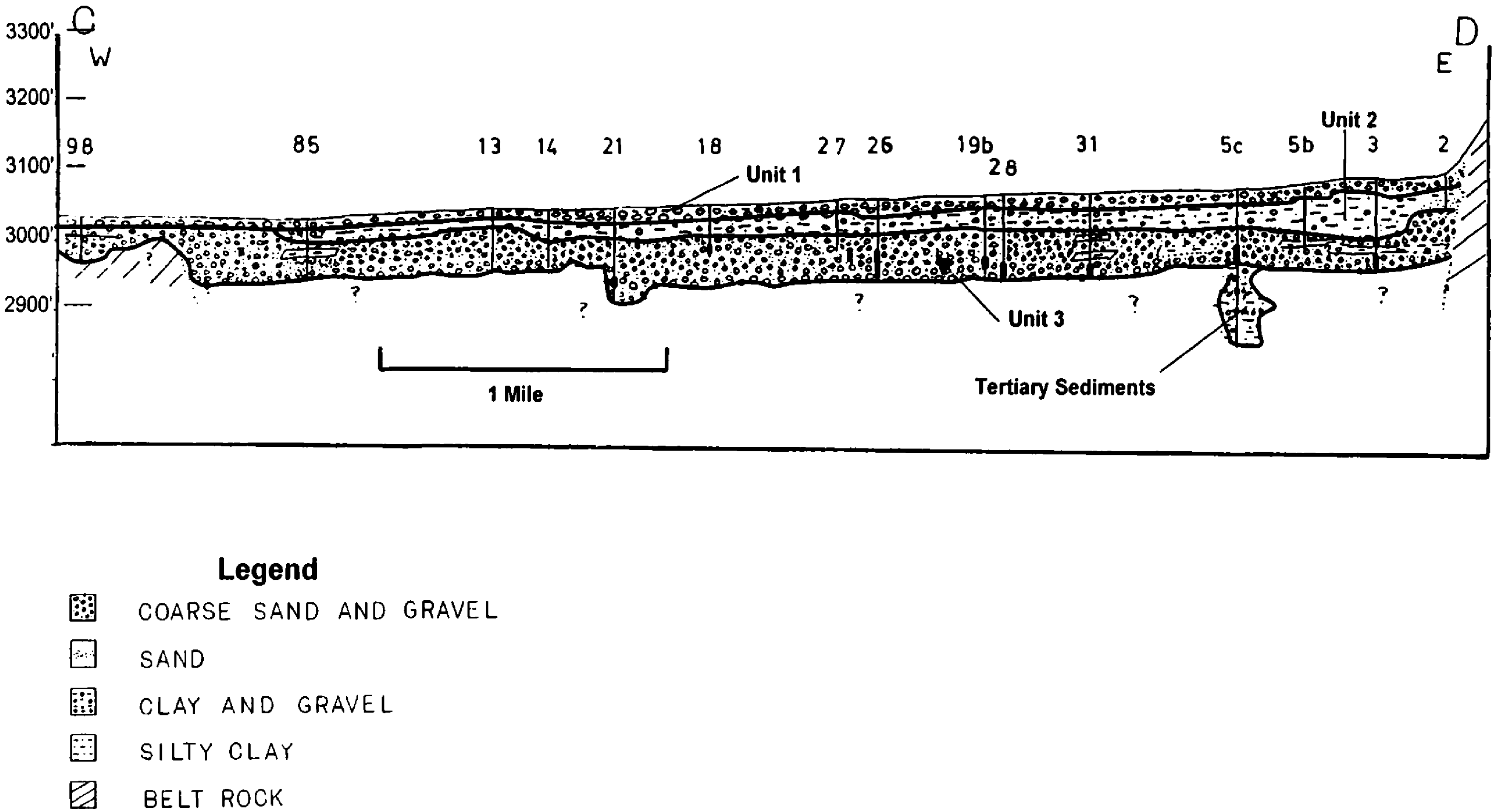


Figure 3: Geologic Cross-section of the Missoula Aquifer. Modified from Morgan (1986).

Tertiary. The Missoula Aquifer is underlain by 2,500-3,500 feet of unconsolidated to semi-consolidated clay, sand and gravel deposited during the arid Tertiary period. This unit has such low water yielding capacity that it is not used for water supply in the valley bottom.

Estimated hydraulic conductivity values within the aquifer range from 4,500 to 18,000 ft/d and the average velocity is 60 ft/d (Miller, 1991). Groundwater flows approximately southwest from the Clark Fork River towards the Bitterroot River (Figure 4). This part of the Missoula Aquifer receives 83% of its recharge from the Clark Fork River (Miller, 1991) and discharges to the Bitterroot River. The Tertiary layer is a possible, unproven recharge source (Woessner, 1988).

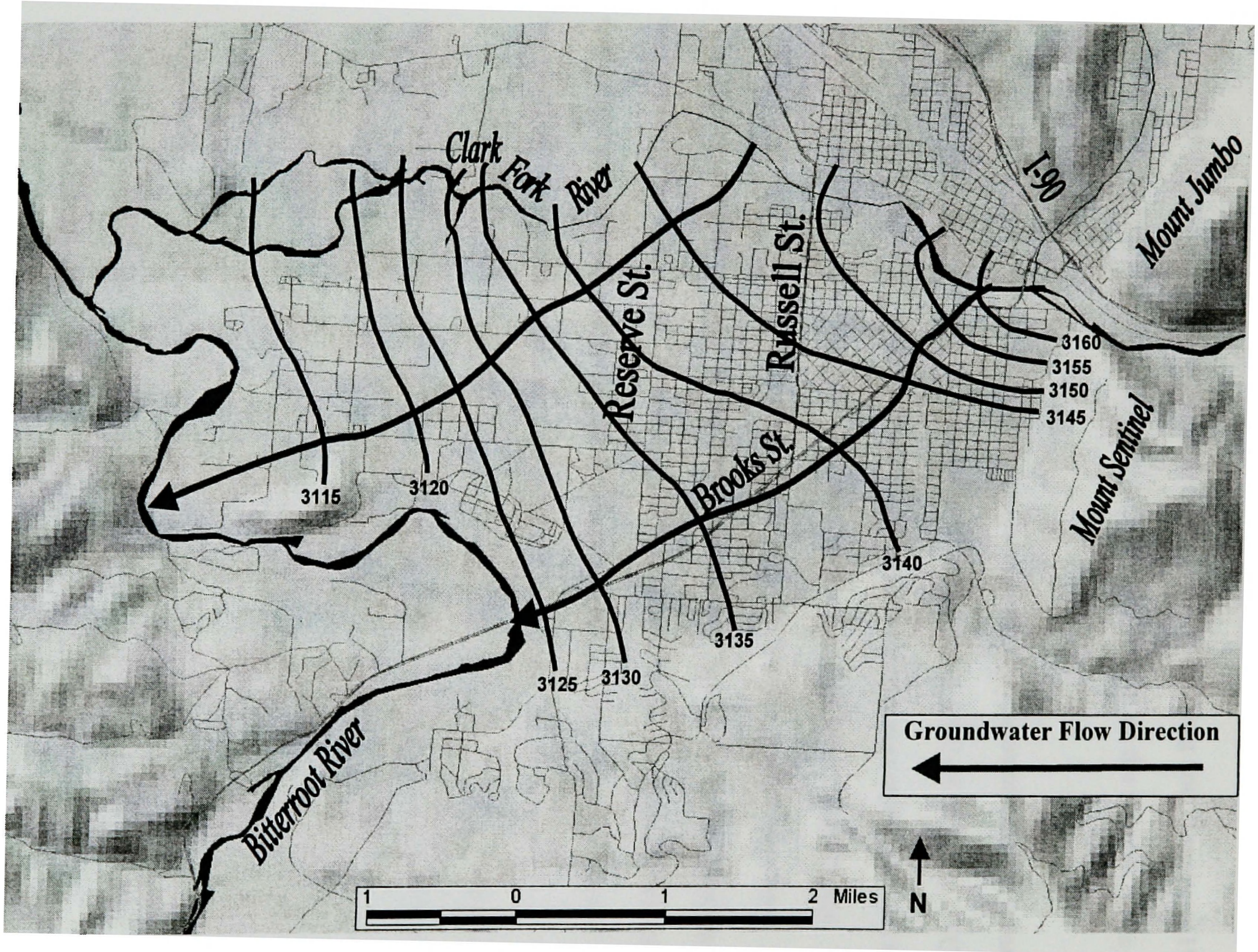


Figure 4: Study Area and Watertable Elevation On 6/21/99 - 6/28/99

Chapter 3: Environmental Tracers: CFCs and $^3H/^3He$

Age-dating With CFCs

The following discussion is taken mostly from Busenberg and Plummer, (1992) and Plummer and Busenberg, (2000). Figure 5 briefly discusses the sources, sinks and transport of CFCs.

Chlorofluorocarbons (CFCs) are synthetic organic compounds used in a variety of industrial and domestic products. The chlorofluorocarbons, CFC-11 ($CFCl_3$), CFC-12 (CF_2Cl_2) and CFC-113 ($C_2F_3Cl_3$), have long atmospheric lifetimes of 44, 180 and 85 years respectively. Atmospheric CFC levels have steadily increased since initial production in the 1930s. Atmospheric levels from 1975 to the present have been continuously monitored; prior levels have been reconstructed from manufacturing, release and photolysis rates. Atmospheric CFC concentrations have been found constant over large areas due to their long lifetimes. As a result, temporal and spatial CFC concentrations in precipitation are known with a high degree of precision.

Ages are calculated by converting groundwater concentrations to atmospheric partial pressures via known solubility relationships and then comparing the atmospheric partial pressures to historic atmospheric CFC levels. The CFC solubility relationships require a recharge temperature at the base of the unsaturated zone. In unsaturated zones >5 m thick, the mean annual air temperature can be used since seasonal temperature variations will be less than 7% of the annual temperature variation at land surface (Cook and Solomon, 1997). In thin, unsaturated zones the recharge temperature can be calculated from dissolved N_2 and noble gas concentrations (Busenberg and Plummer, 1992).

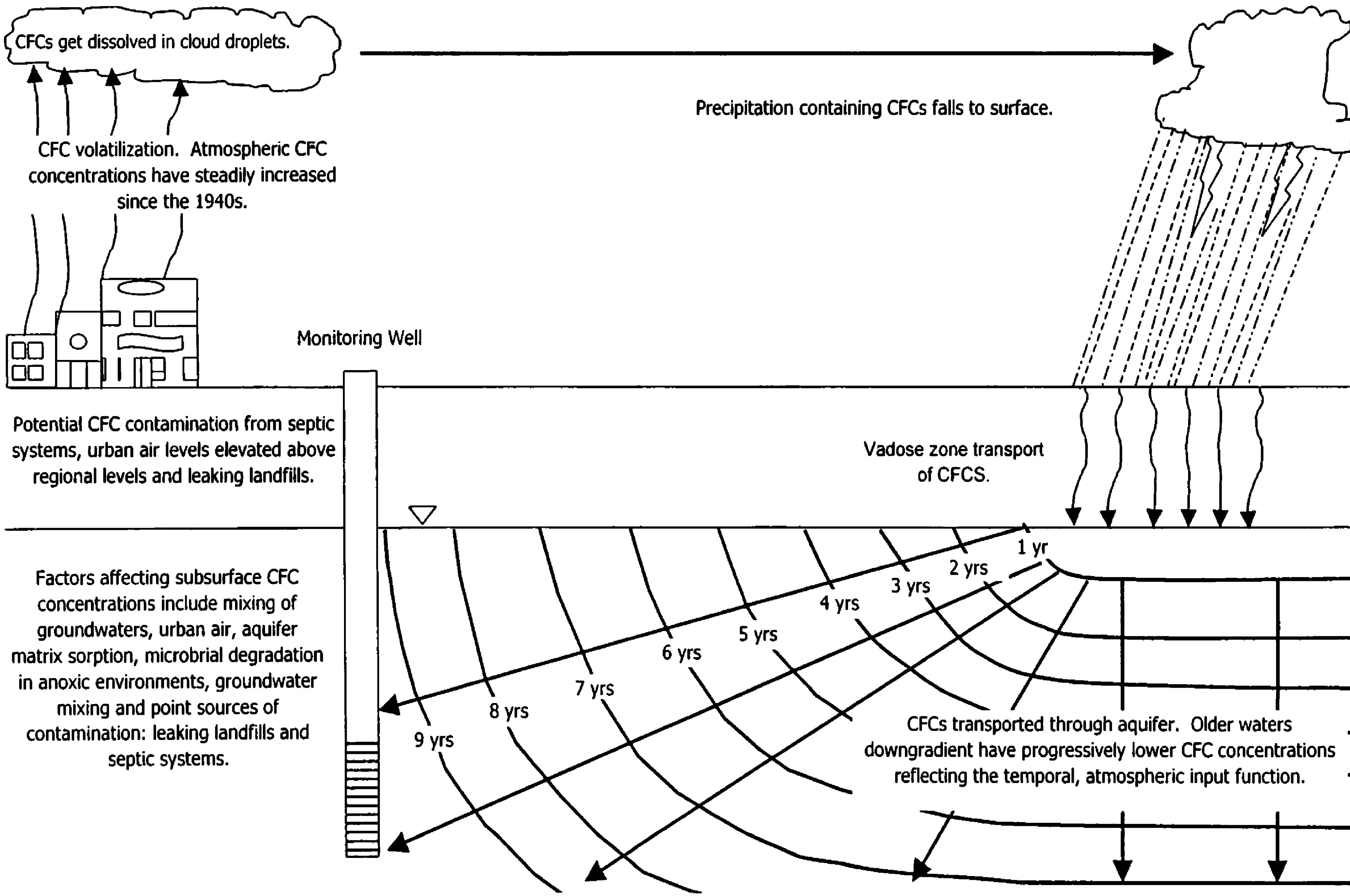


Figure 5: Sources, Sinks and Transport of CFCs

The calculated age is the time elapsed since the water has been isolated from the atmosphere and does not include travel time through the unsaturated zone. These ages should be considered minimum estimates due to the possibilities of groundwater contamination and contamination during the sampling process (Cook and Solomon, 1997).

Measurement of CFCs

Measurement of CFCs begins by stripping the gasses from the water sample and collecting them in a cold trap at –30° C. The gasses are then heated and injected into a gas chromatograph coupled to an electron capture detector. The current detection limit is 0.3 pg/kg (Plummer and Busenberg, 2000). Analytic error for CFC concentrations over 50 pg/kg is approximately ± 3%. Analytic error in CFC ages is ± 4 years in an advective flow system without diffusion or dispersion.

Factors Affecting CFC Concentrations and Ages

Accurate ages cannot be obtained from groundwaters contaminated with CFCs. Contaminated groundwaters are defined as having concentrations higher than can be accounted for by atmospheric partitioning. CFC contamination can come from a number of sources. The occurrence and mechanisms of CFC contamination have not been well studied.

CFC contamination in groundwater systems has been traced to sewage effluent (Busenberg and Plummer, 1992). Urban and industrial areas may have elevated atmospheric CFC levels that can be transferred to precipitation and thus groundwater (Plummer and Busenberg, 2000). In addition, a rapidly transient watertable may trap excess air that eventually dissolves into the sample; younger CFC ages would result from the increased CFC concentrations (Plummer and Busenberg, 2000). Sampling methods and well construction may introduce excess air leading to younger calculated ages in samples (Plummer and Busenberg, 2000).

CFC sorption to the aquifer matrix, especially in aquifers with high organic carbon contents, can result in overestimates of groundwater ages. Also, anaerobic conditions may be conducive to microbial degradation of CFCs leading to overestimates of groundwater ages. Microbial degradation of CFCs may increase with increasing organic carbon content (Cook and Solomon, 1997). Over- and/or underestimation of recharge temperature and elevation, mixing of groundwaters and hydrodynamic dispersion also distort CFC ages.

Tritium/Helium-3 Age-dating

The hydrogen isotope, tritium (^3H), is produced naturally in the atmosphere by cosmic ray bombardment of nitrogen. Tritium then reacts with oxygen to form the molecule $^3H^1HO$ (Clark and Fritz, 1997). Hydrogen isotopes do not appreciably affect the chemistry of the molecules in which they reside. Tritiated water does not react or sorb; it is considered a conservative tracer. Prior to the testing of thermonuclear weapons, natural levels in precipitation were estimated to be from 5 to 15 tritium units (TU) (1 TU = 1 ^3H atom per 10^{18} atoms of H or 1 molecule of $^3H^1HO$ in 10^{18} molecules of ^1H_2O). With the start of above ground nuclear weapons testing in 1951 large quantities of atmospheric tritium were generated; thus tritium levels in precipitation rose quickly and peaked in the early 1960s (Clark and Fritz, 1997) (Figure 6). Michel, (1989) calculated temporal tritium concentrations in precipitation throughout the United States.

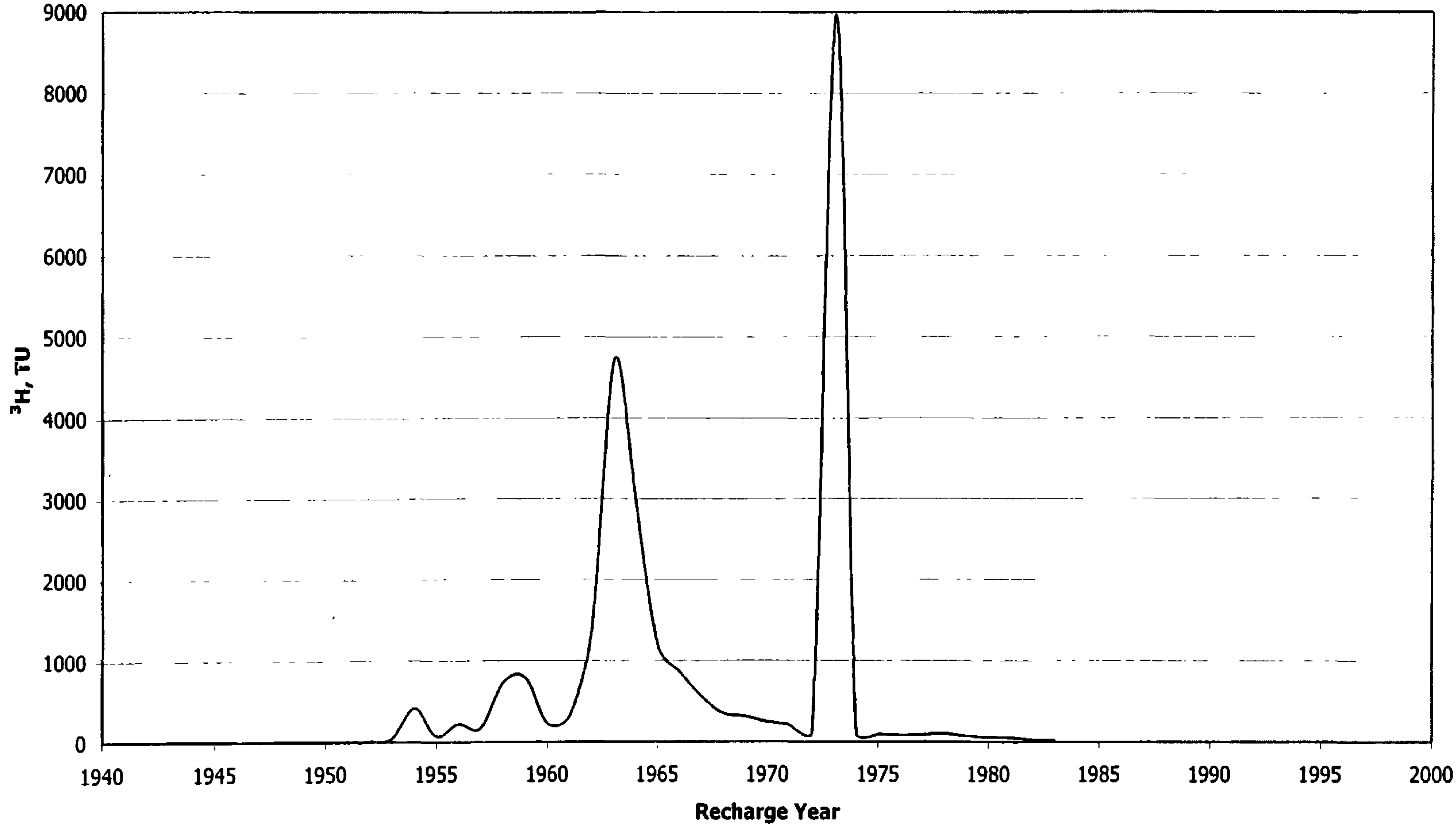


Figure 6: Estimated Tritium In Precipitation For Western Montana, 1940-1983. Based on data from Michel (1989).

The tritium peak in precipitation is reflected in some groundwaters and where detectable is an excellent marker of groundwater recharged in the early 1960s. However, the peak is becoming increasingly difficult to find due to decay, dispersion, diffusion and the required depth resolution.

Tolstikhin and Kamensky (1969) proposed the use of ^3H and its decay product helium-3 (^3He) as a method to age-date groundwater. This method, the $^3H/^3He$ method, requires measurement of concentrations of ^3H and its decay product ^3He. This method is independent of the historical ^3H input function (Clark and Fritz, 1997). It can only be used to date "modern" groundwaters, which are defined as groundwaters with detectable ^3H, generally less than about 50 years old. Figure 7 briefly discusses the sources and movement of ^3H and ^3He in the atmosphere and subsurface.

Measurement of ^3H and ^3He

Tritium concentrations can be measured by scintillation counting after electrolytic enrichment (Ostlund and Dorsey, 1977) or by the He ingrowth method (Clarke et al., 1976). Helium concentrations are measured by mass spectrometry (Rison and Craig, 1983). Errors in age-dates from analytical uncertainties are usually less than 10% (Cook and Solomon, 1997).

When ^3H enters the groundwater it begins to radioactively decay to ^3He. Helium-3 produced by tritium decay is termed tritiogenic ^3He. The tritiogenic ^3He concentration increases with groundwater age. The groundwater age is defined as the time since recharge has intercepted the watertable and uninterrupted tritiogenic ^3He accumulation begins.

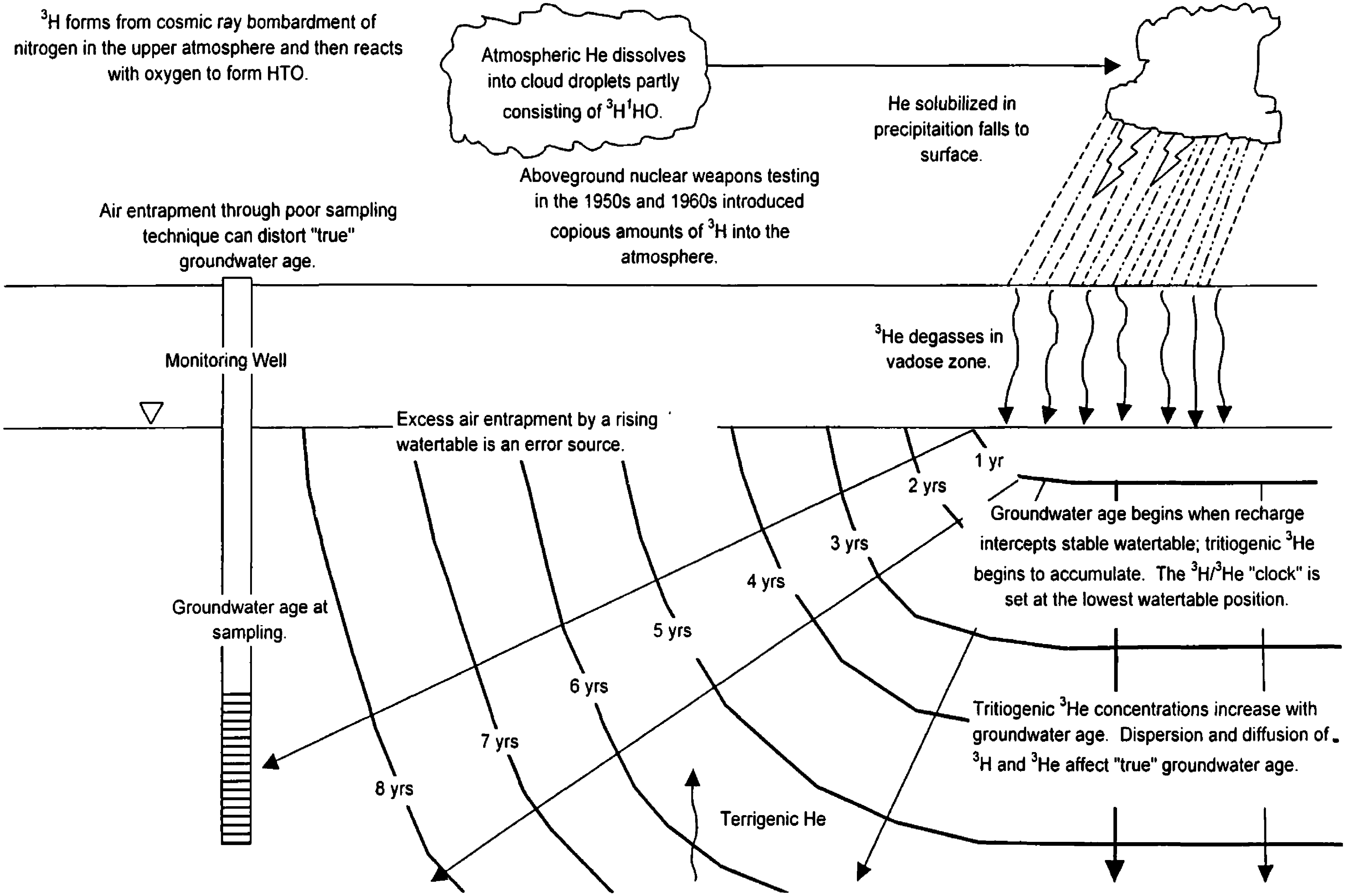


Figure 7: Sources and Movement of ^{3}H and ^{3}He in the Atmosphere and Subsurface.

The $^3H/^3He$ age can be found from the equation:

$$t = \lambda^{-1} * \ln [(^3He_{trit}/^3H)+1] \quad (1)$$

Where t is the groundwater age in years, λ is the ^3H decay constant and equal to 5.576 x 10^{-2} /yr, $^3He_{trit}$ is the tritiogenic ^3He concentration in TU (1 TU of ^3He equals 0.402 pcm^3/kg of ^3He) and ^3H is the measured tritium concentration in TU. Ages are calculated assuming plug flow. If no dispersion or mixing of groundwaters occurs, the $^3H/^3He$ age will accurately reflect the groundwater travel time since intercepting the watertable (Solomon et al., 1992).

Calculating the $^3He_{trit}$ Component

The following discussion is taken largely from Solomon et al., (1992). To calculate the $^3H/^3He$ age, the $^3He_{trit}$ component must be separated from the measured ^3He in the sample. Helium concentrations are composed of the partial isotopic concentrations of ^3He and ^4He; each isotope has various sources.

The total ^4He ($^4He_{tot}$) concentration in groundwater can be separated out as:

$$^4He_{tot} = {}^4He_{sol} + {}^4He_{excess} + {}^4He_{rad} \quad (2)$$

Where:

- $^4He_{sol}$ is the portion of ^4He from atmospheric partitioning. The solubility of atmospheric He is dependent on recharge temperature and recharge elevation. The recharge elevation is estimated and recharge temperature is calculated from N_2 and Ar concentrations. The atmospheric $^3He/^4He$ ratio is 1.38 x 10^{-6} (Clarke et al., 1976).
- $^4He_{excess}$ is the portion of ^4He from excess air entrapment and is calculated from the concentration of dissolved Ne in excess of air-water solubility atmospheric and the

atmospheric $^3He/^4He$ ratio. Heaton and Vogel, (1981) reported supersaturation of N_2, Ar and Ne in groundwaters and proposed excess air entrapment as the mechanism.

- Radiogenic ^4He ($^4He_{rad}$) is the portion of ^4He produced by alpha decay of minerals containing U and Th.

The total ^3He concentration ($^3He_{tot}$) in groundwater can be separated out as:

$$^3\mathbf{He}_{tot} = {}^3\mathbf{He}_{trit} + {}^3\mathbf{He}_{sol} + {}^3\mathbf{He}_{excess} + {}^3\mathbf{He}_{nuc} + {}^3\mathbf{He}_{man} \quad \mathbf{(3)}$$

Where:

- $^3He_{sol}$ is the portion of ^3He from atmospheric partitioning. The solubility of atmospheric He is dependent on recharge temperature and recharge elevation. The recharge elevation is estimated and recharge temperature is calculated from N_2 and Ar concentrations. The atmospheric $^3He/^4He$ ratio is 1.38×10^{-6} (Clarke et al., 1976).
- $^3He_{excess}$ is the portion of ^3He from excess air entrapment, which occurs due to a rapidly rising watertable. $^3He_{excess\ air}$ is calculated from the concentration of dissolved Ne in excess of air-water solubility and the atmospheric $^3He/^4He$ ratio.
- Nucleogenic ^3He ($^3He_{nuc}$) is generated by fission of ^6Li neutrons produced from decay of U-Th series elements.
- $^3He_{man}$ is of mantle origin.

The nucleogenic ^3He and radiogenic ^4He components are collectively termed "terrigneic He". Terrigenic He can be derived from the crust and/or mantle with $^3He/^4He$ ratios of $< 10^{-7}$ and $\sim 10^{-5}$, respectively. The terrigenic He component can usually be ignored due to its relatively small contribution to the total He concentration. The $^3He_{nuc}$ concentration is determined from the $^4He_{rad}$ concentration and the terrigenic He ratio. If large $^4He_{rad}$ concentrations are calculated, then $^3He_{nuc}$ must be calculated. This is not easy because an accurate measure of the $^{3}He/^{4}He$ ratio of crustal-produced He for the specific aquifer is required; this ratio has been determined for few aquifers (Solomon and Cook, 2000).

Ideally, if $^{4}He_{sol}$ is the only source of ^{4}He and no excess air entrapment occurs, then $^{3}He_{trit}$ can be calculated from:

$$\mathbf{^{3}He_{trit} = {^{4}He_{m}} (R_{t=0} - R_{sol}) \ (4)}$$

Where $^{4}He_{m}$ is the measured ^{4}He concentration, $R_{t=0}$ is the $^{3}He/^{4}He$ ratio of the groundwater at the time of sampling and R_{sol} is the $^{3}He/^{4}He$ ratio of water in isotopic equilibrium with the atmosphere.

During sample storage, tritiogenic ^{3}He generation is ongoing. This generation is corrected for by the following:

$$\mathbf{R_{t=0} = R_{m} - ({^{3}H_{t=0}}(1-e^{-\lambda\Delta t})/{^{4}He_{m}}) \ (5)}$$

Where R_{m} is the measured $^{3}He/^{4}He$ ratio, $^{3}H_{t=0}$ is the tritium concentration at time of sampling and Δt is the time elapsed since sampling.

If excess air entrapment is suspected, $^{3}He_{trit}$ is calculated from:

$$\mathbf{^{3}He_{trit} = ({^{4}He_{tot}} * R_{t=0}) + R_{sol} [\alpha' ({^{4}He_{sol}} - {^{4}He_{tot}}) - {^{4}He_{sol}}] \ (6)}$$

Here α' is the air-water fractionation factor. Derivation of α' can be found in Solomon et al., (1992). If air bubble introduction from sampling is suspected, deriving the $^{3}He_{trit}$ component is complex and specific to the sampling method.

Error Sources

Possible error sources of the $^{3}H/^{3}He$ method include groundwater dispersion and mixing, excess air entrapment by a transient watertable and air bubbles introduced during sampling. Dispersion and mixing of distinct groundwaters will affect the calculated groundwater age.

A rapid watertable rise can trap soil air resulting in excess air entrapment (Heaton and Vogel, 1981). A rapidly descending watertable can cause ^{3}He degassing, resetting the $^{3}H/^{3}He$ "clock". Helium-3 accumulation does not begin until the watertable reaches its lowest position. Air bubbles can be introduced and entrapped during sampling, eventually the bubbles dissolve increasing the He concentration.

Chapter 4: Data Collection Methods

Sampling Locations

Sampling locations were selected to form transects along flowpaths between the Clark Fork and Bitterroot Rivers (Figure 8). Shallow/deep nested well pairs were targeted for sampling to allow comparison of flow and chemical characteristics with vertical position within the aquifer. The presence of well logs, total depth, well accessibility and owners consent influenced well choice. Most are monitoring wells, part of a monitoring network regularly used and maintained by the Missoula County Water Quality District. All well locations and well logs are in Appendix A. Wells were sampled for environmental tracers by the Montana Bureau of Mines and Geology (MBMG) with assistance from the author during spring runoff and baseflow conditions in 1999.

Environmental Tracer Sampling

To obtain age-dates, CFCs and dissolved gasses were sampled with a copper bailer apparatus during spring runoff; later, dissolved gasses were sampled with diffusion samplers during baseflow conditions (Figure 9). Tritium samples were collected in glass bottles during spring runoff and baseflow conditions. Full details of the sampling methodology are found in Appendix C. Analyses were performed by the Isotope Geochemistry Laboratory at the University of Utah.

Tertiary Recharge Investigation

Recharge between the Missoula Aquifer and the underlying Tertiary sediments was assessed by taking in situ temperature and specific conductance measurements and measuring head differences between the two units. Also historical water levels and water

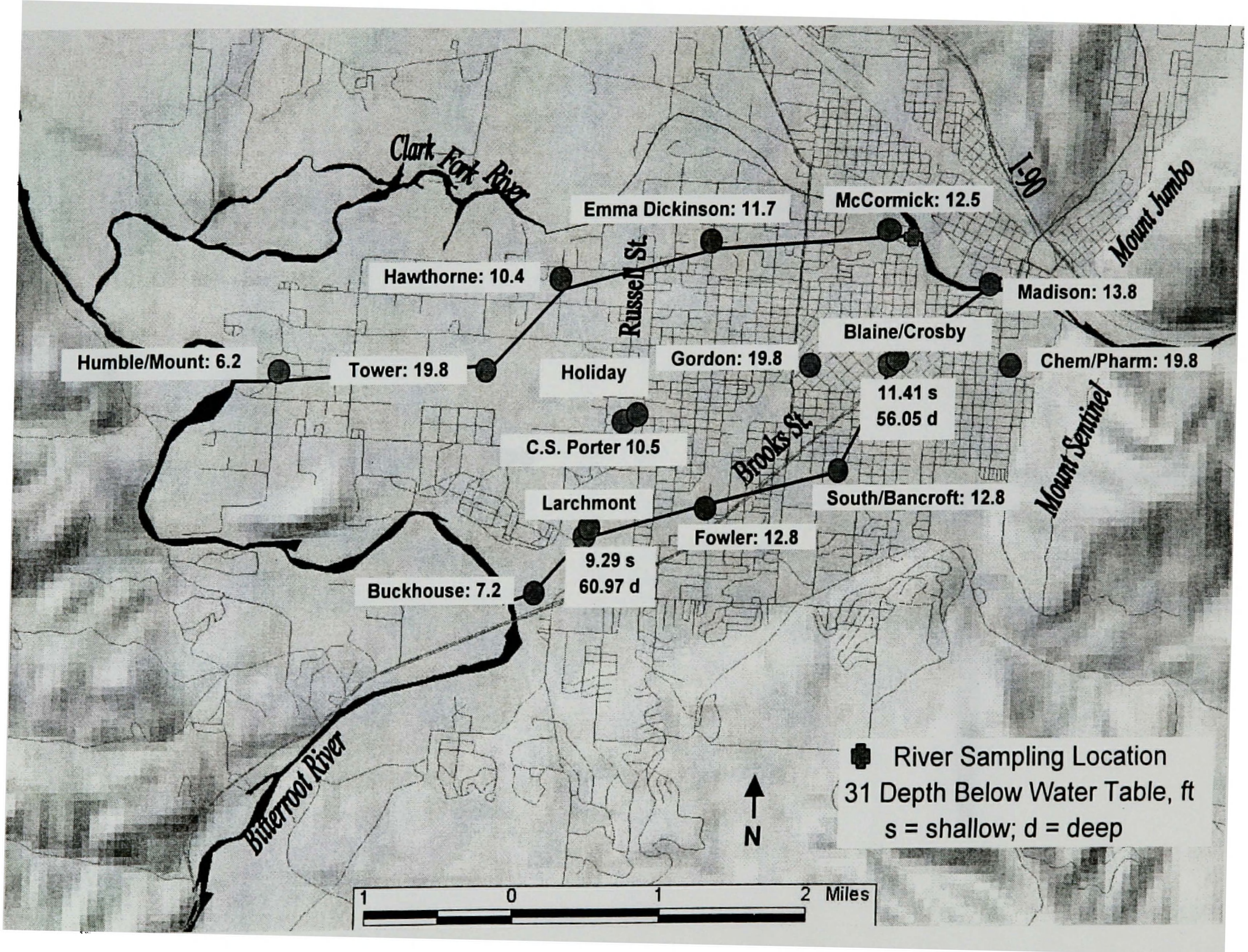


Figure 8: Sampling Locations. Modified from LaFave, 2000.

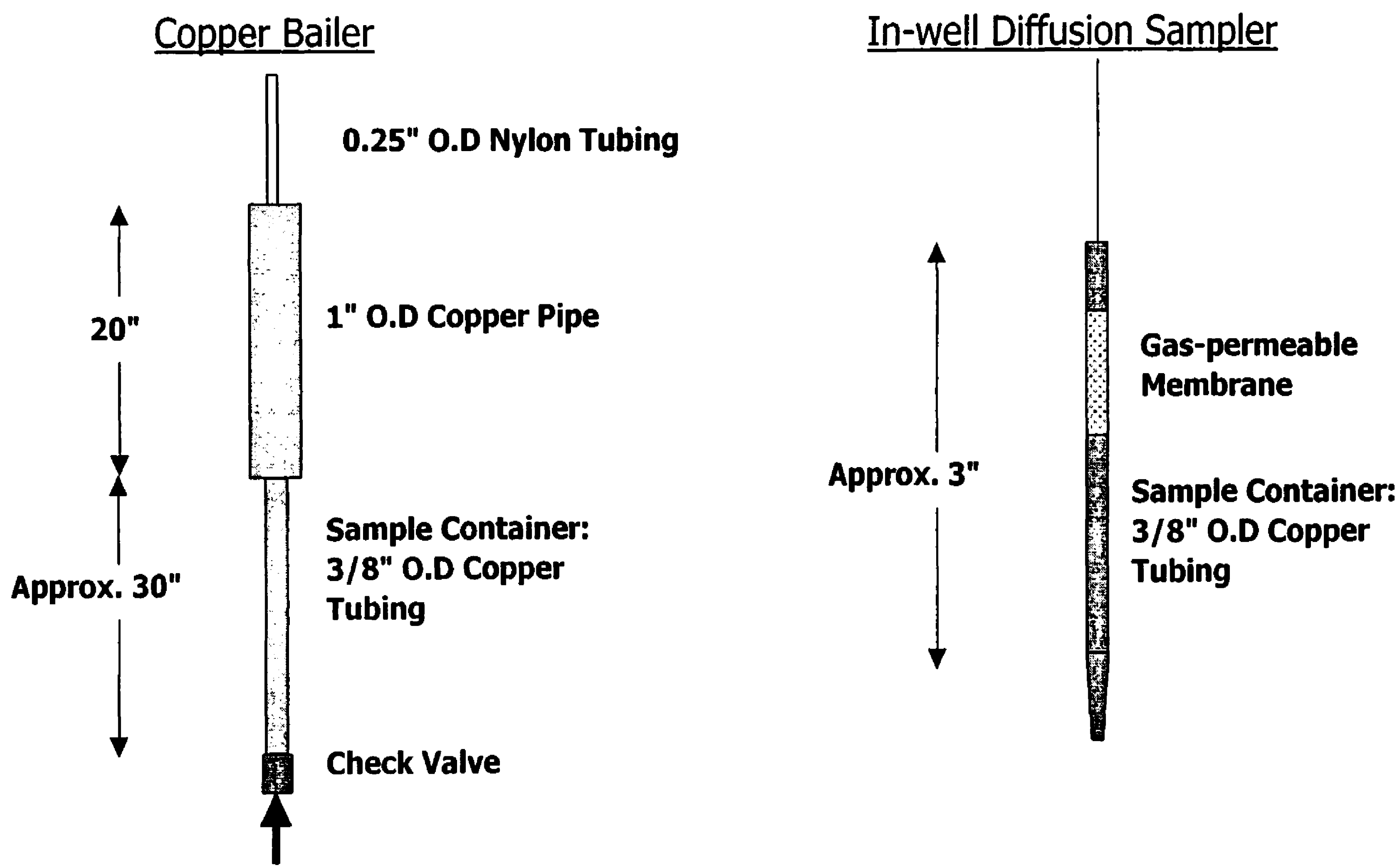


Figure 9: Copper Bailer and In-well Diffusion Sampler Schematics. Modified from LaFave (2000).

quality data in the Blaine/Crosby and Larchmont well nests were evaluated. The Blaine/Crosby and Larchmont well nests are the pairs of shallow and deep wells at the Blaine/Crosby and Larchmont sites (Figure 8).

The measurements were made in a well that had two distinct perforated intervals: one in the Missoula Aquifer and the second in what was presumed to be the Tertiary sediments (denoted as Chem/Pharm in Figure 8). A well packer was inserted between the two perforated intervals, thus permitting measurement of head in each unit. The injection well is part of a geothermal cooling system on the University of Montana campus. Appendix D contains full details of construction and use of the well packing device.

Historic water levels and water quality data from quarterly sampling by the Missoula City-County Health Department were obtained and plotted for the Blaine/Crosby and Larchmont well nests (both perforated in the Missoula Aquifer) to determine presence of vertical gradients in the Missoula Aquifer.

River Recharge Pulse Tracer Test

In an attempt to assess flow velocities near the Clark Fork River, water samples were collected from the Clark Fork River at a walking bridge spanning an irrigation ditch on the north border of the University of Montana campus and at supply wells for the Music and Lodge buildings on the University of Montana campus. The supply wells were continuously pumping during the day. Samples were analyzed for specific conductance and the anions F^-, Cl^-, NO_3^- and SO_4^{2-} by standard methods at the Murdock Environmental Biogeochemistry Laboratory, University of Montana. Appendix E contains full details of the sampling methodology, analysis and QA/QC.

Numerical Modeling

A numerical profile model orientated along a groundwater flow tube between the Clark Fork and Bitterroot Rivers, was constructed to refine hydraulic properties and interpret the geochemical results (Figures 10 and 11). MODFLOW (McDonald and Harbaugh, 1988) as incorporated in Visual MODFLOW 2.8.2.22© (Waterloo Hydrologic, Inc, 1999) was used to simulate groundwater flow. Next, the solute transport model MT3D (Zheng, 1990) as incorporated in Visual MODFLOW 2.8.2.22™ was used to model $^{3}H/^{3}He$ ages by simulating ^{3}H transport and decay through the model for a 2-year period. The ages were modeled using a longitudinal dispersivity value (α_L) equal to 10 ft. King, (1996) reported a maximum α_L value of 10 ft at a distance of 200 ft for the Missoula Aquifer.

Then, groundwater age profiles of the model-simulated ages at the Bitterroot River and Blaine/Crosby, South/Bancroft, Blaine/Crosby and Madison wells were constructed. A constant tritium source concentration of 10 TU was used for the Clark Fork River recharge.

Appendix G contains details of the model's construction, grid, aquifer geometry and boundary conditions, initial head setup, calibration, capabilities and limitations and sensitivity analysis. The Basic Package file and Block Centered Flow file are included in a disk in the back.

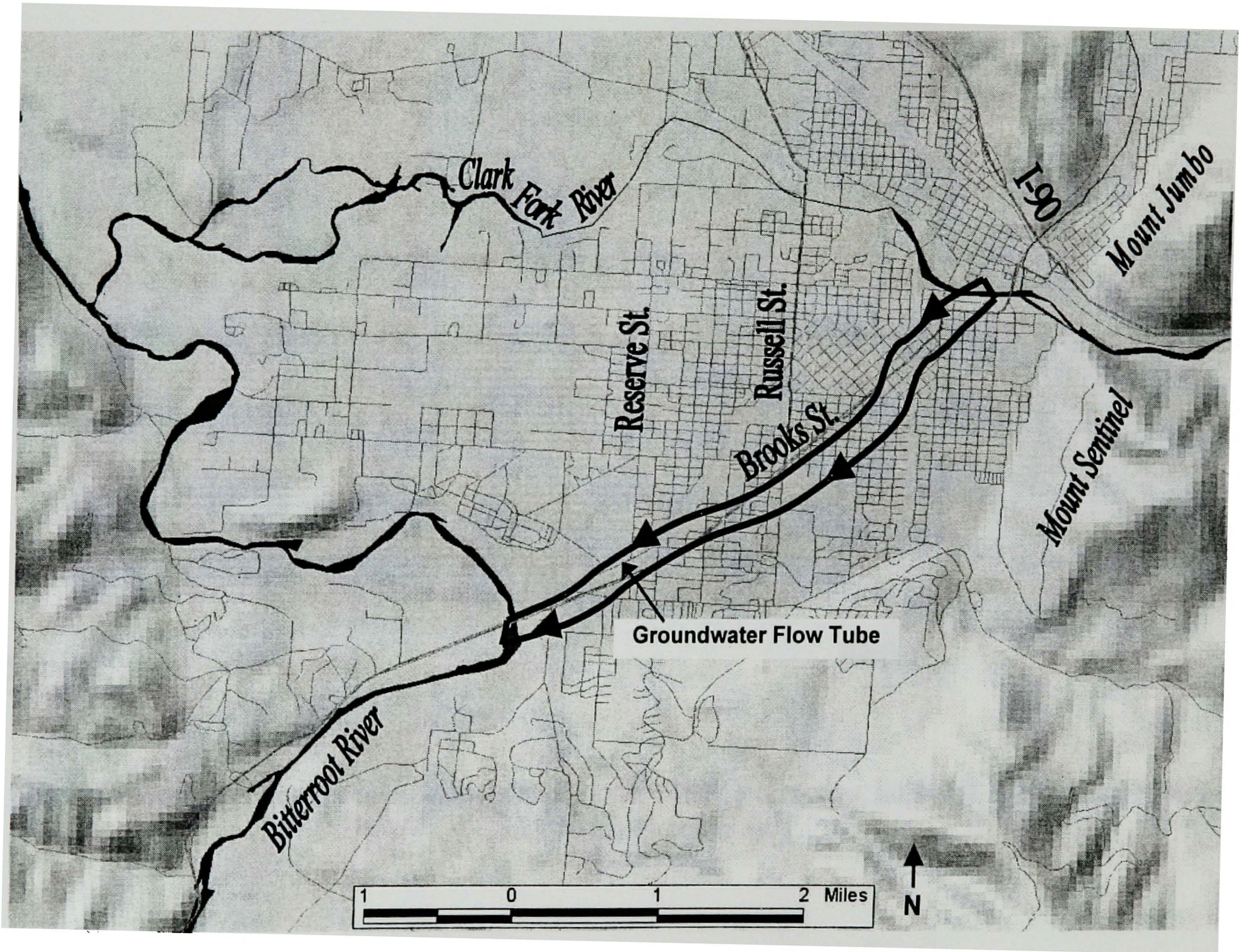
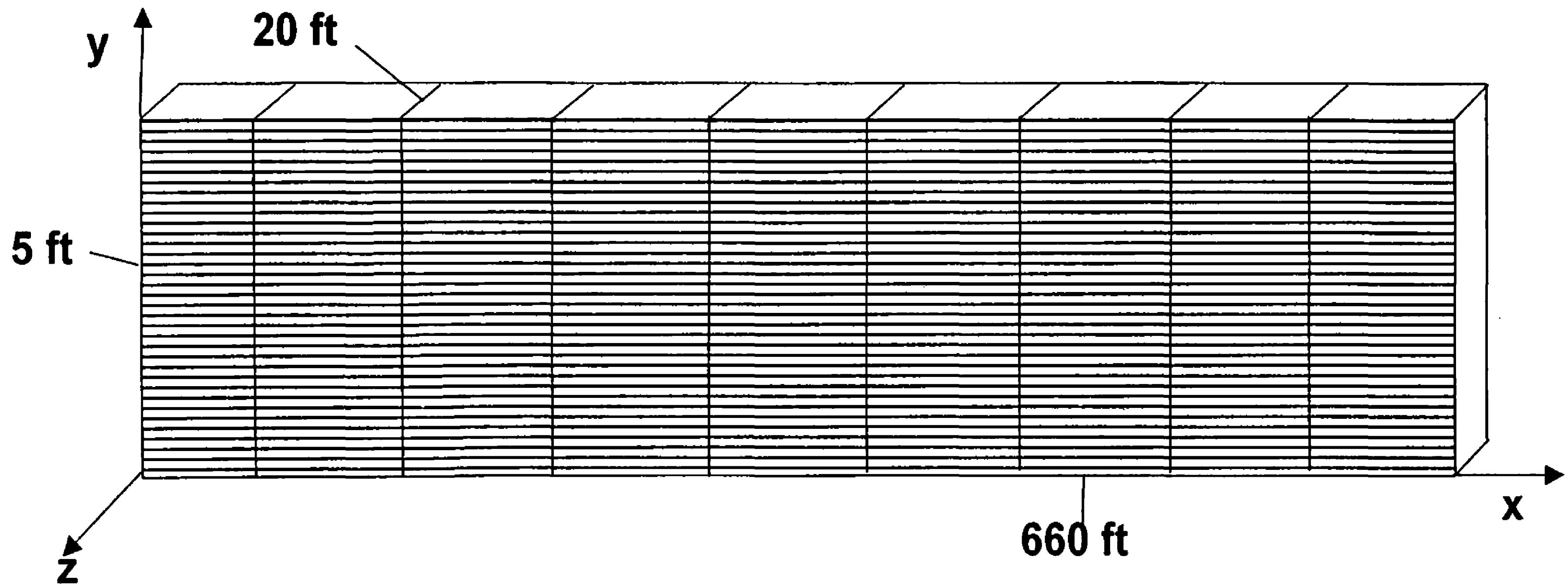


Figure 10: Profile Model Location



Full grid not shown; grid not to scale; Model dimensions: 175 ft. y-direction, 20,944 ft. x-direction, 20 ft. z-directio
rows, 41 columns.

Figure 11: Model Grid and Cell Dimensions

Chapter 5: Results

This chapter reports the results of this study. First, CFC concentrations and ages, $^{3}H/^{3}He$ ages and ^{3}H concentrations are listed and mapped. Next, results of the investigation of recharge by the Tertiary sediments and the River Recharge Pulse Tracer Test are reported. Finally, numerical modeling results are reported.

CFC Ages

Concentrations of CFC-12 obtained during the 1999 spring runoff are listed in Table 1 and mapped in Figure 12. Appendix C lists results of CFC-11 and –12 analyses.

Table 1: CFC Data

Location	CFC-12, pg/kg	Recharge Year	Ratio CFC-11/-12
Clark Fork River	408.68	1999	1.5
McCormick	345.80	1989	1.5
Emma Dickinson	559.81	Contaminated	1.4
Hawthorne	666.21	Contaminated	1.8
Tower	2,296.08	Contaminated	0.7
C.S. Porter	9,074.30	Contaminated	0.1
Humble/Mount	6,213.56	Contaminated	0.7
Madison	399.00	1999	2.0
Blaine/Crosby-s	906.83	Contaminated	0.8
Blaine/Crosby-d	960.03	Contaminated	0.7
South/Bancroft	679.51	Contaminated	1.2
Larchmont-s	9,392.29	Contaminated	0.1
Larchmont-d	1,926.10	Contaminated	0.6

s = shallow, d = deep

Atmospheric CFC-11 levels peaked in 1993 and have declined since. Hence, ages were not calculated using CFC-11 concentrations. The recharge year for each site was calculated assuming a recharge temperature and elevation of 5°C (41°F) and 1,500 meters (4,921.5 feet), respectively.

At all but three sites, the samples had CFC-12 concentrations in excess of air-water solubility. Due to the excess CFC concentrations, the MBMG discontinued CFC sampling. The sites where CFC concentrations were not found to be in excess of

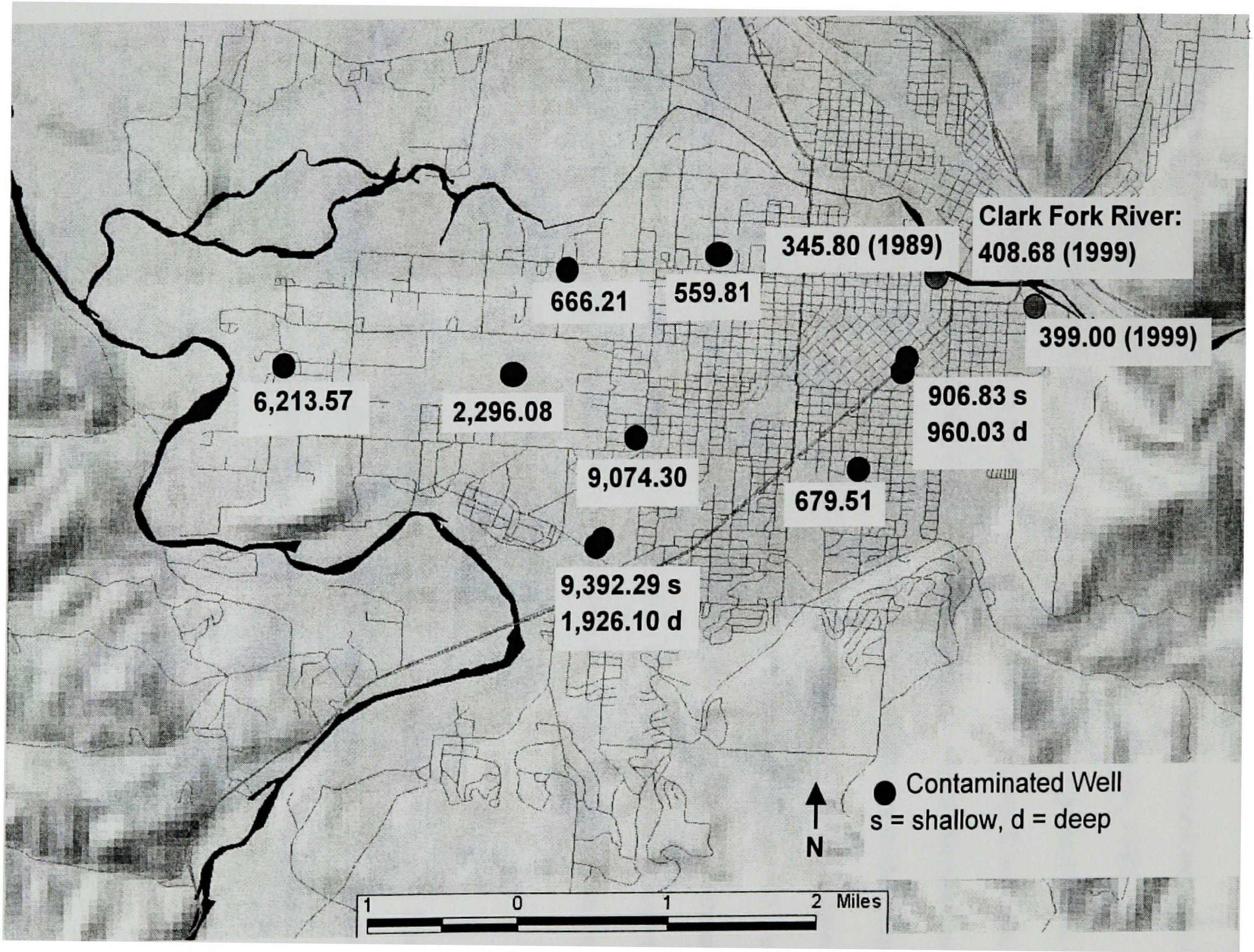


Figure 12: CFC-12 Concentrations (pg/kg) and Recharge Year. Modified from LaFave (2000).

air-water solubility were the Clark Fork River, McCormick Park and Madison St. sites. The remaining sites had CFC-12 concentrations ranging from 559.81 to 9,392.29 pg/kg. These sites are labeled as "contaminated". Note: the EPA has not issued any Maximum Contaminant Levels (MCLs) for CFC-11 and -12 (Hinkle and Snyder, 1997).

Overall, concentrations differ by one order of magnitude. A general trend of increasing concentrations with increasing distance from the Clark Fork River is seen. At the Blaine/Crosby well nest, concentrations were 53.20 pg/kg lower in the shallow well. At the Larchmont well nest, concentrations were 7,466.19 pg/kg lower in the deep well.

The CFC-11/-12 ratio ranges from 0.1 to 2.0. At 7 of the 13 sites the ratio is <1.0, indicating relatively higher CFC-11 concentrations. The sites with ratios <1.0 are closer to the Clark Fork River with the exception of the South/Bancroft site. The remaining 6 sites had ratios >1.0, indicating relatively higher CFC-12 concentrations. In a non-contaminated system, a decrease in CFC-11/-12 ratios downgradient would be expected as CFC-11 adsorbs more readily to the soil matrix than CFC-12.

$^3H/^3He$ Ages

Tritium/helium-3 ages are mapped in Figure 13 and listed in Table 2. The age at the Buckhouse Bridge represents the average of field duplicates. The ^3H, dissolved gas data and $^3H/^3He$ ages from spring runoff and baseflow sampling are displayed in Appendix C.

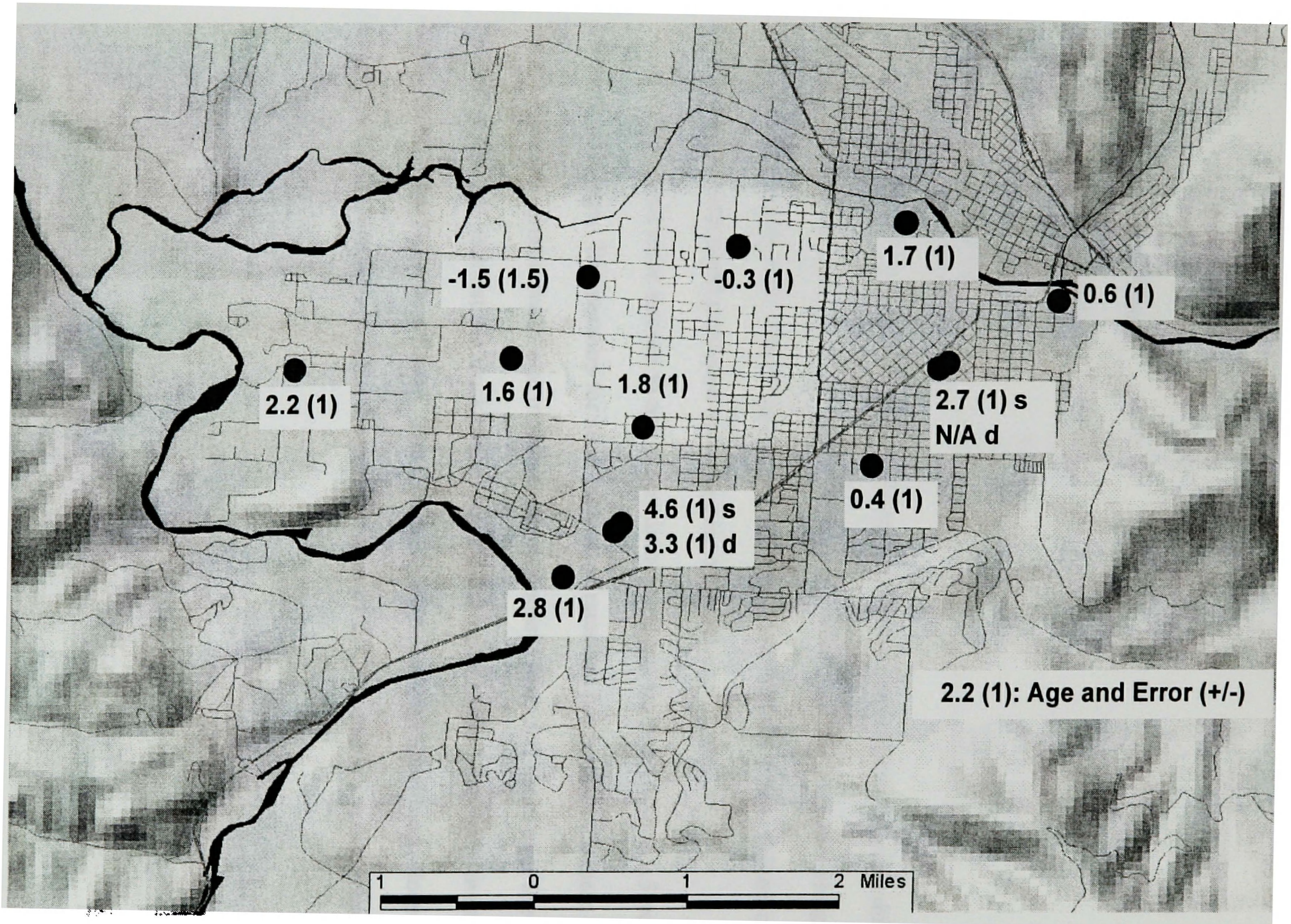


Figure 13: $^{3}H/^{3}He$ Ages (years). Modified from LaFave (2000).

Table 2: $^3H/^3He$ Ages

Site	Age, yrs	Error (±)	Age Range, yrs
Clark Fork River	0	0	N/A
McCormick	1.7	1	0.7 – 2.7
Emma Dickinson	-0.3	1	-1.3 – 0.7
Hawthorne	-1.5	1.5	-3 – 0
Tower	1.6	1	0.6 – 2.6
Humble/Mount	2.2	1	1.2 – 3.2
Madison	0.6	1	-0.4 – 1.6
Blaine/Crosby-s	2.7	1	1.7 – 3.7
South/Bancroft	0.4	1	-0.6 – 1.4
Larchmont-s	4.6	1	3.6 – 5.6
Larchmont-d	3.3	1	2.3 – 4.3
Buckhouse	2.9	1	1.9 – 3.9

s = shallow, d = deep

Similar $^3He/^4He$ ratios were seen using the copper bailer apparatus and diffusion samplers. The R/R_a values ($R/R_a = (^3He/^4He)_{smpl}/(^3He/^4He)_{atm}$) for each sampling method were plotted against each other (Figure 14). Eighty percent of the points fall on or near the line, indicating good precision with the two methods.

Computed error related to age determination ranges from ± 1.0 to ± 1.5 years of the computed age. The reasons for such high error rates are put forth in Chapter 6.

Overall, groundwater age increases downgradient from 0.6 years near the Clark Fork River to 3.2 years at the Buckhouse site and 2.2 years at the Humble/Mount site. Both are near the Bitterroot River. The Blaine/Crosby-shallow, Larchmont-deep and Larchmont-shallow wells yielded the greatest ages of 2.7, 3.3 and 4.6 years, respectively.

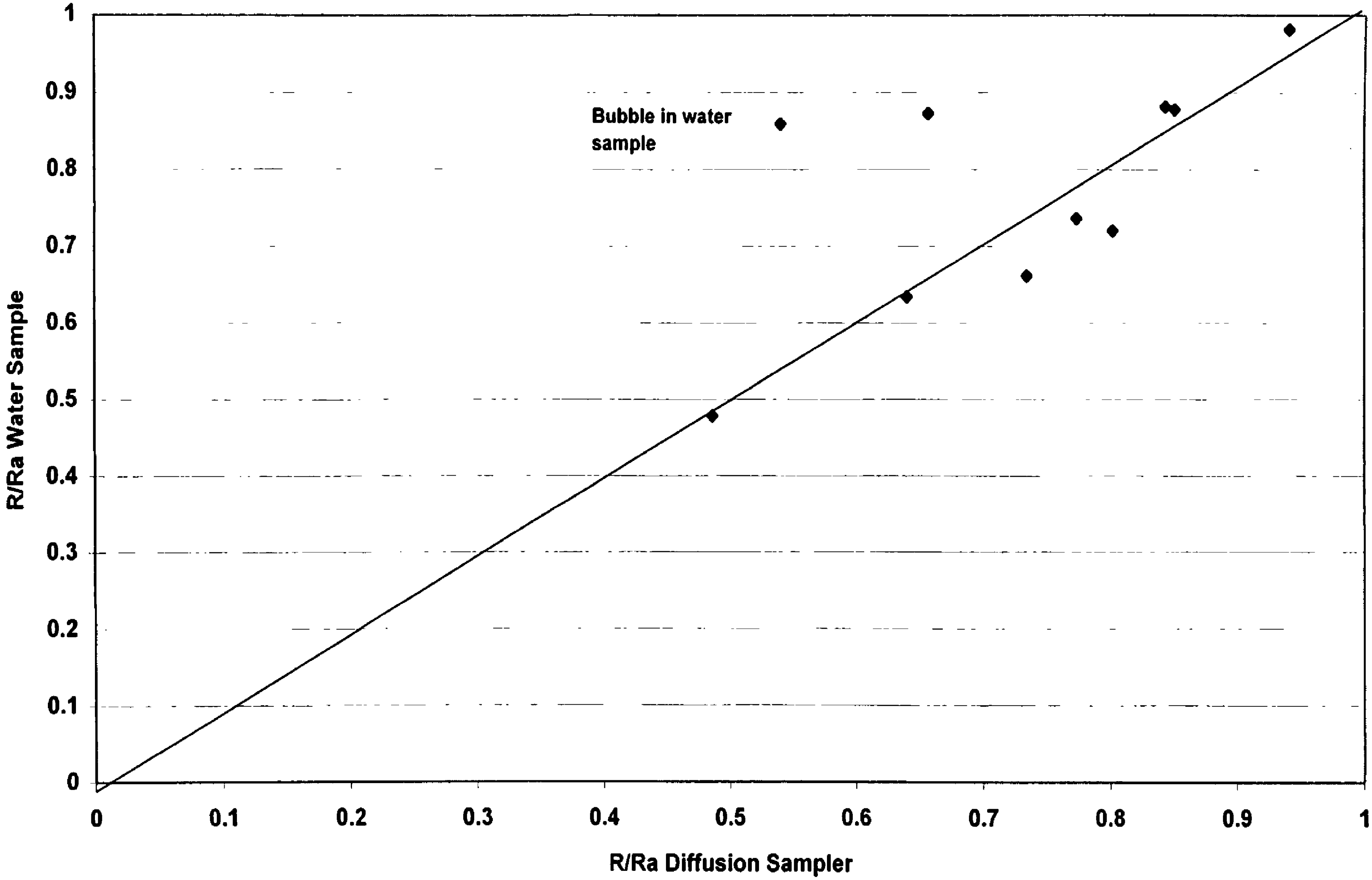


Figure 14: Comparison of Water and Diffusion Samplers. Line drawn for comparison. From LaFave (2000).

Tritium concentrations are mapped in Figure 15 and listed in Table 3.

Table 3: Tritium Concentrations

Location	^3H, TU	Range, TU
Clark Fork River	10.20	9.70 – 10.70
McCormick	8.90	8.50 – 9.30
Mount: between Stephens & Russell	9.47	9.00 – 9.94
Emma Dickinson	8.67	8.24 – 9.10
Hawthorne	10.10	9.60 – 10.60
C. S. Porter	13.13	11.70 – 13.85
Tower	12.06	11.46 – 13.06
Humble/Mount	10.31	9.79 – 10.83
Madison	11.21	10.65 – 11.77
Chem/Pharm	10.1	N/A
Blaine/Crosby-s	12.38	11.76 – 13.00
South/Bancroft	9.10	8.60 – 9.60
Fowler	11.20	10.64 – 11.76
Larchmont-s	12.10	11.50 – 12.70
Larchmont-d	10.90	10.40 – 11.40
Buckhouse	9.44	8.97 – 9.91

s = shallow, d = deep

Values range from 8.67 to 13.06 TU. Overall, ^3H concentrations decrease downgradient from 10.20 TU at the Clark Fork River to 9.44 TU near the Bitterroot River. The Tower, Larchmont-shallow and Blaine/Crosby-shallow wells yielded the highest ^3H concentrations of 12.06, 12.10 and 12.38 TU, respectively.

<u>Evaluation of Recharge By the Tertiary Sediments</u>

To assess the hypothesis of recharge from the underlying Tertiary sediments to the Missoula Aquifer, measurements of temperature, SC and head differences between the two units were made with assistance of Missoula City-County Health Department. Additionally, head differences and chemical trends were evaluated in the Blaine/Crosby and Larchmont well nests.

A downward gradient of –0.016 was seen in the Chem/Pharm well after the well packer had been in place more than half an hour (Appendix D). In situ temperature and

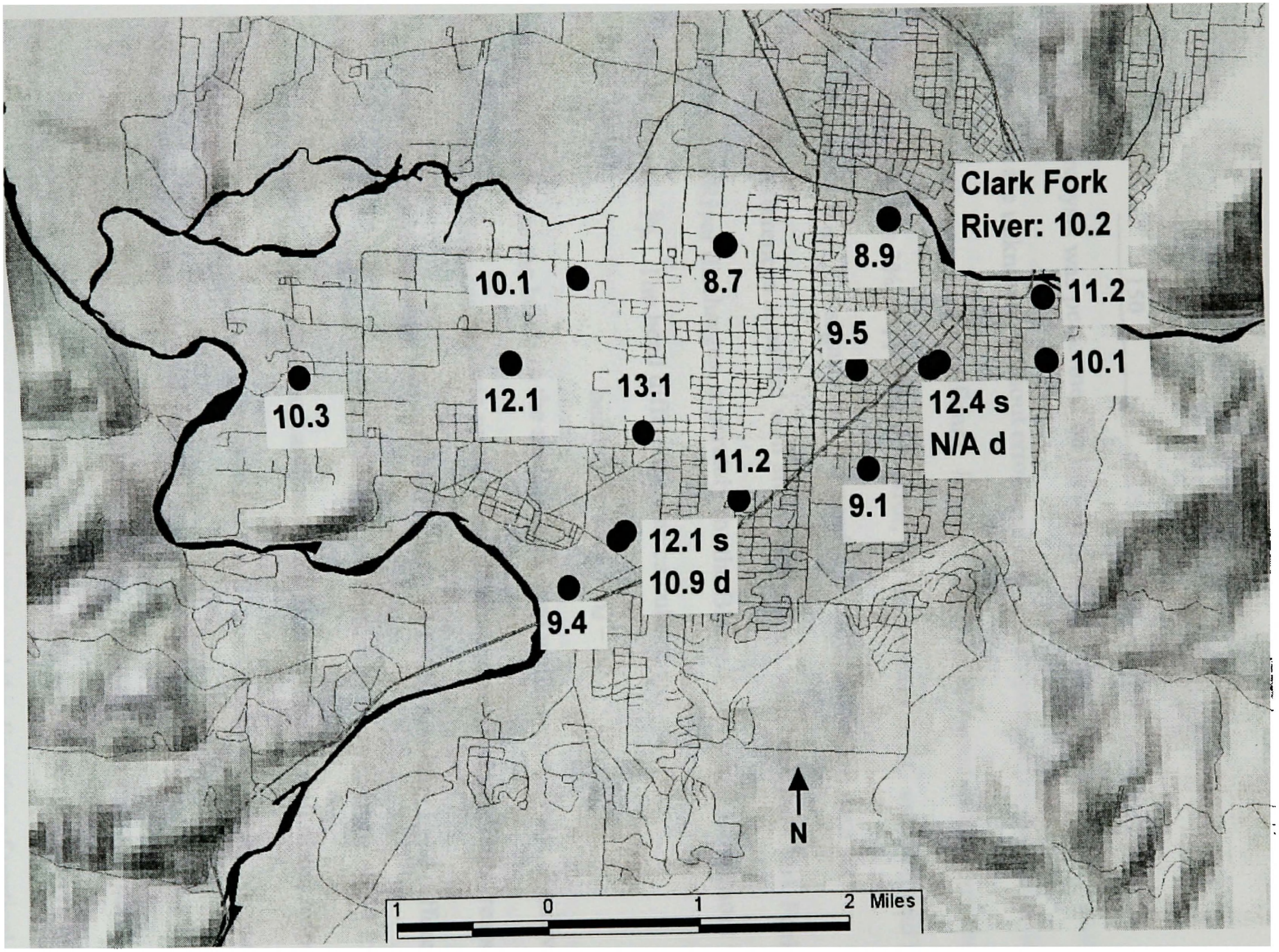


Figure 15: ^{3}H Concentrations (TU). Modified from LaFave (2000).

SC measurements made between the two perforated intervals are summarized below in Table 4.

Table 4: Temperature and SC Values

Depth, feet	Temperature, °C	SC, μ mhos/cm
120	9.3	316
150	9.2	328

No QA/QC analysis was performed on these instruments and the instrument's accuracy and precision are unknown. Without error analysis, it is impossible to determine if the temperature differences are significant. Error of the SC meter used in the river recharge pulse tracer test was 3%. Applying this error, the differences in SC values found in the Chem/Pharm well are not significant. Appendix D contains the full data set.

Head differences at nested well sites were plotted with both the Clark Fork River and Bitterroot River discharges, separately for the Blaine/Crosby and Larchmont well nests (Appendix F). The head difference was calculated as:

$$\text{head difference} = h_d - h_s$$

where h_s and h_d are the heads in the shallow and deep wells, respectively. Positive and negative head differences indicate upward and downward vertical gradients, respectively. The head measurement error was assumed to be 0.14 ft; the resulting head difference error was 0.28 ft. Periodic vertical gradients are seen, which range from -0.44 to 0.015 and from –0.015 to 0.0081 for the Larchmont and Blaine/Crosby well nests, respectively. Stronger vertical gradients were observed at the Blaine/Crosby well nest. No pattern of vertical gradient occurrence and river discharge was noticeable.

Next, for each significant vertical gradient, the head difference and discharge data for the previous 10 days were plotted for the Clark Fork and Bitterroot Rivers in an attempt to identify patterns between river discharge and the direction of vertical gradients

(Appendix F). The highest upward gradient frequency seemed to occur during or close to spring runoff events. During baseflow conditions, vertical gradients were occasionally observed, however, they varied from –0.66 to 0.44.

Evaluation of Chemical Trends of Well Nests

Finally, chemical trends and head for the shallow and deep members of each well nest were plotted to identify geochemical differences between the wells at each well nest and to infer flowpaths (Appendix F). It was hypothesized that if Tertiary recharge is occurring, higher constituent concentrations may be seen in the deep well. However, higher constituent concentrations are seen historically at the shallow wells. Despite the sparse data, some general trends can be seen just before and during spring runoff.

At the Blaine/Crosby well nest Na^+, K^+, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^- and HCO_3^- concentrations generally increase at both wells during spring runoff relative to baseflow conditions. Ca^{2+} generally decreases slightly at both wells.

At the Larchmont well nest, Na^+ and K^+ demonstrate no significant trends. During spring runoff, Ca^{2+} concentrations are generally lower in the shallow well and higher in the deep well. Mg^{2+} and HCO_3^- generally increase in the shallow well and decrease in the deep well. Cl^- and NO_3^- generally decrease in both wells. SO_4^{2-} generally increases in both wells.

<u>River Recharge Pulse Tracer Test</u>

The use of changes in surface-water quality and groundwater recharge as a tracer to determine groundwater travel times was inconclusive. Modeling demonstrated the drawdown from both wells pumping pumping continuously for 180 days to be < 0.01

feet. Only TDS and Cl may show significant differences and could be used as tracers of river chemistry.

Graphs of temporal TDS and Cl concentrations from the Clark Fork River (NWB), Music and Lodge sites as well as Clark Fork River discharge are shown in Figures 16 and 17 (Appendix E). A plot of TDS vs. Cl is shown in Figure 18. This plot shows distinct clusters of values for each site, thus proving there were discernable differences in Cl between the Music and Lodge sites and the NWB site.

Error of the TDS measurement was 3% from field duplicates taken at the Clark Fork River and encompassed TDS variations during the day. At the supply wells of the Music and Lodge buildings, located 1,600 and 2,650 ft downgradient of the Clark Fork River, TDS concentrations were consistently higher than in the Clark Fork River. Unfortunately, minor variations in river water TDS were not clearly discernable at these wells. Significant differences between the wells were seen only during 4 of the 12 well sampling events. Sitewise, only measurements made before the beginning of July showed differences beteween sampling events.

Error of Cl concentrations was 1.1% from lab duplicates. No error analysis was performed on field replicates. Flux patterns of groundwater chemistry in the wells appeared to have matched the Clark Fork River during the period of 6/21 – 7/16 (Figure 19). However results are within possible sampling and analysis error. No attempts were made to estimate groundwater velocities from these data.

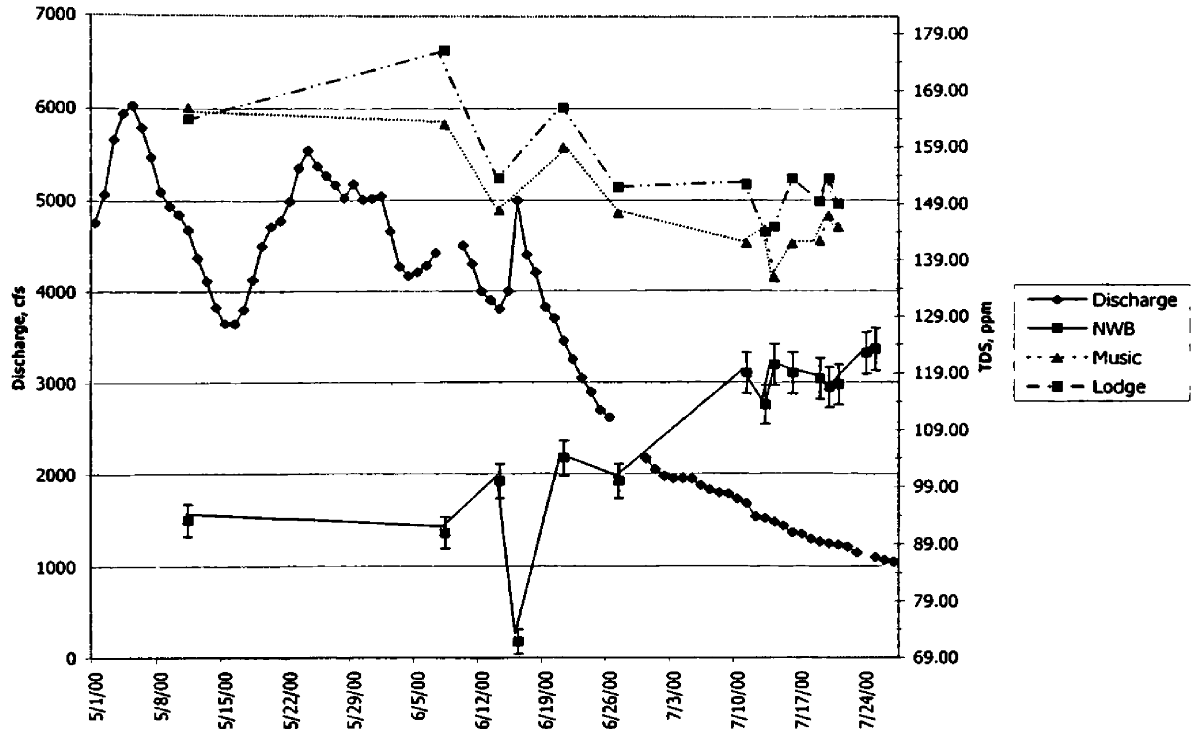


Figure 16: Total Dissolved Solids and Clark Fork River Discharge

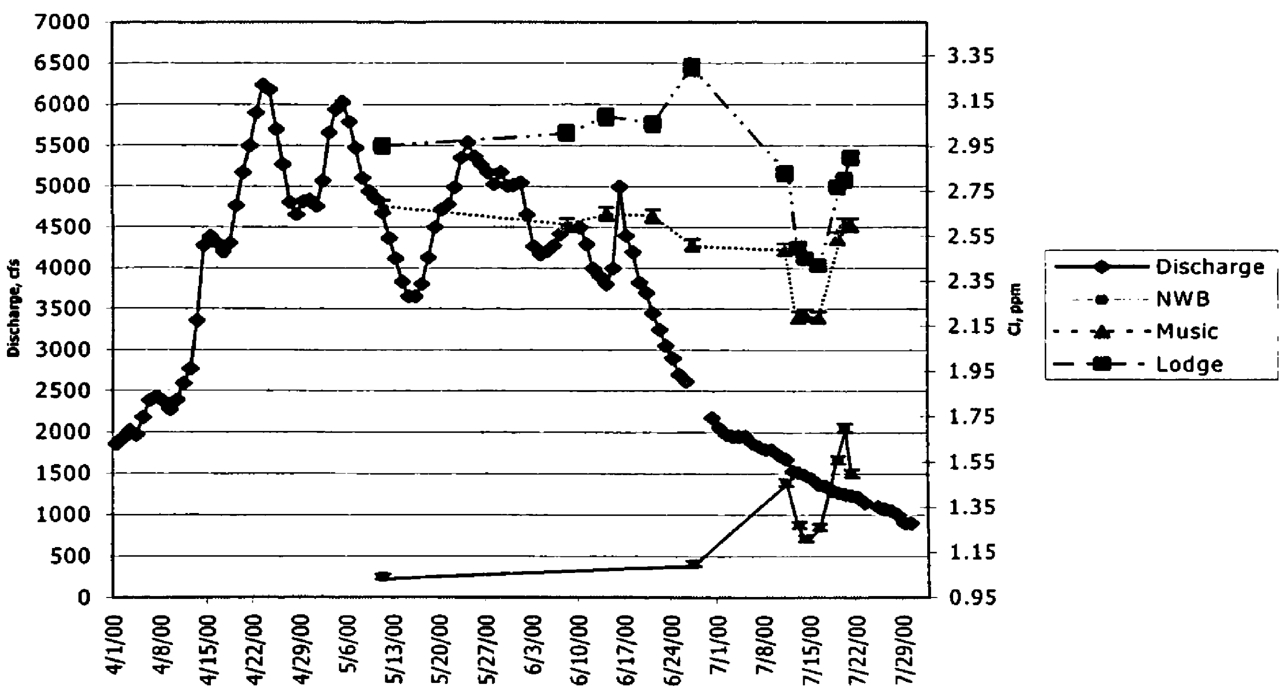


Figure 17: Chloride Concentration and Clark Fork River Discharge

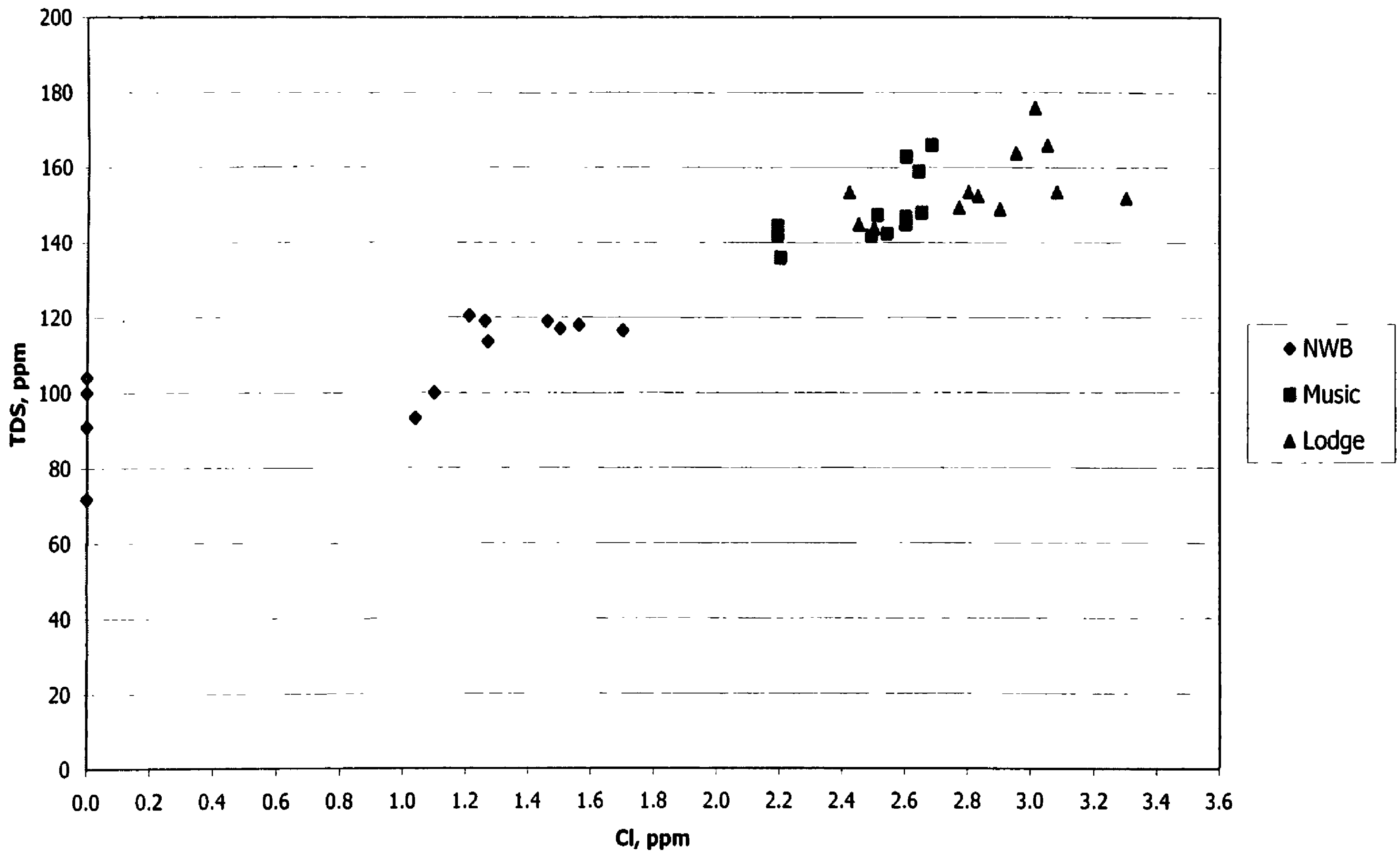


Figure 18: TDS-Cl Correlation

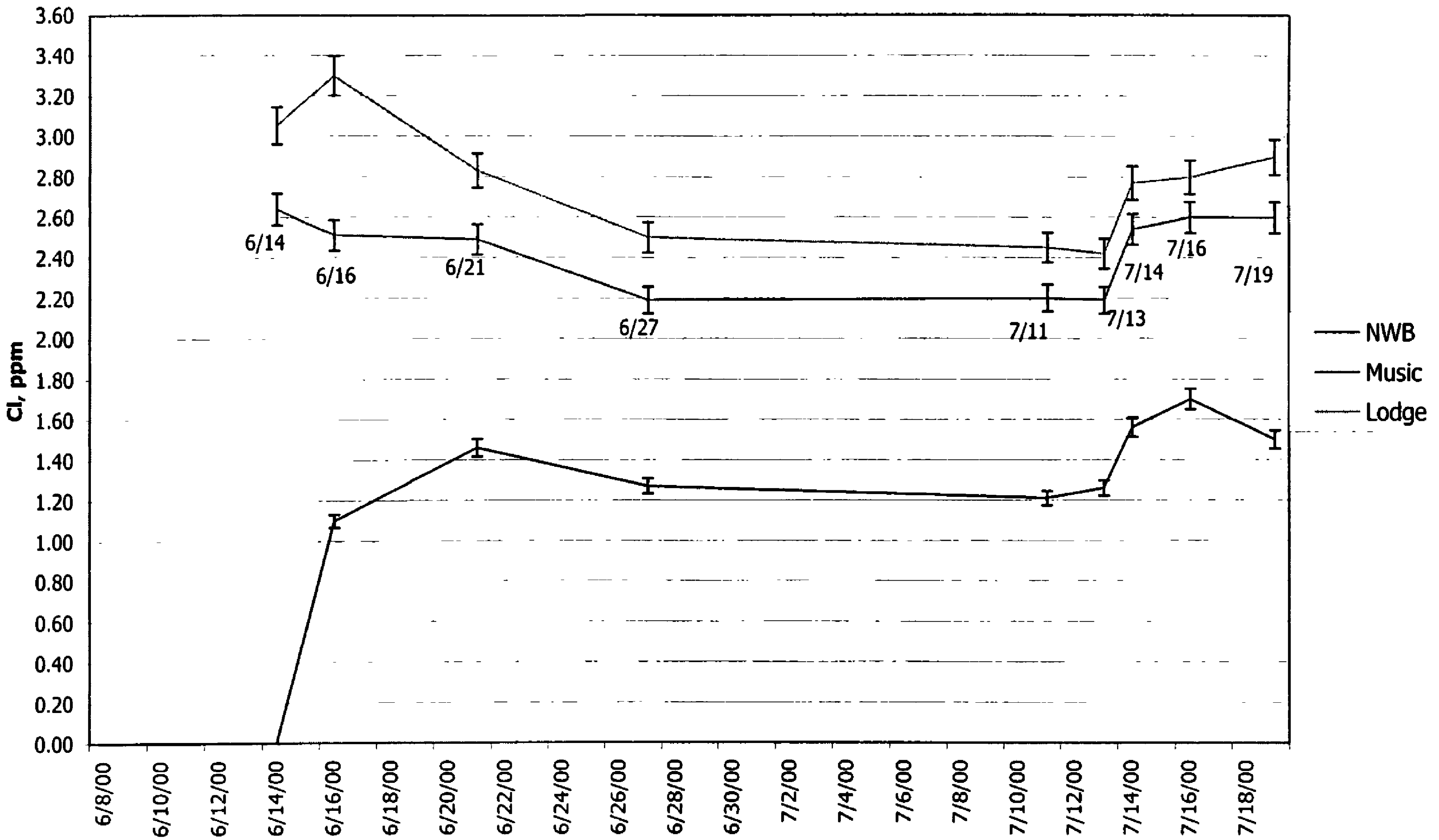


Figure 19: Detailed Comparison of Chloride Variability at the Clark Fork River, Music and Lodge Wells During 6/14 - 7/19.

Numerical Profile Model

Selected areas within the calibrated model are shown in Figures 20 and 21. The final aquifer parameter estimates for steady-state conditions are listed below in Table 5. Velocities were estimated using MODPATH (Pollock, 1989) as incorporated in Visual MODFLOW 2.8.2.22™.

Table 5: Final Aquifer Parameter Estimates of Calibrated Model

Parameter	Estimated Values
K_x	4,900 – 36,000 ft/d
Velocities	Min, Max, Avg = 91, 147, 134 ft/d
Vertical gradients	Clark Fork River: -0.0015; Bitterroot River: +0.0012
Flux	51,340 ft^3/d

Steady-state calibration was achieved by adjusting the magnitude and distribution of hydraulic conductivity values. No attempt was made to calibrate hydraulic conductivity values based on the variability of aquifer sediments described in well logs for wells located within the study area. Hydraulic conductivity values for calibrating the model were adjusted so that heads, vertical gradients and estimated flux rates were simulated (Appendix G). Estimated flux rates were computed based on the work of Miller, (1991) and assumed to be entirely from river leakage. Computed hydraulic conductivity values are dependent on the recharge rate used.

The steady-state flow model was calibrated by varying the hydraulic conductivity distribution until the model matched the following three criteria:

- Measured water levels in the deep wells of the Blaine/Crosby and Larchmont well nests during spring runoff sampling in 1999.
- Estimated flux through the model cross-sectional area, described above.
- Vertical gradients near the Clark Fork River approximating those observed by Peery, (1988).

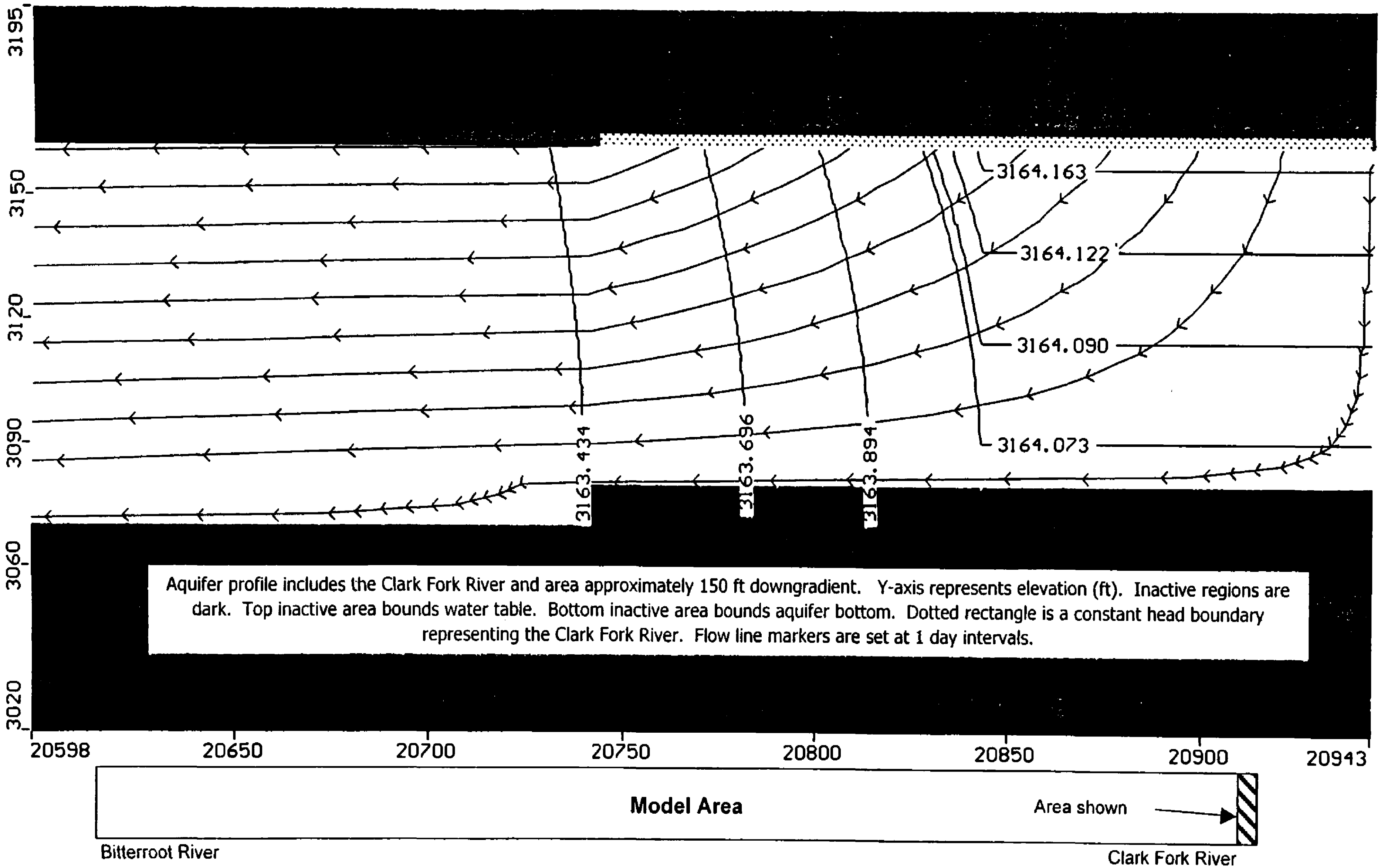


Figure 20: Model Profile at the Clark Fork River

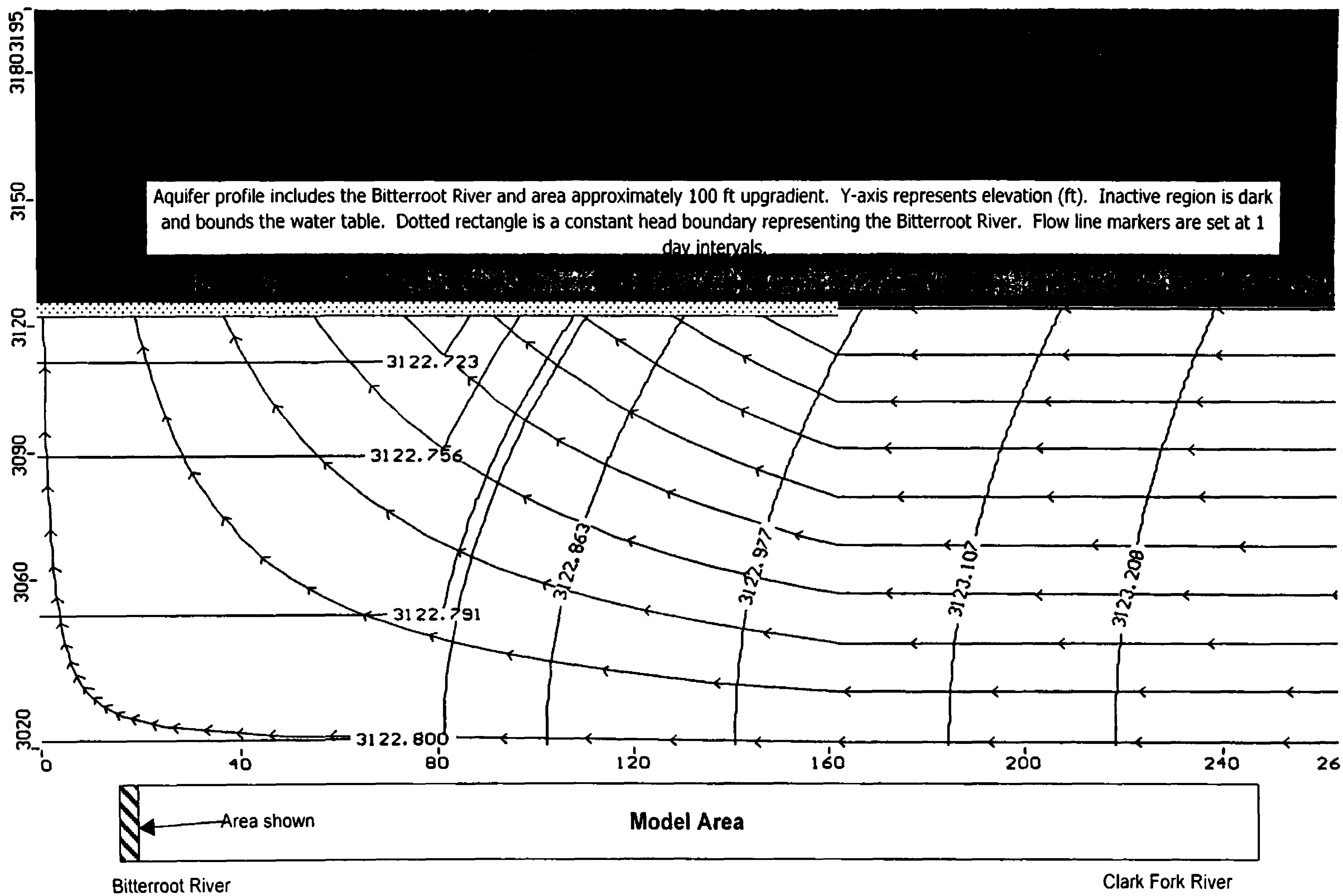


Figure 21: Model Profile at the Bitterroot River

The observed and simulated heads are compared in Table 6 below.

Table 6: Comparison of Observed and Simulated Heads

Well	Observed Head, feet	Simulated Head, feet	Difference, feet
Blaine/Crosby-d	3144.65	3145.21	-0.56
Larchmont-d	3131.53	3130.62	0.91

s = shallow, d = deep

The mean absolute error (MAE) of the calibrated water levels is 0.73 feet. The simulated flux was 51,342 ft^3/d. Estimated flux ranges from 38,512 to 57,768 ft^3/d. Vertical gradients reported by Peery, (1988) and simulated vertical gradients are compared in Table 7.

Table 7: Comparison of Reported and Simulated Vertical Gradients

Area	Reported Vertical Gradients	Simulated Vertical Gradients
Clark Fork River	0.004 – 0.01	0.0015
Bitterroot River	N/A	-0.0012

To evaluate the uncertainty error of the calibrated model results due to uncertainty of estimated aquifer parameters and estimated saturated thickness, sensitivity analyses were performed for head, flux, vertical gradients at the Clark Fork River and average velocities (Appendix G). As an example, for average velocity, saturated thickness was varied ± 10 feet, hydraulic conductivity by ± 50 % and porosity by + 0.15 and –0.1; the results of this sensitivity analysis are displayed in Figure 22.

This model calculated a minimum groundwater velocity of 90.5 ft/d by particle tracking. The corresponding travel time through the model area is 231 days. Miller, (1991) reported a groundwater velocity of 60 ft/d. The corresponding travel time through the model area using his velocity is 366 days.

The hydraulic conductivity distribution of the current groundwater management model for the Missoula Aquifer (Miller, 1991) was projected into the model area of this study and compared to that of this study's model (Figure 23). The hydraulic conductivity

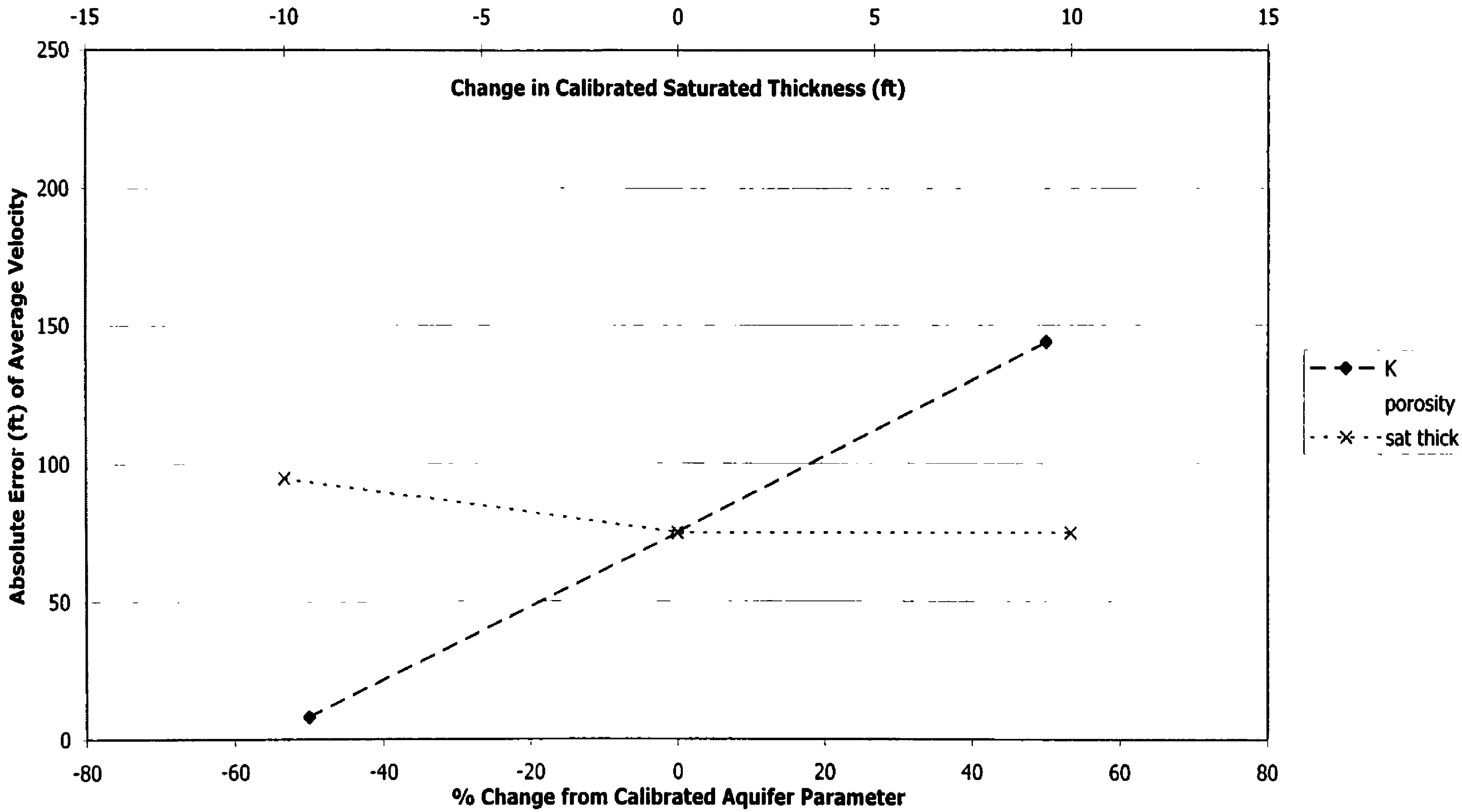
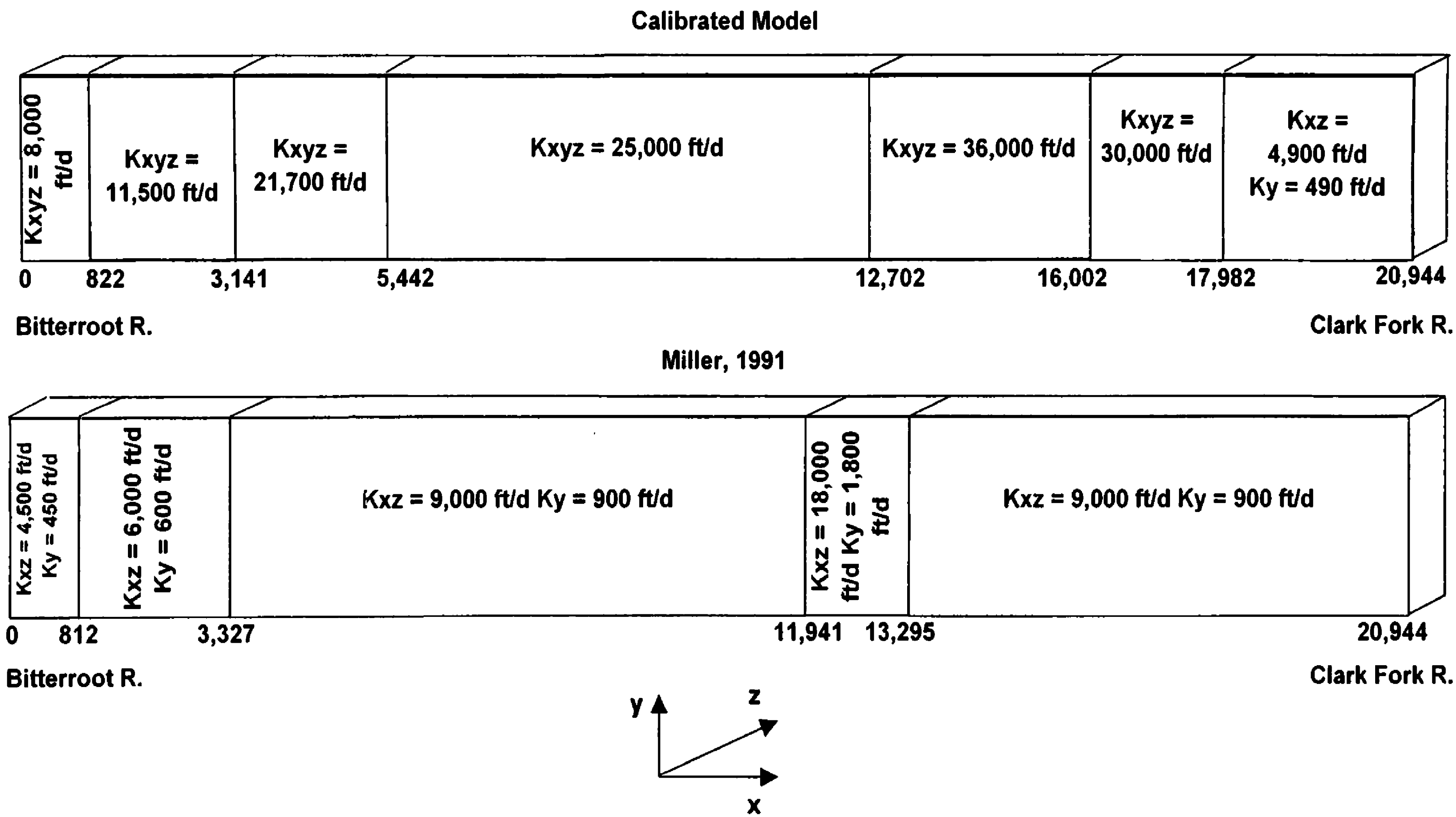


Figure 22: Sensitivity of Average Velocities to Variations of Hydraulic Conductivity, Porosity and Saturated Thickness.



Hydraulic conductivity distributions of calibrated model vs. current groundwater management model (Miller, 1991) projected thro same profile. Coordinate axes appy to both models. Distances in feet.

Figure 23: Model Hydraulic Conductivity Distribution

values of the calibrated model are two to three times higher than reported by Miller, (1991), except in the vicinity of the Clark Fork River where it is nearly half as much.

Results of simulating ^3H decay and transport through the model are listed in Table 8. Visual MODFLOW 2.8.2.22™ (Waterloo Hydrologic, Inc, 1999) simulated ^3H decay using equation 1; the ^3H decay rate was set equal to 1.5278×10^{-4}/d. The longitudinal dispersivity (α_L) value was equal to 10 feet and the vertical dispersivity (α_v) was equal to $0.033(\alpha_L)$.

Table 8: Comparison of Model-simulated and Apparent $^3H/^3He$ Age Ranges (Days)

Location	Model-Simulated Age Range*	$^3H/^3He$ Age Range
Madison	1.0 – 6.6	-146 – 584
Blaine/Crosby-s	27.4 – 29.8	621 – 1351
Blaine/Crosby-d	27.4 – 29.8	N/A
South/Bancroft	47.9 – 49.9	-219 – 511
Larchmont-s	121 – 129	1,314 – 2,044
Larchmont-d	121 – 129	840 – 1570
Buckhouse	286 – 318	694 – 1,424

s = shallow, d = deep.
* Range of ages throughout depths of aquifer.

From the model-simulated $^3H/^3He$ ages, groundwater age profiles were constructed for the Madison, Blaine/Crosby, South/Bancroft, Larchmont wells and also near the Bitterroot River. Appendix G contains all the age profiles listed above. As an example, the Bitterroot River age profile when α_L equals 10 feet is shown in Figure 24. A high degree of age stratification is visible. Ages increase from 286 days at the top of the aquifer to 333 days at the aquifer base.

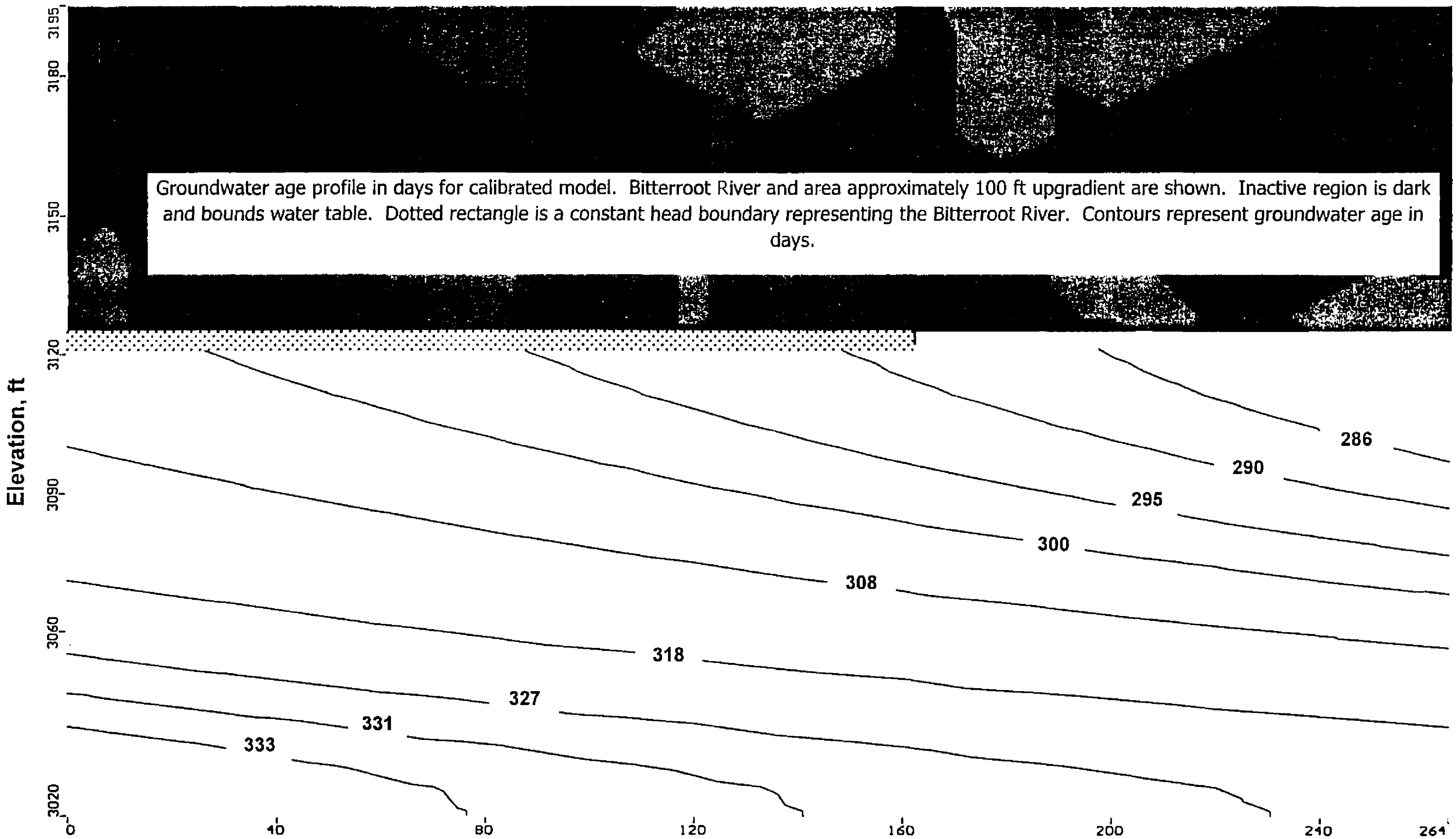


Figure 24: Groundwater Age Profile of Calibrated Model Near the Bitterroot River

Chapter 6: Discussion

This project attempted to refine the magnitude and distribution of hydraulic conductivity values and velocities used in the current groundwater management model (Miller, 1991). The approach to reaching this goal included measuring river recharge pulses and groundwater response, and age-dating groundwater using CFCs and the $^3H/^3He$ method. It was hoped that these methods would yield new and improved estimates of groundwater velocity within the aquifer and allow for calculation of associated hydraulic conductivity values. These new values would be evaluated by using them as input parameters to a numerical model. Modeling results would then be compared to assess how well the model calibrated with these revised values and contrasted with the results of Miller (1991). This attempt was partially successful. The following discussion will attempt to explain the shortcomings and implications of the effort on refining our understanding of how the Missoula Aquifer functions.

Numerical Profile Model

Groundwater ages, gathered from the CFC and $^3H/^3He$ age-dating results, were to be used as one set of calibration criteria for this model. However, due to problems with these methods, presented in the results and discussed later in this chapter, the model was calibrated to physical parameters in order to refine hydraulic properties. The following sections discuss the reasons for choosing a profile model, the means of calibration and the final hydraulic conductivity distribution. The model results are then compared and contrasted with the current groundwater management model (Miller, 1991).

A profile model was chosen so that detailed hydraulic conductivity refinements with depth could be made and vertical flow could be assessed.

The model was calibrated using what were considered reasonable estimates of hydraulic conductivity. Hydraulic conductivity values within the same order of magnitude as those reported by Miller (1991) were considered reasonable. Hydraulic conductivity values reported by Miller (1991) result both from aquifer tests and his calibrated model. The calibrated hydraulic conductivity distribution is not believed to be a unique solution to the calibration criteria. Another hydraulic conductivity distribution may calibrate the model. Saturated thickness may also be varied over the model area to help achieve calibration; however, this parameter is better constrained than the hydraulic conductivity.

Comparison of Models

The calibrated model produced different flow velocities than the current groundwater management model. The following section compares and contrasts the results and the notable differences between this model and the current groundwater management model (Miller, 1991).

The hydraulic conductivity distributions of this model and the current groundwater management model contrasted strongly. The hydraulic conductivity values of this model are approximately two times greater than reported by Miller (1991), except in the vicinity of the Clark Fork River where the hydraulic conductivity of this model is 4,900 ft/d vs. 9,000 ft/d (Miller, 1991).

Flow velocities differed between the models but were within the same order of magnitude. This model calculated a minimum flow velocity equal to 90.5 ft/d and a travel time through the model area equal to 231 days. Miller (1991) reported a flow velocity of 60 ft/d; using this velocity the calculated travel time through the model area is

366 days. The model-calculated flow velocities are dependent on their respective hydraulic conductivity distributions.

Under steady-state conditions, the model was calibrated to three criteria: estimated flux through the model area, vertical gradients near the Clark Fork River (Peery, 1988) and head measurements. Miller (1991) calibrated his model under steady-state and transient conditions, by varying the hydraulic conductivity distribution based on a number of aquifer tests, to two criteria: head measurements and the length of the losing stretch of the Clark Fork River visible on potentiometric maps. Under transient conditions, Miller (1991) calibrated his model to head measurements only, by varying the stage of the Clark Fork River. The mean absolute error of this model is 0.73 feet. Miller (1991) reported mean absolute errors ranging from 0.43 to 1.01 feet from steady-state and transient simulations.

Miller (1991) reported five hydraulic conductivity zones and four hydraulic conductivity values. This model had seven hydraulic conductivity zones and seven hydraulic conductivity values. Both models were two-dimensional. However the profile model also accounts for differences in vertical hydraulic conductivity, simulating anisotropic conditions

Based on these comparisons, hydraulic conductivity values and flow velocities within the valley may be higher than previously thought. Further evaluation of this argument will require additional modeling efforts of flowpaths in other areas of the valley.

River Recharge Pulse Tracer Test

The use of river recharge geochemical pulses to calculate velocity and hydraulic conductivity near the Clark Fork River was inhibited by the lack of contrast between the river and groundwater chemistry. This method holds promise and should be evaluated again during a period of snowmelt and/or a normal spring runoff event to evaluate if significant differences in groundwater chemistry can be observed. If so, refined estimates of groundwater velocity may be possible. During a normal spring runoff, the higher discharge and resulting large recharge pulse would hopefully result in a stronger contrast between the river and groundwater chemistry.

Age-dating With CFCs

Standard use of CFCs to age-date groundwater in the Missoula Aquifer was ineffective because all but two of the wells had concentrations in excess of air-water solubility. The literature suggests that one possible source of CFC loading to groundwater could be from CFC contaminated sewage (Busenberg and Plummer, 1992; DeWalle et al., 1985). Additional sources of CFC contaminants may be from degreasers and refrigerants that have entered the environment.

An attempt was made to examine if septic system effluent recharging the aquifer could be a source of the high CFC-12 concentrations observed. The CFC-12 concentration that would have to be present in a single septic effluent source, in order to achieve the observed concentrations in aquifer groundwater, was estimated. First the CFC-12 mass in the Missoula Aquifer was calculated. Then, the CFC-12 mass contributed by the Clark Fork River was subtracted. Finally, given that 1.) 4,186 unsewered units exist in the study area (MCCHD, 1996) and 2.) the average septic effluent discharge is 200 gal/d (Ver Hey, 1987), the average CFC-12 concentration in septic effluent was calculated to equal 1.27 x 10^8 pg/kg. Details are described in Appendix C. When the average CFC-12 concentration in septic effluent calculated in this study is compared to the measured values from Busenberg and Plummer (1992) and DeWalle et al. (1985) (Table 9), it is seen that the computed value is similar to those reported in the literature.

Table 9: Comparison of CFC-12 in Septic Effluent

Study	CFC Concentrations (pg/kg)
Busenberg and Plummer, (1992)	3.43 x 10^2 – 2.814 x 10^2 pg/kg in surface waters below sewage disposal ponds and sewage returns.
DeWalle et al., (1985)	6.4 x 10^8 pg/kg in household septic effluent.
This Study	1.27 x 10^8 pg/kg

In addition to this estimate, CFC-12 concentrations tend to increase down flowpath (Figure 12). This may be a result of septic system effluent recharge as the number of septic systems/mile^2 increase downgradient (LaFave, 1999).

Note in Figure 25 that in the area west of the highest septic density (>5,120 septic systems/mile^2 (Land and Water, 1996)), 4 of the 5 wells have CFC-12 concentrations one order of magnitude higher than sites to the east (LaFave, 1999).

Additionally, higher inorganic constituent levels, believed to be indicative of anthropogenic recharge (Appendix F), are observed in the shallow wells of the Blaine/Crosby and Larchmont well nests. Woessner et al. (1996) observed elevated inorganic constituent levels in the aquifer downgradient of septic systems.

Based on these analyses, the elevated CFC-12 values observed in the Missoula Aquifer may reflect widespread aquifer recharge by septic effluent. Further strengthening of this argument would require actual sampling of septic system effluent

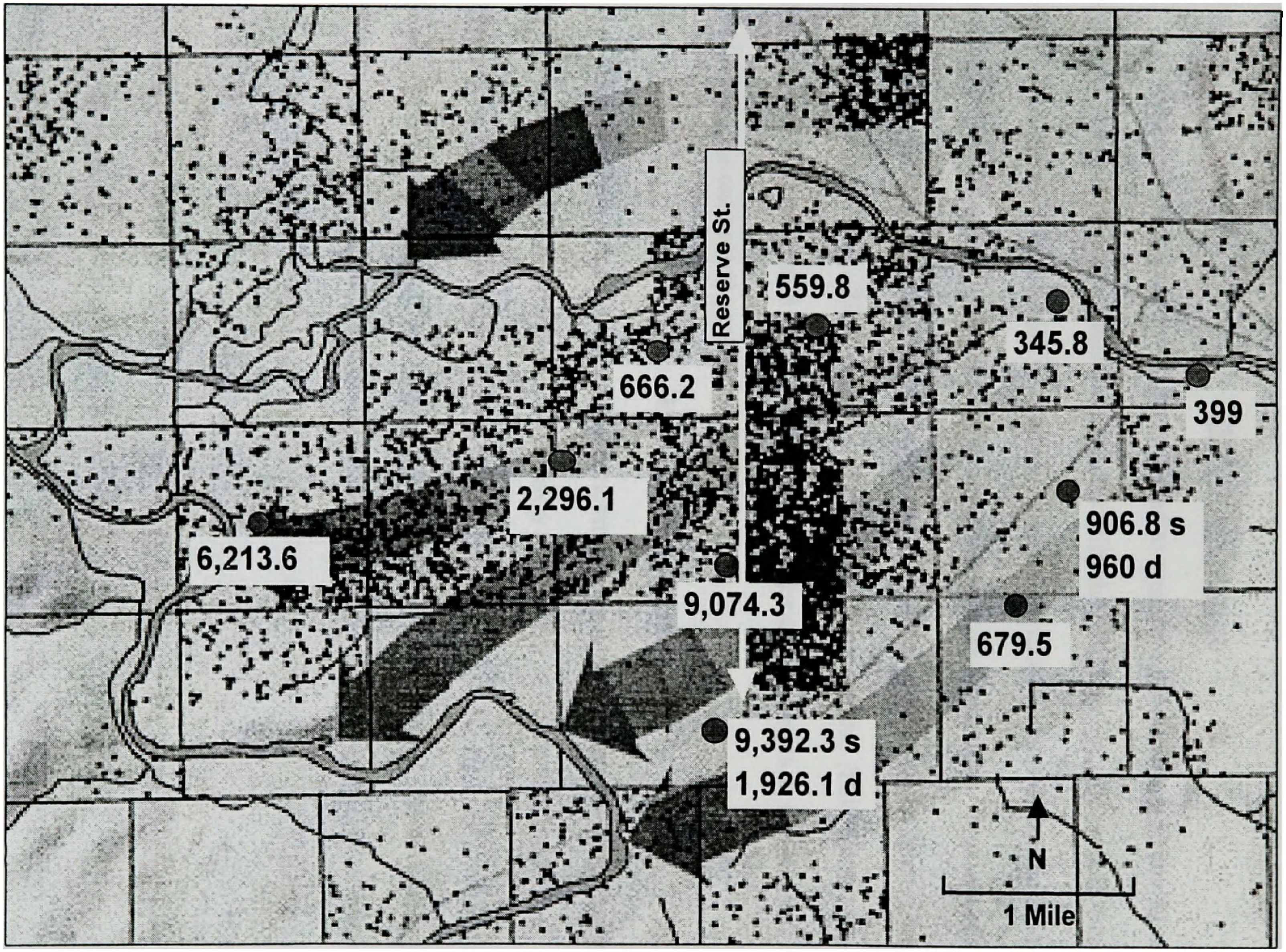


Figure 25: Septic Tank Density. Each dot represents one septic system. CFC-12 concentrations-pg/kg. Modified from Land and Water (1996) and LaFave (2000).

for CFCs. If sufficiently high concentrations of CFCs are not measured, another source of CFC contaminants is needed.

$^3H/^3He$ Age-dating

The $^3H/^3He$ method was also applied to age-date groundwater in the Missoula Aquifer. Despite the large error associated with the $^3H/^3He$ ages, the overall trend of increasing age downgradient fits the conceptual flow model. However, age resolution prohibits calculation of groundwater velocities based on these ages. The use of the $^3H/^3He$ age data was hampered by the discovery of what appears to be excess terrigenic He in the groundwater. First, analysis of this issue is presented. This discussion is then followed by a comparison of computed $^3H/^3He$ ages and attempts at simulating $^3H/^3He$ ages using the calibrated profile model.

Excess Terrigenic He

In most samples the measured concentrations of terrigenic He were higher than expected. $^4He_{rad}$ concentrations ranged from 2.00 x 10^{-9} to 4.20 x 10^{-8} ccSTP/g (Appendix C) vs. commonly reported values of 1.03 x 10^{-9} to 1.31 x 10^{-9} ccSTP/g (Pope et al., 1998). Groundwater age-dating studies of an alluvial aquifer near Dillion, MT (Pope et al., 1998) and of a vesicular, broken-basalt aquifer in south-central Idaho (Plummer et al., 2000) have also encountered high concentrations of $^4He_{rad}$ ranging from 1.11 x 10^{-9} to 1.64 x 10^{-7} ccSTP/g. Age errors ranged from ± 1.0 to ± 1.5 years vs. commonly reported age errors of ± 0.24 to ± 0.36 years (Pope et al., 1998).

The presence of excess terrigenic He hampered calculating $^3H/^3He$ ages with a high degree of precision by making the terrigenic He terms in equations 2 and 3 significant. After solving the ^4He mass balance equation (2) for the $^4He_{rad}$ concentration, the $^{3}He_{terr}$ concentration can be solved for from the $^{4}He_{rad}$ concentration and the terrigenic $^{3}He/^{4}He$ ratio. The terrigenic $^{3}He/^{4}He$ ratio is unique to each aquifer; its value is contingent on the geology and mineralogy of the aquifer.

An association may exist between the high terrigenic He concentrations and radon (^{222}Rn) levels in the Missoula Aquifer. The decay of ^{238}U to ^{206}Pb includes the daughter product ^{222}Rn and eight ^{4}He atoms, among others (Faure, 1986). Therefore it is possible that high terrigenic He concentrations would result from ^{238}U decay.

The $^{4}He_{rad}$ concentration ranges are mapped in Figure 26 and listed in Table 10. The percent relative standard deviation of field duplicates at the Buckhouse well was considered to be the error of these measurements and is ± 25%.

Table 10: $^{4}He_{rad}$ Concentrations and Ranges

Site	$^{4}He_{rad}$ (ccSTP/g)	$^{4}He_{rad}$ Range(ccSTP/g)
Clark Fork River	0	0
McCornick	1.3×10^{-8}	$9.8 \times 10^{-9} - 1.6 \times 10^{-8}$
Emma Dickinson	2.80×10^{-8}	$2.1 \times 10^{-8} - 3.5 \times 10^{-8}$
Hawthorne	2.00×10^{-8}	$1.5 \times 10^{-8} - 2.5 \times 10^{-8}$
Tower	1.70×10^{-8}	$1.3 \times 10^{-8} - 2.1 \times 10^{-8}$
Humble/Mount	1.30×10^{-8}	$9.8 \times 10^{-9} - 1.6 \times 10^{-8}$
CS Porter	2.5×10^{-8}	$2.6 \times 10^{-8} - 4.4 \times 10^{-8}$
Madison	4.2×10^{-8}	$3.2 \times 10^{-8} - 5.2 \times 10^{-8}$
Blaine/Crosby-s	4.0×10^{-8}	$3.0 \times 10^{-8} - 5.0 \times 10^{-8}$
South/Bancroft	2.0×10^{-8}	$1.5 \times 10^{-8} - 2.5 \times 10^{-8}$
Larchmont-s	1.6×10^{-8}	$1.2 \times 10^{-8} - 2.0 \times 10^{-8}$
Larchmont-d	2.1×10^{-8}	$1.6 \times 10^{-8} - 2.6 \times 10^{-8}$
Buckhouse	5.0×10^{-8}	$3.8 \times 10^{-9} - 6.3 \times 10^{-9}$
Buckhouse*	3.5×10^{-8}	$2.6 \times 10^{-9} - 4.4 \times 10^{-9}$

s = shallow, d = deep, *-duplicate, error = ± 25%

Along the modeled aquifer flowpath, differences in $^{4}He_{rad}$ concentrations are indistinguishable between the Madison and Blaine/Crosby-shallow wells and between the South/Bancroft and Larchmont wells. Overall, $^{4}He_{rad}$ concentrations decrease down flowpath.

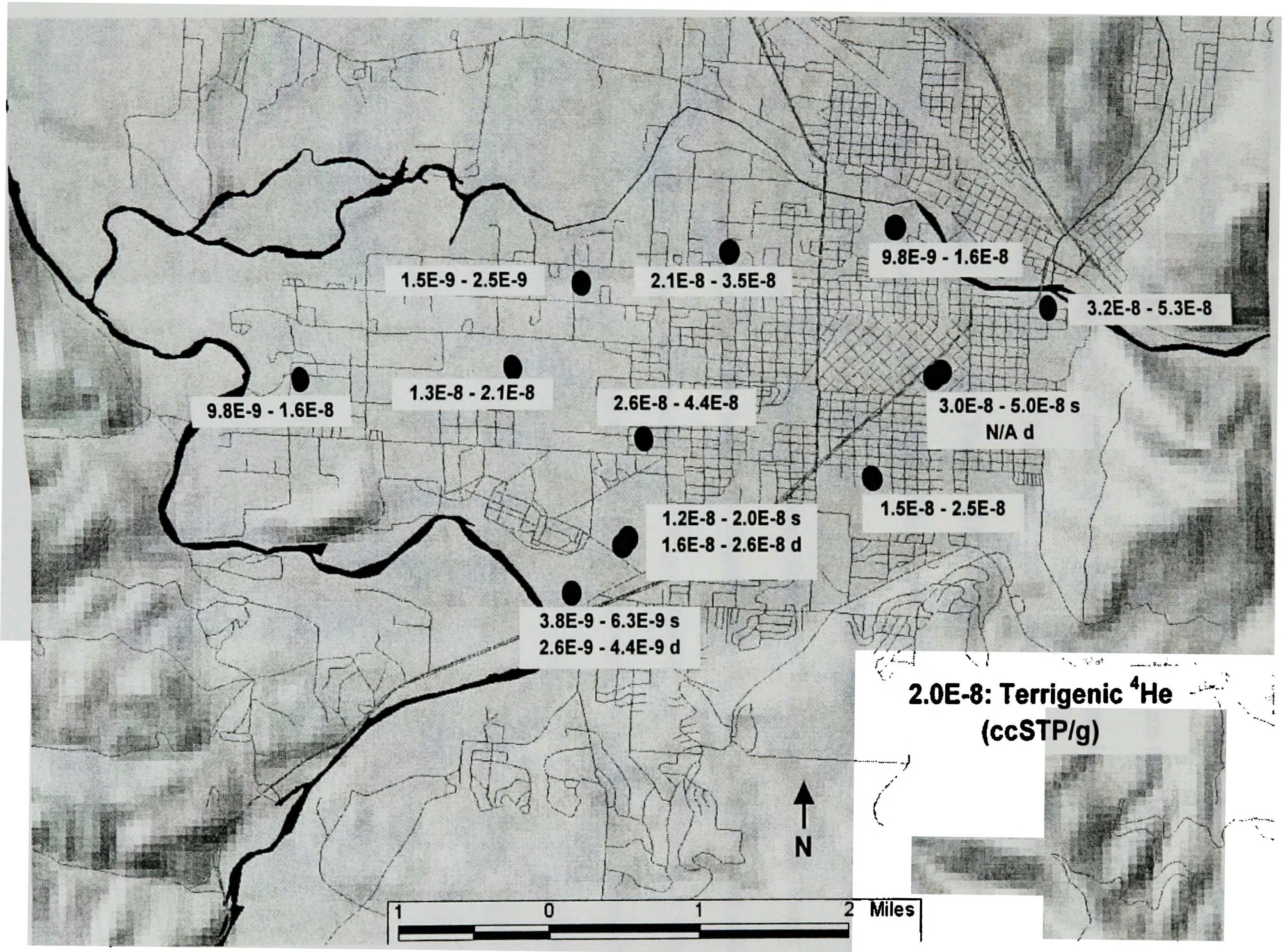


Figure 26: $^{4}He_{rad}$ Concentration Ranges; Error is +/- 25%.

Possible sources of radon and $^4He_{rad}$ (and consequently $^3He_{terr}$) include faults, volcanic ash deposits, granites, clays and silts (Ward, 1997). The Clark Fork Fault crosses the Rattlesnake Valley; faults exist along the base of the Tertiary hills on the north and south sides of Missoula (Ward, 1997). The alluvium that forms the Tertiary hills surrounding the study area is partially composed of volcanic ash, coal, clay and silt (Woessner, 1988; Geldon, 1979). Ward (1997) reported higher radon levels along the South Hills and in the Rattlesnake Valley. Granite cobbles, possibly shed from the Bitterroot Mountains, exist in the riverbed and associated sediments of the Bitterroot River in the southwest portion of the study area. These granite cobbles may contribute the smallest quantities of $^4He_{rad}$ since concentrations are lowest at the Buckhouse well. The Tertiary sediments below the Missoula Aquifer are partially composed of clay (Woessner, 1988) and may be a source of $^4He_{rad}$; clays are generally higher in uranium than sands and gravels (Ward, 1997). The Missoula Aquifer sediments, composed of red and green siltstones (Woessner, 1988) are not likely to produce $^4He_{rad}$. If either the Missoula Aquifer or Tertiary sediments generate $^4He_{rad}$, concentrations would be expected to increase or remain the same down flowpath. Instead, $^4He_{rad}$ concentrations decrease significantly down flowpath, as seen above, indicating $^4He_{rad}$ generation is unlikely. However the effects of dispersion may mask any $^4He_{rad}$ generation if $^4He_{rad}$ is being introduced in a more localized area.

Identifying the sources of terrigenic He and modeling of terrigenic He generation and transport are needed to help resolve this issue. To gain better age precision, the terrigenic $^3He/^4He$ ratio for the Missoula Aquifer must be determined. In an attempt to resolve the terrigenic $^3He/^4He$ ratio of the Missoula Aquifer, water samples from Tertiary wells and samples of Missoula Aquifer and Tertiary sediments have been sent to the Isotope Geochemistry Laboratory of the University of Utah for analysis. These data were not available at present. When available, the data will allow for refinement of the groundwater ages.

Discrepancies Between the Model-simulated and $^3H/^3He$ Ages

The model-simulated ages were used to check the $^3H/^3He$ ages. Model-simulated ages generated by the calibrated model when α_L = 10 ft are listed in Table 11 and compared to the apparent $^3H/^3He$ age ranges.

Table 11: Comparison of Model-simulated and Apparent $^3H/^3He$ Age Ranges (Days)

Location	Model-Simulated Age Range*	Apparent $^3H/^3He$ Age Range
Madison	1.0 – 6.6	-146 – 584
Blaine/Crosby-s	27.4 – 29.8	621 – 1351
Blaine/Crosby-d	27.4 – 29.8	N/A
South/Bancroft	47.9 – 49.9	-219 – 511
Larchmont-s	121 – 129	1,314 – 2,044
Larchmont-d	121 – 129	840 – 1570
Buckhouse	286 – 318	694 – 1,424

s = shallow, d = deep.
* Range of ages throughout depths of aquifer.

The $^3H/^3He$ ages simulated by the calibrated model fit within the range of $^3H/^3He$ ages only at the Madison and South/Bancroft sites. However, at the Blaine/Crosby-shallow and Buckhouse wells and the Larchmont well nest, the model-simulated ages are one order of magnitude younger than the apparent ages. A transient model, simulating temporal gradient variations, may result in groundwater ages that more closely agree with the $^3H/^3He$ ages.

In an attempt to explain the apparent discrepancies between the model-simulated ages and $^3H/^3He$ ages, three simulations were run:

- Hydraulic conductivity was uniformly decreased by 50% over the model area. This resulted in a decrease of flux of 50 % and a corresponding reduction in transport velocity. This scenario was attempted to account for uncertainty in previous computed values of flux and hydraulic conductivity (Miller, 1991).

- α_L was increased from 10 feet to 300 feet in the calibrated model to test the hypothesis that high dispersion values may spread the concentration front and result in lower ^3H concentrations at the Bitterroot River, thus apparent older ages.
- Combining the two scenarios above, the hydraulic conductivity was uniformly decreased by 50% over the model area and α_L was set at 300 feet. The resulting model-simulated $^3H/^3He$ ages at the Bitterroot River in days are listed below in Table 12.

Table 12. Highest Model-simulated $^3H/^3He$ Ages (Days) Using Alternative Parameter Values.

Parameter Values	Age at Bitterroot River	Measured $^3H/^3He$ Age Range
K-50%, α_L = 10 ft	458	
Calibrated K, α_L = 300 ft	360	694 – 1,424
K-50%, α_L =300 ft	485	

All of the model-simulated $^3H/^3He$ ages are younger than the apparent $^3H/^3He$ ages at the Bitterroot River (Table 9). Therefore the age discrepancies cannot be explained either by the error associated with the calculated hydraulic conductivity value reported by Miller (1991) and/or a higher α_L value.

Other possible mechanisms that would result in older $^3H/^3He$ ages than those supported by physical process modeling include ^3H-free water from the underlying Tertiary sediments mixing with recharge water. In equation (1) as the ^3H concentration decreases the groundwater age increases. The older ages may also be due to longer flowpaths through zones of lower hydraulic conductivity. Recharge from the Bitterroot River during spring runoff may cause the $^3H/^3He$ age at the Buckhouse Bridge well to be younger than at the Larchmont well nest.

Radiocarbon dates gathered within the Tertiary sediments by Konizeski and Alt, (1972) are hundreds to thousands of years old. If these ages are reliable, then Tertiary water is ^{3}H-free and mixing of this water with the younger Missoula Aquifer water would result in artificially lengthening computed $^{3}H/^{3}He$ ages.

Conceptually, regional flow from the mountains and Tertiary hills surrounding the study area is recharging the Missoula Aquifer and would most likely exit the sediments in the valley. The following section explores this possible influence.

Influence of ^{3}H-free Tertiary Recharge on $^{3}H/^{3}He$ ages

Tritium concentrations down flowpath in the model area were modeled using the radioactive decay equation (1). The decay rate was 1.53 x 10^{-4} /d. It was assumed that groundwater velocity was 90.5 ft/d, 100% of Missoula Aquifer recharge was from the Clark Fork River and ^{3}H concentrations in recharge were constant. The results are listed in Table 13 and compared to measured values.

Table 13: Comparison of Modeled and Measured ^{3}H

Site	Modeled ^{3}H (TU)	Measured ^{3}H (TU)
Clark Fork River	10.20	9.70 – 10.70
McCormick	10.20	8.50 – 9.30
Emma Dickinson	10.12	8.24 – 9.10
Hawthorne	10.05	9.60 – 10.60
Tower Ave.	9.94	11.46 – 13.06
Humble/Mount	9.83	9.79 – 10.83
Madison St	10.20	10.65 – 11.77
Chem/Pharm	10.16	10.1
Blaine/Crosby s	12.38	11.76 – 13.00
Blaine/Crosby d	10.13	N/A
South/Bancroft	10.06	8.60 – 9.60
CS Porter	9.99	11.70 – 13.85
Fowler	9.99	10.64 – 11.76
Larchmont s	9.91	11.50 – 12.70
Larchmont d	9.91	10.40 – 11.40
Buckhouse	9.87	8.97 – 9.91

s = shallow, d = deep

Tritium concentrations observed within the study area were both higher and lower than at the Clark Fork River. This distribution does not clearly support a measurable presence of deep, ^{3}H-free recharge mixing with the river recharge during groundwater flow. Some of the variation in the observed ^{3}H data may possibly be a function of seasonal variation of the ^{3}H concentration in the Clark Fork River. Review of ^{3}H levels in Ottawa precipitation for the period of 1/95 – 12/97 (IAEA - WMO, 1998) show ^{3}H levels fluctuate from 5 to 10 TU monthly (Figure 27). Similar variation most likely occurs in the river recharge. Additional evidence of the presence of upward leakage of ^{3}H-free water into the Missoula Aquifer would be observed as upward vertical gradients between the Tertiary sediments and the aquifer gravels, and possibly as upward gradients in portions of the Missoula Aquifer. However, at least in the vicinity of the Chem/Pharm well, the measured gradient (-0.016) was downward, not upward. Peery (1988) reported similar downward gradients ranging from -0.004 to -0.01 near the Clark Fork River. Vertical gradients at the Blaine/Crosby and Larchmont well nests, which are finished solely in the Missoula Aquifer, are generally upward. Small upward gradients, were seen during four of the six instances when head difference was measurable at the Blaine/Crosby well nest. Similarly, upward gradients were seen during four of the five instances when head difference was measurable at the Larchmont well nest. The head differences seen at the Blaine/Crosby and Larchmont well nests lend support to the hypothesis of Tertiary recharge may be occurring at the aquifer base over a portion of the valley floor at these sites during some times of the year.

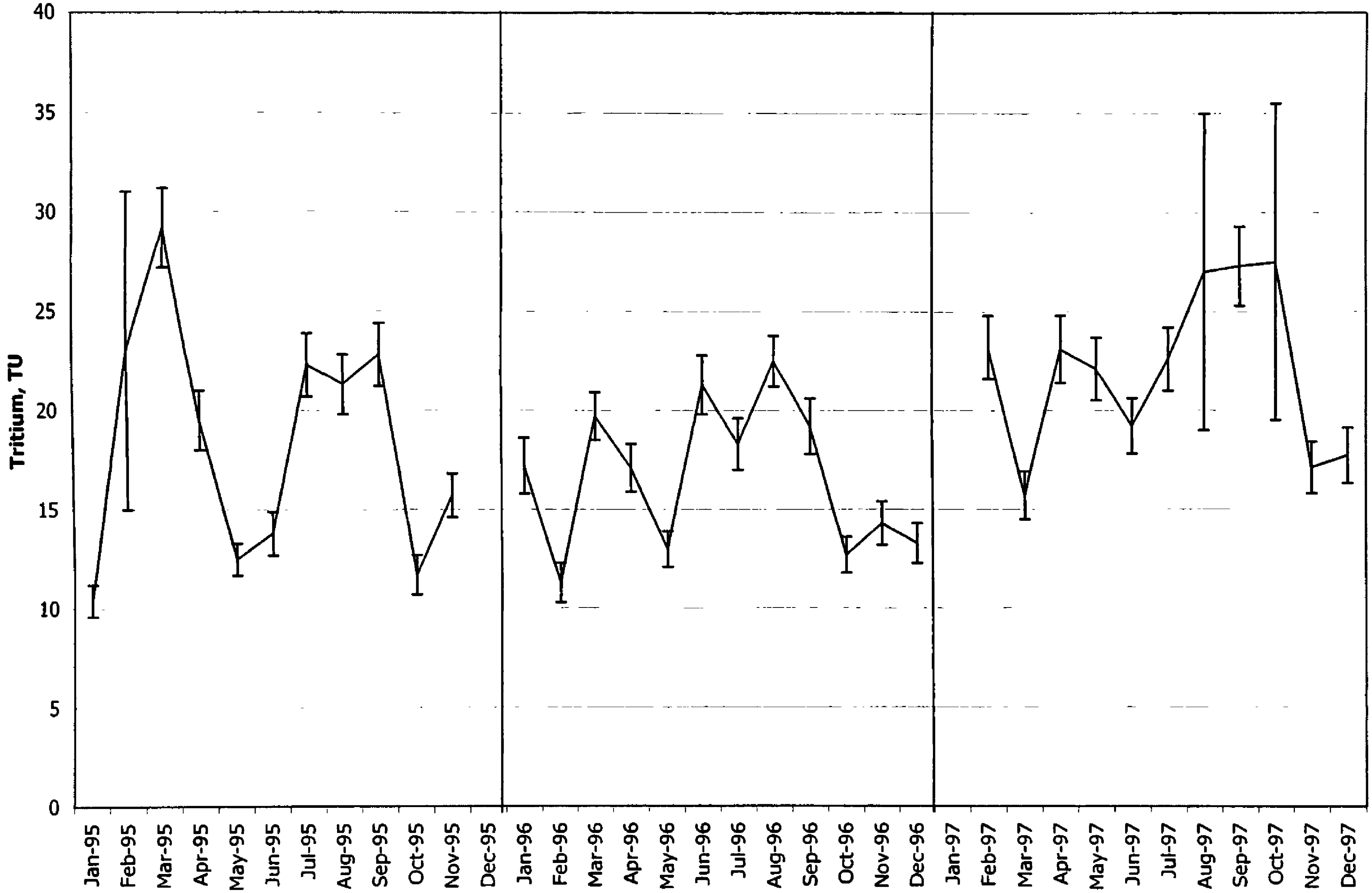


Figure 27: Ottawa Precipitation, 1995-1997.

Chapter 7: Conclusions and Recommendations

Conclusions

The goal of this research was to assess if the environmental tracers $^{3}H/^{3}He$ and CFCs, and conservative inorganic tracers could be used to refine estimates of the magnitude and distribution of hydraulic conductivity and velocities, currently used in groundwater management models for the Missoula Aquifer (Miller, 1991; Land and Water, 1991). The specific objectives of this research were to:

- Evaluate groundwater velocities, the hydraulic conductivity distribution and the presence of vertical gradients within the Missoula Aquifer.
- Evaluate whether the underlying Tertiary sediments are an important recharge source to the Missoula Aquifer.

The following was concluded:

1. The hydraulic conductivity distribution of the calibrated numerical profile model ranged from 4,900 ft/d to 36,000 ft/d; these values are approximately twice as high as reported by Miller, (1991). The minimum flow velocity, calculated using MODPATH (Pollock, 1989), as incorporated into Visual MODFLOW 2.8.2.22™, and calculated travel time through the model area was 90 ft/d and 231 days. Miller, (1991) reported a flow velocity of 60 ft/d; using this velocity, the calculated travel time through the model area is 366 days.
2. The use of the chemical composition of river recharge pulses as environmental tracers was unsuccessful as measurement error exceeded measured changes.
3. CFC-12 concentrations were within air-water solubility at only three sites and ranged from 245.80 to 399.00 pg/kg. At the remaining sites CFC-12 concentrations were in

excess of air-water solubility (559.81 to 9,392.29 pg/kg) and assumed contaminated. Consequently, these results could not be used to age-date the groundwater along a flowpath. Probable sources of CFCs include release of degreasers and refrigerants into recharge and/or groundwater and/or septic system effluent. The distribution and density of septic tanks correlates with spatial variations of CFC-12 concentrations. The calculated average sewage CFC-12 concentration within the study area is 1.27×10^8 pg/kg and is reasonably close to a literature value of 6.40×10^8 (DeWalle et al., 1985). High TDS concentrations were noted in the shallow wells of the well nests. These findings suggest septic effluent as a source of additional inputs of CFCs into the groundwater.

4. Groundwater ages along a flowpath from the Clark Fork River to the Bitterroot River ranged from -1.5 to 4.6 years with error estimates ranging from ± 1 to ± 1.5 years. Elevated levels of terrigenic He were observed, which hampered calculating $^3H/^3He$ ages with high precision. Possible sources of the observed elevated terrigenic He concentrations include the Tertiary sediments underlying and adjacent to the aquifer that are partially comprised of clay and volcanic ash and faults located in the Rattlesnake Valley and along the southern boundary of the study area. Quantifying each source's terrigenic He contribution was beyond the scope of this effort. The terrigenic He ratio of the Missoula Aquifer needs to be resolved to clarify $^3H/^3He$ ages.

5. The model-simulated ages fit within the ranges of $^3H/^3He$ ages only at the Madison and South/Bancroft sites. In an attempt to explain the apparent discrepancies, the hydraulic conductivity distribution was uniformly reduced by 50% and α_L was

increased from 10 feet to 300 feet. Neither of these changes alone or together could make the model-simulated and $^3H/^3He$ ages agree at the Bitterroot River. Recharge of ^3H-free water from the Tertiary sediments at these sites may be a possible explanation. In equation 1, as the ^3H concentration decreases, the groundwater age increases.

6. Observed ^3H concentrations indicate young groundwater and ranged from 8.50 to 13.85 TU. Tritium concentration spikes down flowpath of the river recharge source most likely suggest a variation of ^3H levels in the local river recharge source and/or unidentifiable complexities in groundwater flow paths.
7. Examination of a well perforated in what was considered to be both the Missoula Aquifer and the underlying Tertiary sediments indicated a slight downward gradient within 2,900 feet of the Clark Fork River.
8. Upward gradients seen at the Blaine/Crosby well nest in four of the six measurements and at the Larchmont well nest in four of the five measurements lend support to the hypothesis that recharge from the Tertiary sediments enters the Missoula Aquifer at these sites.

Recommendations

Maintaining the quantity and quality of water in the Missoula Aquifer will require additional refinement of the aquifer flow dynamics and geochemistry. The following recommendations for further and improved research are made:

- To refine the hydraulic conductivity distribution of and flow velocities within the Missoula Aquifer, further modeling of flowpaths should be performed using two-dimensional profile and/or three-dimensional models. This would allow for additional refinement of hydraulic conductivity values as reported by Miller (1991).

- To obtain closer agreement between the model-simulated ages and the $^3H/^3He$ ages, transient models, simulating temporal watertable gradient changes, should be run.
- To refine flow velocities and hydraulic conductivity values near the Clark Fork River, sampling of river recharge pulses should be performed again. The high precision of the SC meter and nearness of University of Montana wells to the Clark Fork River makes sampling of river recharge pulses very easy. Ideally, this experiment should be performed during a spring runoff event with a large contrast in water quality; sampling should be performed daily and/or multiple times during a day.
- To improve groundwater age estimates using the $^3H/^3He$ method and to refine hydraulic conductivity values, the terrigenic $^3He/^4He$ ratio of the aquifer needs to be assessed so that more precise $^3H/^3He$ ages can be computed. A study should be undertaken to further explore the association of radon and terrigenic He and their spatial distributions in the aquifer, particularly in regards to the local geology.
- For better refinement of the internal dynamics of the Missoula Aquifer and to assess evidence of recharge to the Missoula Aquifer from the Tertiary sediment, continuous water level recorders should be installed at the Blaine/Crosby and Larchmont well nests. At the Blaine/Crosby and Larchmont well nests, the head measurement and head difference errors were ± 0.14 and ± 0.28 ft, respectively. This estimated error was a combination of surveying and measurement error. Installing continuous water level recorders at well nests finished in the Missoula Aquifer would allow continuous measurement and greatly reduced error. With continuous measurement, the

occurrence of vertical gradients year-round and the effect of storm events and spring runoff on vertical gradients could be investigated.

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Appendix A

Well Inventory

Well Inventory

M: Number	WQD-ID	Latitude	Longitude	Name	Location	Depth, ft	Perforations. ft
143740		46.8947	-114.0395	Holiday	2325 S. Reserve	99	Open hole
69147		46.8562	-114.0126	Gordon	South side of Mount Ave: between Stephens & Russell	98	Open hole
69344		46.8420	-114.0283	Fowler	2006 Ernest Ave.	90	Open hole
69402	WQD-32	46.8491	-114.0072	South/Bancroft	South/Bancroft	76.3	60.3 - 70.3
69055	WQD-30	46.8732	-114.0099	McCormick	McKormick Park	57	28 - 48
151101	WQD-7	46.8558	-114.0916	Humble/Mount	Humble/Mount	25	5 - 25
151143	WQD-10	46.8680	-114.0291	Emma Dickinson	Emma Dickinson School	45	20 - 45
151161	WQD-8	46.8505	-114.0397	CS Porter	CS Porter School	53	33 - 53
151189	WQD-33	46.8583	-114.0605	Tower	Tower St.	50	38 - 48
151190	WQD-31	46.8558	-114.0015	Blaine/Crosby-shallow	Blaine St./Crosby St.	76.3	66.3 - 76.3
157208	WQD-21	46.8558	-114.0015	Blaine/Crosby-deep	Blaine St./Crosby St.	113	113 - 118
151201	WQD-6	46.8383	-114.0426	Larchmont-shallow	Post Siding Rd.	51	31 - 51
157210	WQD-20	46.8386	-114.0426	Larchmont-deep	Post Siding Rd.	97	87 - 97
151191	WQD-29	46.8661	-113.9883	Madison	Madison St.	53	31 - 51
151200	WQD-5	46.8661	-114.0511	Hawthorne	Hawthorne School	35	10 - 35
67037	WQD-35	46.8334	-114.0508	Buckhouse	Buckhouse bridge	38	24 - 36
121525		46.8579	-113.9850	Chem/Pharm	University of Montana	191.99	110 - 135 154 - 168
143129		46.8601	-113.9800	Music Building	University of Montana	140.5	125.5 - 140.5
160376		46.8619	-113.9827	Lodge Building	University of Montana	128.7	118.7 - 128.7

M: Number: State designation.
WQD ID: Monitoring well owned by City of Missoula.

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: HOLIDAY COMPANYS

GWIC Id: 143740
Location (TRS): 13N 19W 30 DDDD
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: 65
Certificate of Survey: Not Reported

Source of Data: LOG
Latitude (dd): 46.8497
Longitude (dd): -114.0395
Geomethod: NAV-GPS
Datum: 1927
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 99.00
Static Water Level (ft): 39.00
Pumping Water Level (ft): 50.00
Yield (gpm): 100.00
Test Type: AIR
Test Duration: 1.00
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: ROTARY
Driller's Name: CAMP
Driller License: WWC007
Completion Date: Jul 29,1994
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: PUBLIC WATER SUPPLY
Geology/Aquifer: 120SNGR

Hole Diameter Information

No hole diameter records were found.

Annular Seal Information

From	To	Type
0	20.0	BENTONITE SURF. SEAL

Casing Information

From	To	Diameter	Type
-1.5	99.0	6.0	STEEL

Completion Information

No completion records were found.

Lithology Information

From	To	Description
0	39.0	CLAY SAND GRAVEL & BOULDERS
39.0	47.0	CLAY
47.0	56.0	CLAY SAND GRAVEL & WATER
56.0	67.0	CLAY AND GRAVEL
67.0	76.0	CLAY SAND GRAVEL & WATER
76.0	84.0	CLAY
84.0	89.0	CLAY SAND & WATER
89.0	99.0	SAND GRAVEL & WATER

Site Notes

GAS STATION ON WEST SIDE OF RESERVE ST WHERE SOUTH AVE INTERSECTS RESERVE

Well Notes

WELL IS IN USE AT CAR WASH

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: GORDON CONST.

GWIC Id: 69147
Location (TRS): 13N 19W 28 CBAA
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: 10
Lot: 9-12
Certificate of Survey: Not Reported

Source of Data: GW2
Latitude (dd): 46.8562
Longitude (dd): -114.0126
Geomethod: NAV-GPS
Datum: 1927
Addition: UNION
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 78.00
Static Water Level (ft): 48.00
Pumping Water Level (ft): 63.00
Yield (gpm): 90.00
Test Type: AIR
Test Duration: 4.00
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: CABLE
Driller's Name: LIBERTY
Driller License: WWC052
Completion Date: Mar 04,1965
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: DOMESTIC
Geology/Aquifer: 112ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
-1.8	78.0	6.0	STEEL

Annular Seal Information

No annular seal records were found.

Completion Information

No completion records were found.

Lithology Information

From	To	Description
0	8.0	COBBLESTONES AND BOULDERS MIXED IN TAN SILT.
8.0	42.0	COBBLESTONES AND BOULDERS MIXED IN TAN CLAY
42.0	64.0	SAND AND GRAVEL
64.0	71.0	BROWN SANDY CLAY
71.0	75.0	FINE SAND AND GRAVEL. SOME WATER
75.0	78.0	CLEAN COARSE GRAVEL. WATER

Site Notes

WELL IS ON SOUTH SIDE OF MOUNT BETWEEN RUSSEL AND STEPHENS

Well Notes

NO ACCESS TO WELL HEAD. SAMPLED FOR ISOTOPES ALSO

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: FOWLER BRUCE

GWIC Id: 69344
Location (TRS): 13N 19W 32 BDDD
County (MT): MISSOULA
DNRC Water Right: 17945
PWS Id: 02661002
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: LOG
Latitude (dd): 46.8420
Longitude (dd): -114.0283
Geomethod: NAV-GPS
Datum: 1927
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 126.00
Static Water Level (ft): 42.00
Pumping Water Level (ft): 44.00
Yield (gpm): 99.00
Test Type: PUMP
Test Duration: 2.00
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: ROTARY
Driller's Name: CAMP
Driller License: WWC239
Completion Date: Jan 01,1978
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: PUBLIC WATER SUPPLY
Geology/Aquifer: 111ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
-2.0	126.0	6.0	STEEL

Annular Seal Information

No annular seal records were found.

Completion Information

No completion records were found.

Lithology Information

From	To	Description
0	9.0	CLAY SAND AND GRAVEL
9.0	18.0	SAND AND GRAVEL
18.0	55.0	CLAY GRAVEL AND BOULDERS
55.0	76.0	SAND GRAVEL AND WATER
76.0	83.0	TAN CLAY
83.0	94.0	CLAY AND GRAVEL
94.0	115.0	SAND GRAVEL AND WATER
115.0	126.0	CLAY LARGE GRAVEL SAND AND WATER

Site Notes

WELL IS LOCATED IN FRONT OF RESTAURANT/CASINO, ON SE SIDE ADJACENT TO SHRUBS

Well Notes

No notes were found.

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: MISSOULA VALLEY WQD WELL U131933A

GWIC Id: 69402
Location (TRS): 13N 19W 33 BAAA
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: LOG
Latitude (dd): 46.8491
Longitude (dd): -114.0072
Geomethod: MAP
Datum: 1927
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 76.30
Static Water Level (ft): 65.00
Pumping Water Level (ft): 76.00
Yield (gpm): 10.00
Test Type: AIR
Test Duration: .50
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: ROTARY
Driller's Name: CAMP
Driller License: WWC007
Completion Date: Apr 07,1986
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 110ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
0	20.0	6.0	STEEL
0	70.3	4.0	PVC

Annular Seal Information

From	To	Type
0	20.0	CEMENT

Completion Information

From	To	Diameter	Description
60.3	70.3	4.0	#60 SLOT

Lithology Information

From	To	Description
0	7.0	FILL
7.0	15.0	SAND AND GRAVEL
15.0	20.0	FINE SAND: NOT MANY COBBLES - BIT DROPPED FAST
20.0	30.0	MEDIUM SAND AND GRAVEL: 15-20' INCREASE IN WATER
30.0	40.0	SAND AND GRAVEL: ROUNDED - COARSE GRAINED GRAVEL SAND - DRY.
40.0	50.0	MEDIUM GRAINED SAND AND GRAVEL - 39' MOIST COARSE SAND AND GRAVEL: 45' DRYING OUT.
50.0	60.0	SAND AND GRAVEL: FINE SAND AND FINE GRAVEL. MOIST AT 53' - AT 55' STARTED USING DRILLING FLUID. COARSE SAND AND GRAVEL.
60.0	70.3	COARSE GRAVEL. BOTTOM OF HOLE AT 70.25'

Site Notes

WELL ALSO KNOWN AS MV-42; SOUTH BANCROFT

Well Notes

No notes were found.

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: WQD-30 (U. OF MONT. MV-35)

GWIC Id: 69055
Location (TRS): 13N 19W 21 ACADA
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: LOG
Latitude (dd): 46.8732
Longitude (dd): -114.0023
Geomethod: TRS-TWN
Datum: 1927
Addition: MCCORMICK PARK
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 57.00
Static Water Level (ft): 32.00
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: ROTARY
Driller's Name: CAMP
Driller License: WWC007
Completion Date: Dec 16, 1985
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: OTHER
Geology/Aquifer: 110ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
-2.5	57.0	6.0	STEEL

Annular Seal Information

From	To	Type
0	20.0	CEMENT

Completion Information

From	To	Diameter	Description
28.0	48.0	6.0	1/8X1 SLOTS

Lithology Information

From	To	Description
0	40.0	CLAY SAND AND GRAVEL
40.0	45.0	CLAY
45.0	57.5	SILTY CLAY SAND AND GRAVEL

Site Notes

MONITOR WELL IN MCCORMICK PARK

Well Notes

No notes were found.

Montana Bureau of Mines and Geology -- Ground-water Information Center
Site Report for MISSOULA COUNTY WQD WELL W132026D

Location Information

GWIC Id:	151101	Source of Data:	MCWQD
Location (TRS):	13N 20W 26 DBBB	Latitude (dd):	46.8558
County (MT):	MISSOULA	Longitude (dd):	-114.0916
DNRC Water Right:	Not Reported	Geomethod:	MAP
PWS Id:		Datum:	1927
Block:	Not Reported	Addition:	Not Reported
Lot:	Not Reported	Subdivision:	Not Reported
Certificate of Survey:	Not Reported	Type Of Site:	WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft):	25.00	How Drilled:	AIR ROTARY
Static Water Level (ft):	14.00	Driller's Name:	WESTERN WATER WORKS
Pumping Water Level (ft):		Driller License:	Not Reported
Yield (gpm):		Completion Date:	Jan 12, 1995
Test Type:	Not Reported	Special Conditions:	None Reported
Test Duration:		Is Well Flowing?:	No
Drill Stem Setting (ft):		Shut-In Pressure:	
Recovery Water Level (ft):		Well/Water Use:	MONITORING
Recovery Time (hrs):		Geology/Aquifer:	111ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Dia	Description
0.0	25.0	4.0	PVC

Annular Seal Information

From	To	Description
0.0	6.0	BENTONITE/CONCRETE

Completion Information

From	To	Dia	Description
5.0	25.0	4.0	.02 SLOT SCREEN

Lithology Information

From	To	Description
0.0	1.0	TOPSOIL
1.0	12.0	BROWN SAND AND GRAVEL WITH SOME STRINGERS OF TAN CLAY
12.0	29.0	SAND & GRAVEL WET MED-GRAINED SAND SOME SILT
29.0	33.0	SAND AND GRAVEL - SOME SILT

Site Notes
WELL ALSO KNOWN AS WQD-7 WELL LOCATED AT THE SOUTHEAST CORNER OF HUMBLE STREET AND MOUNT AVENUE.

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: MISSOULA COUNTY WQD WELL W131920C

GWIC Id: 151143
Location (TRS): 13N 19W 20 CADA
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: Not Reported
Latitude (dd): 46.8680
Longitude (dd): -114.0291
Geomethod: MAP
Datum: 1927
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 45.00
Static Water Level (ft): 27.00
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: ROTARY
Driller's Name: WESTERN
Driller License: Not Reported
Completion Date: Jan 17,1995
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 110ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
0	20.0	4.0	PVC

Annular Seal Information

From	To	Type
0	15.0	BENTONITE/CONCRETE

Completion Information

From	To	Diameter	Description
20.0	45.0	4.0	0.02 SLOT

Lithology Information

From	To	Description
0	0.5	ASPHALT
0.5	9.0	SAND AND GRAVEL
9.0	24.0	GRAVEL AND SAND WITH CLAY LENSES
24.0	25.0	CLAY - BROWN
25.0	45.0	GRAVEL AND CLAY

Site Notes

WELL ALSO KNOWN AS WQD-10 WELL LOCATED IN BACK PARKING LOT OF EMMA DICKINSON SCHOOL.

Well Notes

No notes were found.

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: MISSOULA COUNTY WQD WELL W131930D

GWIC Id: 151161
Location (TRS): 13N 19W 30 DDADD
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: MCWQD
Latitude (dd): 46.8513
Longitude (dd): -114.0394
Geomethod: MAP
Datum: 1927
Addition: C.S. PORTER SCHOOL
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 53.00
Static Water Level (ft): 39.00
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: ROTARY
Driller's Name: WESTERN
Driller License: Not Reported
Completion Date: Jan 16,1995
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 110ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
0	53.0	4.0	PVC

Annular Seal Information

From	To	Type
0	10.0	BENTONITE/CONCRETE

Completion Information

From	To	Diameter	Description
33.0	53.0	4.0	0.020 SLOT

Lithology Information

From	To	Description
0	1.0	TOPSOIL
1.0	30.0	BROWN SAND AND GRAVEL WITH SOME TAN CLAY
30.0	32.0	MEDIUM BROWN SAND
32.0	38.0	BROWN SAND AND GRAVEL
38.0	53.0	BROWN SAND AND GRAVEL - WATER

Site Notes

WELL ALSO KNOWN AS WQD-8 WELL LOCATED AT C.S. PORTER SCHOOL - SOUTHEAST CORNER

Well Notes

No notes were found.

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: MISSOULA COUNTY WQD WELL U132025D

GWIC Id: 151189
Location (TRS): 13N 20W 25 ADAD
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: WDB
Latitude (dd): 46.8583
Longitude (dd): -114.0605
Geomethod: MAP
Datum: 1927
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 50.00
Static Water Level (ft): 25.20
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: Not Reported
Driller's Name: Not Reported
Driller License: Not Reported
Completion Date: Dec 13,1985
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 110ALVM

Hole Diameter Information

No hole diameter records were found.

Annular Seal Information

No annular seal records were found.

Casing Information

From	To	Diameter	Type
0	50.0	6.0	STEEL

Completion Information

From	To	Diameter	Description
38.0	48.0	6.0	

Lithology Information

From	To	Description
0	5.0	SAND: FINE TO MEDIUM SAND WITH CHIPS - GRANULES AND A FEW SMALL PEBBLES.
5.0	10.0	CHIPS: PREDOMINANTLY CHIPS OF RED AND GREEN QUARTZITE AND PULVERIZED ROCK: ALSO SOME SAND - SOME 5CM COBBLES. HAND DRILLING FROM 7' TO 15'.
10.0	15.0	SAND: CHIPS OF RED AND GREEN QUARTZITE AND SILTITE - FINE SAND - COME PEBBLES.
15.0	20.0	SAND: BIG QUARTZITE CHIPS - FINE SAND AND PEBBLES.
20.0	25.0	SAND: MOIST COARSE SAND WITH 5CM PEBBLES (23-26').
25.0	30.0	CLAY AND PEBBLES AND SAND: WATER AND FIRST CLAY AT 26'.
30.0	35.0	CLAY: LOTS OF CLAY WITH SILT AND SAND. CLAY GETS CLEANER DOWNWARD.
35.0	37.0	CLAY: FAIRLY CLEAN CLAY - LITTLE SAND - FEW PEBBLE (HAD TO ADD WATER AT 38-39'). COULDN'T TAKE WATER LEVEL WHEN ADD 40-60' PIPE DUE TO CLOGGED DRILL STEM.
37.0	40.0	GRAVEL AND MUD: GRAVEL AND MUD WITH CHIPS AND 2-3 CM PEBBLES.
40.0	50.0	GRANULES: GRANULES - PEBBLES - SOME COBBLES. LOTS OF WATER AND MEDIUM SAND.

Site Notes

WELL ALSO KNOWN AS MV-40 WELL IS LOCATED SOUTH OF SPURGIN ROAD BETWEEN THE BASEBALL FIELDS AND THE STATE LAND'S OFFICE.

Well Notes

No notes were found.

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: MISSOULA COUNTY WQD WELL U131928A

GWIC Id: 151190
Location (TRS): 13N 19W 28 ACDAA
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: WDB
Latitude (dd): 46.8578
Longitude (dd): -114.0021
Geomethod: NAV-GPS
Datum: 1983
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 76.30
Static Water Level (ft): 66.00
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: Not Reported
Driller's Name: Not Reported
Driller License: Not Reported
Completion Date: Apr 07,1986
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 111ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
0	76.3	4.0	PVC

Annular Seal Information

From	To	Type
0	20.0	GROUT

Completion Information

From	To	Diameter	Description
66.3	76.3	4.0	#60 SLOT

Lithology Information

From	To	Description
0	15.0	SAND AND GRAVEL
15.0	25.0	GRAVEL
25.0	30.0	COARSE GRAINED SAND AND GRAVEL.
30.0	35.0	VERY FINE GRAINED SAND - CLAY - AND GRAVEL.
35.0	70.0	COARSE GRAINED GRAVEL
70.0	76.3	BOTTOM OF HOLE

Site Notes

WELL ALSO KNOWN AS MV-41 WELL IS LOCATED AT THE SOUTHWEST CORNER OF BLAINE AND CROSBY STREETS, AT ADDRESS 601-DEEP WELL (WQD-21 IS LABELED "DEEP" ON PVC CAP.

Well Notes

No notes were found.

Montana Bureau of Mines and Geology -- Ground-water Information Center
Site Report for MISSOULA WATER QUALITY DISTRICT

Location Information

GWIC Id: 157208
Location (TRS): 13N 19W 28 ACDAA
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: LOG
Latitude (dd): 46.8578
Longitude (dd): -114.0021
Geomethod: NAV-GPS
Datum: 1983
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 113.00
Static Water Level (ft):
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: Not Reported
Driller's Name: MISSOULA WQ DISTRICT
Driller License: Not Reported
Completion Date: Feb 09, 1996
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 111ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Dia	Description
0.0	58.0	8.0	STEEL
0.0	113.0	4.0	PVC

Annular Seal Information

From	To	Description
50.0	110.0	BENTONITE

Completion Information

From	To	Dia	Description
113.0	118.0	4.0	.020 SCREEN

Lithology Information

From	To	Description
0.0	1.0	TOPSOIL
1.0	24.0	SANDY GRAVEL GREY/BROWN
24.0	27.0	SILT SOME SAND & GRAVEL
27.0	34.0	SANDY GRAVEL
34.0	47.0	GRAVEL W/ SOME SILT & SAND
47.0	57.0	SANDY GRAVEL LITTLE TO NO SILT
57.0	63.0	GRAVEL
63.0	67.0	CLAYEY GRAVEL
67.0	118.0	SANDY GRAVEL WB

Site Notes
WELLS ARE LOCATED ON CORNERE OF BLAINE & CROSBY, NEXT TO ROAD INFRONT OF ADDRESS 601

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: MISSOULA COUNTY WQD * W131931

GWIC Id: 151201
Location (TRS): 13N 19W 31 DDBA
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: MCWQD
Latitude (dd): 46.8383
Longitude (dd): -114.0426
Geomethod: NAV-GPS
Datum: 1983
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 51.00
Static Water Level (ft): 39.00
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: ROTARY
Driller's Name: WESTERN
Driller License: Not Reported
Completion Date: Jan 13,1995
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 111ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
0	51.0	4.0	PVC
1.5	6.5	6.0	STEEL

Annular Seal Information

From	To	Type
0	24.0	BENTONITE/CONCRETE

Completion Information

From	To	Diameter	Description
31.0	51.0	4.0	0.020 SLOT

Lithology Information

From	To	Description
0	1.0	TOPSOIL
1.0	4.0	SAND - FINE GRAINED BROWN IN COLOR
4.0	12.0	GRAVEL
12.0	13.0	SAND - FINE GRAINED BROWN IN COLOR
13.0	15.0	GRAVEL
15.0	17.0	CLAY - BROWN
17.0	18.0	GRAVEL AND CLAY
18.0	24.0	SAND - BROWN - WET
24.0	39.0	SAND AND GRAVEL
39.0	44.0	SAND AND GRAVEL - SOME CLAY
44.0	45.0	GRAVEL AND CLAY
45.0	51.0	GRAVEL _ SOME SILT AND CLAY.

Site Notes

LARCHMONT GOLF COURSE NEAR GATE ON POST SIDING ROAD

Well Notes

No notes were found.

Location Information

GWIC Id: 157210
Location (TRS): 13N 19W 31 DDBA
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: LOG
Latitude (dd): 46.8386
Longitude (dd): -114.0426
Geomethod: NAV-GPS
Datum: 1927
Addition: LARCHMONT GOLF COURSE
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 97.00
Static Water Level (ft): 38.00
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: Not Reported
Driller's Name: WESTERN
Driller License: Not Reported
Completion Date: Jan 30, 1996
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 111ALVM

Hole Diameter Information

No hole diameter records were found.

Annular Seal Information

From	To	Description
1.0	85.0	BENTONITE

Lithology Information

From	To	Description
0.0	1.0	TOPSOIL
1.0	5.0	BROWN LOAM
5.0	20.0	SANDY GRAVEL
20.0	30.0	SILTY SAND W/ SOME CLAY
30.0	35.0	SANDY GRAVEL W/ SOME SILT
35.0	46.0	SANDY GRAVEVL W/ CLAY & SILT
46.0	67.0	SILTY GRAVEL WATER
67.0	75.0	SANDY GRAVEL WATER
75.0	80.0	SAND GREY/BROWN WATER
80.0	96.0	GRAVEL W/ SAND
96.0	102.0	CLAYEY SILT NON-WATER BEARING

Casing Information

From	To	Dia	Description
0.0	6.0	6.0	STEEL
0.0	87.0	4.0	PVC

Completion Information

From	To	Dia	Description
87.0	97.0	4.0	.020 SCREEN

Site Notes
WELL AT LARCHMONT GOLF COURSE; WELLS ARE LOCATED AT THE PUBLIC GOLF COURSE ADJACENT TO LARGE GATES IN FENCE (LOCKED), JUST OFF CORNER OF OLD HIGHWAY 93 AND POST SIDING-DEEP WELL IS LABELED ON PVC CAP

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: MISSOULA COUNTY WQD WELL U131922C

GWIC Id: 151191
Location (TRS): 13N 19W 22 CDABD
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: WDB
Latitude (dd): 46.8666
Longitude (dd): -113.9878
Geomethod: TRS-SEC
Datum: 1927
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 53.00
Static Water Level (ft): 36.40
Pumping Water Level (ft):
Yield (gpm): 25.00
Test Type: AIR
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: Not Reported
Driller's Name: Not Reported
Driller License: Not Reported
Completion Date: Dec 16,1985
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 110ALVM

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
0	20.0	10.0	STEEL
15.0	53.0	6.0	STEEL

Annular Seal Information

No annular seal records were found.

Completion Information

From	To	Diameter	Description
31.0	51.0	6.0	DOWN HOLE PERF

Lithology Information

From	To	Description
0	5.0	SOIL: DARK - SANDY - OM RICH.
5.0	10.0	SILTY SAND: LIGHT TAN TO FLESH - SOME PEBBLE CHIPS
10.0	15.0	SILTY SAND: TAN WITH SOME PEBBLES AND COBBLE CHIPS (RED AND GREEN QUARTZITES AND SILTITES).
15.0	23.0	SAMPLE: WET GROUND.
23.0	30.0	SAND AND GRAVEL: WET PEBBLES AND COBBLES - RED AND GREEN SILTITES AND QUARTZITES.
30.0	35.0	SAND AND GRAVEL: WET - PEBBLES AND COBBLES - MANY PEBBLES 2-3CM.
35.0	41.0	FIRST WATER: AT 43' GOOD CLEAN GRAVEL.
41.0	45.0	CLEAN GRAVEL.
45.0	54.5	CLEAN GRAVEL. WENT 11.5' BEYOND SWL TO ALLOW FOR 10' OF PERFORATED WELL CASING.

Site Notes

WELL ALSO KNOWN AS MV-34 WELL IS LOCATED AT THE SOUTH END OF THE MADISON STREET BRIDGE - PARCEL 3

Well Notes

No notes were found.

GWIC Site Report

Montana Bureau of Mines and Geology
Ground-Water Information Center

Owner and Location Information

Site Name: MISSOULA COUNTY WQD * W131919C

GWIC Id: 151200
Location (TRS): 13N 19W 19 CDAAC
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: MCWQD
Latitude (dd): 46.8668
Longitude (dd): -114.0507
Geomethod: Not Reported
Datum: 1983
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 35.00
Static Water Level (ft): 20.00
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: AIR ROTARY
Driller's Name: WESTERN WATER WORKS
Driller License: Not Reported
Completion Date: Jan 11,1995
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: Not Reported

Hole Diameter Information

No hole diameter records were found.

Casing Information

From	To	Diameter	Type
0	6.0	6.0	STEEL
0	35.0	4.0	PVC

Annular Seal Information

From	To	Type
0	4.0	BENTONITE/CONCRETE

Completion Information

From	To	Diameter	Description
10.0	35.0	4.0	0.020 SLOT

Lithology Information

From	To	Description
0	0.5	ASPHALT
0.5	2.0	SAND AND GRAVEL
2.0	3.0	CLAY AND GRAVEL
3.0	6.0	SAND - MEDIUM GRAINED - BROWN IN COLOR
6.0	20.0	SAND AND GRAVEL - SOME DISTINCT LAYERS OF SAND.
20.0	35.0	SILTY SAND AND GRAVEL

Site Notes

No notes were found.

Well Notes

No notes were found.

Montana Bureau of Mines and Geology -- Ground-water Information Center
Site Report for MISSOULA COUNTY WQD WELL U 122001 A

Location Information

GWIC Id: 67037
Location (TRS): 12N 20W 01 ABAD
County (MT): MISSOULA
DNRC Water Right: Not Reported
PWS Id:
Block: Not Reported
Lot: Not Reported
Certificate of Survey: Not Reported

Source of Data: LOG
Latitude (dd): 46.8334
Longitude (dd): -114.0508
Geomethod: TRS-TWN
Datum: 1927
Addition: Not Reported
Subdivision: Not Reported
Type Of Site: WELL

Well Construction and Performance Data (measurements are reported below land surface)

Total Depth (ft): 38.00
Static Water Level (ft): 27.00
Pumping Water Level (ft):
Yield (gpm):
Test Type: Not Reported
Test Duration:
Drill Stem Setting (ft):
Recovery Water Level (ft):
Recovery Time (hrs):

How Drilled: FORWARD ROTARY
Driller's Name: CAMP
Driller License: WWC007
Completion Date: Dec 20, 1985
Special Conditions: None Reported
Is Well Flowing?: No
Shut-In Pressure:
Well/Water Use: MONITORING
Geology/Aquifer: 111ALVM

Hole Diameter Information

No hole diameter records were found.

Annular Seal Information

No annular seal records were found.

Casing Information

From	To	Dia	Description
-2.5	38.0	6.0	STEEL

Completion Information

From	To	Dia	Description
24.0	36.0	6.0	1/8IN TORCH SLOT

Lithology Information

From	To	Description
0.0	5.0	SAND: BUFF COLORED - MEDIUM/FINE SAND WITH CUTTINGS - GRANULES AND SOME PEBBLES.
5.0	10.0	SAND: FINE-MEDIUM SAND WITH RED AND GREEN QUARTZITE PEBBLES AND CHIPS.
10.0	15.0	LOTS OF QUARTZITE CUTTINGS - MAINLY RED WITH SOME
15.0	15.0	GREEN. LITTLE FIME SAND - SOME 2-3 CM PEBBLES
15.0	17.0	SAND AND GRANULES: (NO SAMPLE - BUT MORE FINE SAND AND GRANULES).
17.0	20.0	SAND AND GRANULES. fINE SAND WITH GREEN AND RED QUARTZITES IN CHIPS AND PEBBLES UP TO 3 CM.
20.0	25.0	SAND: MOIST - COARSE TO MEDIUM SAND WITH 4 CM PEBBLES AND CHIPS.
25.0	30.0	SAND: MOIST TO WET - COARSE SAND WITH RED AND GREEN QUARTZITE PEBBLES.
30.0	35.0	SAND: COARSE SAND WITH ARGILLITE CHIPS/GRANULES AND QUARTZITE PEBBLES TO 4 CM.
35.0	38.0	SAND: COARSE SAND TO GRANULES - FEW QUARTZITE CHIPS AND PEBBLES.

Site Notes
WELL IS ALSO KNOWN AS BUCKHOUSE BRIDGE (UMMV-39)

M 121 7 ? ?

Form No. 603 (R 2-85)

WELL LOG REPORT

File No. ______

State law requires that the Bureau's copy be filed by the water well driller within 60 days after completion of the well.

1. WELL OWNER
Name: UNIVERSITY OF MONTANA

2. CURRENT MAILING ADDRESS
Missoula, MT 59812-1371

3. WELL LOCATION
SW ¼ NE ¼ ______ ¼ Section 27
Township 13N N/S Range 19W E/W County Missoula
Govn't Lot ______, or Lot ______, Block ______
Subdivision Name ______
Tract Number ______

4. PROPOSED USE: Domestic ☐ Stock ☐ Irrigation ☐
Other ☒ specify Test Well

5. TYPE OF WORK:
New well ☒ Method: Dug ☐ Bored ☐
Deepened ☐ Cable ☐ Driven ☒
Reconditioned ☐ Rotary ☒ Jetted ☐

6. DIMENSIONS: Diameter of Hole
Dia. 8" in. from g.l. ft. to 300 ft.
Dia. ______ in. from ______ ft. to ______ ft.
Dia. ______ in. from ______ ft. to ______ ft.

7. CONSTRUCTION DETAILS:
Casing; Steel Dia. 8" ID from +2'2" ft. to 198'2 ft.
Threaded ☐ Welded ☒ Dia. ______ from ______ ft. to ______ ft.
Type ______ Wall Thickness .250
Casing; Plastic Dia. ______ from ______ ft. to ______ ft.
Weight ______ Dia. ______ from ______ ft. to ______ ft.
PERFORATIONS: Yes ☒ No ☐
Type of perforator used pulldown
Size of perforations 1 in. by 1/8 in.
______ perforations from 110 ft. to 135 ft.
______ perforations from 154 ft. to 168 ft.
______ perforations from ______ ft. to ______ ft.
SCREENS: Yes ☐ No ☒
Manufacturer's Name ______
Type ______ Model No. ______
Dia. ______ Slot size ______ from ______ ft. to ______ ft.
Dia. ______ Slot size ______ from ______ ft. to ______ ft.
GRAVEL PACKED: Yes ☐ No ☒ Size of gravel ______
Gravel placed from ______ ft. to ______ ft.
GROUTED: To what depth? 20 ft.
Material used in grouting bentonite surface seal

8. WELL HEAD COMPLETION:
Pitless Adapter ☐ Yes ☐ No

9. PUMP (if installed)
Manufacturer's name ______
Type ______ Model No. ______ HP. ______

10. WELL TEST DATA
The information requested in this section is required for all wells. All depth measurements shall be from the top of the well casing.
All wells under 100 gpm must be tested for a minimum of one hour and provide the following information:
a) Air ______ Pump x Bailer ______
b) Static water level immediately before testing 78 ft. If flowing; closed-in pressure ______ psi. ______ gpm.
Flow controlled by: ______ valve, ______ reducers, ______ other, (specify) ______.
c) Depth at which pump is set for test 80½
d) The pumping rate: 350 gpm.
e) Pumping water level 80½ ft. at 8 hrs. after pumping began.
f) Duration of test: Pumping time 8 hrs.
g) Recovery time ______ hrs.
h) Recovery water level 78 ft. at ______ hrs. after pumping stopped.

Wells intended to yield 100 gpm or more shall be tested for a period of 8 hours or more. The test shall follow the development of the well, and shall be conducted continuously at a constant discharge at least as great as the intended appropriation. In addition to the above information, water level data shall be collected and recorded on the Department's "Aquifer Test Data" form.

NOTE: All wells shall be equipped with an access port ½ inch minimum or a pressure gauge that will indicate the shut-in pressure of a flowing well. Removable caps are acceptable as access ports.

11. WAS WELL PLUGGED OR ABANDONED? ______ Yes x No
If yes, how? ______

12. WELL LOG

Depth (ft.) From	To	Formation
0	55	Clay, Gravel & Boulders
55	58	Silty Clay & Gravel
58	63	Sand & Gravel
63	72	Clay & Gravel
72	77	Clay
77	84	Clay & Boulders
84	98	Clay, Gravel, Broken Rock
		Boulders & Seeps of Water
98	137	Clay, Sand, Gravel
		Boulders & Water
137	140	Clay,Bouldsers & Water
140	151	Clay & Gravel
151	168	Sand, Gravel, Clay & Water
168	222	Silty Clay, Gravel &
		Seeps of Water
222	223	Boulder
223	232	Silty Clay, Gravel, &
		Seeps of Water
232	248	Hard Clay, Gravel & a few
		Boulders
248	259	Broken Rock & Clay
259	274	Green Clay, Rock & Gravel
274	300	Brown Clay, Green Rock &
		Seeps of Water

ATTACH ADDITIONAL SHEETS IF NECESSARY

13. DATE COMPLETED November 2, 1990

14. DRILLER/CONTRACTOR'S CERTIFICATION
This well was drilled under my jurisdiction and this report is true to the best of my knowledge.

November 7, 1990
Date

CAMP WELL DRILLING & PUMP SUPPLY
Firm Name

1522 S. 14th W., Missoula, MT 59801
Address

Phil Bakke
Signature

7
License No.

MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION
1520 EAST SIXTH AVENUE HELENA, MONTANA 59620-2301 444-6610

DNRC

m No. 603(5 1 87)

WELL LOG REPORT

File No. ______

State law requires that the Bureau's copy be filed by the water well driller within 60 days after completion of the well.

1. WELL OWNER
Name: UNIVERSITY OF MONTANA

2. CURRENT MAILING ADDRESS
Planning & Construction
Missoula, MT 59812

3. WELL LOCATION
E½ ¼ NE ¼ ____ ¼ Section 27
Township 13 N N/S Range 19 W E/W County Missoula
Govn't Lot ______ or Lot ______ Block ______
Subdivision Name ______
Tract Number MUSIC BLDG A/E 93-30-11

4. PROPOSED USE: Domestic ☐ Stock ☐ Irrigation ☐
Other ☒ specify Production

5. TYPE OF WORK:
New well ☒ Method: Dug ☐ Bored ☐
Deepened ☐ Cable ☐ Driven ☒
Reconditioned ☐ Rotary ☒ Jetted ☐

6. DIMENSIONS: Diameter of Hole
Dia. 8 in. from G.L. ft. to 140'5" ft.
Dia. ______ in. from ______ ft. to ______ ft.
Dia. ______ in. from ______ ft. to ______ ft.

7. CONSTRUCTION DETAILS:
Casing: Steel Dia. 8"ID from +1½ ft. to 125'5 ft.
Threaded ☐ Welded ☒ Dia. ______ from ______ ft. to ______ ft.
Type ______ Wall Thickness .250
Casing: Plastic Dia. ______ from ______ ft. to ______ ft.
Weight ______ Dia. ______ from ______ ft. to ______ ft.
PERFORATIONS: Yes ☐ No ☒
Type of perforator used ______
Size of perforations ______ in. by ______ in.
______ perforations from ______ ft. to ______ ft.
______ perforations from ______ ft. to ______ ft.
______ perforations from ______ ft. to ______ ft.

SCREENS: Yes ☒ No ☐
Manufacturer's Name HOUSTON
Type Stainless Model No. ______
Dia. 8" Slot size 125 from 125'5 ft. to 140'5 ft.
Dia. ______ Slot size ______ from ______ ft. to ______ ft.

GRAVEL PACKED: Yes ☐ No ☒ Size of gravel ______
Gravel placed from ______ ft. to ______ ft.

GROUTED: To what depth? 20 ft.
Material used in grouting bentonite surface seal

8. WELL HEAD COMPLETION:
Pitless Adapter ☐ Yes ☐ No

9. PUMP (if installed)
Manufacturer's name ______
Type ______ Model No. ______ HP. ______

10. WELL TEST DATA
The information requested in this section is required for all wells. All depth measurements shall be from the top of the well casing.

All wells under 100 gpm must be tested for a minimum of one hour and provide the following information:

a) Air ______ Pump x Bailer ______
b) Static water level immediately before testing 55 ft. If flowing; closed-in pressure ______ psi. ______ gpm.
Flow controlled by: ______ valve, ______ reducers, ______ other, (specify) ______
c) Depth at which pump is set for test 90
d) The pumping rate: 500 gpm.
e) Pumping water level 74 ft. at 9 hrs. after pumping began.
f) Duration of test: Pumping time 9 hrs.
g) Recovery time ______ hrs.
h) Recovery water level 55 ft. at ______ hrs. after pumping stopped.

Wells intended to yield 100 gpm or more shall be tested for a period of 3 hours or more. The test shall follow the development of the well, and shall be conducted continuously at a constant discharge at least as great as the intended appropriation. In addition to the above information, water level data shall be collected and recorded on the Department's "Aquifer Test Data" form.

NOTE: All wells shall be equipped with an access port ½ inch minimum or a pressure gauge that will indicate the shut-in pressure of a flowing well. Removable caps are acceptable as access ports.

11. WAS WELL PLUGGED OR ABANDONED? ______ Yes x No
If yes, how? ______

12. WELL LOG

Depth (ft.) From	To	Formation
0	9	Black Dirt & Gravel
9	87	Clay, Gravel & Boulders
87	91	Clay, Gravel & Water
91	96	Clay
96	102	Clay & Gravel
102	124	Clay, Sand, & Gravel with seeps of water
124	140'5"	Clay, Sand, Gravel & Water

ATTACH ADDITIONAL SHEETS IF NECESSARY

13. DATE COMPLETED May 17, 1994

14. DRILLER/CONTRACTOR'S CERTIFICATION
This well was drilled under my jurisdiction and this report is true to the best of my knowledge.

June 17, 1994
Date

CAMP WELL DRILLING & PUMP SUPPLY
Firm Name

1522 S. 14th W. Missoula, MT 59801
Address

[signature] 7
Signature License No.

MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION
1520 EAST SIXTH AVENUE HELENA, MONTANA 59620-2301 444-6610
DNRC

Form No. 603 (R5/95)

WELL LOG REPORT

File No. ______

STATE LAW REQUIRES THIS REPORT BE FILED BY THE DRILLER WITH THE DEPARTMENT WITHIN 60 DAYS AFTER WELL COMPLETION.

1. WELL OWNER NAME:
University of Montana

2. CURRENT MAILING ADDRESS:
Missoula, MT. 59812

3. WELL LOCATION:
NW 1/4 NE 1/4 ____ 1/4 SECTION 27
TWP: 13N RGE: 19 W CNTY: Missoula
GOV'T LOT ____ or LOT ____ TRACT/BLK ____
SUBDIVISION NAME Lodge Building

4. PROPOSED USE:
____ DOMESTIC ____ STOCK ____ IRRIGATION
X OTHER: Industrial

5. TYPE OF WORK:
X NEW WELL METHOD: ____ DUG ____ BORED
____ DEEPENED ____ CABLE ____ DRIVEN
____ RECONDITIONED X ROTARY ____ JETTED

6. DIMENSIONS: Diameter of the hole
DIA: 10 in. from G.L. ft. to 128'9" ft.
DIA: ____ in. from ____ ft. to ____ ft.

7. CONSTRUCTION DETAILS:
Casing: Steel: ____ Threaded X Welded
Type: ____ Wall Thickness: .250
Dia. 10 in. from +2 ft. to 128'9" ft.
Dia. ____ in. from ____ ft. to ____ ft.
Casing: Plastic: Weight ____
Dia. ____ in. from ____ ft. to ____ ft.
Dia. ____ in. from ____ ft. to ____ ft.
Perforations: ____ Yes X No
Type of perforator used ____
Size of perforations ____ in. by ____ in.
____ perforations from ____ ft. to ____ ft.
____ perforations from ____ ft. to ____ ft.
Screens: X Yes ____ No
Manufacturer's Name Huston
Type Stainless Steel Model #. ____
Dia. 10 slot size.125 from 116'9" ft. to 128'8"
Dia. ____ slot size ____ from ____ ft. to ____ ft.
Gravel Packed:
____ Yes X No Gravel size: ____
Gravel placed from ____ ft. to ____ ft.
Grouted: To what depth? 20 ft.
Material used in grouting Bentonite Surface Seal

8. WELL HEAD COMPLETION:
Pitless Adaptor ____ Yes ____ No

9. PUMP: (if installed)
Manufacturer's name ____
Type ____ Model # ____ HP ____

10: WELL TEST DATA: This information is required for all wells. All depth measurements shall be from the top of the well casing. Wells under 100 gpm must be tested for a minimum of one hour.
A) X Air X Pump ____ Bailer
B) Static water level immediately before test 79 ft.
Flowing: closed-in pressure ____ psi. ____ gpm
C) Depth pump is set for test: 84 ft.
D) The pumping rate: 635 gpm
E) Pumping water level 83 ft.
at ____ hours after pumping began.
F) Duration of test: Pumping time 7 hours
G) Recovery time: Immediate hours
H) Recovery water level 79 ft.
at ____ hours after pumping stopped.

Wells intended to yield 100 GPM or more shall be tested for a period of 8 hours or more. The test shall follow the development of the well, and shall be conducted continuously at a constant discharge at least as great as the intended appropriation. In addition to the above information, water level data shall be collected and recorded on the Department's Aquifer Test Data form.
NOTE: All wells shall be equipped with an access port 1/2 inch minimum or a pressure gauge that will indicate the shut-in pressure of a flowing well. Removable caps are acceptable as access ports.

11. WAS WELL PLUGGED OR ABANDONED? ____ Yes X No

12. WELL LOG: (Depth in Feet)

FROM	TO	FORMATION
0	4	Top Soil
4	45	Gravel, Boulders
45	128'9"	Gravel, Boulders, Water

Attach additional sheets, if necessary.

13. DATE COMPLETED: November 11, 1996

14. YELLOWSTONE CLOSURE AREA:
Attach supplement identifying applicable items.

15. DRILLER/CONTRACTOR'S CERTIFICATION
This well was drilled under my jurisdiction and this report is true to the best of my knowledge.
Date: January 15, 1997
Firm Name: Camp Well Drilling & Pump Supply
Address: 1522 South 14th St. West, Missoula, Mt. 59801

Signature ____ #7 License No.

MONTANA DEPARTMENT OF NATURAL RESOUCES AND CONSERVATION
1520 E. 6TH AVE., PO BOX 202301, HELENA, MT, 59620-2301 PHONE: 406-444-6610

Appendix B

Water Level Data

Water Levels, ft

WQD ID	M:Number	Location	Measuring Point Elevation	Date	Head Elevation	Depth Below Measuring Point
WQD-29	M:151191	Madison Street	3191.38	6/22/99	3164.18	27.2
				11/4/99	3155.48	35.9
WQD-31	M:151190	Blaine/Crosby (shallow)	3204.27	6/21/99	3144.38	59.89
				11/4/99	3138.19	66.08
WQD-21	M:157208	Blaine/Crosby (deep)	3204.1	6/21/99	3144.65	59.45
				11/4/99	3138.55	65.55
WQD-32	M:69402	South/Bancroft	3193.56	6/23/99	3141.07	52.49
				11/4/99	3135.71	57.85
WQD-6	M:151201	Larchmont (shallow)	3163.19	6/21/99	3131.48	31.71
				11/4/99	3126.54	36.65
WQD-20	M:157210	Larchmont (deep)	3163.56	6/21/99	3131.53	32.03
				11/4/99	3126.61	36.95
WQD-35	M:67037	Buckhouse Bridge	3149.09	6/28/99	3126.81	22.28
				11/3/99	3122.19	26.9
WQD-10	M:151143	Emma Dickinson	3165.88	6/23/99	3145.11	20.77
				11/3/99	3138.18	27.7
WQD-5	M:151200	Hawthorne School	3151.14	6/28/99	3139.13	12.01
				11/3/99	3133.84	17.3
WQD-33	M:151189	Tower Street	3154.43	6/22/99	3131.24	23.19
				11/3/99	3126.26	28.17
WQD-7	M:151101	Humble/Mount	3122.57	6/21/99	3113.79	8.78
				11/4/99	3108.42	14.15
WQD-8	M:151161	C.S.Porter School	3169.67	6/22/99	3137.25	32.42
				11/4/99	3132.57	37.1
WQD-30	M:69055	McCormick Park	3179.29	6/22/99	3153.86	25.43
				11/3/99	3145.99	33.3

Appendix C

CFCs, ^3H and Dissolved Gasses

Sampling Methodology

CFC's

CFC sampling proceeded in the following manner. First, the head was measured. Then, the well was pumped until three well volumes of water were removed and the redox, specific conductivity (SC), temperature and pH of the discharge were stable.

Next, a copper bailer apparatus was used for sampling. A check valve, designed to break at 10 feet below the water level, was fitted to one end of a 3/8 inch o.d., 30 inch long copper sample tube. The other end was attached to a 1 inch o.d., 20 inch long copper tube with an adaptor. The tubes were lowered with 0.25 inch flexible tubing from a reel. Another adaptor connected the flexible tubing and the 20 inch long copper tube. After reeling the tube up to the surface, the standing water level in the flexible tubing was checked. If the water level was visible and no bubbles were visible, no air bubbles were considered to be in the sample tube. Air bubbles in the sample tube will cause excess air contamination. The sample tube was sealed with refrigerator clamps approximately 1.5 inch from the ends. Next, the adaptor was removed and the end capped with water-filled plastic caps to ensure no air bubbles were trapped in the ends. Then, the check valve was removed and the end capped the same way. Three copper sample tubes were used at each well.

^{3}H and Dissolved Gasses

Dissolved gasses were collected by two sampling methods. The copper bailer apparatus described above was used to collect dissolved gas samples during spring runoff conditions in 1999.

Diffusion samplers were used to collect dissolved gas samples during baseflow conditions in 1999. Weights were attached to the sampler and then set at the desired depth. After 2-3 weeks, the gas concentrations in the diffusion samplers had equilibrated with those in the well. The samplers were then retrieved. Tritium samples were collected in glass bottles.

Site	Age, yrs	Age Range, yrs	$^4He_{terr}$* (ccSTP/g)	Excess Air (ccSTP/g)
Clark Fork River	0	0	0	0
McKormick Park	1.7	0.7-2.7	1.30×10^{-8}	0
Emma Dickinson	-0.3	-1.3 – 0.7	2.80×10^{-8}	0.0019
Hawthorne School	-1.5	-3 – 0	2.00×10^{-8}	0.0025
Tower	1.6	0.6 – 2.6	1.70×10^{-8}	0.0026
Humble/Mount	2.2	1.2 – 3.2	1.30×10^{-8}	0.0018
Madison	0.6	-0.4 – 1.6	4.20×10^{-8}	0.0005
Blaine/Crosby-shallow	2.7	1.7 – 3.7	4.00×10^{-8}	0.001
South/Bancroft	0.4	-0.6 – 1.4	2.00×10^{-8}	0.0023
Larchmont-shallow	4.6	3.6 – 5.6	1.60×10^{-8}	0.0011
Larchmont-deep	3.3	2.3 – 4.3	2.10×10^{-8}	0.0018
Buckhouse	3.2	2.2 – 4.2	5.00×10^{-9}	0.0004
Buckhouse	2.5	1.5 – 3.5	3.50×10^{-9}	0.0011

Tritium

Site	^3H, TU	Error -	Error +	Range, TU	
Emma Dickinson	8.67	0.43	0.43	8.24	9.1
McCormick	8.9	0.4	0.4	8.5	9.3
South/Bancroft	9.1	0.5	0.5	8.6	9.6
Buckhouse Bridge	9.44	0.47	0.47	8.97	9.91
Gordon	9.47	0.47	0.47	9	9.94
Hawthorne School	10.1	0.5	0.5	9.6	10.6
Clark Fork River	10.2	0.5	0.5	9.7	10.7
Humble/Mount	10.31	0.52	0.52	9.79	10.83
Larchmont-shallow	12.1	0.6	0.6	11.5	12.7
Larchmont-deep	10.9	0.5	0.5	10.4	11.4
Fowler	11.2	0.56	0.56	10.64	11.76
Madison St	11.21	0.56	0.56	10.65	11.77
Tower St	12.06	0.6	1	11.46	13.06
Blaine/Crosby-shallow	12.38	0.62	0.62	11.76	13
CS Porter School	13.13	1.43	0.72	11.7	13.85
Chem/Pharm	10.1	N/A	N/A		

CFC Data

M: Number	Location	CFC-11, pmol/kg	CFC-12. pmol/kg	CFC-11, pg/kg	CFC-12, pg/kg	Apparent CFC-12 Recharge Year	Ratio CFC-11/CFC-12
151200	Hawthorne School	9.85	5.51	1352.996	666.2141	contaminated	1.8
151143	Emma Dickinson	6.61	4.63	907.9496	559.8133	contaminated	1.4
69055	McCormick Park	4.22	2.86	579.6592	345.8026	1989	1.5
151191	Madison Street	6.75	3.3	927.18	399.003	1999	2.0
151190	Blaine/Crosby (shallow)	6.3	7.5	865.368	906.825	contaminated	0.8
157208	Blaine/Crosby (deep)	5.4	7.94	741.744	960.0254	contaminated	0.7
151161	C.S.Porter School	6.45	75.05	885.972	9074.296	contaminated	0.1
151201	Larchmont (shallow)	10.69	77.68	1468.378	9392.289	contaminated	0.1
157210	Larchmont (deep)	9.34	15.93	1282.942	1926.096	contaminated	0.6
69402	South/Bancroft	6.78	5.62	931.3008	679.5142	contaminated	1.2
151189	Tower Street	13.79	18.99	1894.194	2296.081	contaminated	0.7
151101	Humble/Mount	35.03	51.39	4811.721	6213.565	contaminated	0.7
....	Clark Fork	3.88	3.38	532.957	408.676	1999	1.1

Dissolved Gas Data

Location	N28	Ar40	Ne20	He4	R/Ra	Comment
Gordon	0.019061196	0.000441156	2.34315E-07	1.15523E-07	0.536	
Fowler	0.015025081	0.000334943	1.91963E-07	7.92516E-08	0.697	
South/Bancroft	0.017509106	0.000428118	2.54463E-07	4.69226E-08	0.662	Helium data is approximate
McCormick	0.194000000	0.002430000	4.16E-06	1.47E-06	0.899	Large bubble in sample
Holiday	0.131505881	0.001748123	2.54165E-06	8.59839E-07	0.906	
Humble/Mount	0.01710116	0.000463259	2.2965E-07	6.669E-08	0.882	
Emma Dickinson	0.015736588	0.000444546	1.86892E-07	5.55417E-08	0.873	
CS Porter	0.015573245	0.000422443	2.10547E-07	8.48997E-08	0.640	
Tower	0.016753984	0.000434555	2.51488E-07	7.46102E-08	0.721	
Blaine/Crosby-shallow	Leaked	Leaked	Leaked	Leaked	Leaked	
Madison	0.021653526	0.000535472	3.08991E-07	8.4481E-08	0.859	Moderate amount of excess
Hawthorne	0.016117808	0.000456559	2.06696E-07	5.71387E-08	0.981	
Larchmont-shallow	0.014349446	0.000404276	1.99813E-07	5.71604E-08	0.878	
Blaine/Crosby-deep	0.016587779	0.000404696	2.15388E-07	1.1707E-07	0.479	
Larchmont-deep	0.016429846	0.000420308	2.26561E-07	7.89384E-08	0.737	
Clark Fork	0.013671652	0.000369844	1.83818E-07	4.8322E-08	0.963	

Water samples from spring runoff conditions, 1999. Concentrations in ccSTP/g

Location	XN28	XAr40	XO32	XKr84	XNe20	XHe4	R/Ra
Buckhouse	8.37E-01	9.77E-03	1.53E-01	7.26E-07	1.71E-05	5.78E-06	0.982
Buckhouse	8.53E-01	9.89E-03	1.34E-01	6.45E-07	1.67E-05	5.73E-06	0.965
McCormick	9.85E-01	1.13E-02	1.35E-05	7.91E-07	2.00E-05	8.20E-06	0.798
South/Bancroft	8.63E-01	9.46E-03	1.27E-01	7.03E-07	1.78E-05	7.90E-06	0.733
Humble Mount	8.52E-01	9.55E-03	1.34E-01	6.54E-07	1.74E-05	6.89E-06	0.843
Emma Dickinson	9.74E-01	1.10E-02	1.49E-02	6.16E-07	2.06E-05	1.01E-05	0.656
C.S. Porter	8.78E-01	9.87E-03	1.12E-01	7.14E-07	1.81E-05	9.66E-06	0.634
Tower	8.91E-01	9.78E-03	9.88E-02	7.51E-07	1.87E-05	7.84E-06	0.802
Blaine/Crosby-shallow	9.65E-01	1.10E-02	2.44E-02	7.76E-07	1.94E-05	1.12E-05	0.593
Blaine/Crosby-deep	9.64E-01	1.10E-02	2.55E-02	7.99E-07	1.98E-05	1.36E-05	0.486
Madison	8.97E-01	1.08E-02	9.17E-02	7.41E-07	1.84E-05	1.11E-05	0.540
Hawthorne	9.06E-01	1.00E-02	8.38E-02	7.30E-07	1.91E-05	6.38E-06	0.941
Larchmont-shallow	8.86E-01	9.96E-03	1.04E-01	5.44E-07	1.74E-05	7.26E-06	0.851
Larchmont-deep	9.11E-01	1.02E-02	7.91E-02	5.11E-07	1.86E-05	8.30E-06	0.773
Chem/Pharm (160 ft)	8.60E-01	1.02E-02	1.30E-01	6.81E-07	1.81E-05	9.77E-06	0.585
Chem/Pharm (185 ft)	9.51E-01	1.12E-02	3.80E-02	7.32E-07	1.99E-05	1.13E-05	0.561

Diffusion Samplers from baseflow conditions, 1999. Values above are dry volume fractions in equilibrium with water sample.

Septic Effluent CFC-12 Concentration Calculation

The following describes the method by which the CFC-12 concentration in septic effluent was calculated for the Missoula Aquifer.

First the study area's surface area was divided into NE and SW sections. The division was based on an order of magnitude difference in CFC-12 concentrations seen between the two sections. Then, each section's surface area was estimated by overlaying a transparency grid, counting squares and multiplying the number of squares by the unit surface area.

Surface Areas	
Total surface area	3.82E x 10^8 ft^2
NE section surface area	1.85E x 10^8 ft^2
SW section surface area	1.97E x 10^8 ft^2

Second, within each section, the aquifer depth was split midway between the two perforated intervals of each section's well nest (SW – Larchmont well nest, NE – Blaine/Crosby well nest). The split was based on differences between the deep well's CFC-12 concentration at each section's well nest and the average CFC-12 concentrations of each section's shallow wells. Then, using each the depth of each aquifer fraction and a porosity of 0.2, water volumes for the upper and lower aquifer fractions of each section were estimated.

Water Volumes of the Aquifer Fractions	
Upper aquifer, NE section	1.57E x 10^{10} L
Lower aquifer, NE section	5.77 x 10^{10} L
Upper aquifer, SW section	1.67 x 10^{10} L
Lower aquifer, SW section	1.17 x 10^{11} L

Third, the CFC-12 mass in the aquifer was estimated. For each of the four aquifer fractions, the CFC-12 mass was calculated using the aquifer fraction's average CFC-12 concentration; the total CFC-12 mass of the aquifer was estimated by summing the four CFC-12 masses and equaled 4.02 x 10^{-1} kg.

Spatial average CFC-12 concentrations	
Avg CFC-12, NE, upper,	5.58E x 10^2 pg/kg
Avg CFC-12, NE, lower,	9.60E x 10^2 pg/kg
Avg CFC-12, SW, upper,	6.74E x 10^3 pg/kg
Avg CFC-12, SW, lower,	1.93E x 10^3 pg/kg

Fourth, the portion of the aquifer's CFC-12 mass contributed by the Clark Fork River was calculated and subtracted from the total CFC-12 mass in the aquifer. The fraction of the aquifer's water volume, contributed by the Clark Fork River, was estimated to be 83% (Miller, 1991) or 1.72 x 10^{11} L. The CFC-12 concentration of the Clark Fork River was measured to equal 4.08 x 10^2 pg/kg. Then, the aquifer's CFC-12 mass contributed by the Clark Fork River, was estimated to be 5.95 x 10^{-2} kg. The difference between the aquifer's total CFC-12 mass and the Clark Fork River's contribution equals 4.02 x 10^{-1} kg. This residual was considered the estimated CFC-12 mass contributed by sewage.

Fifth, the septic effluent CFC-12 concentration was calculated. The average total sewage discharge/day for the study area was estimated to equal 836,564 gallons or 3,168,802 L (based on an average discharge of 200 gal/d (Ver Hey, 1987) and 4,186 unsewered units in the study area). The CFC-12 mass contributed by sewage was divided by the average total sewage discharge/day to yield the estimated septic effluent CFC-12 concentration: 1.27 x 10^8 pg/kg.

This is the estimated CFC-12 concentration in septic effluent necessary for the study area's 4,186 unsewered units to add the CFC-12 mass contributed by sewage (4.02 x 10^{-1} kg) to the aquifer in one day.

This calculation described in an equation format would be:

$$[CFC-12]_{septic\_effluent} = \frac{\left[\sum_{i=1}^{4}(V_i * [CFC-12]_i)\right] - \left[0.83 * [CFC-12]_{CFR} * \sum_{i=1}^{4} V_i\right]}{(D * number\_of\_unsewered\_units)}$$

Where 1 = NE portion of the upper aquifer (L), 2 = NE portion of the lower aquifer (L), 3 = SW portion of the upper aquifer (L) and 4 = SW portion of the lower aquifer. V = water volume (L). D = average septic discharge (L)/unit/day.

Appendix D

Tertiary Recharge

Appendix D describes the construction and use of the well packing device that aided in measurement of head differences between the Missoula Aquifer and the underlying Tertiary sediments. Finally, water level measurements made while the packer was in place are listed (Table A.1).

Construction and Use of the Well Packing Device

The packing device was constructed in the following manner (Fig. A.1). To 17 inches of 4 inches i.d. schedule-40 pvc pipe, 3 reducers were attached with pipe cement to reduce to 1.0 inches. A 4 inch inner tube was fitted around the 6 inch o.d. pipe and up against the reducers with silicone caulk. A hole was drilled in the 6 inch o.d. pipe for the inner tube stem to fit through. A 0.25 inch hole was drilled through the largest reducer, through which 0.25 inch o.d. flexible tubing was inserted and attached to the inner tube stem with silicone caulk and a hose ring. The inner tube stem had the needle valve removed.

Before lowering the packing device into the well, the inner tube was deflated with a peristaltic pump to ensure the device would fit down the well casing. When at the desired depth, the inner tube was inflated with a bicycle pump. The surface end of the flexible tubing had a needle valve adaptor attached. A hose clamp sealed the tubing to the adapter.

The packing device was lowered to the desired depth by attaching 20' lengths of schedule-40, 0.25 inch o.d., belled coupling, pvc pipe with pipe cement. The joint was allowed to dry 6 minutes and supported over the well by resting the belled coupling on a plywood jig. Then the packing device and pipe were lowered and allowed to rest on the jig while the next length of pipe was attached. A safety line was tied to the packing

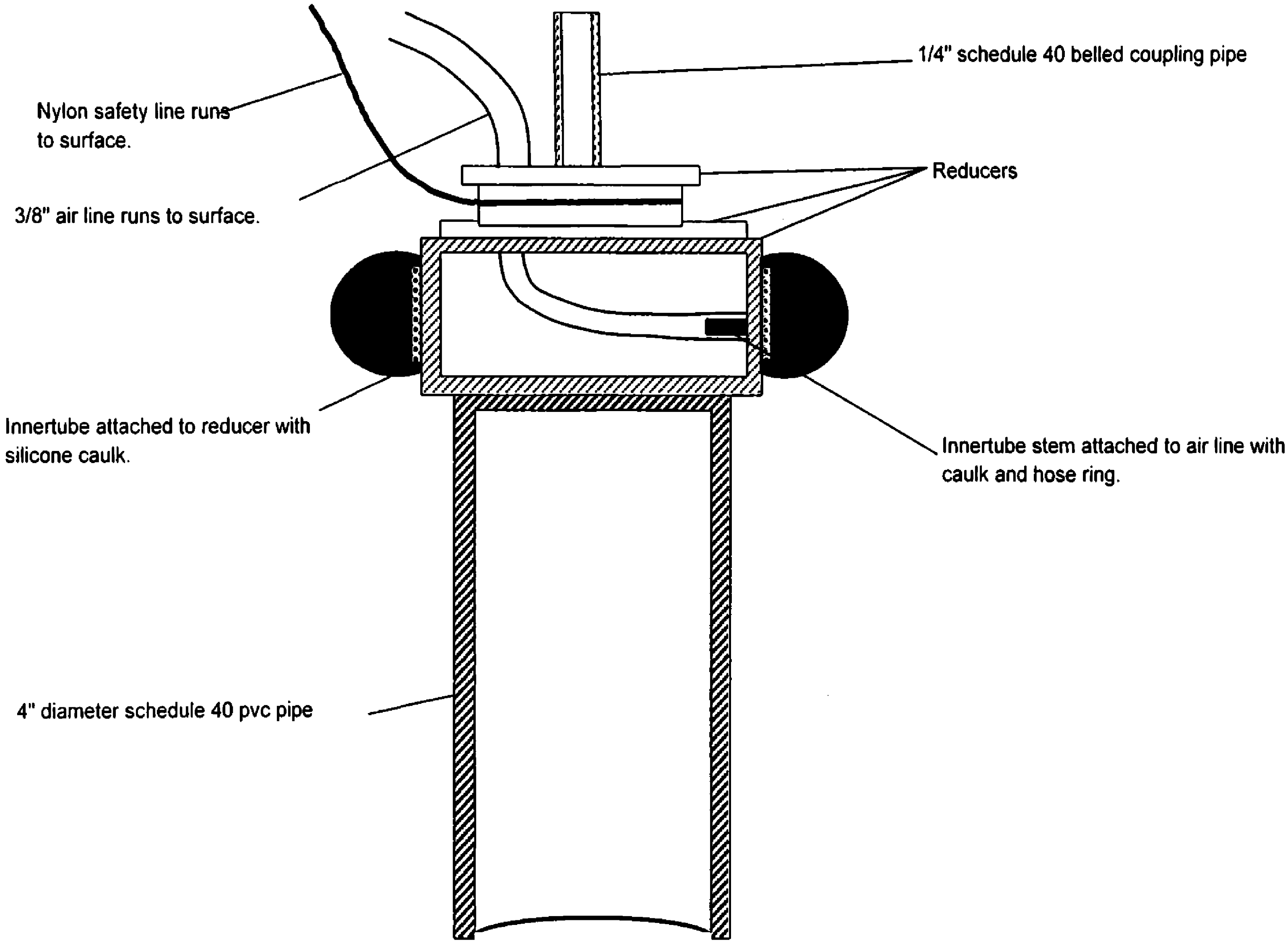


Figure A.1: Cross-section of Well Packer

device and let out along with the flexible tubing as the packing device was lowered. The safety line and flexible tubing were taped to the lengths of pipe with duct tape.

To remove the packing device, the inner tube was deflated with a peristaltic pump. As the packing device was pulled up, each belled coupling was fitted into the jig and a length of pipe was sawed off.

The well was considered sealed when the inflated packing device could not be pulled up. The water level inside the 0.25 inch pipe was considered to be the head in the Tertiary formation; the water level in the well casing was considered to be the head in the Missoula Valley Aquifer. After the packer was set at the desired depth, the water levels were allowed to equilibrate before measuring the head. Table A.1 lists the water levels in the Missoula Aquifer and what was considered to be the Tertiary formation.

Table A.1: Depth to Water

Measurement	Time	Tertiary	Missoula Aquifer	Difference
1	N/A	83.5781	....	....
2	N/A	83.5156	....	....
3	3:21 PM	83.5365	82.8802	-0.6563
4	3:45 PM	83.5521	82.7969	-0.7552
5	3:59 PM	83.5260	82.8906	-0.6354
			Average	-0.6823

All measurements listed in feet from top of casing. Date: 4/5/00 at the Chem/Pharm well located on the University of Montana campus between the Health Science Building and Pharmacy Extension.

Appendix E

River Recharge Pulse Tracer Test

River Recharge Pulse Tracer Test

Sampling Methodology

At the Music and Lodge buildings, samples were taken from faucets on the supply lines running between the supply well and respective building. The wells are part of a geothermal cooling system and run continuously during the day from late spring through summer. Therefore, the sample's chemistry was considered to be representative of the groundwater chemistry and unaffected by the well casing.

Depth integrated sampling was performed at a location on the south shore and east side of the walking bridge that spans the irrigation ditch on the north side of campus (NWB). This water was considered to be representative of the Clark Fork River.

At each site two, acid-washed, 250-ml bottles, pre-filled with millique (MQ) water, were used to collect samples. The bottles were rinsed twice with sample and then filled. One bottle was measured for specific conductance (μmhos/cm) with a specific conductivity (SC) meter in the field and lab. At the lab, sample from the second bottle was syringe-filtered with a 0.4 :m filter and then analyzed for F^-, Cl^-, NO_3^- and SO_4^{2-}. Anion analysis was performed with a Dionex DX-500 ion chromatograph.

QA/QC

The SC meter precision was determined by measuring specific conductance of five replicate samples taken on 7/24/00 at the NWB site (Table A.2). The relative standard deviation (mean/standard deviation) was 1.229%.

Table A.2: SC Meter Precision Data

	TDS in Field		TDS in Lab		
Bottle #	**mS/cm**	**ppm**	**mS/cm**	**ppm**	**% Difference***
1	0.244	122	0.233	116.5	4.508%
2	0.245	122.5	0.22	110	10.204%
3	0.240	120	0.238	119	0.833%
4	0.238	119	0.242	121	1.681%
5	0.240	120	0.242	121	0.833%
average	0.2414	120.7	0.235	117.5	3.612%
stdev	0.002966	1.4832397	0.009165	4.5825757	3.982%
% rel stdv	1.229%	1.229%	3.900%	3.900%	110.251%

* % Difference Between Field and Lab Measurements

Since sampling was not performed at the same time each event, the homogeneity of specific conductance values of the river throughout the day was tested. Eight samples were taken throughout the day on 7/25/00 (Table A.3).

Table A.3: Specific Conductance Homogeneity of the Clark Fork River on 7/25/00

	TDS in Field		TDS in Lab		
	mS/cm	**ppm**	**mS/cm**	**ppm**	**% Difference***
8:07 AM	0.243	121.5	0.237	118.5	2.469%
10:00 AM	0.245	122.5	0.241	120.5	1.633%
11:00 AM	0.235	117.5	0.235	117.5	0.000%
12:00 PM	0.244	122.0	0.245	122.5	0.410%
1:00 PM	0.243	121.5	0.243	121.5	0.000%
2:00 PM	0.237	118.5	0.237	118.5	0.000%
4:00 PM	0.239	119.5	0.241	120.5	0.837%
8:30 PM	0.242	121.0	0.242	121.0	0.000%
average	0.241	120.5	0.240125	120.0625	0.669%
stdev	0.003586	1.7928429	0.003441	1.7204132	0.930%
rel stdev	1.488%	1.488%	1.433%	1.433%	139.110%

* % Difference Between Field and Lab Measurements

The relative standard deviation was 1.488%, indicating that time of day had a negligible effect on river specific conductance values. The homogeneity of specific conductance values was not tested for at the Lodge and Music Building wells.

To encompass 95% of the variability of the meter and river, two standard deviations, or an error of 3%, was used for the error bars of the TDS values.

To test the accuracy of the SC meter, the method for determining TDS from Standard Methods For the Examination of Water and Wastewater (American Public Health Association, 1989) was used. The five replicate samples described above were used. Three, clean 500-ml beakers and one clean 300-ml beaker were used. After preheating the beakers for 20 minutes at 180°C to drive off any residual moisture, the beakers were allowed to cool in a dessicator. When cool, each beaker was marked and then weighed. After each beaker was placed on the scale, it was only handled wearing rubber gloves. Body oils will noticeably affect the beaker weight. Next, each replicate sample was syringe-filtered with a 0.45 :m filter into an assigned beaker. The (beaker + sample) weight was recorded. Then, still wearing gloves, each beaker was put in an oven to dry overnight at 180°C. The oven door was left slightly ajar to permit the moisture-saturated air to escape. The next morning, each beaker was removed and set in a dessicator to cool. Rubber gloves were still used when handling the beakers. After cooling, each beaker was weighed while wearing gloves. TDS in ppm was calculated by the following formula:

TDS (ppm) = ((beaker + solids) – beaker)/ sample volume

TDS concentrations were converted to specific conductance values by multiplying by 500 (Table A.4)

Table A.4: SC Meter Accuracy Check

Sample #	Beaker Wt, mg	H_2O Vol., L	Beaker + Solids, mg	TDS, ppm	Field TDS, ppm	Lab TDS, ppm
1	130,008.8	0.21605	130,044.9	167.0910	122.0	116.5
2	224,744.1	0.22213	224782.9	174.6725	122.5	110.0
3	229,057.3	0.21993	229094.9	168.6900	120.0	119.0
4	220,998.8	0.22978	221,040.2	180.1723	119.0	121.0
			Average	172.6565		
			Stdev	5.979415		
			% Rel. Stdev	3.463%		

These values were plotted against the values measured during sampling (Fig. A.2).

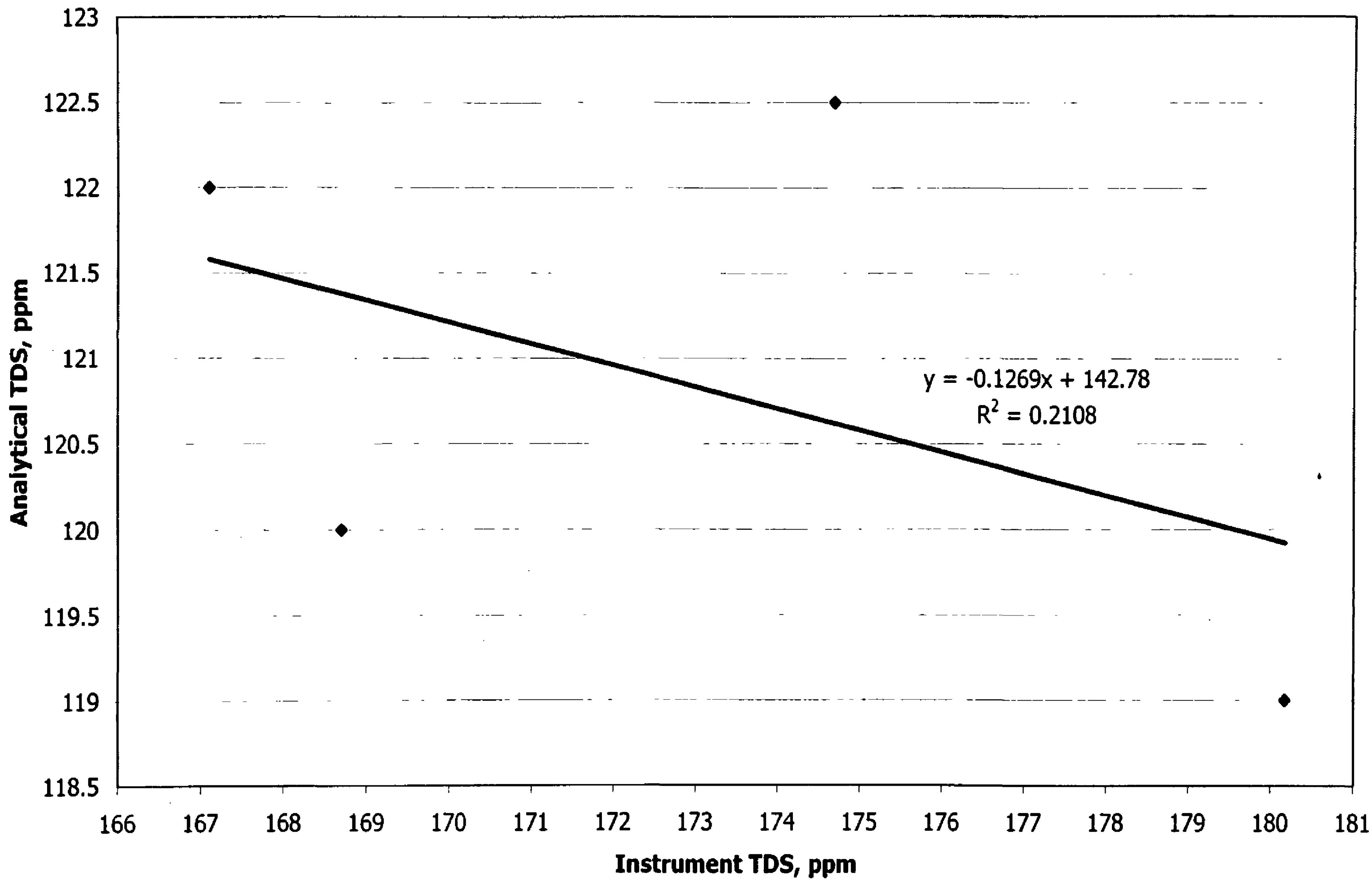


Figure A.2: Instrument vs. Analytical TDS

Linear regression was performed on the data set. The R^2 value was 0.2108 indicating the two sets of values were not correlated and the SC meter has poor accuracy.

This limited QA/QC analysis assessed the validity of the measured river specific conductivity values. From the limited QA/QC analysis the following conclusions are made:

- The SC meter is very precise, but very inaccurate.
- The time of day does not have a significant effect on the measured river specific conductance values.

Date	Sample	F	Cl	NO_2-N	NO_3-N	PO_4-P	SO_4
5/11/00	Lodge Blank	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
	NWB Blank	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
	Music Blank	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
	Lodge	0.14	2.95	BMDL	0.31	BMDL	19.41
	Music	BMDL	2.68	BMDL	0.30	BMDL	18.28
	NWB	0.04	1.04	0.00	0.06	0.00	9.59
6/8/00	Lodge	0.17	3.01	BMDL	0.29	BMDL	18.04
	Music	0.16	2.60	BMDL	0.28	BMDL	14.69
	NWB	0.10	BMDL	BMDL	BMDL	BMDL	8.89
6/14/00	Music	0.16	2.65	BMDL	0.03	BMDL	16.56
	Lodge	0.19	3.08	BMDL	0.28	BMDL	21.07
	NWB	BMDL	BMDL	BMDL	BMDL	BMDL	12.58
6/16/00	NWB	BMDL	BMDL	BMDL	BMDL	BMDL	11.45
6/21/00	Lodge	0.21	3.05	BMDL	0.29	BMDL	20.24
	Music	0.17	2.64	BMDL	0.29	BMDL	15.98
	NWB	BMDL	BMDL	BMDL	BMDL	BMDL	12.96
6/27/00	Lodge	0.24	3.30	BMDL	0.27	BMDL	17.66
	Music	0.21	2.51	BMDL	0.26	BMDL	13.78
	NWB	0.05	1.10	BMDL	BMDL	BMDL	12.61
7/11/00	Lodge	0.24	2.83	BMDL	0.27	BMDL	16.50
	Music	0.22	2.49	BMDL	0.27	BMDL	13.15
	NWB	0.16	1.46	BMDL	BMDL	BMDL	16.09
7/13/00	Lodge	0.15	2.50	BMDL	0.29	BMDL	16.57
	Music	0.14	2.19	BMDL	0.28	BMDL	13.20
	NWB	0.13	1.27	BMDL	0.02	BMDL	18.03
7/14/00	Lodge	0.15	2.45	BMDL	0.28	BMDL	16.48
	Music	0.14	2.20	BMDL	0.29	BMDL	13.24
	NWB	0.14	1.21	BMDL	0.02	BMDL	17.52
7/16/00	Lodge	0.15	2.42	BMDL	0.27	BMDL	16.32
	Music	0.15	2.19	BMDL	0.28	BMDL	13.13
	NWB	0.14	1.26	BMDL	0.02	BMDL	18.32
7/19/00	Lodge	0.16	2.77	BMDL	0.28	BMDL	16.13
	Music	0.16	2.54	BMDL	0.29	BMDL	13.21
	NWB	0.26	1.56	BMDL	BMDL	BMDL	17.42
7/20/00	Lodge	....	2.8	0	0.36	....	15.6
	Music	....	2.6	0	0.37	....	12.8
	NWB	....	1.7	0	0.00	....	17.7
7/21/00	Lodge	....	2.9	0	0.36	....	15.6
	Music	....	2.6	0	0.36	....	12.8
	NWB	....	1.5	0	0.00	....	15.5

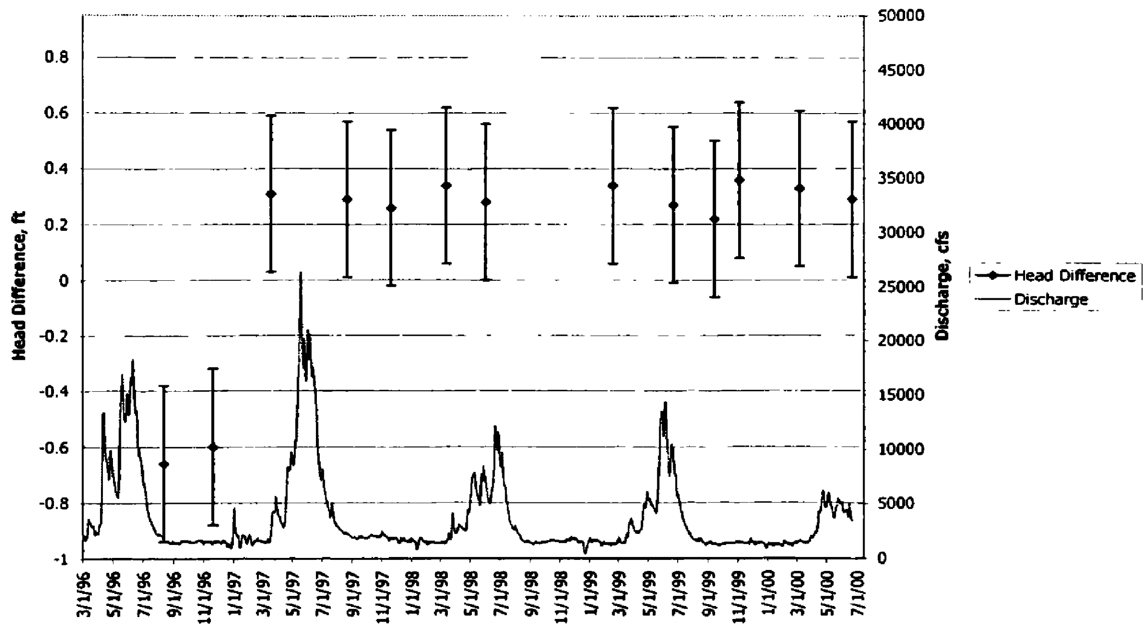
Date	Sample	Field TDS mS/cm	Field TDS ppm	Lab TDS mS/cm	Lab TDS ppm
	Lodge	0.29	145	0.316	158
5/11/00	Music	0.3	150	0.332	166
	NWB	....	....	0.184	92
	Lodge	0.352	176	0.346	173
6/8/00	Music	0.326	163	0.325	162.5
	NWB	0.182	91	0.189	94.5
	Music	0.296	148	0.301	150.5
6/14/00	Lodge	0.307	153.5	0.327	163.5
	NWB	0.2	100	0.185	92.5
6/16/00	NWB	....	....	0.188	94
	Lodge	0.332	166	0.338	169
6/21/00	Music	0.318	159	0.316	158
	NWB	0.208	104	0.201	100.5
	lodge	0.304	152	0.304	152
6/27/00	music	0.295	147.5	0.287	143.5
	NWB	0.2	100	0.206	103
	lodge	0.305	152.5	0.298	149
7/11/00	music	0.284	142	0.278	139
	NWB	0.238	119	0.229	114.5
	lodge	0.288	144	0.302	151
7/13/00	music	0.289	144.5	0.278	139
	NWB	0.227	113.5	0.228	114
	lodge	0.29	145	0.279	139.5
7/14/00	music	0.272	136	0.282	141
	NWB	0.241	120.5	0.235	117.5
	lodge	0.307	153.5	0.148	74
7/16/00	music	0.284	142	0.275	137.5
	NWB	0.238	119	0.243	121.5
	lodge	0.299	149.5	0.305	152.5
7/19/00	music	0.285	142.5	0.284	142
	NWB	0.236	118	0.242	121
	lodge	0.307	153.5	0.283	141.5
7/20/00	music	0.294	147	0.29	145
	NWB	0.233	116.5	0.223	111.5
	lodge	0.298	149	0.293	146.5
7/21/00	music	0.29	145	0.288	144
	NWB	0.234	117	0.228	114

Appendix F

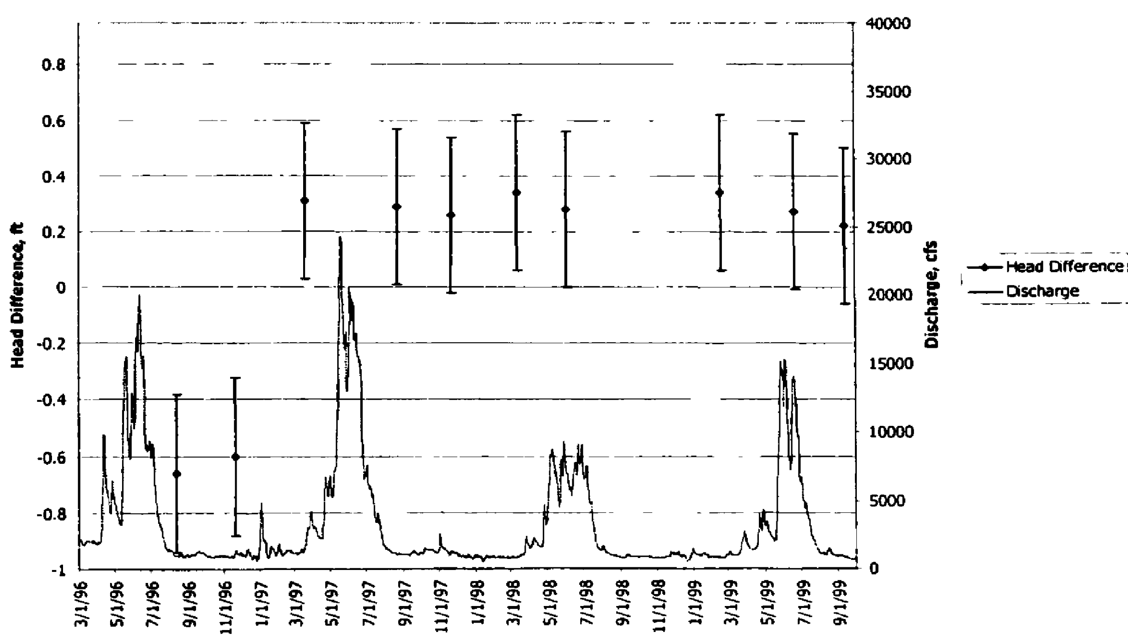
Vertical Gradients

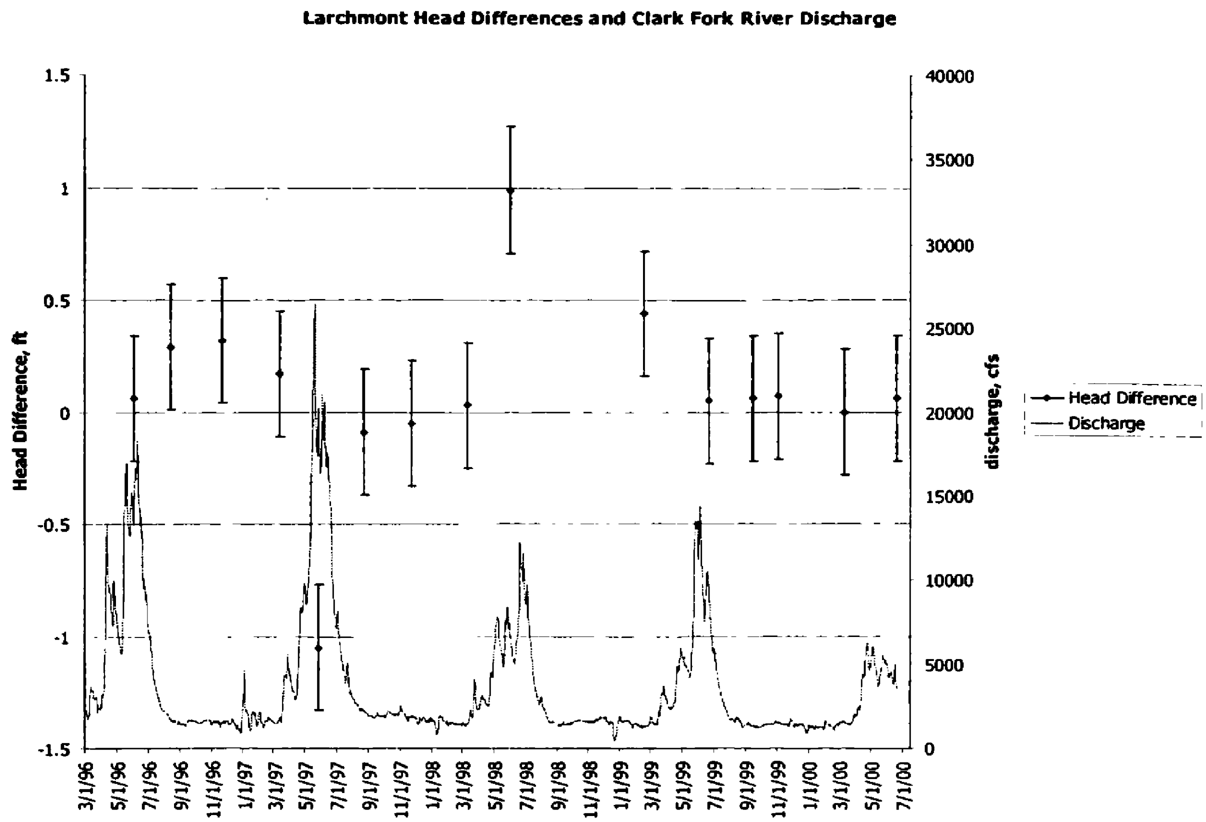
Head Differences and Discharge: Blaine/Crosby and Larchmont Well Nests

Blaine/Crosby Head Differences and Clark Fork River Discharge



Blaine/Crosby Head Differences and Bitterroot River Discharge




Larchmont Head Differences and Clark Fork River Discharge
Head Difference, ft
discharge, cfs
Head Difference
Discharge
1.5
1
0.5
0
-0.5
-1
-1.5
40000
35000
30000
25000
20000
15000
10000
5000
0
3/1/96
5/1/96
7/1/96
9/1/96
11/1/96
1/1/97
3/1/97
5/1/97
7/1/97
9/1/97
11/1/97
1/1/98
3/1/98
5/1/98
7/1/98
9/1/98
11/1/98
1/1/99
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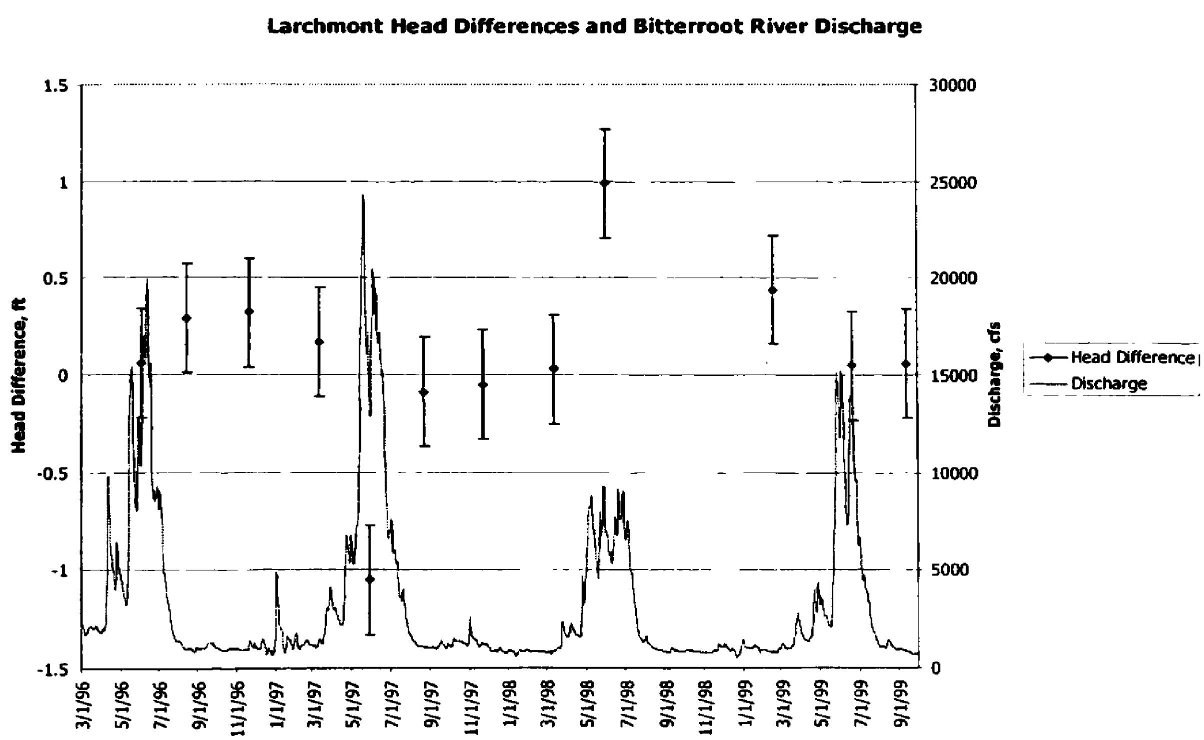
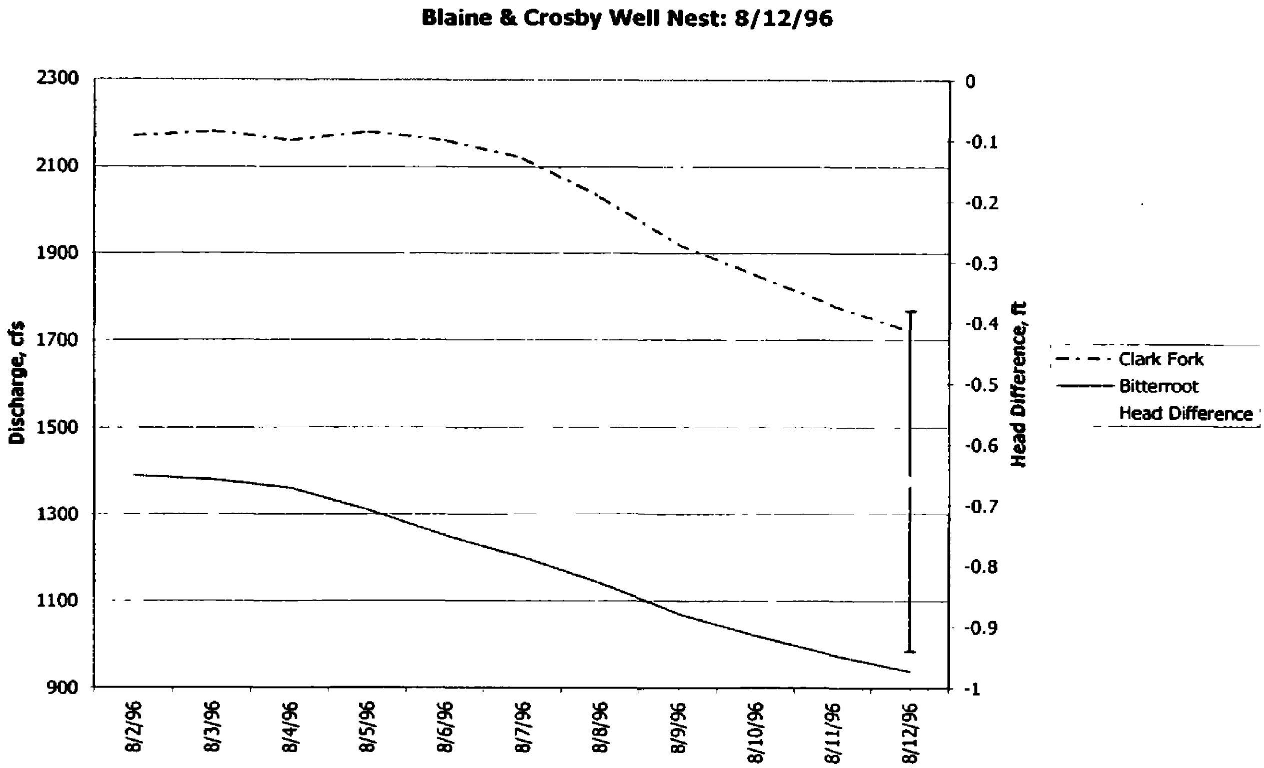
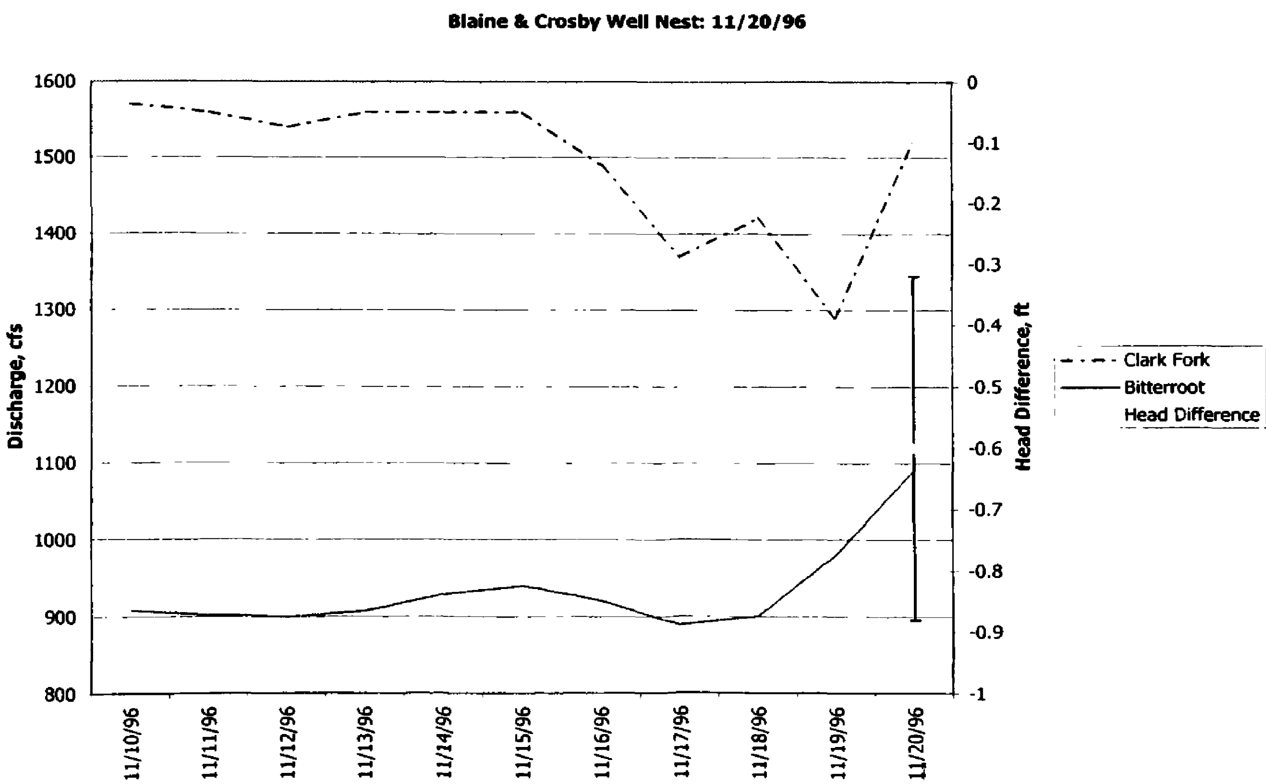
3/1/00
5/1/00
7/1/00

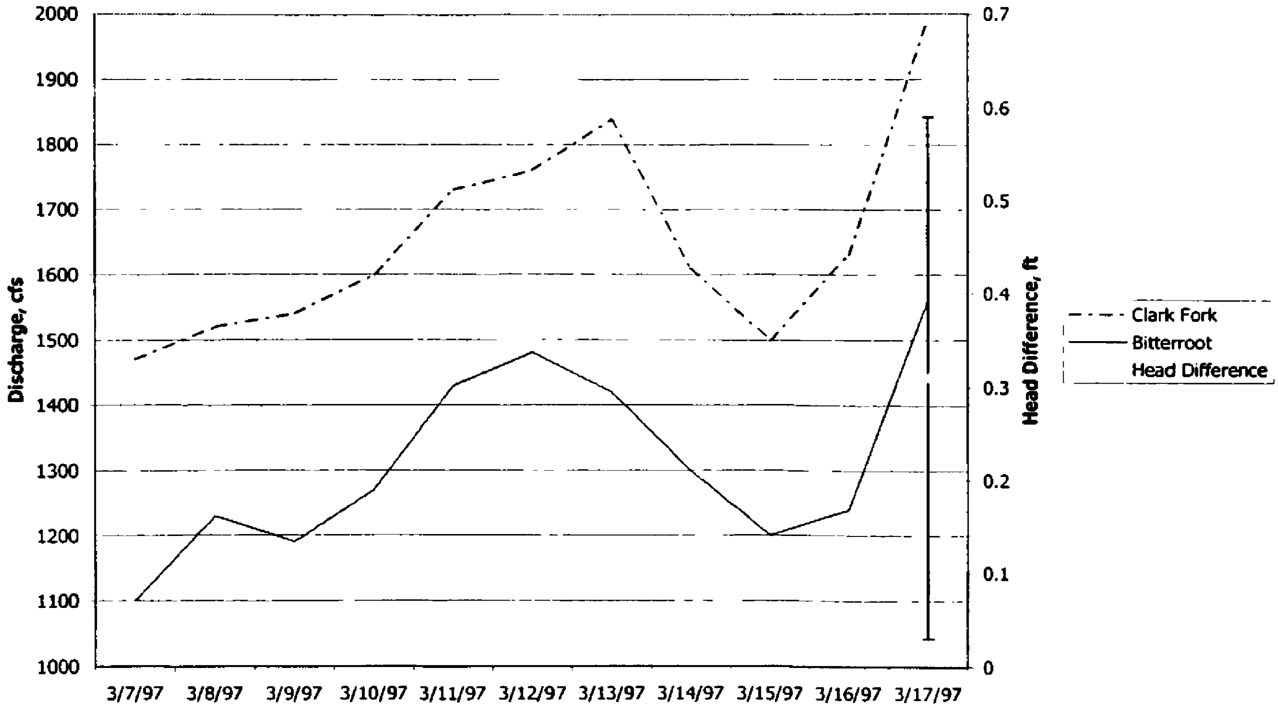

Larchmont Head Differences and Bitterroot River Discharge
Head Difference, ft
Discharge, cfs
Head Difference
Discharge
1.5
1
0.5
0
-0.5
-1
-1.5
30000
25000
20000
15000
10000
5000
0
3/1/96
5/1/96
7/1/96
9/1/96
11/1/96
1/1/97
3/1/97
5/1/97
7/1/97
9/1/97
11/1/97
1/1/98
3/1/98
5/1/98
7/1/98
9/1/98
11/1/98
1/1/99
3/1/99
5/1/99
7/1/99
9/1/99

Head Difference and Discharge Including Previous 10 Days: Blaine/Crosby Well Nest

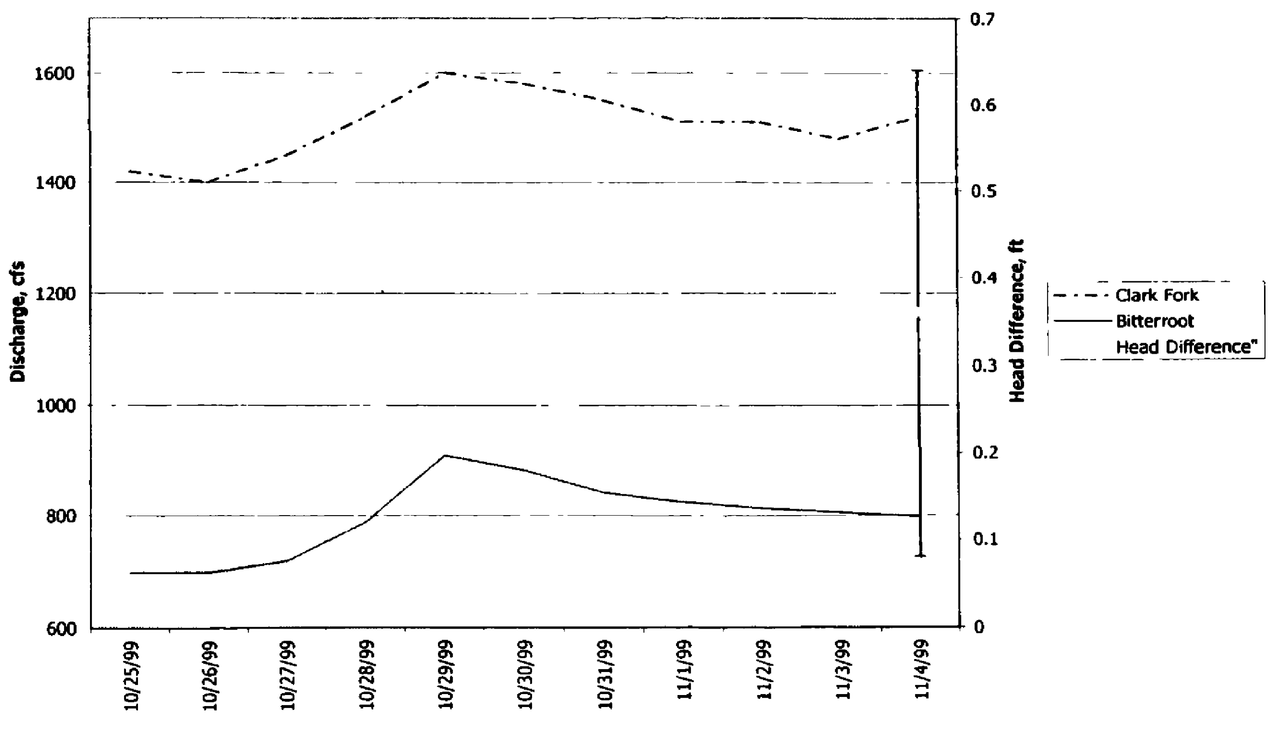

Blaine & Crosby Well Nest: 8/12/96
Discharge, cfs
2300
2100
1900
1700
1500
1300
1100
900
Head Difference, ft
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
8/2/96
8/3/96
8/4/96
8/5/96
8/6/96
8/7/96
8/8/96
8/9/96
8/10/96
8/11/96
8/12/96
Clark Fork
Bitterroot
Head Difference

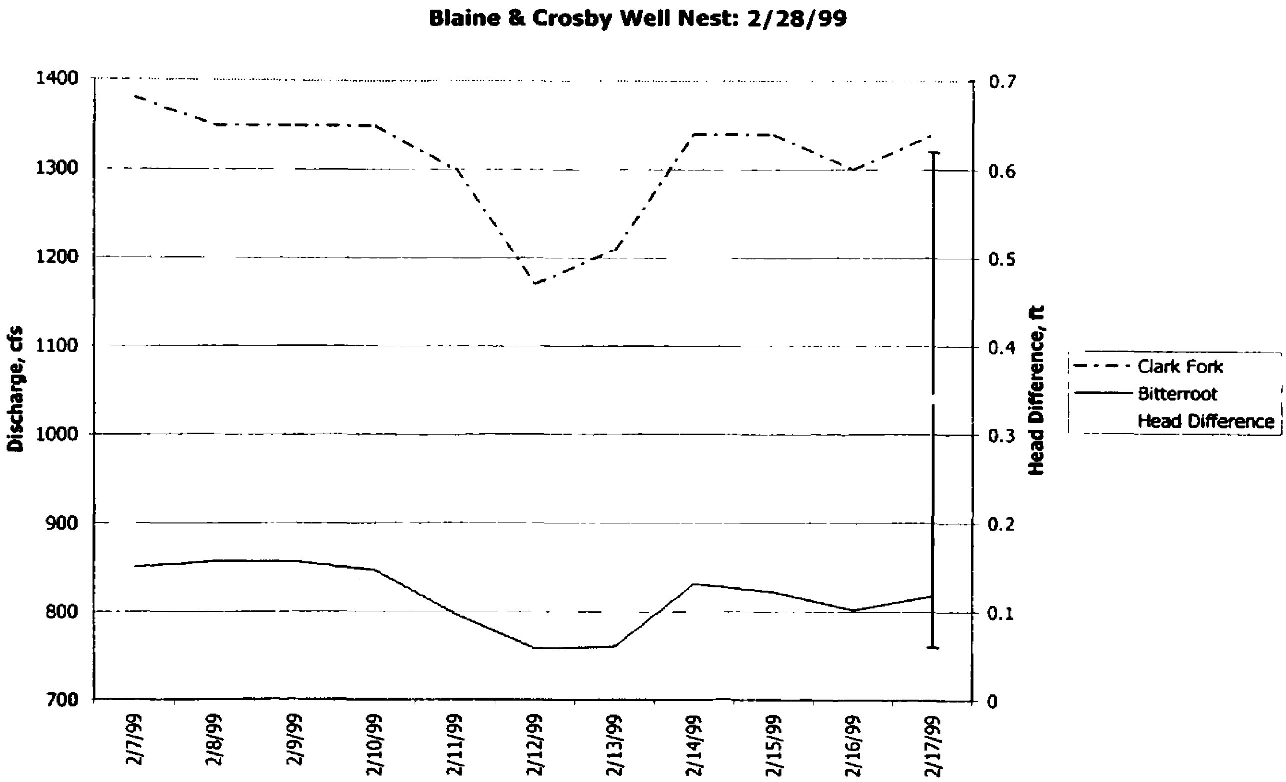

Blaine & Crosby Well Nest: 11/20/96
Discharge, cfs
1600
1500
1400
1300
1200
1100
1000
900
800
Head Difference, ft
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
11/10/96
11/11/96
11/12/96
11/13/96
11/14/96
11/15/96
11/16/96
11/17/96
11/18/96
11/19/96
11/20/96
Clark Fork
Bitterroot
Head Difference

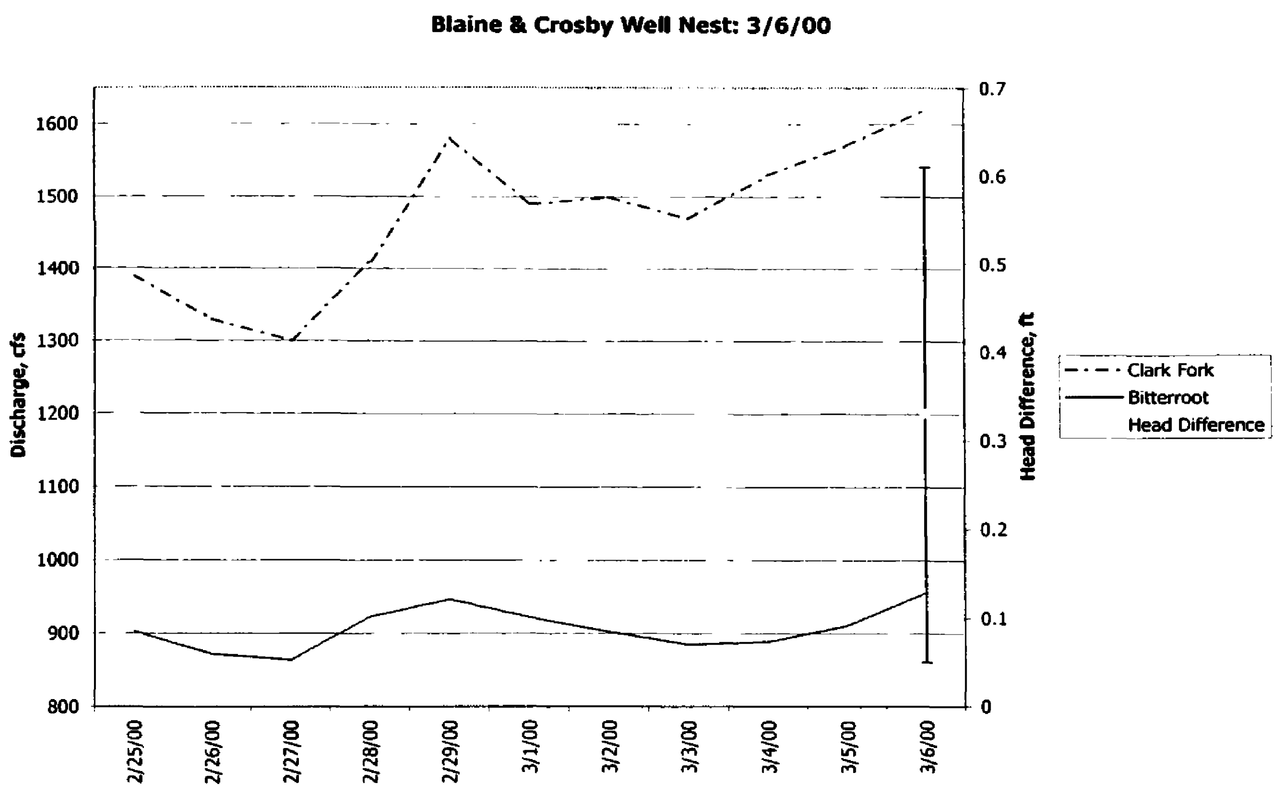
Blaine & Crosby Well Nest: 3/17/98

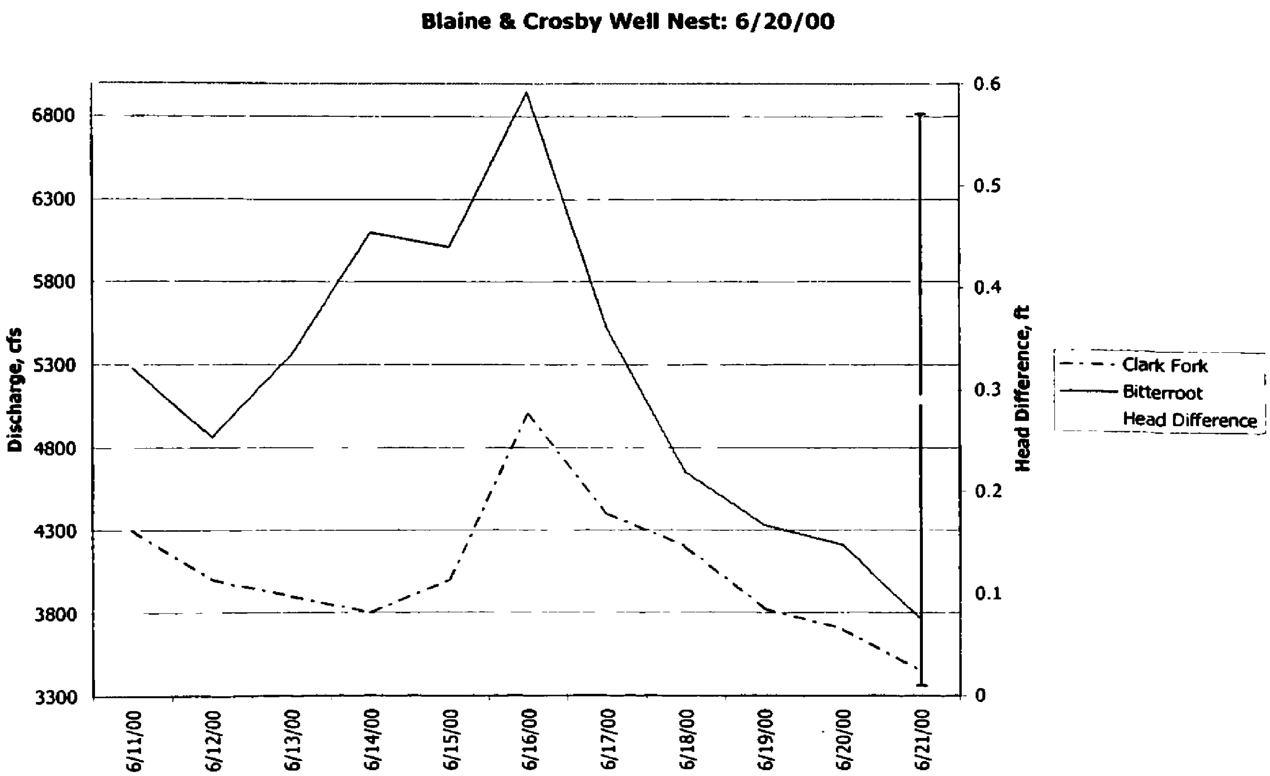


Blaine & Crosby Well Nest: 11/4/99




Blaine & Crosby Well Nest: 2/28/99
Discharge, cfs
Head Difference, ft
1400
1300
1200
1100
1000
900
800
700
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2/7/99
2/8/99
2/9/99
2/10/99
2/11/99
2/12/99
2/13/99
2/14/99
2/15/99
2/16/99
2/17/99
Clark Fork
Bitterroot
Head Difference

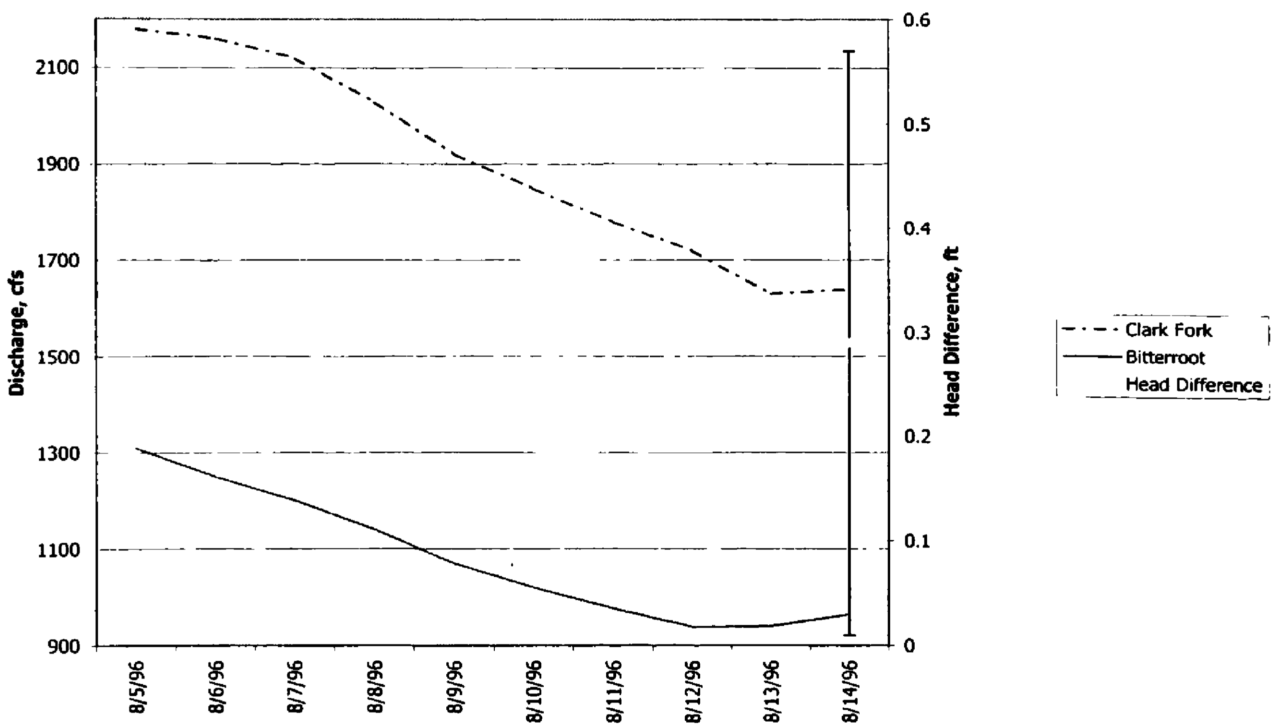

Blaine & Crosby Well Nest: 3/6/00
Discharge, cfs
Head Difference, ft
1600
1500
1400
1300
1200
1100
1000
900
800
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2/25/00
2/26/00
2/27/00
2/28/00
2/29/00
3/1/00
3/2/00
3/3/00
3/4/00
3/5/00
3/6/00
Clark Fork
Bitterroot
Head Difference



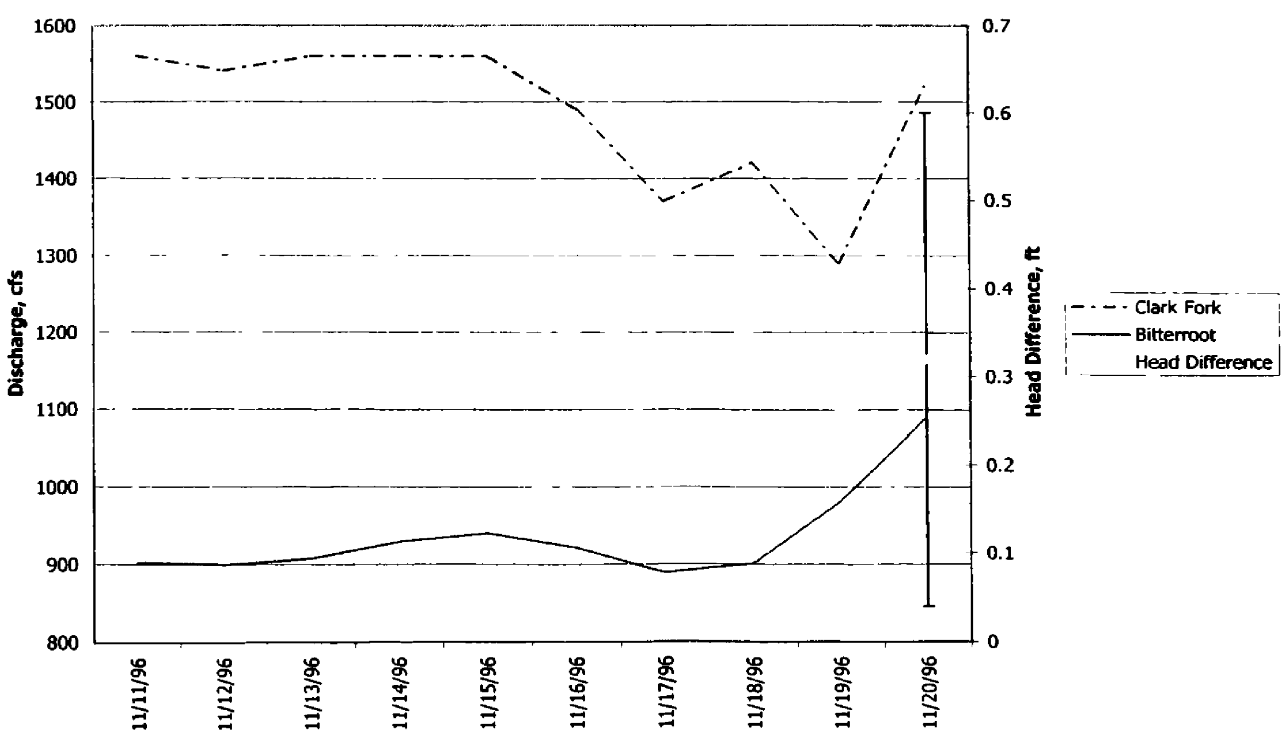
Blaine & Crosby Well Nest: 6/20/00
Discharge, cfs
3300
3800
4300
4800
5300
5800
6300
6800
Head Difference, ft
0
0.1
0.2
0.3
0.4
0.5
0.6
6/11/00
6/12/00
6/13/00
6/14/00
6/15/00
6/16/00
6/17/00
6/18/00
6/19/00
6/20/00
6/21/00
Clark Fork
Bitterroot
Head Difference

Head Difference and Discharge Including Previous 10 Days: Larchmont Well Nest

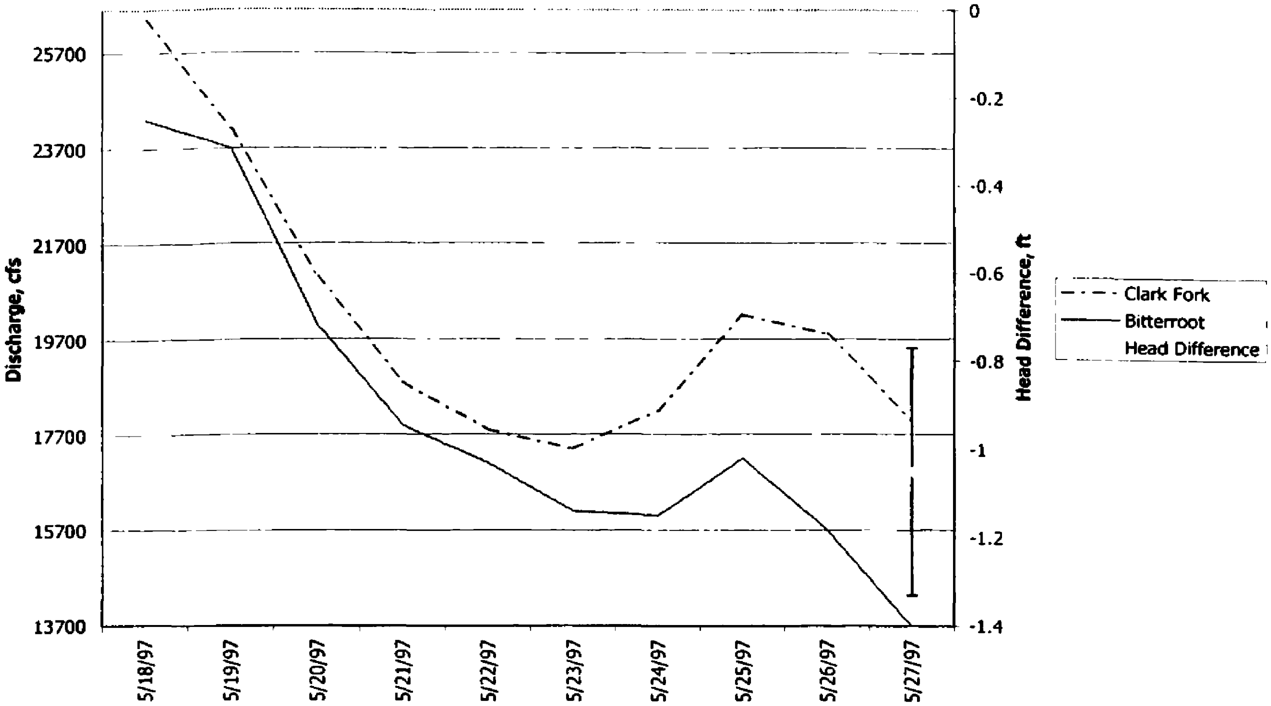
Larchmont Well Nest: 8/14/96



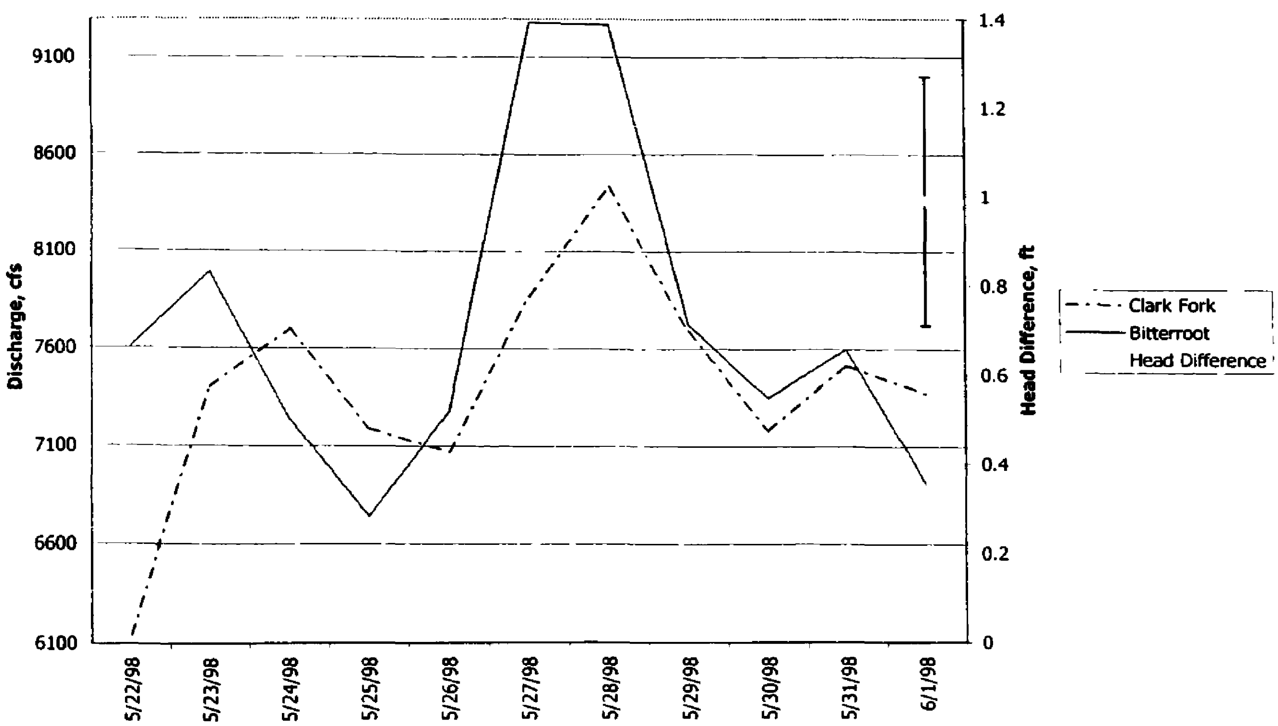
Larchmont Well Nest: 11/20/96



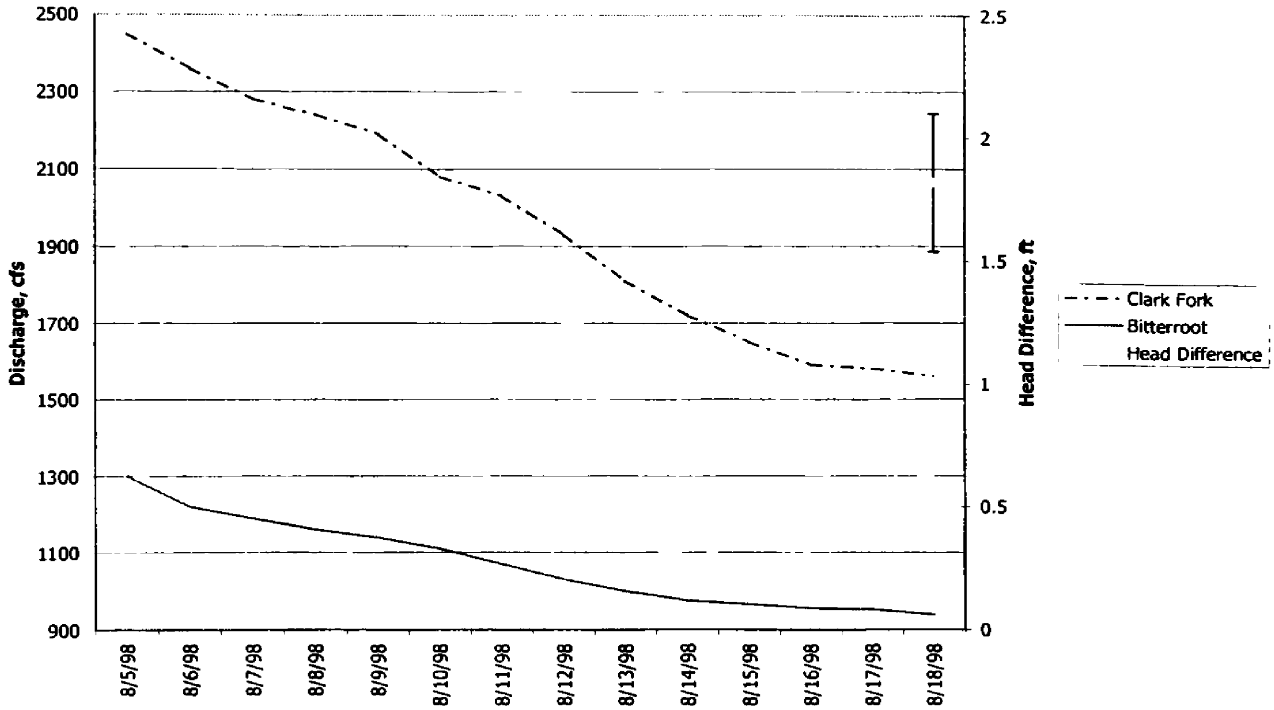
Larchmont Well Nest: 5/27/97



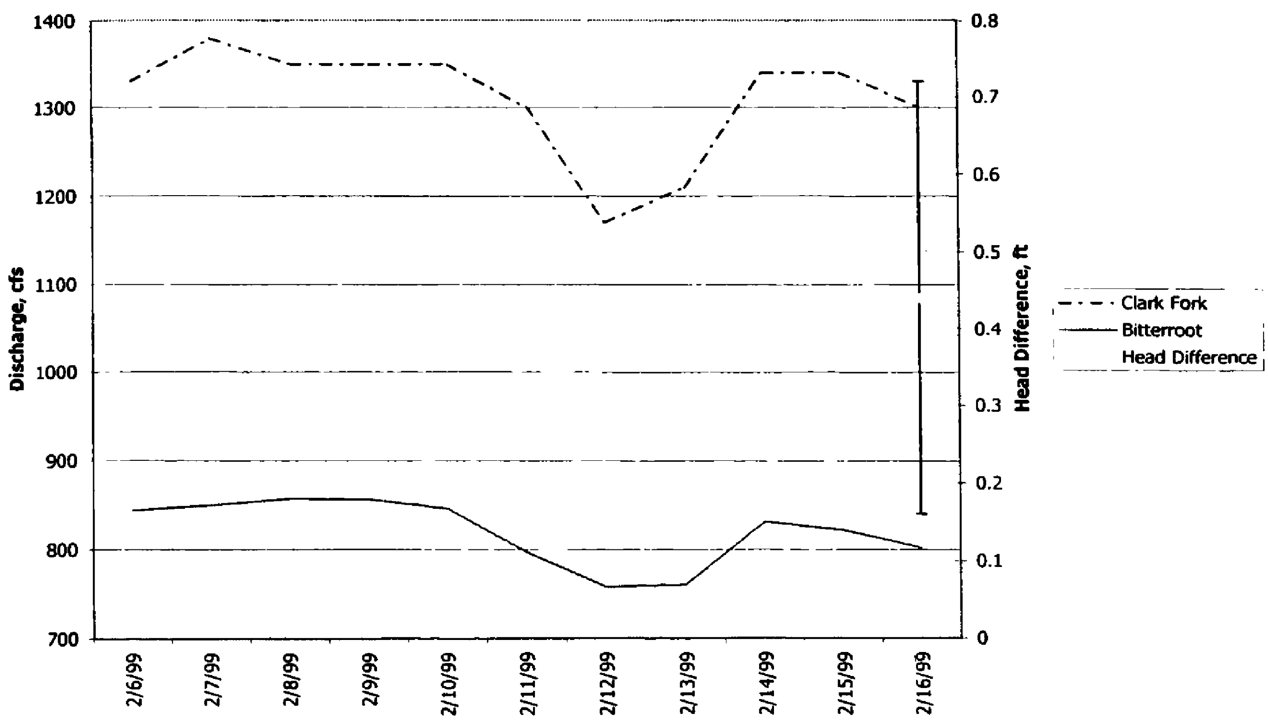
Larchmont Well Nest: 6/1/98



Larchmont Well Nest: 8/18/98



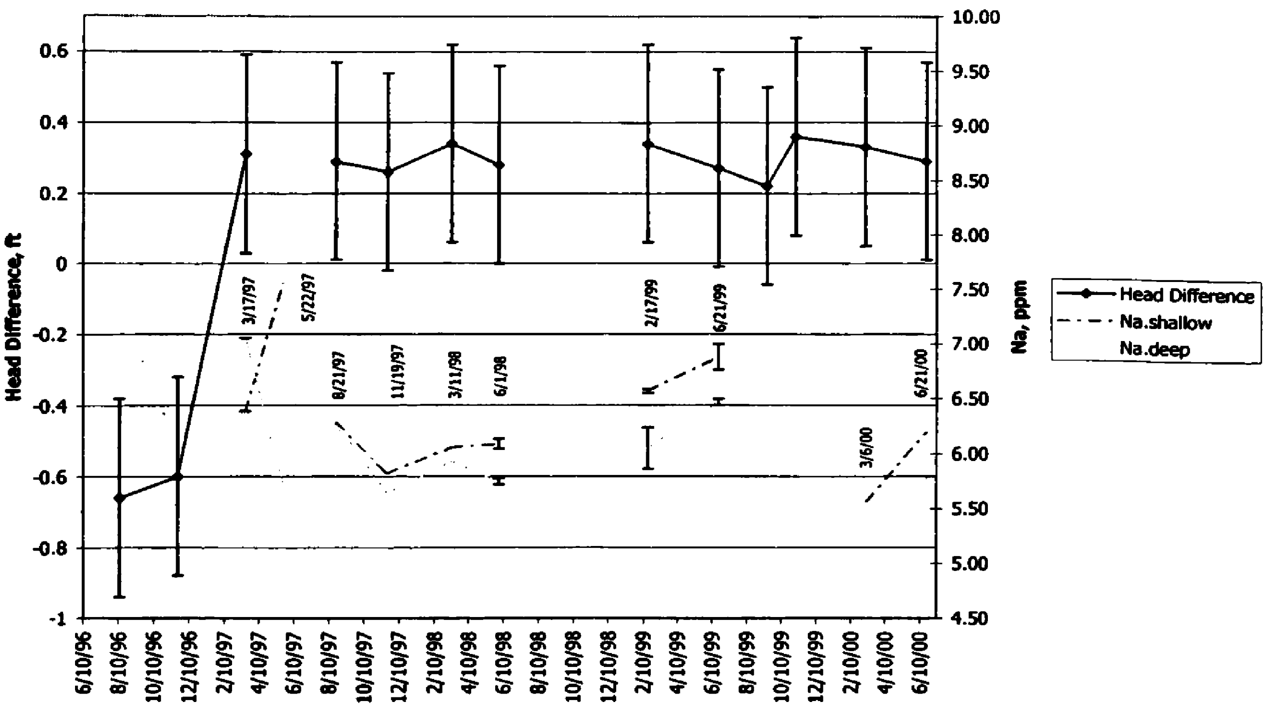
Larchmont Well Nest: 2/16/99



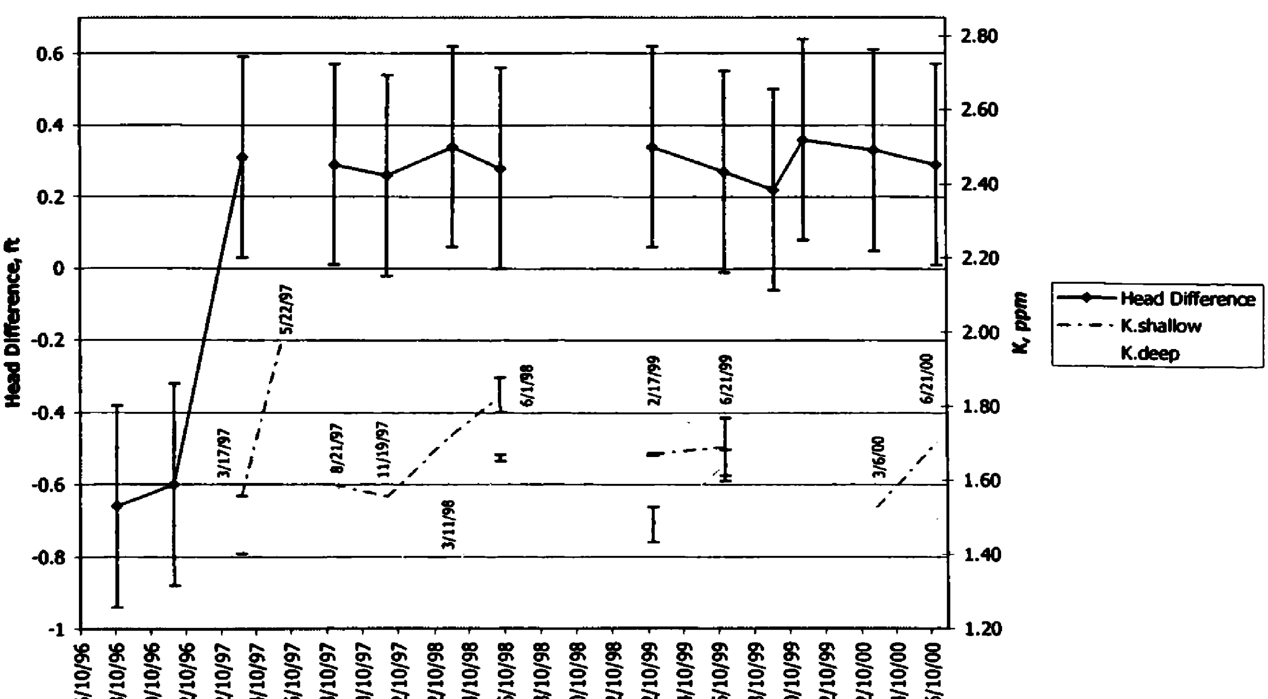
Head Differences and Inorganic Ion Concentrations:

Blaine/Crosby Well Nest

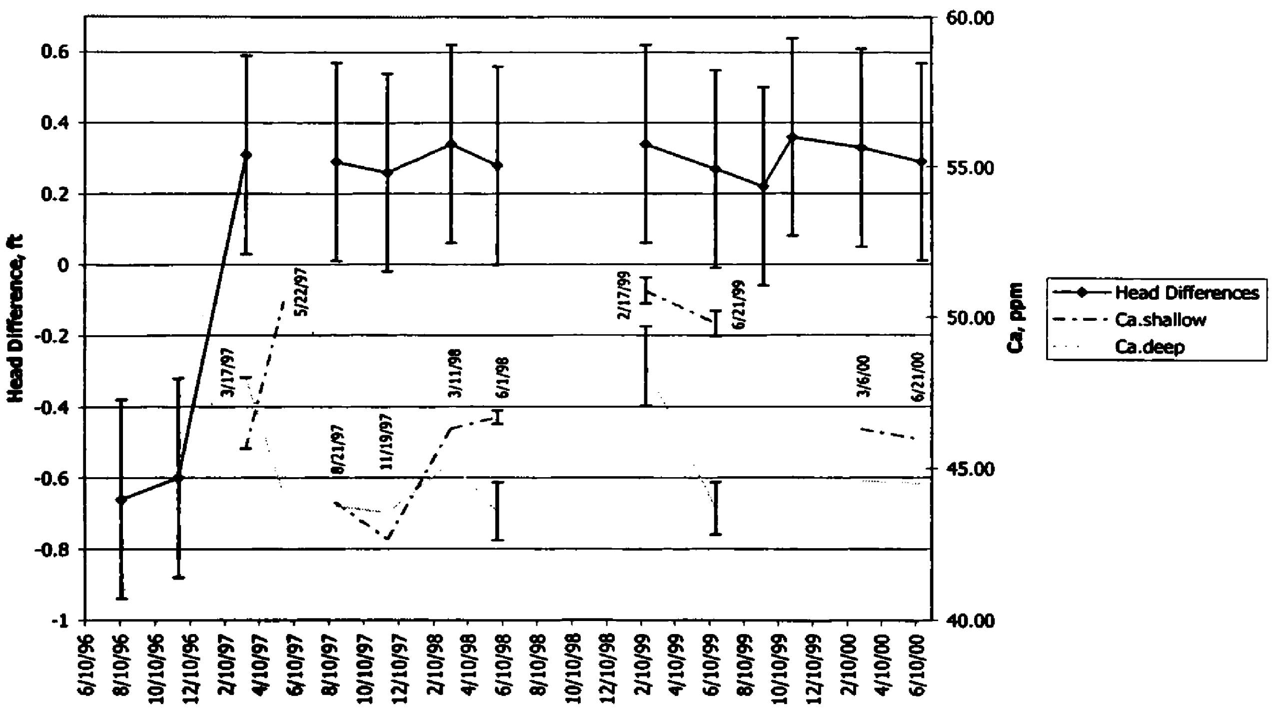
Blaine/Crosby [Na] and Head Differences



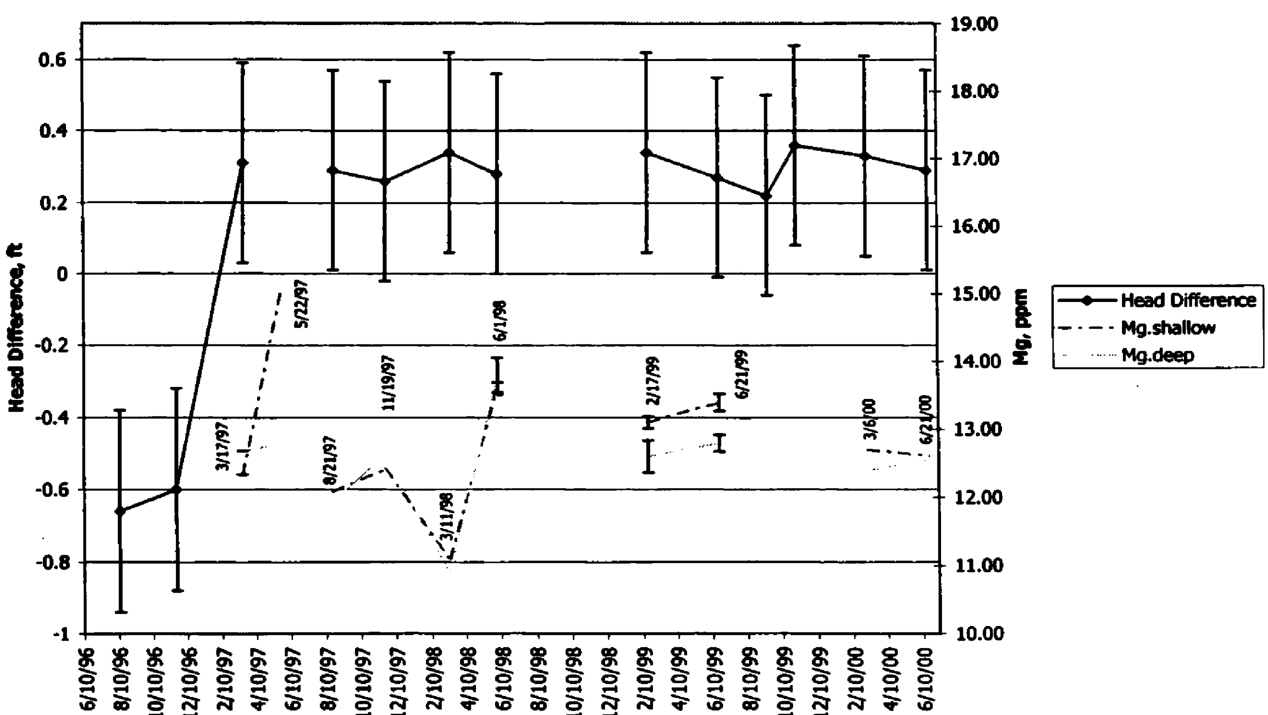
Blaine/Crosby [K] and Head Differences



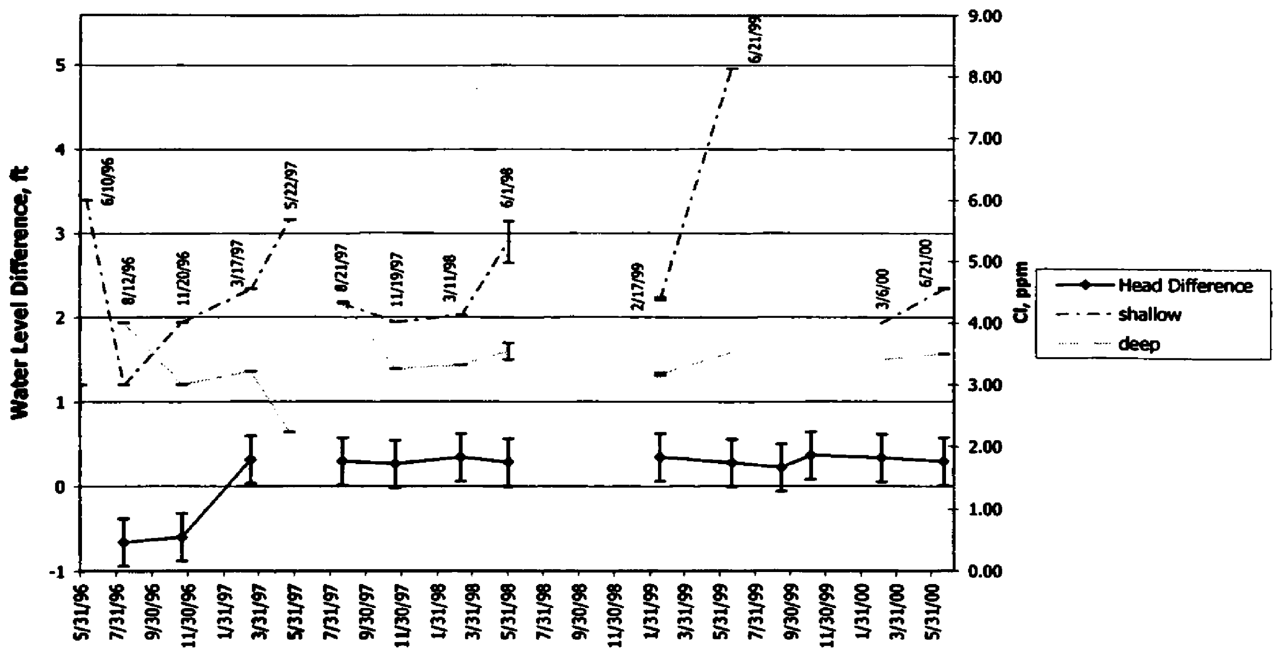
Blaine/Crosby [Ca] and Head Differences



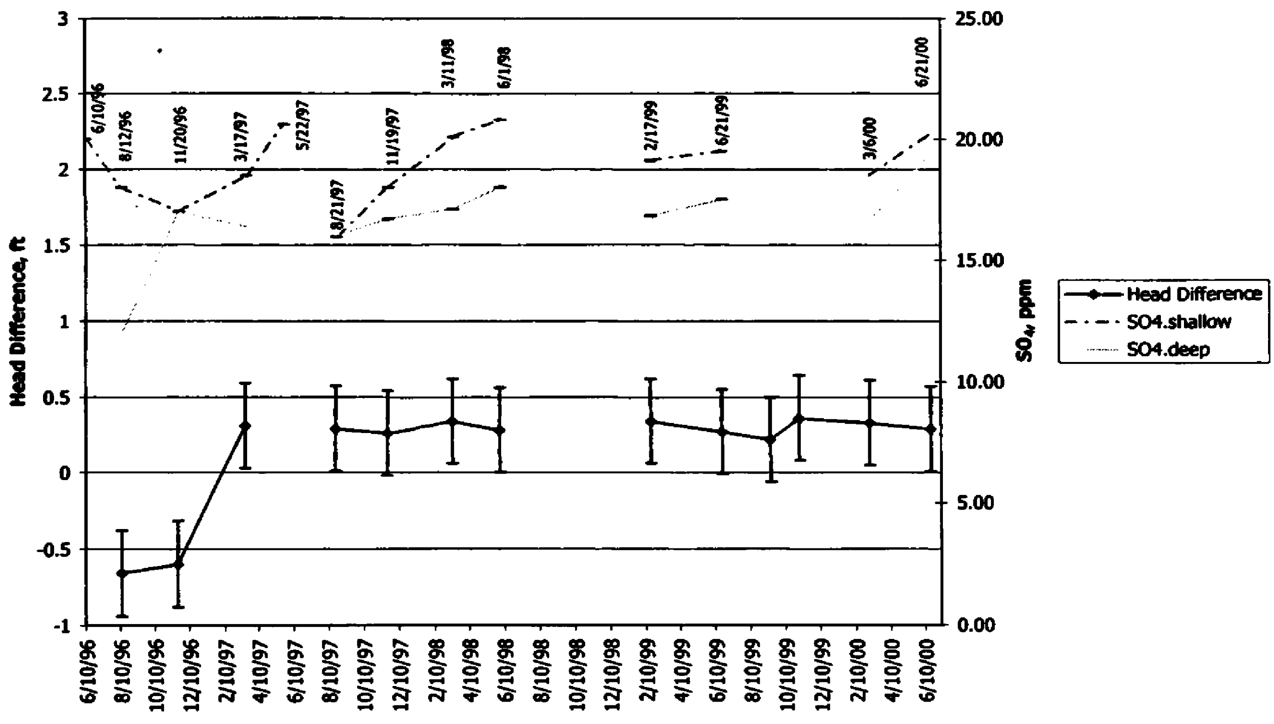
Blaine/Crosby [Mg] and Head Differences



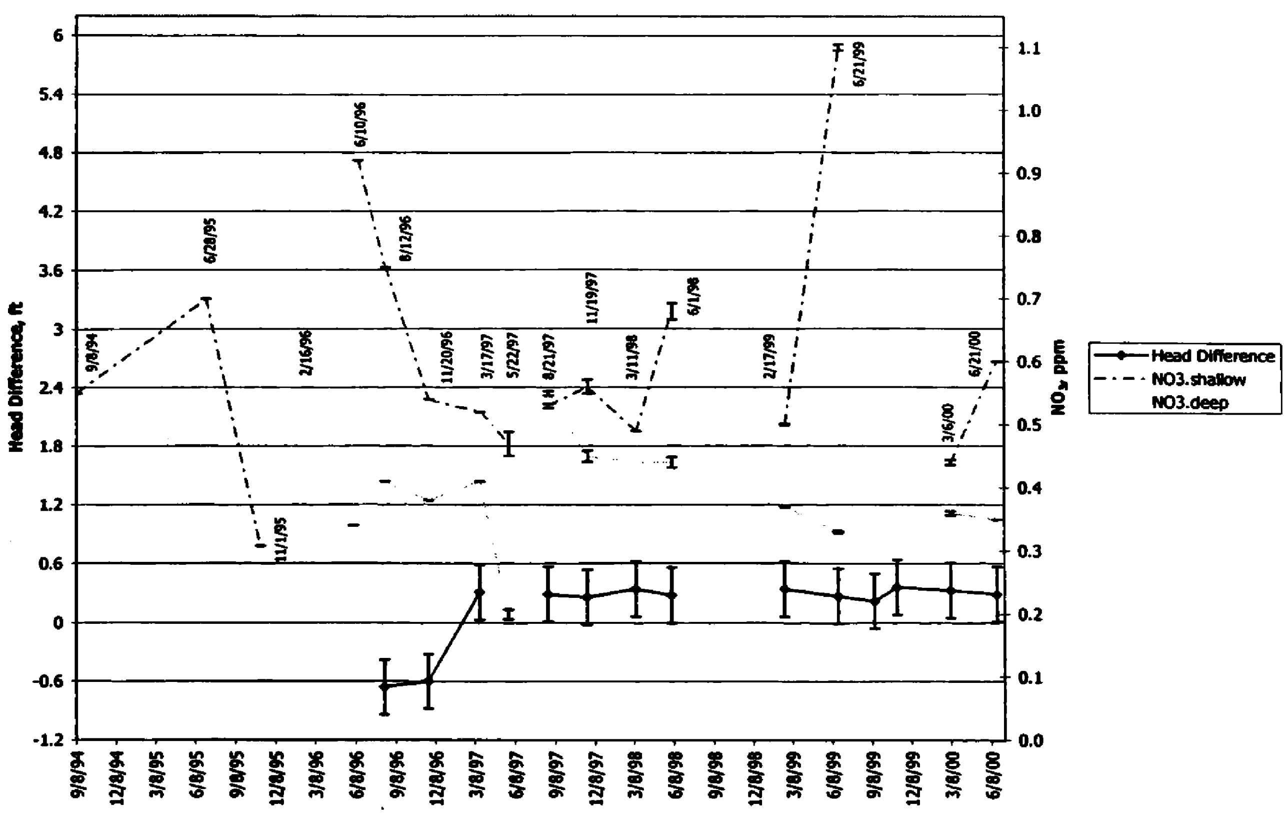
Blaine/Crosby [Cl] and Head Differences



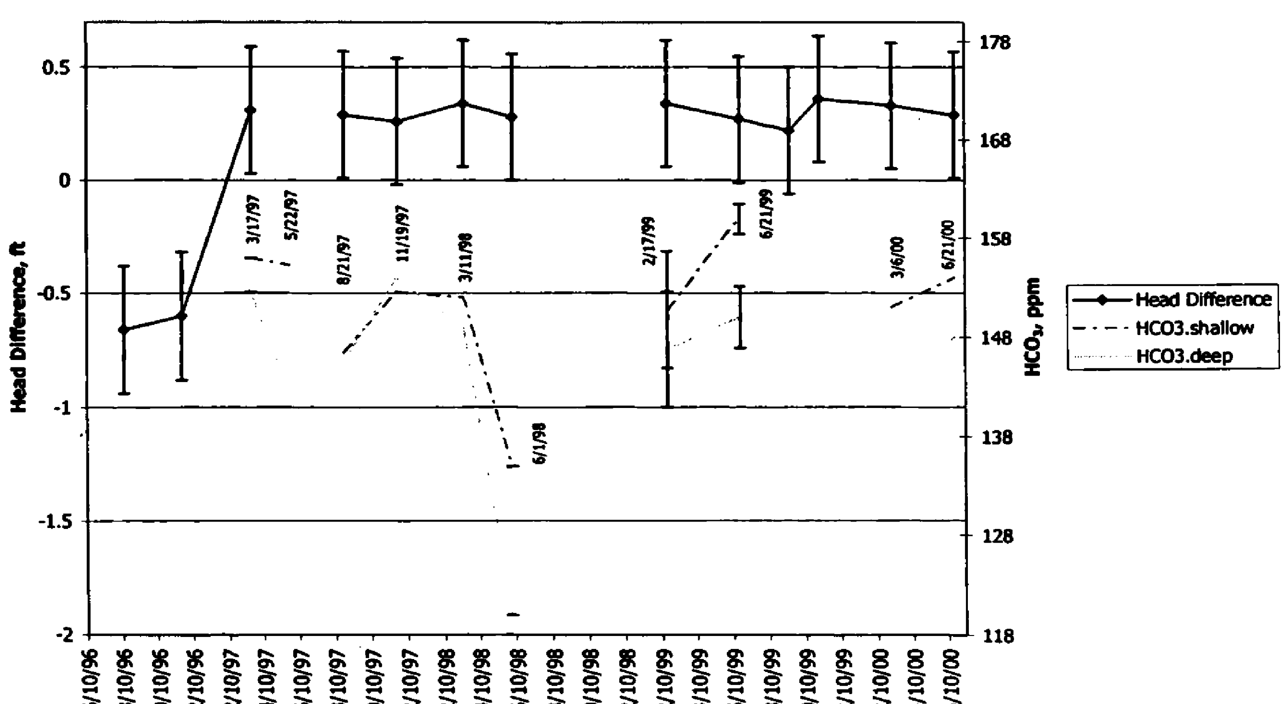
Blaine/Crosby [SO$_4$] and Head Differences



Blaine/Crosby [NO_3] and Head Differences



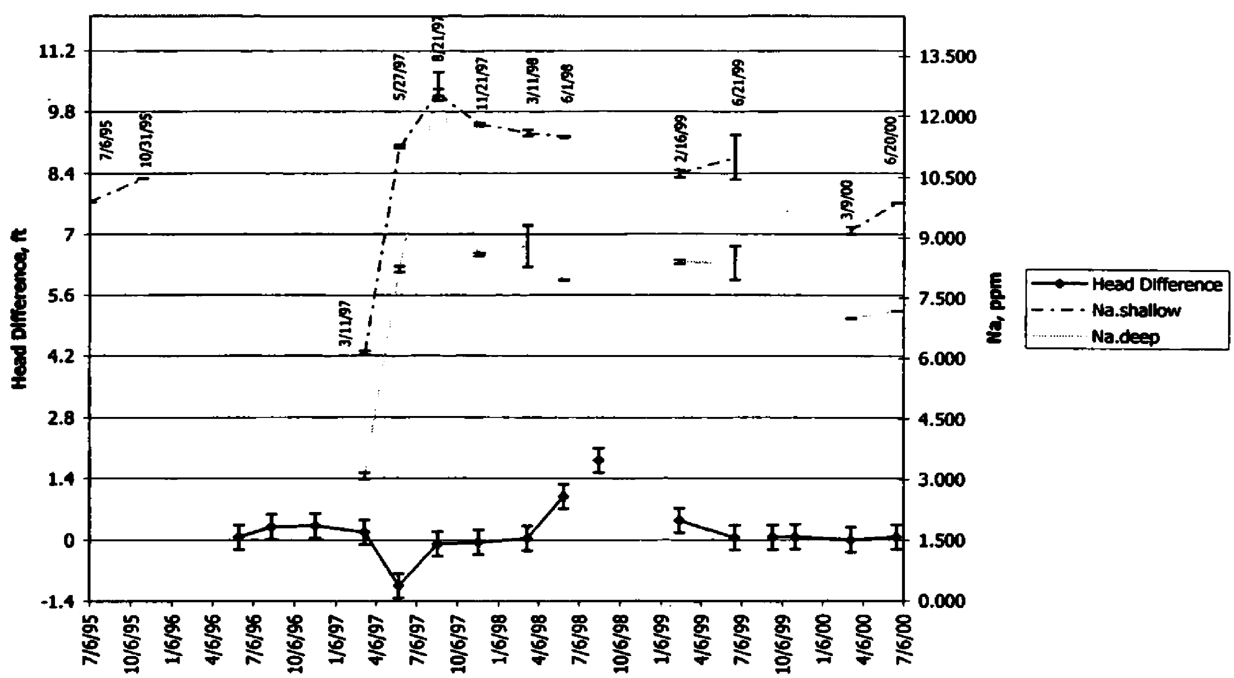
Blaine/Crosby [HCO_3] and Head Differences



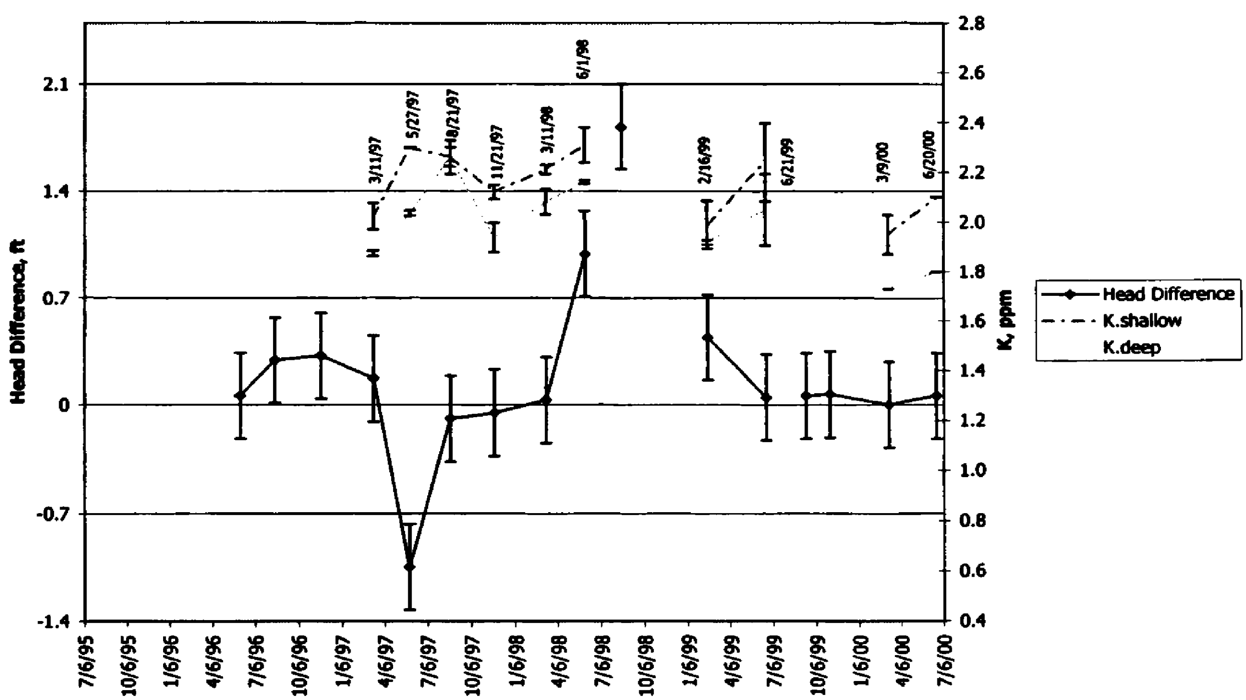
Head Differences and Inorganic Ion Concentrations:

Larchmont Well Nest

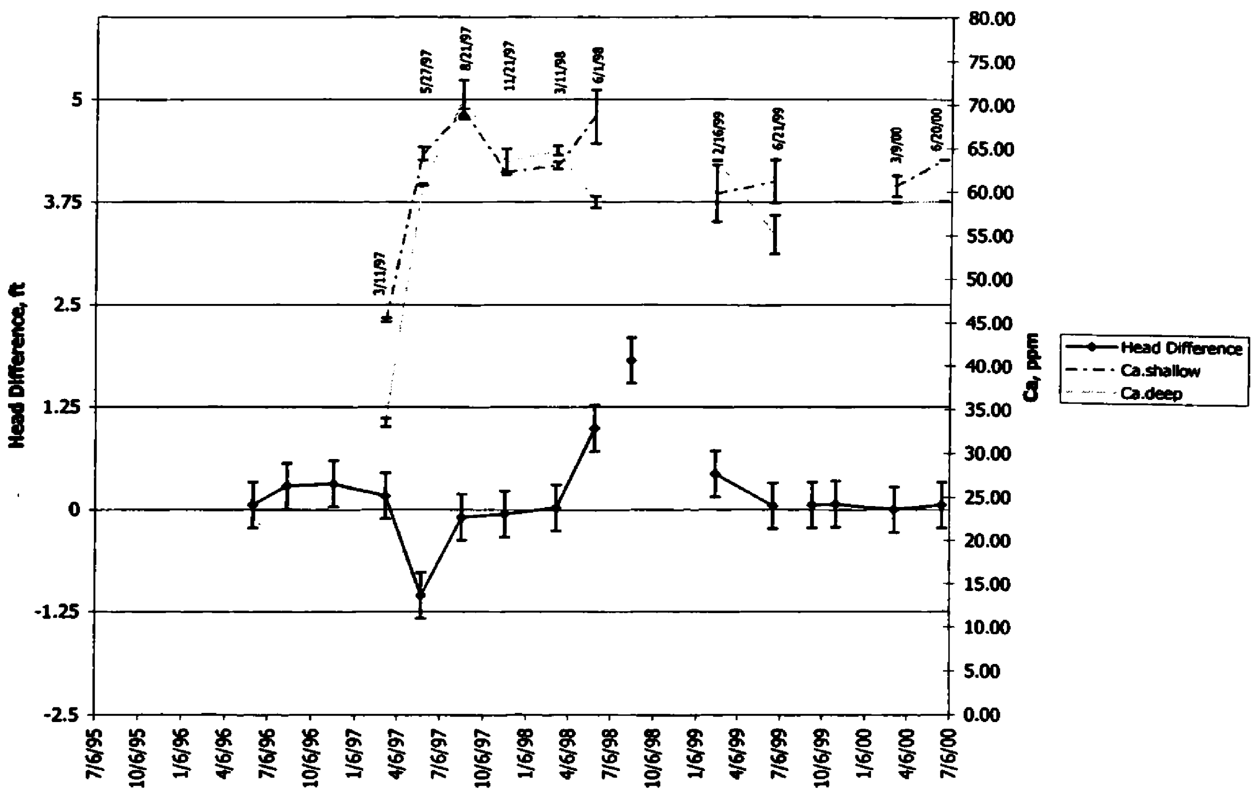
Larchmont [Na] and Head Differences



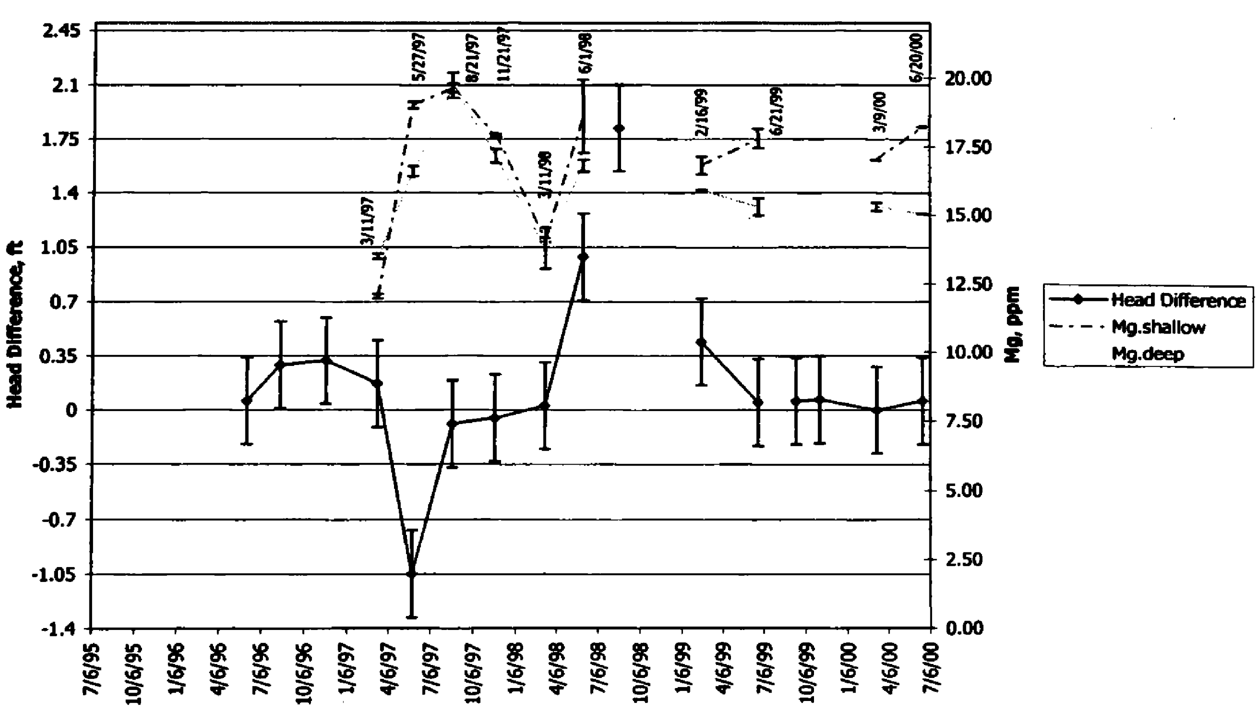
Larchmont [K] and Head Differences



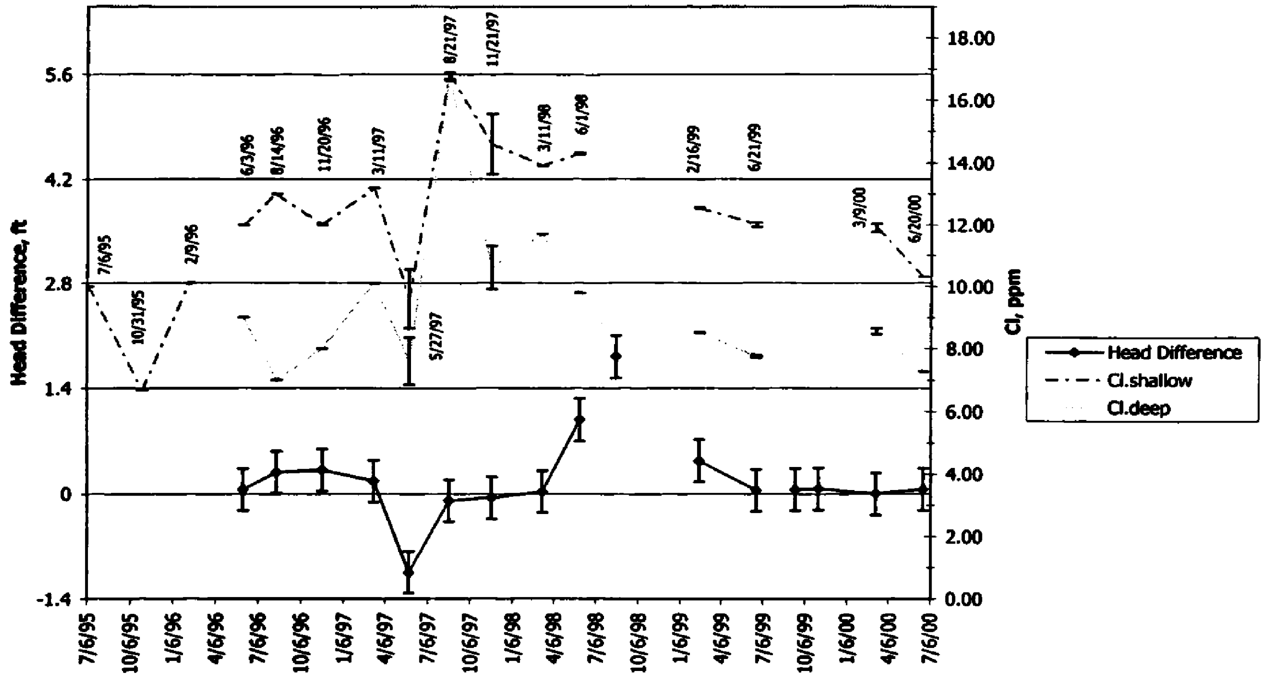
Larchmont [Ca] and Head Differences



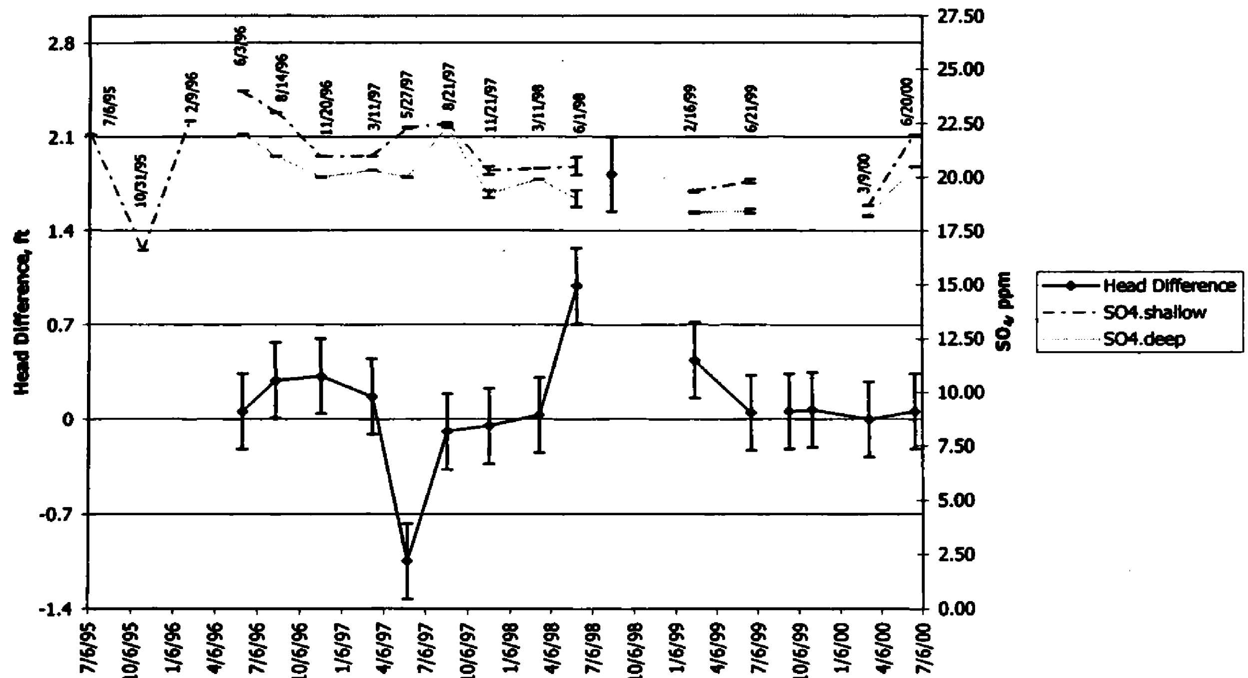
Larchmont [Mg] and Head Differences



Larchmont [Cl] and Head Differences



Larchmont [SO_4] and Head Differences



Appendix G

Numerical Profile Model

Numerical Profile Model

A numerical profile model was constructed and calibrated that simulated flow in cross-section along a flow line starting near the Madison St. well, roughly paralleling Brooks St. and ending at the Bitterroot River near the Buckhouse Bridge. This model is calibrated to flow conditions observed during 6/99 sampling.

Model Construction

The model was constructed using Visual ModFlow 2.8.2.22©; a version of the USGS 3-D groundwater flow model, MODFLOW (McDonald and Harbaugh, 1988) with graphical user interface features. It was chosen because it is popular and has particle tracking capabilities. This aquifer was simulated as unconfined.

Model Grid

MODFLOW (McDonald and Harbaugh, 1988) uses a block-centered grid system. Head is calculated at the middle of each cell. The model grid size was 20,944 ft along the y-axis by 175 ft along the x-axis and 1 layer thick. The cell dimensions were 5 ft wide by 162.15 - 660 ft long. Cell widths of 5 ft minimized error in the simulated water levels without being restricted by memory requirements. Cell lengths of 660 ft were used throughout the model except when cells were shortened to end at watertable elevation contours and represent the widths of the Bitterroot and Clark Fork Rivers. The final grid had 70 rows and 41 columns.

Aquifer Geometry and Boundary Conditions

The depth to aquifer bottom was interpreted from Figure A.3. Cells below the interpolated aquifer bottom were made inactive to simulate the tight Tertiary sediments. The cells above the interpolated potentiometric surface resided were also made inactive.

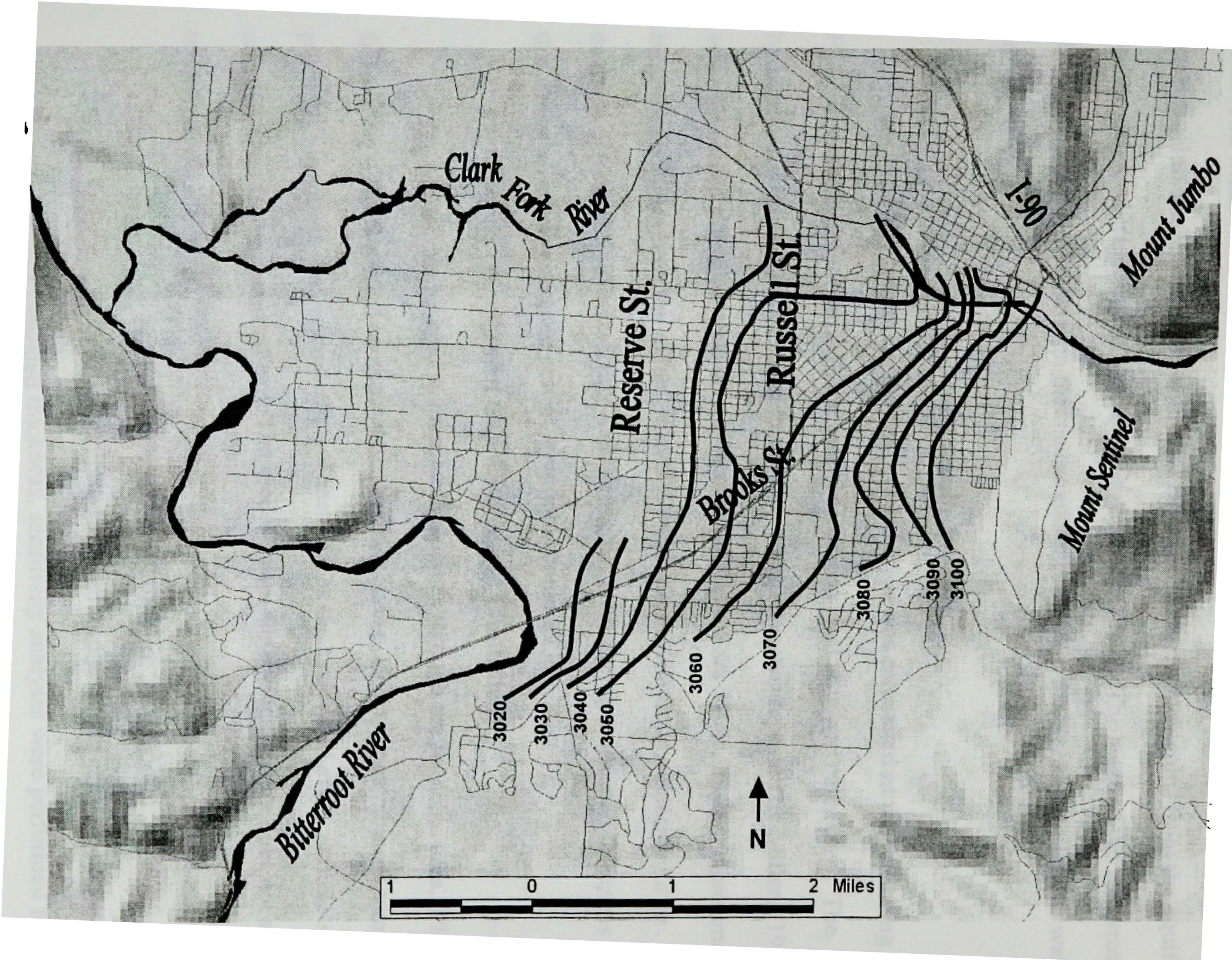


Figure A.3: Aquifer Base Elevation (ft) Map

To simulate leakage from the Clark Fork River, a constant head boundary was used. The water table elevation beneath the Clark Fork River was set to the measured water level in the Madison St. well. The Bitterroot River, which gains from the aquifer was modeled with a constant head boundary (Clark, 1986). The stage of the Bitterroot River was set 2.3 ft lower than the measured water level in the Buckhouse Bridge well (Clark, 1986).

Hydraulic Properties

An initial hydraulic conductivity distribution was calculated in the following way. First, an estimated flux through the model cross-sectional area was calculated. The hydraulic conductivity value used in the flux calculation was reported by Miller, (1991), who performed pumping tests on a well near the Clark Fork River. Flux was assumed to be constant throughout the model. Finally, hydraulic conductivity values could be calculated from the estimated flux and the gradient and average saturated thickness for the model area between each pair of watertable contours in Figure 3.

Model Capabilities and Limitations

The model can be used to calculate velocities through the modeled area. Plumes from point sources cannot be simulated. MT3D (Zheng, 1990), a contaminant transport program, calculates the concentration at each cell as the average of every particle's concentration in the specified cell. The model's two-dimensional nature does not allow transverse dispersion to occur.

Sensitivity Analysis

To evaluate the error of the calibrated model results due to error of estimated aquifer parameters and saturated thickness, sensitivity analyses were performed for head, flux, vertical gradients at the Clark Fork River and average velocities. Hydraulic conductivity, porosity, saturated thickness and specific yield were varied over a reasonable range of values listed in Table A.4.

Table A.4: Variable Magnitude of Change

Variable	Magnitude of Change
Hydraulic Conductivity	+/- 50%
Porosity	+ 0.15, - 0.1
Saturated Thickness	+/- 10 feet
Specific Yield	+/- 0.1

Variables were changed one at a time while all others were kept constant.

Results of each sensitivity analysis are displayed in Figures A.4 – A.7. Average velocity was affected by hydraulic conductivity, porosity and saturated thickness. Flux, gradients and head were only affected by saturated thickness. Specific yield did not affect any of the model results.

Finally, the lowest and highest possible velocities were simulated by changing variables by the magnitudes listed in Table A.5 and calcualted by particle tracking.

Table A.5 Variable Changes to Achieve Lowest and Highest Velocities

Variable	Lowest Velocity	Highest Velocity
Hydraulic Conductivity	- 50%	+ 50%
Porosity	+ 0.15	- 0.1
Saturated Thickness	+ 10 ft	- 10 ft

The results of simulating the lowest and highest minimum velocities are compared to the calibrated model and displayed in Table A.6.

Table A.6 Lowest and Highest Simulated Velocities

Simulation	Velocity, ft/d
Lowest velocity	28
Calibrated model	90
Highest Velocity	369

Figure A.4: Sensitivity of Average Velocities to Variations of Hydraulic Conductivity, Porosity and Saturated Thickness

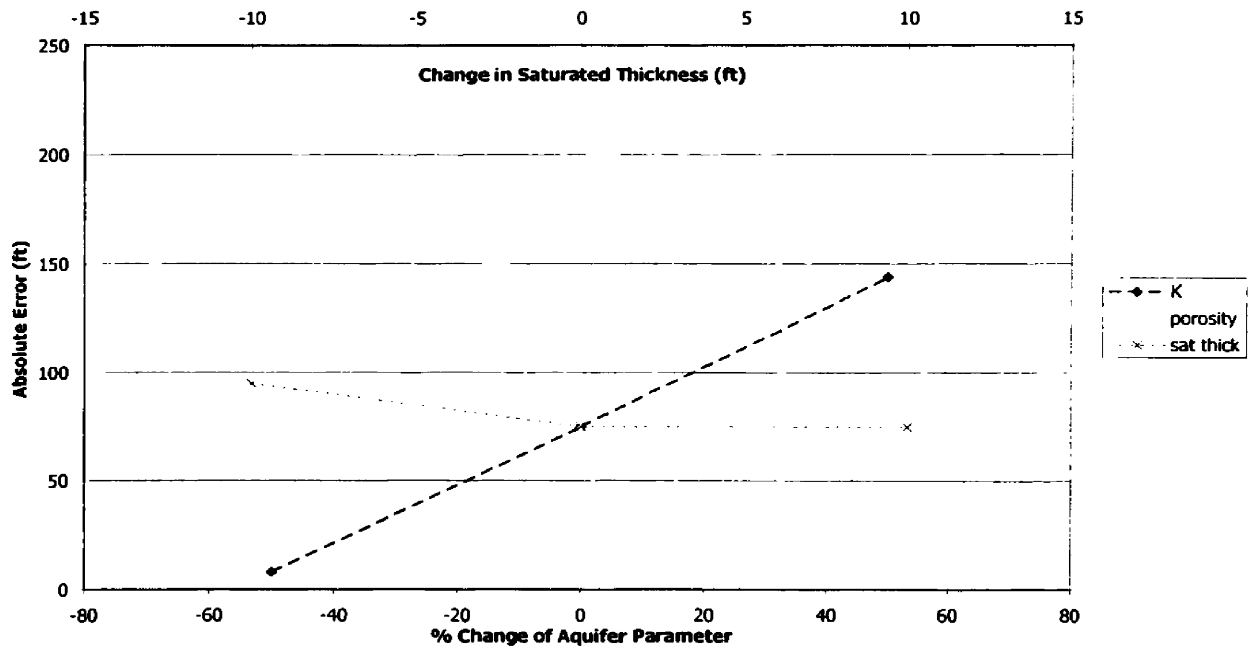


Figure A.5: Sensitivity of Water Levels and Flux to Variations of Saturated Thickness

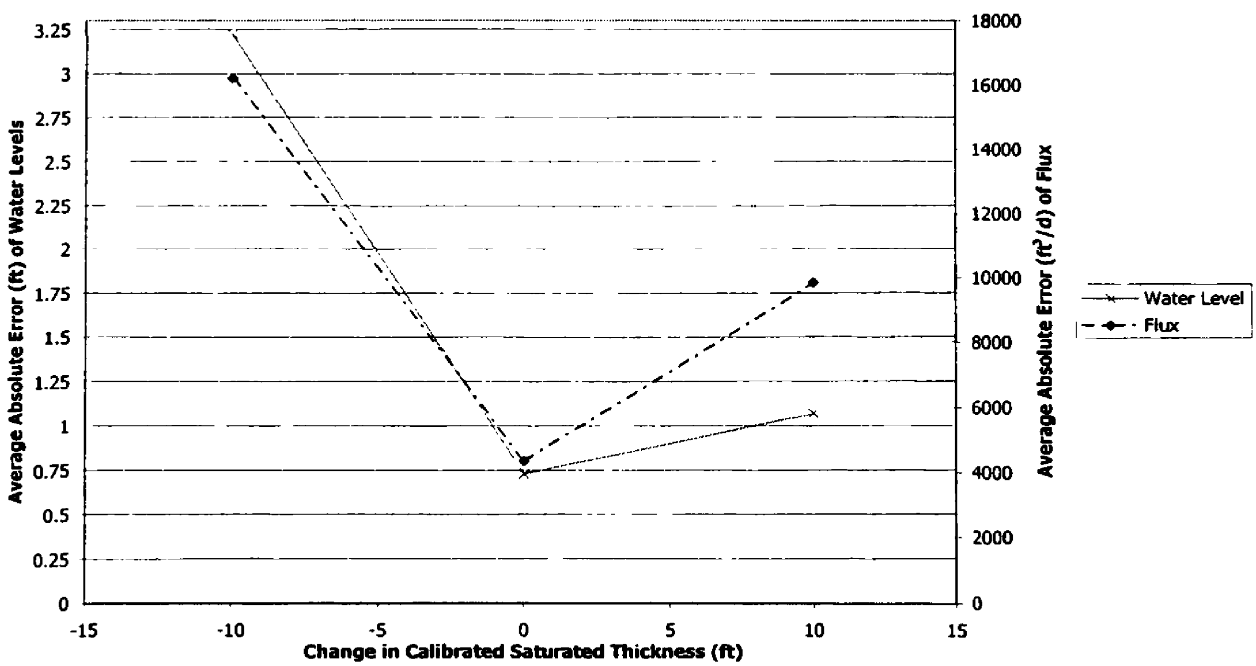
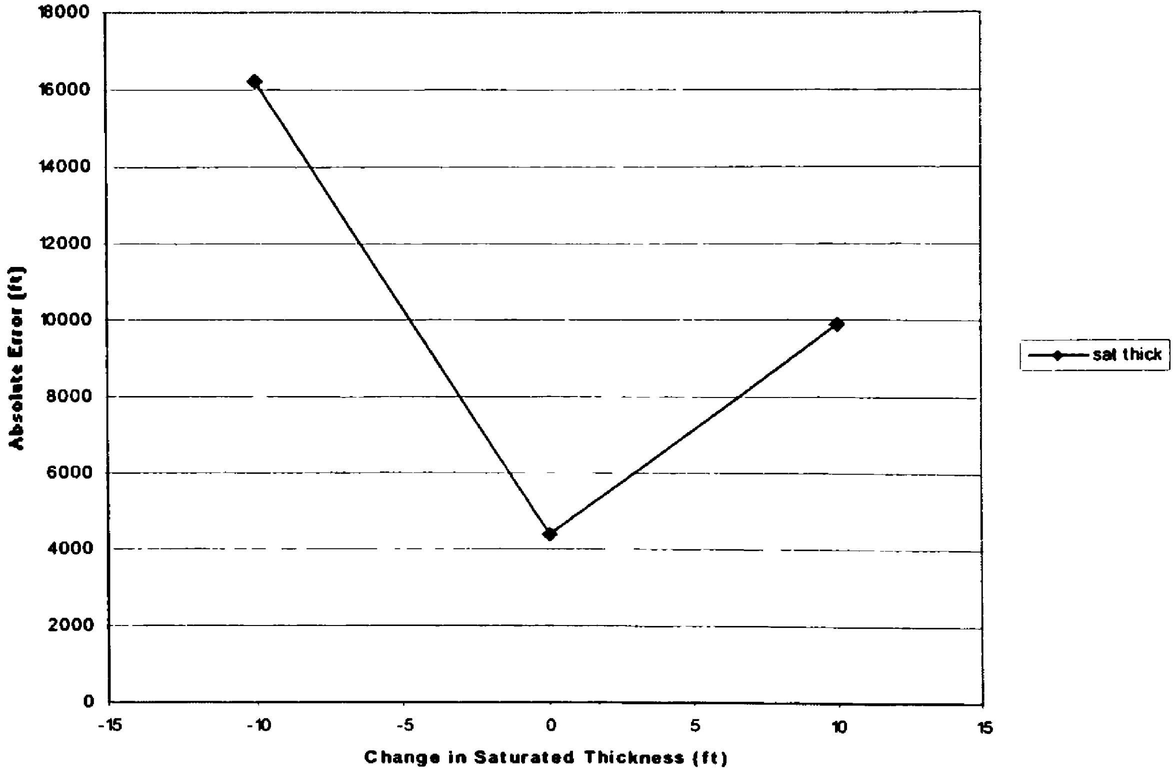
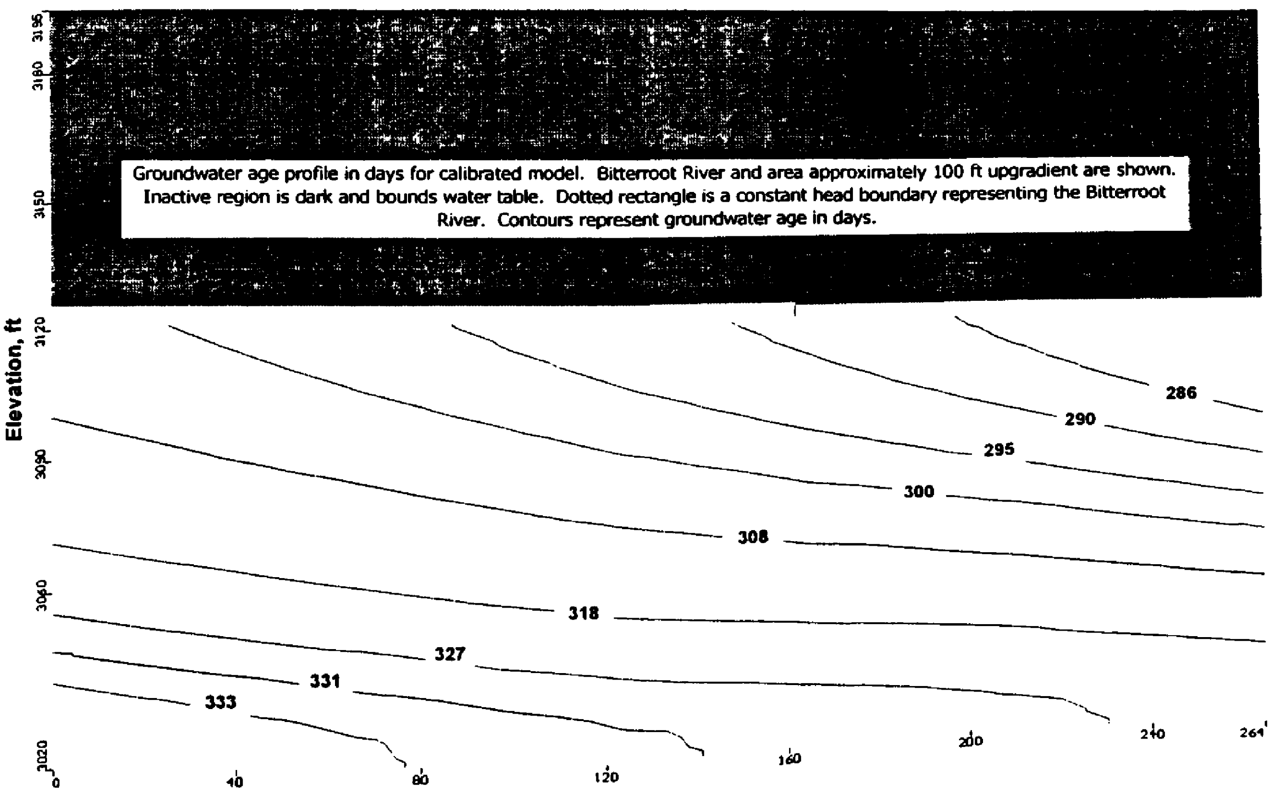
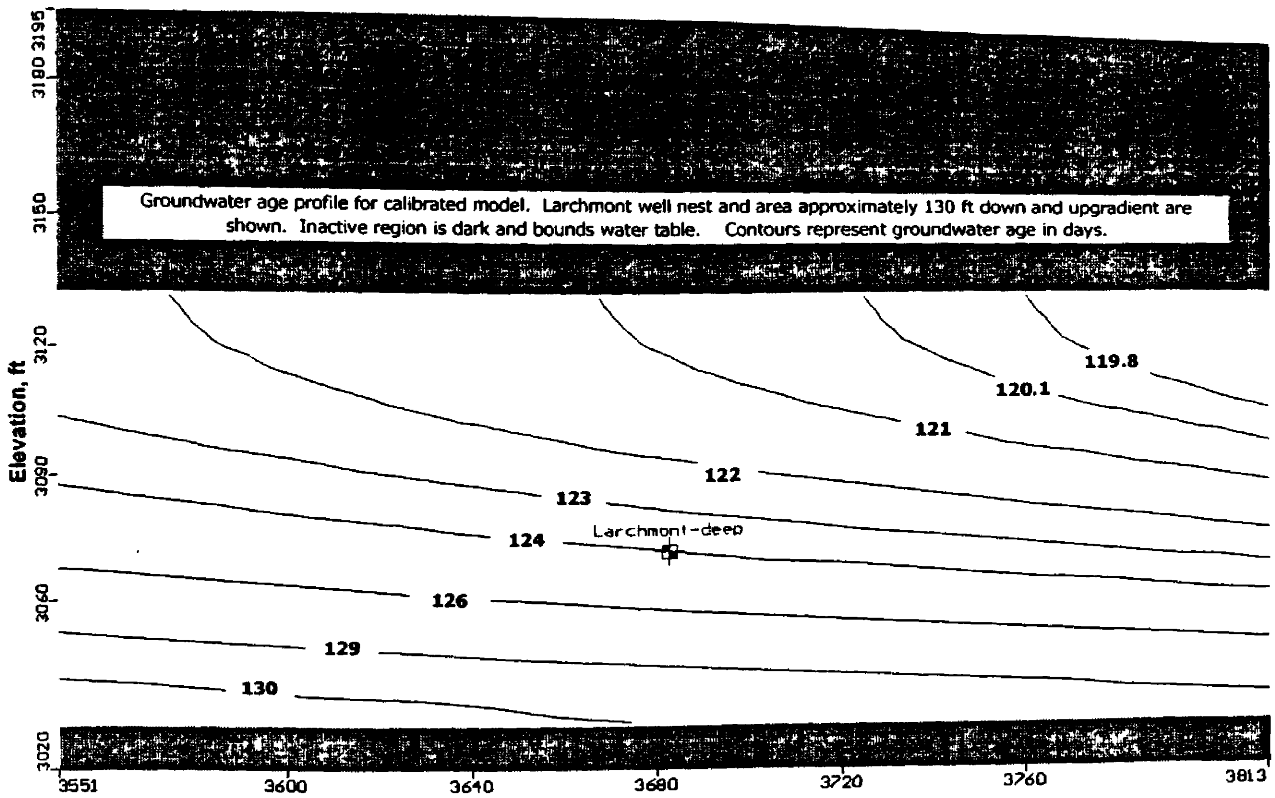


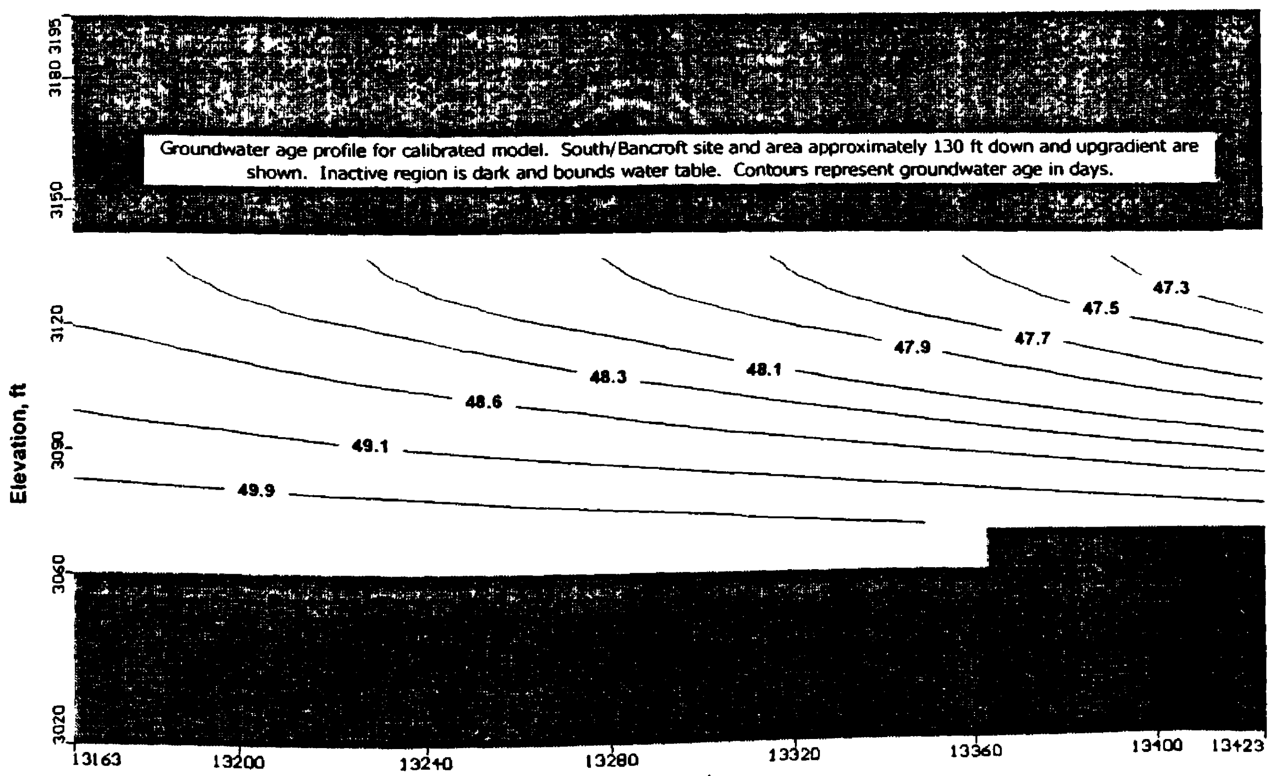
Figure A.6: Sensitivity of Flux to Variations of Saturated Thickness.

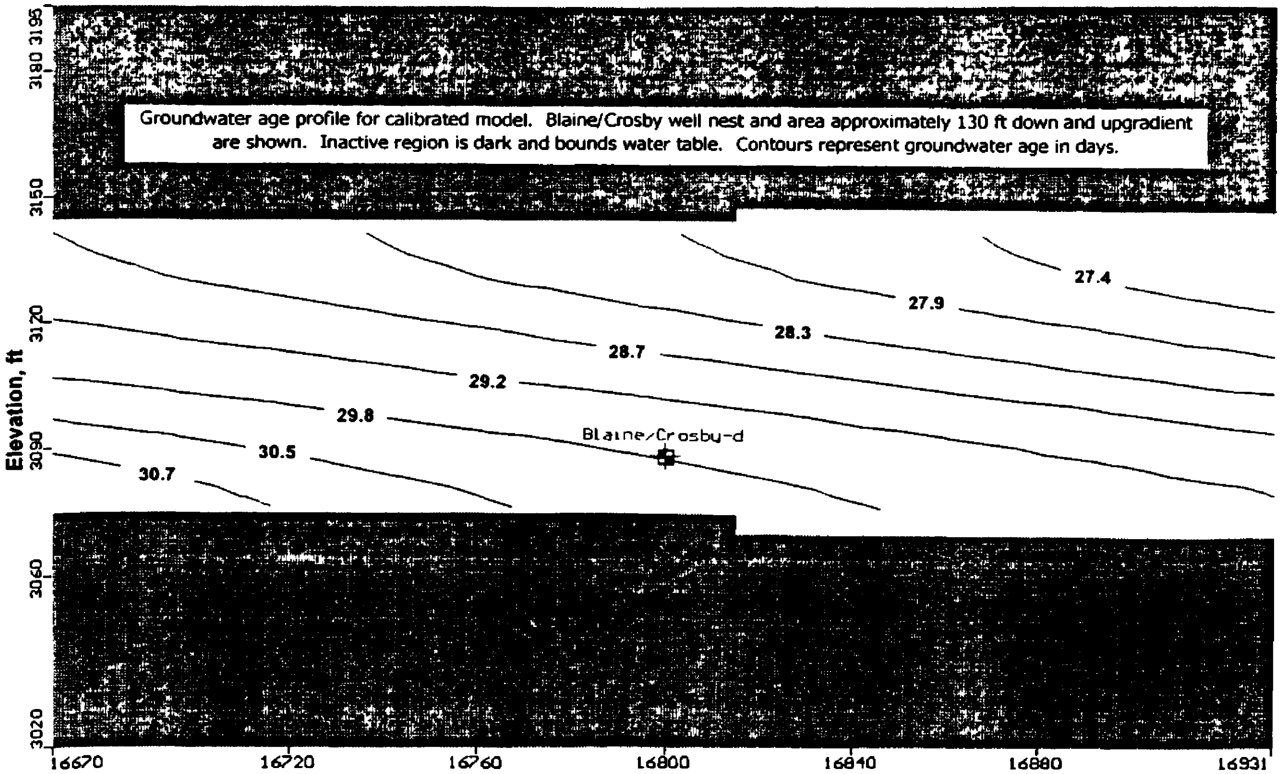


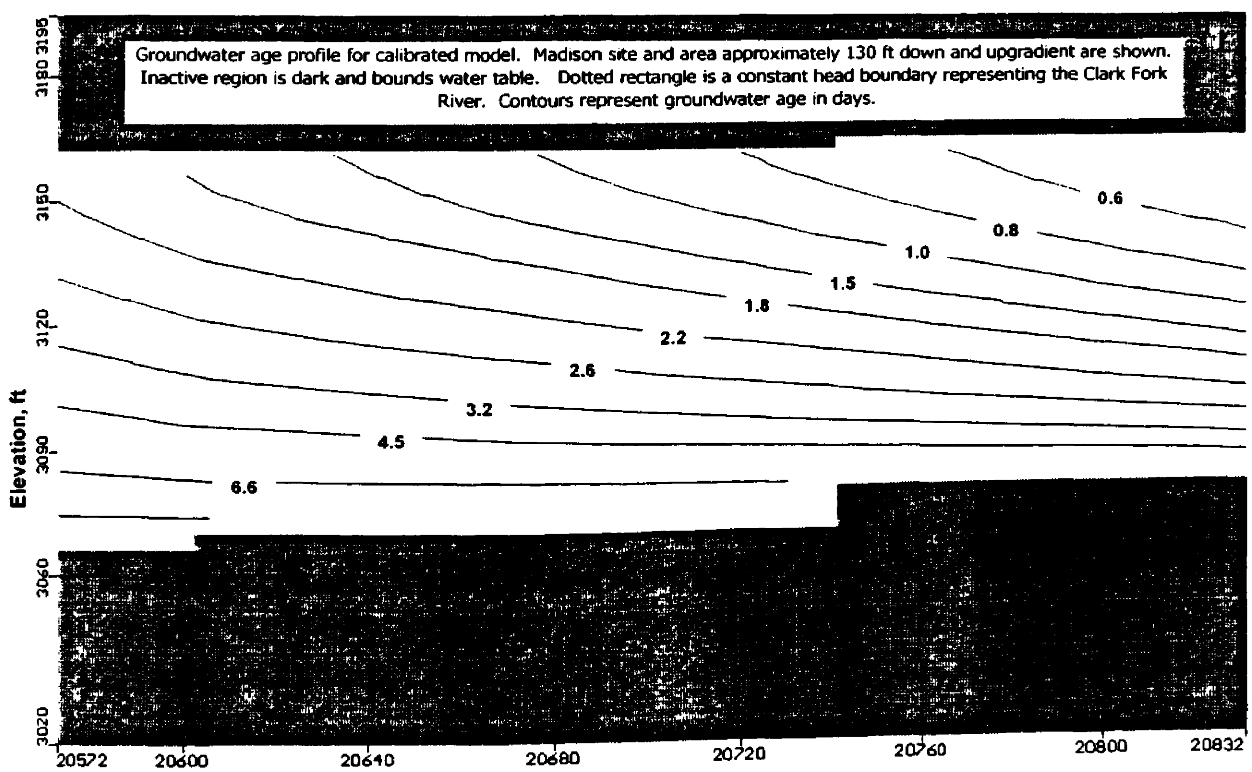


Groundwater age profile in days for calibrated model. Bitterroot River and area approximately 100 ft upgradient are shown. Inactive region is dark and bounds water table. Dotted rectangle is a constant head boundary representing the Bitterroot River. Contours represent groundwater age in days.


Groundwater age profile for calibrated model. Larchmont well nest and area approximately 130 ft down and upgradient are shown. Inactive region is dark and bounds water table. Contours represent groundwater age in days.
Elevation, ft
3195
3180
3150
3120
3090
3060
3020
119.8
120.1
121
122
123
124
126
129
130
Larchmont-deep
3551
3600
3640
3680
3720
3760
3813


Groundwater age profile for calibrated model. South/Bancroft site and area approximately 130 ft down and upgradient are shown. Inactive region is dark and bounds water table. Contours represent groundwater age in days.
Elevation, ft
3195
3180
3150
3120
3090
3060
3020
47.3
47.5
47.7
47.9
48.1
48.3
48.6
49.1
49.9
13163
13200
13240
13280
13320
13360
13400
13423


Groundwater age profile for calibrated model. Blaine/Crosby well nest and area approximately 130 ft down and upgradient are shown. Inactive region is dark and bounds water table. Contours represent groundwater age in days.
Elevation, ft
3195
3180
3150
3120
3090
3060
3020
27.4
27.9
28.3
28.7
29.2
29.8
30.5
30.7
Blaine/Crosby-d
16670
16720
16760
16800
16840
16880
16931


Groundwater age profile for calibrated model. Madison site and area approximately 130 ft down and upgradient are shown. Inactive region is dark and bounds water table. Dotted rectangle is a constant head boundary representing the Clark Fork River. Contours represent groundwater age in days.
Elevation, ft
3195
3180
3150
3120
3090
3060
3020
0.6
0.8
1.0
1.5
1.8
2.2
2.6
3.2
4.5
6.6
20572
20600
20640
20680
20720
20760
20800
20832