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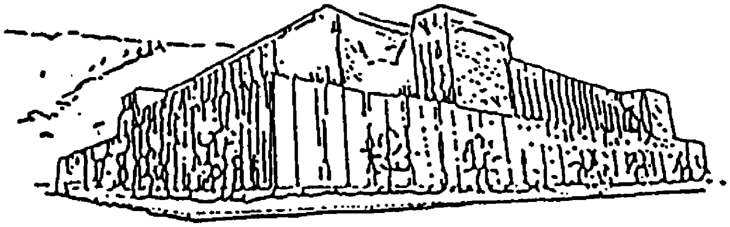

Groundwater Quantity and Quality of the Eight Mile, Ravalli County, Montana

by
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B.S., Montana College of Mineral Science
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Presented in partial fulfillment of requirements
for the degree of
Master of Science
The University of Montana
Spring, 1998

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Groundwater Quantity and Quality of the Eight Mile, Ravalli County, Montana (162 pages)

Director: Dr. William W. Woessner WWW 5/18/98

This study was undertaken to determine the quantity and quality of groundwater at the Eight Mile, located in a rapidly developing rural area where groundwater is used as a source of drinking water and as a treatment sink for septic effluent.

Residential wells in the Eight Mile are completed in two separate confined aquifers. The upper aquifer, EM-1, is composed of sand and gravel lenses interbedded with leaky sandy-clay lenses and includes one perched flow zone. In the central part of the study area, the leaky sandy-clay changes to massive clay. The deep aquifer, EM-2, is a water-bearing zone about 300 feet below land surface, and is isolated from EM-1 by this massive clay. EM-1 spans the entire study area and can be considered as six distinct flow zones by identification of differing recharge areas using hydrographic and potentiometric evidence. In general, adequate amounts of groundwater exist to support the population of about 375 households, although in lower-productivity zones groundwater is much more limited. At higher land surface elevations, distance to productive water-bearing zones is deepest and productivity is lower than on the valley floor. At locations on the valley floor, near the old bed of Eight Mile Creek and toward the Bitterroot River, distance to productive water-bearing zones is less and wells are more productive. Hydrographic evidence indicates that irrigation practices impact deeper EM-1 flow zones in an annual cycle of withdrawal and recovery while contributing significant recharge to the perched lens at the northern end of the study area.

Specific conductance measurements classify the study area's groundwater as Class I, high quality water. During the study period, no samples of Eight Mile groundwater exceeded 5 milligrams liter^{-1} nitrate-N concentrations. Rural development and population growth will increase demand on the groundwater resource and the scale of impacts due to multiple conflicting uses of the resource. In view of the continuing development of the Bitterroot Valley, the establishment of water quality districts is recommended.

Acknowledgments

I would like to thank the Eight Mile well owners who allowed me access to their wells for data collection. Without their cooperation, this study would not have been possible. Thanks also to DeAnn Dutton and Dave Briar of the U.S. Geological Survey Water Resources Division for my field training. I am grateful to Professor Jim Sears of the University of Montana (UM) Geology Department who provided assistance and advice toward my understanding of the complexities of the Eight Mile's subsurface geology, and to Professor Hans Zuuring of the University of Montana Forestry School for salvaging my GIS map files.

I would like to acknowledge the assistance of Terry, Gabe and Paul Neujahr and Joe Wearing for helping me to survey the study area. My son Joe Wearing also assisted with static water level measuring many times. I have especially appreciated Joe's cheerful assistance and unfailing sense of humor throughout this long project.

Thanks to Ellen Stewart Montenegro and Cheri McConkey for assistance with editing this manuscript and to Cecilia Johnson and Ann Ulrich of the USDA Forest Service for advising on producing graphics.

Finally, I would like to thank my committee: Dave Briar, US Geological Survey; Professor Jerry J. Bromenshenk, UM Division of Biological Sciences; Professor Tom Roy; UM Environmental Studies; and Committee Chair and Professor Bill Woessner, UM Geology Department. I have appreciated the unique contributions and guidance each committee member provided to my work on this project.

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Chapter 1: Introduction

Problem Description

The population of Ravalli County, Montana grew by 38.2% between 1990 and 1997 (Ludwick, 1998), elevating countywide concerns about possible impacts to groundwater quantity and quality. The Eight Mile, located at the northern edge of the county (Figure 1.1), typifies the rapid growth experienced throughout Ravalli County. Eight Mile residents use groundwater as their sole source of water for drinking and for other domestic uses. To identify impacts of development to groundwater, current conditions should be compared with redevelopment conditions. Unfortunately, previously-collected data describing baseline conditions are scant, scattered, and not temporally connected.

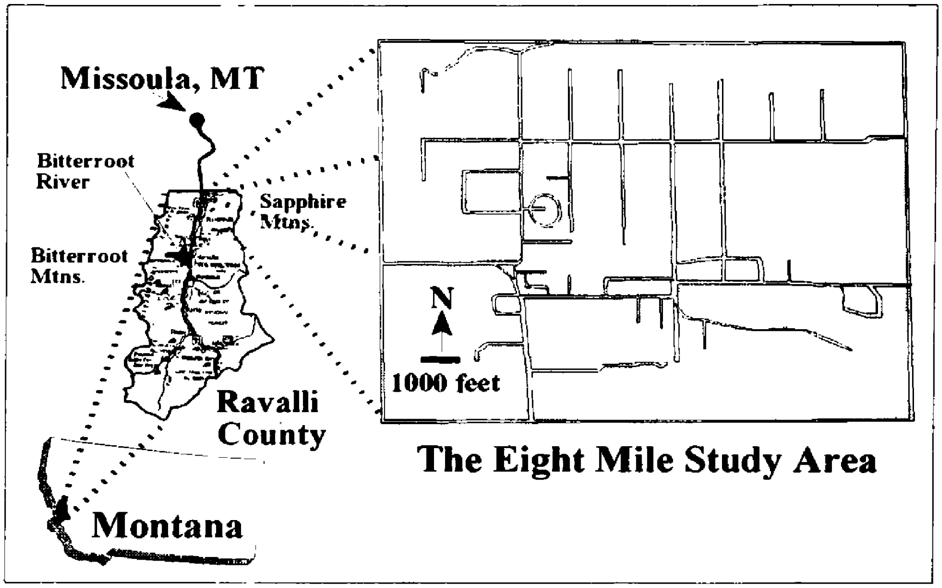

Figure 1.1. Study Area Location

In recognition of Eight Mile residents' concerns and problems associated with the lack of data, in July 1994 the Ravalli County Commission authorized the United States Geological Survey (USGS) Water Resources Division to study groundwater in Ravalli County, concentrating efforts at three separate sites, one of which was the Eight Mile. This thesis uses water level and water chemistry data collected for the Eight Mile portion of the USGS study. USGS personnel will also issue a report using these data. The goal of this thesis was to establish the hydrogeology of the Eight Mile and to evaluate impacts of development on the groundwater resource.

Literature Review

The United States (U.S.) Environmental Protection Agency (EPA) recognizes that septic systems pollute groundwater with nitrate and other waste components (EPA, 1995). Spalding and Exner (1993) reviewed the occurrence of nitrate in groundwater across the U.S. and found that septic systems and fertilizers were significant sources. They found that nitrate contamination decreased with increasing organic carbon in the soil, temperature, and rainfall. They concluded that climate conditions in the southeast U.S. favored nitrate attenuation while groundwaters of the western U.S. were more susceptible to nitrate contamination.

Yen, et al., (1996) examined a USGS data set collected from rural areas in the Midwest. They determined that increasing urbanization, fertilizer use and the presence of dissolved oxygen increased nitrate loading to shallow groundwater. Kolpin, et al., (1994) drew similar conclusions from their study of herbicides and nitrates in the Midwest U.S.

Kaufmann (1978) reported on his intensive study of the groundwater quantity and quality of the Las Vegas valley in Nevada. He found that the area's shallow aquifer had already been contaminated with nitrate from septic drain fields and leaking sewer lines.

Ragone, et al., (1980) found that sewered and non-sewered areas of Nassau County, Long Island had similar nitrate concentrations in groundwater. They concluded that, while groundwater quality of sewered areas was probably recovering slowly from past nitrate input from septic systems, inputs from lawn fertilizers and animal wastes had masked the improvement. Eckhardt et al., (1986) reported that Long Island's groundwater nitrate concentrations were directly proportional to agricultural practices and housing density, and that sewer systems had lowered the area's water table by removing septic drain field inputs from the groundwater system.

USGS personnel modeled effects to groundwater quantity of increased pumping for four basins in Nevada, and identified serious potential risks of aquifer dewatering to all four basins.

They did not examine impacts of increased housing development to water quality (Thomas, et al., 1989; Harrill and Pressler, 1994; Prudic and Herman, 1996; Berger, et al., 1996).

In the early 1990's, Metzger, et al., (1997), studied land subsidence and diminishing groundwater quality due to groundwater withdrawal by an increasing number of residential wells in Atherton, California. They found elevated nitrate concentrations in some samples. The nitrate source was not identified, but leaking sewer lines and fertilizer use were suspected.

Reflecting the current interest in nitrate impacts to groundwater systems, in western Montana, King (1996) modeled nitrate plumes emanating from septic drain fields in Missoula County to assess cumulative impacts of increasing residential development to groundwater quality. McCamant (1996) examined the impacts to Rock Creek, a blue-ribbon trout stream in western Montana, of nitrate loading from rural septic systems. Both studies examined effects of nitrate loading to shallow, highly transmissive, water table aquifers, which differ from the groundwater conditions found at the Eight Mile.

Previous Work in the Study Area

McMurtrey, et al., (1972) conducted a USGS groundwater investigation of Ravalli County in the late 1950's. They focused on the hydrology of the entire Bitterroot Valley so research was conducted at a very large field scale, on an area that fringed upon but did not encompass the Eight Mile. McMurtrey included a groundwater sample from one Eight Mile well for water chemistry characterization and three other wells for water level measurements. Similarly, the USGS collected some data in the Bitterroot Valley for the Regional Aquifer System Analysis (RASA) in the 1980's, but this was a regional-scale field study and did not include wells in the Eight Mile (Briar, 1997).

In 1992 a private study was performed by Howard Newman, a consultant, for the developers of the Paradise Acres subdivision in the southwest quadrant of the Eight Mile study area. Newman conducted eight aquifer tests, collected water level measurements from 22 wells in July 1992, sampled 24 wells for nitrate analysis, and modeled the anticipated impacts of 58 additional wells and septic systems. He concluded that the proposed subdivision would not elevate nitrate more than 0.26 milligrams liter^{-1}. Newman's unpublished report (1993) provides a "snapshot" of Paradise Acres' July 1992 groundwater, but not conditions in the Eight Mile as a whole.

Study Area Description

The 36 mile^2 Eight Mile basin is located 17 miles south of Missoula (Figure 1.1). The study area covers more than four square miles of the basin's mouth, and is bisected by Eight Mile Creek (Figure 1.2), which flowed perennially from the Sapphire Mountains until it was dammed at the reservoir in the southeast quadrant of Township (T) 10 North (N), Range (R) 19 West (W), Section 8. The creek still discharges to the Bitterroot River during high runoff years.

Terraces, or benches, rising in steps on both sides of the Bitterroot River's flood plain, have

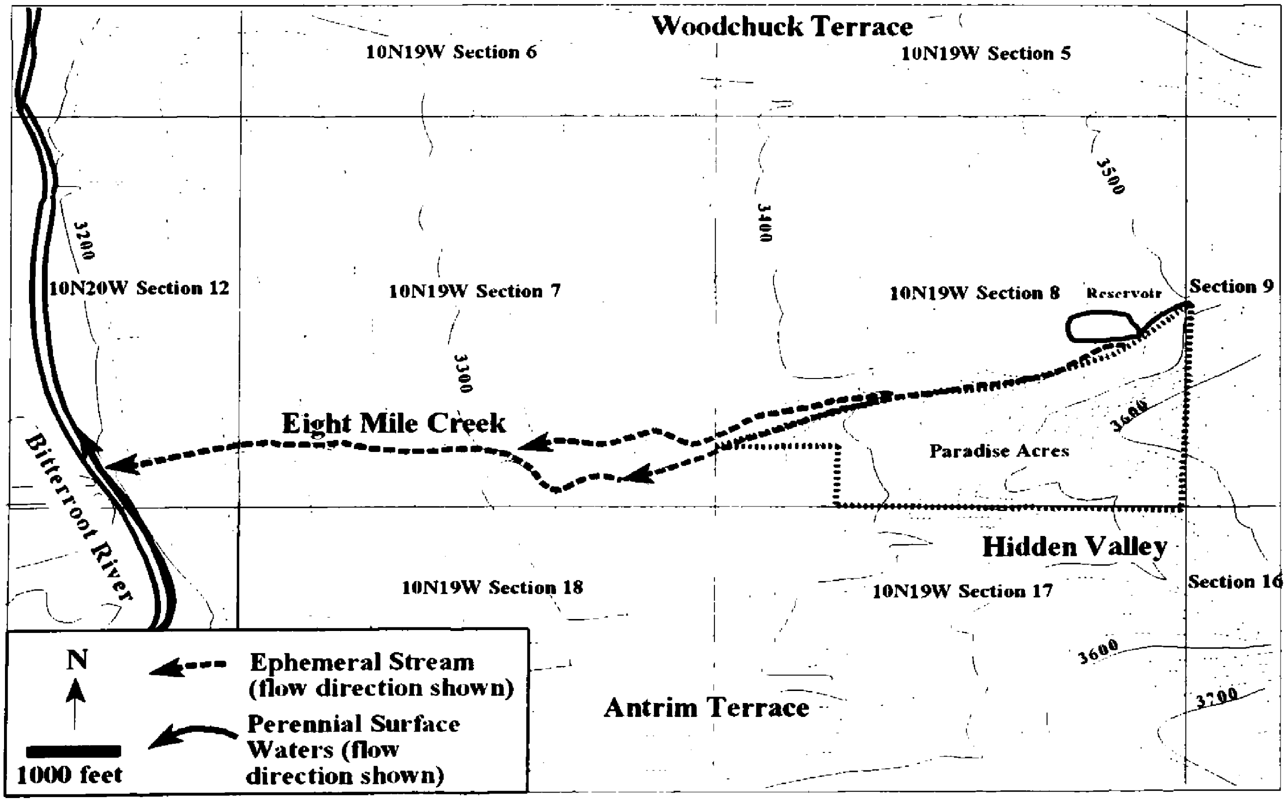

Figure 1.2. Study Area Topography, Surface Water Features, and Section Identifiers

been incised by the river's major tributaries, forming alluvial valleys subordinate to the main valley. The Eight Mile is such a subordinate valley, sited on both low and high benches. The study area is bounded on the west by the Bitterroot River, on the north by the base of Woodchuck Terrace, on the east by sections 4, 9, and 16, and on the south by Antrim Terrace. (The names used here conform to topographic features found on Stevensville and Florence USGS quadrangle maps). Boundaries were selected as drainage divides around the basin's mouth and also as a function of the availability of residential wells to be used for monitoring water levels.

A study area street map (Figure 1.3) is provided below to orient readers to study area street names, which are used in cross section names and in references to study area neighborhoods. Fetter's (1988) glossary of hydrogeologic terms is provided in Appendix J.

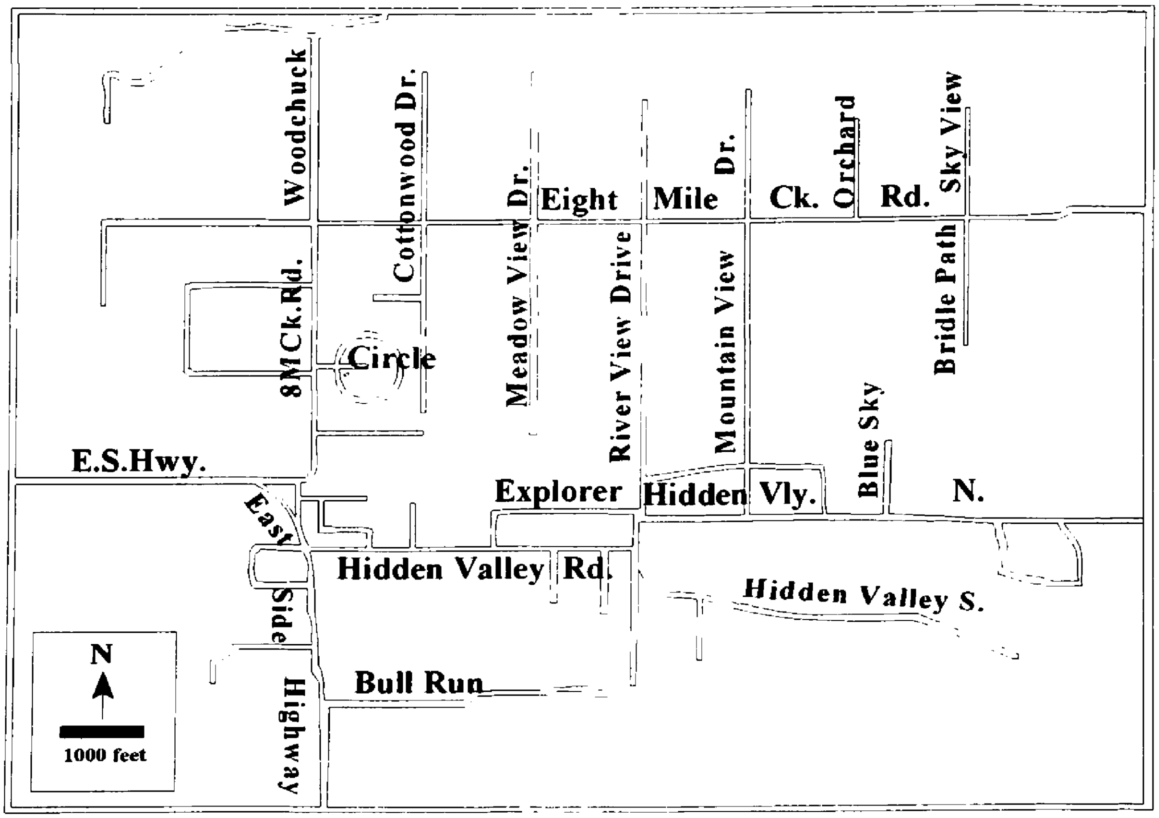

Figure 1.3. Eight Mile Area Street Map

Chapter 2: Methods

Study Area Establishment

In the summer of 1994 study area boundaries and monitoring wells were selected and well owners' permissions to collect data at their wells were obtained. Monitoring wells were added to the study as it progressed to gather additional data or to replace wells withdrawn from the study.

Numbering and naming conventions

Monitoring wells and duplicates were numbered with the prefix "8M". Aquifers in the Eight Mile flow fields were named EM-1 and EM-2. General descriptors were added as suffixes to EM-1 when naming its flow zones. Well logs used in cross sections were named by streets.

Measuring point locations determined in three dimensions

Figure 2.1 grids monitoring wells in the study area. The grid key and well depths are given in Table 2.1. Monitoring well measuring points elevations (usually the casing tops) were surveyed and corrected to a known elevation above mean sea level (provided by Professional Consultants of Missoula, Montana). Wells were located using street maps and aerial photos. Table 2.2 shows quarter-quarter-quarter-quarter section locations, in algebraic-quadrant notation (Figure 2.2).

Data Collection and Analysis Methods

Water level data

Static water levels were measured with a steel tape approximately every 10 weeks, with 10 data sets collected. Recovering water levels were taken when measurements stabilized to 0.03 feet. Appendix B contains a table of all static water levels measured for this project.

Water sample collection and analysis

After three well volumes of water were purged from wells, specific conductance and temperature were measured. Samples and duplicates were collected, stored on ice, and analyzed.

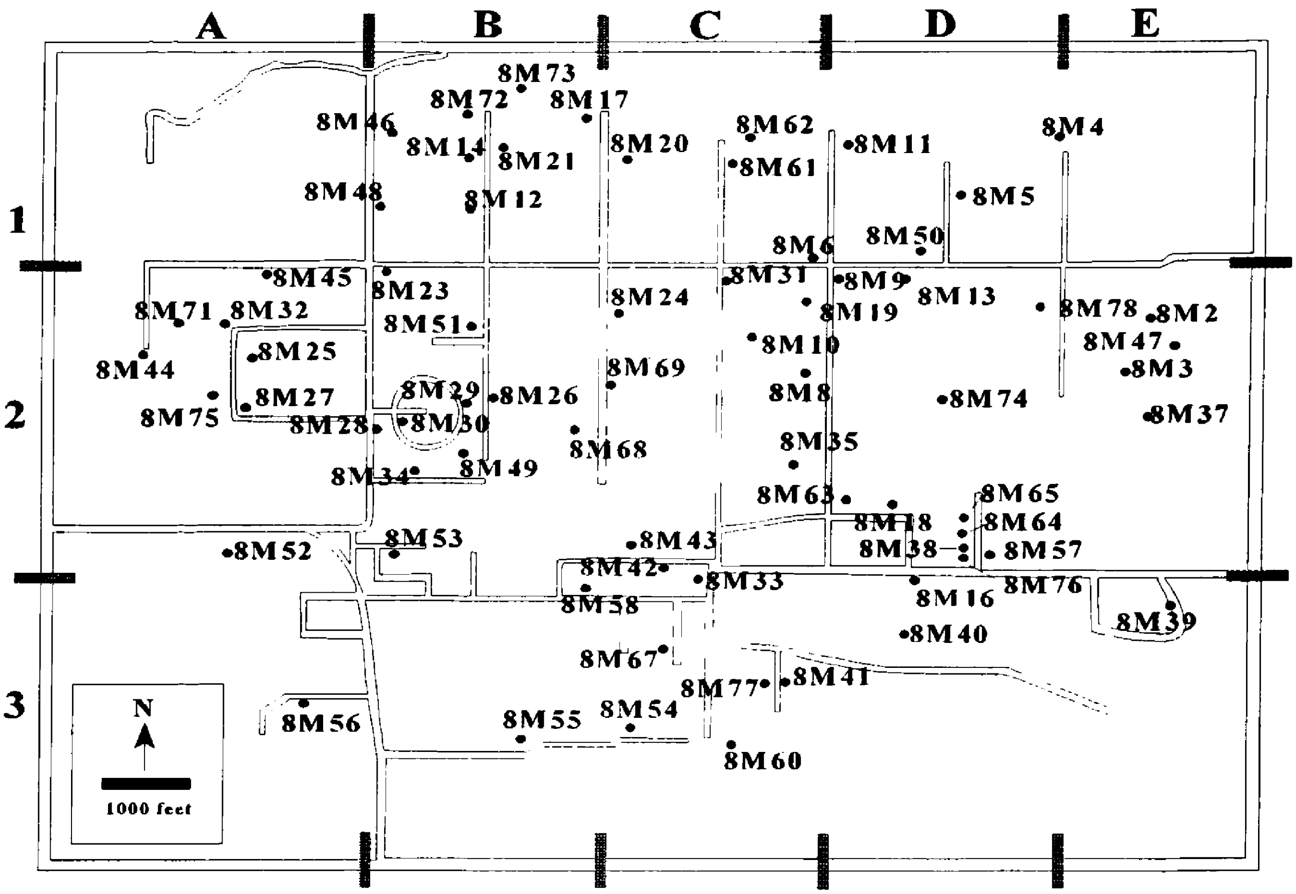

Figure 2.1. Eight Mile Study Area Well Locations

Table 2.1. Monitoring Wells' Grid Locations

Measuring well, grid location, well depth below land surface (ft.)											
8M02	E2	340	8M23	B2	104	8M42	C2	99	8M61	C1	48
8M03	E2	287	8M24	C2	158	8M43	C2	76	8M62	C1	13
8M04	D1	75	8M25	A2	80	8M44	A2	75	8M63	D2	107
8M05	D1	120	8M26	B2		8M45	A2	95	8M64	D2	180
8M06	C1	290	8M27	A2	57	8M46	B1	80	8M65	D2	170
8M08	C2	117	8M28	B2	110	8M47	E2	290	8M67	C3	95
8M09	D2	295	8M29	B2	85	8M48	B1	130	8M68	B2	72
8M10	C2	126	8M30	B2	80	8M49	B2	60	8M69	C2	120
8M11	D1	80	8M31	C2	200	8M50	D1	300	8M71	A2	95
8M12	B1	85	8M32	A2	100	8M51	B2	88	8M72	B1	148
8M13	D2	319	8M33	C3	75	8M52	A2	80	8M73	B1	81
8M14	B1	109	8M34	B2	59	8M53	B2	140	8M74	D2	261
8M16	D3	161	8M35	C2	69	8M54	C3	122	8M75	A2	90
8M17	B1	71	8M37	E2	210	8M55	B3	140	8M76	D2	168
8M18	D2	124	8M38	D2	187	8M56	A3	59	8M77	C3	
8M19	C2	320	8M39	E3	279	8M57	D2	186	8M78	D2	421
8M20	C1	135	8M40	D3	120	8M58	B3	75			
8M21	B1	84	8M41	C3	178	8M60	C3	160			

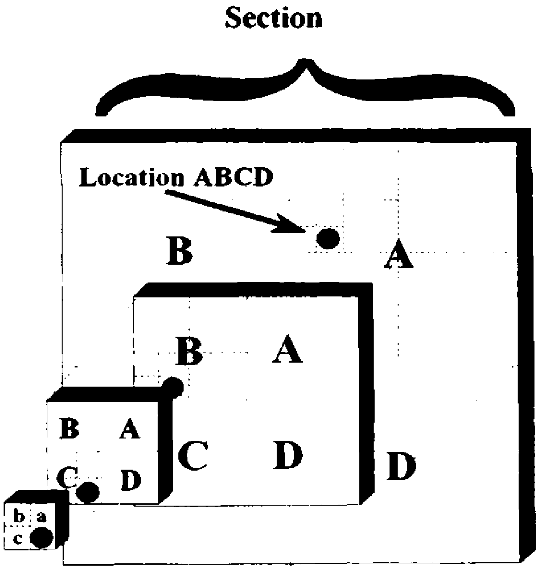

Figure 2.2. Quarter-Quarter-Quarter Quarter Section Locating Method

Table 2.2. Monitoring wells, quarter section locations, and casing elevations

Well #	Township and Range	Section, Quarter Section	Elev. Above MSL	Well #	Township and Range	Section, Quarter Section	Elev. Above MSL	Well #	Township and Range	Section, Quarter Section	Elev. Above MSL
8M01	10N19W	09 ABCC		8M27	10N20W	12 DAAD	3244.24	8M53	10N19W	07 CDCC	3269.42
8M02	10N19W	08 ADAD	3501.18	8M28	10N19W	07 CACB	3274.82	8M54	10N19W	18 ADCA	3353.24
8M03	10N19W	08 ADDC	3489.54	8M29	10N19W	07 CAAD	3301.97	8M55	10N19W	18 ACCD	3307.26
8M04	10N19W	05 DDCC	3472.50	8M30	10N19W	07 CACA	3284.12	8M56	10N19W	18 BCBD	3230
8M05	10N19W	08 ABBC	3450.21	8M31	10N19W	08 BCBB	3383.68	8M57	10N19W	08 DCCD	3469.08
8M06	10N19W	08 BBDD	3410.05	8M32	10N20W	12 ADDB	3232.56	8M58	10N19W	18 ABAD	3311.64
8M07	Duplicate			8M33	10N19W	18 AAAA	3343.04	8M59	Duplicate		
8M08	10N19W	08 CBAA	3402.24	8M34	10N19W	07 CDBA	3282.57	8M60	10N19W	17 BCCC	3372.60
8M09	10N19W	08 BDBB	3417.44	8M35	10N19W	08 CBDD	3375.40	8M61	10N19W	05 CCCC	3381.61
8M10	10N19W	07 ADBC	3348.52	8M36	Duplicate			8M62	10N19W	05 CCCD	3390.88
8M11	10N19W	05 CDCC	3401.11	8M37	10N19W	08 DAAC	3483.73	8M63	10N19W	08 CDBD	
8M12	10N19W	07 BAAD	3308.06	8M38	10N19W	08 DCCC	3462.95	8M64	10N19W	08 DCCA	
8M13	10N19W	08 BDAB	3435.28	8M39	10N19W	16 BBBC	3519.82	8M65	10N19W	08 DCCA	3456.74
8M14	10N19W	06 CDDD	3312.92	8M40	10N19W	17 BACC	3413.53	8M66	Not Used		
8M15	Duplicate			8M41	10N19W	17 BCAB	3390.56	8M67	10N19W	18 AADB	3328.59
8M16	10N19W	17 BAAA	3437.45	8M42	10N19W	18 AAAB	3336.57	8M68	10N19W	07 DBDA	3332.56
8M17	10N19W	06 DCDA	3343.30	8M43	10N19W	07 DDDB	3326.83	8M69	10N19W	07 DABB	3341.98
8M18	10N19W	08 CDAC	3407.31	8M44	10N20W	12 ACDD	3216.41	8M70	Duplicate		
8M19	10N19W	08 BCAD	3404.68	8M45	10N19W	07 BCBB		8M71	10N20W	12 ADCA	3227.83
8M20	10N19W	06 DDCC	3355.09	8M46	10N19W	06 CDCB	3291.07	8M72	10N19W	06 CDDA	3307.32
8M21	10N19W	06 DCCC	3317.93	8M47	10N19W	09 BCCC	3494.33	8M73	Not Used		
8M22	Duplicate			8M48	10N19W	07 BABC	3284.74	8M74	10N19W	08 DBBD	3439.59
8M23	10N19W	07 BDBB	3284.11	8M49	10N19W	07 CDAA	3297.58	8M75	10N20W	12 DABD	3228.60
8M24	10N19W	08 BCCB	3381.79	8M50	10N19W	08 BADD	3444.60	8M76	10N19W	08 DCCC	
8M25	10N20W	12 ADDD	3246.00	8M51	10N19W	07 BDDA	3308.21	8M77	10N19W	17 BCAB	3382.92
8M26	10N19W	07 DBBC		8M52	10N20W	12 DDDD	3221.89	8M78	10N19W	08 ACAD	3452.65

within 48 hours by ion chromatography for nitrate-N and chloride. Detection limits for both ions were 0.1 milligrams liter^{-1}.

Drillers' log data

Drillers' logs were obtained from the Montana Bureau of Mines Butte Field Office (BoM) and the Department of Natural Resources and Conservation (DNRC). The logs were matched to wells, located to the quarter-quarter-quarter-quarter section, and their elevations interpolated. Appendix A contains a list of well logs used in this thesis.

Cross section preparation method

Nine transects, mainly along streets, were plotted to a grid; well locations were projected to the nearest transect(s); and logged formation data were drawn down in cross section. This technique presented several sources of error. First, drillers' logs lack deep data in zones of ample groundwater because drillers stop upon reaching abundant water. Second, many drillers log formations in 5-foot or larger increments, overgeneralizing data. Third, drillers' descriptions vary with training (Sears, Spring 1997), increasing variation in the data set.

Potentiometric and flow direction maps

Static water levels were plotted on study area maps, and best-fit positions were determined for contour lines. Contour lines and distances were measured to obtain hydraulic gradient ratios.

Hydrograph preparation and analysis

Using static water levels, hydrographs were constructed to chart water level changes over time. Comparisons of hydrographs to each other gave rise to flow zone analysis. In Appendix G individual hydrographs are compared with their static water levels at the time of well construction.

Well group statistics

After identifying flow zones, well log data were sorted to zones by their location and box plots prepared by plotting parameters by maximum, median, and minimum values.

Transmissivity estimates and groundwater quantity estimation

Transmissivities were estimated using drillers' pumping test data in sequential iterations of the Theis Equation. Results were sorted by flow zones, screened for outliers, and averaged for a final value of transmissivity (T) for each flow zone. Groundwater quantity was estimated using T in Darcy's Law to solve for groundwater flux. Details of this method can be found in Appendix E.

Maps and figures

Spatial attributes such as section and topographic contour lines were digitized from USGS quadrangle maps and working aerial photos and were registered in PAMAP/GIS and then imported from the GIS as digital bitmapped images into presentations software.

Chapter 3: Results

Section 1: Geological Framework

Stratigraphy

The study area is covered by a soil veneer overlying approximately 30 feet of quaternary alluvium *(Qal)* described by drillers as unconsolidated sand, gravel and cobbles. In their description of the *Qal* McMurtrey, et al., (1972) distinguished between flood-plain alluvium (*Qfa*), low terrace alluvium (*Qla*), high terrace alluvium (*Qha*), and identified Tertiary sediments (*Ts*). Figure 3.1 shows the Eight Mile portion of McMurtrey's geologic map with added features noted in the legend.

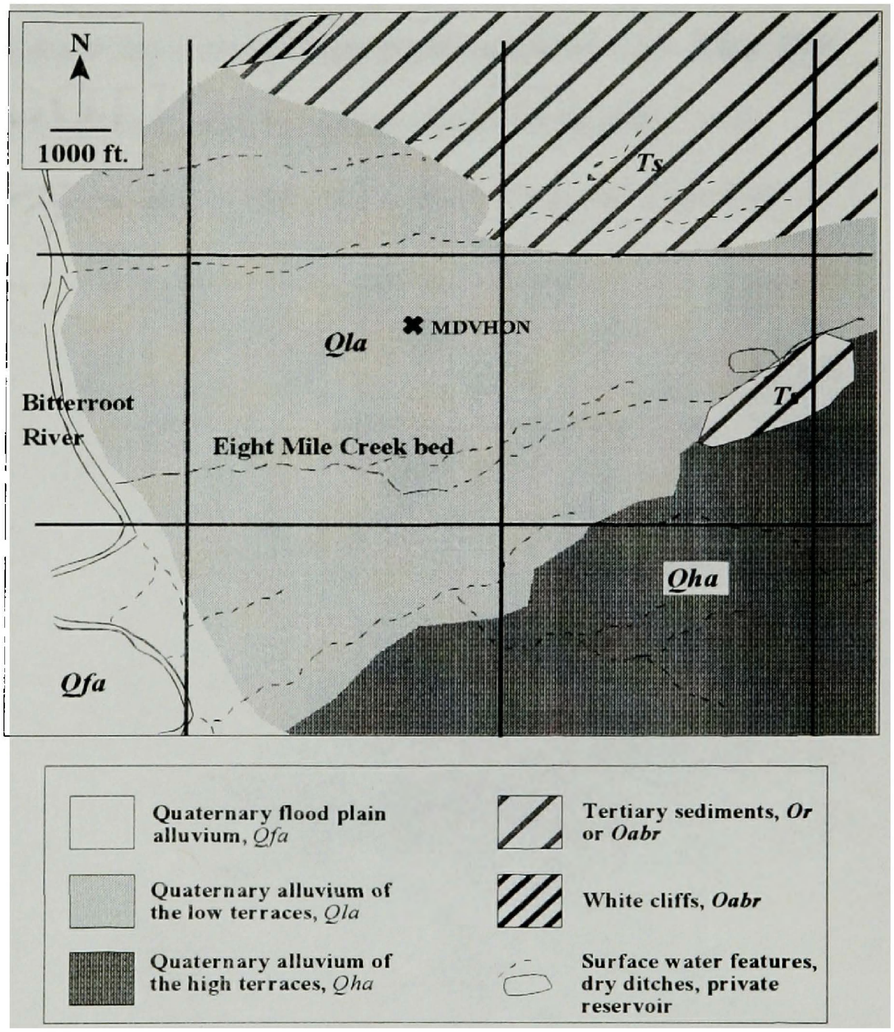

Figure 3.1. Eight Mile Portion of Geologic Map after McMurtrey, 1972

Study area *Qal* is composed of Tertiary-Miocene Six Mile Creek gravels *(Msmc)* which have been eroded from above-lying areas and reworked (Sears, 1996). (The names "Six Mile Creek" and "Eight Mile Creek" are coincidentally similar; there is no spatial relationship between them). The Six Mile Creek sediments appear as "blankets of coarse gravel ... with beds of sand and mud sandwiched between (Alt and Hyndman, 1986) and lie above or in place of the recently-described Tertiary Oligocene Ancestral Bitterroot River (*Oabr*) granitic sands, and late-Oligocene to early-Miocene Renova *(Or)(30-25 m.y.a.)* volcanic ash deposits. Tributary to the ancestral Bitterroot River, ancestral courses of Eight Mile Creek dissected, incised and reworked *Oabr* sediments while transporting and depositing its own sediment load. Eight Mile deposits interwove with *Oabr* and the Renova, and were later overlain by Six Mile Creek formation, generating the complex sedimentary stratification which contains the Eight Mile's groundwater.

A generalized cross section of Eight Mile's stratigraphy is given in Figure 3.2. The position, thickness, continuity, and depth of strata shown vary widely across the study area, so no scale is provided.

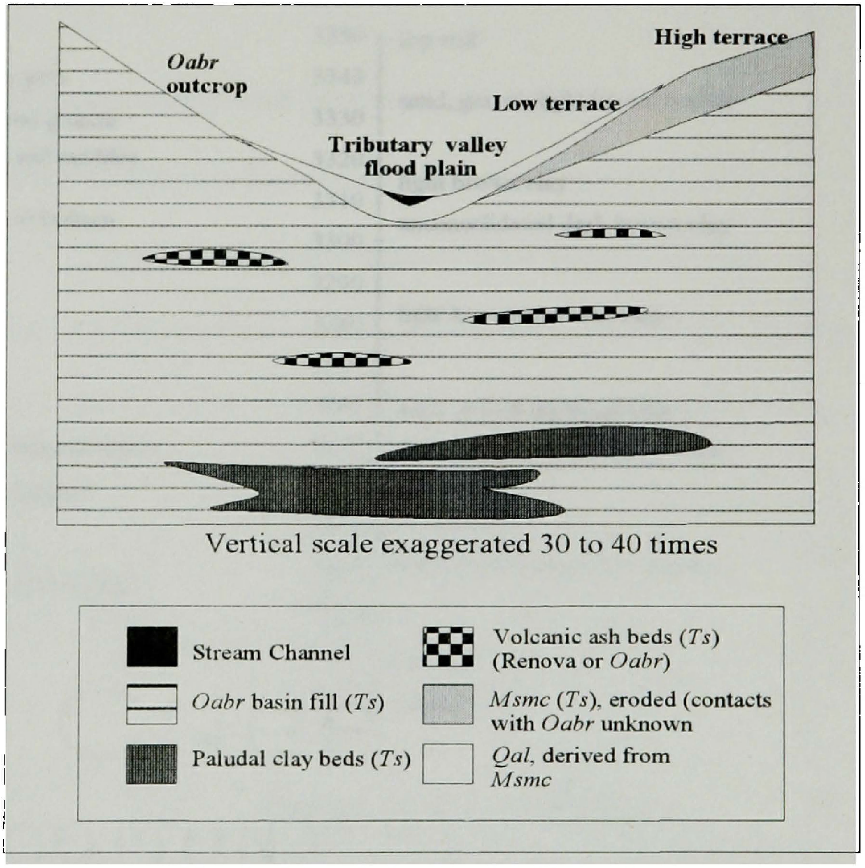

Figure 3.2. Conceptual Model of Eight Mile Basin Fill

Detailed descriptions of the *Oabr* and *Ts* clay

In 1996, Sears discovered the *Oabr* and described its unique composition of rapidly-weathered granitic detritus deposited as sand, gravel, feldspar particles and mylonite pebbles, in a "well-layered series of sand, gravel, and clay beds . . . vary(ing) from fine- to coarse-grained, . . . commonly very well-sorted by grain size (Sears, 1996). The Oabr crops out near the study area at the white cliffs in T10NR19WS6. The stratigraphy of the White Cliffs, described by McMurtrey, et al., (1972) is presented in Figure 3.3 side-by-side with the drillers' formation description for well MDVHON. The location of well MDVHON is shown in Figure 3.1, and its driller's log can be found in Appendix I. Figure 3.3 shows the stacking of multiple continuous sand, gravel and clay lenses in the *Oabr* across the Eight Mile Valley floor and through the Woodchuck Terrace.

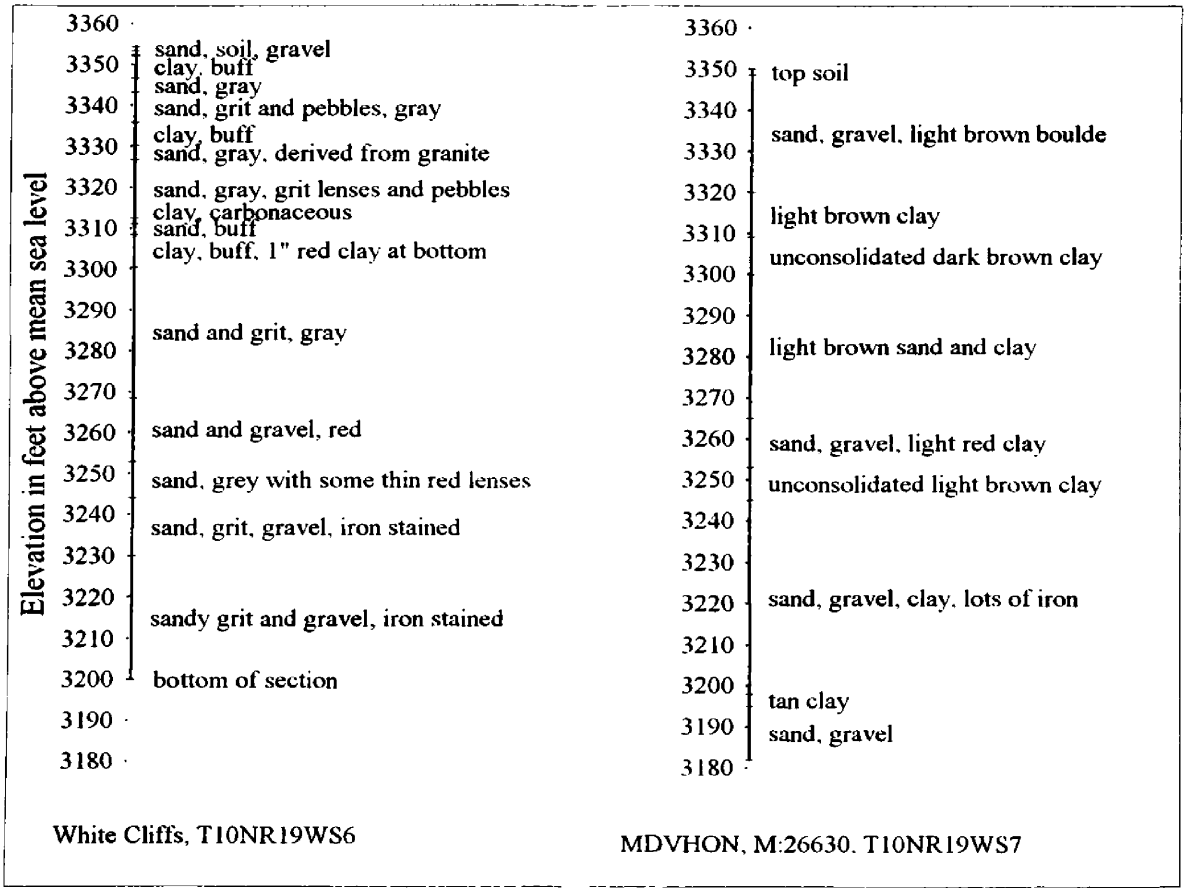

Figure 3.3. Stratigraphy of White Cliffs, after McMurtrey, et.al., (1972) and Formation Description from Well Log MDVHON

Because clay and ash have similar water-retaining properties, study area deposits of each are not differentiated in cross sections prepared for this thesis. Drillers describe volcanic ash deposits which are probably Renova, but are indistinguishable from those deposits described by Sears as “degraded volcanic ash that was redistributed by the Bitterroot River currents (Sears, 1996). The *Oabr* also contains clay and sandy-clay lenses in the upper 200 feet of the subsurface.

At depths greater than 200 feet, especially in upland areas, drillers encounter massive tan-to-blue-green clay beds. McMurtrey et al., (1972) described these as paludal (marshland) in origin and observed that the clay's color is a function of “the proportion of bentonite (green-to-white), to flood-plain silt (brown), to carbon (black) . . . a bluish cast often prevails in moist conditions and, because of this, much of the clay, regardless of its true color, is described in drillers' logs as blue clay.” These clay beds may have been formed at the bases of alluvial fans as ancestral Eight Mile Creek deposited its fines (McMurtrey, 1972).

Section 2: Hydrogeology and Hydrostratigraphy

In general, hydraulic properties of different formations in the study area are well understood. Six Mile Creek “gravels . . . produce large quantities of good water” (Alt and Hyndman, 1986). The water-bearing properties of the *Oabr* vary with the degree of consolidation and proportion of sand to clay in the strata of interest (Sears, 1996). *Ts* clays retain water but transmit it very poorly to wells, unless the driller intercepts transmissive sand or gravel running through the formation (Alt and Hyndman, 1986).

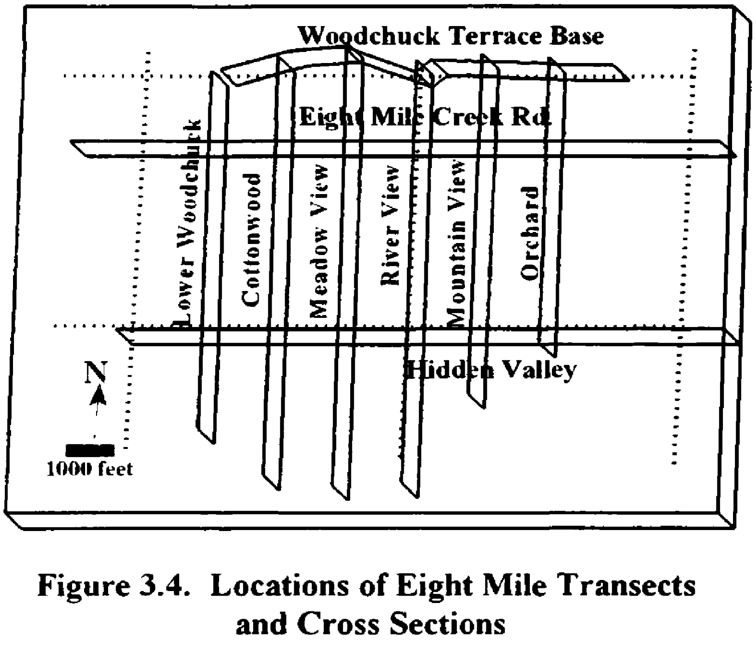

Figure 3.4. Locations of Eight Mile Transects and Cross Sections

The occurrence and placement of specific water-yielding strata were determined by mapping the study area in cross section. Nine transects along study area streets (Figure 3.4) were selected, well locations were projected to the nearest transect(s), and drillers' logged formation data were drawn down. East-west trending cross sections are 1) Woodchuck Terrace Base, 2) Eight Mile Creek Road, and 3) Hidden Valley. North-south trending cross sections are 4) Lower Woodchuck, 5) Cottonwood, 6) Meadow View, 7) River View, 8) Mountain View, and 9) Orchard. Findings from study of the cross sections are presented below. The cross sections and discussions are in Appendix D. A list of drillers' logs used to compile the cross sections can be found in Appendix A.

Findings from cross sections

In the western part of the study area, the first usable water is found in high-yielding lenses at shallow depths, well depths average less than 100 feet, and sand and gravel lenses are stacked between clay lenses in intervals ranging from 15 to 25 feet. At mid valley floor elevations, the sub surface stacking interval between water-yielding sand and gravel lenses increases to 40 feet or more in places. In the eastern part of the study area, stacking intervals exceed 100 feet.

In general, depth to water and confining pressure increase with increasing land surface elevation, with the exception that, throughout the study area, shallow high yielding groundwater lenses occur near Eight Mile Creek or its dry bed. At the highest land surface elevations, massive clay layers are sparsely interfingered with thin sand and gravel lenses. Identifying the continuity of these water-yielding lenses becomes increasingly difficult with increasing land surface elevation.

The cross sections identify two aquifers (also called hydrostratigraphic units): EM-1 which consists of the upper, hydraulically connected, stacked water-yielding lenses, and EM-2 (10NR19W, Section 8B) which is the deep stratum hydraulically disconnected from Aquifer EM-1. A few logs from new well construction in the Eight Mile's upland areas indicate additional very deep water-bearing zones.

Section 3: Potentiometric Maps and Groundwater Flow Direction

Groundwater energy

Groundwater flows from areas of high total energy, or hydraulic head, to areas of low head. Total head is the sum of elevation head (groundwater energy due to elevation) and pressure head (groundwater energy due to pressure from overlying water and overburden). Potentiometric maps show contour lines of equal head, called equipotential lines, for a given time. Groundwater flow is generally interpreted to be normal to equipotential lines. The hydraulic gradient (the change in energy head over distance) is derived from these plots. Where possible drillers prefer to finish water wells below low permeability materials, such as clay, in an effort to protect wells from contamination. These materials have the added effect of confining underlying groundwater. Confining conditions are confirmed when the static water level in a well casing is higher than the top of the tapped-water-bearing stratum, as noted on drillers' logs. For both confined and unconfined conditions, head is measured as water level elevation in wells..

Inspection of drillers' logs confirmed that this study's monitoring wells were completed in confined conditions except for wells 8M8 (formation descriptions were too sparse to assess its confined or unconfined character), 8M4 and 8M17 in the EM-1-Terrace Base flow zone, and 8M27, 8M56 and 8M75 in the EM-1-River flow zone. In both zones, multiple drillers' logs for nearby wells described at least semi-confining conditions; this analysis has been conducted on that basis. However, these wells may be located where confining clay lenses are discontinuous.

When the water table forms the top of the saturated material, the aquifer is considered unconfined, or a water table aquifer. At the water table, groundwater energy is attributable solely to elevation head. Anecdotal evidence and drillers' logs indicate there may be a water table aquifer around the old Eight Mile Creek bed, but well owners using this aquifer did not participate in this study.

Construction of potentiometric maps

Assumptions of ideal conditions made when constructing a potentiometric map are that it describes a single aquifer with horizontal flow (Domenico, et al., 1990). Ideally, equipotential lines in two-dimensional plan view describe groundwater energy from land's surface to the bottom of the aquifer; vertical gradients or flows are not present. However layered materials of different hydraulic conductivities (already shown by cross sectional analysis to occur at Eight Mile) cause vertical distortion of equipotential lines and vertical flow. In the study area's Section 7, water levels consistently reflected differences of 20 feet between neighboring wells finished in different layers of the stacked-groundwater-flow system. Figure 3.5 (based on a model found in Fetter, 1988) shows effects to heads at two hypothetical wells from layering of materials with two different hydraulic conductivities. Well W1 is finished where head is higher above an arbitrary datum than well W2.

Figure 3.5 shows how static water levels at the wells might vary as a function of this heterogeneity of the aquifer, although wells are near neighbors and draw water from the same lens.

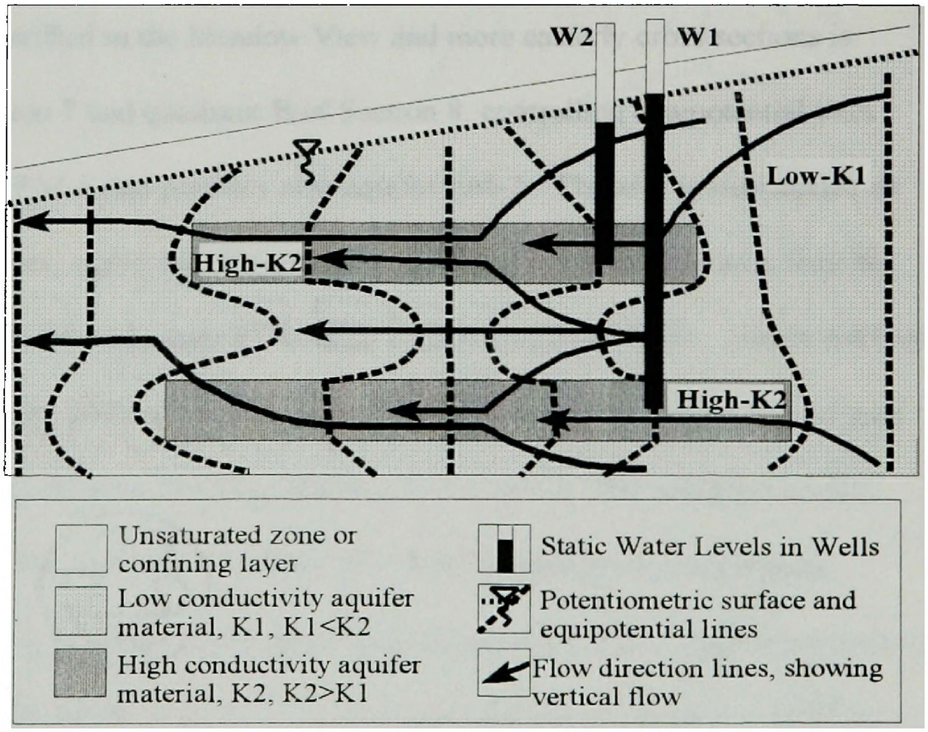

Figure 3.5. Conceptual Model of Eight Mile Heterogeneities in Cross Section, Showing Effects to the Groundwater Potential, after Fetter (1988)

Two potentiometric maps with flow direction lines were prepared for Unit EM-1 using August 1995 (in Figure 3.6, page 18) and May 1996 (Figure 3.7, page 19) water level data, respectively representing low-and-high static water levels during the study period. These maps were drawn to generalize effects of vertical gradients which occur at the Eight Mile. Because data for Unit EM-2 were scant, only one generalized map (Figure 3.8, page 20) was prepared.

Findings from potentiometric maps

In general, EM-1 groundwater travels westerly toward the Bitterroot River. Both EM-1 maps show that around the terraces, equipotential lines follow topographic lines indicating that groundwater flows into the study area from the terraces rather than from under them. Similarly, both maps' equipotential lines extend around the sides of the Hidden Valley ravine, indicating that groundwater flows along a subsurface path down the ravine. Equipotential lines confirm observations from cross sections that groundwater mounds north of Eight Mile Creek's bed.

The massive clay identified in the Meadow View and more easterly cross sections is located in quadrant A of Section 7 and quadrant B of Section 8, controlling equipotential lines around the deep flow zone of EM-1 and possibly also aquifer EM-2. The area is surrounded on three sides by equipotential lines, signifying that groundwater flows into this deep area from the north, east, and south as water-bearing lenses of the EM-1 upper-stack pinch-out. Had it not been designated as a separate unit, the 3220-foot equipotential line of Unit EM-1 would wind around EM-2, describing an extremely steep hydraulic gradient of 0.15 to 0.25. For comparison, the general gradient of Unit EM-1 is 0.02. Darcy's Law, $Q = KAi$, shows that under constant discharge (Q) and area (A), a tenfold increase in gradient (i) must result from a tenfold decrease in hydraulic conductivity (K) of the aquifer matrix. This analysis of hydraulic gradient additionally confirms the finding that upper water-bearing zones are pinched out by a lower conductivity zone around EM-2 and EM-1-Deep.

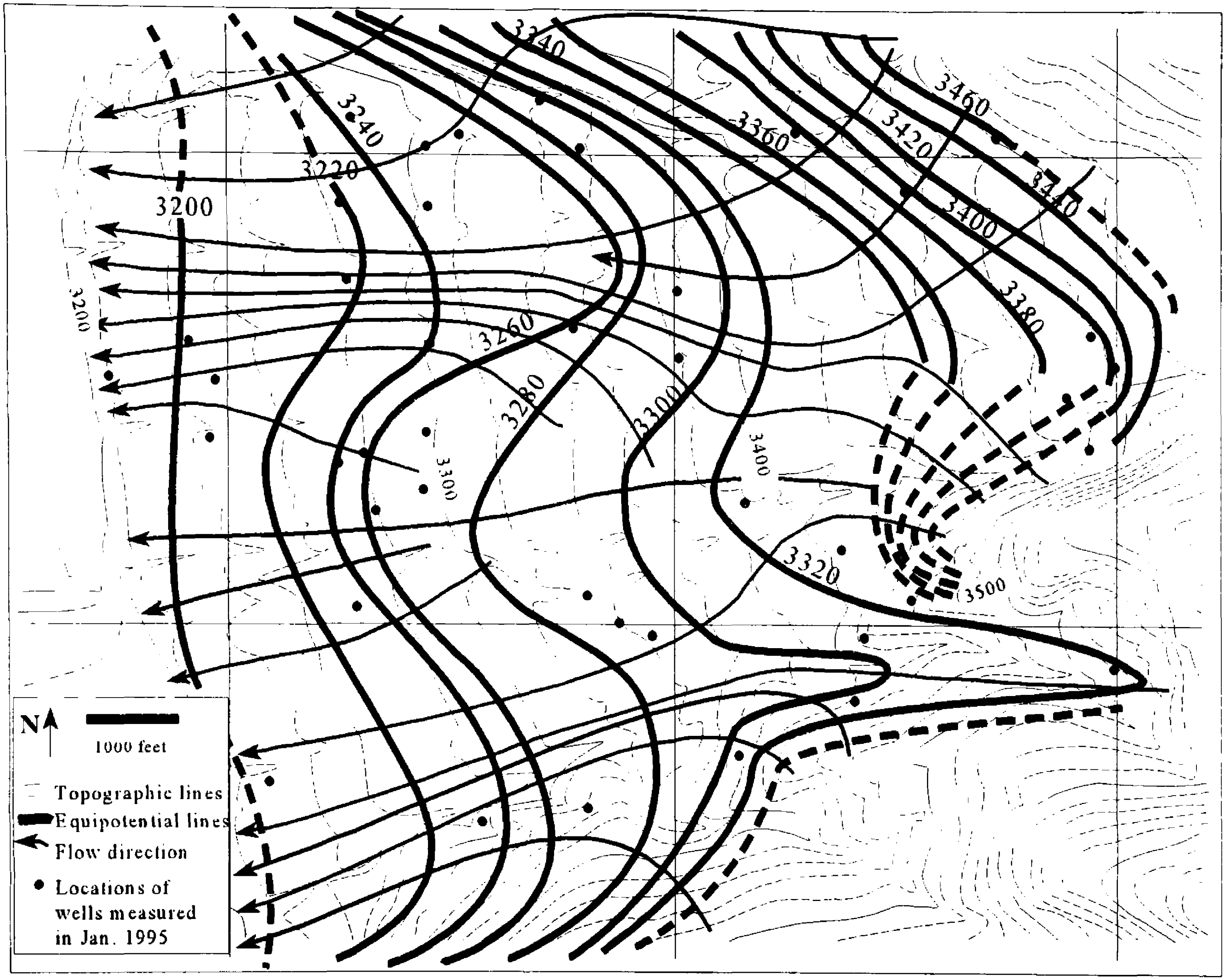

Figure 3.6. Potentiometric Surface and Flow Direction Map of Aquifer EM-1, January 1995

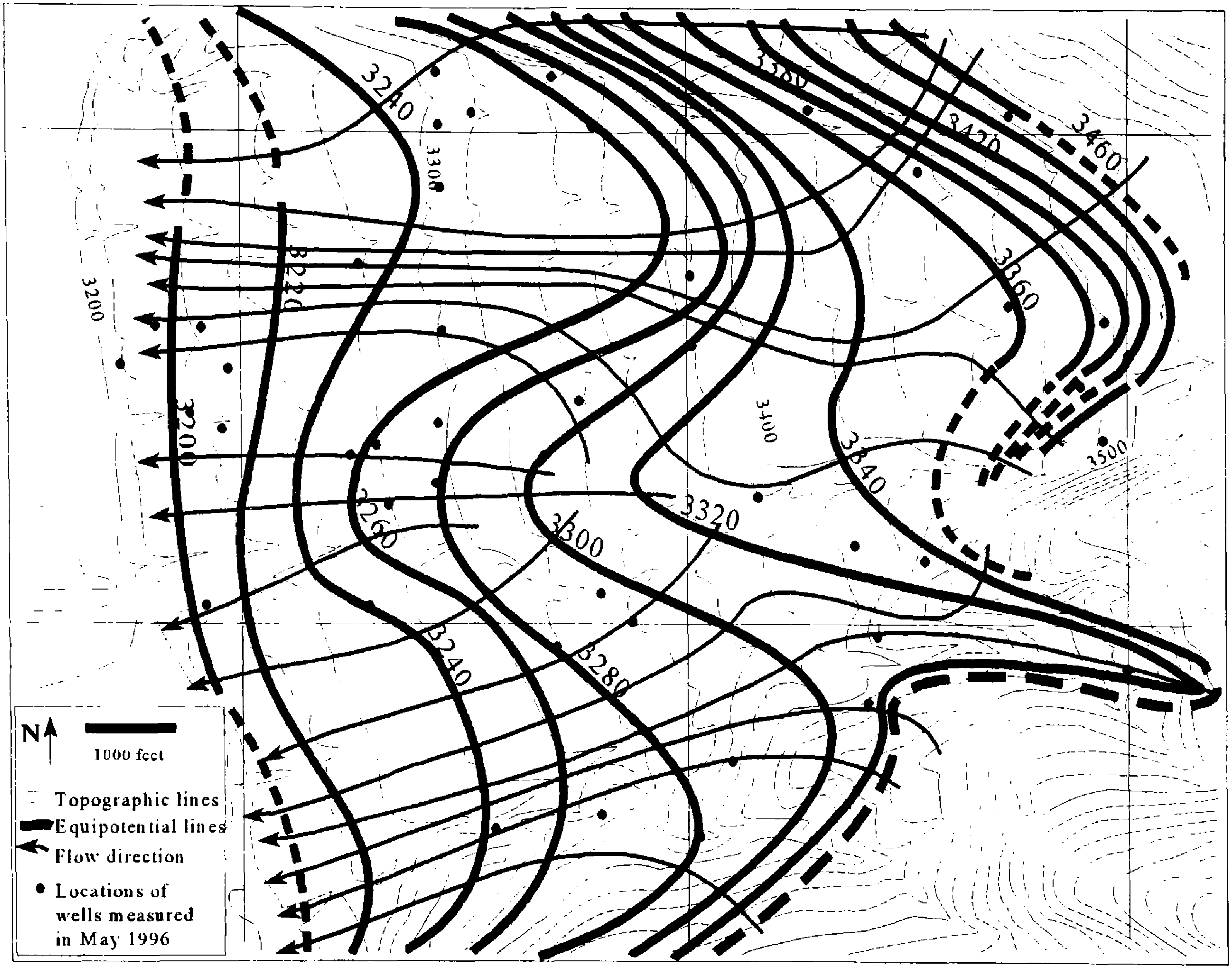

Figure 3.7. Potentiometric Surface and Flow Direction Map of Aquifer EM-1, May 1996

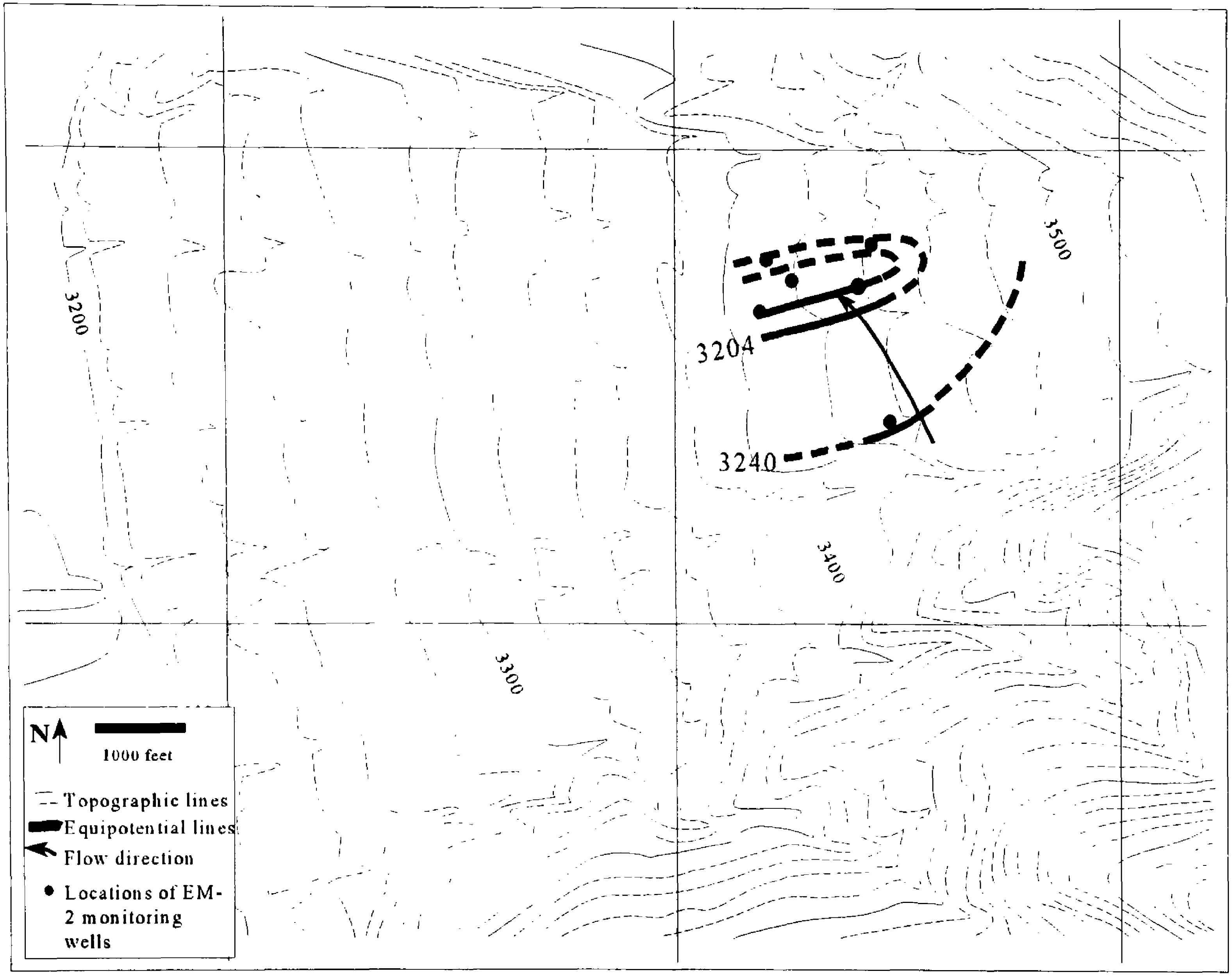

Figure 3.8. Generalized Potentiometric Surface and Flow Direction Map of Aquifer EM-2

Section 4: Hydrograph Analysis

Static groundwater levels respond to changes in surface water levels and to periods of groundwater recharge and withdrawal. Hydrographs record these responses as rising, falling, and static limbs. In this context, static water levels are not just a measurement of groundwater energy, but also of groundwater quantity; measurements taken over many years are useful for assessing the long-term balance between groundwater recharge and withdrawal. Although the period of this study was insufficient to determine if the Eight Mile's groundwater quantity has been impacted by development, these data can serve as baseline data for future comparisons.

Hydrographs for individual wells (Appendix G) were prepared from static water level data then grouped by location and by similarities including the magnitude of overall change, and the length and duration of rising, falling, and static hydrograph limbs. These groupings identified flow zones within the aquifer flow field. Hydrograph groups were readjusted based on visual best-fit comparisons and, finally, were contrasted to examine variation between groups.

Diifferences in hydrograph-group shapes can be attributed to differences in groundwater recharge sources, which are indicated by the originating points of the flow-direction arrows in Figures 3.6 through 3.8. Reference to those locations identifies recharge areas along the Sapphire Mountain foothills, upper Eight Mile Creek, the Hidden Valley ravine, and the terraces which are criss-crossed with irrigation systems. Differences of shape between groups are also caused by discontinuous clay lenses, which distort ideal groundwater flow paths and static water levels.

Within groups, hydrographs show that water levels in EM-1's stacked water yielding lenses respond in lock step with each other to groundwater flux, indicating they are hydraulically connected even though their respective static water levels vary by as much as 20 feet. EM-1 flow zones are named EM-1 with the suffixes Terrace Base, Upland, Hidden Valley, Main, Deep and River. Aquifer EM-2 is a solitary flow zone. Flow zone locations are shown in Figure 3.9.

EM-1-Terrace Base, EM-1-Upland, and EM-1-Hidden Valley lie at the study area's north, east, and south margins respectively and have different recharge sources in the Eight Mile basin. The perched lens at the base of Woodchuck Terrace, EM-1-Terrace Base, is recharged by spring runoff and irrigation. EM-1-Upland is recharged by Eight Mile Creek's upper reaches, by water leaking from the reservoir, by releases from the reservoir at high water and by irrigation. EM-1-Hidden Valley contains wells finished at the base of Antrim Terrace; flow direction arrows indicate it is recharged from high terrace areas.

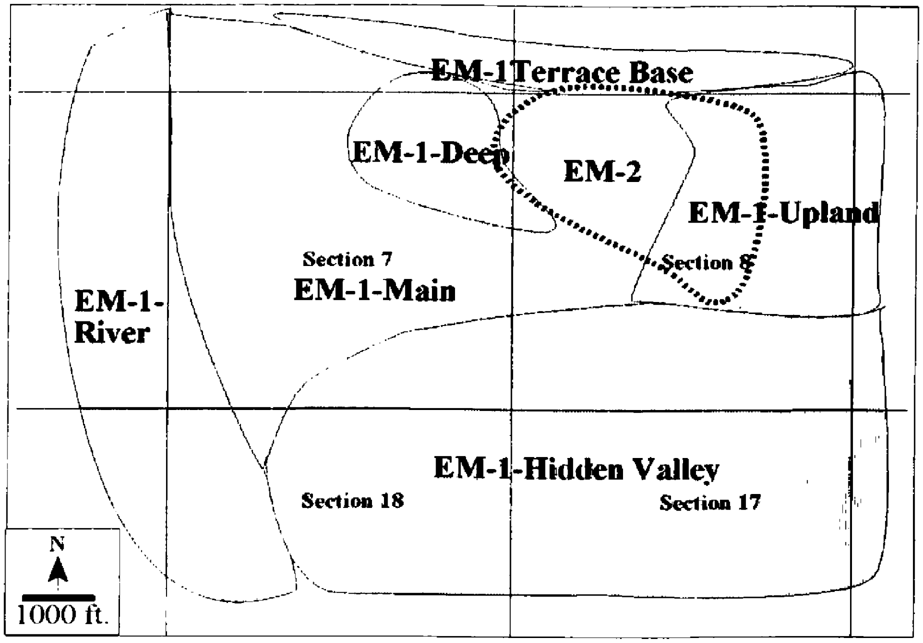

Figure 3.9. Location of Eight Mile Flow Zones of Aquifers EM-1, and EM-2

The following hydrograph discussion starts with the EM-1-Terrace Base flow zone and proceeds clockwise to the study area's interior. Hydrograph magnitude of difference refers to the absolute difference between maximum and minimum static water levels at individual wells. Hydrograph shape consists of the length and duration of rising, falling, and static limbs.

EM-1-Terrace Base

EM-1-Terrace Base hydrographs (Figures 3.10.a. and b. and c.) are presented in three figures to preserve interesting features. The magnitude of change is 5 feet. The wells with early data show falling limbs from August 1994 to June 1995, with rising limbs following from June to August 1995, and falling limbs between August 1995 and May 1996, in an annual cycle. The

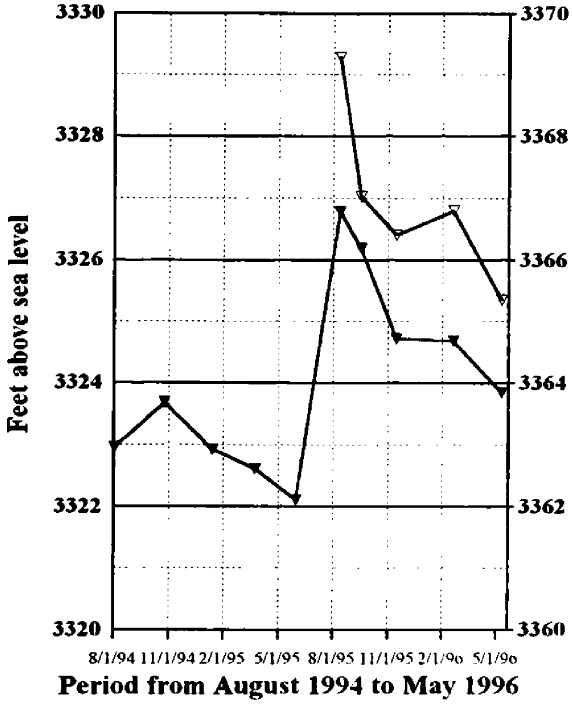

Figure 3.10.a. Hydrograph: EM-1-TB: 8M17 and 8M61

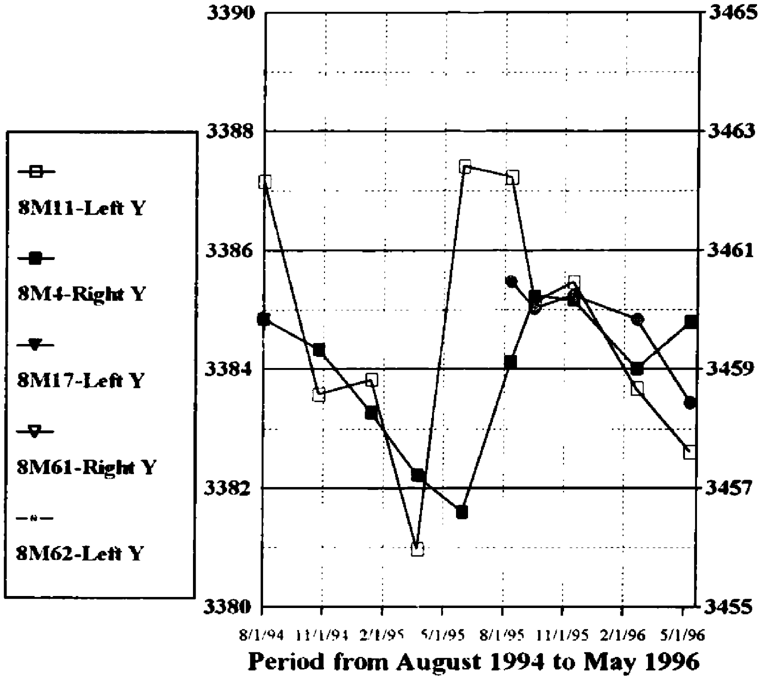

Figure 3.10.b. Hydrograph: EM-1-TB: 8M4, 8M11 and 8M62

Figure 3.19.c. shows the hydrograph for well 8M5 and provides another chart of 8M11 to allow comparison.

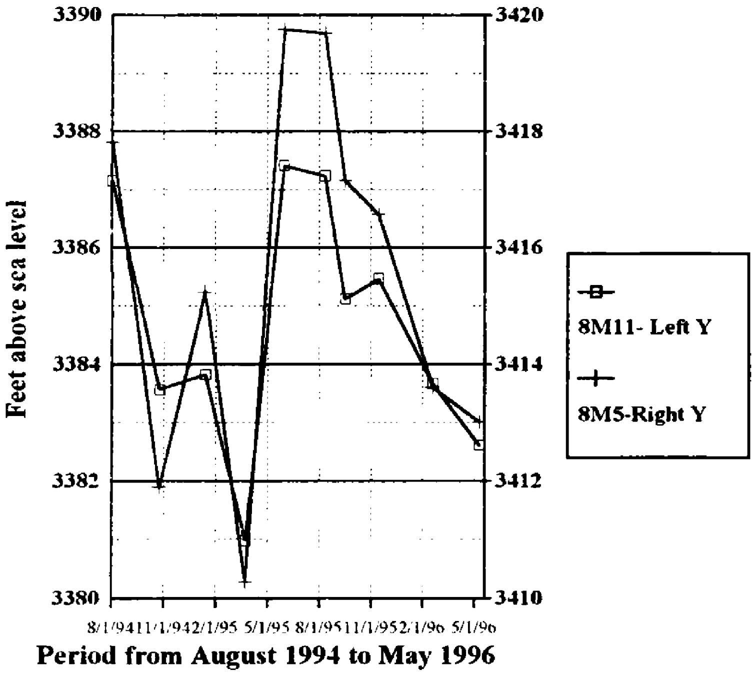

Figure 3.10.c. Hydrograph: EM-1-TB: 8M11 and 8M5

timing of the water level fluctuations is most likely tied to both spring runoff and irrigation schedules which start in the spring and finish in the early fall. Well 8M5 appears to be finished in a transition zone between EM-1-Terrace Base and EM-1-Main; its hydrograph fits best in this group, but other parameters fit better in EM-1-Main.

EM-1-Upland

EM-1-Upland hydrographs, Figure 3.11, show a magnitude of difference of between 12 to 40 feet: the largest range of all study area flow zones. Between March and May of 1995, water levels of this flow zone fell between 10 and 35 feet, indicating rapid groundwater withdrawal. Between August 1994 and March 1995, and from summer of 1995 to the end of the study period, hydrographs limbs rose, indicating cycles of recovery from groundwater withdrawal. During the summer of 1995, Well 8M37 pumped sand, which may be an indicator of stress on the resource. The problem abated after the static water level rose in the well.

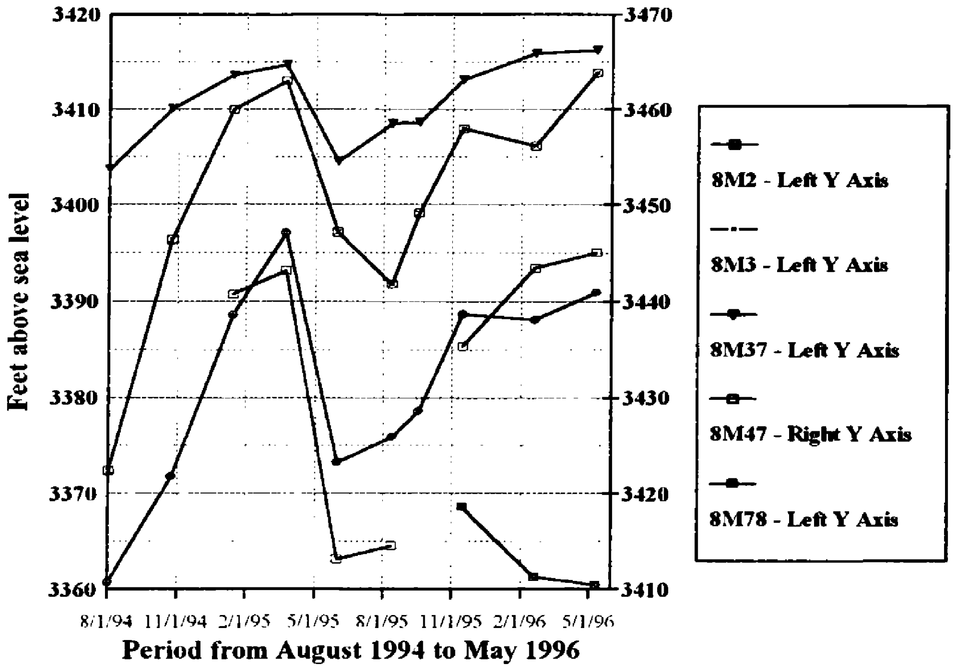

Figure 3.11. Hydrograph: EM-1-Upland

EM-1-Hidden Valley

All EM-1-Hidden Valley hydrograph limbs fell between August 1994 and January of 1995 (Figure 3.12) after which static water levels began to rise and, apart from a small falling or static period during August and September of 1995, continued to rise throughout the duration of the study period. The falling periods of the first and second years would probably show greater agreement if 1995 had not been a relatively wet year compared to 1994.

Hydrographs for wells in the center of the study area, for example 8M18, are similar to those at the southern study area margin, for example 8M54 or 8M60; since hydrographs for wells 8M54, 8M60 or other wells at the southern margin do not show boundary effects, it is possible that the EM-1-Hidden Valley flow zone may extend beyond this study's boundaries.

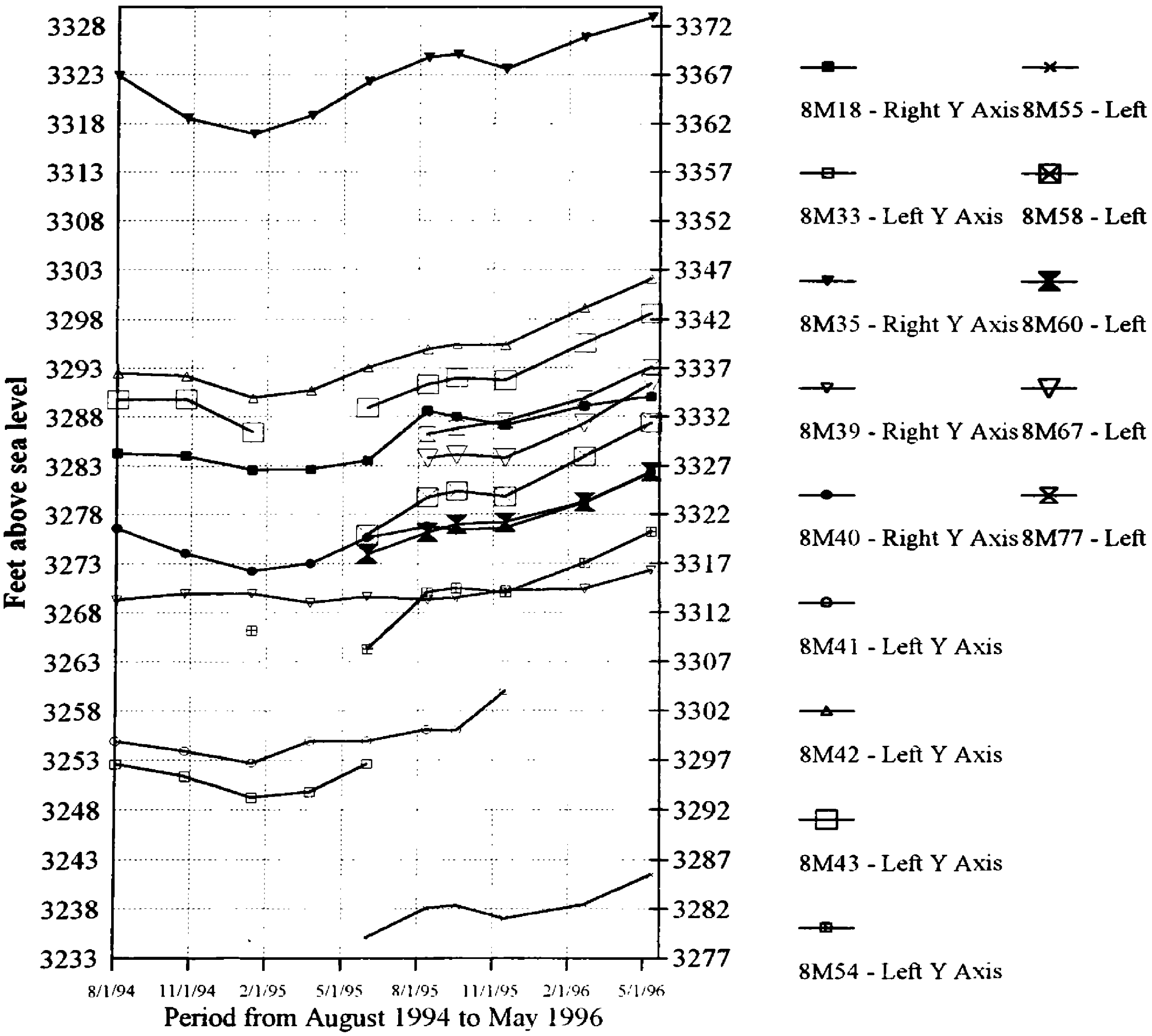

Figure 3.12. Hydrograph: EM-1-Hidden Valley

EM-1-Main

The EM-1-Main flow zone is recharged from the EM-1-Hidden Valley, EM-1-Upland, and from the EM-1-Terrace Base flow zones. Hydrographs of EM-1-Main (Figure 3.13) vary more than the EM-Hidden Valley group, but group members have more in common with each other than with those from other groups. EM-1-Main's magnitude of change was 6 feet and its shape showed rising limbs after August 1995.

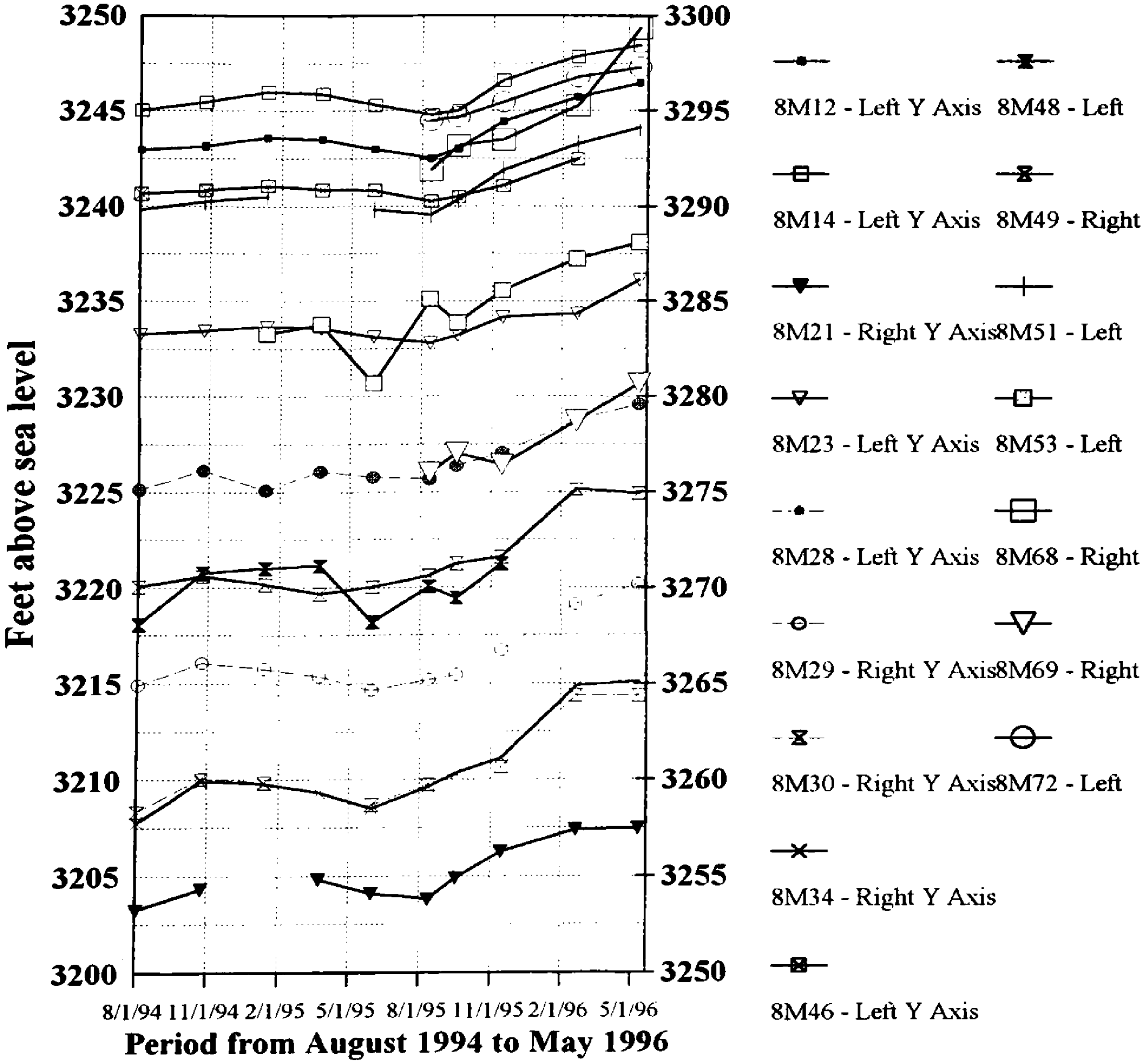

Figure 3.13. Hydrograph: EM-1-Main

EM-1-Main contains wells finished in different water yielding lenses of the main aquifer stack. Wells 8M48, 8M53 and 8M69, with similar hydrographs, are finished in deeper lenses than neighboring wells 8M28, 8M29 and 8M30. Hydrograph comparisons show similarities in rising and falling limbs, with differences during summer 1995, which may reflect different response to heavy demand for groundwater in different parts of the EM-1-stack of water yielding lenses.

The hydrographs for 8M49, 8M34 and 8M30 are very similar to those in EM-1-Hidden Valley emphasizing the interconnected hydrostratigraphy of of EM-1 flow zones.

EM-1-River

Figure 3.14 shows the EM-1-River hydrographs. The magnitude of change is 4 feet. Rising and falling limbs appear to be muted when compared to hydrographs from the other EM-1 groups. This could be caused as groundwater merges from up-gradient sources with variable peaks and troughs. Hydrographs show fairly good agreement except for 8M32's large trough which may have been due to measurement error (the pump came on at the moment of measuring) and 8M44's large peak, which may also be due to an unknown measurement error. The peak falls within the expected magnitude of change, and may reflect a site specific irrigation or runoff input.

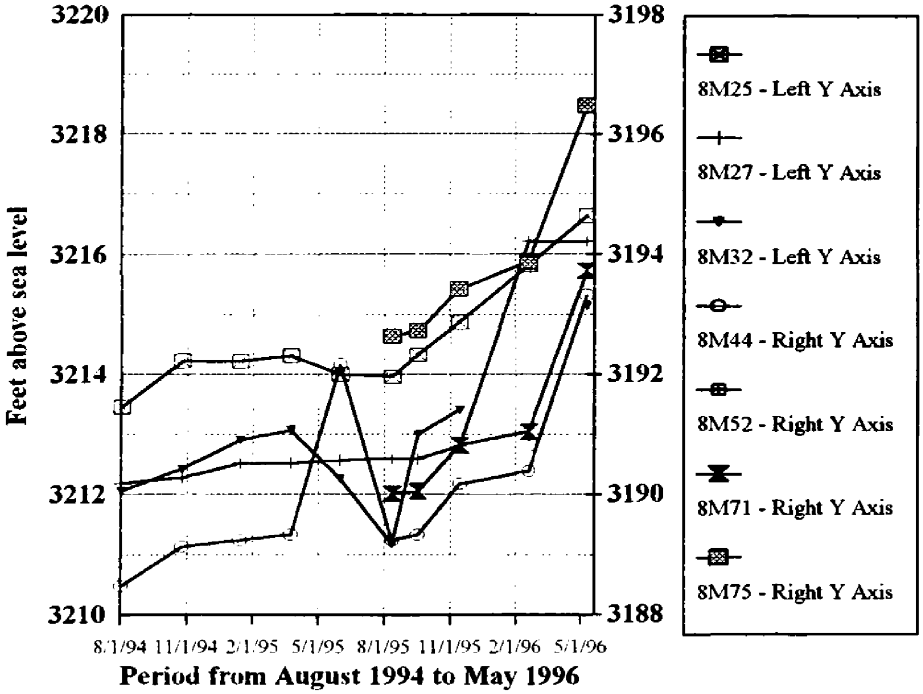

Figure 3.14. Hydrograph: EM-1-River

EM-1-Deep

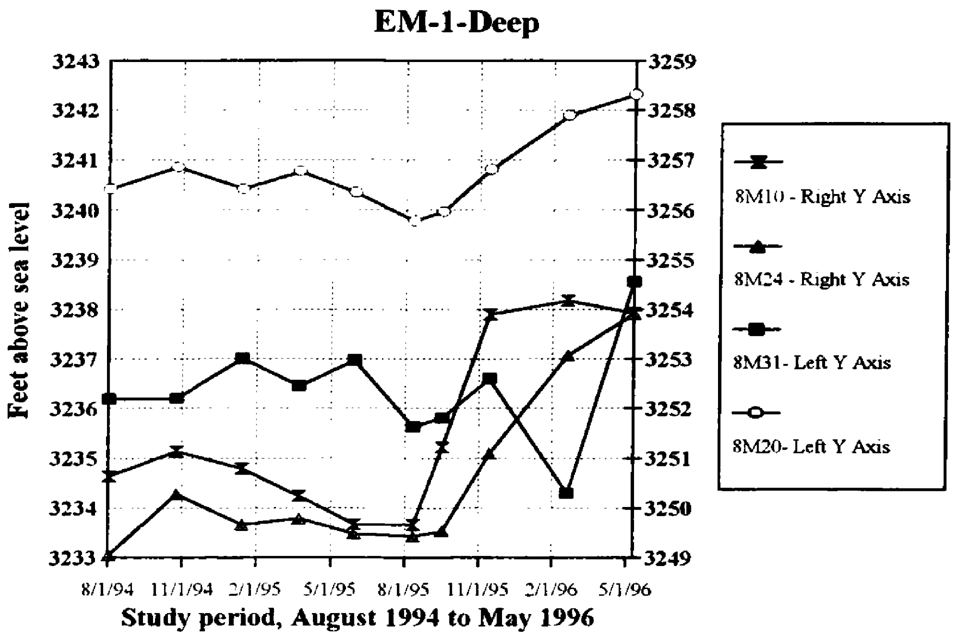

Figure 3.15. Hydrograph: EM-1-Deep

This group, shown in Figure 3.15, contains four wells with similar hydrograph behavior, located near each other in the study area and connected to one of the deeper lenses in the stack of water bearing lenses. This group's magnitude of change varies between 3 and 5 feet. Careful comparison of the hydrographs shows agreement between 8M31 and 8M20, 8M20 and 8M24, and 8M24 and 8M10. During the first year of the study all hydrographs except 8M10 showed little change, with rising limbs at the 1-year mark as at other EM-1 flow zones. Well 8M31 shows some similarity to hydrographs of aquifer EM-2 in its rising limb of August 1995, indicating that vertical gradients may occur between the EM-1 flow field and EM-2. Well 8M10 shares characteristics of the EM-1-Main and EM-1 Hidden Valley groups, showing transition affects between flow zones, and showing that EM-1-Deep is in fact a member of Unit EM-1 and not a separate hydrostratigraphic unit, as is EM-2.

Aquifer EM-2

Aquifer EM-2 is located in the north-west quadrant of T10NR19W Section 8. Hydrographs of wells in this aquifer do not behave as if they are hydraulically connected to wells in the EM-1 aquifer but exhibit excellent agreement with each other in their hydrographs, shown in Figure 3.16. The magnitude of change is about 5 feet, with all the wells showing rising limbs from August of both 1994 and 1995. Limbs showed little change between November 1994 and June 1995 then fall about 4 feet, indicating an annual cycle of groundwater extraction and recovery.

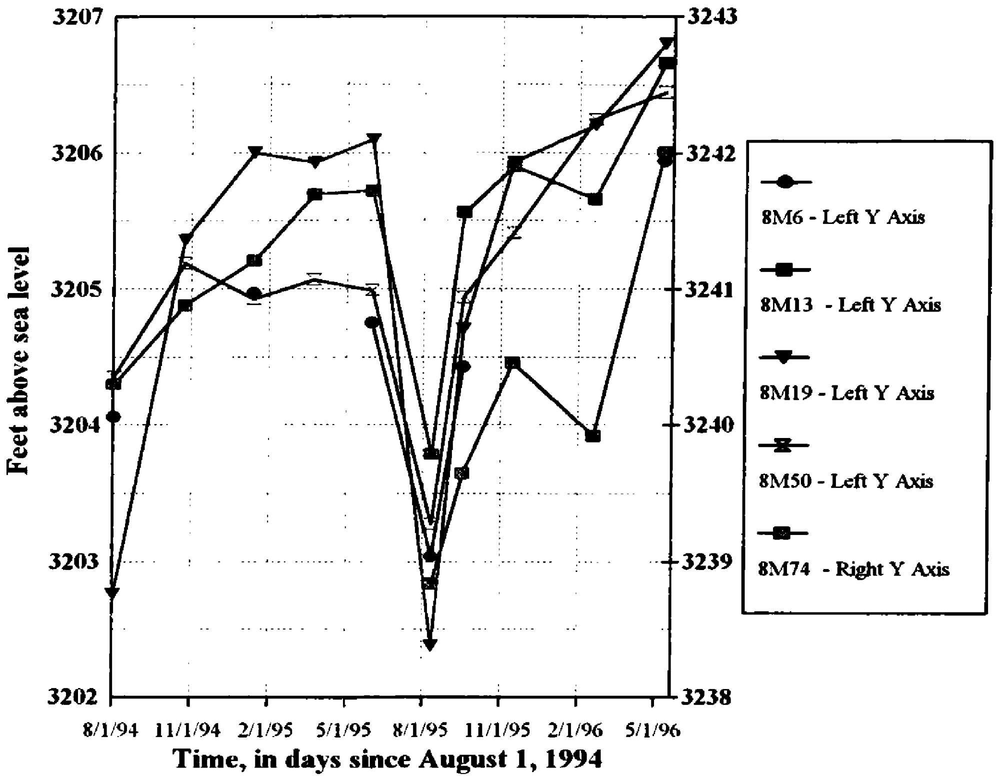

Figure 3.16. Hydrograph: EM-2

Sample sizes of hydrograph groups

Hydrographs were prepared from wells for which three or more static water levels had been measured. Sample sizes of the resulting groups are given in Table 3.1 below.

Table 3.1 Sample Sizes of Hydrograph Groups and Subgroups

	EM-1	EM-1-Terrace Base	EM-1-Upland	EM-1-Hidden Valley	EM-1-Main	EM-1-River	EM-1-Deep	EM-2	Total
Sample Size	51	5	5	14	16	7	4	5	56

Section 5: Comparison of Flow Zone Parameters

In the previous section, flow zones of Eight Mile aquifers EM-1 and EM-2 were identified by grouping hydrographs of monitoring well data. In this section, flow zone groundwater parameters of well depth, static water level and transmissivity, as well as physical and chemical characteristics, are charted. When applicable, available data from all located wells were used. Appendices C and F provide additional information about the data sets.

Well depth

Figure 3.17 shows well depths and also shows the range of EM-1 values which spanned the entire data set. EM-1 flow zones are reasonably distinguished by their well depths; EM-1-Upland and EM-2 areas have the deepest wells of all Eight Mile flow zones.

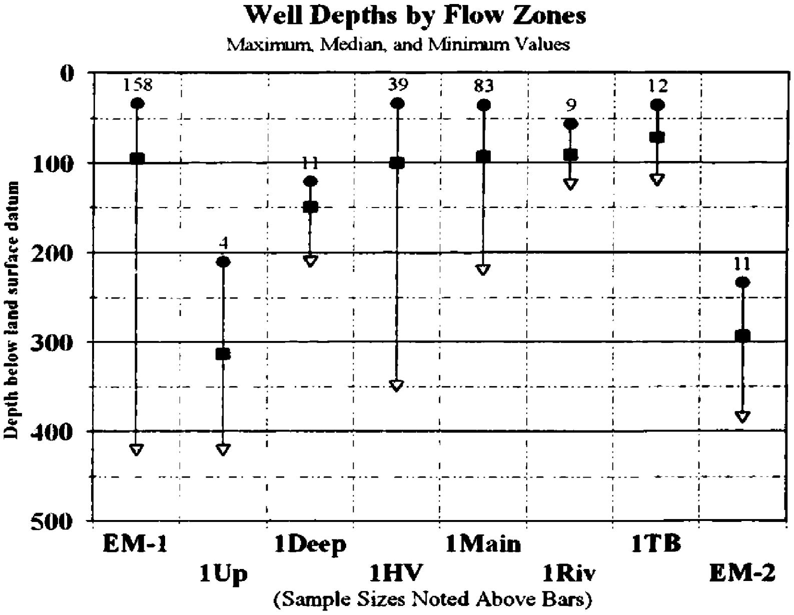

Figure 3.17. Well Depths by Flow Zones

Static water levels

In Figure 3.18, static water levels of EM1-Deep, EM1-Main, EM-1-River, and EM-1-Terrace Base show tightly-grouped values, while EM-1-Hidden Valley and EM-1-Upland each have one deep well with a deep static water level, extending the data ranges and increasing variation.

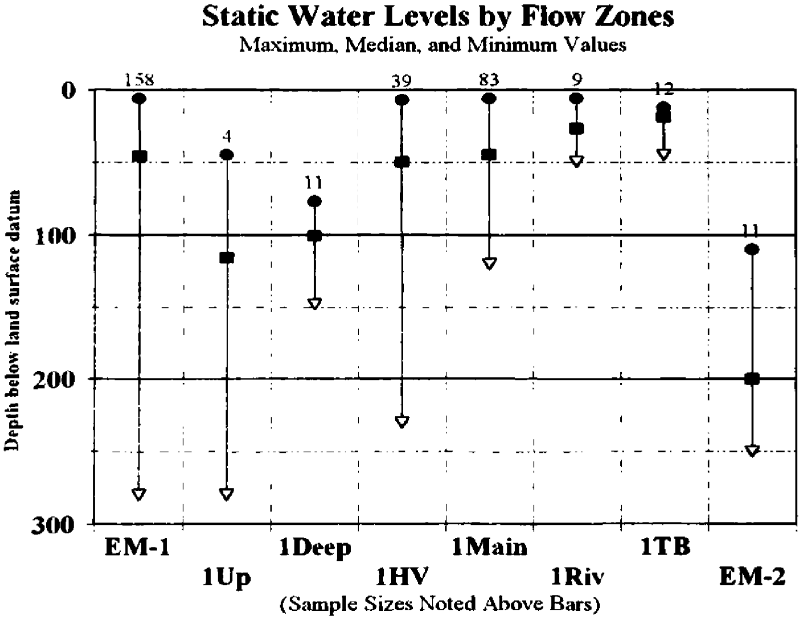

Figure 3.18. Static Water Levels by Flow Zones

Specific conductance and temperature

Aquifer-water samples were measured between August of 1994 and June of 1995 for specific conductance and temperature and are shown in Figures 3.19 and 3.20.

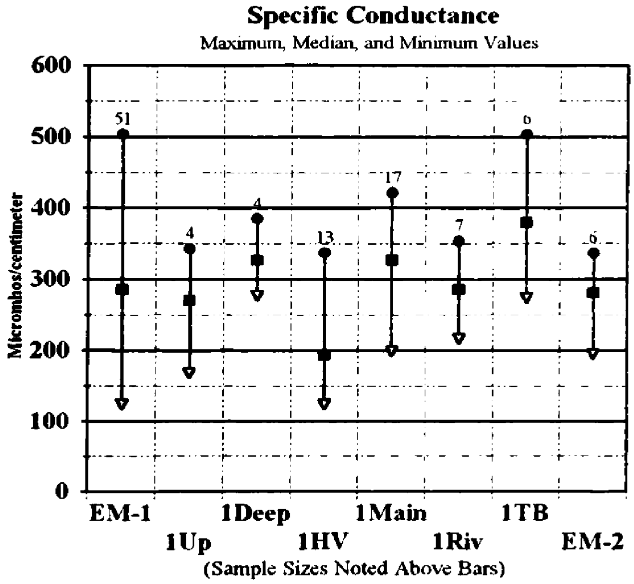

Figure 3.19. Specific Conductance by Flow Zones

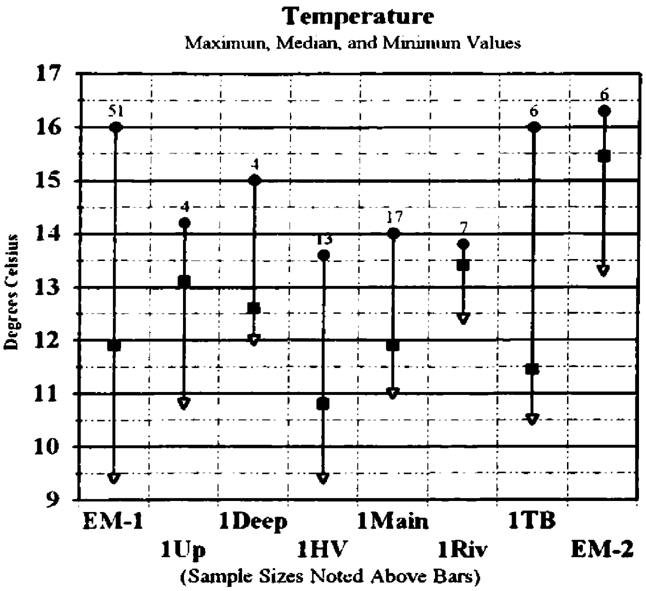

Figure 3.20. Groundwater Temperature by Flow Zones

Specific conductance measures the electrical current that can pass across 1 centimeter of sample water. Eight Mile specific conductance data spanned only 0.4 millimhos centimeter $^{-1}$. EM-1-Terrace Base was at the high end of the range of values, while EM-1-Upland and EM-1-HV were at the low end. Figure 3.20 shows that groundwater temperature ranged over only 7 degrees Celsius. Differences between groups were slight for both physical properties.

Nitrate and chloride concentrations

Distribution of nitrate and chloride is of interest as an indicator of flow zone water quality. The range of nitrate concentrations shown in Figure 3.21 has been scaled to 10 milligrams liter $^{-1}$ to emphasize each group's standing against national drinking water standards for public water supplies. Chloride data in Figure 3.22 is of interest because its relative abundance helps to indicate the source of nitrate as either fertilizer and animal waste if low, or septic systems if high.

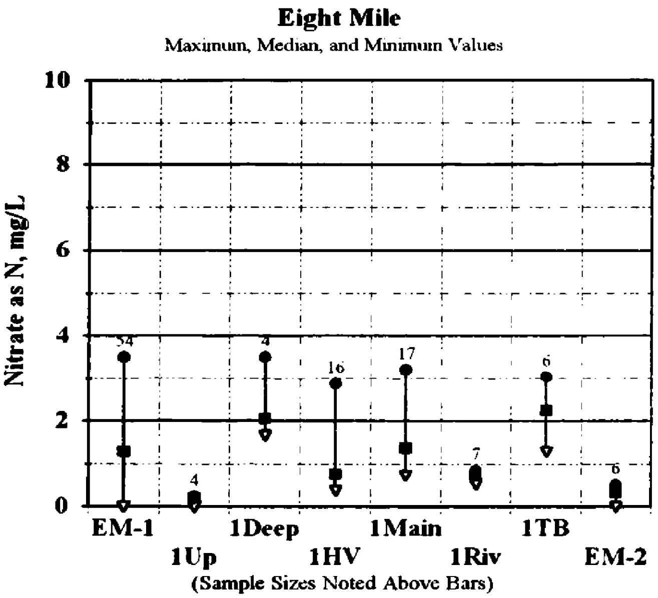

Figure 3.21. Nitrate Concentrations by Flow Zones

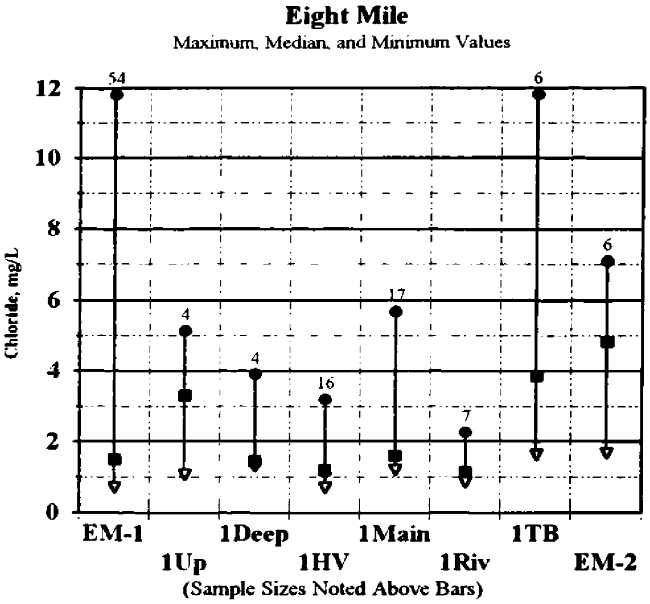

Figure 3.22. Chloride Concentrations by Flow Zones

EM-1-Hidden Valley and EM-1-Main showed relatively high maximum but fairly low median nitrate-N concentrations, while EM-1-Terrace Base and EM-1-Deep had relatively high maximum and median concentrations. EM-1-Upland and EM-2 showed very low concentrations; nitrate may be removed from those deep, reducing flow zones by denitrification mechanisms.

Chloride concentrations were highest at EM-1-Terrace Base. Nitrate and chloride distribution are shown in Section 7.

Transmissivity

Transmissivity is "the rate at which water . . . is transmitted through a unit width of an aquifer" (Fetter, 1988). The values plotted in Figure 3.23 were estimated from drillers'

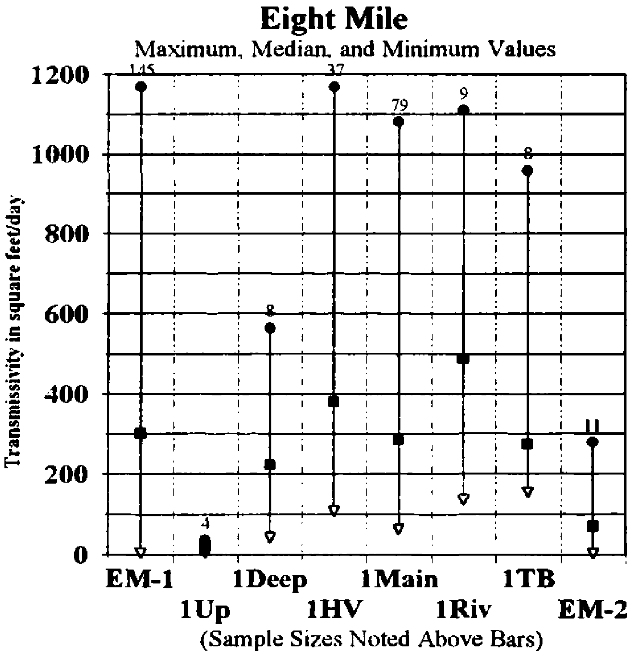

Figure 3.23. Transmissivity by Flow Zones

pump test data using successive iterations of the Theis equation, as described in Chapter 2 and and Appendix E. The range of values is consistent with fine, medium, and coarse sand mixed with gravel (Domenico et al., 1990).

Section 6: Discharge Calculations and the Groundwater Budget

Groundwater discharge calculations

Groundwater discharge calculations for the Eight Mile drainage were prepared using the one-dimensional form of Darcy's Law: $Q = TLi$ where Q is groundwater discharge in feet^3 day^{-1}; T is the estimated average transmissivity of each water bearing zone in feet^2 day^{-1}; L is the length of a transect line normal to the direction of groundwater flow, in feet, and i is the dimensionless hydraulic gradient. Hydraulic gradient values were measured from Figures 3.15-17. Table 3.2 shows averaged transmissivity estimates and averaged gradient estimates for flow zones, which are required for estimating groundwater flux using Darcy's Law. Figure 3.24 locates transect lines.

Table 3.2 Hydraulic Parameters of Eight Mile Flow Zones

Flow Zone	i	T (ft^2/d)
EM-1-Terrace Base	0.032	350
EM-1-Upland	0.056	20
EM-1-Hidden Valley	0.021	435
EM-1-Main	0.018	350
EM-1-River	0.018	490
EM-1-Deep	0.059	275
EM-2	0.018	100

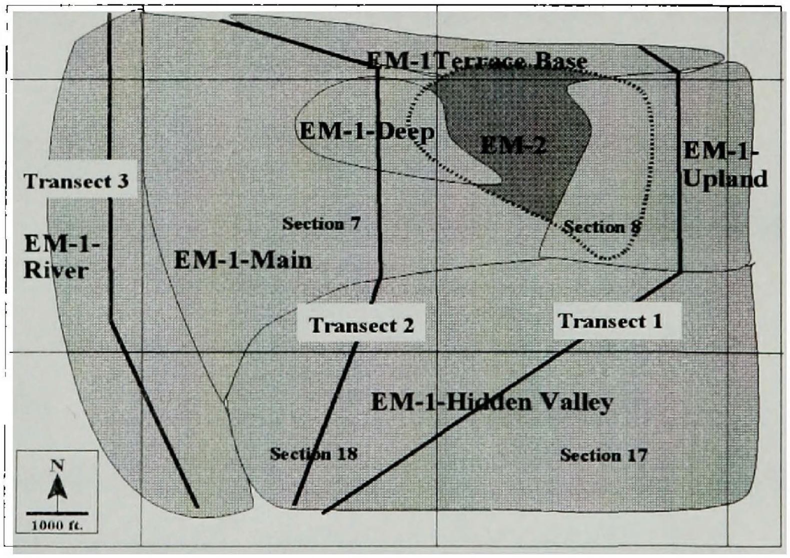

Figure 3.24. Flow Zone Transect Locations

The rounded results of groundwater flux calculations are presented in Table 3.3 on the following page.

Table 3.3. Estimated Groundwater Discharge Across Transect Lines, using Darcy's Law.

Transect	Flow Zone	i	T (ft^2/d)	L, (feet)	Q, $ft.^3/day$	Q, acre-ft./year	Q, acre-ft./study period
Transect 1	EM-1-TB	0.032	350	950	10,500	90	160
Transect 1	EM1-Upland	0.056	20	3,900	4,500	40	70
Transect 1	EM2	0.018	100	2,700	5,000	40	80
Transect 1	EM1-HV	0.021	435	8,100	74,000	620	1,140
Total Transect 1					**94,000**	**790**	**1,450**
Transect 2	EM1-TB	0.032	350	3,000	33,500	280	520
Transect 2	EM1-Deep	0.059	275	1,600	26,000	220	400
Transect 2	EM1-Main	0.018	350	2,150	13,500	110	210
Transect 2	EM1-HV	0.021	435	4,600	42,000	350	650
Total Transect 2					**115,000**	**960**	**1,770**
Transect 3	EM1-River	0.018	490	10,000	88,000	750	1,360
Total Transect 3					**88,000**	**750**	**1,360**

Groundwater budget

The Eight Mile groundwater budget between August 1, 1994 and May 31, 1996 is::

Groundwater in (acre-ft.): = Groundwater out (acre-ft.): ± change in storage

Flux in through Transect 1: 1,450
Recharge by domestic/septic inputs: 280
Recharge by precipitation: 230
Total groundwater in: 1,960 acre-feet

Domestic use: 350
Evapotranspirational losses: 70
Flux out through Transect 3: 1,360
Total groundwater out: 1,780 acre-feet

The budget was prepared by estimating that over 2.75 square miles of study area between Transects 1 and 3, 375 Eight Mile households used 450 gallons of water each day (Newman, 1993) for 670 study period days. Two-thirds of this water is estimated to have been lost to evapotranspiration between May and September of years 1994 and 1995 and the remaining water returned to the groundwater system through septic fields. Groundwater consumed by irrigation on the main valley floor is accounted for under domestic use. Irrigation recharge is also accounted for under domestic recharge to the groundwater system.

Although the study area is recharged by surface water, quantities were not identified for this budget. Effective recharge by precipitation was estimated to have been 10% of 16 inches received on the valley floor during non-growing season months of the study. (Ver Hey, in 1987, used a 15% effective recharge rate for Missoula's coarser sand and gravel). Precipitation received during the growing season is assumed to have been lost to evapotranspiration before entering the groundwater system. Precipitation data for the Missoula weather station were obtained from the National Weather Service. The change in storage was calculated to have been less than 1 acre-foot, and so was disregarded. While budget inputs balance to outflows with less than 10% error, readers are reminded that this budget is based on parameters derived from very rough estimates.

Section 7: Occurrence and Distribution of Nitrate and Chloride

Sampling Eight Mile's groundwater for common ions, metals, and dissolved gases was beyond the scope of this thesis. These parameters were considered in the larger USGS study which found that radon concentrations in Eight Mile's groundwater exceeded 1994 proposed standards for public water supplies at all 13 sampled wellheads. See Appendix H for more information.

Significance of nitrate and chloride

Nitrate is not usually a natural constituent of groundwater, except where aquifers are composed of marine shale or its erosional products. When fixed by microorganisms, nitrate may percolate to groundwater in small concentrations but during the growing season, it is usually consumed first by vegetation or microbes in the soil or vadose zones. Detroy, et al., (1988) note that nitrate-N in groundwater over three milligrams liter^{-1} indicates anthropogenic loading.

While nitrate is an essential nutrient, its overabundance may injure human and watershed health. In sensitive infants, it causes methemoglobinemia, or "blue-baby syndrome", and in older people it can be converted in the gastrointestinal tract to cancer-causing nitrosamine (EPA/625/4-89/024, 1990). Excess nitrate fertilizes surface waters, increasing biomass and turbidity, decreasing dissolved oxygen, and degrading water quality. To protect public health, EPA drinking water standards for public water supplies limit nitrate-N to 10 milligrams liter^{-1}. Since septic system wastes normally have higher chloride concentrations than animal wastes or fertilizers, relative concentrations of chloride can be used to assist in identifying nitrate sources. EPA limits chloride to 250 miligrams liter^{-1} as a secondary contaminant (1994).

Estimation of background concentrations of nitrate and chloride

Natural nitrate and chloride background concentrations for the study area are unknown. They are not determinable from this work because groundwater was already impacted by development at the start of this study. Newman estimated background nitrate-N at Paradise Acres to be 2.12 milligrams liter^{-1} in 1993. McMurtrey, et al., (1972), sampled water from one 60-foot-deep Eight Mile well in Section 7 in 1955 and found 2.0 milligrams liter^{-1} of chloride and 2.4 milligrams liter^{-1} nitrate, which is equal to 0.54 milligrams liter^{-1} of nitrate-N. For comparison, three of this study's wells, 8M34, 8M49, and 8M53, in the same quarter-quarter section had nitrate-N concentrations of 1.5, 0.9 and 1.3 milligrams liter^{-1}, and chloride concentrations of 1.4, 1.5 and 1.2 milligrams liter^{-1} respectively. McMurtrey's single sample may have been impacted by Eight Mile agricultural land use at the time of his study.

Although pre development background concentrations are unidentifiable, current baselines for future comparisons can be determined from sampling. This study's samples averaged 1.3 milligrams liter^{-1} of nitrate-N and 2.5 milligrams liter^{-1} of chloride. Nitrate-N and chloride baselines for Eight Mile groundwater should range around these values. The use of nitrate-N concentrations as benchmarks of groundwater degradation is codified in Montana, and will be discussed Chapter 4. Nitrate-N and chloride data can be found in Appendix C.

Nitrate-N and chloride distribution

Nitrate-N and chloride distributions are shown in Figures 3.25 and 3.26. Nitrate-N concentrations were elevated at and below EM-1-Terrace Base, throughout EM-1-Main, and at EM-1-Hidden Valley around Paradise Acres. EM-1-Upland and EM-2 had low nitrate-N concentrations; however, denitrification may occur in these deep zones and will be discussed below.

Chloride concentrations exceeded 1 milligram liter^{-1} throughout most of the study area, but were elevated at EM-1-Terrace Base and EM-1-Main. Elevated chloride linked with elevated nitrate-N strongly

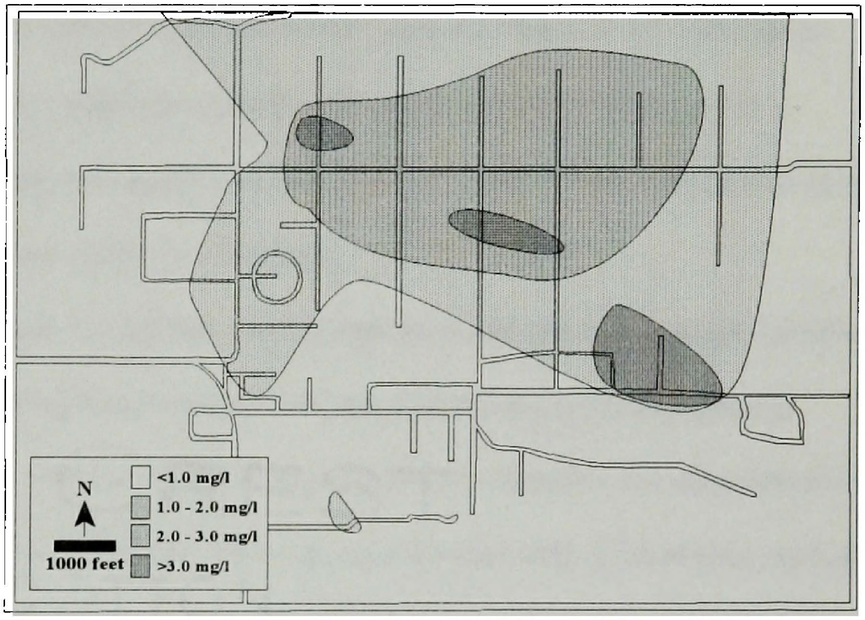

Figure 3.25. Eight Mile Nitrate Distribution, August 1994 - August 1995

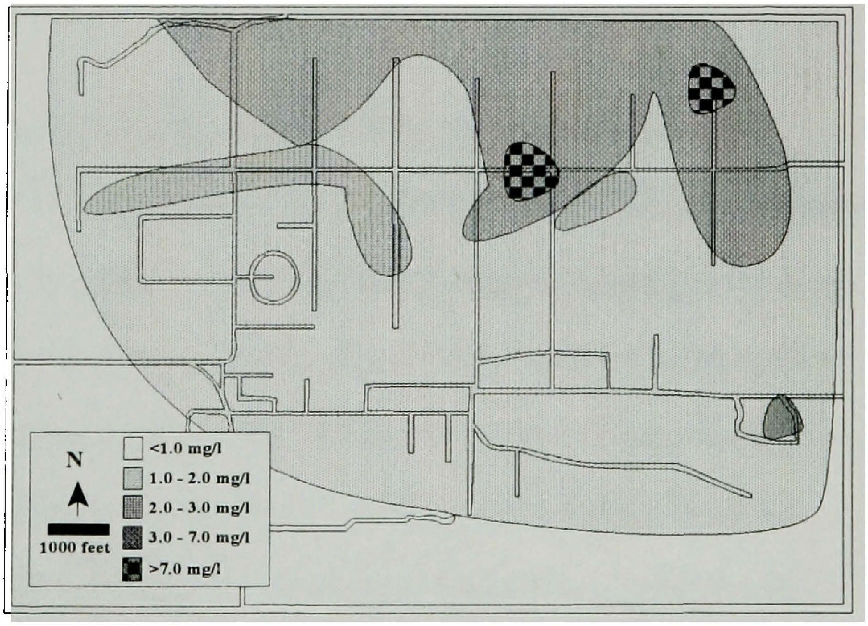

Figure 3.26. Eight Mile Chloride Distribution, August 1994 - August 1995

suggests septic loading of Eight Mile's groundwater in these flow zones. Chloride in samples from EM-2 wells averaged 4.3 milligrams liter^{-1} and from EM-1-Upland wells averaged 3.2 milligrams liter^{-1}, which was relatively high when compared to other flow zones, even though both had low nitrate concentrations. The odor of hydrogen sulfide gas was observed at wellheads at both flow zones, indicating reducing conditions at depth. Since nitrate is known to convert to nitrogen gas or ammonium under reducing conditions, the possibility that nitrate and chloride have migrated throughout these flow zones cannot be ruled out.

Even properly-working septic drain fields have limited ability to attenuate nitrate, because plants can only take it up during the growing season. Penning animals around wellheads is a common practice in the Eight Mile. Nitrate-N from these and fertilizer sources can percolate to the subsurface or migrate there via failed well seals. Once nitrate has entered the groundwater system, vertical gradients and flow arising from the presence and position of clay layers in the stacked aquifer system contribute to migration and mixing. Gaps, or discontinuities of clay layers provide pathways for nitrate migration to deeper water-bearing lenses of the stacked aquifer system.

Mass balance

Depending upon household size, individual septic systems load underlying shallow groundwater with between 18.4 and 27.1 pounds of nitrate-N and between 14.9 and 17.1 pounds of chloride annually (Ver Hey, 1987). Using these values, the estimated 375 households in the Eight Mile loaded between 3.5 and 5.1 tons of nitrate-N and between 2.8 and 3.2 tons of chloride yearly to their groundwater. Using an annual groundwater flux of 830 acre feet (averaged from Table 3.3), Eight Mile septic systems will generate concentrations of 3.0 to 4.5 milligrams liter^{-1} of nitrate-N and 2.5 to 2.8 milligrams liter^{-1} of chloride, assuming perfect mixing. Actual averaged concentrations observed were 1.3 milligrams liter^{-1} of nitrate-N and 2.5 milligrams liter^{-1} of chloride. Chloride is more conserved than nitrate-N in groundwater, conforming to this finding.

Chapter 4: Overview of Montana's Groundwater Protection Policies

Management of groundwater quantity

Montana's waters belong to the State, which allocates use-rights under the Water Use Act, using the prior appropriation doctrine. Precepts of this doctrine are "first in time is first in right," and that allocated water be put to "beneficial use". Forfeitures of unused water have been rare but may be more likely during the Water Court's ongoing review and adjudication of water rights.

The Department of Natural Resources and Conservation (DNRC) authorizes new groundwater appropriations and requires those who propose to pump more than 35 gallons minute^{-1} to apply for and be granted Permits of Water Right. Issuance of new rights follows a series of public meetings, which follow investigation of basin hydrology, prior appropriations, water availability, municipal needs, maintenance of in-stream flows, rights held by Native American tribes, waters reserved by compacts, and so on. New applications for large-scale water rights are scrutinized far more thoroughly and restrictively than in the past. Those domestic well owners who pump less than 35 gallons minute^{-1} may apply for a Permit or a Certificate of Water Right, or may not file at all. Since a Certificate of Water Right provides its owner(s) only with a priority date and does not assure maintenance of head, many domestic users opt not to file. However, disputes between well users or between surface and groundwater users are resolved in civil court where the holder of the earliest certified priority date will be most likely to prevail (McAlpin, 1997).

If residents believe that their basin's waters are over appropriated, they can petition the DNRC to close the basin or to limit further appropriations. The DNRC can also initiate closure petitions (Montana Code Annotated (MCA) 85-2-506 to 509). Several basins have been so closed, or new well construction limited. Montana's legislature can enact basin-closure legislation and did so in 1995 when it closed the Upper Clark Fork Basin. Montana's counties have no jurisdiction over water appropriations; however, in 1997 the Ravalli County Sanitarian's Office instituted a permitting process for new wells, so as to gain formal access to drillers' logs (Kammerer, 1997).

Through its authority to grant use-rights, the DNRC manages distribution of Montana's waters. DNRC's limited authority over water quality occurs during the water rights permitting process, which allows challenge of new permits if water quality is likely to be degraded by issuance (McAlpin, 1997). Water quality protection falls to several other agencies, discussed below.

Protection of groundwater quality

Montana's groundwater protection policy is tied to its 1972 Constitution, which affirms every Montanan's inalienable right to a clean and healthy environment (Article II, Section 3) and charges every Montanan with the responsibility of maintaining and improving their environment for present and future generations (Article IX, Section 1). The legislature is charged with the responsibility of protecting the "environmental life support system" from degradation. This constitutional duty, combined with legislative response to the Federal Safe Drinking Water Act, resulted in the codification of Montana's policy of non degradation of state waters. Non degradation "is the public policy . . . to: 1) conserve water by protecting, maintaining, and improving the quality and potability of water for public water supplies, wildlife, fish and aquatic life, agriculture, industry, recreation, and other beneficial uses; and 2) provide a comprehensive program for the prevention, abatement, and control of water pollution" (MCA 75-5-101).

To assess degradation, Montana's Department of Environmental Quality (DEQ) compares current concentrations of contaminants with known baselines. The method for determining baselines is under review at the time of writing, but will likely be set as contaminant concentrations measured during or after either 1971 or 1993; 1993 is the most likely date (Horpestad, 1997).

In 1995, under pressure from special interests, the legislature weakened non degradation policy by writing exclusions into the statutes (MCA 75-5-303), (Montana Environmental

Information Center (MEIC), et al., 1997). Nitrate discharged to groundwater from domestic septic systems was excluded (MCA 75-5-103(5)) by classifying these discharges as non significant, unless concentrations exceed 5.0 milligrams liter^{-1} nitrate-N for conventional septic systems, or 7.5 milligrams liter^{-1} for level two treatment (MCA 75-5-301(4-d) at the boundaries of mixing zones [(MCA 75-5-103-(18) and Administrative Rules of Montana (ARM) 17-30-502 - 517)]. Session notes from 1995 state that "the legislature intends that degradation be allowed in limited circumstances and under certain conditions . . . provided that water quality protection practices are implemented that limit degradation to the extent determined to be economically and technologically feasible" (MCA Annotations, 1996). The constitutionality of the exclusion found in MCA 75-5-317-(2)(j) is to be tested in 1998 by an appeal to Montana's Supreme Court in the matter of MEIC and Women's Voices for the Earth vs. Montana DEQ.

Although residential well users drink groundwater at their own risk, if groundwater pollution that exceeds Federal drinking water standards is discovered the DEQ will respond and attempt to identify the contaminant source, halt further contamination, and issue citation(s). If a pollution source cannot be identified, DEQ will refer well owners to their health departments (Meek, 1997). County health departments have the authority to petition the state for basin closure based upon identification of risks to human health due to water quality degradation. Ravalli County well owners who contact their sanitarian's office with concerns of well contamination will be advised on water-quality testing and well disinfection methods (Kammerer, 1997).

In 1991, the Montana legislature established the "Local Water Quality District (WQD) Act," giving counties the right to create groundwater protection districts and wellhead protection programs to protect recharge zones of public drinking water wellheads. Bitterrooters have divided opinions on whether or not their groundwater should be protected by formation of a WQD or by basin closure; some fear their real property will lose value as a result of groundwater degradation while others fear losing their rights to control and develop their real property (Rider, 1997).

Summary: Problems with current groundwater policies

Montana's groundwater is owned by the state, and is held in common by all Montanans. It is appropriated with the primary aim of use. Although some well users pay modest permitting fees, none pay use fees, generating a disincentive to conserve from which arises the mechanism of slow degradation known as "the tragedy of the commons," the inevitable outcome being the resource's ruin (Hardin, 1968).

Similarly, although construction of residential septic systems must initially be approved and permitted, rural Montanans pay no fees for subsurface septic disposal. The only incentive for users to minimize degradation of water quality is to protect their private wellheads; cumulative impacts become down-gradient neighbors' problems. So, in its role as a diluting mechanism for septic effluent, groundwater is also functionally a commons and subject to inevitable ruin. Either of the two conflicting uses of Montana's rural groundwater are sufficient to eventually ruin the resource as population pressure increases; in combination, the rate can only increase.

The recent DNRC reorganization may allow it to better deal with stresses of population growth on groundwater. DEQ personnel believe that the pre-1995 non degradation standard with regard to nitrate was unrealistic and its exclusion necessary (Horpestad, 1997). In 1995 the Legislature agreed and "moved the (policy) goalpost," which will neither lessen the amount of Montana's groundwater pollution, nor mitigate its effects, but will delay the time of reckoning.

Sooner or later, Montanans must bear the increasing costs of maintaining their environmental life support system; unfortunately, when costs fall to them individually many respond by diminishing their assessment of how much maintenance is required, stymying the process of finding and implementing long-term protective policy solutions.

Chapter 5: Conclusions and Recommendations

The goal of this study was to establish the hydrogeology of the Eight Mile and evaluate if the groundwater resource has been impacted by development. This goal has been largely met.

Groundwater supplies are adequate for the present population of the Eight Mile. The estimated 375 households cumulatively require approximately 23,000 cubic feet of water daily, and have an estimated 100,000 cubic feet of groundwater from which to draw daily. Whether or not this volume exceeds the carrying capacity of the groundwater system is a determination not made in this thesis, but should be considered by county planners before further development is allowed. It is critical that the finding of 100,000 cubic feet day^{-1} of groundwater flux not be misinterpreted as an upper limit of groundwater availability for residential well development, because to do so would result in massive de watering and possible subsequent compaction and destruction of the transmissive capabilities of Eight Mile's aquifers.

Of the 23,000 cubic feet of water used daily, it is estimated that at least 45 percent is returned to the aquifer system via septic drain fields during summer months, and considerably more is returned off-growing-season. It is important to note that while groundwater is pumped by residential wells from mid-to deep-water-bearing strata, it is returned by drain fields to the shallowest stratum, so care must be taken to avoid over-pumping deep, lower-productivity strata.

It is important to caution that EM-1-Upland, EM-1-Deep and EM-2 are less productive and transmissive than other EM-1 flow zones, and water levels of those flow zones will decline in response to increased demands with greater amplitude than at other parts of the flow field.

Groundwater quality had very probably already been impacted by septic effluent by the time of this study, although it is impossible to determine to what degree; nitrate-N concentrations measured between August 1994 and June 1995 fall into the category of insignificant degradation as codified by the Montana Legislature. Eight Mile baseline concentrations for nitrate-N reasonably range between 1 and 3 milligrams liter^{-1}. During the study period, water quality with regard to specific conductance measurements fell within the classification for high quality, Class I waters. USGS "quality of water" sampling during September of 1995 determined that dissolved radon gas levels exceeded the EPA's 1994 proposed drinking water standard of 300 pico Curies liter^{-1} at all 13 Eight Mile wells sampled, with maximum concentrations of 1080 pico Curies liter^{-1} found at wells pumping from EM-1-River and EM-1-Terrace Base. The EPA is expected to issue a revised standard within the next several years, at which time radon concentrations in Eight Mile groundwater should be reevaluated. Concerned Eight Mile residents are encouraged to have their drinking water and basements tested for radon gas, and abate as necessary. Residents are also advised to have their well water tested routinely for nitrate-N, chloride, and microbial pathogens; illness of family members ought not to be the first indicator of drinking water contamination.

Sound well construction will be of paramount importance in maintaining groundwater quality because poorly-constructed and abandoned wells provide conduits for contamination to migrate between land surface and water-bearing strata.

Montana's groundwater protection policies were set before our current rapid growth and development, and may be inadequate for dealing with impacts to our groundwater resource. Because rapid development is expected to continue in the Bitterroot Valley, the establishment of water quality districts is recommended. Such districts will allow additional study of the valley's groundwater supplies, allow local management of the resource, and promote sustainable use.

Further study of rapidly-developing basins subordinate to the Bitterroot Valley on both benches, is recommended to improve understanding of the entire aquifer system and to allow reasonable valley-wide estimates of the quantity and quality of the groundwater resource.

Sources

Alt, D. and D. W. Hyndman. 1986. Roadside Geology of Montana. Mountain Press Publishing Company, Missoula, Montana. 427 pages.

Berger, D.L., W.C. Ross, et al. 1996. Hydrogeology and simulated effects of urban development on water resources of Spanish Springs Valley, Washoe County, West-central Nevada. U.S.G.S. Water-Resources Investigations Report 96-4297. 80 pages.

Briar, D. 1997. Hydrologist, U.S.G.S. Water Resource Division, Helena, MT. Personal communication. November 1997.

Buckley, L. 1997. Information Systems Support Sepcialist, Montana Bureau of Mines and Geology, Butte, Montana. Personal communication, November, 1977.

Burkhardt, V. 1983. Unpublished Senior Thesis. The Geology and groundwater resources of the north bench, near Stevensville, Montana. University of Montana, Geology Department.

Carlson, C. Spring, 1996. Personal communication. Carlson Drilling Inc., Corvallis, Montana.

Detroy, M., P. Hunt, and M. Holub. 1988. Ground-Water-Quality-Monitoring program in Iowa: Nitrate and Pesticides in shallow aquifers. U.S. Geological Survey, Water-Resources Investigations Report 88-4123.

Driscoll, F. G. 1986. Groundwater and Wells, Second Edition. Johnson Filtration Systems, Inc., St. Paul, Minnesota. 1089 pages.

Domenico, P. A. and F. W. Schwartz. 1990. Physical and Chemical Hydrogeology. John Wiley and Sons, Inc. New York, N.Y. 824 pages.

Eckhardt, D.A., W. J. Flipse, Jr., and E. T. Oaksford. 1989. Relation between land use and ground-water quality in the upper glacial aquifer in Nassau and Suffolk Counties, Long Island, New York. U.S.G.S. Water-Resources Investigations, Report 86-4142.

Eslinger, A. 1995. Personal communication. Eslinger Drilling and Pump Service, Corvallis, Montana.

Fedkiw, J. 1991. Nitrate Occurrence in U.S. Waters (and Related Questions). U.S. Department of Agriculture , unnumbered publication.

Fetter, C.W. 1988. Applied Hydrogeology, Second Edition. Macmillan Publishing Company, New York. 592 pages.

French, R. Grant administrator, Bitter Root Water Forum. Personal communication, November 1997.

Hardin, G. 1968. The tragedy of the commons. Science 162: 1243-1248.

Harrill, J.R. and A.M. Preissler. 1994. Ground-water flow and simulated effects of development in Stagecoach Valley, a small, partly drained basin in Lyon and Storey Counties, western Nevada. U.S.G.S Professional Paper 1409-H.

Horpestad, A., Ph.D. 1997. Supervisor, Standards and Economic Analysis Section, Resource Protection Planning Bureau, Department of Environmental Quality, State of Montana. Personal communications in November and December of 1997.

Horwich, P. 1993. Water quality nondegradation in Montana: is any deterioration too much? Public Land Law Review, Vol.14, Pp. 145-188.

Kammerer, J. 1997. Personal communication with Ravalli County Sanitarian. Hamilton, MT.

Kaufmann, R. F. August, 1978. Land and water use effects on ground-water quality in Las Vegas Valley. EPA-600/2-78-179.

King., J. J. 1996. The cumulative effects of septic system disposal on groundwater quality in selected portions of Missoula County, Montana. Unpublished Master of Science thesis, Geology Department, University of Montana.

Leopold, L. and T. Dunne. 1978. Water in Environmental Planning. Freeman, New York. 818 pages.

Ludwick, J. "Bitterroot still first in growth". Missoulian, March 18, 1998.

Metzger, L. F. and J. L. Fio. 1997. Ground-water development and the effects on ground-water levels and water quality in the town of Atherton, San mateo County, California. USGS Water-Resources Investigations Report 97-4033. Pp. 1-19.

McAlpin, W. 1997. Montana Department of Natural Resources and Conservation, Missoula Field Office. Personal communication, October 10, 1997.

McCamant, T. 1996. The role of the groundwater system in controlling nutrient loading of a pristine trout stream, western Montana. Unpublished Master of Science thesis, Geology Department, University of Montana.

McMurtrey, R. G., R. L. Konizeski, et al. 1972. Geology and Water Resources of the Bitterroot Valley of Southwestern Montana. Geological Survey Water-Supply Paper 1889. United States Government Printing Office, Washington, D.C.

Meek, J. 1997. Section Supervisor, Water Protection Section, Planning Prevention and Assistance Division, Pollution Prevention Bureau, Department of Environmental Quality, State of Montana. Personal communication, November 1997.

Montana Code Annotated. 1997. Annotations available were those published in 1996.

Montana Department of Natural Resources and Conservation. 1993. Water Rights in Montana. Helena, MT.

Montana Environmental Information Center and Women's Voices for the Earth, Appellants, v. Montana Department of Environmental Quality, Respondents. Case #97-455 brief, filed 9/30/97 to the Montana Supreme Court.

National Research Council. 1995. Nitrate and Nitrite in Drinking Water. National Academy Press, Washington D.C.

Newman, H. 1993. Hydrologic and Nitrate Analysis of Paradise Acres, Florence, Montana. Prepared for Professional Consultants, Inc., Missoula, Montana.

Prudic, D. E. and M. E. Herman. 1996. Ground-water flow and simulated effects of development in Paradise Valley, a bsin tributary to the Humboldt River in Humboldt County, Nevada. U.S. G.S. Professional Paper 1409-F.

Ragone, S. E., B. G. Katz, et al. 1980. Nitrogen in ground water and susrface water from sewered and unsewered areas, Nassau County, Long Island, New York. U.S.G.S. Water Resources Investigations 80-21.

Rider, J. "Ebbing aquifers worry residents in the Bitterroot; Source of concern: new development". Missoulian, November 16, 1997.

Sears, J. W., Ph.D. October 1996. Field Guide to Tertiary Formations along the east side of the Bitterroot Valley, Stevensville to Eightmile Creek, Ravalli County, Montana. University of Montana Geology Department, Missoula, Montana.

Sears, J. W., Ph.D. Spring 1997. Personal communications. University of Montana Geology Department, Missoula, Montana.

Snoeyink, V. and D. Jenkins. 1980. Water Chemistry. Wiley, New York. 461 pages.

Spalding, R.F., and M.E. Exner. 1993. Occurrence of nitrate in ground water - a review. Journal of Environmental Quality, Vol. 22, No. 3, Pp. 392-402.

Tarlock, A., D., J. N. Corbridge, Jr., and D.H. Getches. 1993. Water Resource Management: A Casebook in Law and Public Policy, Fourth Edition. Foundation Press, Inc. Westbury, N.Y. 930 pages.

Thomas, J. M., S. M. Carlton and L.B. Hines. 1989. Ground-water hydrology and simulated effects of development in Smith Creek Valley, a hydrologically closed basin in Lander County, Nevada. U.S.G.S. Professional Paper 1409-E.

United States Environmental Protection Agency. May, 1995. Protecting Our Ground Water. EPA-813-F-95-002.

United States Environmental Protection Agency. February, 1994. National Primary Drinking Water Standards. EPA 810-F-94-001A.

United States Environmental Protection Agency. June, 1990. Risk Assessment, Management and Communication of Drinking Water Contamination. EPA/625/4-89/024.

United States Environmental Protection Agency Safe Drinking Water Hotline. May, 1998. 1-800-426-4791.

United States Geological Survey. 1967. Stevensville Quadrangle, Montana-Ravalli County, 7.5 Minute Series Topographic Map. Number N4630-W11400/7.5. Denver, Colorado.

Ver Hey, M.E. Contributions to potable water contamination from septic system effluent in unsewered areas underlain by coarse sand and gravel substrates. Masters Thesis, University of Montana Environmental Studies Department, 1987.

Whitten, D. G. A. and J. R.V. Brooks. 1972. Dictionary of Geology. Penguin Books. New York.

Wilson, K. J. 1994. Wellhead Protection Planning: A comparison of two communtiie's approaches. Missoula, Montana and Polson, Montana. Unpublished M.S. Thesis, University of Montana Environmental Studies Department.

Yen, S. T., S. Liu, and D.W. Kolpin. October 1996. Analysis of nitrate in near-surface aquifers in the mid continental United States: An application of the inverse hyperbolic sine Tobit model. Water Resources Research, Vol. 32, No. 10, p. 3003.

Appendix A: Listing of Well Logs, M: Identifiers, Locations, Estimated Elevations, Certificate of Water Right Number

The following lists all well drillers' logs with identified well locations, used during this study. Except for 8M monitoring wells, land surface elevations (LSD) were estimated from USGS quadrangle maps of the study area. Well depth (DP) and static water level (SWL) data were obtained from driller's logs. Well owner data are current as of 1996.

Table A.1. Listing of Well Drillers' Log Data

Well #	M:	DNRC Cert# G76H	TNS/RN	SXN	1/4 ID	CURRENT OWNER	LOG NAME	ADDRESS	APRX LSD	WELL DIA	DP	SWL
8M01			10N19W	09	ABCC	Roger Mikesell				6		
8M02	136257		10N19W	08	ADAD	Edward & Lorraine Coulter	Glen Mikesell	605 Eight Mile Creek Road	3499.98	6	340	145
8M03	130913	85151	10N19W	08	ADDC	Guy & Terry Sharp	Guy Sharp	5560 Bridle Path Ln.	3489.24	6	287	87
8M04	151314		10N19W	05	DDCC	Mike Krout	Alan Zeiler	5651 SkyVw. Dr.	3470.8	6	60	20
8M05	133852	85272	10N19W	08	ABBC	Mark Smith	℅ Mark Twite Const.	5628 Orchard Ln.	3448.41	6	120	45
8M06	63442	25466	10N19W	08	BBDD	Jim & Sue Schatzka	Mike Houseman	5422 Mountain Vw. Dr.	3408.45	6	290	200
8M08	143713		10N19W	08	CBAA	Mary Scott	Mike Wilton	5545 Mountain Vw. Dr. S.	3400.84	6	160	63
8M09	63535	77247	10N19W	08	BDBB	Michael Ferguson	Martin/Hensler	475 Eight Mile Creek Road	3415.74	6	295	220
8M10	151317		10N19W	07	ADBC	Don & Molly Verrue			3346.62	6	126	
8M11	129425		10N19W	05	CDCC	Lyra Kester	Lyra Kester	5656 Mountain Vw. N.	3399.01	6	80	18
8M12	63445		10N19W	07	BAAD	Bruce Allen	Mark Finlay	5629 Cottonwood Dr. N.	3306.56	6	85	53
8M13	63536	77247	10N19W	08	BDAB	Tracy Beaver Williams	Wilbur Hensley	495 Eight Mile Creek Road	3432.98	6	319	228
8M14	63477		10N19W	06	CDDD	Jim Trotter	Joe Wahrer	5653 Cottonwood Dr. N.	3310.72	6	109	64
8M16	140666		10N19W	17	BAAA		Bob Bielby	457 Hdn. Vly. Rd. N.	3435.95	6	161	119
8M17	151324 63882	55230	10N19W	06	DCDA	Naomi and Al Slagell	Edgell/ Duxbury	5665 MeadowVw. Dr. N.	3340.2	6	71	12
8M18	63533		10N19W	08	CDAC	Tim Marquardt (Mike)	Robert Bielby	326 Arlington	3405.61	6	124	76
8M19	129423		10N19W	08	BCAD	Dan & Connie Stephens	Stephens	5569 Mountain Vw. Dr. S.	3402.78	6	320	200
8M20	124553		10N19W	06	DDCC	Roger Boehrs	Roger Boehrs	5654 MeadowVw. Dr. N.	3352.29	6	135	110
8M20-I	63444	60064	10N19W	06	DDCC	Roger Boehrs	Roger Boehrs	5654 MeadowVw. Dr. N.	3352.29	6	85	12
8M21	63884	55317	10N19W	06	DCCC	Alan Foss	David Edgell	5515 Cottonwood Dr. N.	3314.83	6	84	50
8M23	140665		10N19W	07	BDBB	Paul & Cindy Anderson	Michael Wilton	273 Eight Mile Rd.	3282.26	6	104	43

Well #	M:	DNRC Cert# G76H	TNS/RN	SXN	1/4 ID	CURRENT OWNER	LOG NAME	ADDRESS	APRX LSD	WELL DIA	DP	SWL
8M24	63523		10N19W	08	BCCB	Ken Martin	Will Zeiler	5568 RiverVw. Dr. S.	3379.89	6	158	130
8M25			10N20W	12	ADDD	Anderson-Earl AnneWatson			3244.3	6		
8M26			10N19W	07	DBBC	Dawn Buffum				6		
8M27	63483	17781	10N20W	12	DAAD	Larry & Jan Bicha	Larry Bicha	210 Cormoret Loop	3242.99	6	57	30
8M28	137474	87784	10N19W	07	CACB	James Clotfelter	Gary Van Tassel	171 Eight Mile Creek Road	3273.12	6	110	40
8M29	63493		10N19W	07	CAAD	Allen Gebhardt	Alan Zeiler	5544 Circle Dr.	3300.02	6	85	38
8M30			10N19W	07	CACA	Jason & Chantil Breen		5483 Circle Dr.	3282.67	6		
8M31	63522		10N19W	08	BCBB	Allen Baumberger	Allen Baumberger	415 Eight Mile Creek Rd	3381.38	6	200	148
8M32	64099	63615	10N20W	12	ADDB	Guy & Peg Andersen	Tom Wilcox	247 Cormoret Loop	3236.46	6	100	27
8M33	63526		10N19W	18	AAAA	Keith McCormick	Will Zeiler	348 Hdn. Vly. Rd.	3341.84	6	75	50
8M33-2	136258		10N19W	18	AAAA	Keith McCormick	Keith McCormick	348 Hdn. Vly. Rd.	0	6	85	48
8M34	63489		10N19W	07	CDBA	Mick & Pauline Claridge	Donald Beyer	230 Todd Ln.	3281.47	6	59	20
8M35	63511		10N19W	08	CBDD	Mark Herbert	Mark Herbert	4406 Mountain Vw. Dr. S.	3374.7	6	69	43
8M37	123130		10N19W	08	DAAC	Robert & Carla Bielby	Bob Bielby	P.O. Box 425	3481.78	6	210	45
8M38	132276		10N19W	08	DCCC	Brian Huseby	Dennis Ruana	5407 Blue Sky Ln.	3461.85	6	187	140
8M39	151319		10N19W	16	BBBC	A. Rawlins/L Pulis			3518.12	6	279	
8M40			10N19W	17	BACC	Karin Lau			3411.33	6		
8M41	63556	37787	10N19W	17	BCAB	Bevery Maier	Gerald Morris	5318 Timberline	3388.46	6	178	68
8M42	63530	75711	10N19W	18	AAAB		Will Zeiler	343 Explorer Way	3334.37	6	99	45
8M43	132272		10N19W	07	DDDB	Rick & Cindy Johnson	Kevin Billingslea	332 Explorer Way	3325.13	6	76	40
8M44	64102	61243	10N20W	12	ACDD	Jerry & Shirley Harper	Tom Wilcox	209 Surrey Ln.	3213.61	6	75	25
8M45	63957	63614	10N19W	07	BCBB	Joel & Kim Block	Tom Wilcox	199 Surrey Ln.	3262	6	95	50
8M46	132270		10N19W	06	CDCB	Ralph Brown	Robert Brown	5629 Lwr. Woodchuck Rd.	3288.72	6	80	46
8M46-2	148037		10N19W	06	CDCB	Rob Brown	Rob Brown	5629 Lwr. Woodchuck	3288.72	6	79	50
8M47	128879		10N19W	09	BCCC	Dolores & Glen Mikesell	Glen Mikesell	Box 315, Florence	3492.33	6	290	30
8M48	63476		10N19W	07	BABC	Jane Finlay	Mel Finlay	5628 Lwr. Woodchuck Rd.	3282.99	6	130	80
8M49	63880	49236	10N19W	07	CDAA	Pat Van De Hey	Elroy A. Brunner	270 Todd Ln.	3295.23	6	60	21
8M50			10N19W	08	BADD	Kathy Mehring			3442.2	6		
8M51	26601		10N19W	07	BDDA	Eldon Hatch	Mack Blankenship	202 Brandi Ln.	3306.21	6	88	66
8M52	151321		10N20W	12	DDDD	Eileen Sisson			3220.69	6		5
8M53	151323		10N19W	07	CDCC	Paula Fisk	Gary Ince Constr.	115 Blackfoot Ln.	3267.32	6	140	25
8M54	124575		10N19W	18	ADCA	Lynn & Jim Jensen			3351.94	6	122	90
8M55	151322 130919		10N19W	18	ACCD	Lynn Gardiner	Lee Hiniker	262 Bull Run Lot #1	3305.91	6	105	74

Well #	M:	DNRC Cert# G76H	TNS/RN	SXN	1/4 ID	CURRENT OWNER	LOG NAME	ADDRESS	APRX LSD	WELL DIA	DP	SWL
8M56	63608	61228	10N19W	18	BCBD		T & T Constr.	165 Huckleberry Ln.	3230	6	59	27
8M57	136371	87732	10N19W	08	DCCD	Dennis & Linda Ruana	Dennis Ruana Jr.	5408 Blue Sky Ln.	3467.48	6	186	153
8M58			10N19W	18	ABAD	Mr. and Mrs. Arthur Christ			3310.14	6		
8M60	63573	52020	10N19W	17	BCCC	Pam Luoma -new house site	Joe M. Smallwood	Meadowlark Ln.	3371.2	6	160	94
8M61	63431	75199	10N19W	05	CCCC	R. Johnson-house	Joe Wahrer	5656 RiverVw. Dr.	3380.36	6	48	18
8M62			10N19W	05	CCCD	R. Johnson - pasture			3388.28	60		
8M63	63532	70281	10N19W	08	CDBD	James Paske	Jim Paske	314 Arlington	3395	6	107	72
8M64	128870		10N19W	08	DCCA	Jeannie & Rod Morgan	Bob Bielby	5413 Blue Sky Ln.		6	180	125
8M65	138444		10N19W	08	DCCA	Mahesh Mistry	Bob Bielby	5423 Blue Sky Ln.	3454.84	6	170	120
8M67	63596		10N19W	18	AADB	David & Connie Ibey	David N. Ibey		3326.84	6	95	36
8M68	124552	81005	10N19W	07	DBDA	Eve & Myron Wight	Myron & Eve Wight	5519 MeadowVw. S.	3330.91	6	72	38
8M69	124557		10N19W	07	DABB	Carl & Maria Tiefenthaler	Allen Zeiler	5544 MeadowVw.	3340.38	6	120	60
8M71	64103 151318		10N20W	12	ADCA	Susan Doverspike	Samuel C. Nicolet		3226.58	6	95	32
8M72	63422		10N19W	06	CDDA	Terry & Roberta Dye	Roberta Dye		3306.22	6	148	51
8M73	123123		10N19W	06	DCBC	Andy McCarthy	Andy McCarthy		3324.35	6	81	
8M74	151313	93390	10N19W	08	DBBD	Shelley & Lee Hiniker	Lee Hiniker	5514 Bridlepath Ln.	3438.69	6	261	200
8M75	64117	2880	10N20W	12	DABD	Mike Saunders	Roy Louis Nicolet	215 Cormoret Loop	3226.35	6	90	27
8M76	123132		10N19W	08	DCCC	Roberts-tenant/Pam McCoy	Karl-Heinz, McCoy	NW Blue Sky & Hdn. Vly.		6	168	145
8M77			10N19W	17	BCAB	Rick Raines			3381.72	6		
8M78	153228		10N19W	08	ACAD	Russell Pooley	Russ Pooley	Bridlepath Ln.	3451.15	6	421	280
ANT1		57707	10N19W	07	DCCB	Scott & Tracy Crawford	Walter J. Pocha	170 Antrim Way	3295	6	96	20
ANT2	63501 63439	47080	10N19W	07			Stan Wekkin	250 Antrim Ln.	3300	6	66	21
ANT4	63434	26616	10N19W	07	DCCC	Frank Benkowsky	Frank Binkowsky	240 Antrim Way		6	80	
ARL 20	127486		10N19W	08	CCCB	Rod Everson	Rod Everson		3360	6	52	42
ARL A	63539	C77813	10N19W	08	CCBD	William & Margaret Lindstrom	Bill Lindstrum	258 Arlington	3362.5	6	79	50
ARL B	63452	66635	10N19W	07	DDDB	Kelly Mikesell	Bill Walton		3345	6	57	33
ARL D	63570	72205	10N19W	08	CDAD	Bessie & John Evans	Dick Renfro	5474 Saratoga Rd.	3420	6	152	94
ARL2	63454	66694	10N19W	08	CCDD		Jeff Webber		3380	6	74	46
ARLC	63569	71348	10N19W	08	CCAC		Chuck Jenne	Arlington Dr.	3370	6	75	50
AV1	141851		10N19W	18	BBCB	Larry Conrad	Will Zeiler	Apple Vly., Lot 5A, Blk. 1	3230	6	118	6
AV2			10N19W	18	BBAB	Kevin Billingslea	Kevin Billingslea	Apple Vly., Lot 1A, Blk. 1	3260	6	150	28
AV3	124576	79600	10N19W	18	BBDC	Donald Patterson	Will Zeiler	Apple Vly.	3240	6	124	12

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BF1		82111	10N19W	07	CDCD	David & Donna Boddington	Gary Ince	127 Blackfoot Ln.	3275	6	108	11
BF2	63463		10N19W	07	CDDC		Gary Ince Constr.	Lot 1, Arrowhead Acres	3270	6	100	18
BFA	63590	66641	10N19W	07	CDCC	Brian Roberts	Gary Ince	124 Blackfoot Ln.	3275	6	80	6
BFA-2	155809	66641	10N19W	07	CDCC	Luis & Tammy Hall	Luis & Tammy Hall	124 Blackfoot Ln.	3275	6	95	9
BLA	134140		10N19W	07	BDCA	Bill & Toni Lewis	Mac Blankenship	210 Brandi Ln.	3290	6	134	65
CDA	134505	87809	10N19W	07	CABD		Dick Renfro	72 Center Court	3290	6	83	56
CDB	63491	89385	10N19W	07	CACA	Dulac	Wendell Kenney	5493 Circle Dr.	3280	6	36	22
CDD	63466	76686	10N19W	07	CAAC	Dave R. Bair	Will Zieler	5533 Circle Dr.	3290	6	107	60
CDE	141847		10N19W	07	CABA	Bob Boyce	Alan Zeiler	5558 Circle Dr.	3285	6	94	56
CDF	151121		10N19W	07	CAAC		Mark Anderson	Lot 9, Circle Square	3290	6	93	62
CDG	126215		10N19W	07	CABD		Rod Renfro	Circle Square, Lot 10	3280	6	130	47
CDH	139831		10N19W	07	CABC		Tom Vanorio	Circle Square, Lot 9	3275	6	64	26
CDI			10N19W	07	CADC	Nancy Palaski	Dick Renfro	5514 Circle Dr.	3290	6	147	69
CDJ	143077	91242	10N19W	07	CAAC	Mike Anderson	Mike Anderson	Circle Dr.	3295	6	59	44
CDK	63487		10N19W	07	CACA		Louis Anderson	Circle Square, Lot 26	3280	6	39	23
CL1	63484	11144	10N19W	07	CBAC	Manthie	Marvin Manthie		3260	6	153	50
CORA	128861		10N19W	07	BCCA	Linda Courter	Linda Courter	N Corm Loop	3265	6	94	40
CORB	121484	19974	10N19W	07	CBDA	Harold Smith	Harold Smith	171 Cormoret Loop	3262	6	72	36
CORC	64118	6103	10N20W	12	DDAD		Gary Zabel	5501 Cormoret Loop	3235	6	91	23
CORE-1	63482	18086	10N20W	12	DAAA	Angelo Plomaritis	Angelo Plomaritis	Cormoret Loop	3250	6	129	38
CORE-2			10N20W	12	DAAA	Angelo Plomaritis	Angelo Plomaritis	Cormoret Loop	3250	6	159	28
CORE-2	63959	18086	10N20W	12	DAAA	Angelo Plomaritis	Angelo Plomaritis	Cormoret Loop	3250	6	159	28
CORF	63487	16580	10N19W	07	BCDD	Remberto Hernandez	Remberto Hernandez		3275	6	86	40
CORG	63435	24026	10N19W	07	BCDC	Robert Stevens	Robert Stevens		3265	6		
CW1	124554	3317	10N19W	06	CDDD	Chere Hauntz	Chere Hauntz	5665 Cottonwood Dr. N.	3310	6	91	61
CW2	135657		10N19W	07	ABBC	Greer	David Edgel	5628 Cottonwood Dr.	3320	6	126	60
CW20	139834		10N19W	07	DCBB	Sally Carlson	Tom Vanorio	Cottonwood Dr.	3310	6	77	27
CW3	63462	74827	10N19W	07	BADA		Mark Finlay	Cottonwood Dr.	3310	6	220	86
CW30	63474		10N19W	07	BAAA		David Edgell	Riv. Orch., Blk. 2, Lot 3-B	3310	6	100	55
CW31	153191		10N19W	06	CDCA	Karl & Donna May	Karl & Donna May	5673 N. Cottonwood Dr.	3290	6	130	76
CW32	63515	53997	10N19W	07	ABCC		Carles I. White		3320	6	89	70
CW4A-1			10N19W	07	ACBC	R. and S. Kirkpatrick	Todd Peters	5580 Cottonwood	3320	6	107	62
CW4A-2			10N19W	07	ACBC	R. and S. Kirkpatrick	Todd Peters	5580 Cottonwood	3320	6	225	
CW4B	144542		10N19W	07	ACBC	R. and S. Kirkpatrick	Todd Peters	5580 Cottonwood	3320	6	131	75

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CW5	63496	82143	10N19W	07	DBBB	Roger Haynes	H. Stanley Antrim	5544 Cottonwood Dr. S.	3320	14	150 390	33
CW6	137475		10N19W	07	CADD	Mike Hubbard	Mike Wilton	5505 Cottonwood Dr.	3300	6	100	40
CW7	63446		10N19W	07	DBCC	Todd & Monica Johnson	Cliff Olson	5506 Cottonwood Dr.	3310	6	75	25
CW8	63474	56696	10N19W	07	BAAA	Harris, James and Linda	David Edgell	5640 Cottonwood	3315	6	100	52
CW9	141858	90425	10N19W	07	ABCC	Dick Renfro	Dick Renfro		3325	6	91	67
CWA	63438		10N19W	07	BDAA	Colleen Frank	Joe Wahrer	5593 Cottonwood Dr. S.	3305	6	80	56
EH2	63495		10N19W	07	CBCC		Ronald Meeks		3245	6	120	30
EH3	124568	78965	10N19W	18	BBDB		George Kuspa	Apple Vly., Lot 3A, Blk. 2	3245	6	63	26
EH4	63494	67687	10N19W	07	CCCD	Tony & Patricia Piccinini	Tony Matheny	6015 East Side Highway	3250	6	130	14
EH5	63480	52038	10N19W	07	CCDB	Robert Wofford	Robert Wofford	112 Eight Mile Road	3360	6	100	30
EM1	124551		10N19W	07	BDCB	Highway Baptist Church	Hwy Baptist Church	Eight Mile Creek Rd.	3280	6	102	60
EM4	63447		10N19W	07	BDAB	Mack & Sharon Blankenship	Joe Wahrer	317 Eight Mile Creek Rd.	3300	6	83	50
EMA-1	63520		10N19W	08	ABDD	Harry & Lorri Lippy	Harry & Lorri Lippy	580 Eight Mile Creek Rd.	3480	6	385	117
EMA-2	63507	76767 76752	10N19W	08	ABDD	Lorrie Lippy	Sean Warren	580 Eight Mile Creek Rd.	3480	6	36	18
EMA-3	63524	25514	10N19W	08	ABDD		Beth Warren	580 Eight Mile Creek Rd.	3480	6	380	110
EMB		91261	10N19W	08	BDBA	Bill Ball	Bill Ball	487 Eight Mile Creek Rd.	3420	6	300	228
EMC	136256	88356	10N19W	07	CBDD	Ron Becker	Ron Becker	174 Eight Mile Creek Rd.	3275	6	80	38
EMD	63443	82834	10N19W	07	BDAB	Lynden & Leena Clark	Joe Wahrer	289 Eight Mile Creek Rd.		6	80	60
EME	124555		10N19W	07	BDBA		Joe Wahrer	283 Eight Mile Creek Rd.	3295	6	86	58
EMF	63436		10N19W	07	CDBC		Dennis Price		3260	6	45	25
EMG	63486	43659	10N19W	07	CDCB	Dwight Povsha	H. Stanley Antrim	133 Eight Mile Rd.	3270	6	150	32
EMJ	141306	89464	10N19W	07	BDBB	Dale Buechler	Mike Wilton	275 Eight Mile Rd.	3295	6	140	55
EX1	126886	81418	10N19W	07	DDCD	George Kuspa	George Kuspa	Explorer Way	3335	6	60	30
EX20		81777	10N19W	07	DCDC	Mike Martin	Gary Reichert	276 Explorer Way	3310	6	107	30
EXA	127482	83715	10N19W	18	AABA	Gere Norgaard	Will Zeiler	331 Explorer Way	3330	6	80	40
EXB	145845	92109	10N19W	07	DCDD	Jon Beckett	Kevin Schultz	304 Explorer Way	3320	6	81	32
EXC	138443	88390	10N19W	18	ABAB	Larry Hollinder	Todd Peters	299 Explorer Way	3315	6	63	30
EXD	139835		10N19W	18	ABAC	Gene Durand	Todd Peters	285 Explorer Way	3305	6	62	30
EXE	128872	83936	10N19W	17	BBBC	John Bielby	John Bielby	357 Explorer Way	3350	6	120	44
EXF			10N19W	18	AABB	Jim Graham	Jim Graham		3315	6	122	26
FHB	63460	64589	10N19W	18	BBAA	Marc Thomas	Leo and Sandy Block	5395 Flathead Dr.	3265	6	90	32
FHC	63451		10N19W	18	BABA	Karen Smith	Ince/Andersen/Smith	5371 Flathead Dr.	3275	6	76	30

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FHD	63459		10N19W	18	BABA		Gary Ince	Lot 12, Arrowhead Acres	3280	6	110	20
FHE	63485		10N19W	07	CDDC		Gary Ince	Lot 5, Arrowhead Acres	3275	6	80	25
FHF	63468		10N19W	18	BBAA		Gary Ince Constr.	Lot 9, Arrowhead Acres	3265	6	140	8
FHG	136367	69064	10N19W	18	BABB	Clarence and Marisa Stephens	Gary Ince for Stephens	5388 Flathead Dr.	3265	6	80	12
Fhf	122194		10N19W	18	BABA		Gary Ince Constr.	Arrowhead Acres Lot 16	3265	6	160	60
FHI	122186		10N19W	18	BAAB		Gary Ince Constr.	Arrowhead Acres Lot 13	3275	6	200	40
GV1	127485	83626	10N19W	18	BAAA	Robert & Laurel Rock	Alvin Gruebele	5367 Grand Vista Dr.	3290	6	72	12
GV2	63450	63646	10N19W	07	DCCC		Roland Dimmitt	5385 Grand Vista Dr.	3290	6	44	16
HV1	63563	83891	10N19W	17	AABA		Leonard Grigonis			6	205	107
HV2	63531	65859	10N19W	08	CCCD	Dianna Gundlach	Dianna Gundlach	Hdn. Vly. N.	3360	6	78	47
HV20		63700	10N19W	16	BBB	Voehlke/Leavey	Robert C. De Smidt	627 N. Hdn. Vly.	3540	6	320	200
HV3		72162	10N19W	17	AAA	Doug Ratliff	Doug Ratliff	Approx, DNRC file	3480	6	195	170
HV4	63566	57740	10N19W	17	AAB	Gene O'Toole	Gene O'Toole	361 Hdn. Vly.	3460	6	180	140
HVA	63585	56756	10N19W	18	ABBC	Norman L. Hughes	Norman L. Hughes	252 Hdn. Vly. Rd.	3295	6	49	7
HVD	134507	87090	10N19W	17	BABB	Dennis Stevens	Dennis Stevens	439 Hdn. Vly. Rd.	3380	6	90	70
HVE	63568	70275	10N19W	17	BADC	Rod & Debra Hall	Rod & Debra Hall	442 Hdn. Vly. S.	3420	6	188	138
HVF	63584	52023	10N19W	18	BAAC	Charles L. Hornstein, Jr.	Charles L. Hornstein, Jr.	200 Hdn. Vly. Rd.	3280	6	145	40
HVG	63610	21604	10N19W	18	BADA	McCostlin	Max & Evelyn Malef	201 Hdn. Vly. Road	3280	6	78	16
HVH		92167	10N19W	18	ABBD	George & Mae Marshall	George & Mae Marshall	266 Hdn. Vly. Rd.	3290	6	106	13
HVI	124574	80151	10N19W	18	ABBA	John E. & Jolynn True	John E. & Jolynn True	264 Hdn. Vly. Rd.	3310	6	80	20
HVJ	124571	80947	10N19W	18	ABCC	Robert Mettler	Tom Anderson	295 Hdn. Vly. Road	3285	6	68	30
HVK	63527	74298	10N19W	18	AABC	Everett Nelson	Will Zeiler	310 Hdn. Vly.	3330	6	64	41
IBEY	143715		10N19W	18	AADC	Connie Ibey	Connie Ibey			6	100	44
LA1	154939		10N19W	08	ACAA		Lee Hiniker		3475	6	480	160
LA2	155566		10N19W	08	ACBA		Scott Byrne	Riv. Orch., Blk. 4, Lot 18A-2	3365	6	418	193
LH2			10N19W	18	ACBA		Lee Hiniker	Spur Ln.	3290	6	45	22
LWC1	63883	53976	10N19W	07	BABB	Jim Johnson	David Edgell	5560 Lwr. Wood Chuck	3282	6	92	35
MDV1		55359	10N19W	07	ABAD	Koeppen, M & L	David Edgell	5629 Meadow Vw. Dr.	3340	6	150	77
MDV2	63470	57759	10N19W	07	ACDA	Chris Marquardt	Tom Bauer	5569 Meadow Vw.	3340	6	104	72
MDV20	147586		10N19W	07	ABDD	Kowalski?	Lee Hiniker		3340	6	289	250
MDV3	127483	81481	10N19W	07	ADCB	Richard and Sharon Renfro	Richard Renfro	5568 Meadow Vw.	3343	6	119	92
MDV31	63417	57758	10N19W	07	ACAD		Tom Bauer	Riv. Orch./Blk. 2, Lot 25-B	3340	6	117	72
MDV32	63500	62601	10N19W	07	DCAA	Clifford & Judy McCarley	Clifford McCarley	Riv. Orch., Blk. 2, Lot 18-B	3325	6	108	20
MDV33	63505		10N19W	07	DDCB		H. Stanley Antrim		3320	12	84	30

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MDV34	126883		19N19W	07	DDBD	Jan Wehrli	Jan Wehrli	Riv. Orch., Blk. 3, Lot 15-A	3300	6	83	47
MDV35		85251	10N19W	18	ACDC	Bill Thomas	John VanLaven	275 Bull Run	3340	6	120	87
MDV36	158116		10N19W	07	DCDA	Jason Shorten	Jason Shorten	Riv. Orch., Blk. 2, Lot 17B	3320	6	101	20
MDV4	141857		10N19W	07	ABDA	Dick Renfro	Dick Renfro		3340	6	121	90
MDV5		78905	10N19W	07	DBAA	Sharon Renfro	Dick Renfro		3335	6	105	61
MDV6	127481		10N19W	07	ADCC	Richard Renfro	Richard Renfro		3340	6	88	65
MDVA	63472	24613	10N19W	07	AACC	Michael & Sherie Neumann	Robert Greene	5604 Meadow Vw.	3345	6	210	90
MDVB	128869		10N19W	07	DBAD		Thomas M. Longhurst	5533 Meadow Vw. S.	3330	6	68	43
MDVC	63457	70407	10N19W	07	DACC	Mary Boebel	Will Zeiler	5518 Meadow Vw.	3340	6	99	45
MDVDid	136374		10N19W	07	AACB	Forwood	John Diddel	5616 Meadow Vw.	3340	6	135	101
MDVFin	134510		10N19W	18	AACA	Gary Finch	Gary Finch	5376 Buttercup Ln.	3325	6	73	46
MDVHAV	63557		10N19W	17	BCBC	John Haven	John Haven		3360	6	112	88
MDVHON	26630	88464	10N19W	07	ADBB	Honea	Nick Bickish		3350	6	168	108
MDVKir	63475	61277	10N19W	07	ACDD	John Kirstine	Jon Cusker	5557 MeadowVw. Dr.	3330	6	100	50
MDVMax1			10N19W	07	ABAA	Maxwell	Joe Wahrer	5643 Meadow Vw. Dr.	3340	6	99	81
MDVMax2	63473		10N19W	07	ABAA	Thomas or Eve Maxwell	T.or E. Maxwell	5643 Meadow Vw. Dr.	3340	6	127	95
MTV1	155562		10N19W	08	BBAA		Lee Hiniker		3405	6	294	195
MTV2	63516	63454	10N19W	08	BBDA	Craig & Sherry Standberg	Richard E. Renfro	Mountain Vw. N.	3410	6	276	220
MTV3	63521	53975	10N19W	08	BABC	Roger & Terry Wingo	Roger & Terry Wingo	5595 Mountain Vw. Dr.	3415	6	320	207
MTV4	145852		10N19W	08	BCDD	Adam and Michelle Rush	Mike Wilton	5557 Mountain Vw. Dr. S.	3410	6	90	70
MTV5			10N19W	08	CABB		Wilber Hensler		3410	6	365	190
MTVA	63506	35109	10N19W	08	CBDC	Volker	Bruce Scott	5511 Mountain Vw. Dr.		6	34	13
MW	63553	62703	10N19W	16	BBAB	Tom Mc Cleerey	Tom Mc Cleerey	5373 Maranatha Way	3580	6	350	230
NF1	64125	60065	10N20W	13	AAAA	David & Debra Hansen	David & Debra Hansen	55393 New Fann Way	3240	6	100	4
OR1	63518		10N19W	05	CDDD	Jim Mapledoram	Jim Mapledoram			6	74	33
OR2	122189	90541 78961	10N19W	08	BAAB		Joe Lunceford	5642 Orchard Ln.	3440	6	86	43
OR3	63519	72209	10N19W	08	ABBB		Donald Felde		3460	6	68	34
OR4-1	144548		10N19W	08	BADA		Mike Wahrer	5617 Orchard Ln.	3445	6	160	95
OR4-2	144548		10N19W	08	BADA		Mike Wahrer	5617 Orchard Ln.	3445	6	357	237
OR5	145847		10N19W	08	BAAD	John Polutnik	John Polutnik	5629 Orchard Dr.	3345	6	78	32
RV1	26609		10N19W	07	ADAA	Monk	Nick Bickish	River Vw. Dr. S.		6	145	126
RV2	141849		10N19W	08	BBBC	Mike Smith	Mark Anderson		3377.5	6	234	180
RV20	63575	78461	10N19W	18	ADDD	Kevin Schultz	Kevin Schultz	329 Bull Run	3400	6	152	115

Well #	M:	DNRC Cert# G76H	TNS/RN	SXN	1/4 ID	CURRENT OWNER	LOG NAME	ADDRESS	APRX LSD	WELL DIA	DP	SWL
RV21	120443		10N19W	07	ADDD	Jim & Bev Hendrickson	Dick Renfro	5565 RiverVw. Dr.	3370	6	162	120
RV22	124550	80152	10N19W	18	ADDB	Doug Allington	Doug Allington	326 Bull Run	3360	6	122	90
RV23	134512	85259	10N19W	18	ADAB	Dan Jenkins	Lee & Shelly Hiniker	5388 Simental Trail	3310	6	74	48
	63509	61146	10N19W	07	DDAA	Pat Carey	Pat Carey	Riv. Orch. Blk. 3, Lots A&B	3360	6	67	45
RV25	128924		10N19W	18	ADAC		Lee & Shelley Hiniker	Bull Run, Lot 11	3320	6	102	65
RV26	130917		10N19W	18	ADAC		Lee & Shelley Hiniker	Bull Run, Lot 12	3320	6	98	61
RV27	155564		10N19W	07	DAAD		Lee Hiniker	Riv. Orch., B-3, Lot 11-B	3370	6	76	50
RV28	155777		10N19W	06	DDDD	Dick Renfro	Dick Renfro	Riv. Orch., B3, Lot 2B	3380	6	44	12
RVA			10N19W	08	BBCC	Don Griffith	Don Griffith		3380	6	259	180
RVB	63884	53998	10N19W	07	AADD	Kurt Brunner	David Edgel	5403 RiverVw.		6	164	130
RVC	63525		10N19W	07	AADA	Terry & Synthia Tams	Ted W. Brosam		3377.5	6	150	115
RVD	141307		10N19W	08	CBBB	James Pancoast	James Pancoast	5544 RiverVw. Dr. S.	3380	6	102	75
RVE	63512		10N19W	07	DADA	Terry & Rebecca Falcon	Don Niemeir		3365	6	71	44
RVF	63508		10N19W	08	CCBC	Bill Lindstrom	Bill Lindstrom		3355	6	32	16
RVG			10N19W	07	DDAD	James & Deborah Hunt	Melvin Siira		3355	6	63	43
RVH	143712	96997	10N19W	08	CBBC		Mike Wilton	Riv. Orch., Blk. 3, Lot 19-A	3375	6	117	70
SL1	128932	85170	19N20W	12	ADBC	Chuck Jenne	Chuck Jenne	Surrey Ln.	3230	6	75	50
VA1	153229		10N19W	08	ACDA	abandoned	Lee Vandeburgh	5573 Larson Ln.	3465	6	495	
VA2	153227		10N19W	08	ACDD	Lee & Vickie Vandeburgh	Lee Vandeburgh	5573 Larson Ln.	3465	6	73	40
LWCZab	63497	56688	10N19W	07	CDBB	Zabarko	Drake Lamm	149 Todd Ln.	3270	6	58	20

Appendix B: Summary of Static Water Levels

The following summarizes static water level measurements by monitoring well. Measuring point description, elevation and location for each well can be found in Appendix G.

	Aug94	Oct94	Jan95	Mar95	May95	Aug95	Sept95	Nov95	Feb96	May96
8M2	3372.43	3396.42	3413.00	3413.06	3397.17	3391.79	3399.16	3408.05	3406.20	3413.87
8M3	3360.74	3371.80	3388.61	3397.09	3373.27	3375.88	3378.59	3388.72	3388.10	3390.93
8M4	3459.85	3459.33	3458.27	3457.22	3456.60	3459.12	3460.23	3460.17	3459.01	3459.79
8M5	3417.81	3411.89	3415.24	3410.27	3419.75	3419.69	3417.17	3416.57	3413.61	3413.01
8M6	3204.06		3204.97		3204.75	3203.04	3204.43			3205.94
8M8	3339.62	3328.37								
8M9	3201.40									
8M10	3250.64	3251.15	3250.80	3250.25	3249.68	3249.67	3251.23	3253.90	3254.17	3253.92
8M11	3387.16	3383.57	3383.82	3380.98	3387.42	3387.24	3385.12	3385.47	3383.67	3382.61
8M12	3242.96	3243.16	3243.62	3243.49	3242.98	3242.47	3242.99	3244.46	3245.73	3246.49
8M13	3204.30	3204.88	3205.21	3205.69	3205.72	3203.79	3205.56	3205.90	3205.66	3206.66
8M14	3245.06	3245.49	3246.03	3245.92	3245.32	3244.79	3245.01	3246.63	3247.88	3248.45
8M16	3315.54	3314.51	3312.99	3312.77	3314.75	3316.14	3316.31	3316.60	3318.92	3320.51
8M17	3322.96	3323.68	3322.93	3322.62	3322.11	3326.79	3326.20	3324.72	3324.68	3323.84
8M18	3328.36	3328.11	3326.59	3326.70	3327.62	3332.62	3332.13	3331.22	3333.13	3334.13
8M19	3202.76	3205.36	3206.00	3205.93	3206.10	3202.38	3204.71	3205.93	3206.21	3206.80
8M20	3240.42	3240.85	3240.41	3240.77	3240.35	3239.79	3239.97	3240.81	3241.89	3242.32
8M21	3253.26	3254.31		3254.82	3254.11	3253.78	3254.88	3256.25	3257.39	3257.48
8M23	3233.29	3233.47	3233.71	3233.61	3233.13	3232.79	3233.23	3234.18	3234.38	3236.13
8M24	3249.05	3250.29	3249.67	3249.79	3249.49	3249.44	3249.54	3251.10	3253.07	3253.91
8M25	3213.46	3214.22	3214.22	3214.31	3214.00	3213.96	3214.33	3214.87	3215.82	3216.64
8M27	3212.18	3212.28	3212.51	3212.52	3212.56	3212.60	3212.59	3212.81	3216.21	3216.21
8M28	3225.11	3226.12	3225.08	3226.11	3225.78	3225.66	3226.38	3227.05	3228.75	3229.59
8M29	3264.93	3266.08	3265.80	3265.40	3264.68	3265.23	3265.44	3266.75	3269.15	3270.21
8M30	3258.34	3265.00	3259.87		3258.72	3259.77		3260.68	3264.42	3264.41
8M31	3236.19	3236.20	3237.00	3236.45	3236.98	3235.63	3235.81	3236.61	3234.30	3238.56
8M32	3212.06	3212.42	3212.91	3213.07	3212.26	3211.18	3213.00	3213.41		3215.14
8M33	3296.61	3295.39	3293.31	3293.81	3296.67					
8M34	3257.77	3259.94	3259.81	3259.35	3258.54	3259.66	3260.35	3261.15	3264.88	3265.13
8M35	3322.95	3318.62	3317.02	3318.87	3322.40	3324.91	3325.22	3323.69	3326.97	3329.03
8M37	3403.74	3410.15	3413.68	3414.77	3404.54	3408.58	3408.69	3413.20	3415.90	3416.27
8M38	3325.05	3325.12	3324.04							
8M39	3313.38	3314.00	3314.02	3313.08	3313.68	3313.39	3313.56	3314.28	3314.50	3316.36
8M40	3320.68	3318.11	3316.34	3317.04	3319.69	3320.88	3320.49	3320.71	3323.32	3326.44
8M41	3298.93	3297.97	3296.75	3298.92	3298.92	3309.00	3306.00	3304.11		
8M42	3292.53	3292.25	3291.00	3290.73	3293.08	3294.98	3295.51	3295.38	3299.18	3302.20
8M43	3289.83	3289.88	3286.50		3288.98	3291.37	3292.09	3291.80	3295.63	3298.66
8M44	3188.48	3189.14	3189.24	3189.33	3192.16	3189.24	3189.33	3190.17	3190.39	3193.32
8M46	3240.66	3240.85	3241.09	3240.91	3240.85	3240.27	3240.49	3241.06	3242.49	
8M47			3440.74	3443.20	3413.20	3414.55		3435.38	3443.46	3445.08
8M48	3218.11	3220.79	3221.06	3221.15	3218.22	3226.00	3219.49	3221.27		

	Aug94	Oct94	Jan95	Mar95	May95	Aug95	Sept95	Nov95	Feb96	May96
8M49	3279.00	3270.65	3270.20	3269.69	3276.00	3270.64	3271.27	3271.62	3275.14	3274.95
8M50	3204.36	3205.19	3204.93	3205.07	3204.99	3203.28	3204.94	3205.41	3206.25	3206.45
8M51	3239.83	3240.26	3240.54		3239.82	3239.55	3240.36	3241.87	3243.26	3244.13
8M52	3215.00			3215.64	3216.30	3215.82	3215.95	3216.65	3217.85	3219.60
8M53			3233.31	3233.79	3230.69	3235.14	3233.89	3235.60	3237.25	3238.10
8M54			3266.28		3264.35	3270.10	3270.57	3270.11	3273.08	3276.29
8M55			3234.77		3235.12	3238.09	3238.41	3237.04	3238.50	3241.46
8M56			3201							
8M57					3316.63					
8M58					3275.95	3279.84	3280.46	3279.86	3284.05	3287.47
8M60					3273.96	3276.25	3277.02	3277.25	3279.34	3282.46
8M61						3369.29	3367.04	3366.41	3366.81	3365.35
8M62						3385.48	3385.02	3385.24	3384.84	3383.43
8M65						3338.84	3339.18	3339.05	3336.95	3340.60
8M67						3283.81	3284.21	3283.88	3287.43	3291.51
8M68						3291.87	3293.19	3293.48	3295.27	3299.38
8M69						3276.00	3277.05	3276.45	3278.73	3280.68
8M71						3191.00	3195.00	3190.82	3191.04	3193.73
8M72						3244.47	3244.68	3245.49	3246.82	3247.29
8M74						3238.84	3239.65	3240.46	3239.92	3242.01
8M75						3192.63	3192.72	3193.42	3193.88	3196.48
8M77						3286.29	3286.88	3287.63	3289.93	3293.22
8M78								3368.63	3361.30	3360.47

Appendix C: Table C.1. Physical and Chemical Groundwater Data

Site	Sample Date	Conductance	Temp (C)	Nitrate-N	Chloride
8M02	8/2/94	339	14.2	bd	5.078
8M03	8/2/94		12.5	bd	5.153
8M04	8/2/94	504	10.5	1.766	11.822
8M05	8/3/94	274	12.2	2.631	1.64
8M06	8/3/94	315	15.5	bd	7.104
8M07	8/3/94			bd	7.131
8M08	8/3/94	306	11.0	3.128	1.606
8M09	8/8/94	291	15.8	bd	4.809
8M10	8/4/94	359	12.7	3.501	3.913
8M11	8/4/94	340	11.4	2.747	3.67
8M12	8/8/94	386	11.9	3.198	5.684
8M13	8/8/94	243	14.8	0.526	2.054
8M14	8/9/94	404	12.0	1.474	4.711
8M16	8/8/94	237	11.3	0.94	1.296
8M17	8/9/94	419	11.5	1.285	4.028
8M18	8/9/94	338	10.5	2.88	1.518
8M19	8/15/94	271	16.3	bd	5.314
8M20	8/16/94	277	12.5	1.673	1.347
8M21	8/10/94	409	11.1	1.433	4.678
8M23	8/10/94	353	12.5	1.298	2.726
8M24	8/10/94	386	12.0	2.438	1.55
8M25	8/15/94	286	13.6	0.754	1.815
8M26	8/15/94	263	12.8	0.804	4.447
8M27	8/15/94	292	13.0	0.694	1.086
8M28	9/27/94	327	11.9	1.886	1.281
8M29	8/15/94	267	12.7	0.857	1.449
8M30	8/16/94	272	12.0	1.107	1.347
8M31	8/16/94	294	15.0	1.665	1.302
8M32	8/16/94	338	13.0	0.849	1.127
8M33	8/24/94	168	11.5	0.497	0.96
8M34	8/16/94	228	11.5	1.5	1.329
8M35	8/16/94	198	10.0	1.294	1.204
8M37	8/23/94	168	13.7	0.245	1.075
8M38	8/23/94	280	10.8	2.538	1.591
8M39	8/24/94	184	13.6	0.729	3.205
8M40	8/19/94	182	9.4	0.38	0.997
8M41	8/19/94	193	10.4	0.787	1.094
8M42	8/19/94	185	10.7	0.63	1.069
8M43	8/22/94	124	11.2	0.731	1.139
8M44	8/22/94	264	13.6	0.786	1.003
8M45	8/24/94	366	13.7	0.625	2.041
8M46	9/27/94	417	12.0	1.38	4.374
8M47	9/27/94	201	10.8	0.199	1.512
8M48	9/27/94	306	13.6	0.723	1.482
8M49	9/27/94	214	11.0	0.914	1.487
8M50	9/27/94	337	15.4	bd	4.846
8M51	9/27/94	351	14.0	1.934	1.595
8M52	9/28/94	216	13.4	0.523	0.858
8M53	9/27/94	276	11.2	1.344	1.204
8M54	6/8/95			0.487	1.218
8M55	6/8/95			1.613	0.712
8M58	6/8/95			0.592	1.18
8M59	6/8/95			0.596	1.199
8M61	8/28/95	297	11.1	1.859	3.164
8M62	8/28/95	443	16.0	3.04	5.648
8M63	8/28/95	257	10.1	2.602	1.597
8M64				1.973	1.45
8M65	8/28/95	274	11.0	2.479	1.612
8M67	8/28/95	175	11.0	0.389	1.064
8M68	8/28/95	199	11.5	0.823	1.201
8M69	8/28/95	334	11.8	1.964	2.031
8M70				1.947	2
8M71	8/28/95	354	12.4	0.752	2.258
8M72	8/28/95	421	12.6	1.21	4.536
8M74	8/28/95	195	13.3	0.155	1.671
8M75	8/28/95	283	13.8	0.762	1.165
8M76	8/28/95			2.497	1.549

Appendix D: Cross Sections

Nine cross sections were prepared from Eight Mile well logs' formation data. East-west trending cross sections are 1) Woodchuck Terrace Base, 2) Eight Mile Creek Road, and 3) Hidden Valley. North-south trending cross sections are 4) Lower Woodchuck, 5) Cottonwood, 6) Meadow View, 7) River View, 8) Mountain View, and 9) Orchard. Vertical exaggerations vary.

Discussion of east-west trending cross sections (from north to south)

The Woodchuck Terrace Base cross section, Figure D.1 on page 63, maps a perched flow zone at the Woodchuck Terrace base. Perching occurs as groundwater flows through a channel of transmissive sand and gravel situated significantly higher in elevation than other water-yielding zones of the aquifer. Perching is not obvious in this cross section, but is easily seen at the northern portions of north-south trending cross sections. The zone is hydraulically connected to other water-bearing strata at the northern edge of the basin and contributes groundwater to deeper lenses around Orchard and Cottonwood Drives. The cross section shows that the flow zone consists of sand, gravel, and clay lying below the *Qal*. Drillers' logs indicate that the zone's groundwater is semi-confined. Stratigraphy below the zone is unknown, but to the south is clay-dominated.

The Eight Mile Creek Road cross section, Figure D.2 on page 64, shows two relatively shallow, transmissive zones at lower elevations, stacking of water-bearing lenses throughout the valley, an increasing proportion of clay at higher elevations, and a wide range of static water levels at highest elevations. This range is an artifact of well distance from the transect; wells near the old Eight Mile Creek bed or the reservoir where its waters are impounded have shallower static water levels than wells with locations nearer to Eight Mile Creek Road.

Well drillers indicate that shallow groundwater in the Mountain View North vicinity is bypassed as unsuitable because it is either rusty or scant, or because the aquifer formation is too fine for successfully finishing wells (personal communications, Carlson and Eslinger, 1996 and 1997). Instead, drillers finish wells in EM-2, a 300-feet-deep continuous, confined water-bearing lens which is hydraulically separate from the valley's main water-yielding strata. Some wells drilled east of Orchard Drive and south of Eight Mile Creek Road miss EM-2 and are either finished in even deeper lenses, or abandoned. Drillers' logs indicate that this cross section's most eastern parts consist of massive tan to blue-green paludal clay beds at depth.

The Hidden Valley cross section, Figure D.3 on page 65, shows that at high elevations at the eastern part of the study area the subsurface is clay-dominated. With increasing land surface elevation, drilling depths increase and static water levels and water-yielding channels thin. Westwardly, continuous stacked water-yielding strata continue toward the Bitterroot River where depth to water, static water levels, and finished wells are at their shallowest.

Discussion of north-south cross sections (from west to east)

Of the north-south trending group of cross sections, the Lower Woodchuck, Figure D.4 on page 66, shows four shallow, stacked water-yielding lenses, indicating a large productive region, which also accounts for lack of deep data. In this cross section, the shallowest groundwater, static water levels, and well completion depths are found nearest the old Eight Mile Creek bed.

The Cottonwood cross section, Figure D.5 on page 67, also reveals an abundance of water-yielding sand and gravel lenses, interspersed with definable clay lenses, and shows shallow groundwater near the old Eight Mile Creek bed. Wells finished in this area are of shallow to moderate depth; however, two deep irrigation wells, CW5 and CW3, have been drilled and one domestic well, CW4, has been deepened in this area. Findings from these logs are interesting enough to warrant further discussion. Well CW5, constructed in 1952, is a 14-inch diameter irrigation well that was built for high production. Originally drilled to 390 feet, it was backfilled to 155 feet by the driller because the hole did not yield water below that level. CW5 is a 6-inch irrigation well drilled in 1989. Its driller found water to 220 feet in four distinct water-yielding zones. CW4, which lies between the other two wells on Cottonwood Drive, was deepened in 1994 from 107 to 225 feet, after the original well failed (personal communication with well owner, 1997). In combination, data from these three well logs indicate that although this part of the study area has an apparent abundance of transmissive groundwater lenses at shallow to moderate depths, at greater depths it may be unproductive. (See Appendix I for logs of CW3, CW4 and CW5).

The Meadow View cross section, Figure D.6 on page 68, shows three stacked water-bearing lenses. Groundwater is shallowest near the old Eight Mile Creek bed, dropping off to either side. Clay dominates to the north, pinching out the upper water-yielding lenses except the perched flow zone at the far north.

The southern part of the River View cross section, Figure D.7 on page 69, shows two stacked lenses. Pinch-out of the upper water-yielding strata continues to the north. A deep (250+ feet) water-yielding zone, part of the EM-2 aquifer, provides water to several wells in this area.

The northern part of the Mountain View cross section, Figure D.8 on page 70, shows that the study area's northern subsurface is clay-dominated. Aquifer EM-2 is over 300 feet deep in places. As with the other cross sections, the shallowest groundwater is near the old Eight Mile Creek bed. The perched zone is shown above the main valley aquifer in the far north.

The Orchard cross section, Figure D.9 on page 71, shows that the perched zone at the base of Woodchuck Terrace supplies some water to well 8M5. This cross section shows the deep aquifer EM-2 and several other small channels at even greater depth, and also shows that water-yielding strata are neither continuous nor well connected in the northeastern, upland part of the study area. To the south, the wells around and at the foot of the Paradise Acres subdivision (located in Figure 1.2) are all finished in the same water-yielding stratum.

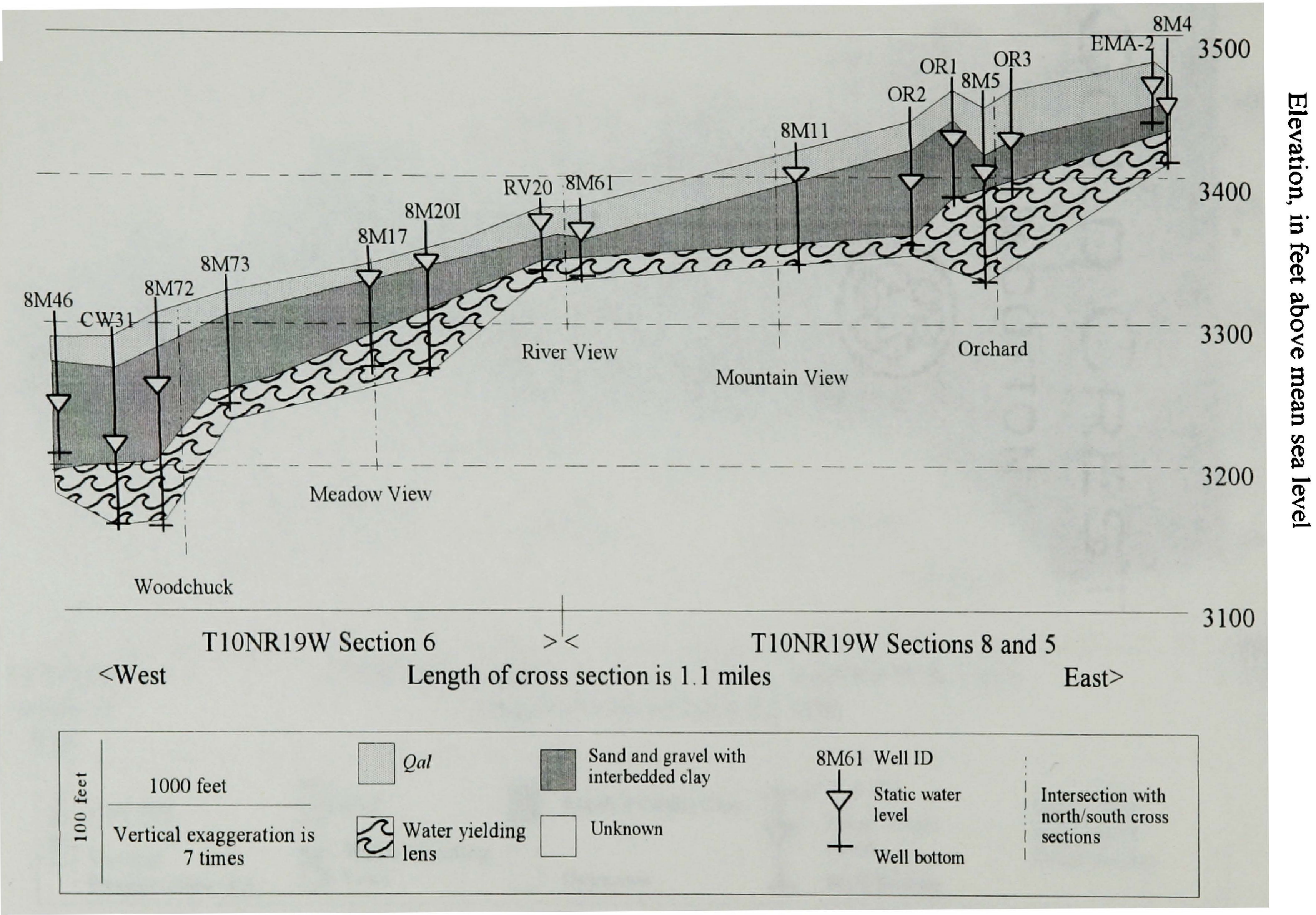


Figure D.1. Woodchuck Terrace Base Cross Section

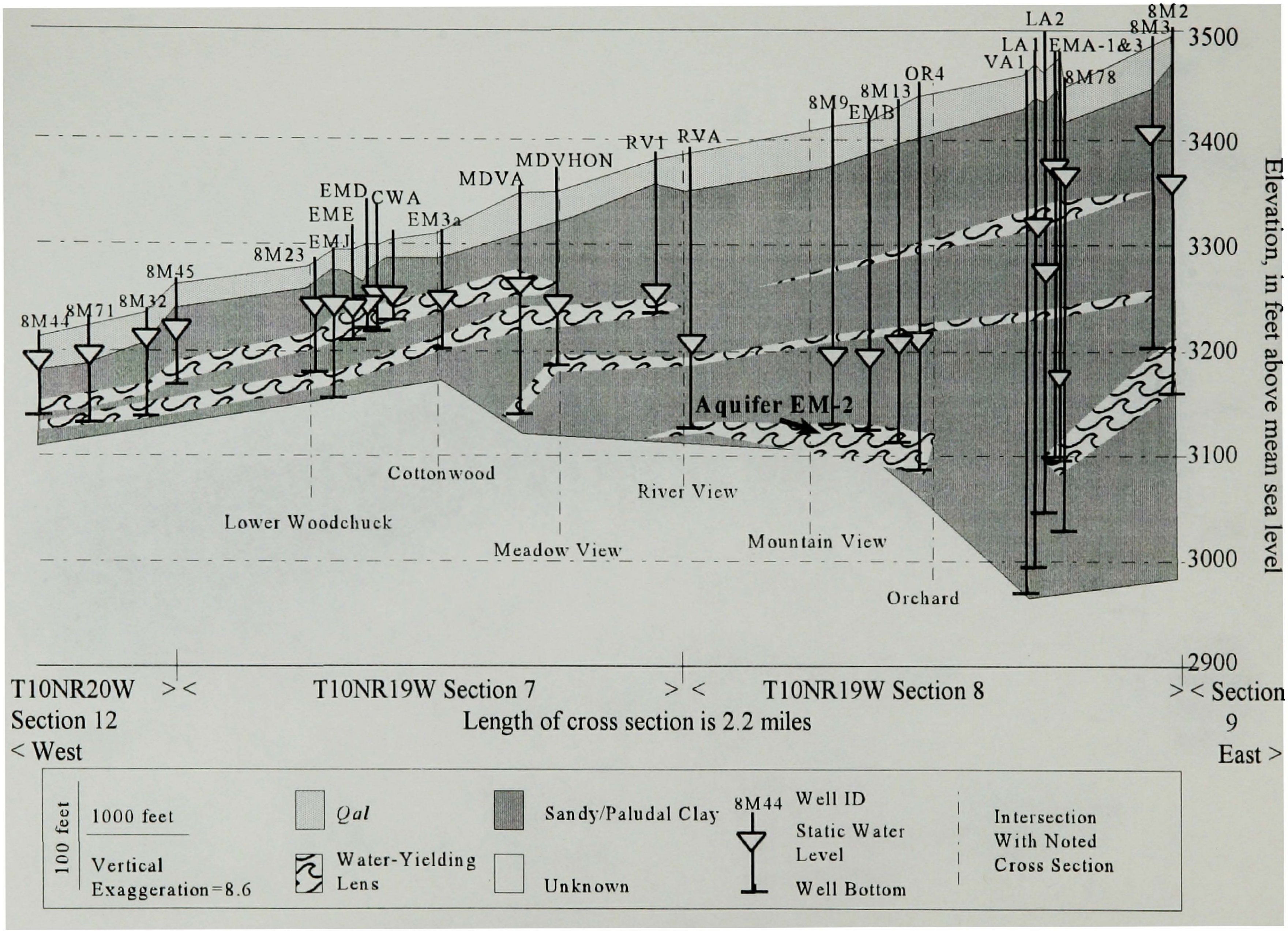


Figure D.2. Eight Mile Creek Road Cross Section

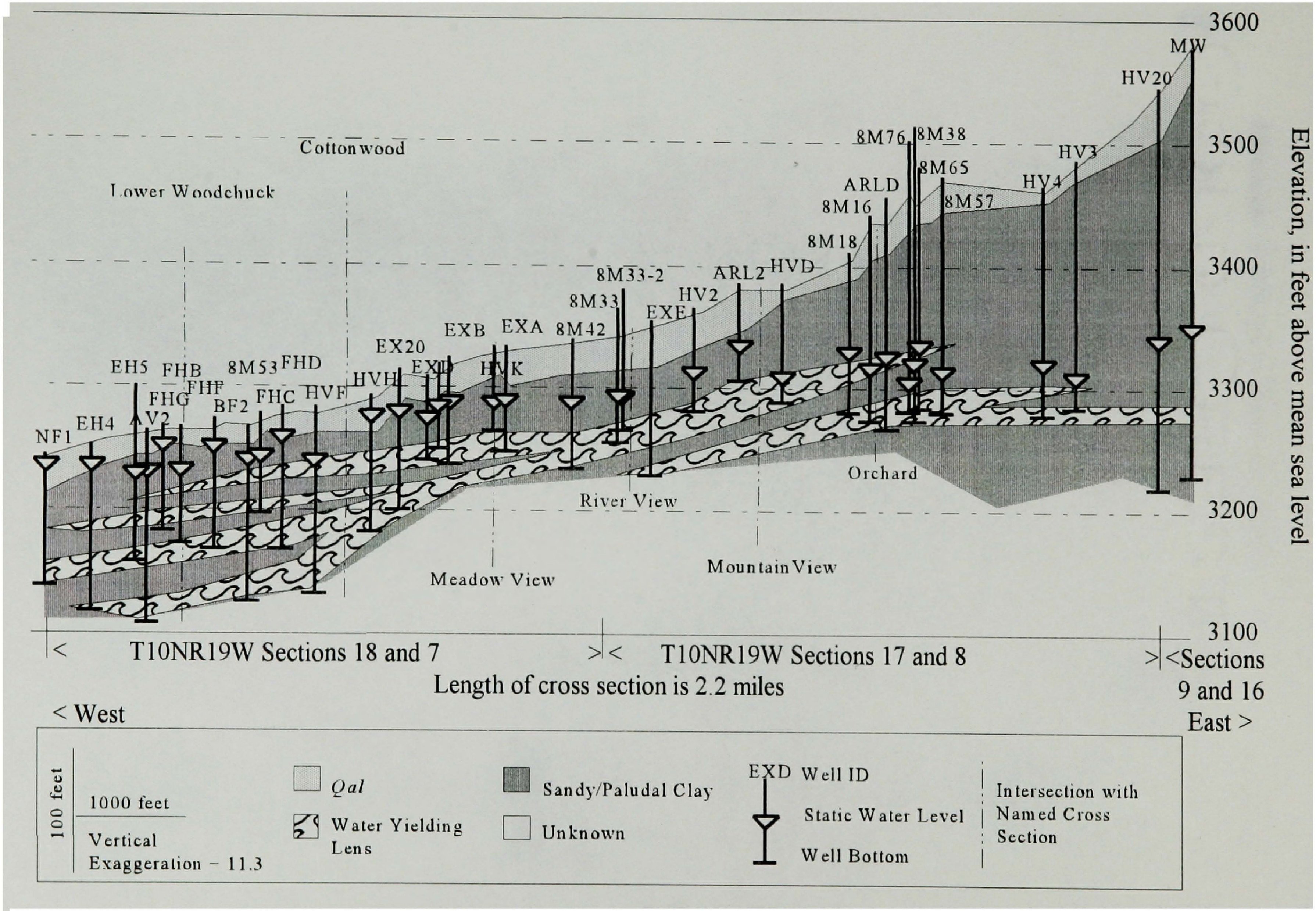


Figure D.3. Hidden Valley Cross Section

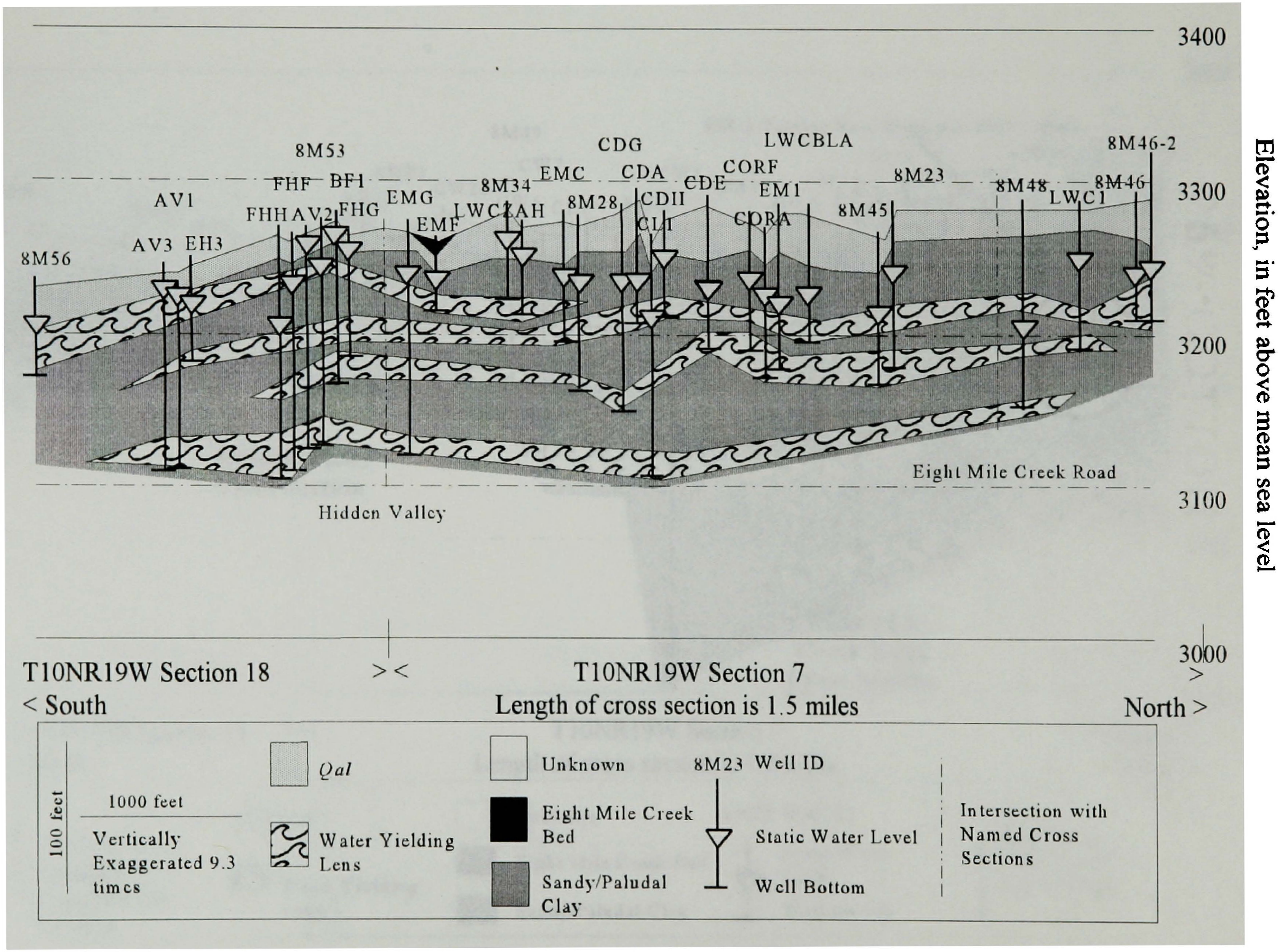


Figure D.4. Lower Woodchuck Cross Section

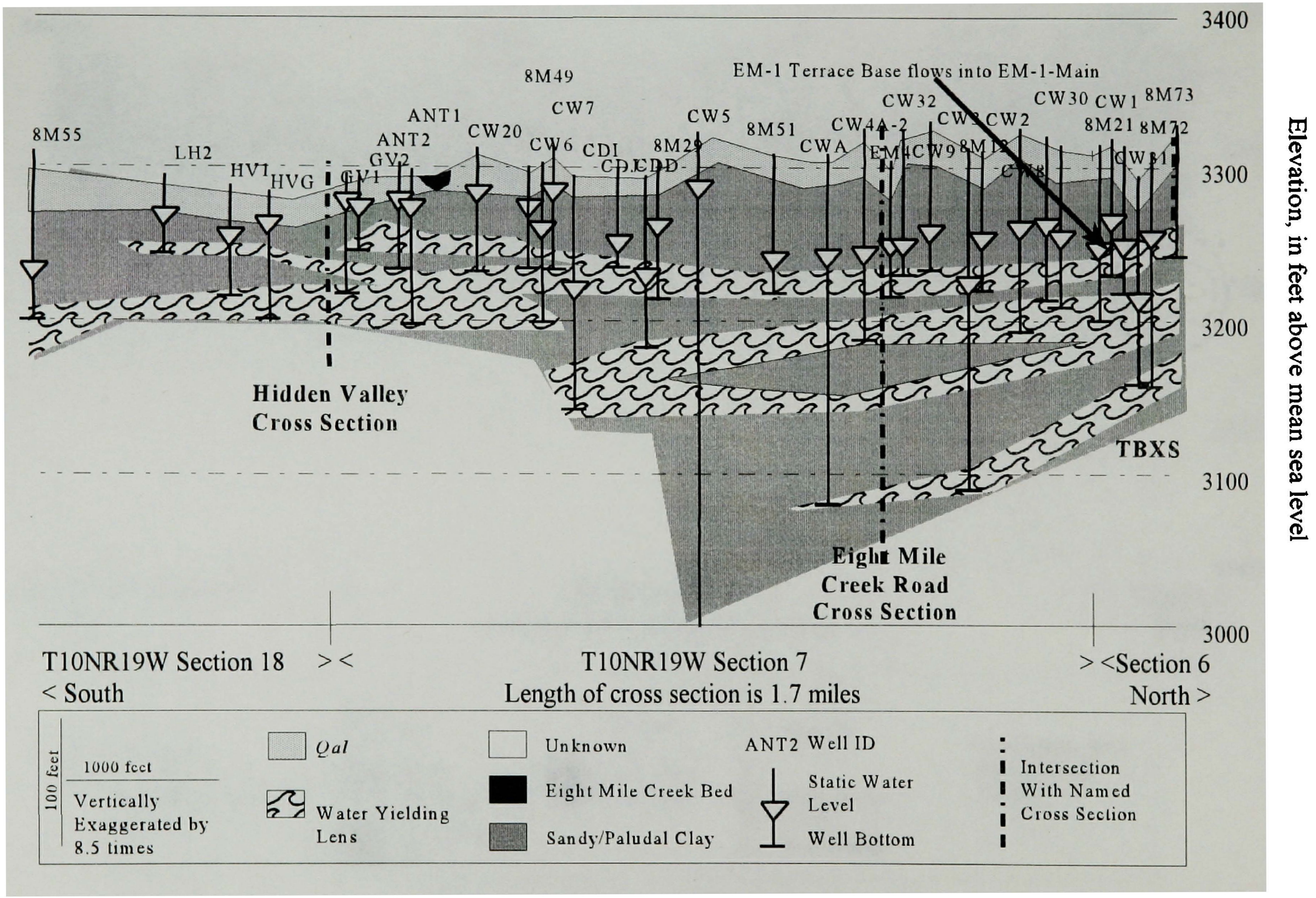


Figure D.5. Cottonwood Cross Section

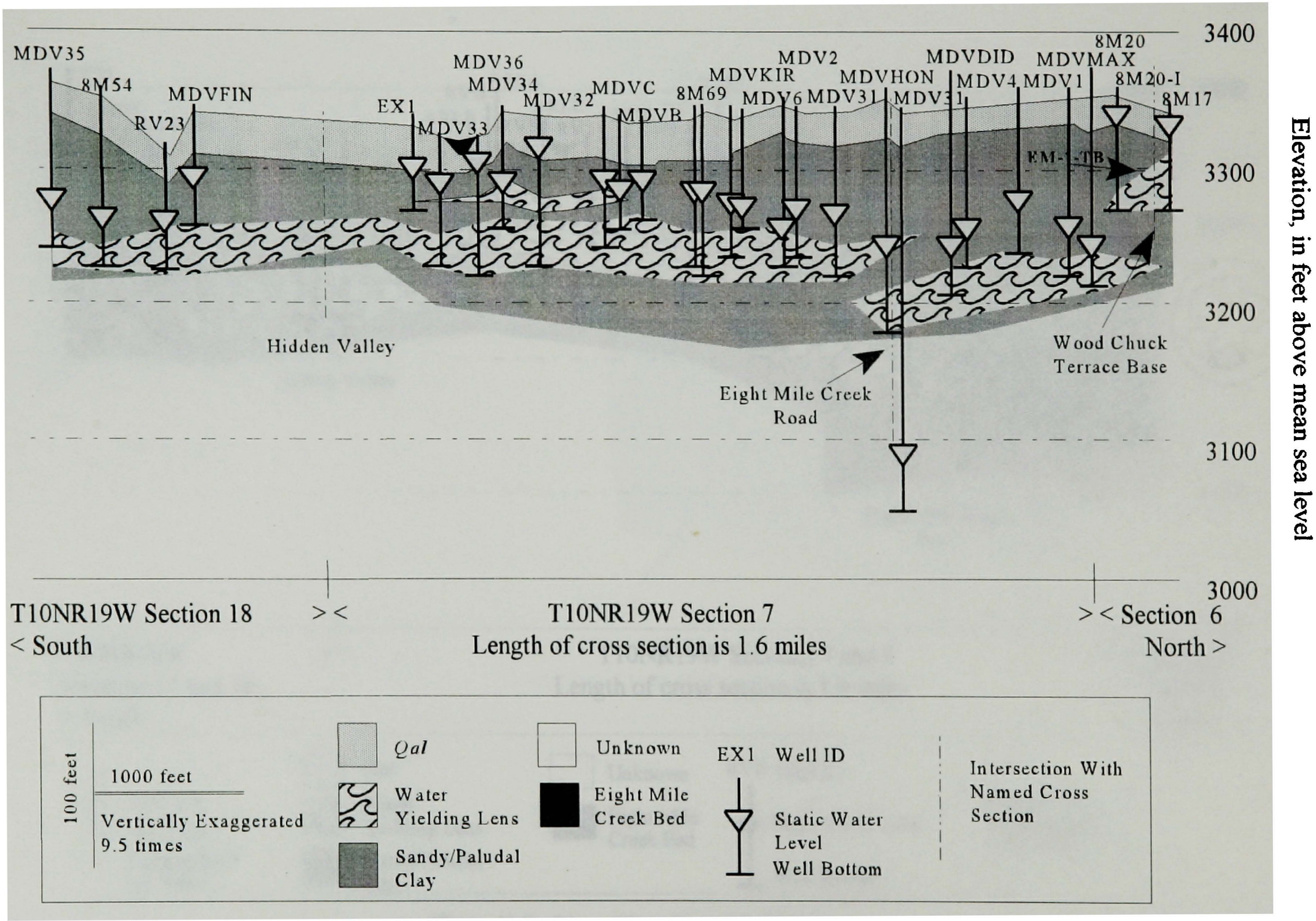


Figure D.6. Meadow View Cross Section

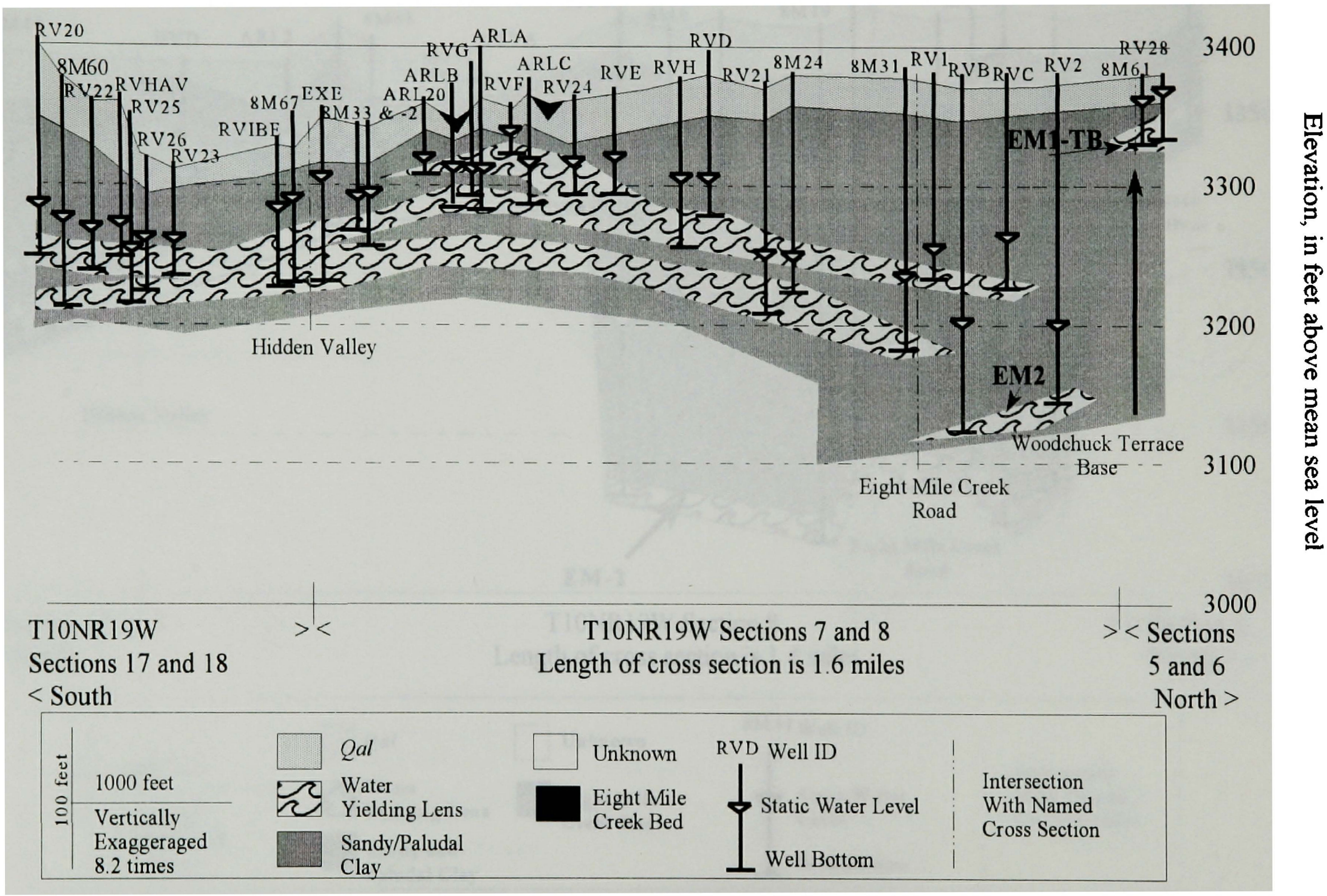


Figure D.7. River View Cross Section

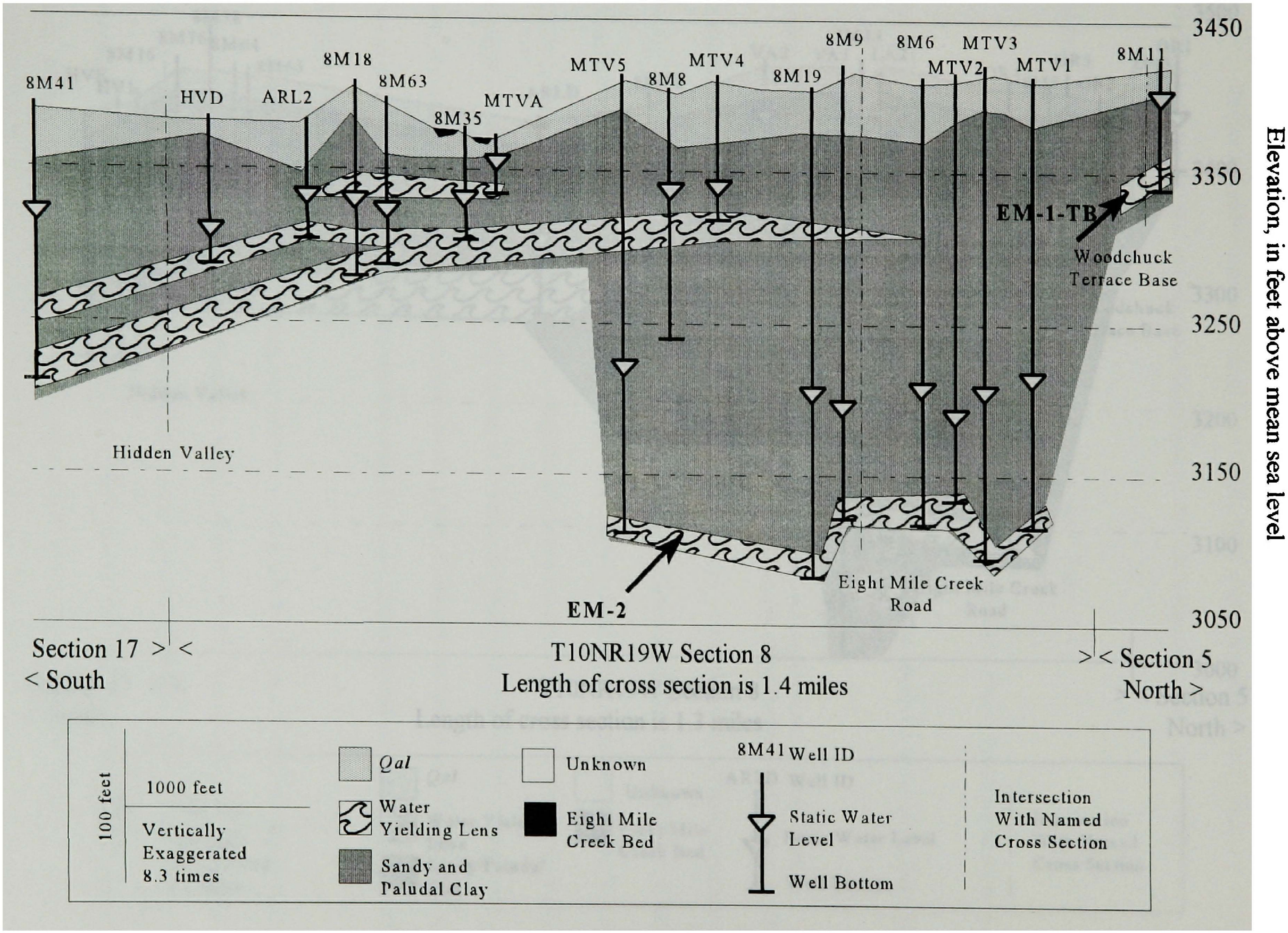


Figure D.8. Mountain View Cross Section

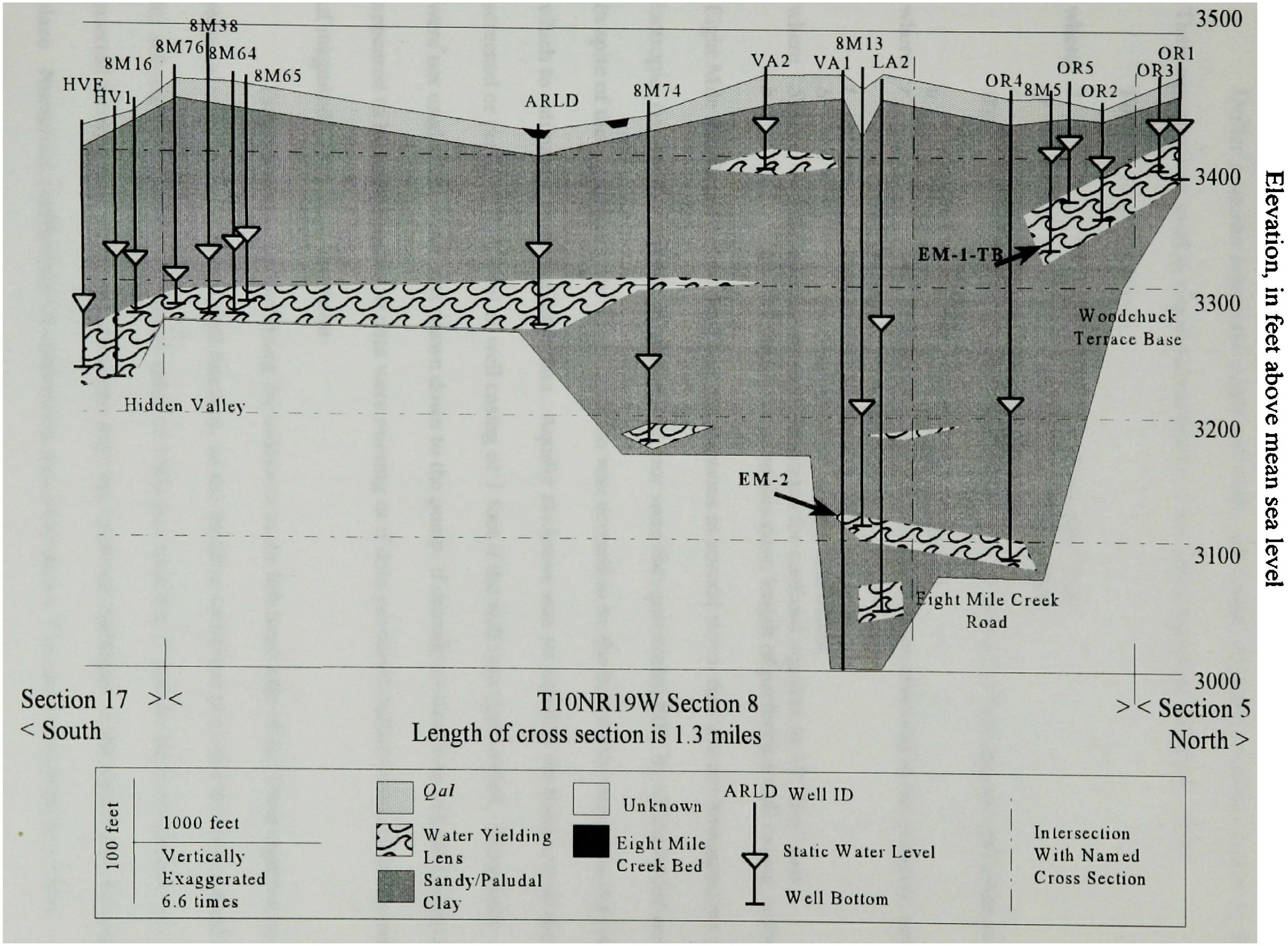


Figure D.9. Orchard Cross Section

Appendix E: Transmissivity Estimation

Driller's aquifer tests were single-well tests, with single drawdown measurements, so the Theis equation was used in sequential iterations of the Theis Equation (Driscoll, 1986).

For $T = 114.6\,Q\,W(u)/s$,

where T = Transmissivity, in gallons day^{-1} foot^{-1}
Q = well test discharge in gallons minute^{-1}
s = test draw down in feet, and
$W(u)$ = $-0.5772-ln(u)+u-u^2/(2*2!) + u^3/(3*3!) - u^4/(4*4!)$, the dimensionless well function in which
u = $1.87\,(r^2S)\,/\,T\,t$, dimensionless and
where r = well radius (since draw down values were observed in the pumping wells), in feet,
t = time of the test, in days, and
S = $S_s b$, the dimensionless storage coefficient,
where S_s = specific storage, estimated for confined aquifers as 10^{-6} feet^{-1} and
b = aquifer thickness, or in this case, length of perforated well casing, in feet.

Eight Mile aquifer(s) violate the Theis assumptions in several ways: they are not homogeneous nor isotropic, nor are they infinite in areal extent, nor were they penetrated fully by all the tested wells. In spite of these problems, the Theis equation was deemed to be the best mathematical model with which to estimate T from available data. Aquifer thickness was set equal to the thickness of the screened or perforated interval of well casing or 1 foot if the well was open-ended. Pump tests were not used when water was drawn down to the pump, if drawdown time was instantaneous or appeared to be unreasonable, if data were missing or if data produced outliers more than one order of magnitude away from the mean.

Transmissivity, besides being the unknown in the left hand side of the Theis equation is a required variable in the nested well function, so the iterative technique provided the easiest method for solving the equation. An initial value of 1000 was used for T, and the derived solution was inserted through four successive iterations until the solutions stabilized to the hundredths decimal place. Numerical coefficients are conversion factors to derive T in units of gallons day^{-1} foot^{-1}, which were divided by feet^3 7.48 gallons^{-1} to convert to units of feet^2 day^{-1}. The following table provides calculated values for *T* by flow zone.

Well	Flow Zone	Location			(T)	outlier
MTVA	EM-1-HV	10N19W	08	CBDC	1170.19	
LH2	EM-1-HV	10N19W	18	ACBA	299.95	
HVA	EM-1-HV	10N19W	18	ABBC	147.54	
EXD	EM-1-HV	10N19W	18	ABAC	633.37	
HVK	EM-1-HV	10N19W	18	AABC	341.09	
HVJ	EM-1-HV	10N19W	18	ABCC	735.81	
8M35	EM-1-HV	10N19W	08	CBDD	529.23	
MDVFin	EM-1-HV	10N19W	18	AACA	224.65	
ARL2	EM-1-HV	10N19W	08	CCDD	423.55	
RV23	EM-1-HV	10N19W	18	ADAB	425.12	
8M33	EM-1-HV	10N19W	18	AAAA	445.90	
ARLC	EM-1-HV	10N19W	08	CCAC	549.66	
ARL A	EM-1-HV	10N19W	08	CCBD	731.66	
HVI	EM-1-HV	10N19W	18	ABBA	396.93	
8M33-2	EM-1-HV	10N19W	18	AAAA	604.81	
HVD	EM-1-HV	10N19W	17	BABB	824.48	
8M67	EM-1-HV	10N19W	18	AADB	996.57	
RV26	EM-1-HV	10N19W	18	ADAC	382.19	
8M42	EM-1-HV	10N19W	18	AAAB	202.66	
IBEY	EM-1-HV	10N19W	18	AADC	229.10	
RV25	EM-1-HV	10N19W	18	ADAC	300.52	
HVH	EM-1-HV	10N19W	18	ABBD	109.93	
8M63	EM-1-HV	10N19W	08	CDBD	969.63	
MDV35	EM-1-HV	10N19W	18	ACDC	236.00	
EXE	EM-1-HV	10N19W	17	BBBC	584.36	
EXF	EM-1-HV	10N19W	18	AABB		92
RV22	EM-1-HV	10N19W	18	ADDB	206.12	
8M18	EM-1-HV	10N19W	08	CDAC	211.72	
RV20	EM-1-HV	10N19W	18	ADDD	469.78	
8M60	EM-1-HV	10N19W	17	BCCC	536.26	
8M65	EM-1-HV	10N19W	08	DCCA	365.74	
8M41	EM-1-HV	10N19W	17	BCAB	160.69	
HV4	EM-1-HV	10N19W	17	AAB	244.82	
8M64	EM-1-HV	10N19W	08	DCCA	376.09	
8M57	EM-1-HV	10N19W	08	DCCD	366.85	
8M38	EM-1-HV	10N19W	08	DCCC	423.55	
HV3	EM-1-HV	10N19W	17	AAA		1297
HV20	EM-1-HV	10N19W	16	BBB	200.80	
MW	EM-1-HV	10N19W	16	BBAB	127.21	
				avg	437.42	
				std dev	257.67	
				max	1170.19	
				median	382.19	
				min	109.93	
				count	37	2

Well	Flow Zone	Location			(T)	outlier
8M27	EM-1-Riv	10N20W	12	DAAD	816.99	
8M56	EM-1-Riv	10N19W	18	BCBD	488.61	
EH3	EM-1-Riv	10N19W	18	BBDB	541.51	
SL1	EM-1-Riv	10N20W	12	ADBC	137.41	
CORC	EM-1-Riv	10N20W	12	DDAD	272.04	
8M71	EM-1-Riv	10N20W	12	ADCA	382.00	
8M32	EM-1-Riv	10N20W	12	ADDB	1110.75	
AV1	EM-1-Riv	10N19W	18	BBCB	135.69	
AV3	EM-1-Riv	10N19W	18	BBDC	498.29	
				avg	487.03	
				stds	317.00	
				max	1110.75	
				med	488.61	
				min	135.69	
				count	9	0

EMA-2	EM-1-TB	10N19W	08	ABDD	218.09	
RV28	EM-1-TB	10N19W	06	DDDD	153.79	
8M61	EM-1-TB	10N19W	05	CCCC	262.89	
8M04	EM-1-TB	10N19W	05	DDCC		63
OR3	EM-1-TB	10N19W	08	ABBB		21118
8M17	EM-1-TB	10N19W	06	DCDA	959.22	
OR1	EM-1-TB	10N19W	05	CDDD		7073
OR5	EM-1-TB	10N19W	08	BAAD	286.87	
8M11	EM-1-TB	10N19W	05	CDCC	370.17	
8M20-I	EM-1-TB	10N19W	06	DDCC	262.78	
OR2	EM-1-TB	10N19W	08	BAAB		6557
8M05	EM-1-TB	10N19W	08	ABBC	312.45	
				avg	353.28	
				std dev	252.97	
				max	959.22	
				med	274.88	
				min	153.79	
				count	8	4

8M37	EM-1-Up	10N19W	08	DAAC	5.76	
8M03	EM-1-Up	10N19W	08	ADDC	9.57	
8M02	EM-1-Up	10N19W	08	ADAD	38.46	
8M78	EM-1-Up	10N19W	08	ACAD	25.57	
				avg	19.84	
				std dev	15.09	
				max	38.46	
				median	17.57	
				min	5.76	
				count	4	0

Well	Flow Zone	Location			(T)	outlier
CDB	EM-1-M	10N19W	07	CACA	276.34	
CDK	EM-1-M	10N19W	07	CACA	809.26	
GV2	EM-1-M	10N19W	07	DCCC	193.99	
EMF	EM-1-M	10N19W	07	CDBC	319.62	
ARLB	EM-1-M	10N19W	07	DDDB	345.11	
Zah	EM-1-M	10N19W	07	CDBB	416.41	
8M34	EM-1-M	10N19W	07	CDBA	247.05	
8M49	EM-1-M	10N19W	07	CDAA	344.36	
CDH	EM-1-M	10N19W	07	CABC	142.37	
RV24	EM-1-M	10N19W	07	DDAA	498.29	
MDVB	EM-1-M	10N19W	07	DBAD	229.68	
8M68	EM-1-M	10N19W	07	DBDA	101.71	
CORB	EM-1-M	10N19W	07	CBDA	789.11	
CW7	EM-1-M	10N19W	07	DBCC	449.80	
RV27	EM-1-M	10N19W	07	DAAD	155.86	
FHC	EM-1-M	10N19W	18	BABA	563.22	
8M43	EM-1-M	10N19W	07	DDDB	401.86	
CW20	EM-1-M	10N19W	07	DCBB	275.99	
HVG	EM-1-M	10N19W	18	BADA	266.14	
8M46-2	EM-1-M	10N19W	06	CDCB	163.04	
EMD	EM-1-M	10N19W	07	BDAB	151.55	
FHG	EM-1-M	10N19W	18	BABB	367.90	
BFA	EM-1-M	10N19W	07	CDCC		1184
8M46	EM-1-M	10N19W	06	CDCB	336.81	
FHE	EM-1-M	10N19W	07	CDDC	484.81	
CWA	EM-1-M	10N19W	07	BDAA	306.89	
EM4	EM-1-M	10N19W	07	BDAB	169.47	
CDA	EM-1-M	10N19W	07	CABD	155.86	
MDV34	EM-1-M	10N19W	07	DDBD	90.41	
8M21	EM-1-M	10N19W	06	DCCC	373.61	
MDV33	EM-1-M	10N19W	07	DDCB	70.45	
8M12	EM-1-M	10N19W	07	BAAD	285.44	
CORF	EM-1-M	10N19W	07	BCDD	456.17	
MDV6	EM-1-M	10N19W	07	ADCC	348.87	
8M51	EM-1-M	10N19W	07	BDDA	181.94	
CW32	EM-1-M	10N19W	07	ABCC	229.68	
MTV4	EM-1-M	10N19W	08	BCDD	338.94	
FHB	EM-1-M	10N19W	18	BBAA	250.39	
CW9	EM-1-M	10N19W	07	ABCC	341.35	
CW1	EM-1-M	10N19W	06	CDDD	198.46	
LWC1	EM-1-M	10N19W	07	BABB	763.79	
CDF	EM-1-M	10N19W	07	CAAC	180.12	
CDE	EM-1-M	10N19W	07	CABA	301.31	
CORA	EM-1-M	10N19W	07	BCCA	226.71	
MDVMax1	EM-1-M	10N19W	07	ABAA	649.35	
MDVKir	EM-1-M	10N19W	07	ACDD	274.83	
MDV2	EM-1-M	10N19W	07	ACDA	593.28	
MDV31	EM-1-M	10N19W	07	ACAD	541.51	
8M45	EM-1-M	10N19W	07	BCBB	625.87	
ANT1	EM-1-M	10N19W	07	DCCB	572.12	
MDVC	EM-1-M	10N19W	07	DACC	105.82	
BF2	EM-1-M	10N19W	07	CDDC	322.61	
CW6	EM-1-M	10N19W	07	CADD	996.57	
EH5	EM-1-M	10N19W	07	CCDB		47
MDV36	EM-1-M	10N19W	07	DCDA	772.78	
EM1	EM-1-M	10N19W	07	BDCB	84.69	
MDV5	EM-1-M	10N19W	07	DBAA	101.12	
EX20	EM-1-M	10N19W	07	DCDC	81.36	
BF1	EM-1-M	10N19W	07	CDCD	82.04	
MDV32	EM-1-M	10N19W	07	DCAA	533.79	
8M14	EM-1-M	10N19W	06	CDDD	74.99	
FHD	EM-1-M	10N19W	18	BABA	588.65	
MDV3	EM-1-M	10N19W	07	ADCB	211.66	
8M69	EM-1-M	10N19W	07	DABB	319.74	
CW2	EM-1-M	10N19W	07	ABBC	248.44	
CW31	EM-1-M	10N19W	06	CDCA	403.31	
8M48	EM-1-M	10N19W	07	BABC	460.61	
EH4	EM-1-M	10N19W	07	CCCD	652.44	
CW4B	EM-1-M	10N19W	07	ACBC	175.49	
BLA	EM-1-M	10N19W	07	BDCA	67.62	
FHF	EM-1-M	10N19W	18	BBAA	765.43	
HVF	EM-1-M	10N19W	18	BAAC	214.35	
CDI	EM-1-M	10N19W	07	CADC		58
8M72	EM-1-M	10N19W	06	CDDA	230.45	
EMG	EM-1-M	10N19W	07	CDCB		1301
CW5	EM-1-M	10N19W	07	DBBB	1081.39	
CL1	EM-1-M	10N19W	07	CBAC	1003.04	
FHH	EM-1-M	10N19W	18	BABA	407.53	
8M08	EM-1-M	10N19W	08	CBAA	143.71	
RV21	EM-1-M	10N19W	07	ADDD	279.49	
MDVHon	EM-1-M	10N19W	07	ADBB	190.81	
FHI	EM-1-M	10N19W	18	BAAB	64.20	
CW3	EM-1-M	10N19W	07	BADA	184.11	
				avg	350.70	
				stdev	235.74	
				max	1081.39	
				median	285.44	
				min	64.20	
				count	79	4

Well	Flow Zone	Location			(T)	outlier
MDV4	EM-1-dp	10N19W	07	ABDA	220.70	
MDVMax2	EM-1-dp	10N19W	07	ABAA	560.48	
8M20	EM-1-dp	10N19W	06	DDCC		1851
MDVDid	EM-1-dp	10N19W	07	AACB	224.65	
RV1	EM-1-dp	10N19W	07	ADAA		1608
MDV1	EM-1-dp	10N19W	07	ABAD	247.01	
RVC	EM-1-dp	10N19W	07	AADA	566.22	
OR4-1	EM-1-dp	10N19W	08	BADA		7
RVB	EM-1-dp	10N19W	07	AADD	208.84	
8M31	EM-1-dp	10N19W	08	BCBB	143.53	
MDVA	EM-1-dp	10N19W	07	AACC	42.91	
				avg	276.79	
				stdev	188.25	
				max	566.22	
				med	222.68	
				min	42.91	
				count	8	3

Well	Flow Zone	Location			(T)	outlier
RV2	EM-2	10N19W	08	BBBC	71.19	
RVA	EM-2	10N19W	08	BBCC	147.16	
MDV20	EM-2	10N19W	07	ABDD	122.83	
MTV2	EM-2	10N19W	08	BBDA	176.94	
8M06	EM-2	10N19W	08	BBDD	67.06	
MTV1	EM-2	10N19W	08	BBAA	60.23	
8M13	EM-2	10N19W	08	BDAB	163.94	
8M19	EM-2	10N19W	08	BCAD	279.49	
OR4-2	EM-2	10N19W	08	BADA	32.78	
EMA-3	EM-2	10N19W	08	ABDD	4.73	
EMA-1	EM-2	10N19W	08	ABDD	6.05	
				avg	102.95	
				stdev	84.14	
				max	279.49	
				med	71.19	
				min	4.73	
				count	11	0

Table T.1. Results of Transmissivity Estimations by Flow Zone

Rounded average values of *T* were used for calculating groundwater flux through the study area. Also, the table calculating values for all EM-1 wells is not presented, to avoid redundancy.

Appendix F: Flow Zone Parameter Statistics

Table F.1 Flow Zone Parameter Statistics (Static water levels indicated as SWL).

Well #	Flow Zone	Depth	SWL	Well #	Flow Zone	Depth	SWL	Well #	Flow Zone	Depth	SWL
MTVA	EM-1-HV	34	13	EMA-2	EM-1-TB	36	18	RV2	EM-2	234	180
LH2	EM-1-HV	45	22	RV28	EM-1-TB	44	12	RVA	EM-2	259	180
HVA	EM-1-HV	49	7	8M61	EM-1-TB	48	18	MDV20	EM-2	289	250
EXD	EM-1-HV	62	30	8M04	EM-1-TB	60	20	MTV2	EM-2	276	220
HVK	EM-1-HV	64	41	OR3	EM-1-TB	68	34	8M06	EM-2	290	200
HVJ	EM-1-HV	68	30	8M17	EM-1-TB	71	12	MTV1	EM-2	294	195
8M35	EM-1-HV	69	43	OR1	EM-1-TB	74	33	8M13	EM-2	319	228
MDVFin	EM-1-HV	73	46	OR5	EM-1-TB	78	32	8M19	EM-2	320	200
ARL2	EM-1-HV	74	46	8M11	EM-1-TB	80	18	OR4-2	EM-2	357	237
RV23	EM-1-HV	74	48	8M20-I	EM-1-TB	85	12	EMA-3	EM-2	380	110
8M33	EM-1-HV	75	50	OR2	EM-1-TB	86	43	EMA-1	EM-2	385	117
ARLC	EM-1-HV	75	50	8M05	EM-1-TB	120	45		Average	309	192
ARL A	EM-1-HV	79	50		Average	71	25		Std Dev	49	45
HVI	EM-1-HV	80	20		Std Dev	23	12		Max	385	250
8M33-2	EM-1-HV	85	48		Max	120	45		Median	294	200
HVD	EM-1-HV	90	70		Median	73	19		Min	234	110
8M67	EM-1-HV	95	36		Min	36	12		Count	11	11
RV26	EM-1-HV	98	61		Count	12	12				
8M42	EM-1-HV	99	45								
IBEY	EM-1-HV	100	44	8M27	EM-1-Riv	57	30				
RV25	EM-1-HV	102	65	8M56	EM-1-Riv	59	27				
HVH	EM-1-HV	106	13	EH3	EM-1-Riv	63	26				
8M63	EM-1-HV	107	72	SL1	EM-1-Riv	75	50				
MDV35	EM-1-HV	120	87	CORC	EM-1-Riv	91	23				
EXE	EM-1-HV	120	44	8M71	EM-1-Riv	95	32				
EXF	EM-1-HV	122	26	8M32	EM-1-Riv	100	27				
RV22	EM-1-HV	122	90	AV1	EM-1-Riv	118	6				
8M18	EM-1-HV	124	76	AV3	EM-1-Riv	124	12				
RV20	EM-1-HV	152	115		Average	87	26	MDV4	EM-1-Dp	121	90
8M60	EM-1-HV	160	94		Std Dev	25	12	MDVMax2	EM-1-Dp	127	95
8M65	EM-1-HV	170	120		Max	124	50	8M20	EM-1-Dp	135	110
8M41	EM-1-HV	178	68		Median	91	27	MDVDid	EM-1-Dp	135	101
HV4	EM-1-HV	180	140		Min	57	6	RV1	EM-1-Dp	145	126
8M64	EM-1-HV	180	125		Count	9	9	MDV1	EM-1-Dp	150	77
8M57	EM-1-HV	186	153					RVC	EM-1-Dp	150	115
8M38	EM-1-HV	187	140	8M37	EM-Up	210	45	OR4-1	EM-1-Dp	160	95
HV3	EM-1-HV	195	170	8M03	EM-Up	287	87	RVB	EM-1-Dp	164	130
HV20	EM-1-HV	320	200	8M02	EM-Up	340	145	8M31	EM-1-Dp	200	148
MW	EM-1-HV	350	230	8M78	EM-Up	421	280	MDVA	EM-1-Dp	210	90
	Average	120	73		Average	315	139		Average	154	107
	Std Dev	67	53		Std Dev	89	102		Std Dev	28	21
	Max	350	230		Max	421	280		Max	210	148
	Median	100	50		Median	314	116		Median	150	101
	Min	34	7		Min	210	45		Min	121	77
	Count	39	39		Count	4	4		Count	11	11

Well #	Flow Zone	Depth	SWL	Well #	Flow Zone	Depth	SWL	Well #	Flow Zone	Depth	SWL
CDB	EM-1-M	36	22	MDV33	EM-1-M	84	30	8M14	EM-1-M	109	64
CDK	EM-1-M	39	23	8M12	EM-1-M	85	53	FHD	EM-1-M	110	20
GV2	EM-1-M	44	16	CORF	EM-1-M	86	40	MDV3	EM-1-M	119	92
EMF	EM-1-M	45	25	MDV6	EM-1-M	88	65	8M69	EM-1-M	120	60
ARL B	EM-1-M	57	33	8M51	EM-1-M	88	66	CW2	EM-1-M	126	60
Zah	EM-1-M	58	20	CW32	EM-1-M	89	70	CW31	EM-1-M	130	76
8M34	EM-1-M	59	20	MTV4	EM-1-M	90	70	8M48	EM-1-M	130	80
8M49	EM-1-M	60	21	FHB	EM-1-M	90	32	EH4	EM-1-M	130	14
CDH	EM-1-M	64	26	CW9	EM-1-M	91	67	CW4B	EM-1-M	131	75
RV24	EM-1-M	67	45	CW1	EM-1-M	91	61	BLA	EM-1-M	134	65
MDVB	EM-1-M	68	43	LWC1	EM-1-M	92	35	FHF	EM-1-M	140	8
8M68	EM-1-M	72	38	CDF	EM-1-M	93	62	HVF	EM-1-M	145	40
CORB	EM-1-M	72	36	CDE	EM-1-M	94	56	CDI	EM-1-M	147	69
CW7	EM-1-M	75	25	CORA	EM-1-M	94	40	8M72	EM-1-M	148	51
RV27	EM-1-M	76	50	MDVMax1	EM-1-M	99	81	EMG	EM-1-M	150	32
FHC	EM-1-M	76	30	MDVKir	EM-1-M	100	50	CW5	EM-1-M	150	33
8M43	EM-1-M	76	40	MDV2	EM-1-M	104	72	CL1	EM-1-M	153	50
CW20	EM-1-M	77	27	MDV31	EM-1-M	117	72	FHH	EM-1-M	160	60
HVG	EM-1-M	78	16	8M45	EM-1-M	95	50	8M08	EM-1-M	160	63
8M46-2	EM-1-M	79	50	ANT1	EM-1-M	96	20	RV21	EM-1-M	162	120
EMD	EM-1-M	80	60	MDVC	EM-1-M	99	45	MDVHON	EM-1-M	168	108
FHG	EM-1-M	80	12	BF2	EM-1-M	100	18	FHI	EM-1-M	200	40
BFA	EM-1-M	80	6	CW6	EM-1-M	100	40	CW3	EM-1-M	220	86
8M46	EM-1-M	80	46	EH5	EM-1-M	100	30		Average	69	57
FHE	EM-1-M	80	25	MDV36	EM-1-M	101	20		Std Dev	81	64
CWA	EM-1-M	80	56	EM1	EM-1-M	102	60		Max	421	280
EM4	EM-1-M	83	50	MDV5	EM-1-M	105	61		Median	94	80
CDA	EM-1-M	83	56	EX20	EM-1-M	107	30		Min	0	0
MDV34	EM-1-M	83	47	BF1	EM-1-M	108	11		Count	83	83
8M21	EM-1-M	84	50	MDV32	EM-1-M	108	20				

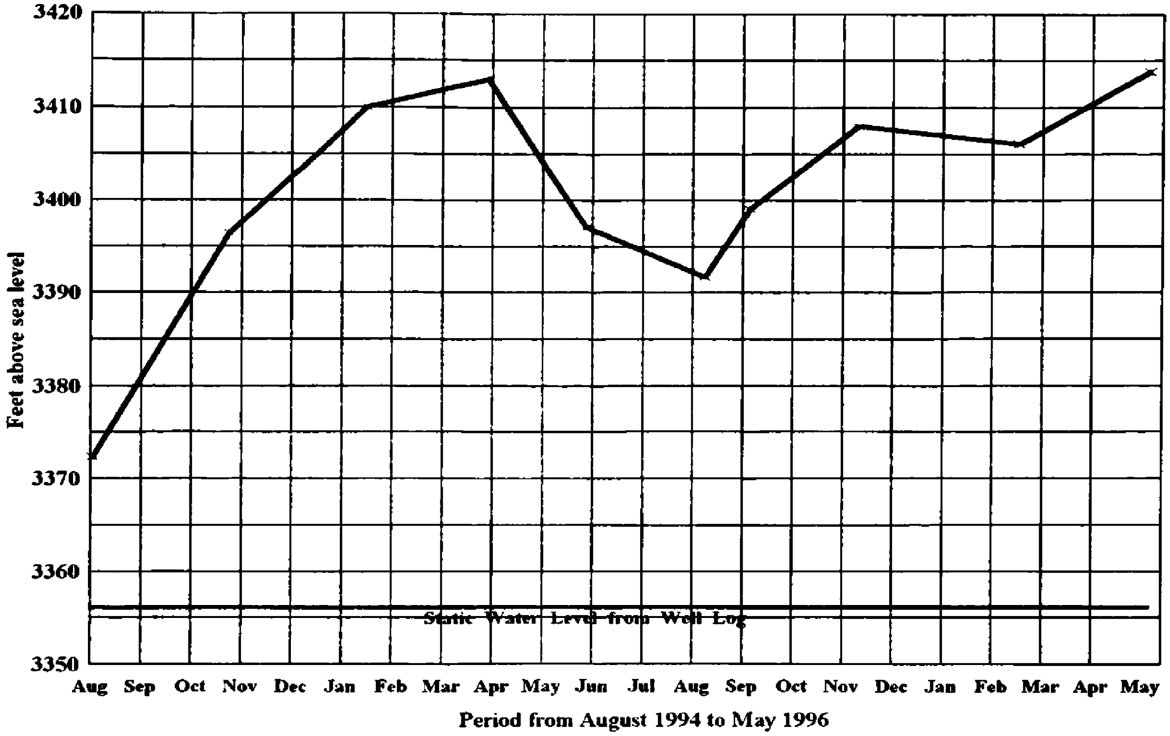
The values above were sorted by location (which can be cross referenced for most of these wells in Appendix A). The compiled summary statistics for EM-1 wells are not presented, to avoid redundancy.

Appendix G: Individual Well Hydrographs

The following hydrographs show static water levels at each monitoring well for the duration of the study period. Static water levels noted by drillers at the time of well construction are also plotted.

Information provided for each well head includes this study's identification number, the Montana Bureau of Mines unique M: identifier, well location to quarter-quarter-quarter-quarter section, and measuring point description and elevation.

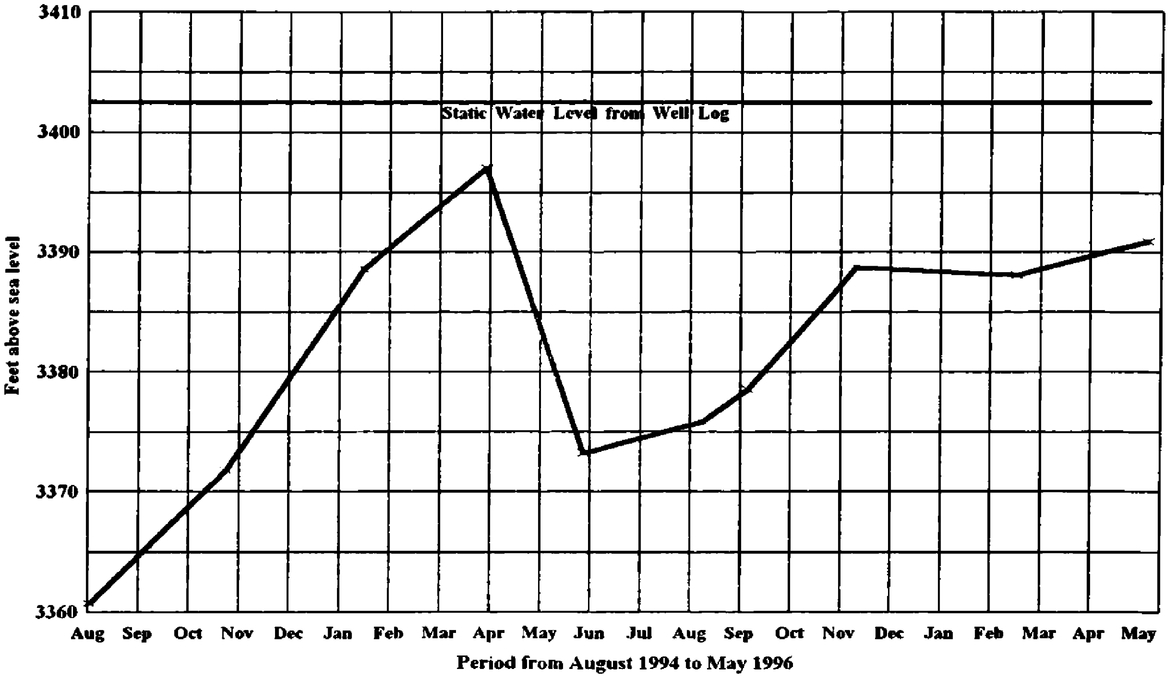
Hydrograph 8M2



Well identification: 8M2, M:136257
Location: T10NR19W S08 ADAD
Measuring point is top of casing (feet above mean sea level): 3501.2
Measuring point (feet above land surface): 1.2

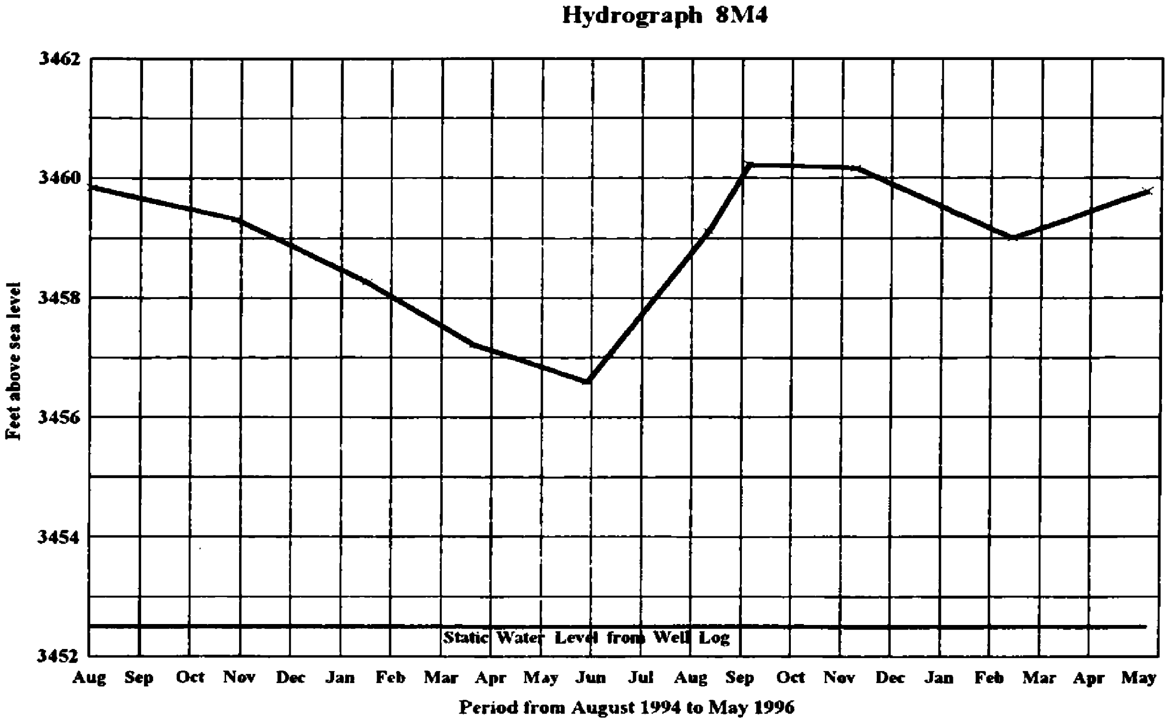
Date	Measurement
08/02/94	3372.4
10/25/94	3396.4
01/14/95	3410.0
03/26/95	3413.1
06/03/95	3397.2
08/15/95	3391.8
09/20/95	3399.2
11/18/95	3408.0
02/23/96	3406.2
05/15/96	3413.9

Hydrograph 8M3



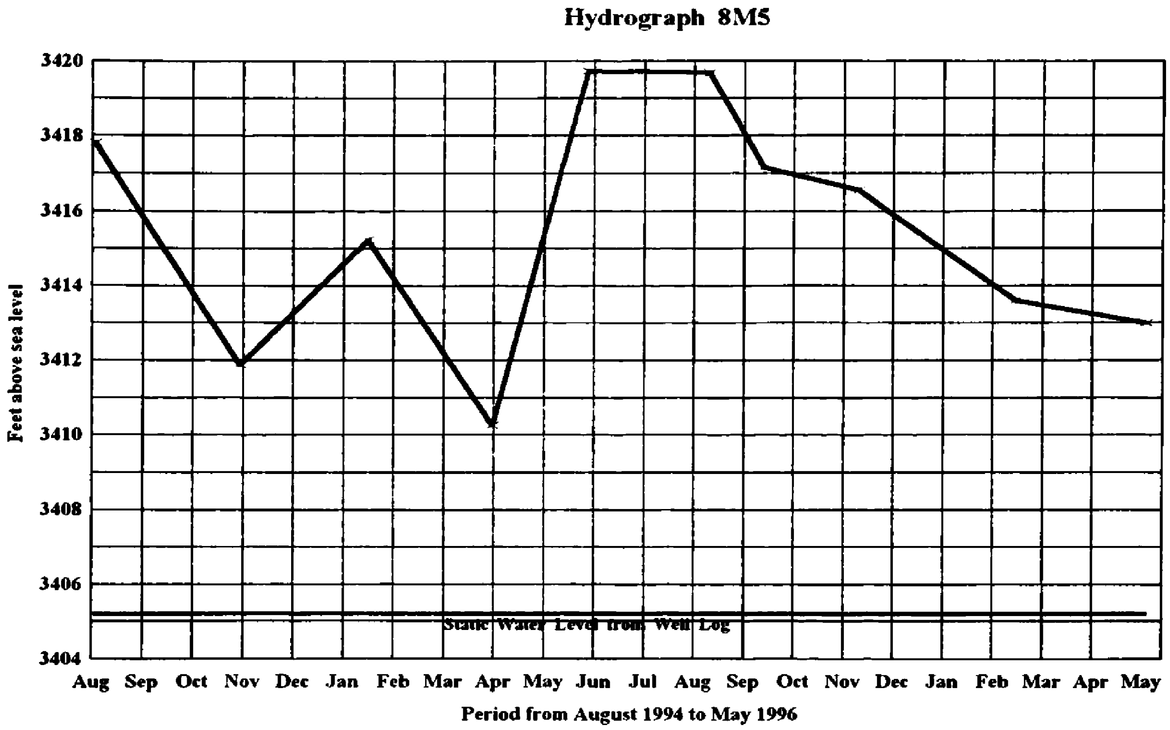
Well identification: 8M3, M:130913
Location: T10NR19W S08 ADDC
Measuring point is top of casing (feet above mean sea level): 3489.5
Measuring point (feet above land surface): 0.3

Date	Measurement
08/02/94	3360.7
10/25/94	3371.8
01/18/95	3388.6
04/03/95	3397.1
06/03/95	3373.3
08/15/95	3375.9
09/12/95	3378.6
11/18/95	3388.7
02/26/96	3388.1
05/17/96	3390.9



Well identification: 8M4, M:151314
Location: T10NR19W S05 DDCC
Measuring point is top of casing (feet above mean sea level): 3472.5
Measuring point (feet above land surface): 1.7

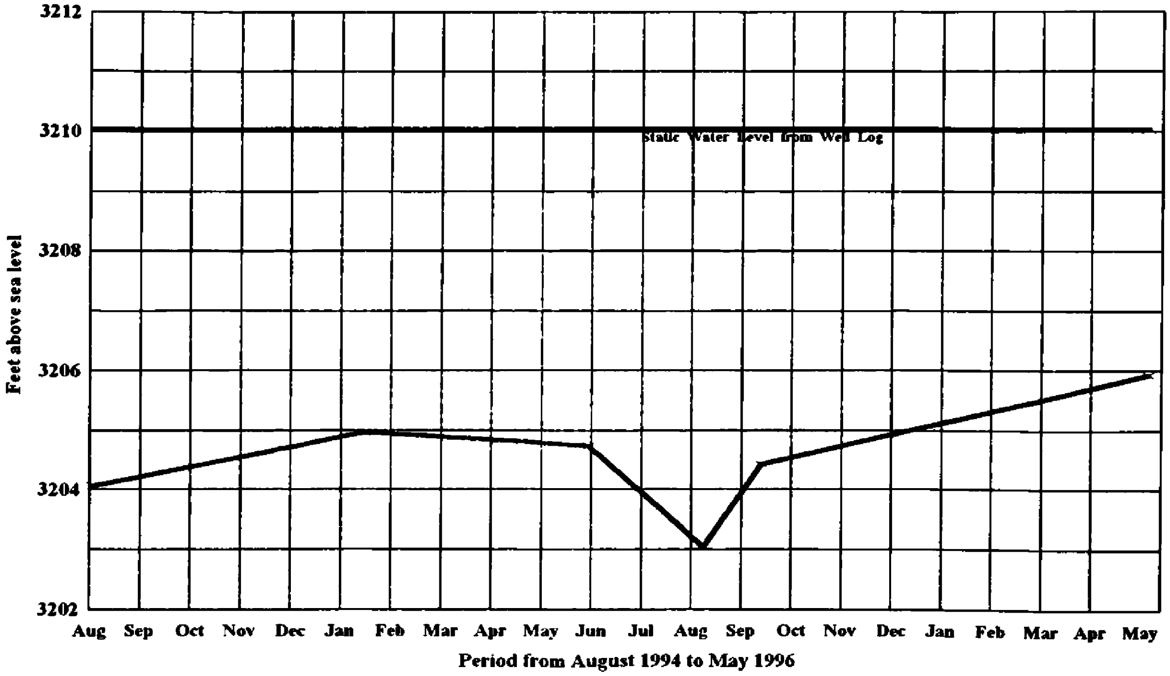
Date	Measurement
08/02/94	3459.8
10/30/94	3459.3
01/19/95	3458.3
03/26/95	3457.2
06/04/95	3456.6
08/18/95	3459.1
09/12/95	3460.2
11/17/95	3460.2
02/23/96	3459.0
05/16/96	3459.8



Well identification: 8M5, M:133852
Location: T10NR19W S08 ABBC
Measuring point is top of casing (feet above mean sea level): 3450.2
Measuring point (feet above land surface): 1.8

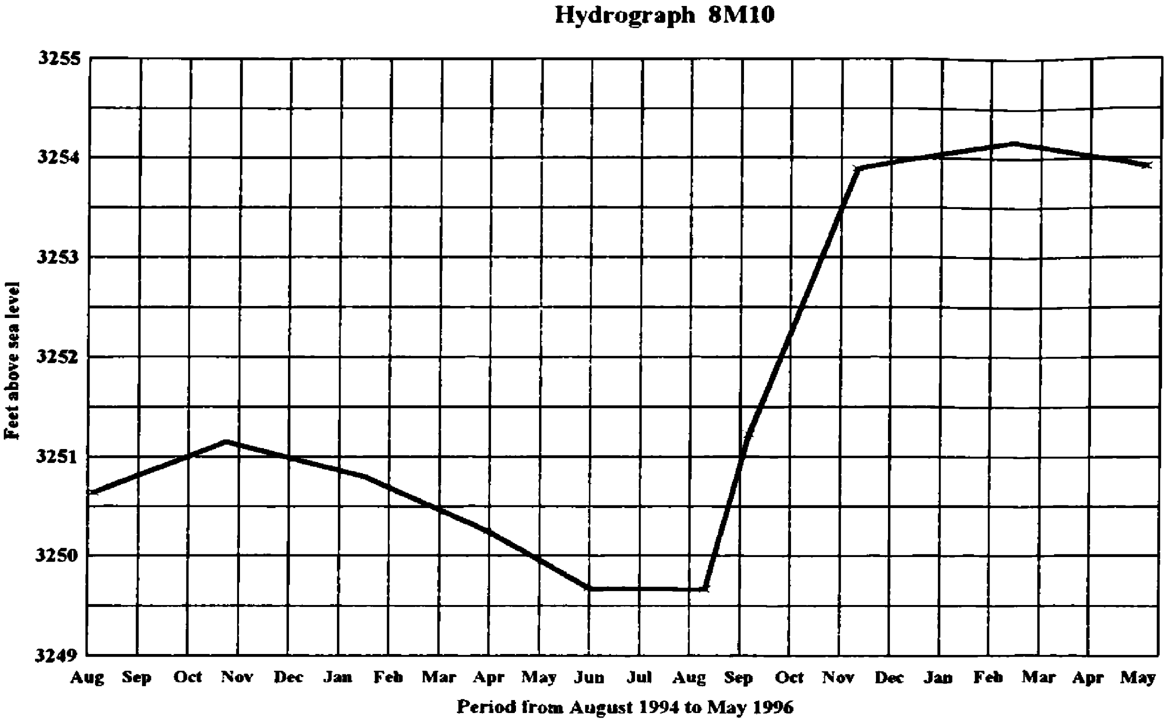
Date	Measurement
08/03/94	3417.8
10/31/94	3411.9
01/18/95	3415.2
04/05/95	3410.3
06/03/95	3419.8
08/17/95	3419.7
09/20/95	3417.2
11/18/95	3416.6
02/24/96	3413.6
05/15/96	3413.0

Hydrograph 8M6



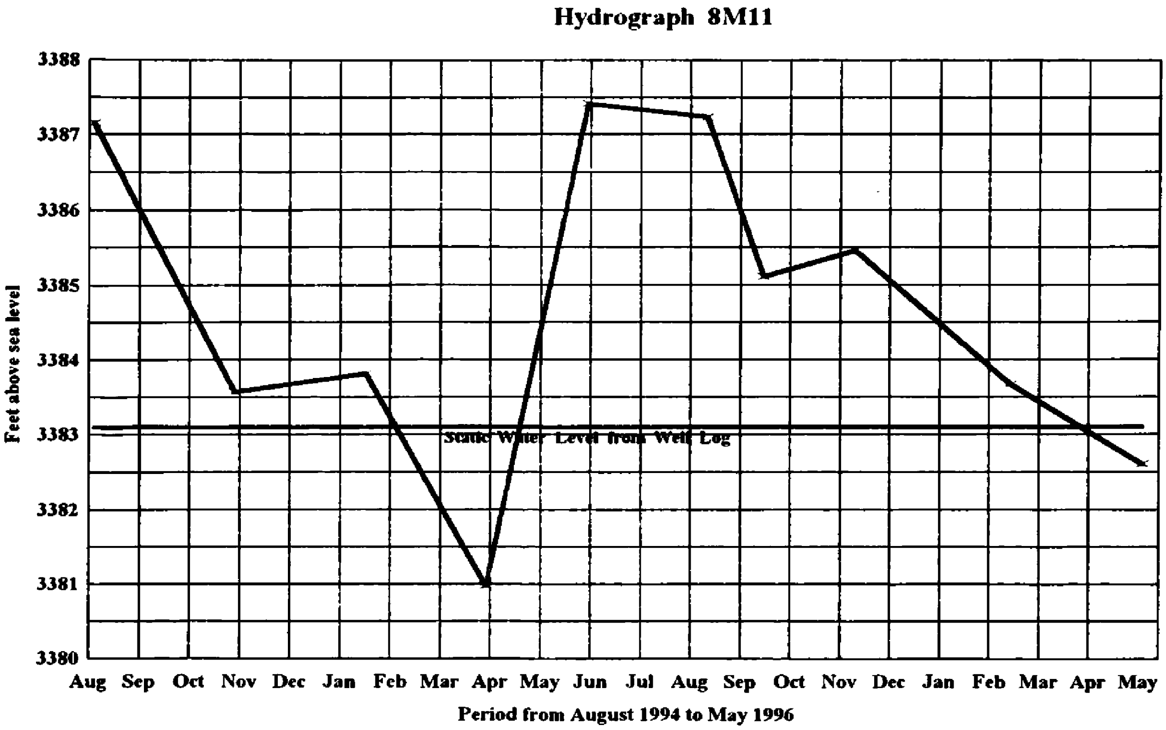
Well identification: 8M6, M:63442
Location: T10NR19W S08 BBDD
Measuring point is access port (feet above mean sea level): 3410.1
Measuring point (feet above land surface): 1.6

Date	Measurement
08/03/94	3204.1
01/18/95	3205.0
06/05/95	3204.8
08/15/95	3203.0
09/20/95	3204.4
05/17/96	3205.9



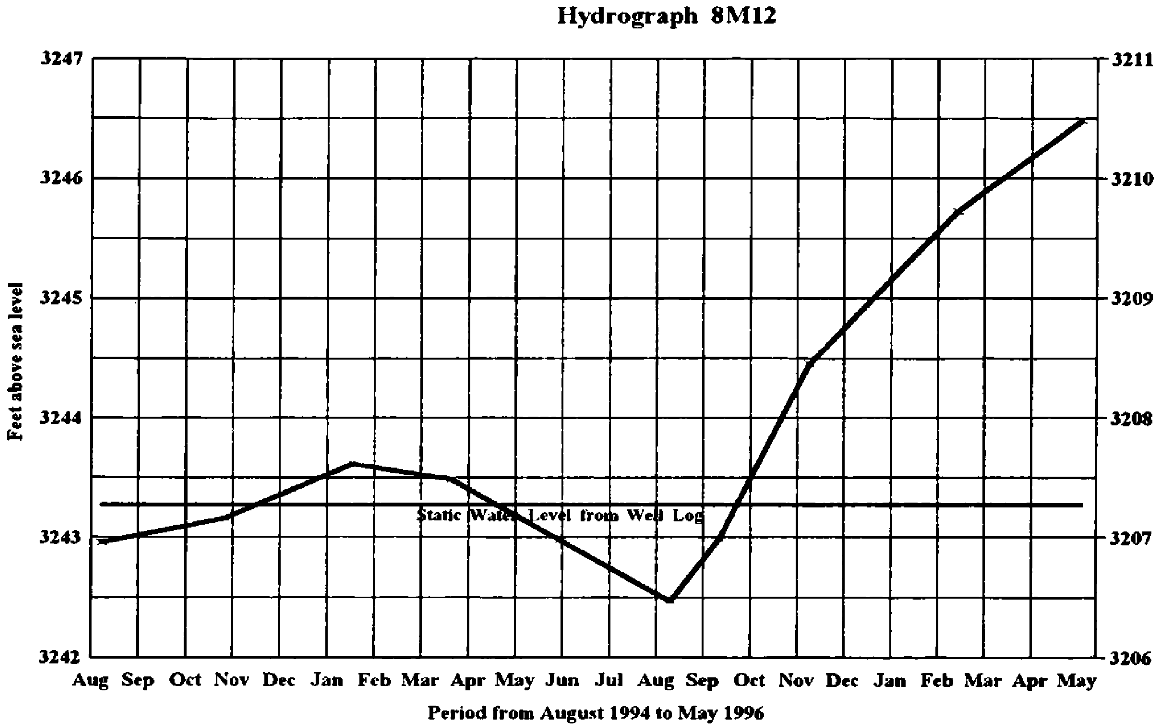
Well identification: 8M10, M:151317
Location: T10NR19W S07 ADBC
Measuring point is top of casing (feet above mean sea level): 3348.5
Measuring point (feet above land surface): 1.9

Date	Measurement
08/04/94	3250.6
10/25/94	3251.2
01/19/95	3250.8
04/05/95	3250.2
06/06/95	3249.7
08/17/95	3249.7
09/13/95	3251.2
11/19/95	3253.9
02/24/96	3254.2
05/16/96	3253.9



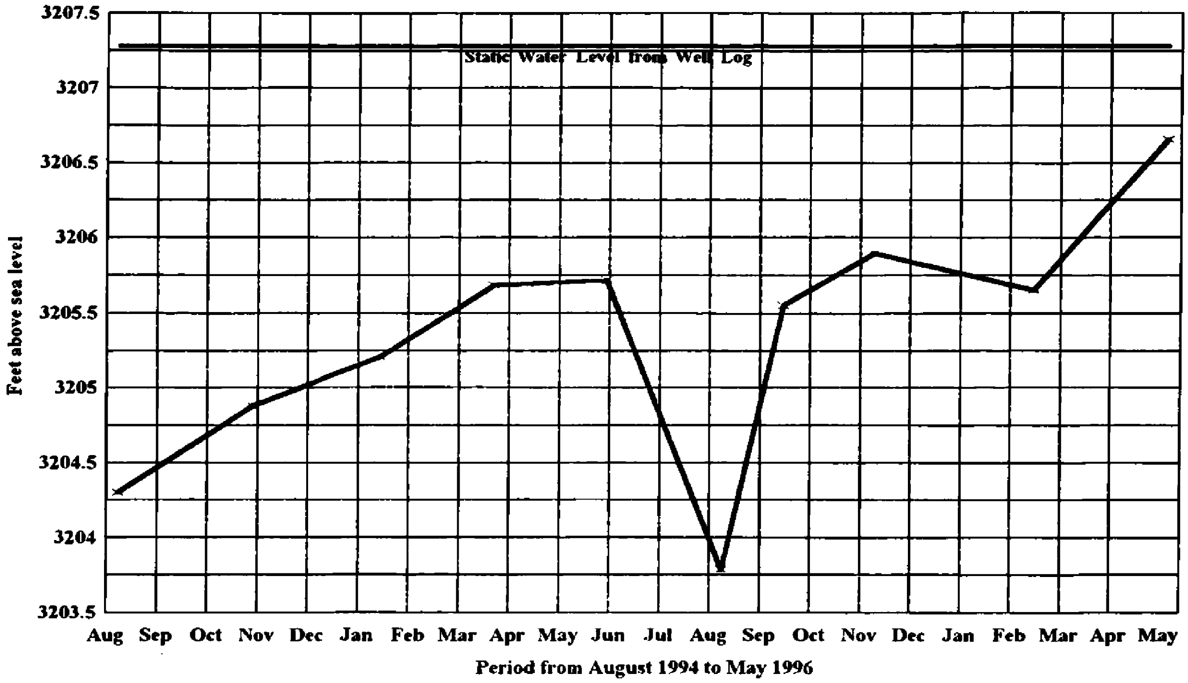
Well identification: 8M11, M:129425
Location: T10NR19W S05 CDCC
Measuring point is access port (feet above mean sea level): 3401.1
Measuring point (feet above land surface): 2.1

Date	Measurement
08/04/94	3387.2
10/30/94	3383.6
01/19/95	3383.8
04/03/95	3381.0
06/05/95	3387.4
08/18/95	3387.2
09/22/95	3385.1
11/18/95	3385.5
02/23/96	3383.7
05/15/96	3382.6



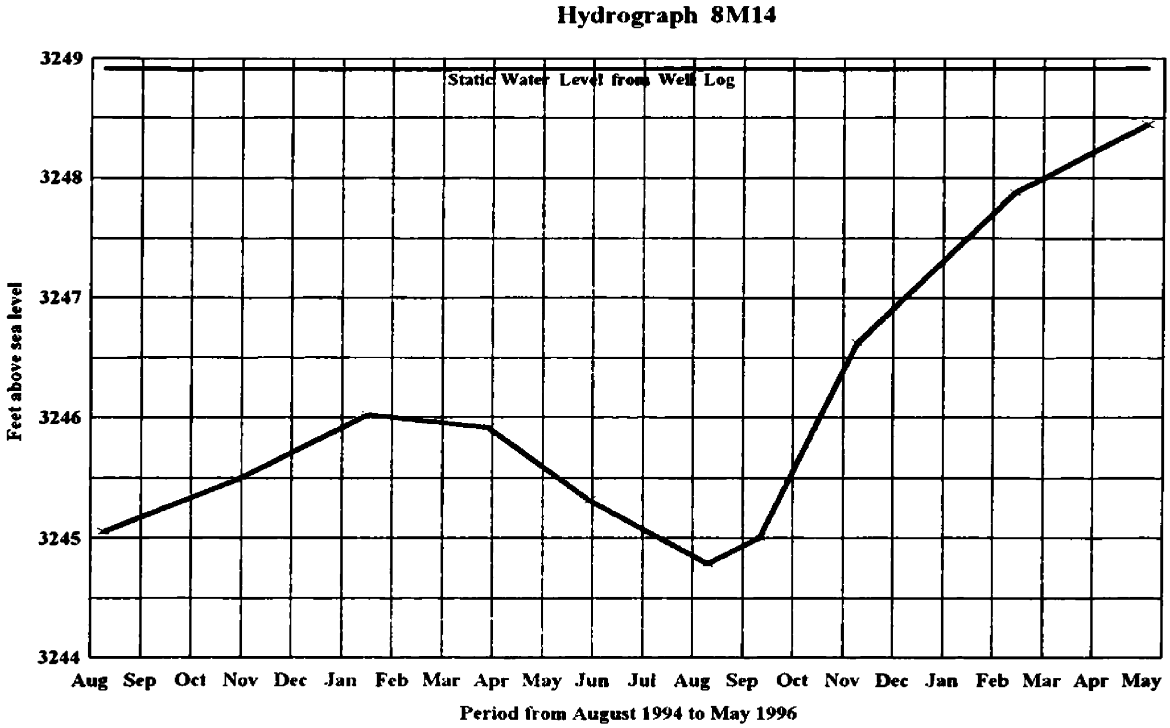
Well identification: 8M12, M:63445
Location: T10NR19W S07 BAAD
Measuring point is top of casing (feet above mean sea level): 3308.1
Measuring point (feet above land surface): 1.5
Static water level from well log plotted on right Y axis

Date	Measurement
08/08/94	3243.0
10/27/94	3243.2
01/19/95	3243.6
03/26/95	3243.5
06/05/95	3243.0
08/17/95	3242.5
09/18/95	3243.0
11/17/95	3244.5
02/23/96	3245.7
05/15/96	3246.5


Hydrograph 8M13

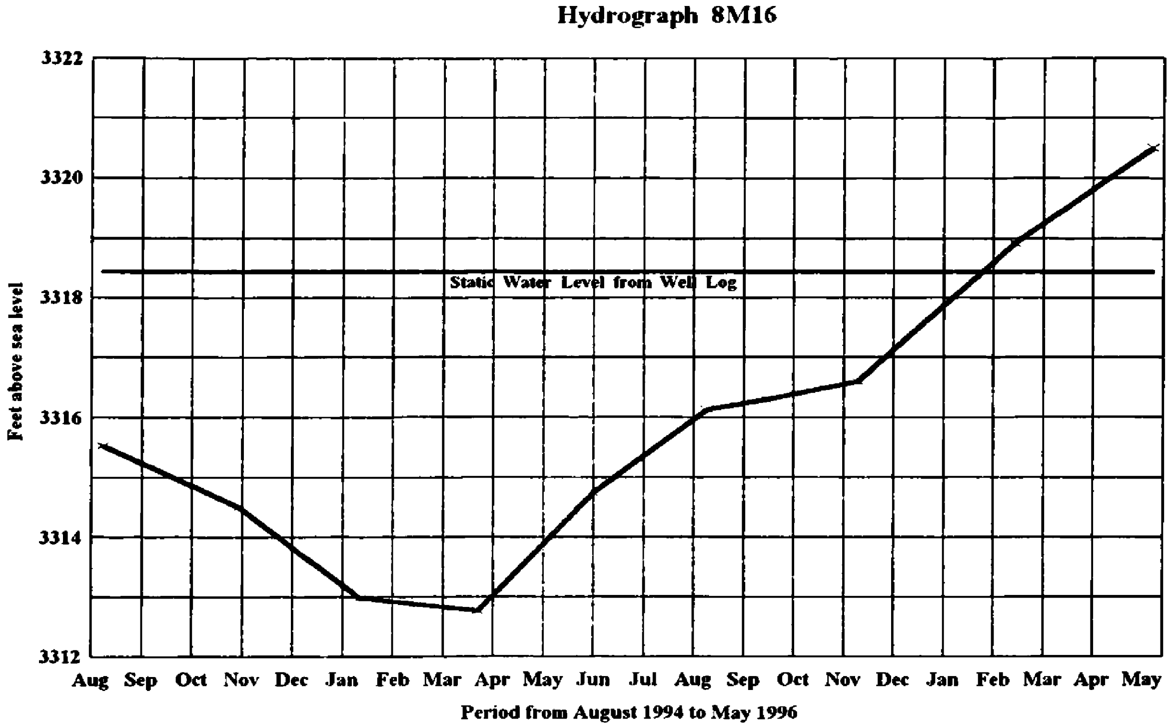
Well identification: 8M13, M:63536
Location: T10NR19W S08 BDAB
Measuring point is top of casing (feet above mean sea level): 3435.3
Measuring point (feet above land surface): 2.3

Date	Measurement
08/08/94	3204.3
10/30/94	3204.9
01/16/95	3205.2
03/27/95	3205.7
06/05/95	3205.7
08/15/95	3203.8
09/22/95	3205.6
11/17/95	3205.9
02/24/96	3205.7
05/17/96	3206.7



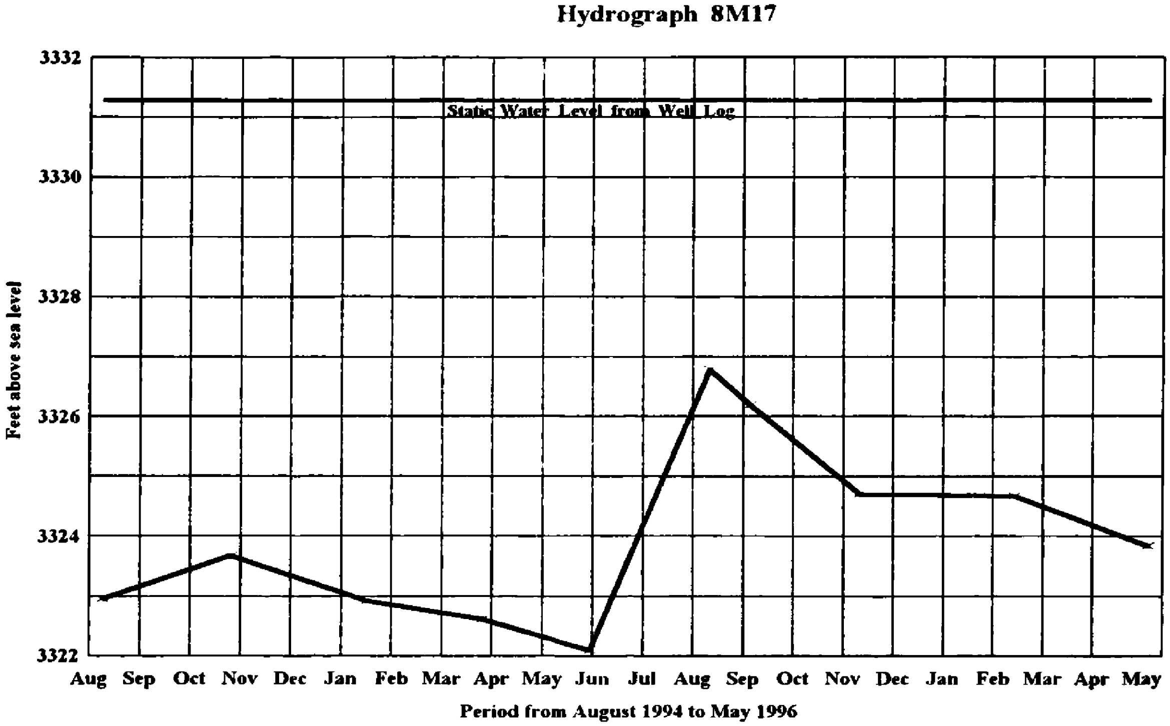
Well identification: 8M14, M:63477
Location: T10NR19W S06 CDDD
Measuring point is top of casing (feet above mean sea level): 3312.9
Measuring point (feet above land surface): 2.2

Date	Measurement
08/09/94	3245.1
10/30/94	3245.5
01/19/95	3246.0
04/03/95	3245.9
06/05/95	3245.3
08/17/95	3244.8
09/18/95	3245.0
11/17/95	3246.6
02/23/96	3247.9
05/15/96	3248.5



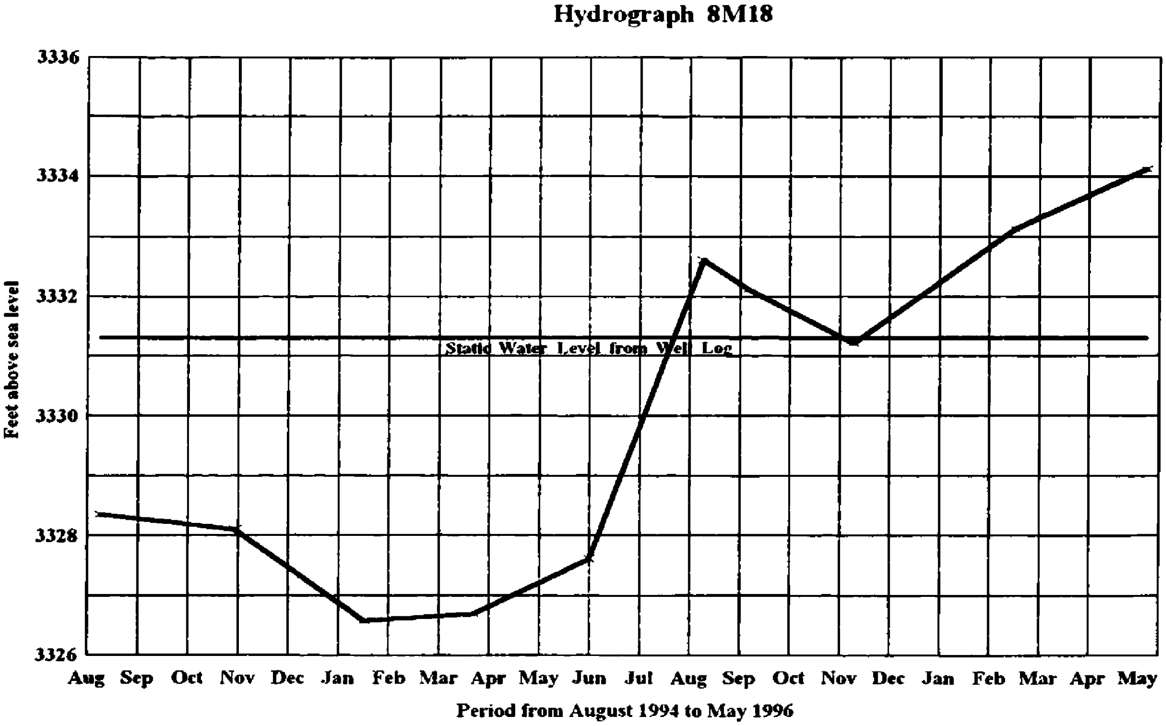
Well identification: 8M16, M:140666
Location: T10NR19W S17 BAAA
Measuring point is top of casing (feet above mean sea level): 3437.5
Measuring point (feet above land surface): 1.5

Date	Measurement
08/08/94	3315.5
10/31/94	3314.5
01/14/95	3313.0
03/27/95	3312.8
06/06/95	3314.8
08/16/95	3316.1
09/21/95	3316.3
11/17/95	3316.6
02/23/96	3318.9
05/18/96	3320.5



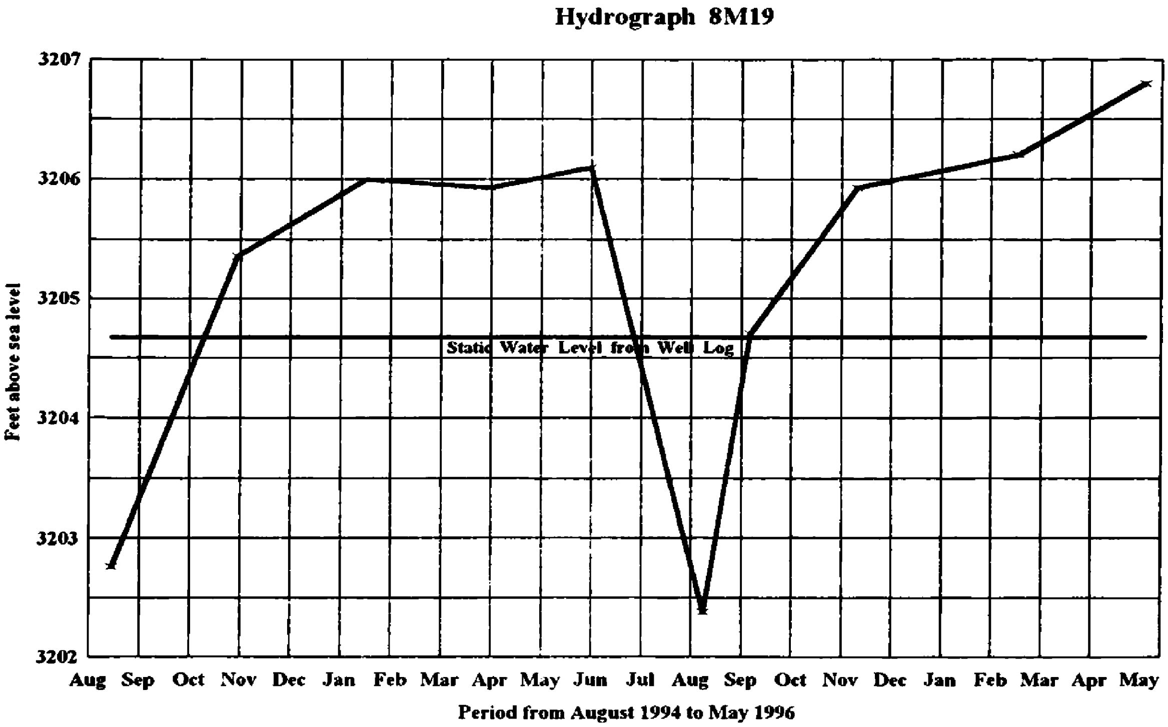
Well identification: 8M17, M:151324/63882
Location: T10NR19W S06 DCDA
Measuring point is top of casing (feet above mean sea level): 3343.3
Measuring point (feet above land surface): 3.1

Date	Measurement
08/09/94	3323.0
10/27/94	3323.7
01/19/95	3322.9
03/31/95	3322.6
06/05/95	3322.1
08/18/95	3326.8
09/12/95	3326.2
11/19/95	3324.7
02/23/96	3324.7
05/16/96	3323.8



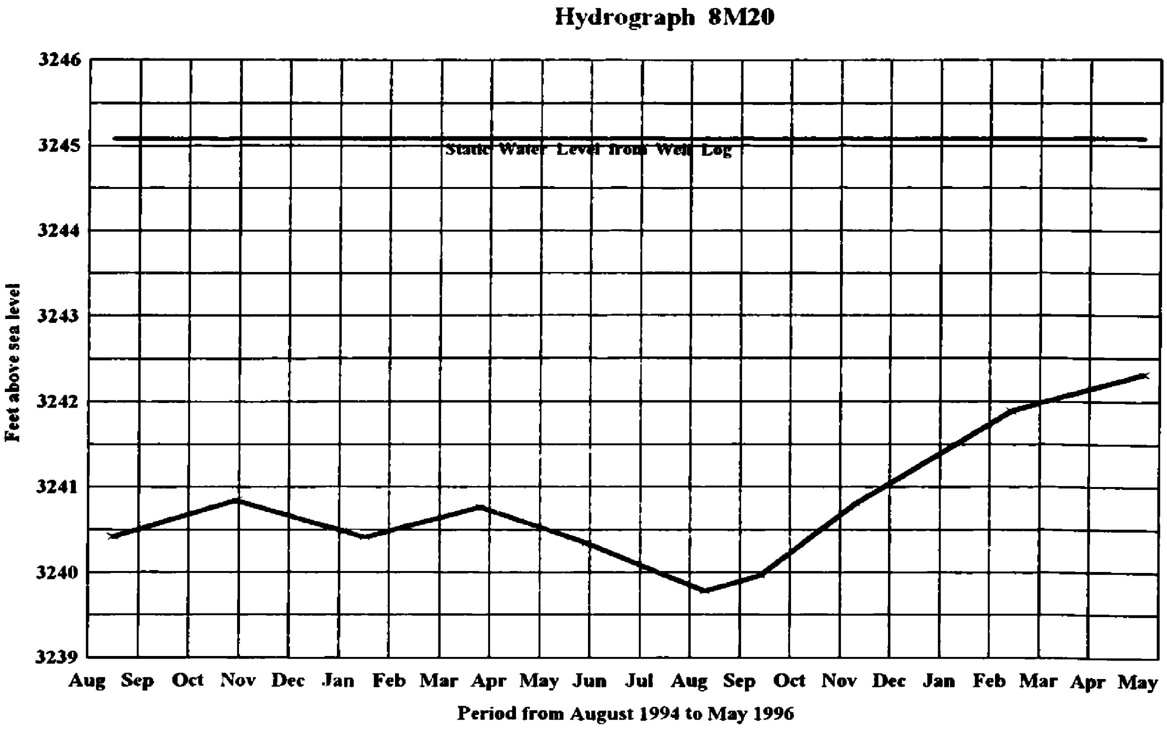
Well identification: 8M18, M:63533
Location: T10NR19W S08 CDAC
Measuring point is top of casing (feet above mean sea level): 3407.3
Measuring point (feet above land surface): 1.7

Date	Measurement
08/09/94	3328.4
10/31/94	3328.1
01/19/95	3326.6
03/27/95	3326.7
06/06/95	3327.6
08/16/95	3332.6
09/13/95	3332.1
11/17/95	3331.2
02/25/96	3333.1
05/17/96	3334.1



Well identification: 8M19, M:129423
Location: T10NR19W S08 BCAD
Measuring point is top of casing (feet above mean sea level): 3404.7
Measuring point (feet above land surface): 1.9

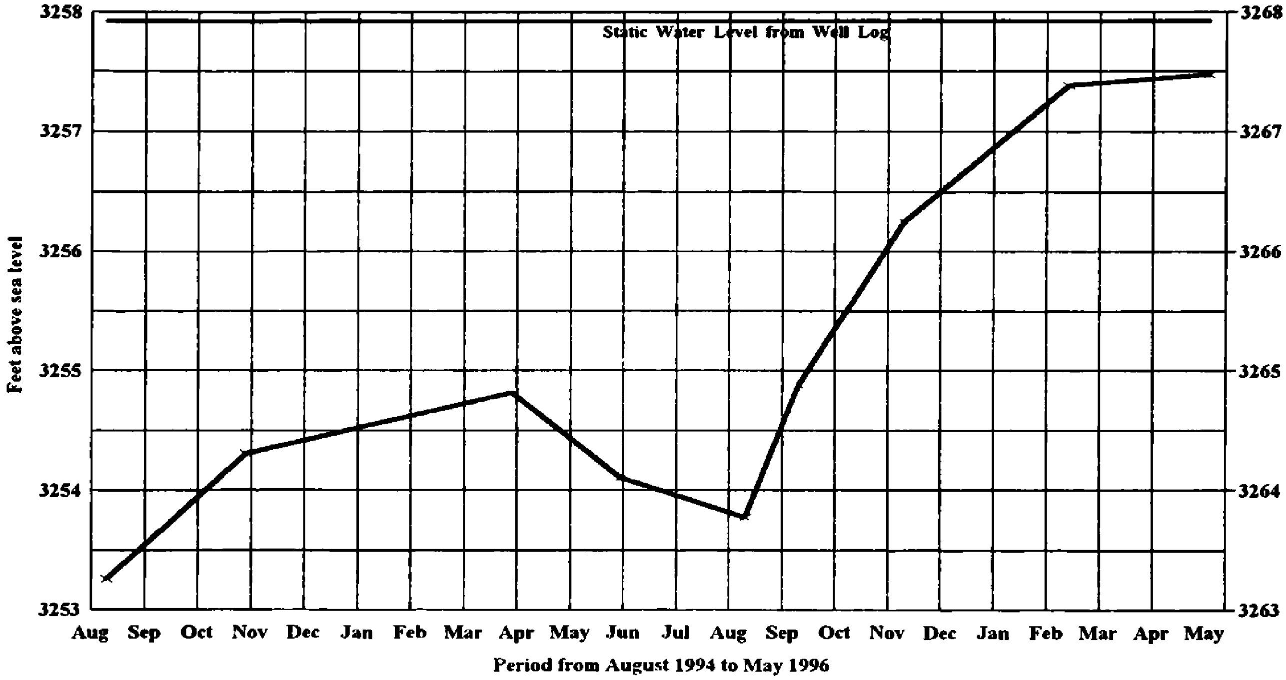
Date	Measurement
08/15/94	3202.8
10/31/94	3205.4
01/18/95	3206.0
04/05/95	3205.9
06/06/95	3206.1
08/15/95	3202.4
09/13/95	3204.7
11/18/95	3205.9
02/26/96	3206.2
05/15/96	3206.8



Well identification: 8M20, M:124553
Location: T10NR19W S06 DDCC
Measuring point is top of casing (feet above mean sea level): 3355.1
Measuring point (feet above land surface): 2.8

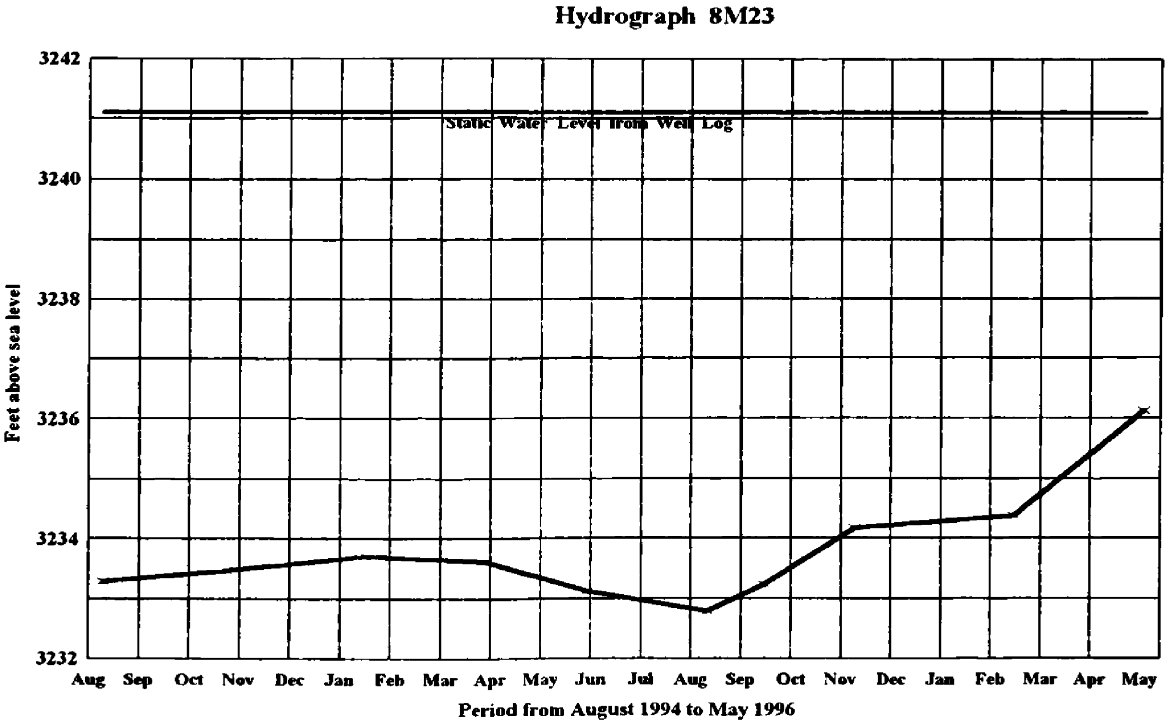
Date	Measurement
08/16/94	3240.4
10/31/94	3240.9
01/19/95	3240.4
03/31/95	3240.8
06/05/95	3240.4
08/17/95	3239.8
09/20/95	3240.0
11/18/95	3240.8
02/23/96	3241.9
05/15/96	3242.3

Hydrograph 8M21



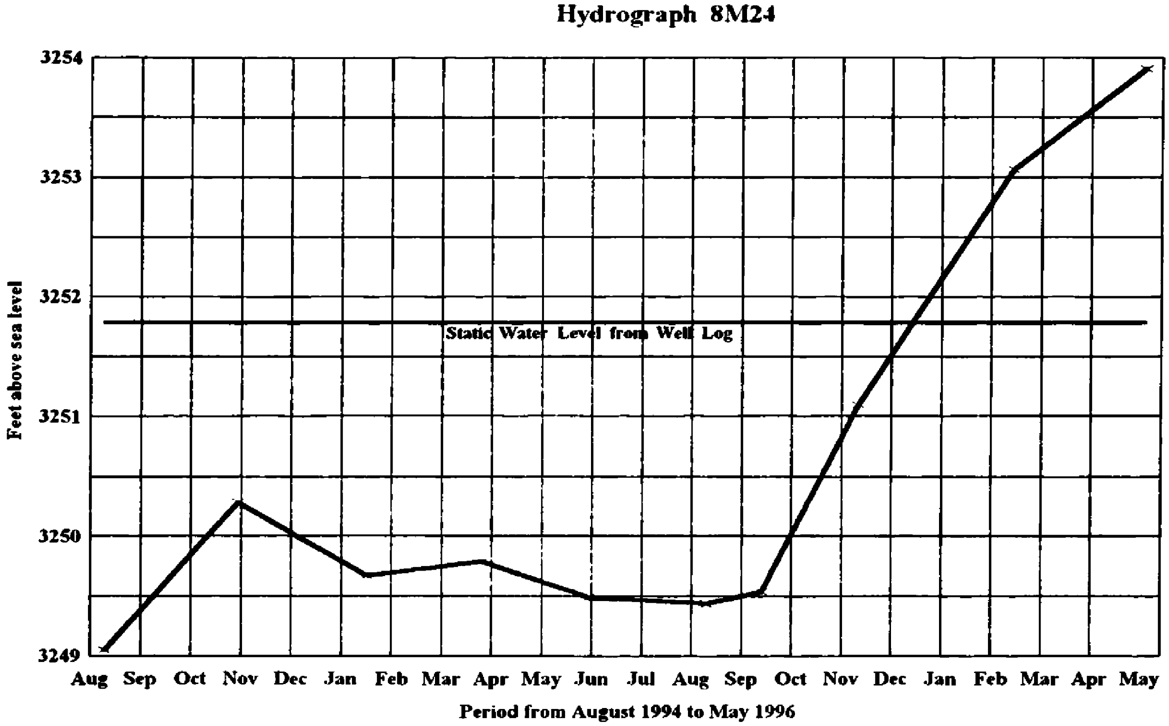
Well identification: 8M21, M:63884
Location: T10NR19W S06 DCCC
Measuring point is top of casing (feet above mean sea level): 3317.9
Measuring point (feet above land surface): 3.1
Static water level from well log plotted on right Y axis

Date	Measurement
08/10/94	3253.3
10/30/94	3254.3
04/03/95	3254.8
06/05/95	3254.1
08/17/95	3253.8
09/17/95	3254.9
11/18/95	3256.2
02/23/96	3257.4
05/15/96	3257.5



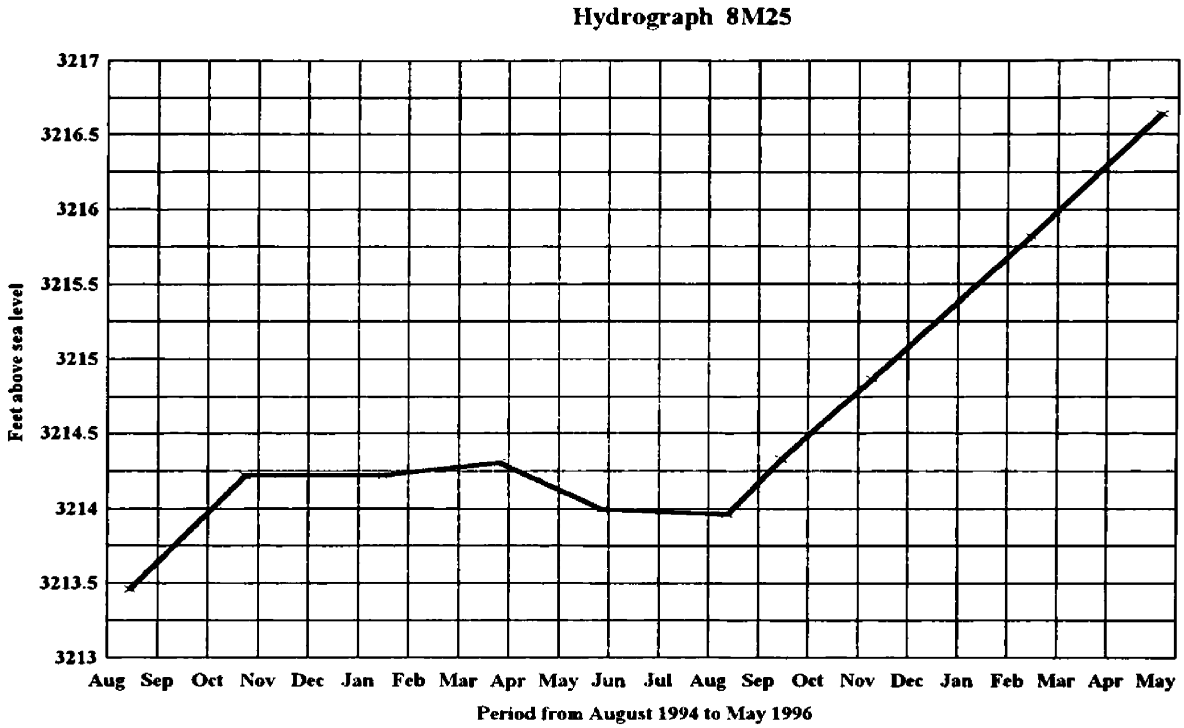
Well identification: 8M23, M:140665
Location: T10NR19W S07 BDBB
Measuring point is top of casing (feet above mean sea level): 3284.1
Measuring point (feet above land surface): 1.85

Date	Measurement
08/10/94	3233.3
10/25/94	3233.5
01/18/95	3233.7
04/03/95	3233.6
06/05/95	3233.1
08/18/95	3232.8
09/22/95	3233.2
11/17/95	3234.2
02/24/96	3234.4
05/15/96	3236.1



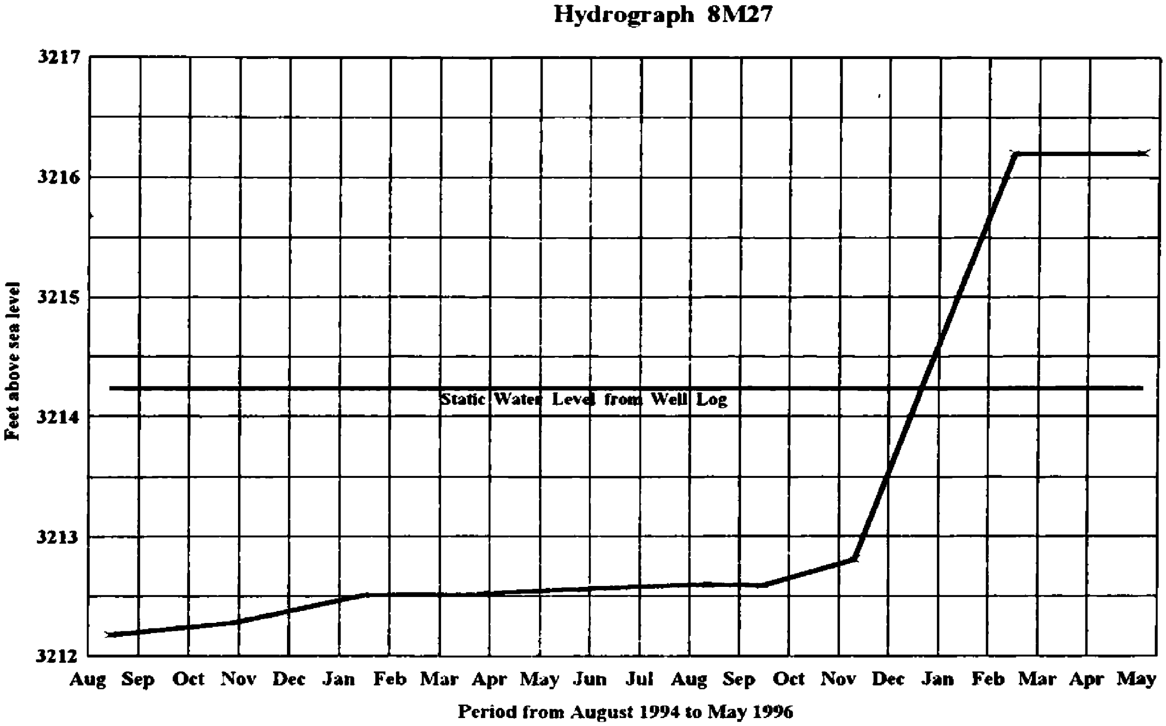
Well identification: 8M24, M:63523
Location: T10NR19W S08 BCCB
Measuring point is top of casing (feet above mean sea level): 3381.8
Measuring point (feet above land surface): 1.9

Date	Measurement
08/10/94	3249.0
10/31/94	3250.3
01/19/95	3249.7
03/31/95	3249.8
06/05/95	3249.5
08/17/95	3249.4
09/20/95	3249.5
11/19/95	3251.1
02/23/96	3253.1
05/15/96	3253.9



Well identification: 8M25
Location: T10NR20W S12 ADDD
Measuring point is top of casing (feet above mean sea level): 3246.0
Measuring point (feet above land surface): 1.7

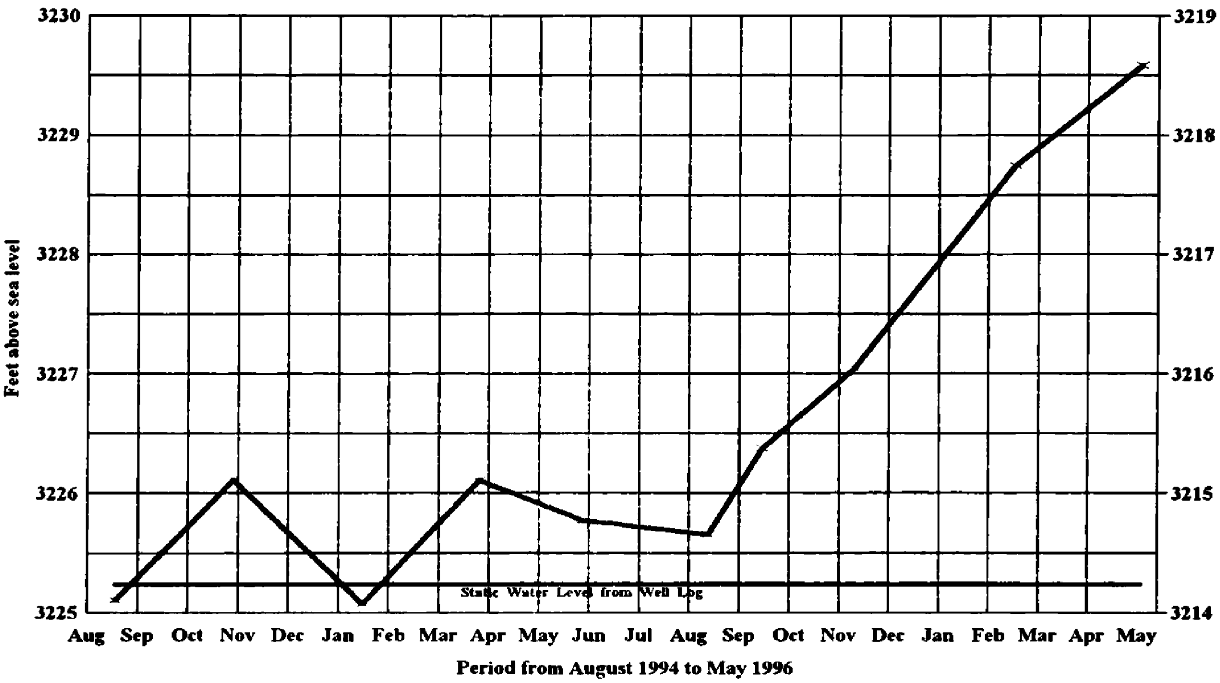
Date	Measurement
08/15/94	3213.5
10/25/94	3214.2
01/18/95	3214.2
03/31/95	3214.3
06/03/95	3214.0
08/19/95	3214.0
09/22/95	3214.3
11/17/95	3214.9
02/24/96	3215.8
05/15/96	3216.6



Well identification: 8M27, M:63483
Location: T10NR20W S12 DAAD
Measuring point is access port (feet above mean sea level): 3244.2
Measuring point (feet above land surface): 1.25

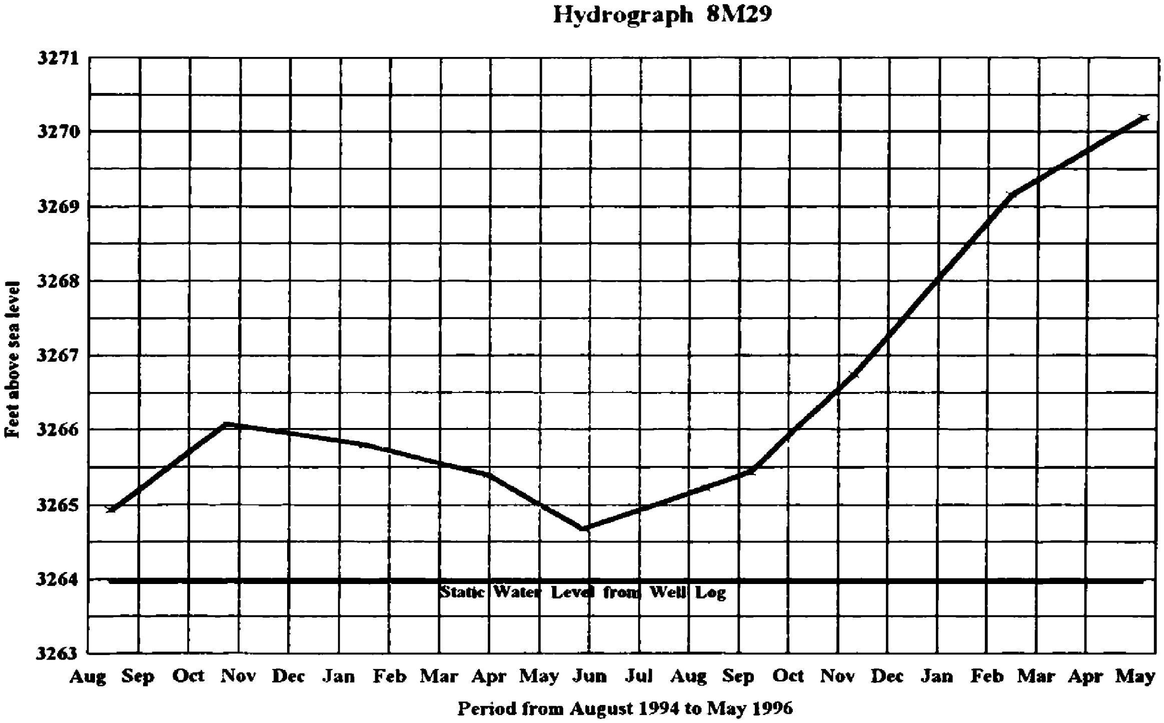
Date	Measurement
08/15/94	3212.2
10/30/94	3212.3
01/18/95	3212.5
03/31/95	3212.5
06/03/95	3212.6
08/19/95	3212.6
09/22/95	3212.6
11/18/95	3212.8
02/25/96	3216.2
05/15/96	3216.2

Hydrograph 8M28



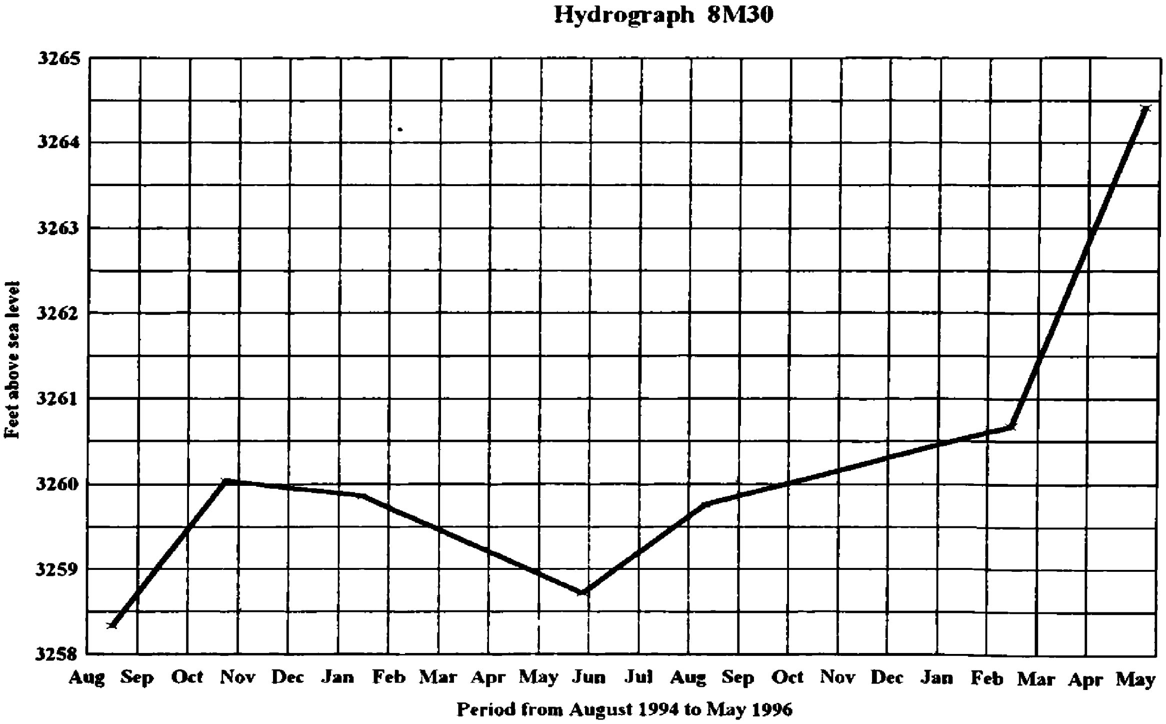
Well identification: 8M28, M:137474
Location: T10NR19W S07 CACB
Measuring point is top of casing (feet above mean sea level): 3274.8
Measuring point (feet above land surface): 1.7
Static water level from well log plotted on right Y axis

Date	Measurement
08/18/94	3225.1
10/30/94	3226.1
01/18/95	3225.1
03/31/95	3226.1
06/03/95	3225.8
08/19/95	3225.7
09/22/95	3226.4
11/18/95	3227.0
02/26/96	3228.8
05/15/96	3229.6



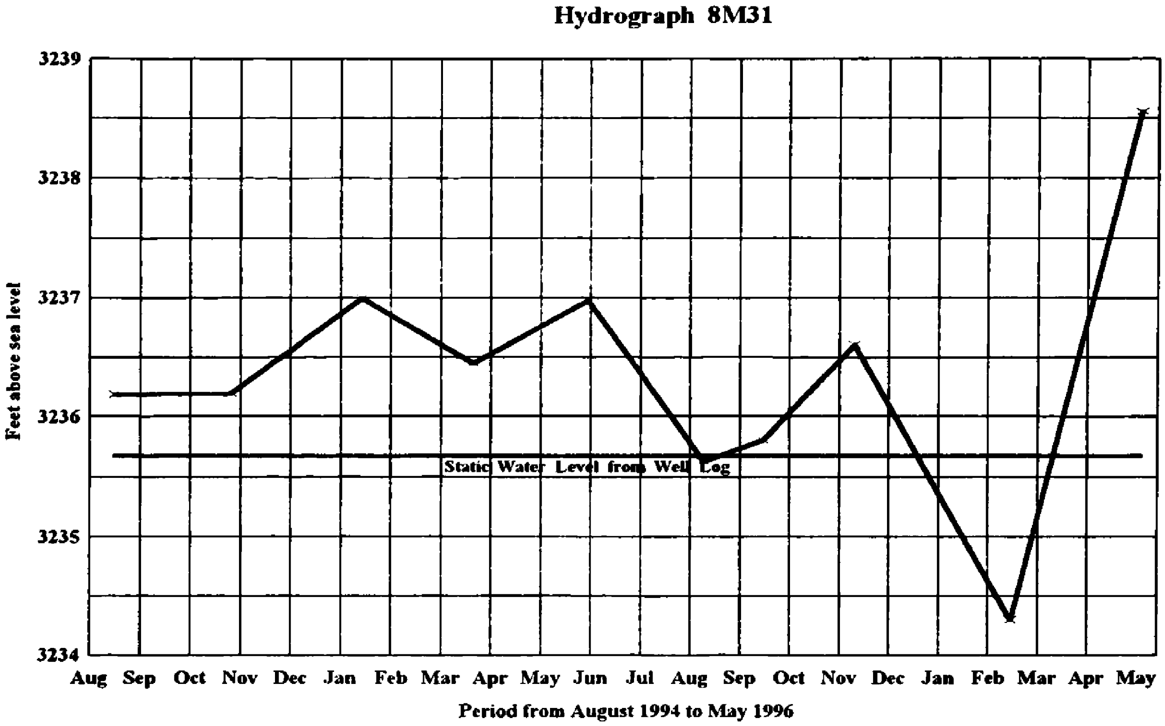
Well identification: 8M29, M:63493
Location: T10NR19W S07 CAAD
Measuring point is top of casing (feet above mean sea level): 3302.0
Measuring point (feet above land surface): 2.0

Date	Measurement
08/15/94	3264.9
10/25/94	3266.1
01/18/95	3265.8
04/05/95	3265.4
06/03/95	3264.7
08/18/95	3265.2
09/15/95	3265.4
11/18/95	3266.8
02/24/96	3269.2
05/16/96	3270.2



Well identification: 8M30
Location: T10NR19W S07 CACA
Measuring point is top of casing (feet above mean sea level): 3284.1
Measuring point (feet above land surface): 1.5

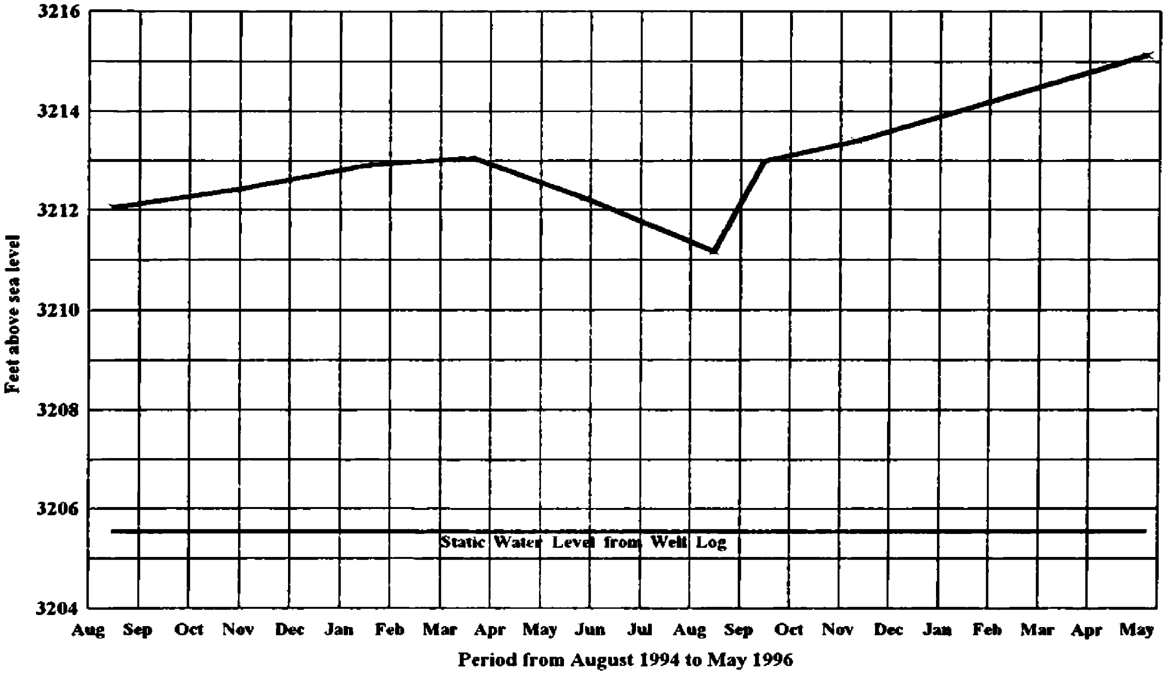
Date	Measurement
08/16/94	3258.3
10/25/94	3260.0
01/18/95	3259.9
06/03/95	3258.7
08/18/95	3259.8
02/24/96	3260.7
05/16/96	3264.4



Well identification: 8M31, M:63522
Location: T10NR19W S08 BCBB
Measuring point is access port (feet above mean sea level): 3383.7
Measuring point (feet above land surface): 2.3

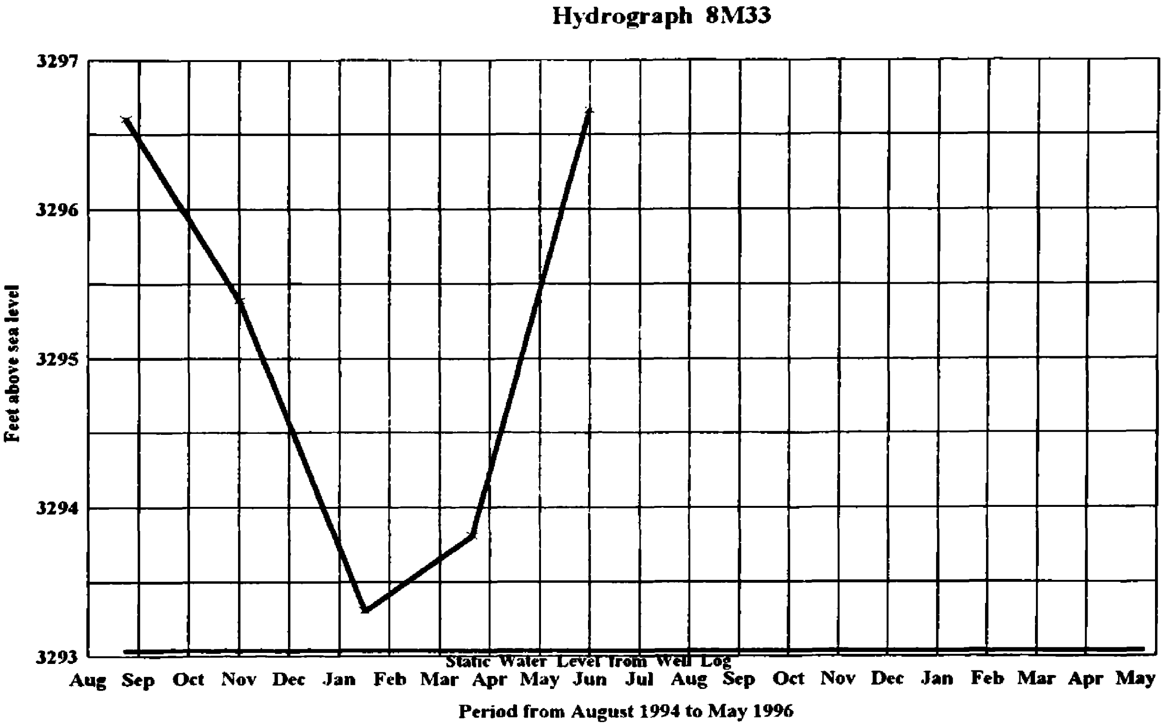
Date	Measurement
08/16/94	3236.2
10/27/94	3236.2
01/16/95	3237.0
03/26/95	3236.4
06/05/95	3237.0
08/16/95	3235.6
09/22/95	3235.8
11/18/95	3236.6
02/24/96	3234.3
05/15/96	3238.6

Hydrograph 8M32



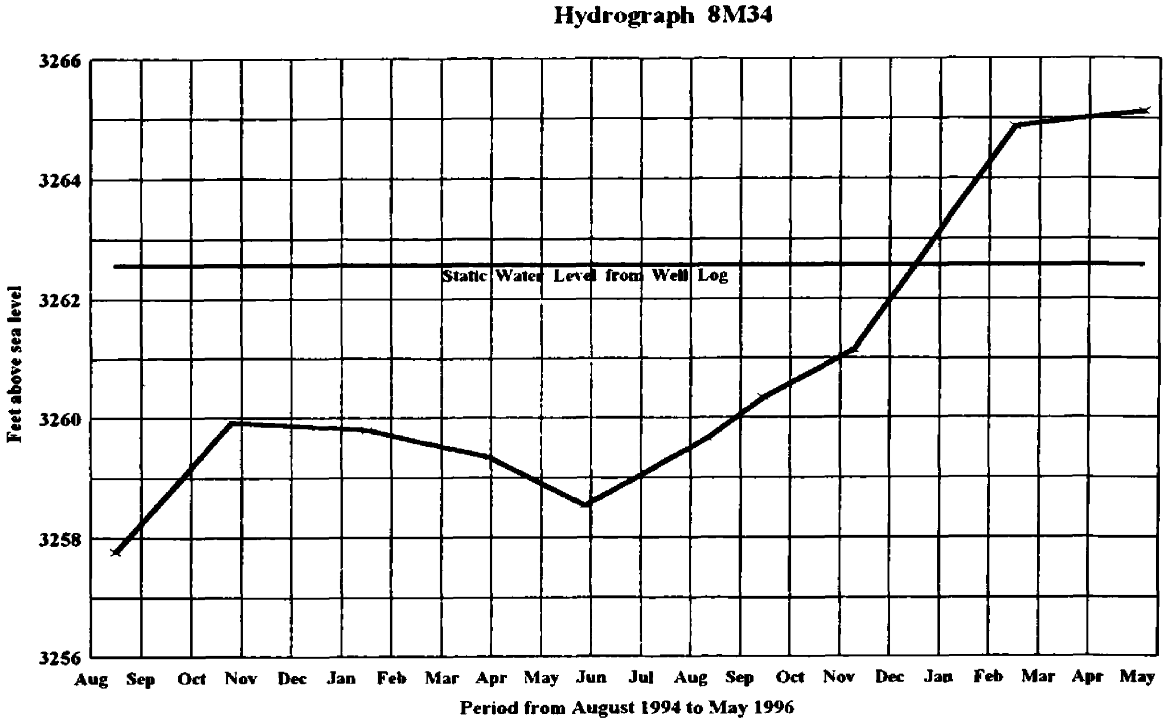
Well identification: 8M32, M:64099
Location: T10NR20W S12 ADDB
Measuring point is access port (feet above mean sea level): 3232.6
Measuring point (feet above land surface): -3.9

Date	Measurement
08/16/94	3212.1
10/30/94	3212.4
01/19/95	3212.9
03/26/95	3213.1
06/03/95	3212.3
08/22/95	3211.2
09/22/95	3213.0
11/19/95	3213.4
05/17/96	3215.1



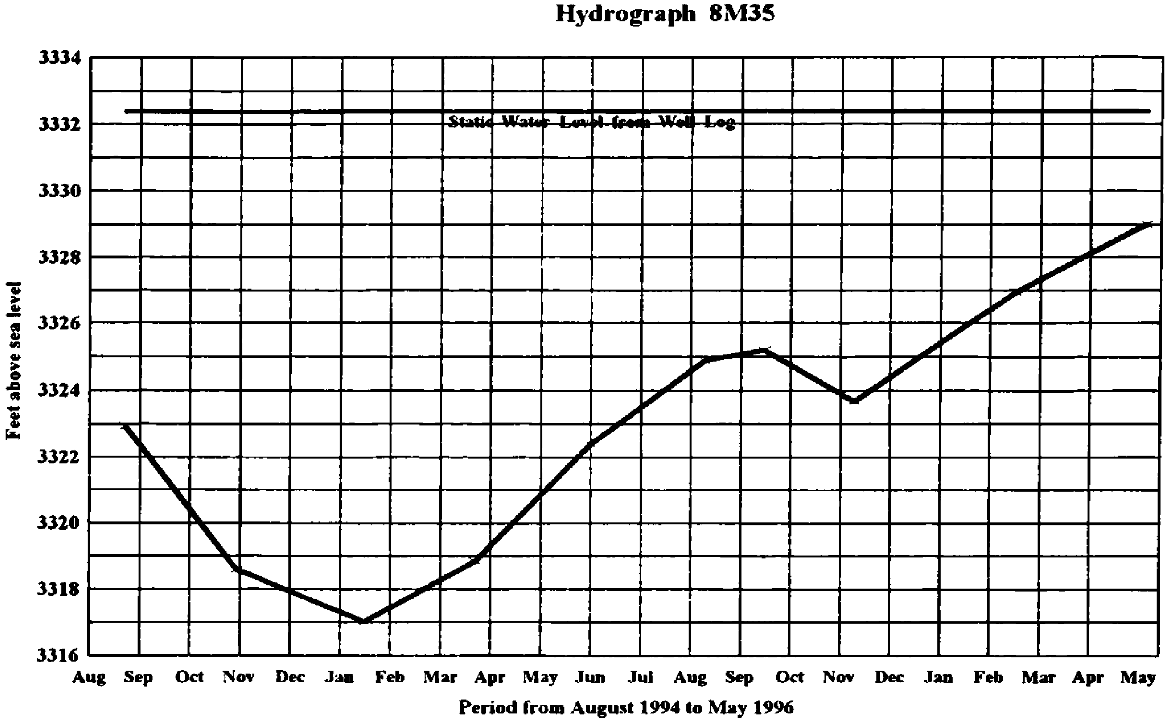
Well identification: 8M33, M:63526
Location: T10NR19W S18 AAAA
Measuring point is top of casing (feet above mean sea level): 3343.0
Measuring point (feet above land surface): 1.2

Date	Measurement
08/24/94	3296.6
11/02/94	3295.4
01/19/95	3293.3
03/26/95	3293.8
06/06/95	3296.7



Well identification: 8M34, M:63489
Location: T10NR19W S07 CDBA
Measuring point is access port (feet above mean sea level): 3282.6
Measuring point (feet above land surface): 1.1

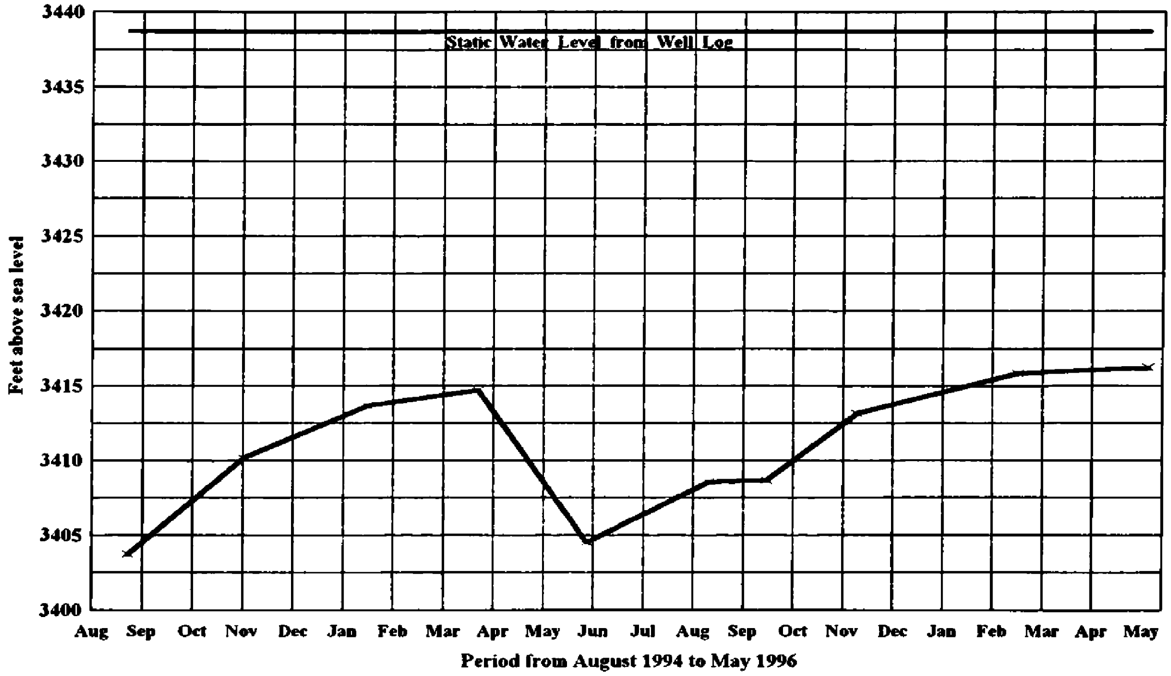
Date	Measurement
08/16/94	3257.8
10/27/94	3259.9
01/19/95	3259.8
04/05/95	3259.4
06/03/95	3258.5
08/18/95	3259.7
09/22/95	3260.4
11/17/95	3261.2
02/25/96	3264.9
05/15/96	3265.1



Well identification: 8M35, M:63511
Location: T10NR19W S08 CBDD
Measuring point is access port (feet above mean sea level): 3375.4
Measuring point (feet above land surface): 0.7

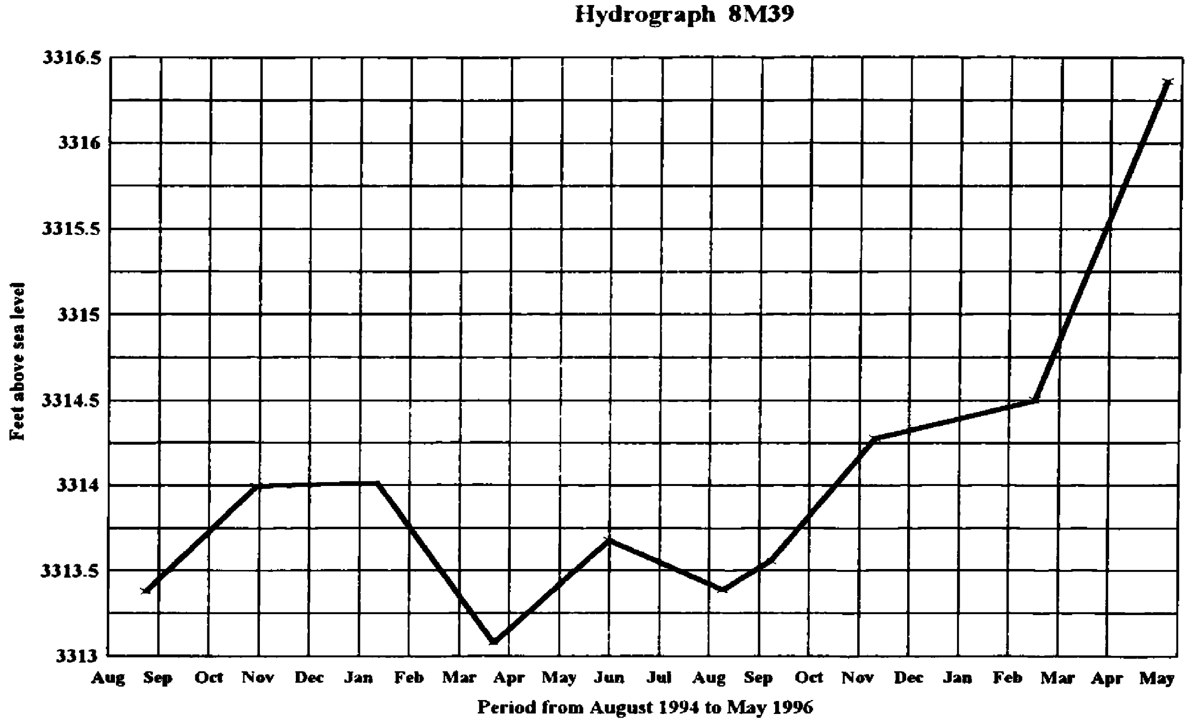
Date	Measurement
08/23/94	3323.0
10/31/94	3318.6
01/18/95	3317.0
03/27/95	3318.9
06/06/95	3322.4
08/16/95	3324.9
09/22/95	3325.2
11/17/95	3323.7
02/25/96	3327.0
05/16/96	3329.0

Hydrograph 8M37



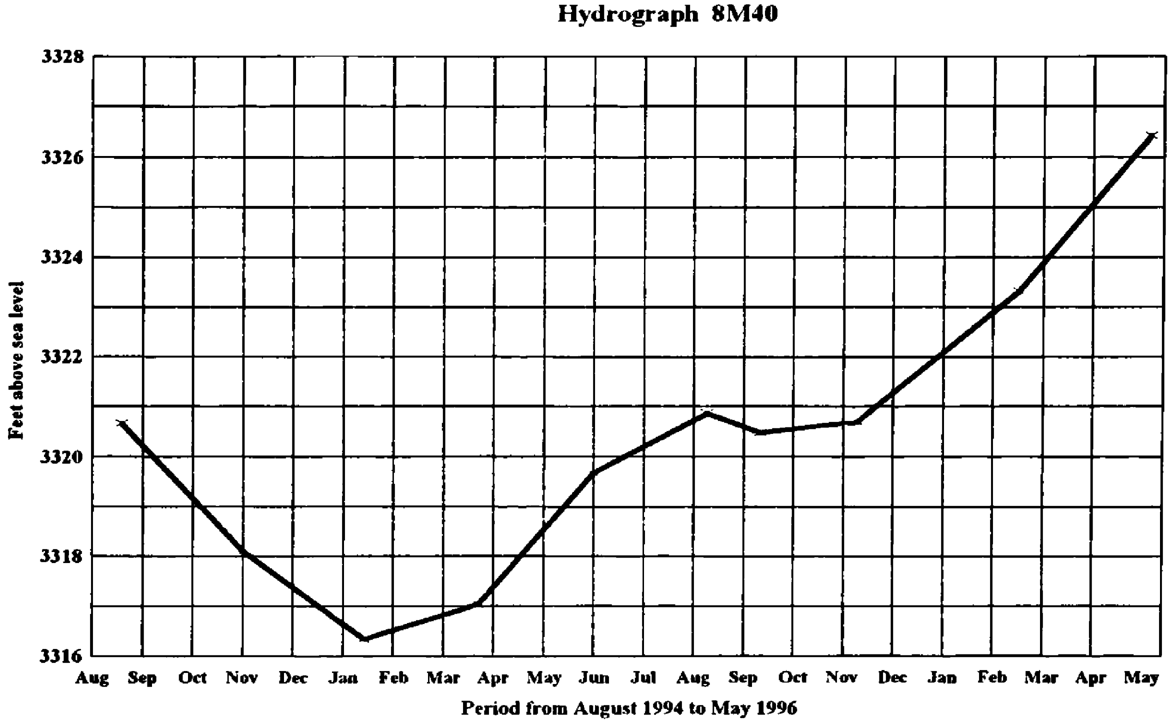
Well identification: 8M37, M:123130
Location: T10NR19W S08 DAAC
Measuring point is top of casing (feet above mean sea level): 3483.7
Measuring point (feet above land surface): 2.0

Date	Measurement
08/23/94	3403.7
11/02/94	3410.2
01/18/95	3413.7
03/27/95	3414.8
06/03/95	3404.5
08/17/95	3408.6
09/22/95	3408.7
11/17/95	3413.2
02/25/96	3415.9
05/16/96	3416.3



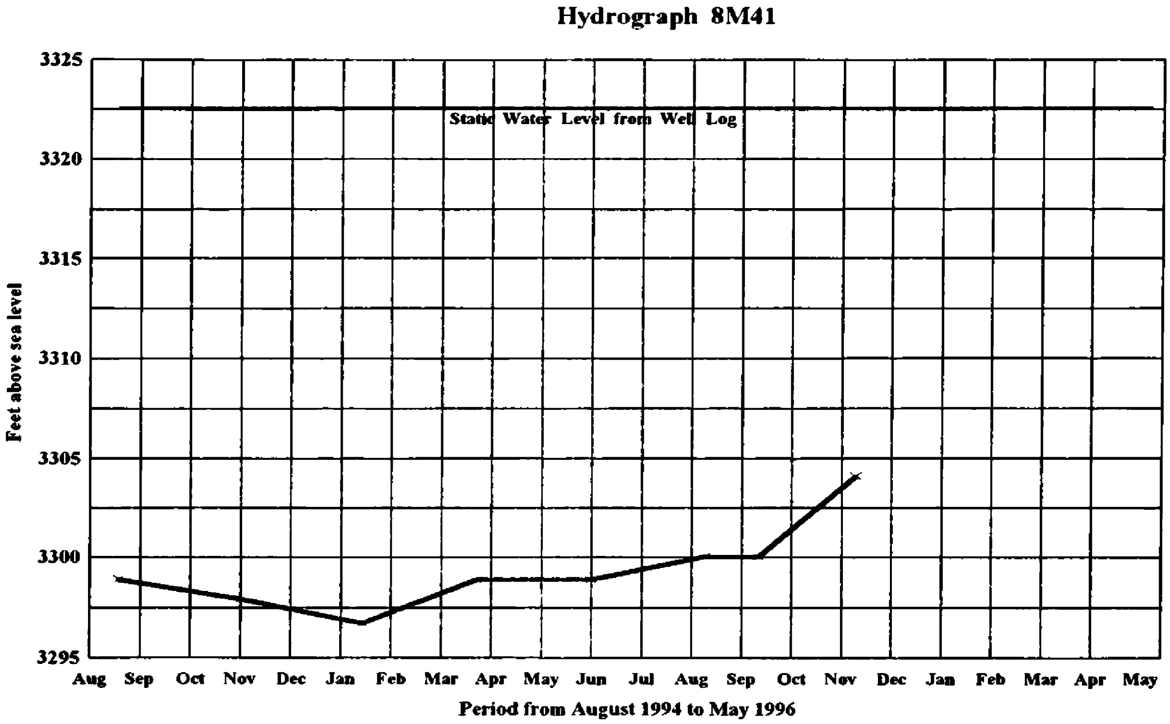
Well identification: 8M39, M:151319
Location: T10NR19W S16 BBBC
Measuring point is access port (feet above mean sea level): 3519.8
Measuring point (feet above land surface): 1.7

Date	Measurement
08/24/94	3313.4
10/31/94	3314.0
01/14/95	3314.0
03/27/95	3313.1
06/06/95	3313.7
08/16/95	3313.4
09/15/95	3313.6
11/18/95	3314.3
02/25/96	3314.5
05/16/96	3316.4



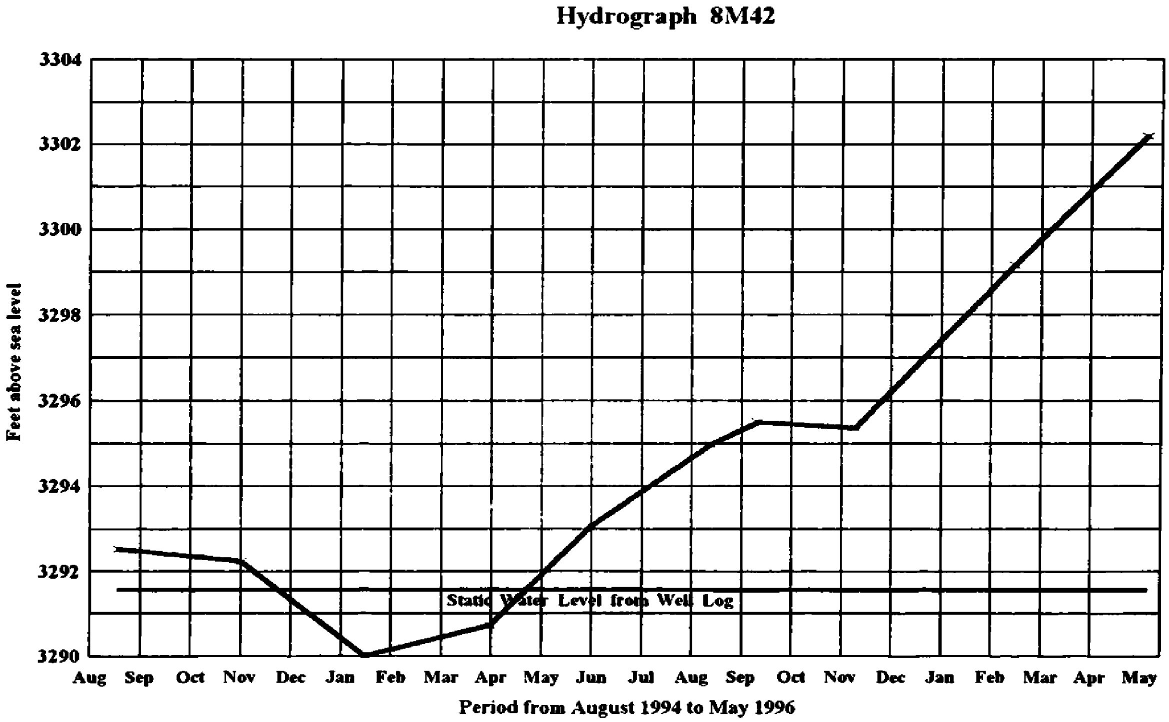
Well identification: 8M40
Location: T10NR19W S17 BACC
Measuring point is top of casing (feet above mean sea level): 3413.5
Measuring point (feet above land surface): 2.2

Date	Measurement
08/19/94	3320.7
11/02/94	3318.1
01/16/95	3316.3
03/27/95	3317.0
06/06/95	3319.7
08/16/95	3320.9
09/18/95	3320.5
11/17/95	3320.7
02/25/96	3323.3
05/17/96	3326.4



Well identification: 8M41, M:63556
Location: T10NR19W S17 BCAB
Measuring point is top of casing (feet above mean sea level): 3390.6
Measuring point (feet above land surface): 2.1

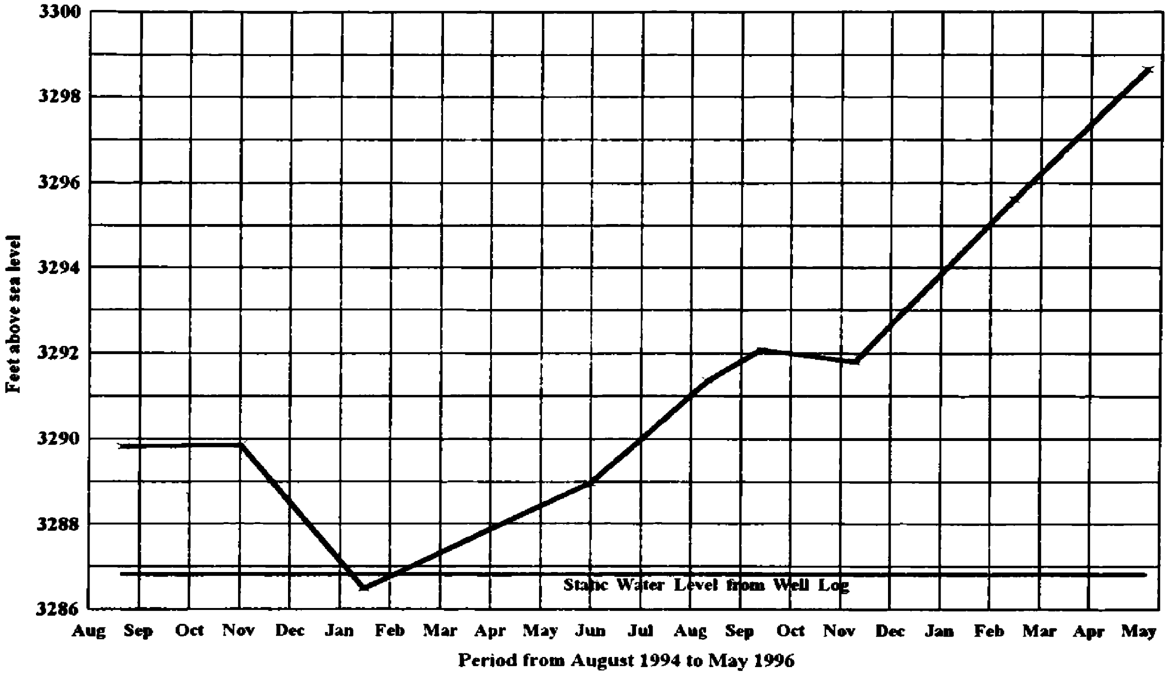
Date	Measurement
08/19/94	3298.9
11/02/94	3298.0
01/16/95	3296.8
03/27/95	3298.9
06/06/95	3298.9
08/17/95	3300.1
09/18/95	3300.1
11/17/95	3304.1



Well identification: 8M42, M:63530
Location: T10NR19W S18 AAAB
Measuring point (feet above mean sea level): 3336.6
Measuring point (feet above land surface): 2.2

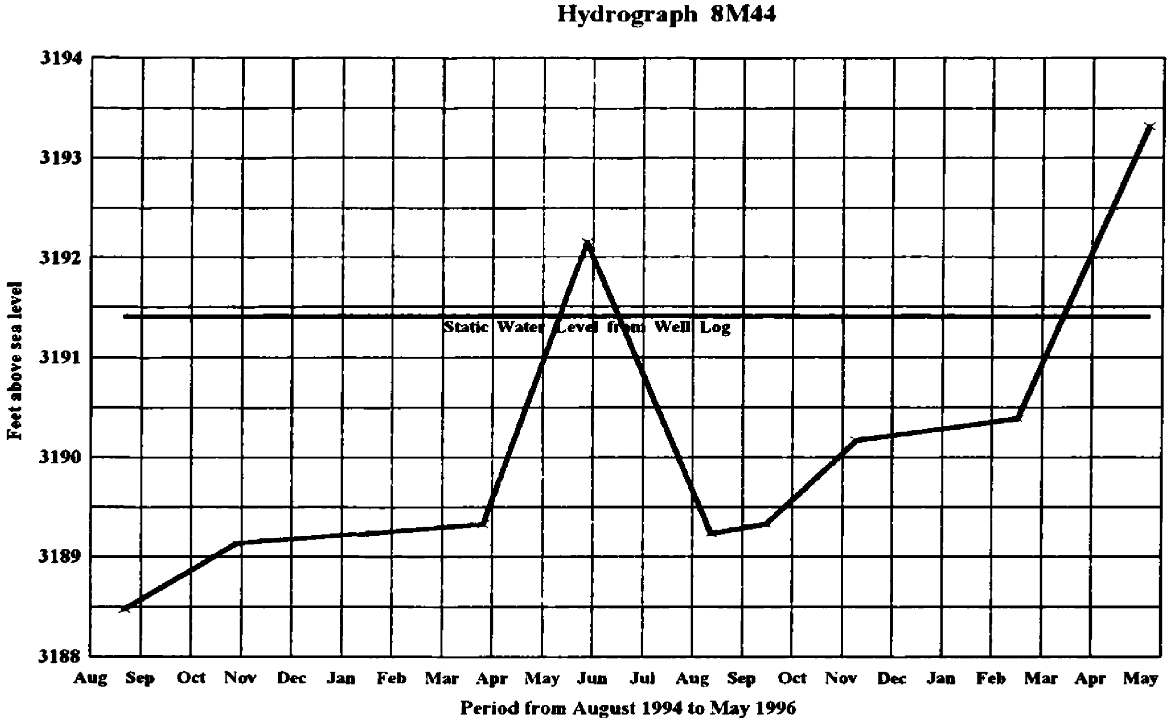
Date	Measurement
08/19/94	3292.5
11/02/94	3292.2
01/18/95	3290.0
04/05/95	3290.7
06/06/95	3293.1
08/19/95	3295.0
09/18/95	3295.5
11/17/95	3295.4
02/24/96	3299.2
05/16/96	3302.2

Hydrograph 8M43



Well identification: 8M43, M:132272
Location: T10NR19W S07 DDDB
Measuring point is top of casing (feet above mean sea level): 3326.8
Measuring point (feet above land surface): 1.7

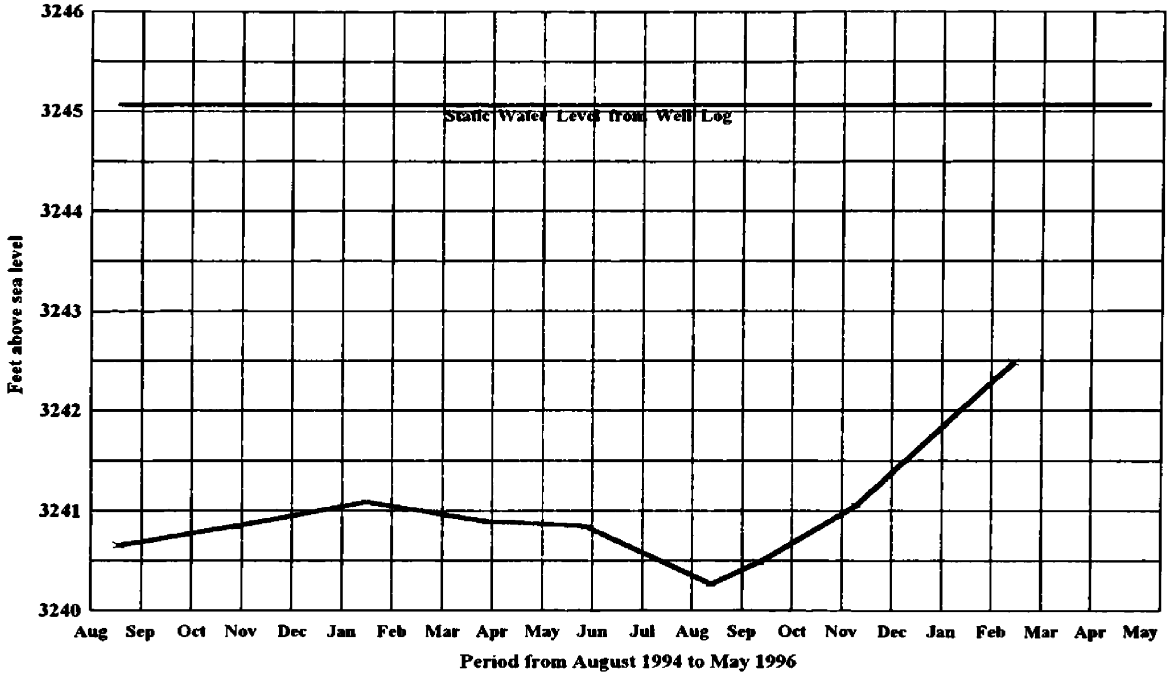
Date	Measurement
08/22/94	3289.8
11/02/94	3289.9
01/18/95	3286.5
06/06/95	3289.0
08/18/95	3291.4
09/20/95	3292.1
11/17/95	3291.8
02/24/96	3295.6
05/16/96	3298.7



Well identification: 8M44, M:64102
Location: T10NR20W S12 ACDD
Measuring point is top of casing (feet above mean sea level): 3216.4
Measuring point (feet above land surface): 2.8

Date	Measurement
08/22/94	3188.5
10/30/94	3189.1
01/16/95	3189.2
03/31/95	3189.3
06/03/95	3192.2
08/19/95	3189.2
09/22/95	3189.3
11/17/95	3190.2
02/25/96	3190.4
05/16/96	3193.3

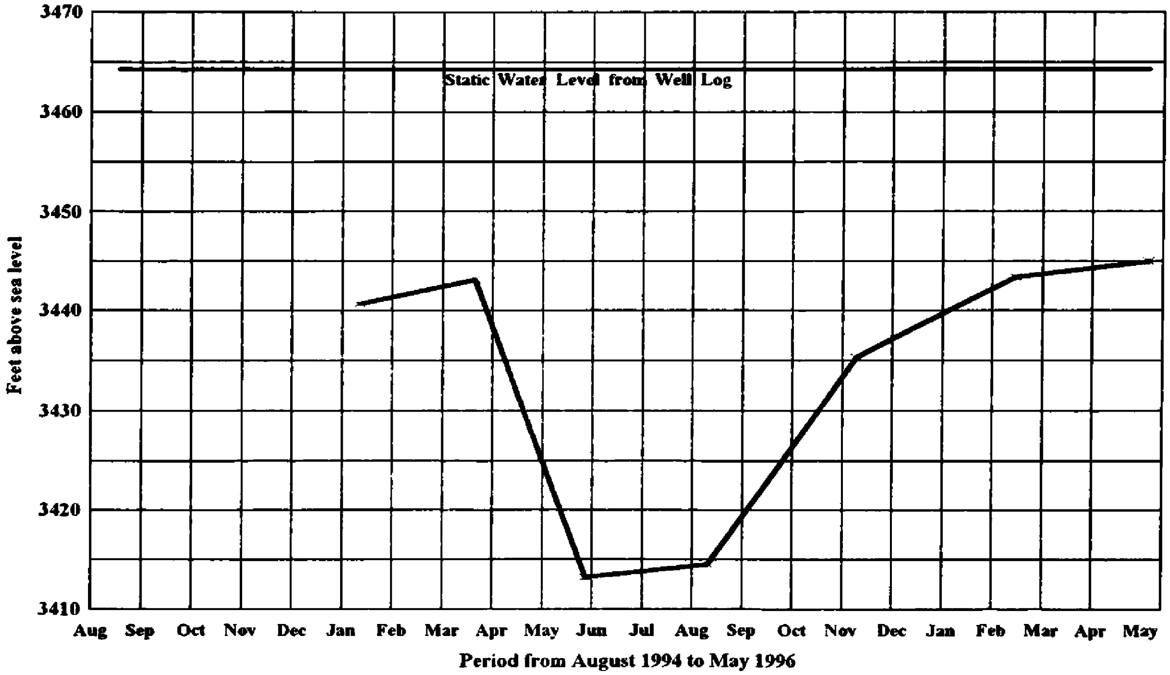
Hydrograph 8M46



Well identification: 8M46, M:132270
Location: T10NR19W S06 CDCB
Measuring point is top of casing (feet above mean sea level): 3291.1
Measuring point (feet above land surface): 2.4

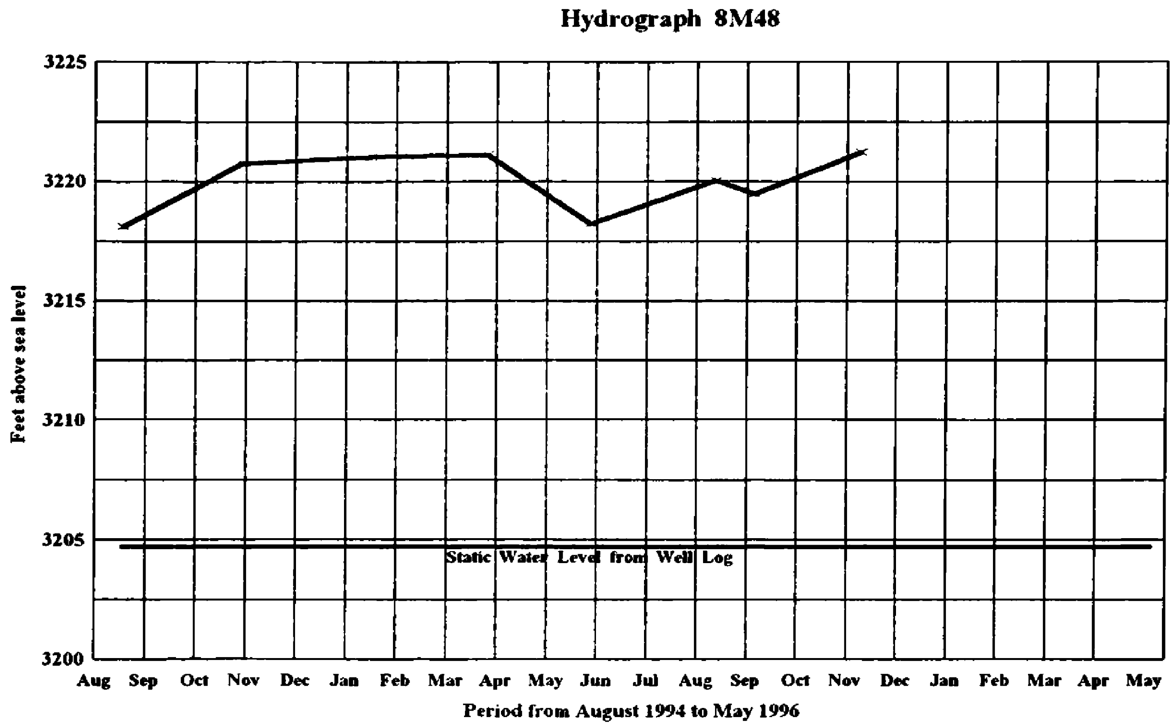
Date	Measurement
08/18/94	3240.7
10/30/94	3240.9
01/18/95	3241.1
03/31/95	3240.9
06/03/95	3240.9
08/19/95	3240.3
09/18/95	3240.5
11/17/95	3241.1
02/23/96	3242.5

Hydrograph 8M47



Well identification: 8M47, M:128879
Location: T10NR19W S09 BCCC
Measuring point is top of casing (feet above mean sea level): 3494.3
Measuring point (feet above land surface): 2.0

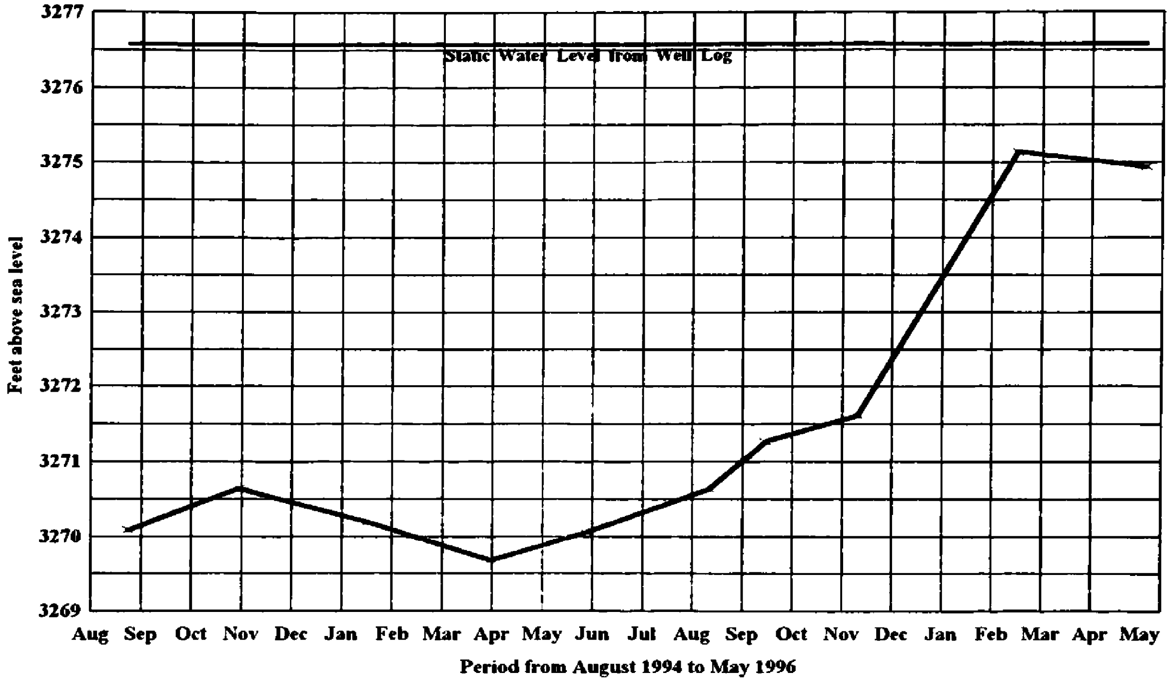
Date	Measurement
01/14/95	3440.7
03/26/95	3443.2
06/03/95	3413.2
08/17/95	3414.6
11/17/95	3435.4
02/24/96	3443.5
05/16/96	3445.1



Well identification: 8M48, M:63476
Location: T10NR19W S07 BABC
Measuring point is top of casing (feet above mean sea level): 3284.7
Measuring point (feet above land surface): 1.8

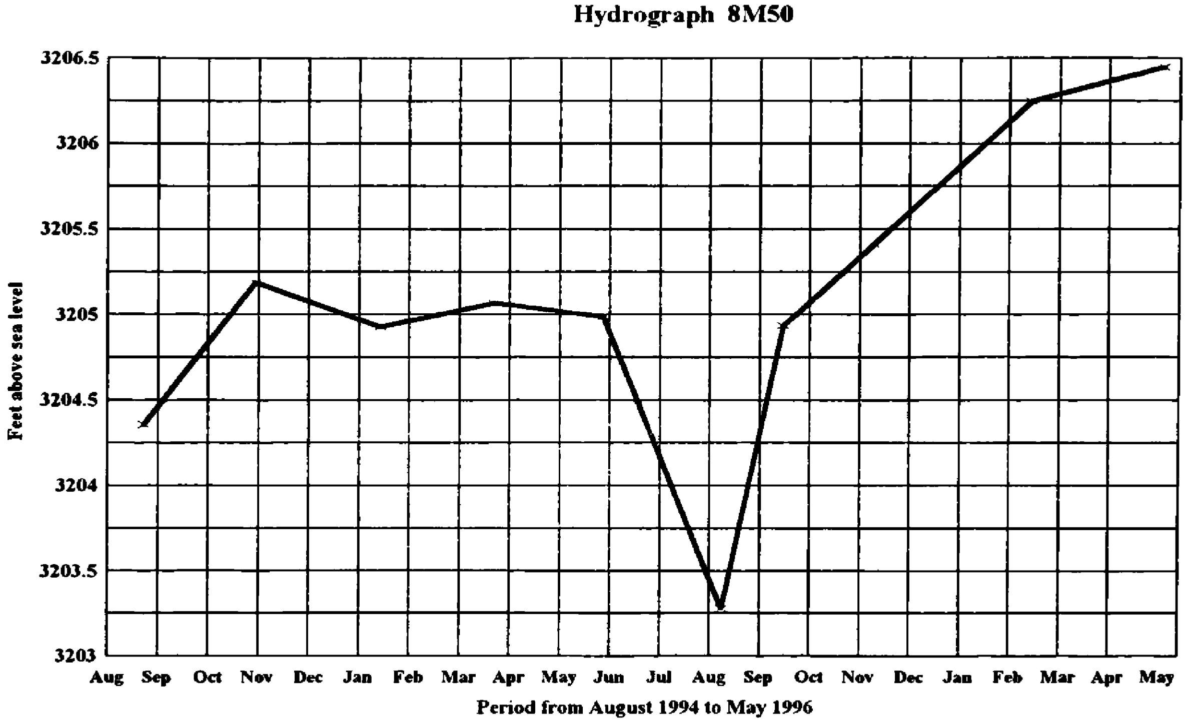
Date	Measurement
08/18/94	3218.1
10/30/94	3220.8
01/18/95	3221.1
03/31/95	3221.2
06/03/95	3218.2
08/19/95	3220.1
09/12/95	3219.5
11/17/95	3221.3

Hydrograph 8M49



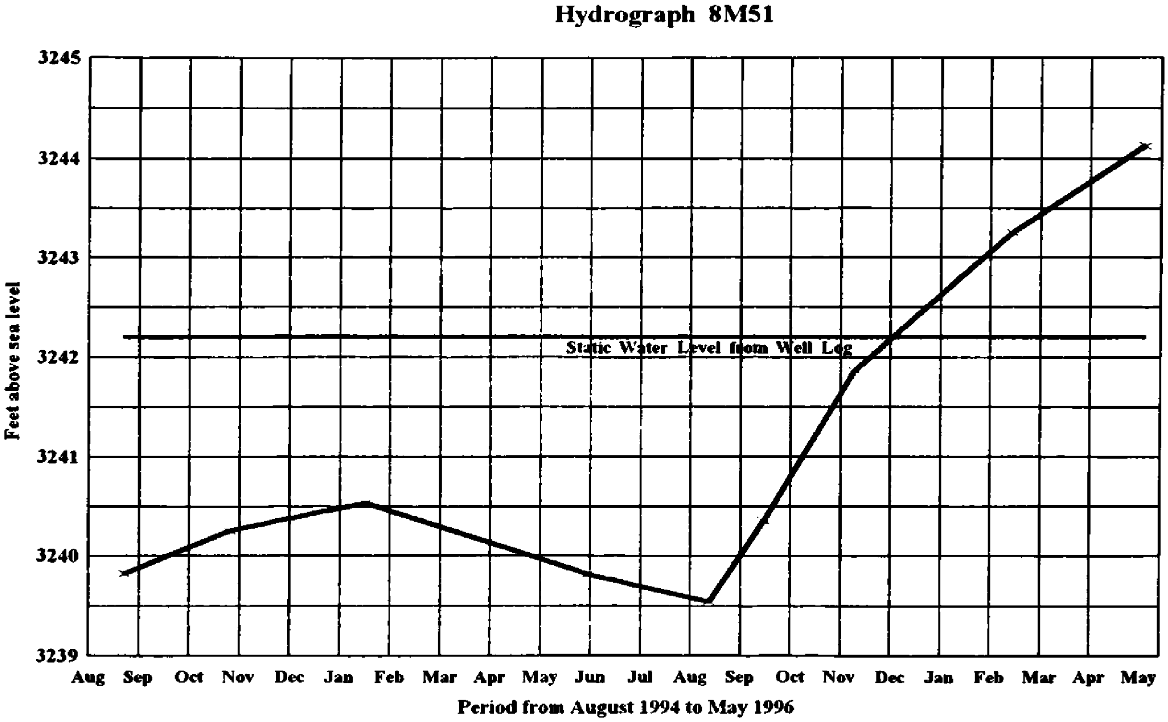
Well identification: 8M49, M:63880
Location: T10NR19W S07 CDAA
Measuring point access port (feet above mean sea level): 3297.6
Measuring point (feet above land surface): 2.4

Date	Measurement
08/24/94	3270.1
10/31/94	3270.6
01/19/95	3270.2
04/05/95	3269.7
06/03/95	3270.1
08/18/95	3270.6
09/22/95	3271.3
11/18/95	3271.6
02/25/96	3275.1
05/15/96	3275.0



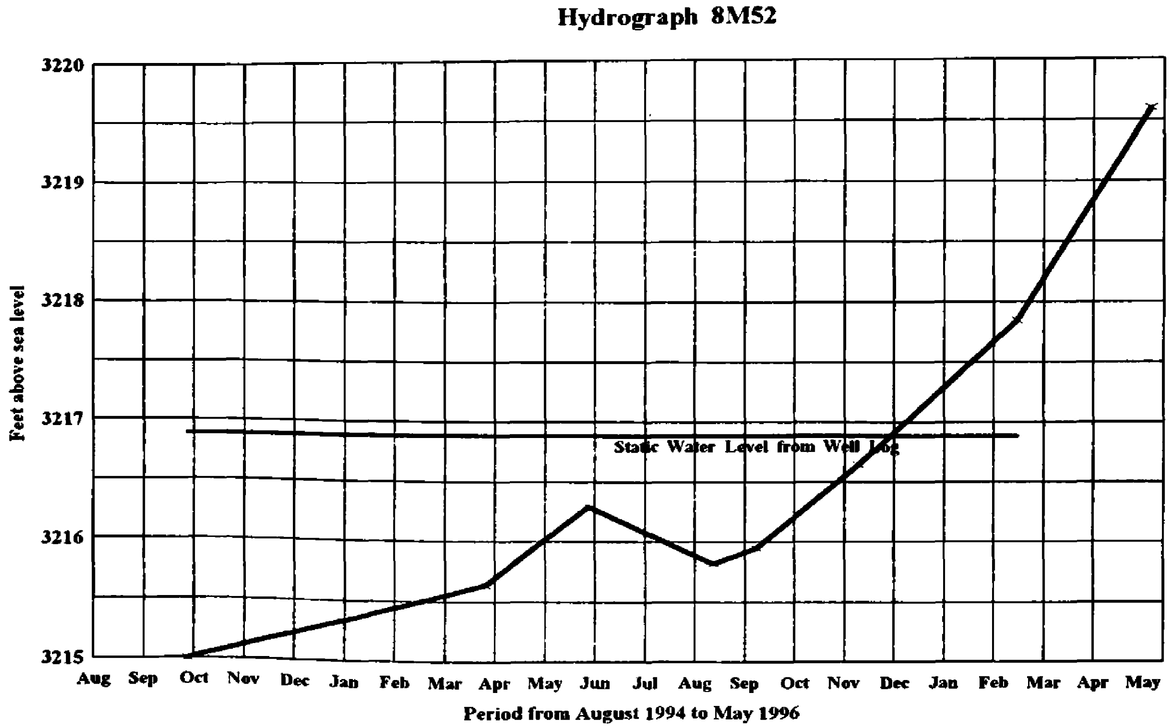
Well identification: 8M50
Location: T10NR19W S08 BADD
Measuring point is top of casing (feet above mean sea level): 3444.6
Measuring point (feet above land surface): 2.4

Date	Measurement
08/23/94	3204.4
10/31/94	3205.2
01/16/95	3204.9
03/27/95	3205.1
06/03/95	3205.0
08/15/95	3203.3
09/22/95	3204.9
11/17/95	3205.4
02/23/96	3206.2
05/15/96	3206.4



Well identification: 8M51, M:26601
Location: T10NR19W S07 BDDA
Measuring point is top of casing (feet above mean sea level): 3308.2
Measuring point (feet above land surface): 2.0

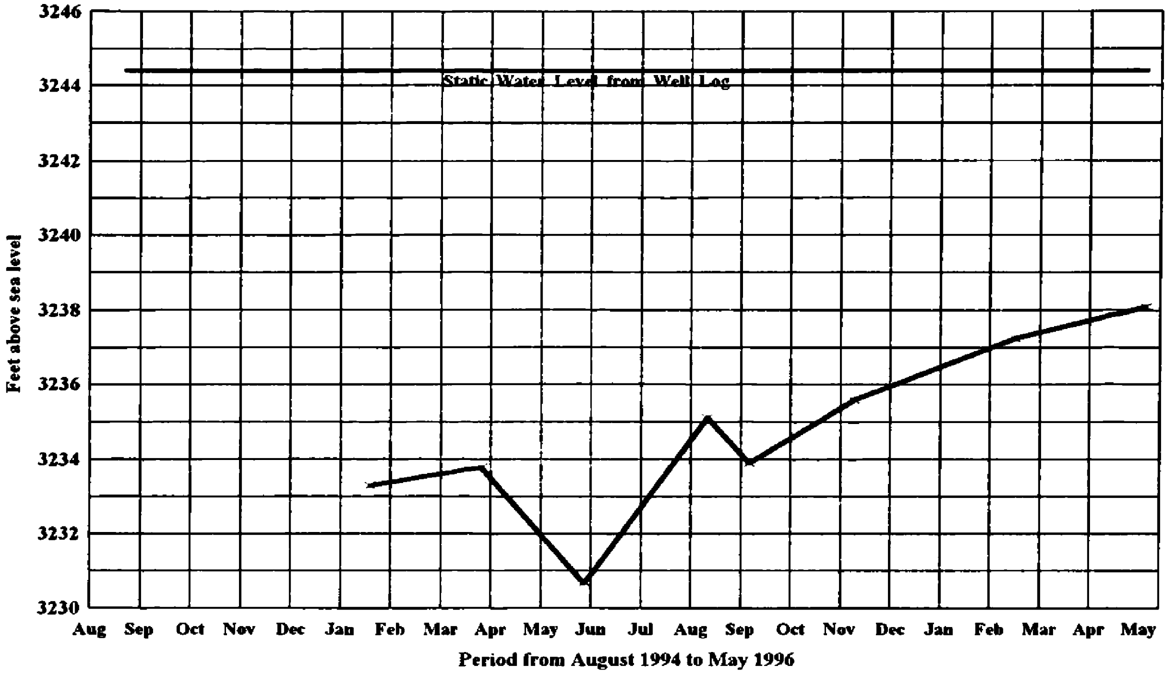
Date	Measurement
08/23/94	3239.8
10/27/94	3240.3
01/19/95	3240.5
06/05/95	3239.8
08/19/95	3239.6
09/22/95	3240.4
11/17/95	3241.9
02/23/96	3243.3
05/15/96	3244.1



Well identification: 8M52, M:151321
Location: T10NR20W S12 DDDD
Measuring point is top of casing (feet above mean sea level): 3221.9
Measuring point (feet above land surface): 1.2

Date	Measurement
09/28/94	3215.0
03/31/95	3215.6
06/03/95	3216.3
08/19/95	3215.8
09/15/95	3216.0
11/17/95	3216.6
02/24/96	3217.8
05/17/96	3219.6

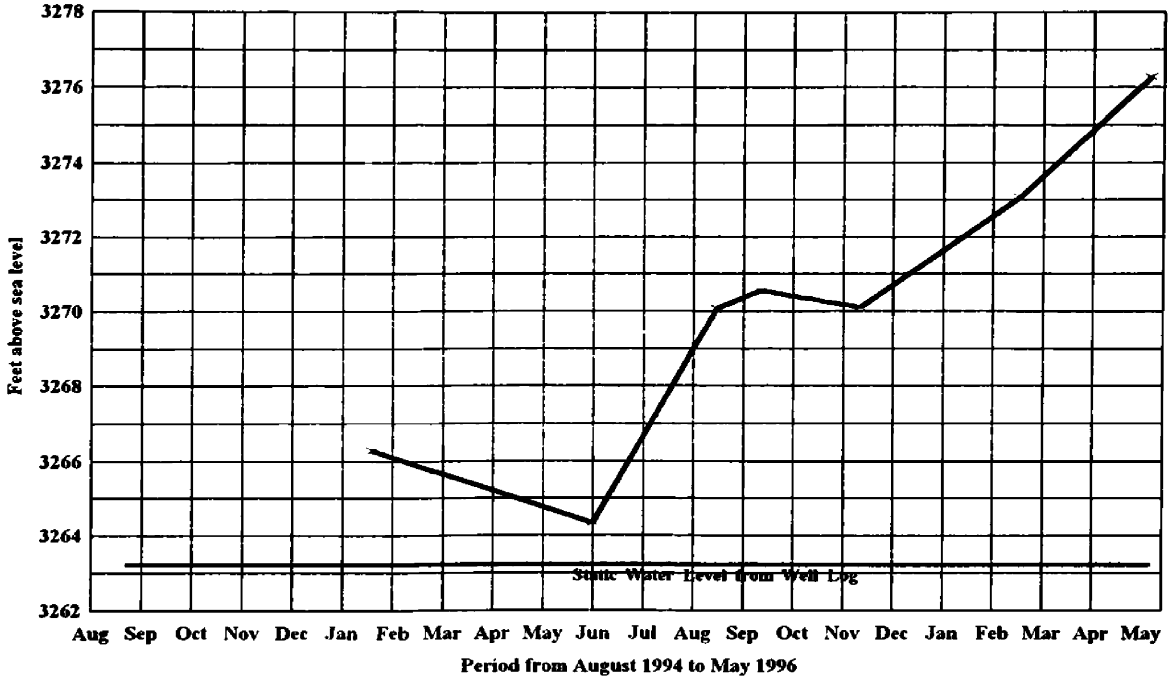
Hydrograph 8M53



Well identification: 8M53, M:151323
Location: T10NR19W S07 CDCC
Measuring point is top of casing (feet above mean sea level): 3269.4
Measuring point (feet above land surface): 2.1

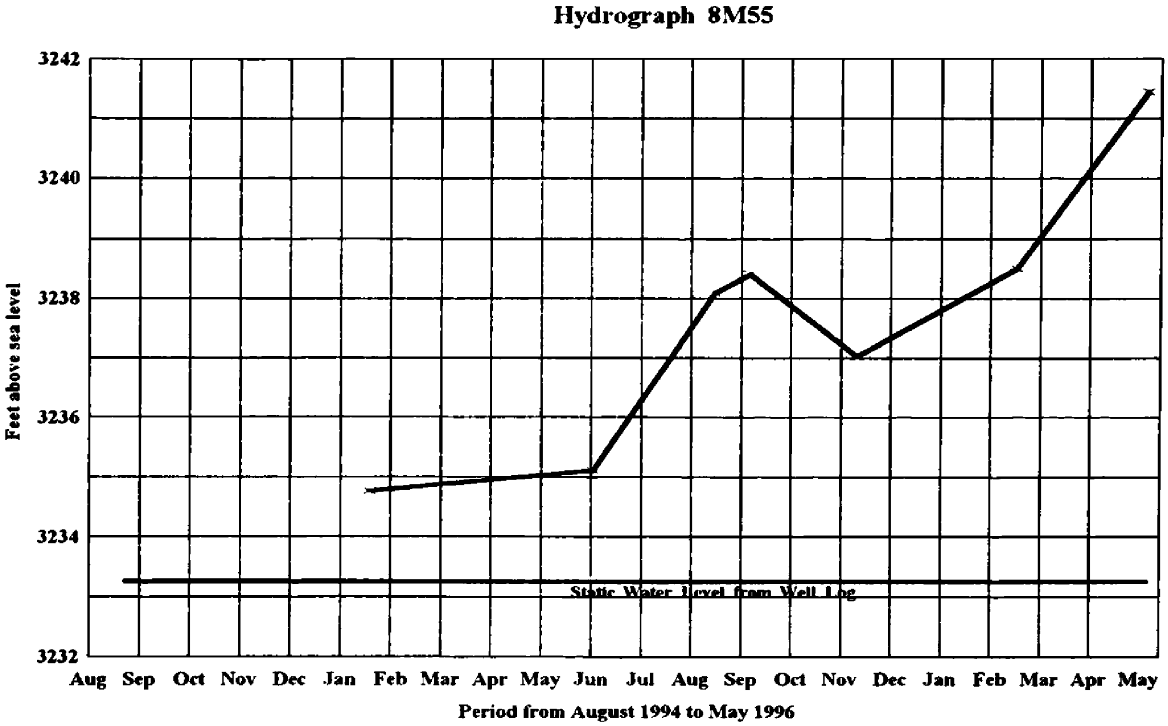
Date	Measurement
01/21/95	3233.3
03/31/95	3233.8
06/03/95	3230.7
08/18/95	3235.1
09/13/95	3233.9
11/17/95	3235.6
02/25/96	3237.2
05/16/96	3238.1

Hydrograph 8M54



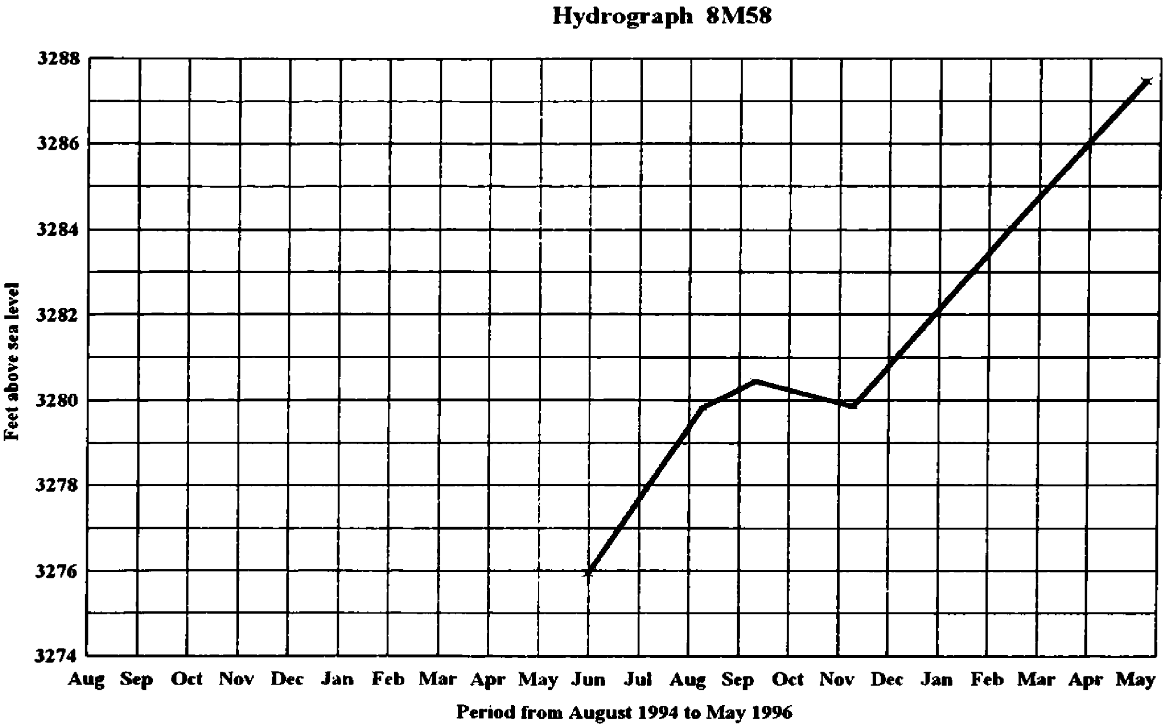
Well identification: 8M54, M:124575
Location: T10NR19W S18 ADCA
Measuring point is top of casing (feet above mean sea level): 3353.2
Measuring point (feet above land surface): 1.3

Date	Measurement
01/21/95	3266.3
06/06/95	3264.4
08/22/95	3270.1
09/18/95	3270.6
11/19/95	3270.1
02/26/96	3273.1
05/17/96	3276.3



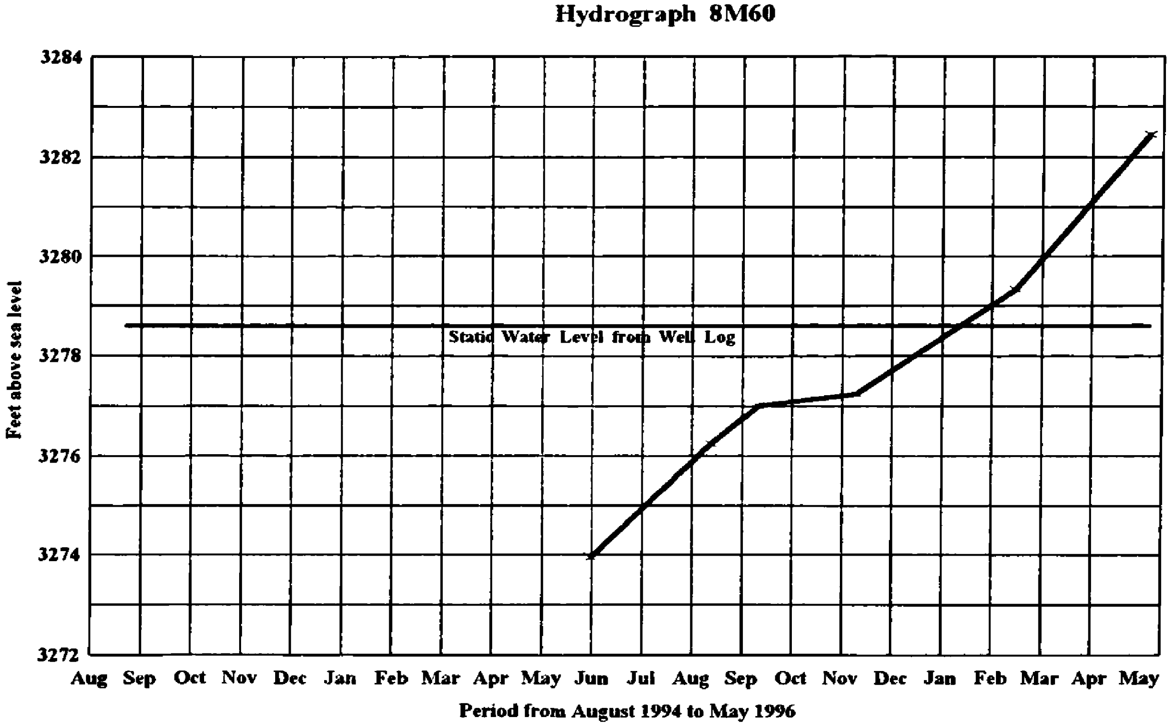
Well identification: 8M55, M:151322/130919
Location: T10NR19W S18 ACCD
Measuring point is top of casing (feet above mean sea level): 3307.3
Measuring point (feet above land surface): 1.4

Date	Measurement
01/21/95	3234.8
06/08/95	3235.1
08/22/95	3238.1
09/13/95	3238.4
11/19/95	3237.0
02/26/96	3238.5
05/17/96	3241.5



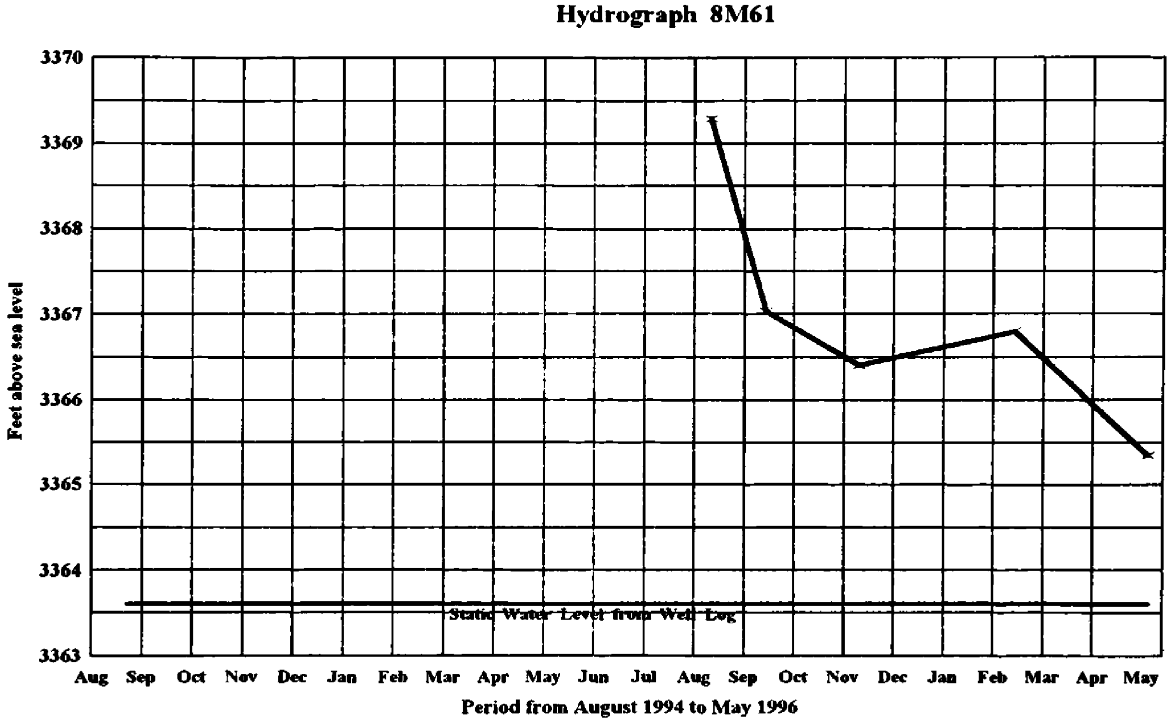
Well identification: 8M58
Location: T10NR19W S18 ABAD
Measuring point is top of casing (feet above mean sea level): 3311.6
Measuring point (feet above land surface): 1.5

Date	Measurement
06/06/95	3276.0
08/16/95	3279.8
09/18/95	3280.5
11/17/95	3279.9
02/23/96	3284.0
05/16/96	3287.5



Well identification: 8M60, M:63573
Location: T10NR19W S17 BCCC
Measuring point is top of casing (feet above mean sea level): 3372.6
Measuring point (feet above land surface): 1.4

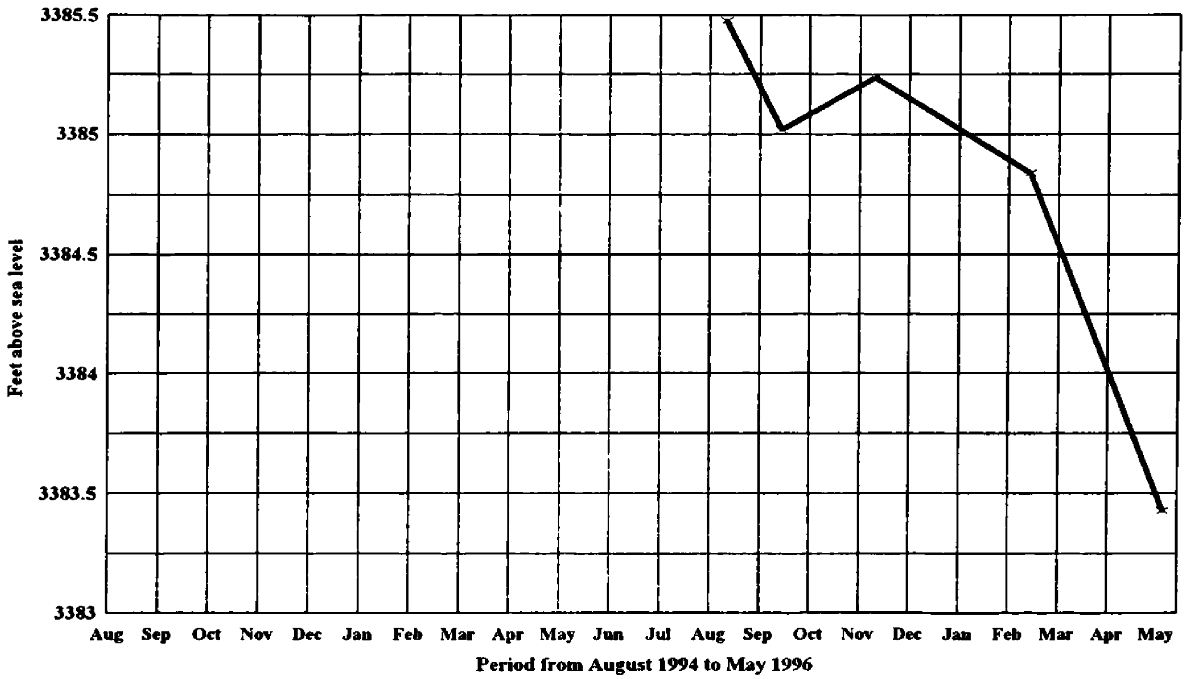
Date	Measurement
06/06/95	3274.0
08/19/95	3276.2
09/18/95	3277.0
11/17/95	3277.2
02/24/96	3279.3
05/17/96	3282.5



Well identification: 8M61, M:63431
Location: T10NR19W S05 CCCC
Measuring point access port (feet above mean sea level): 3381.6
Measuring point (feet above land surface): 1.3

Date	Measurement
08/18/95	3369.3
09/21/95	3367.0
11/18/95	3366.4
02/23/96	3366.8
05/16/96	3365.4

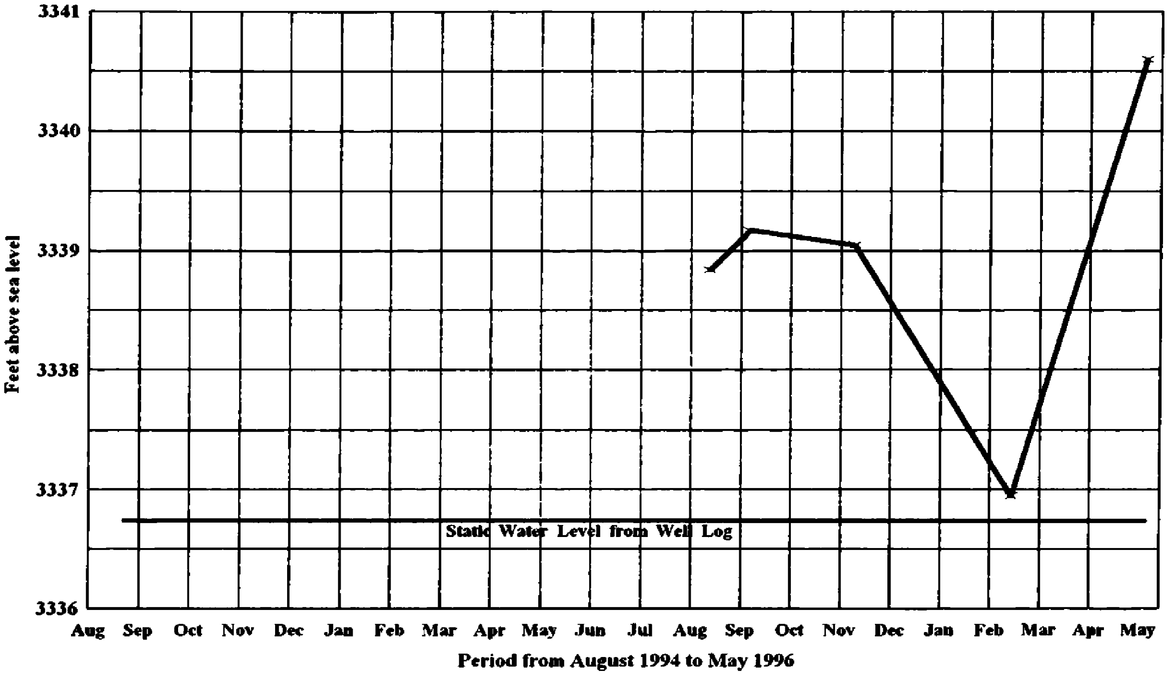
Hydrograph 8M62



Well identification: 8M62
Location: T10NR19W S05 CCCD
Measuring point square access port around pipes (feet above mean sea level): 3390.9
Measuring point (feet above land surface): 2.6

Date	Measurement
08/18/95	3385.5
09/21/95	3385.0
11/18/95	3385.2
02/23/96	3384.8
05/16/96	3383.4

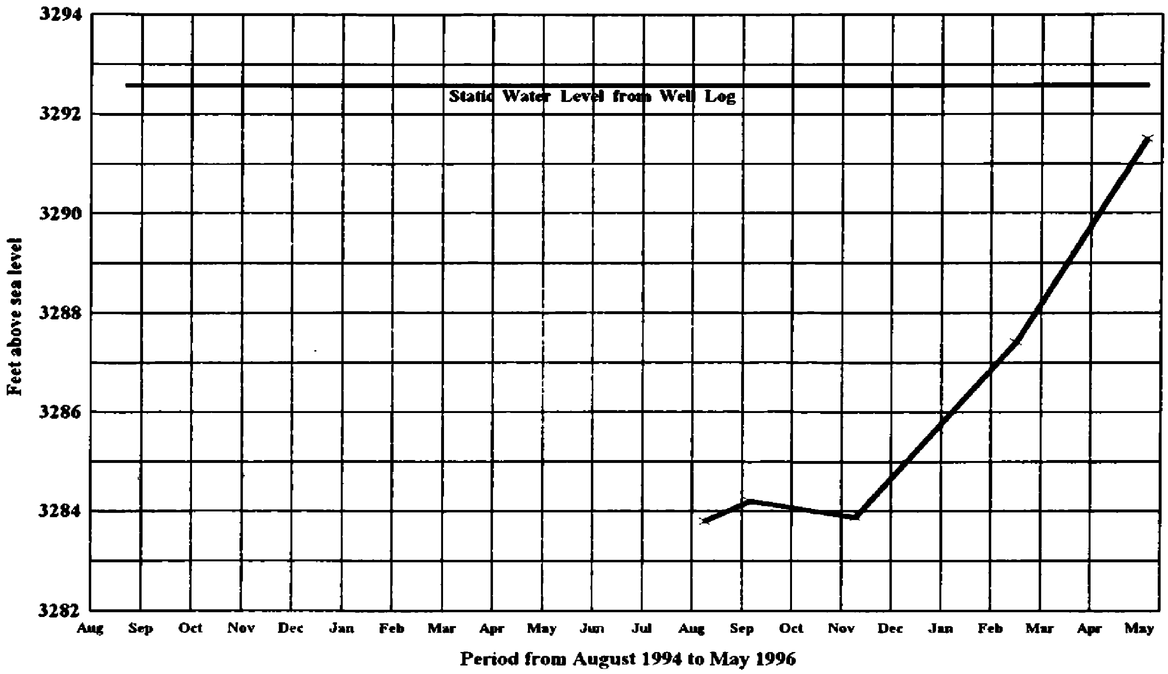
Hydrograph 8M65



Well identification: 8M65, M:138444
Location: T10NR19W S08 DCCA
Measuring point is top of casing (feet above mean sea level): 3456.7
Measuring point (feet above land surface): 1.9

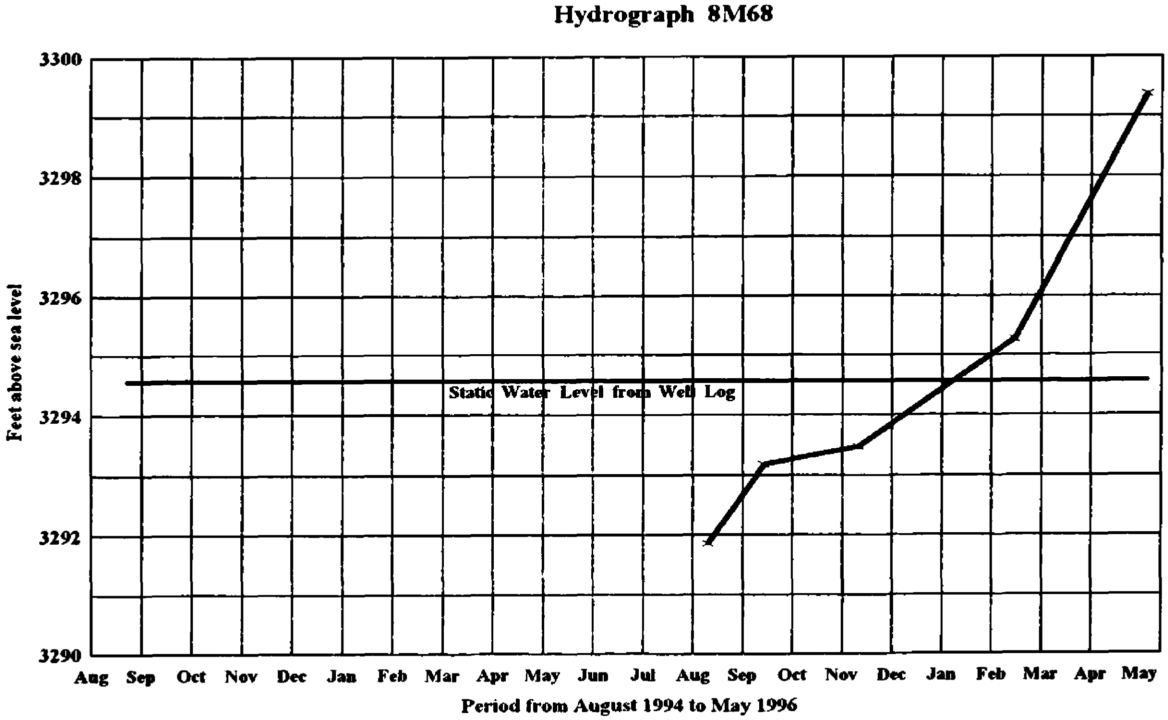
Date	Measurement
08/19/95	3338.8
09/13/95	3339.2
11/17/95	3339.0
02/23/96	3337.0
05/16/96	3340.6

Hydrograph 8M67



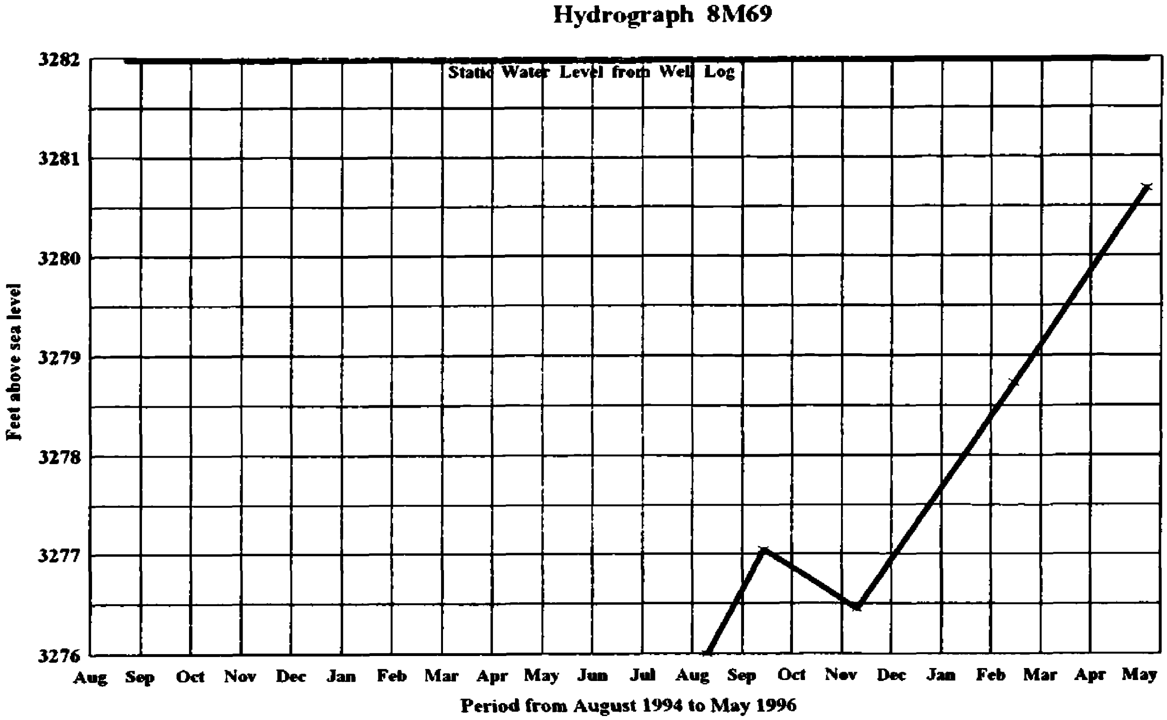
Well identification: 8M67, M:63596
Location: T10NR19W S18 AADB
Measuring point is top of casing (feet above mean sea level): 3328.6
Measuring point (feet above land surface): 1.8

Date	Measurement
08/16/95	3283.8
09/13/95	3284.2
11/17/95	3283.9
02/25/96	3287.4
05/16/96	3291.5



Well identification: 8M68, M:124552
Location: T10NR19W S07 DBDA
Measuring point access port (feet above mean sea level): 3332.6
Measuring point (feet above land surface): 1.7

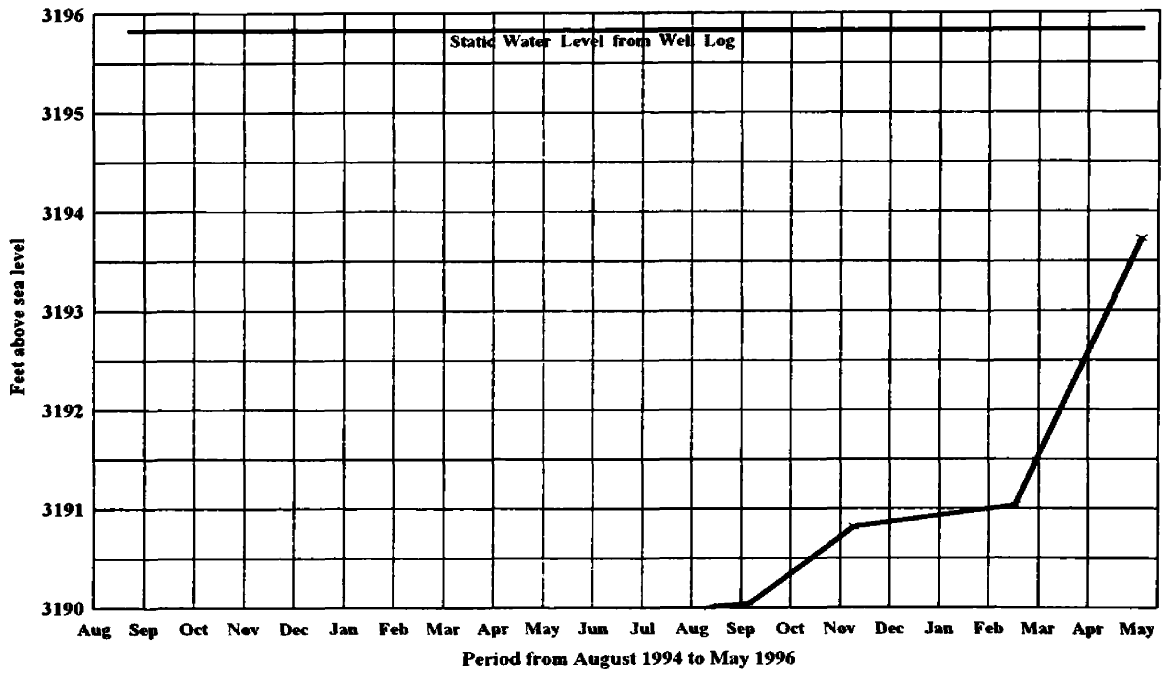
Date	Measurement
08/17/95	3291.9
09/21/95	3293.2
11/19/95	3293.5
02/24/96	3295.3
05/16/96	3299.4



Well identification: 8M69, M:124557
Location: T10NR19W S07 DABB
Measuring point is top of casing (feet above mean sea level): 3342.0
Measuring point (feet above land surface): 1.6

Date	Measurement
08/17/95	3276.0
09/21/95	3277.0
11/18/95	3276.4
02/24/96	3278.7
05/16/96	3280.7

Hydrograph 8M71



Well identification: 8M71, M:64103/151318

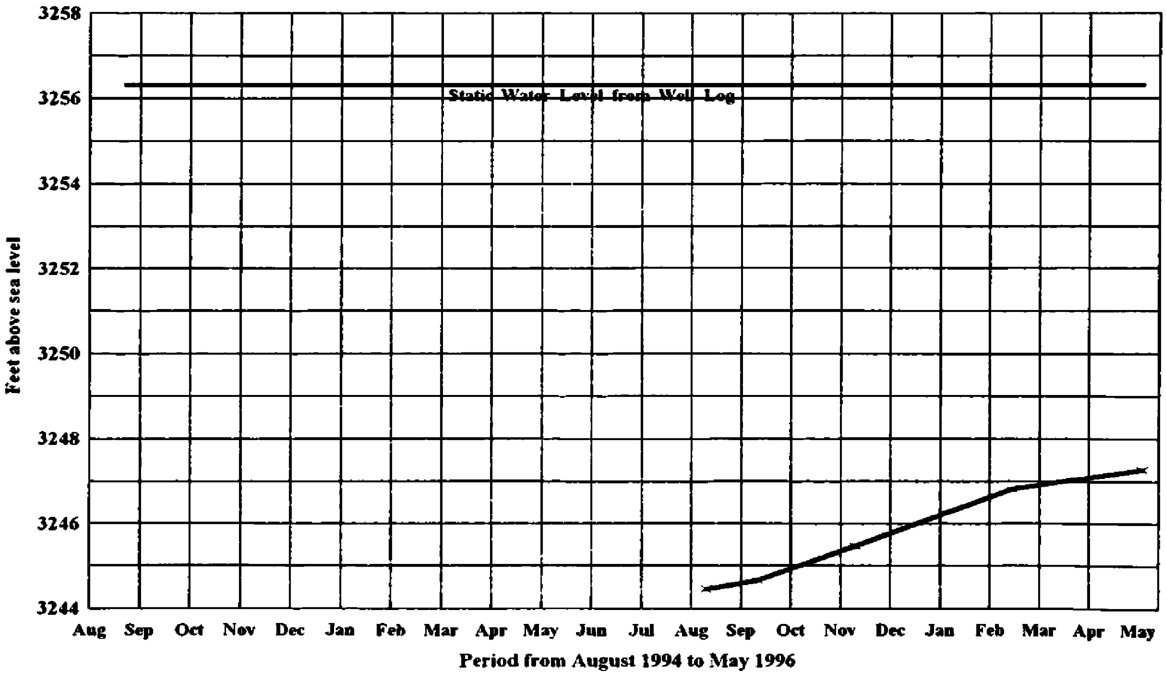
Location: T10NR20W S12 ADCA

Measuring point is access port (feet above mean sea level): 3227.8

Measuring point (feet above land surface): 1.5

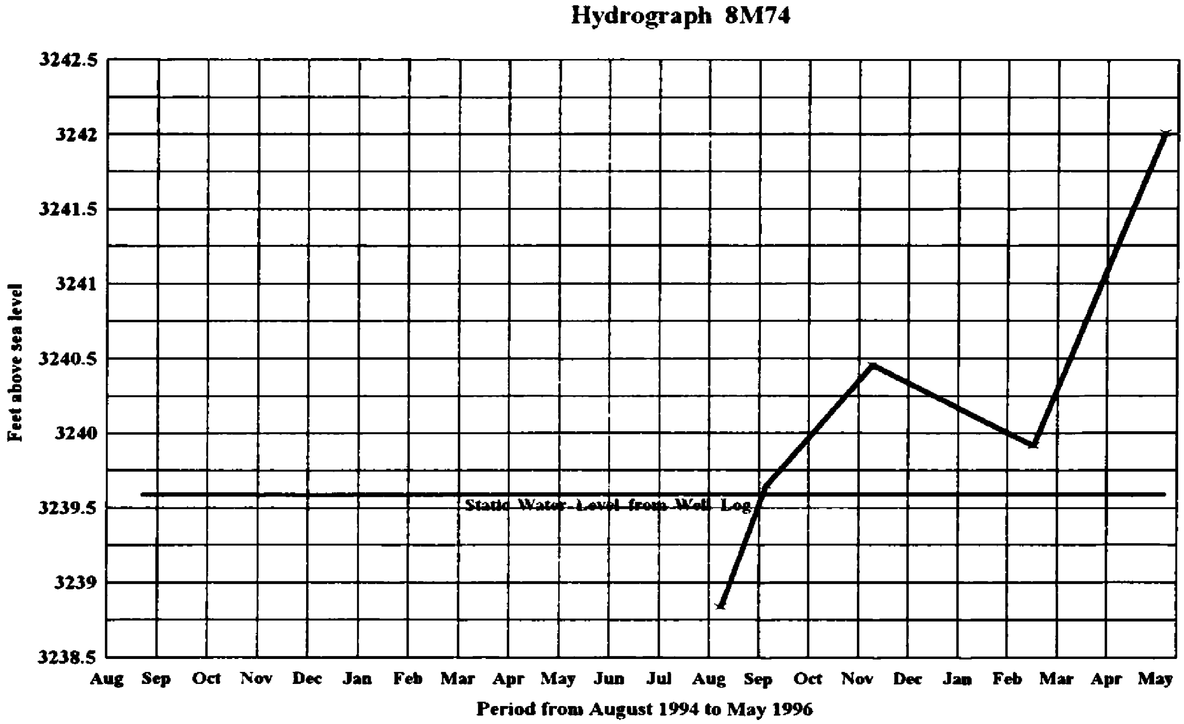
Date	Measurement
08/19/95	3190.0
09/13/95	3190.0
11/17/95	3190.8
02/26/96	3191.0
05/15/96	3193.7

Hydrograph 8M72



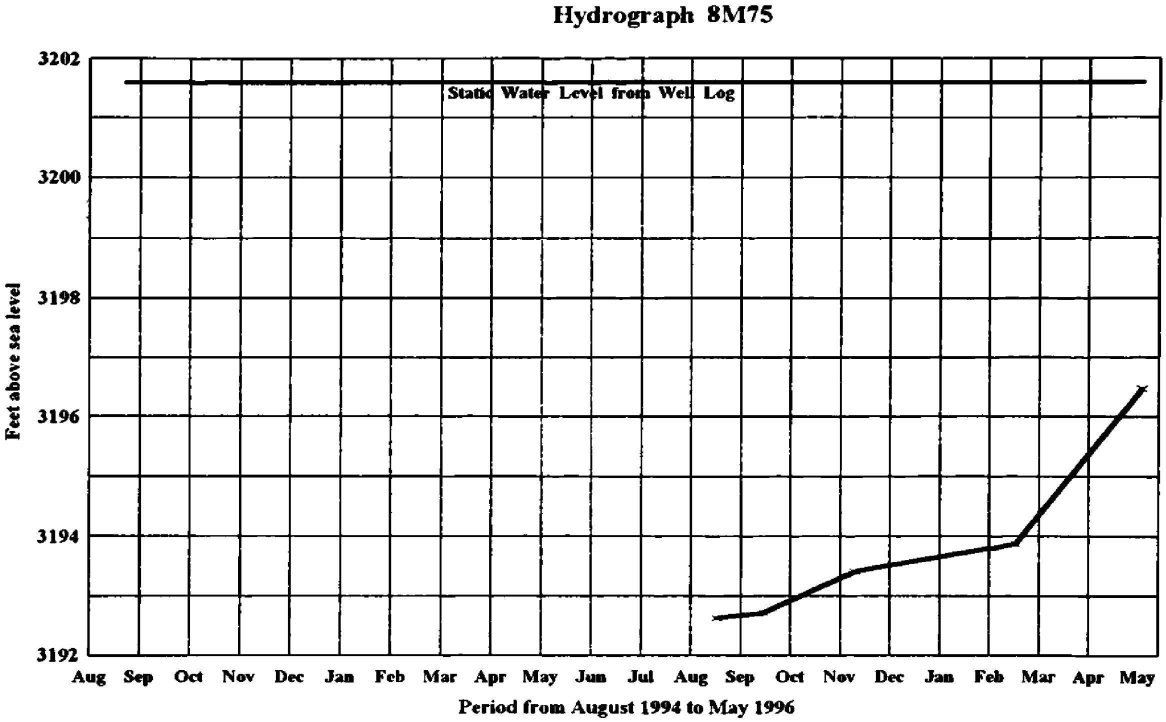
Well identification: 8M72, M:63422
Location: T10NR19W S06 CDDA
Measuring point is top of casing (feet above mean sea level): 3307.3
Measuring point (feet above land surface): 1.1

Date	Measurement
08/17/95	3244.5
09/18/95	3244.7
11//18/95	3245.5
02/23/96	3246.8
05/15/96	3247.3



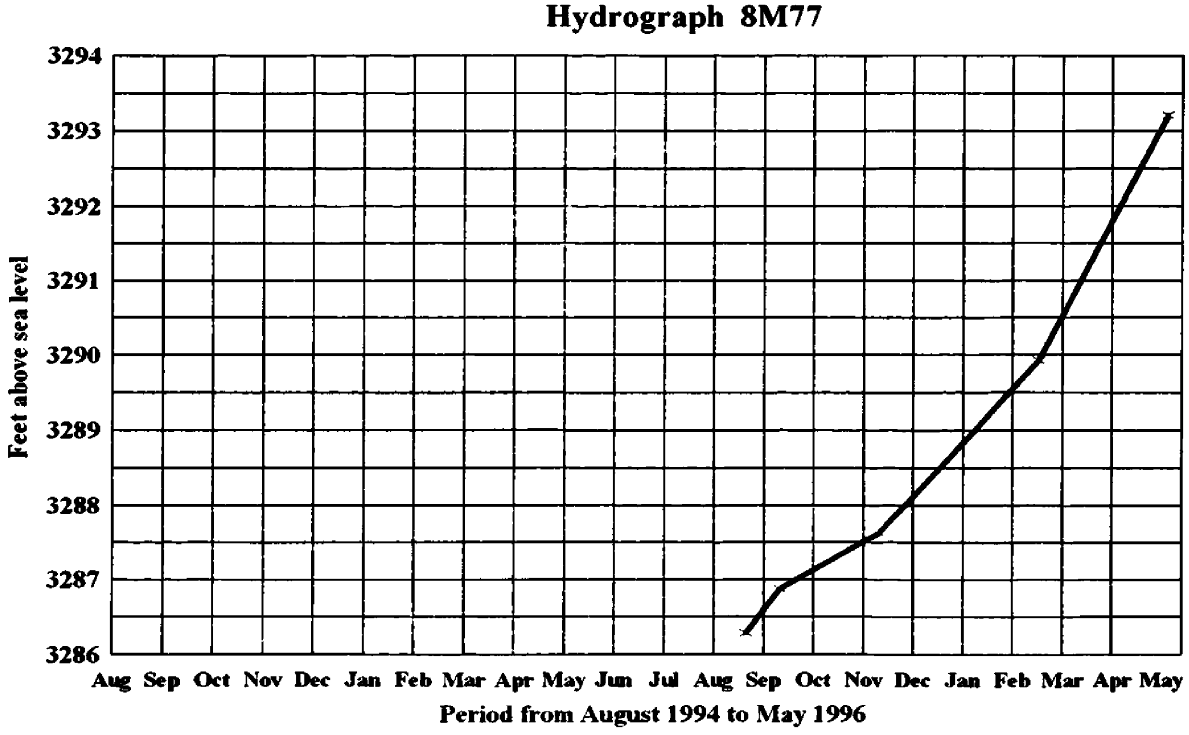
Well identification: 8M74, M:151313
Location: T10NR19W S08 DBBD
Measuring point is top of casing (feet above mean sea level): 3439.6
Measuring point (feet above land surface): 0.9

Date	Measurement
08/15/95	3238.8
09/12/95	3239.6
11//17/95	3240.5
02/26/96	3239.9
05/17/96	3242.0



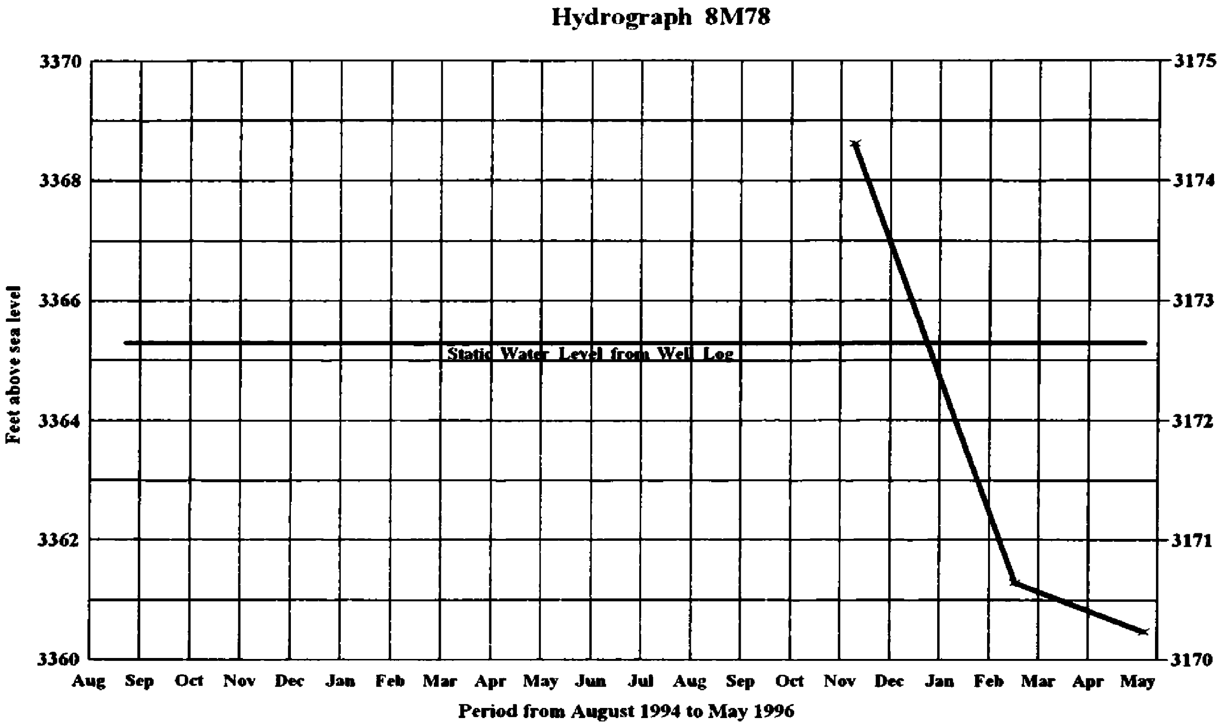
Well identification: 8M75, M:64117
Location: T10NR20W S12 DABD
Measuring point is access port (feet above mean sea level): 3228.6
Measuring point (feet above land surface): 2.3

Date	Measurement
08/24/95	3192.6
09/22/95	3192.7
11/18/95	3193.4
02/26/96	3193.9
05/15/96	3196.5



Well identification: 8M77
Location: T10NR19W S17 BCAB
Measuring point is top of casing (feet above mean sea level): 3382.9
Measuring point (feet above land surface): 1.2

Date	Measurement
08/28/95	3286.3
09/18/95	3286.9
11/18/95	3287.6
02/26/96	3289.9
05/16/96	3293.2



Well identification: 8M78, M:153228
Location: 10NR19W S08 ACAD
Measuring point is top of casing (feet above mean sea level): 3452.7
Measuring point (feet above land surface): 1.5
Static water level from well log plotted on right Y axis

Date	Measurement
11/17/95	3368.6
02/26/96	3361.3
05/16/96	3360.5

Appendix H: Radon Occurrence

Radon, a carcinogen, occurs in groundwater as the result of the radioactive decay of material in the aquifer matrix. Exposure pathways include inhaling aerosols released from water while showering. Currently, the EPA has not set a primary drinking water standard for radon. A standard is not expected to be issued until at least the year 2000 (U.S. EPA Safe Drinking Water Hotline, 1998). EPA's 1994 list of national primary drinking water standards included a proposed standard for radon of 300 pico Curies per liter (pCi/L).

In September 1995, 13 groundwater samples were collected at various Eight Mile monitoring wellheads and sent to the Montana Bureau of Mines and Geology in Butte, MT for radon analysis. The following table lists findings.

Well ID	Flow Zone	Date	Radon 222 (pCi/L)
8M53	EM-1-Hidden Valley	9/13/95	410.
8M55	EM-1-Hidden Valley	9/13/95	660.
8M18	EM-1-Hidden Valley	9/13/95	510.
8M65	EM-1-Hidden Valley	9/13/95	550.
8M39	EM-1-Hidden Valley	9/15/95	650.
8M67	EM-1-Hidden Valley	9/13/95	810.
8M48	EM-1-Main	9/12/95	500.
8M29	EM-1-Main	9/15/95	760.
8M52	EM-1-River	9/15/95	580.
8M71	EM-1-River	9/13/95	1080.
8M4	EM-1-Terrace Base	9/12/95	1080.
8M19	EM-2	9/13/95	710.
8M74	EM-2	9/12/95	810.

Two methods of radon abatement exist: the first is aeration of water before it enters the house, and the second is carbon filtration (U.S. EPA Safe Drinking Water Hotline, 1998). Interested readers can contact the Radon Hotline at (1-800-55RADON at the time of writing) for more information.

Appendix I: Selected Well Logs

The following are well logs for this study's wells:

ID Number	Well Log Name	History
CW3	Mark Finlay	Well is 220 feet deep
CW4A-1	Todd Peters	Original well 107 feet deep, collapsed, replaced with CW4B
CW4A-2	Todd Peters	Legal description is the same as CW4A-1 and CW4B, located nearby those wells, 225 feet deep
CW4B	Todd Peters	Replacement well, depth is 131 feet
CW5	H. Stanley Antrim	Log to 390 feet deep
MDVHON	Nick Bickish	Stratigraphy similar to White Cliffs area

CW3
WELL LOG REPORT

Form No. 603 (R 2-86)

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 MARK FINLAY

2. CURRENT MAILING ADDRESS
5629 Cottonwood Dr.
Florence, MT 59833

3. WELL LOCATION
____ ¼ ____ ¼ ____ ¼ Section ____
Township ____ N/S Range ____ E/W County Ravalli
Gov't Lot ____, or Lot 6B, Block 2
Subdivision Name Riverview Orchards
Tract Number Plat # 344

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

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

6. DIMENSIONS: Diameter of Hole
Dia. 6 in. from g.l. ft. to 220 ft.
Dia. ____ in. from ____ ft. to ____ ft.
Dia. ____ in. from ____ ft. to ____ ft.

7. CONSTRUCTION DETAILS:
Casing; Steel Dia. 6" ID from +1½ ft. to 218 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 190 ft. to 195 ft.
____ perforations from ____ ft. to ____ 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 X Pump ____ Bailer ____
b) Static water level immediately before testing 86 ft. If flowing; closed-in pressure ____ psi. ____ gpm.
Flow controlled by: ____ valve, ____ reducers, ____ other, (specify) ____.
c) Depth at which pump is set for test 175
d) The pumping rate: 60 gpm.
e) Pumping water level 175 ft. at 1 hrs. after pumping began.
f) Duration of test: Pumping time 1 hrs.
g) Recovery time ____ hrs.
h) Recovery water level 86 ft. at 1 hrs. after 140 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	12	Sand, Gravel & Water
12	18	Clay
18	76	Sand & Clay
76	83	Sand & Watr
83	86	Sand, Small Gravel & Water
86	110	Sand & Water
110	115	Sand, small gravel & water
115	121	Sand & Water
121	146	Clay
146	172	Sand & Water
172	184	Clay
184	187	Sand & Water
187	195	Sand, small gravel & Water
195	209	Clay & Gravel
209	213	Sand & Water
213	220	Clay, Broken Rock & Water

ATTACH ADDITIONAL SHEETS IF NECESSARY

13. DATE COMPLETED December 1, 1989

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

December 5, 1989
Date

CAMP WELL DRILLING & PUMP SUPPLY
Firm Name

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

Signature
7
License No

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

DNRC

CW4A-1

Form No. 603 (R 2-89)

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 Todd [illegible]

2. CURRENT MAILING ADDRESS
[illegible]
[illegible] 59?33

3. WELL LOCATION
NW ¼ NW ¼ SE ¼ Section 8
Township 10 N/S Range 3 E/W County [illegible]
Govn't Lot ____, or Lot 25 A, Block 2
Subdivision Name [illegible]
Tract Number [illegible]

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

5. TYPE OF WORK:

New well	☒	Method: Dug	☐	Bored	☐
Deepened	☐	Cable	☐	Driven	☐
Reconditioned	☐	Rotary	☒	Jetted	☐

6. DIMENSIONS: Diameter of Hole
Dia. 6 in. from +18" ft. to 127 ft.
Dia. ____ in. from ____ ft. to ____ ft.
Dia. ____ in. from ____ ft. to ____ ft.

7. CONSTRUCTION DETAILS:
Casing; Steel Dia.____ from____ft. to____ft.
Threaded ☐ Welded ☒ Dia. 6 from +18" ft. to 127 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 ____
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? 18 ft.
Material used in grouting [illegible]

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 X Pump ____ Bailer ____
b) Static water level immediately before testing 62 ft. If flowing; closed-in pressure ____ psi. ____ gpm. Flow controlled by: ____ valve, ____ reducers, ____ other. (specify) ____
c) Depth at which pump is set for test ____
d) The pumping rate: 10 gpm.
e) Pumping water level ____ ft. at ____ hrs. after pumping began.
f) Duration of test: Pumping time 1 hrs.
g) Recovery time 2 min hrs.
h) Recovery water level 62 ft. at 2 min 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	1	[illegible]
1	50	[illegible]
50	55	[illegible]
55	70	[illegible]
70	73	[illegible]
73	126	[illegible]
126	127	[illegible]

ATTACH ADDITIONAL SHEETS IF NECESSARY

13. DATE COMPLETED [illegible] 13 19??

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

[illegible]
Date

Firm Name [illegible]

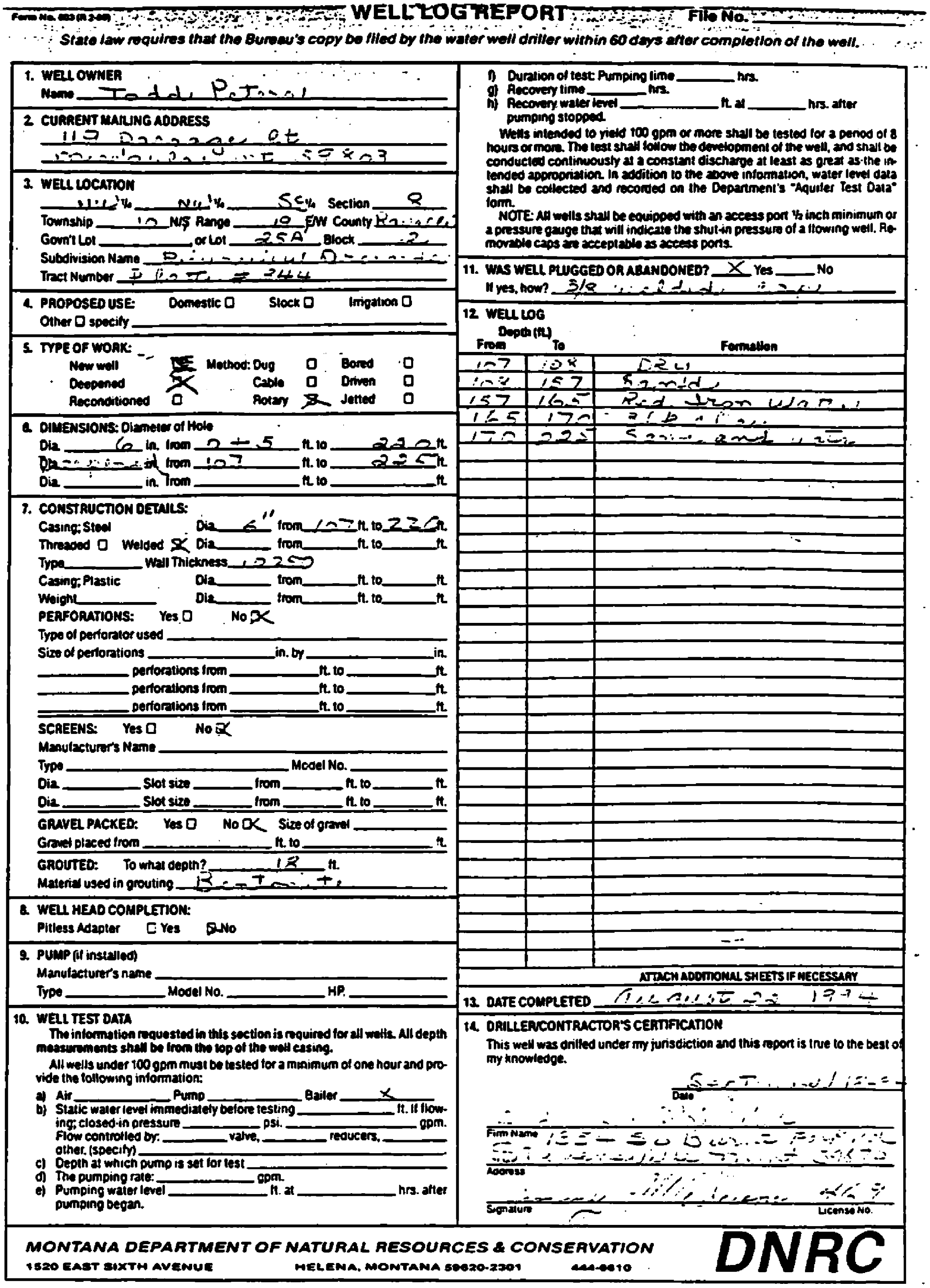
Address

Signature [illegible] License No. [illegible]

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

DNRC

CW4A-2



Form No. 603 (R 2-88) **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 Todd Pet[illegible]

2. CURRENT MAILING ADDRESS
119 [illegible]
[illegible] 59803

3. WELL LOCATION
NW ¼ NW ¼ SE ¼ Section 8
Township 10 N/S Range 19 E/W County [illegible]
Gov't Lot ______, or Lot 25A Block 2
Subdivision Name [illegible]
Tract Number [illegible] # 244

4. PROPOSED USE: Domestic ☐ Stock ☐ Irrigation ☐
Other ☐ specify ______

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

6. DIMENSIONS: Diameter of Hole
Dia. 6 in. from 0 + 5 ft. to 220 ft.
Dia. [illegible] in. from 107 ft. to 225 ft.
Dia. ______ in. from ______ ft. to ______ ft.

7. CONSTRUCTION DETAILS:
Casing; Steel Dia. 6" from 107 ft. to 220 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 ______
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? 18 ft.
Material used in grouting Bentonite

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 ______ Bailer X
b) Static water level immediately before testing ______ ft. If flowing; closed-in pressure ______ psi. ______ gpm.
Flow controlled by: ______ valve, ______ reducers, ______ other, (specify) ______
c) Depth at which pump is set for test ______
d) The pumping rate: ______ gpm.
e) Pumping water level ______ ft. at ______ hrs. after pumping began.
f) Duration of test: Pumping time ______ hrs.
g) Recovery time ______ hrs.
h) Recovery water level ______ 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? X Yes ______ No
If yes, how? 3/8 [illegible]

12. WELL LOG

Depth (ft.) From	To	Formation
107	108	Dry
108	157	Sandy
157	165	Red Iron Water
165	170	[illegible]
170	225	Sand and [illegible]

ATTACH ADDITIONAL SHEETS IF NECESSARY

13. DATE COMPLETED August 2[illegible] 1994

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

Sept. [illegible] 1994
Date

[illegible]
Firm Name

[illegible]
Address

[illegible] 469
Signature License No.

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

CW4-B

Form No. 603 (R 3-88)

WELL LOG REPORT

File No. 39772

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 Todd Peters

2. CURRENT MAILING ADDRESS
119 Passage Ct
Missoula, MT 59801

3. WELL LOCATION
Corner ¼ ¼ Section 7
Township 10 [✓ N]/S Range 19 E/[✓ W] County Rav.
Govn't Lot or Lot Block
Subdivision Name Florence
Tract Number 8 mile Creek Rd

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

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

6. DIMENSIONS: Diameter of Hole
Dia. 6 in. from 0 ft. to 131 ft.
Dia. in. from ft. to ft.
Dia. in. from ft. to ft.

7. CONSTRUCTION DETAILS:
Casing; Steel Dia. 6" from +18" to 131 ft.
Threaded ☐ Welded ☒ Dia. from ft. to ft.
Type A53B 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 Ed
Type Steel Model No. 1
Dia. 6" Slot size 5" from 123 ft. to 128 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? ARM, 36, 21, 654(4)
Material used in grouting Bentonite and Cont

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

9. PUMP (if installed)
Manufacturer's name N/A
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 Bailer X
b) Static water level immediately before testing 25 ft. If flowing; closed-in pressure psi. gpm. Flow controlled by: valve, reducers, other, (specify)
c) Depth at which pump is set for test 120
d) The pumping rate: 30 gpm.
e) Pumping water level 120 ft. at 0 hrs. after pumping began.
f) Duration of test: Pumping time 3 hrs.
g) Recovery time 3 Mins
h) Recovery water level 25 ft. at 5 min's ~~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	32	Sand, gravel Boulders
32	58	sand
58	64	Brown Clay
64	128	sand, gravel; W.B.
128	131	clay plug

ATTACH ADDITIONAL SHEETS IF NECESSARY

13. DATE COMPLETED 9-1-94

14. DRILLER/CONTRACTOR'S CERTIFICATION

This well was drilled under my jurisdiction and this report is true to the best of my knowledge.

Date 9-1-94
Firm Name Valley Drilling
Address Box 220 Corvallis Mt
Signature
License No. #60

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

DNRC

CW5

10 N., 19 W.
County Ravalli

MONTANA BUREAU OF MINES AND GEOLOGY
Butte, Montana

WATER WELL LOG

Owner **S. Stanley Antrim** Address **Stevensville, Montana**

Driller **Archie Remior (Liberty Drill Co.)** Address **Missoula, Montana.**

Date Started **March 22, 1952.** Date Completed **8/11/52.**

Location: Sec **7** T **10 N.** R **19 W** ¼ sec **South-east**

Type of well **Drilled** Equipment used **churn drill**

Domestic ☐ Municipal ☐ Stock ☐ Irrigation ☒

Industrial ☐ Railroad ☐ Other:

Casing	0	ft to	68	ft	Type	steel	Size	14 inch
	68	ft to	152	ft	Type	Steel Perforated.	Size	14 inch
	152	ft to	160	ft	Type	Solid Rein-forced.	Size	14 inch

Perforated or Screened: Ft **68** to ft **152** Ft to ft

Type of screen or perforations **No screen except factory perforated casing. Open hole bottom.**

Static Water level, for non-flowing well: **27 to 33 feet.** feet

Shut in pressure, for flowing well: lb./sq in on (date)

Pumping water level **105** feet at **400** gal per min

How tested: **Turbine and diesel power**

Length of test **48 hours.**

(Gravel packing, cementing, packers, type of shut-off, depth of shut-off)

ell drilled with 24 inch shoe, casing packed with screened gravel to bott
160 feet. While operating well with sprinklers following spring, the ca
illed at bottom with sand and clay for about 12 feet cutting off some flo
ut was [redacted] capacity all summer. I
forts to [redacted]
fall of 1953, a solid 10 inch casing was inserted and carried on down to

(see reverse side)

CW5 page 2

Log of Well

380 feet. C samples below original set ing were so unfavorable that 10 inch casing was pulled. The hole was filled in with screened gravel (1/4 to 3/4 i . size) back up to 150 feet. Static water level again sto at 33 feet d capacity abou as original.

Depth, feet		Description of Material Drilled
From	To	
0	23	Boulders and small rocks
23	39	Sandy clay
39	50	White sand
50	55	Brown clay
55	57	Sand, some course and water bearing
57	68	Soft clay and sand
68	80	Brown clay
80	90	White sand and water bearing
90	110	Sand and clay streaks
110	130	Sand and clay
130	145	Clay
145	155	Course sand and water bearing
155	175	Course sand and small gravel
175	190	Clay Open holed to 205 ft. before setting the 14"
190	205	Course sand casing @ 160 ft. bottom
205	215	Yellow clay and little san
215	243	Blue clay
243	246	Sand with little gravel
246	263	Yellow clay
263	265	Sand and gravel
265	278	Blue clay
278	281	Sand and gravel
281	291	Blue clay
291	322	Straight sand
322	334	Brown clay with tree particles
334	345	Sand
345	375	Gravel - no water
375	380	Sand, clay

Form No. 603 (R 2-89)

MDVHon

WELL LOG REPORT

File No. 674

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 Nick Bickish

2. CURRENT MAILING ADDRESS

P.O.Box 700
Florence, Mt 5983

3. WELL LOCATION

¼ ¼ ¼ Section
Township N/S Range E/W County Ravalli
Govn't Lot , or Lot 7 A , Block
Subdivision Name Riverview Orchards
Tract Number

4. PROPOSED USE: Domestic X Stock Irrigation
Other : specify

5. TYPE OF WORK:

New well X Method: Dug Bored
Deepened Cable X D
Reconditioned Rotary Jetted

6. DIMENSIONS: Diameter of Hole

Dia. 6 in. from +2 ft. to 168 ft.
Dia. in. from ft. to ft.
Dia. in. from ft. to ft.

7. CONSTRUCTION DETAILS:

Casing; Steel Dia from ft to ft
Threaded Welded X Dia. 6" from +2 ft to 168 ft
Type 17.2 Wall Thickness ½
Casing; Plastic Dia. from ft. to ft
Weight Dia. from ft to ft

PERFORATIONS: Yes X No
Type of perforator used Torch
Size of perforations 5 in by 5/32 in.
perforations from 160 ft. to 165 ft.
perforations from ft to 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 X Size of gravel
Gravel placed from ft to ft

GROUTED: To what depth? 18 ft
Material used in grouting Bentonite

8. WELL HEAD COMPLETION:

Pitless Adapter Yes X No

9. PUMP (if installed)

Manufacturer's name [illegible]
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 Bailer X
b) Static water level immediately before testing 108 ft. If flowing, closed-in pressure psi gpm
Flow controlled by valve reducers
other, (specify)
c) Depth at which pump is set for test 162
d) The pumping rate: 30 gpm
e) Pumping water level 152 ft at 1½ hrs. after pumping began
f) Duration of test: Pumping time 1½ hrs.
g) Recovery time ½ hrs.
h) Recovery water level 108 ft. at 1 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	1½	Top soil
1½	30	Sand, gravel, light brown boulde
30	41	Light brown clay
41	50	Unconsolidated dark brown clay
50	85	Light brown sand & clay
		Saturation
85	97	Sand, gravel, light red clay
		1.4 GPM
97	105	Unconsolidated light brown clay
105	152	Sand, gravel, clay. Lots of iro
		6.0 GPM
152	155	Tan clay
155	168	Sand & gravel
		Water bearing
		3' pack

ATTACH ADDITIONAL SHEETS IF NECESSARY

13. DATE COMPLETED 11/06/91

14. DRILLER CONTRACTOR'S CERTIFICATION

This well was drilled under my jurisdiction and this report is true to the best of my knowledge.

11/11/91
Date

Eslinger Drilling
Firm Name

Corvallis, Mt. 59828
Address

andy Eslinger
Signature

36
License No.

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

DNRC

Appendix J: Glossary

The following is copied directly from Fetter (1988).

Adiabatic expansion The process that occurs when an air mass rises and expands without exchanging heat with its surroundings.

Adsorption The attraction and adhesion of a layer of ions from an aqueous solution to the solid mineral surfaces with which it is in contact.

Advection The process by which solutes are transported by the motion of flowing ground water.

Aliquot One of a number of equal-sized portions of a water sample that is being analyzed.

Alluvium Sediments deposited by flowing rivers. Depending upon the location in the floodplain of the river, different-sized sediments are deposited.

American Rule A ground-water doctrine that holds that an overlying property owner has the right to use only a reasonable amount of ground water.

Anisotropy The condition under which one or more of the hydraulic properties of an aquifer vary according to the direction of flow.

Antecedent moisture The soil moisture present before a particular precipitation event.

Aquiclude A low-permeability unit that forms either the upper or lower boundary of a ground-water flow system.

Aquifer Rock or sediment in a formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.

Aquifer, confined An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer.

Aquifer, perched A region in the unsaturated zone where the soil may be locally saturated because it overlies a low-permeability unit.

Aquifer, semiconfined An aquifer confined by a low-permeability layer that permits water to slowly flow through it. During pumping of the aquifer, recharge to the aquifer can occur across the confining layer. Also known as a leaky artesian or leaky confined aquifer.

Aquifer test *See* pumping test.

Aquifer, unconfined An aquifer in which there are no confining beds between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Water-table aquifer is a synonym.

Aquifuge An absolutely impermeable unit that will neither store nor transmit water.

Aquitard A low-permeability unit that can store ground water and also transmit it slowly from one aquifer to another.

Artificial recharge The process by which water can be injected or added to an aquifer. Dug basins, drilled wells, or simply the spread of water across the land surface are all means of artificial recharge.

Average linear velocity *See* seepage velocity.

Bail-down test A type of slug test performed by using a bailer to remove a volume of water from a small-diameter well.

Bailer A device used to withdraw a water sample from a small-diameter well or piezometer. A bailer typically is a piece of pipe attached to a wire and having a check valve in the bottom.

Barrier boundary An aquifer-system boundary represented by a rock mass that is not a source of water.

Baseflow That part of stream discharge from ground water seeping into the stream.

Baseflow recession The declining rate of discharge of a stream fed only by baseflow for an extended period. Typically, a baseflow recession will be exponential.

Baseflow-recession hydrograph A hydrograph that shows a baseflow-recession curve.

Bladder pump A positive-displacement pumping device that uses pulses of gas to push a water-quality sample toward the surface.

Borehole geochemical probe A water-quality monitoring device that is lowered into a well on a cable and that can make a direct reading of such parameters as pH, *Eh*, temperature, and specific conductivity.

Borehole geophysics The general field of geophysics developed around the lowering of various probes into a well.

Boring A hole advanced into the ground by means of a drilling rig.

Boussinesq equation The general equation for two-dimensional unconfined transient flow.

Caliper log A borehole log of the diameter of an uncased well.

Capillary forces The forces acting on soil moisture in the unsaturated zone, attributable to molecular attraction between soil particles and water.

Capillary fringe The zone immediately above the water table, where water is drawn upward by capillary attraction.

Casing *See* well casing.

Cation exchange capacity The ability of a particular rock or soil to absorb cations.

Cementation The process by which some of the voids in a sediment are filled with precipitated materials, such as silica, calcite, and iron oxide, and which is a part of diagenesis.

Chemical activity The molal concentration of an ion multiplied by a factor known as the activity coefficient.

Clastic dike Intrusion of sediment forced into fractures in rock or sediments.

Cleat The vertical planes of fracture that are found in coal.

Collection lysimeter A device installed in the unsaturated zone to collect a water-quality sample by having the water drain downward by gravity into a collection pit.

Combining weight *See* equivalent weight.

Common-ion effect The decrease in the solubility of a salt dissolved in water already containing some of the ions of the salt.

Condensation The process that occurs when an air mass is saturated and water droplets form around nuclei or on surfaces.

Confining bed A body of material of low hydraulic conductivity that is stratigraphically adjacent to one or more aquifers. It may lie above or below the aquifer.

Connate water Interstitial water that was not buried with a rock but which has been out of contact with the atmosphere for an appreciable part of a geologic period.

Contact spring A spring that forms at a lithologic contact where a more permeable unit overlies a less permeable unit.

Contaminant *See* pollutant.

Current meter A device that is lowered into a stream in order to record the rate at which the current is moving.

Darcian velocity *See* specific discharge.

Darcy's law An equation that can be used to compute the quantity of water flowing through an aquifer.

Debye-Hückel equation A means of computing the activity coefficient for an ionic species.

Density The mass or quantity of a substance per unit volume. Units are kilograms per cubic meter or grams per cubic centimeter.

Depression spring A spring formed when the water table reaches a land surface because of a change in topography.

Depression storage Water from precipitation that collects in puddles at the land surface.

Dew point The temperature of a given air mass at which condensation will begin.

Diagenesis The chemical and physical changes occurring in sediments before consolidation or while in the environment of deposition.

Diffusion The process by which both ionic and molecular species dissolved in water move from areas of higher concentration to areas of lower concentration.

Digital computer model A model of ground-water flow in which the aquifer is described by numerical equations, with specified values for boundary conditions, that are solved on a digital computer.

Dipole array A particular arrangement of electrodes used to measure surface electrical resistivity.

Direct precipitation Water that falls directly into a lake or stream without passing through any land phase of the runoff cycle.

Dirichlet condition A boundary condition for a ground-water computer model where the head is known at the boundary of the flow field.

Discharge The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.

Discharge area An area in which there are upward components of hydraulic head in the aquifer. Ground water is flowing toward the surface in a discharge area and may escape as a spring, seep, or baseflow or by evaporation and transpiration.

Discharge velocity *See* specific discharge.

Dispersion The phenomenon by which a solute in flowing ground water is mixed with uncontaminated water and becomes reduced in concentration. Dispersion is caused by both differences in the velocity that the water travels at the pore level and differences in the rate at which water travels through different strata in the flow path.

Distribution coefficient The slope of a linear Freundlich isotherm.

Drainage basin The land area from which surface runoff drains into a stream system.

Drainage divide A boundary line along a topographically high area that separates two adjacent drainage basins.

Drawdown A lowering of the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping of ground water from wells.

Dupuit assumptions Assumptions for flow in an unconfined aquifer that (1) the hydraulic gradient is equal to the slope of the water table, (2) the streamlines are horizontal, and (3) the equipotential lines are vertical.

Dupuit equation An equation for the volume of water flowing in an unconfined aquifer; based upon the Dupuit assumptions.

Duration curve A graph showing the percentage of time that the given flows of a stream will be equaled or exceeded. It is based upon a statistical study of historic streamflow records.

Dynamic equilibrium A condition in which the amount of recharge to an aquifer equals the amount of natural discharge.

Effective grain size The grain size corresponding to the 10 percent finer by weight line on the grain-size distribution curve.

Effective pore fraction The ratio of the porosity available for fluid flow to the total porosity of a rock or sediment.

Effective porosity *See* porosity, effective.

Electrical resistance model An analog model of ground-water flow based upon the flow of electricity through a circuit containing resistors and capacitors.

Electrical sounding An earth-resistivity survey made at the same location by putting the electrodes progressively farther apart. It shows the change of apparent resistivity with depth.

Electromagnetic conductivity A method of measuring the induced electrical field in the earth to determine the ability of the earth to conduct electricity. Electromagnetic conductivity is the inverse of electrical resistivity. Also known as electric conductivity and terrain conductivity.

English Rule A ground-water doctrine that holds that property owners have the right of absolute ownership of the ground water beneath their land.

Equilibrium constant The number defining the conditions of equilibrium for a particular reversible chemical reaction.

Equipotential line A line in a two-dimensional ground-water flow field such that the total hydraulic head is the same for all points along the line.

Equipotential surface A surface in a three-dimensional ground-water flow field such that the total hydraulic head is the same everywhere on the surface.

Equivalent weight The formula weight of a dissolved ionic species divided by the electrical charge. Also known as combining weight.

Eutrophication The process of accelerated aging of a surface-water body; caused by excess nutrients and sediments being brought into the lake.

Evaporation The process by which water passes from the liquid to the vapor state.

Evapotranspiration The sum of evaporation plus transpiration.

Evapotranspiration, actual The evapotranspiration that actually occurs under given climatic and soil-moisture conditions.

Evapotranspiration, potential The evapotranspiration that would occur under given climatic conditions if there were unlimited soil moisture.

Fault spring A spring created by the movement of two rock units on a fault.

Field blank A water-quality sample where highly purified water is run through the field-sampling procedure and sent to the laboratory to detect if any contamination of the samples is occurring during the sampling process.

Field capacity The maximum amount of water that the unsaturated zone of a soil can hold against the pull of gravity. The field capacity is dependent on the length of time the soil has been undergoing gravity drainage.

Finite-difference model A particular kind of a digital computer model based upon a rectangular grid that sets the boundaries of the model and the nodes where the model will be solved.

Finite-element model A digital ground-water–flow model where the aquifer is divided into a mesh formed of a number of polygonal cells.

Flow net The set of intersecting equipotential lines and flowlines representing two-dimensional steady flow through porous media.

Flow, steady The flow that occurs when, at any point in the flow field, the magnitude and direction of the specific discharge are constant in time.

Flow, unsteady The flow that occurs when, at any point in the flow field, the magnitude or direction of the specific discharge changes with time. Also called transient flow or nonsteady flow.

Fluid potential The mechanical energy per unit mass of fluid at any given point in space and time.

Force potential The sum of the kinetic energy, elevation energy, and pressure at a point in an aquifer. It is equal to the hydraulic head times the acceleration of gravity.

Fossil water Interstitial water that was buried at the same time as the original sediment.

Fracture spring A spring created by fracturing or jointing of the rock.

Fracture trace The surface representation of a fracture zone. It may be a characteristic line of vegetation or linear soil-moisture pattern or a topographic sag.

Free energy A measure of the thermodynamic driving energy of a chemical reaction. Also known as Gibbs free energy or Gibbs function.

Freundlich isotherm An empirical equation that describes the amount of solute adsorbed onto a soil surface.

Gamma-gamma radiation log A borehole log in which a source of gamma radiation as well as a detector are lowered into the borehole. This log measures bulk density of the formation and fluids.

Gamma log *See* natural gamma radiation log.

Gauss-Seidel A particular type of method for solving for the head in a finite-difference ground-water model.

Ghyben-Herzberg principle An equation that relates the depth of a salt-water interface in a coastal aquifer to the height of the fresh-water table above sea level.

Glacial-lacustrine sediments Silt and clay deposits formed in the quiet waters of lakes that received meltwater from glaciers.

Glacial outwash Well-sorted sand, or sand and gravel, deposited by the meltwater from a glacier.

Glacial till A glacial deposit composed of mostly unsorted sand, silt, clay, and boulders and laid down directly by the melting ice.

Gouge Soft, ground-up rock formed between the moving surfaces of a geological fault.

Ground-penetrating radar A surface geophysical technique based upon the transmission of repetitive pulses of electromagnetic waves into the ground. Some of the radiated energy is reflected back to the surface and the reflected signal is captured and processed.

Ground water The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.

Ground-water basin A rather vague designation pertaining to a ground-water reservoir that is more or less separate from neighboring ground-water reservoirs. A ground-water basin could be separated from adjacent basins by geologic boundaries or by hydrologic boundaries.

Ground water, confined The water contained in a confined aquifer. Pore-water pressure is greater than atmospheric at the top of the confined aquifer.

Ground-water flow The movement of water through openings in sediment and rock; occurs in the zone of saturation.

Ground-water mining The practice of withdrawing ground water at rates in excess of the natural recharge.

Ground water, perched The water in an isolated, saturated zone located in the zone of aeration. It is the result of the presence of a layer of material of low hydraulic conductivity, called a perching bed. Perched ground water will have a perched water table.

Ground water, unconfined The water in an aquifer where there is a water table.

Grout curtain An underground wall designed to stop ground-water flow; can be created by injecting grout into the ground, which subsequently hardens to become impermeable.

Hantush-Jacob formula An equation to describe the change in hydraulic head with time during pumping of a leaky confined aquifer.

Hardness A measure of the amount of calcium, magnesium, and iron dissolved in the water.

Hazen method An empirical equation that can be used to approximate the hydraulic conductivity of a sediment on the basis of the effective grain size.

Head, total The sum of the elevation head, the pressure head, and the velocity head at a given point in an aquifer.

Hele-Shaw model An analog model of ground-water flow based upon the movement of a viscous fluid between two closely spaced, parallel plates.

Heterogeneous Pertaining to a substance having different characteristics in different locations. A synonym is nonuniform.

Hollow-stem auger A particular kind of a drilling device whereby a hole is rapidly advanced into sediments. Sampling and installation of the equipment can take place through the hollow center of the auger.

Homogeneous Pertaining to a substance having identical characteristics everywhere. A synonym is uniform.

Horizontal profiling A method of making an earth-resistivity survey by measuring the apparent resistivity using the same electrode spacings at different grid points around an area.

Humidity, absolute The amount of moisture in the air as expressed by the number of grams of water per cubic meter of air.

Humidity, relative Percent ratio of the absolute humidity to the saturation humidity for an air mass.

Humidity, saturation The maximum amount of moisture that can be contained by an air mass at a given temperature.

Hvorslev method A procedure for performing a slug test in a piezometer that partially penetrates a water-table aquifer.

Hydraulic conductivity A coefficient of proportionality describing the rate at which water can move through a permeable medium. The density and kinematic viscosity of the water must be considered in determining hydraulic conductivity.

Hydraulic diffusivity A property of an aquifer or confining bed defined as the ratio of the transmissivity to the storativity.

Hydraulic gradient The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

Hydraulic head *See* head, total.

Hydrochemical facies Bodies of water with separate but distinct chemical compositions contained in an aquifer.

Hydrodynamic dispersion The process by which ground water containing a solute is diluted with uncontaminated ground water as it moves through an aquifer.

Hydrogeology The study of the interrelationships of geologic materials and processes with water, especially ground water.

Hydrograph A graph that shows some property of ground water or surface water as a function of time.

Hydrologic equation An expression of the law of mass conservation for purposes of water budgets. It may be stated as inflow equals outflow plus or minus changes in storage.

Hydrology The study of the occurrence, distribution, and chemistry of all waters of the earth.

Hydrophyte A type of plant that grows with the root system submerged in standing water.

Hydrostratigraphic unit A formation, part of a formation, or group of formations in which there are similar hydrologic characteristics allowing for grouping into aquifers or confining layers.

Hygroscopic water Water that clings to the surfaces of mineral particles in the zone of aeration.

Ideal gas A gas having a volume that varies inversely with pressure at a constant temperature and that also expands by 1/273 of its volume at 0° C for each degree rise in temperature at constant pressure.

Image well An imaginary well that can be used to simulate the effect of a hydrologic barrier, such as a recharge boundary or a barrier boundary, on the hydraulics of a pumping or recharge well.

Infiltration The flow of water downward from the land surface into and through the upper soil layers.

Infiltration capacity The maximum rate at which infiltration can occur under specific conditions of soil moisture. For a given soil, the infiltration capacity is a function of the water content.

Injection well A well drilled and constructed in such a manner that water can be pumped into an aquifer in order to recharge it.

Interception The process by which precipitation is captured on the surfaces of vegetation before it reaches the land surface.

Interception loss Rainfall that evaporates from standing vegetation.

Interflow The lateral movement of water in the unsaturated zone during and immediately after a precipitation event. The water moving as interflow discharges directly into a stream or lake.

Intermediate zone That part of the unsaturated zone below the root zone and above the capillary fringe.

Intrinsic permeability Pertaining to the relative ease with which a porous medium can transmit a liquid under a hydraulic or potential gradient. It is a property of the porous medium and is independent of the nature of the liquid or the potential field.

Ion exchange A process by which an ion in a mineral lattice is replaced by another ion that was present in an aqueous solution.

Isocon A line drawn on a map to indicate equal concentrations of a solute in ground water.

Isohyetal line A line drawn on a map, all points along which receive equal amounts of precipitation.

Isotropy The condition in which hydraulic properties of the aquifer are equal in all directions.

Jacob straight-line method A graphical method using semilogarithmic paper and the Theis equation for evaluating the results of a pumping test.

Juvenile water Water entering the hydrologic cycle for the first time.

Karst The type of geologic terrane underlain by carbonate rocks where significant solution of the rock has occurred due to flowing ground water.

Kemmerer sampler A sampling device that can be lowered either into a deep well or into a lake in order to retrieve a water sample from a particular depth in the well or the lake.

Kinematic viscosity The ratio of dynamic viscosity to mass density. It is obtained by dividing dynamic viscosity by the fluid density. Units of kinematic viscosity are square meters per second.

Laminar flow That type of flow in which the fluid particles follow paths that are smooth, straight, and parallel to the channel walls. In laminar flow, the viscosity of the fluid damps out turbulent motion. *Compare with* Turbulent flow.

Langmuir isotherm An empirical equation that describes the amount of solute adsorbed onto a soil surface.

Land pan A device used to measure free-water evaporation.

Laplace equation The partial differential equation governing steady-state flow of ground water.

Law of mass action The law stating that for a reversible chemical reaction the rate of reaction is proportional to the concentrations of the reactants.

Leachate Water that contains a high amount of dissolved solids and is created by liquid seeping from a landfill.

Leachate collection system A system installed in conjunction with a liner to capture the leachate that may be generated from a landfill so that it may be taken away and treated.

Leaky confining layer A low-permeability layer that can transmit water at sufficient rates to furnish some recharge to a well pumping from an underlying aquifer. Also called aquitard.

Lineament A natural linear surface longer than a mile (1500 meters).

Liner A low-permeability material, such as clay or plastic sheeting, that is put beneath a landfill in order to capture any leachate generated so as to help to prevent ground-water contamination.

Lithologic log A record of the lithology of the rock and soil encountered in a borehole from the surface to the bottom. Also known as a well log.

Lysimeter A field device containing a soil column and vegetation; used for measuring actual evapotranspiration.

Magmatic water Water associated with a magma.

Magnetometer A geophysical device that can be used to locate items that disrupt the earth's localized magnetic field; can be used for finding buried steel.

Manning equation An equation that can be used to compute the average velocity of flow in an open channel.

Maximum contaminant level The highest concentration of a solute permissible in a public water supply as specified in the National Interim Primary Drinking Water Standards for the United States.

Maximum contaminant level goal A nonenforceable health goal for solutes in drinking water; set at a level to prevent known or anticipated adverse effects with an adequate margin of safety.

Micrograms per liter A measure of the amount of dissolved solids in a solution in terms of micrograms of solute per liter of solution.

Milliequivalents per liter A measure of the concentration of a solute in solution; obtained by dividing the concentration in milligrams per liter by equivalent weight of the ion.

Milligrams per liter A measure of the amount of dissolved solids in a solute in terms of milligrams of solute per liter of solution.

Model calibration The process by which the independent variables of a digital computer model are varied in order to calibrate a dependent variable such as a head against a known value such as a water-table map.

Model field verification The process by which a digital computer model that has been calibrated and verified is tested to see if it can predict the field response of an aquifer to some transient condition.

Model verification The process by which a digital computer model that has been calibrated against a steady-state condition is tested to see if it can generate a transient response, such as the decline in the water table with pumping, that matches the known history of the aquifer.

Moisture potential The tension on the pore water in the unsaturated zone due to the attraction of the soil–water interface.

Molality A measure of chemical concentration. A one-molal solution has one mole of solute dissolved in 1000 grams of water. One mole of a compound is its formula weight in grams.

Molarity A measure of chemical concentration. A one-molar solution has one mole of solute dissolved in one liter of solution.

Mutual-prescription doctrine A ground-water doctrine stating that in the event of an overdraft of a ground-water basin, the available ground water will be apportioned among all the users in amounts proportional to their individual pumping rates.

Natural gamma radiation log A borehole log that measures the natural gamma radiation emitted by the formation rocks. It can be used to delineate subsurface rock types.

Neumann condition The boundary condition for a ground-water–flow model where a flux across the boundary of the flow region is known.

Neutron log A borehole log obtained by lowering a radioactive element, which is a source of neutrons, and a neutron detector into the well. The neutron log measures the amount of water present; hence, the porosity of the formation.

Nonequilibrium type curve A plot on logarithmic paper of the well function. $W(u)$ as a function of u.

Observation well A nonpumping well used to observe the elevation of the water table or the potentiometric surface. An observation well is generally of larger diameter than a piezometer and typically is screened or slotted throughout the thickness of the aquifer.

Overland flow The flow of water over a land surface due to direct precipitation. Overland flow generally occurs when the precipitation rate exceeds the infiltration capacity of the soil and depression storage is full. Also called Horton overland flow.

Packer test An aquifer test performed in an open borehole; the segment of the borehole to be tested is sealed off from the rest of the borehole by inflating seals, called packers, both above and below the segment.

Permafrost Perenially frozen ground, occurring wherever the temperature remains at or below 0° C for two or more years in a row.

Permeameter A laboratory device used to measure the intrinsic permeability and hydraulic conductivity of a soil or rock sample.

Phreatic cave A cave that forms below the water table.

Phreatophyte A type of plant that typically has a high rate of transpiration by virtue of a taproot extending to the water table.

Phreatic water Water in the zone of saturation.

Piezometer A nonpumping well, generally of small diameter, that is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short well screen through which water can enter.

Piezometer nest A set of two or more piezometers set close to each other but screened to different depths.

Polar coordinates The means by which the position of a point in a two-dimensional plane is described; based upon the radial distance from the origin to the given point and the angle between a horizontal line passing through the origin and a line extending from the origin to the given point.

Pollutant Any solute or cause of change in physical properties that renders water unfit for a given use.

Pore space The volume between mineral grains in a porous medium.

Porosity The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

Porosity, effective The volume of the void spaces through which water or other fluids can travel in a rock or sediment divided by the total volume of the rock or sediment.

Porosity, primary The porosity that represents the original pore openings when a rock or sediment formed.

Porosity, secondary The porosity that has been caused by fractures or weathering in a rock or sediment after it has been formed.

Potentiometric map A contour map of the potentiometric surface of a particular hydrogeologic unit.

Potentiometric surface A surface that represents the level to which water will rise in tightly cased wells. If the head varies significantly with depth in the aquifer, then there may be more than one potentiometric surface. The water table is a particular potentiometric surface for an unconfined aquifer.

Prior-appropriation doctrine A doctrine stating that the right to use water is separate from other property rights and that the first person to withdraw and use the water holds the senior right. The doctrine has been applied to both ground and surface water.

Public trust doctrine A legal theory holding that certain lands and waters in the public domain are held in trust for use by the entire populace. It is especially applicable to navigable waters.

Pumping cone The area around a discharging well where the hydraulic head in the aquifer has been lowered by pumping. Also called cone of depression.

Pumping test A test made by pumping a well for a period of time and observing the change in hydraulic head in the aquifer. A pumping test may be used to determine the capacity of the well and the hydraulic characteristics of the aquifer. Also called aquifer test

Quantification limit The lower limit to the range in which the concentration of a solute can be determined by a particular analytical instrument.

Radial flow The flow of water in an aquifer toward a vertically oriented well.

Rating curve A graph of the discharge of a river at a particular point as a function of the elevation of the water surface.

Recharge area An area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area.

Recharge basin A basin or pit excavated to provide a means of allowing water to soak into the ground at rates exceeding those that would occur naturally.

Recharge boundary An aquifer system boundary that adds water to the aquifer. Streams and lakes are typically recharge boundaries.

Recharge well A well specifically designed so that water can be pumped into an aquifer in order to recharge the ground-water reservoir.

Recovery The rate at which the water level in a well rises after the pump has been shut off. It is the inverse of drawdown.

Regolith The upper part of the earth's surface that has been altered by weathering processes. It includes both soil and weathered bedrock.

Resistivity log A borehole log made by lowering two current electrodes into the borehole and measuring the resistivity between two additional electrodes. It measures the electrical resistivity of the formation and contained fluids near the probe.

Retardation A general term for the many processes that act to remove the solutes in ground water; for many solutes the solute front will travel more slowly than the rate of the advecting ground water.

Reverse type curve A plot on logarithmic paper of the well function $W(u)$ as a function of $1/(u)$.

Reynolds number A number, defined by an equation, that can be used to determine whether flow will be laminar or turbulent.

Riparian doctrine A doctrine that holds that the property owner adjacent to a surface-water body has first right to withdraw and use the water.

Rock, igneous A rock formed by the cooling and crystallization of a molten rock mass called magma.

Rock, metamorphic A rock formed by the application of heat and pressure to preexisting rocks.

Rock, plutonic An igneous rock formed when magma cools and crystallizes within the earth.

Rock, sedimentary A rock formed from sediments through a process known as diagenesis or formed by chemical precipitation in water.

Rock, volcanic An igneous rock formed when molten rock called lava cools on the earth's surface.

Root zone The zone from the land surface to the depth penetrated by plant roots. The root zone may contain part or all of the unsaturated zone, depending upon the depth of the roots and the thickness of the unsaturated zone.

Runoff The total amount of water flowing in a stream. It includes overland flow, return flow, interflow, and baseflow.

Safe yield The amount of naturally occurring ground-water that can be economically and legally withdrawn from an aquifer on a sustained basis without impairing the native ground-water quality or creating an undesirable effect such as environmental damage. It cannot exceed the increase in recharge or leakage from adjacent strata plus the reduction in discharge, which is due to the decline in head caused by pumping.

Saline-water encroachment The movement, as a result of human activity, of saline ground water into an aquifer formerly occupied by fresh water. Passive saline-water encroachment occurs at a slow rate owing to a general lowering of the fresh-water potentiometric surface. Active saline-water encroachment proceeds at a more rapid rate owing to the lowering of the fresh-water potentiometric surface below sea level.

Salt-water encroachment *See* saline-water encroachment.

Sand model A scale model of an aquifer; built using a porous medium to demonstrate ground-water flow.

Sanitary landfill The disposal of solids and, in some instances, semisolid and liquid wastes by burying the material to shallow depths, usually in unconsolidated materials.

Saprolite A soft, earthy, decomposed rock, typically clay-rich, formed in place by chemical weathering of igneous and metamorphic rocks.

Saturated zone The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.

Saturation ratio The ratio of the volume of contained water in a soil to the volume of the voids of the soil.

Schlumberger array A particular arrangement of electrodes used to measure surface electrical resistivity.

Screen *See* well screen.

Sediment An assemblage of individual mineral grains that were deposited by some geologic agent such as water, wind, ice, or gravity.

Seepage velocity The actual rate of movement of fluid particles through porous media.

Seismic refraction A method of determining subsurface geophysical properties by measuring the length of time it takes for artificially generated seismic waves to pass through the ground.

Shelby tube A sampling device that is pushed into an unconsolidated aquifer ahead of the drill bit. Typically, the Shelby tube is pushed by hydraulic means.

Single-point resistance log A borehole log made by lowering a single electrode into the well with the other electrode at the ground surface. It measures the overall electrical resistivity of the formation and drilling fluid between the surface and the probe.

Sinkhole spring A spring created by ground water flowing from a sinkhole in karst terrane.

Slug test An aquifer test made either by pouring a small instantaneous charge of water into a well or by withdrawing a slug of water from the well. A synonym for this test, when a slug of water is removed from the well, is a bail-down test.

Slurry wall An underground wall designed to stop ground-water flow; constructed by digging a trench and backfilling it with a slurry rich in bentonite clay.

Soil liquefaction A process that occurs when saturated sediments are shaken by an earthquake. The soil can lose its strength and cause the collapse of structures with foundations in the sediment.

Soil moisture The water contained in the unsaturated zone.

Solubility product The equilibrium constant that describes a solution of a slightly soluble salt in water.

Specific capacity An expression of the productivity of a well, obtained by dividing the rate of discharge of water from the well by the drawdown of the water level in the well. Specific capacity should be described on the basis of the number of hours of pumping prior to the time the drawdown measurement is made. It will generally decrease with time as the drawdown increases.

Specific discharge An apparent velocity calculated from Darcy's law; represents the flow rate at which water would flow in an aquifer if the aquifer were an open conduit.

Specific electrical conductance The ability of water to transmit an electrical current. It is related to the concentration and charge of ions present in the water.

Specific retention The ratio of the volume of water the rock or sediment will retain against the pull of gravity to the total volume of the rock or sediment.

Specific weight The weight of a substance per unit volume. The units are newtons per cubic meter.

Specific yield The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take many months to occur.

Spiked sample A water sample to which a known quantity of a solute has been added so that the accuracy of the laboratory in analyzing the sample can be determined.

Split-spoon sample A sample of unconsolidated material taken by driving a sampling device ahead of the drill bit in a boring. The split-spoon sampler is typically advanced by the repetitive dropping of a weight.

Spontaneous potential log A borehole log made by measuring the natural electrical potential that develops between the formation and the borehole fluids.

Stagnation point A place in a ground-water flow field at which the ground water is not moving. The magnitude of vectors of hydraulic head at the point are equal but opposite in direction.

Stem flow The process by which rainwater drips and flows down the stems and branches of plants.

Stiff pattern A graphical means of presenting the chemical analysis of the major cations and anions of a water sample.

Storage, specific The amount of water released from or taken into storage per unit volume of a porous medium per unit change in head.

Storativity The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to the specific yield. Also called storage coefficient.

Storm hydrograph A graph of the discharge of a stream over the time period when, in addition to direct precipitation, overland flow, interflow, and return flow are adding to the flow of the stream. The storm hydrograph will peak owing to the addition of these flow elements.

Stream, gaining A stream or reach of a stream, the flow of which is being increased by inflow of ground water. Also known as an effluent stream.

Stream, losing A stream or reach of a stream that is losing water by seepage into the ground. Also known as an influent stream.

Successive overrelaxation method A particular type of method for solving for the head in a finite-difference ground-water model.

Suction lysimeter A device for withdrawing pore water samples from the unsaturated zone by applying tension to a porous ceramic cup.

Swallow hole A vertical shaft in a karst terrane leading from a surface stream into an underground cavern.

Tensiometer A device used to measure the soil-moisture tension in the unsaturated zone.

Tension The condition under which pore water exists at a pressure less than atmospheric.

Theis equation An equation for the flow of ground water in a fully confined aquifer.

Theissen method A process used to determine the effective uniform depth of precipitation over a drainage basin with a nonuniform distribution of rain gages.

Throughflow The lateral movement of water in an unsaturated zone during and immediately after a precipitation event. The water from throughflow seeps out at the base of slopes and then flows across the ground surface as return flow, ultimately reaching a stream or lake.

Time of concentration The time it takes for water to flow from the most distant part of the drainage basin to the measuring point.

Tortuosity The actual length of a ground-water–flow path, which is sinuous in form, divided by the straight-line distance between the ends of the flow path.

Transmissivity The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.

Transpiration The process by which plants give off water vapor through their leaves.

Trilinear diagram A method of graphically plotting the chemical composition of the major anions and cations of a water sample.

Turbidity Cloudiness in water due to suspended and colloidal organic and inorganic material.

Turbulent flow That type of flow in which the fluid particles move along very irregular paths. Momentum can be exchanged between one portion of the fluid and another. Compare with Laminar flow.

Uniformity coefficient The ratio of the grain size that is 60 percent finer by weight to the grain size that is 10 percent finer by weight on the grain-size distribution curve. It is a measure of how well or poorly sorted sediment is.

Unsaturated zone The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched ground water, may exist in the unsaturated zone. Also called zone of aeration and vadose zone.

Vadose cave A cave that occurs above the water table.

Vadose water Water in the zone of aeration.

Vadose zone *See* unsaturated zone.

Viscosity The property of a fluid describing its resistance to flow. Units of viscosity are newton-seconds per meter squared or pascal-seconds. Viscosity is also known as dynamic viscosity.

Volatile organic compound (VOC) An organic compound that is characterized by being highly mobile in ground water and which is readily volatilized into the atmosphere.

Water budget An evaluation of all the sources of supply and the corresponding discharges with respect to an aquifer or a drainage basin.

Water content The weight of contained water in a soil divided by the total weight of the soil mass.

Water equivalent The depth of water obtained by melting a given thickness of snow.

Water quality criteria Values for dissolved substances in water based upon their toxicological and ecological impacts.

Water table The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells.

Water-table cave A cave that forms at the approximate position of the water table.

Water-table map A specific type of potentiometric-surface map for an unconfined aquifer; shows lines of equal elevation of the water table.

Weir A device placed across a stream and used to measure the discharge by having the water flow over a specifically designed spillway.

Well casing A solid piece of pipe, typically steel or PVC plastic, used to keep a well open in either unconsolidated materials or unstable rock.

Well development The process whereby a well is pumped or surged to remove any fine material that may be blocking the well screen or the aquifer outside the well screen.

Well, fully penetrating A well drilled to the bottom of an aquifer, constructed in such a way that it withdraws water from the entire thickness of the aquifer.

Well function An infinite-series term that appears in the Theis equation of ground-water flow.

Well interference The result of two or more pumping wells, the drawdown cones of which intercept. At a given location, the total well interference is the sum of the drawdowns due to each individual well.

Well log *See* lithologic log.

Well, partially penetrating A well constructed in such a way that it draws water directly from a fractional part of the total thickness of the aquifer. The fractional part may be located at the top or the bottom or anywhere in between in the aquifer.

Well screen A tubular device with either slots, holes, gauze, or continuous-wire wrap; used at the end of a well casing to complete a well. The water enters the well through the well screen.

Wenner array A particular arrangement of electrodes used to measure surface electrical resistivity.

Wilting point The soil-moisture content below which plants are unable to withdraw soil moisture.

Winters Doctrine A United States doctrine holding that when Indian reservations were established, the federal government also reserved the water rights necessary to make the land productive.

Xerophyte A desert plant capable of existing by virtue of a shallow and extensive root system in an area of minimal water.

Zone of aeration *See* unsaturated zone.