Y/TS-1166

Y-12

OAK RIDGE
Y-12
PLANT

LOCKHEED MARTIN

EVALUATION OF CROSS BOREHOLE TESTS AT SELECTED WELLS IN THE MAYNARDVILLE LIMESTONE AND COPPER RIDGE DOLOMITE AT THE OAK RIDGE Y-12 PLANT

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May 1995

Prepared for the
Environmental Management Department
Health, Safety, Environment, and Accountability Organization
Oak Ridge Y-12 Plant
Oak Ridge, Tennessee 38731

managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract
DE-AC05-84OR21400

MANAGED BY
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

UCN-13672 (26 6-95)

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ABBREVIATIONS

BCV	Bear Creek Valley
Ccr	Copper Ridge Dolomite
Cmn	Maynardville Limestone
DI	Deionized water
Elev	Elevation in feet above mean sea level
K	Hydraulic conductivity
ORR	Oak Ridge Reservation
s	Drawdown, or in this report, 'draw-up' which is the water level measured at time t minus the water level measured at time t=0
S	Storage coefficient
SC	Specific Conductance (μmhos/cm)
t	Time
T	Transmissivity
TD	Total depth of a well below ground surface
Temp	Temperature (°C)
WL	Water level

EXECUTIVE SUMMARY

Several waste disposal sites are located on or adjacent to the karstic Maynardville Limestone (Cmn) and the Copper Ridge Dolomite (Ccr) at the Department of Energy Y-12 Plant. These formations receive contaminants from nearby disposal sites, and transport of these contaminants through the formations can be quite rapid due to the karst flow system. Groups of wells, aligned perpendicular to strike, were drilled to investigate the characteristics of the Cmn, and these wells are identified as Pickets. In order to evaluate transport processes through the karst aquifer, the formations must be characterized. As one component of this characterization effort, cross borehole tests were conducted where water was injected into one well at a site, and water level responses were monitored in nearby wells to determine the directions in which quick flow is more dominant. The ultimate objective of the studies of the Cmn is to characterize the hydrologic characteristics of the karst aquifer and to identify the generalized configuration of the conduit systems and portions subject to a significant quick flow component (i.e., higher hydraulic conductivity zones). The resultant conceptual model will be useful in constructing numerical models to be used to predict flow paths.

The purpose of conducting cross borehole tests at Picket wells in the Cmn was to determine the directions in which conduits may be connected in different portions of the karst aquifer. Rapid fluid velocities and locally high hydraulic conductivities are associated with cavity occurrence. It is noted that tests which result in no response in monitored wells are inconclusive. No responses may be a result of poor hydrologic communication, or simply insufficient volumes of water may have been introduced into the system to produce a response in particular locations in the aquifer.

For each test at the five Picket locations, deionized water was injected into a source well from a tank truck containing ≈3000 gallons. Tests were conducted by injecting water under pressure in order to obtain a rapid, sharp injection pulse. Injection pressures between 30 and 80 psi were used during the various tests. Pressure transducers were installed in up to 10 monitor wells, and Hydrolab probes, measuring temperature and specific conductance, were installed in up to five monitor wells surrounding a source well.

Cross borehole testing was successfully used to identify hydrologic communication between individual wells in both the quick flow and slower flow regimes. Quick flow areas are characterized by rapid water level rises and recessions, whereas slower, diffuse flow is characterized by long responses showing broad curves for water level rise and fall. Picket W, where wells are generally deep and are not completed in cavities, showed the slowest water level responses of any of the Picket wells tested. The best evidence for quick flow behavior was obtained at Picket J (between GW-734 and GW-722-32 and GW-722-33) and at Picket A (between GW-684 and GW-683 and the SS-5 spring). The rapid water level responses to injection were expected at these locations based on previous drilling data. The monitored zones in the three wells in Picket J are at nearly the same elevations, and all three zones contain cavities. Hence, a direct hydrologic connection was not surprising. Similarly, at Picket A, increased turbidity occurred in the SS-5 spring during drilling of both GW-683 and GW-684 indicating the wells were hydrologically connected to the spring. No other wells in Picket A showed hydrologic communication with the injection well. Evidence for quick flow between injection and monitor wells was also observed at Pickets B and C. Significant quick flow can therefore be expected throughout Bear Creek Valley (BCV), yet the directions of this flow may vary locally from site to site.

In order to evaluate preferential quick flow directions, a summary of possible flow paths based on observed responses between injection and monitor wells was made based on the location of completion zones relative to one another. The following observations do not include Picket W which is not in an area representative of quick flow in BCV. Most wells at different elevations, perpendicular to strike and across strata from the injection well did not show a hydrologic response to the injection. Only one well in this category showed a response, and that was fairly weak. When completion intervals of wells are located at the same elevations (at depths <150 ft), rapid responses are generally seen, even when the monitor well is located across strata and perpendicular to strike. Rapid responses suggestive of quick flow are also seen regularly when zones are along dip from one another, regardless of whether they are along strike, perpendicular to strike or at some angle to strike. Rapid responses can also be expected in directions that are both along strike and dip, yet only one example of this situation occurs in the data set. Very slow, or no responses were observed in the along strike, across strata category. Considering Picket W only, more rapid flow appears to occur along strike, although none of the responses exhibited quick flow characteristics. In summary, rapid fluid velocities can be expected along dip, and at shallow depths in all lithologies and at various angles to strike. The up- and down-dip hydrologic connections appear to be most prominent within zone 2. Hence, in any hydrologic modeling of this aquifer, considerably higher hydraulic conductivities should be assigned to the shallow (<150 ft) depths when modeling a large scale problem. Smaller scale problems should take into account the higher hydraulic conductivities expected in along strike and dip directions.

The results of this study support conclusions made from previous studies in the Cmn. Significant conduit development occurs in the shallow depths and the conduits are likely to be well interconnected. The possible anastomotic pattern of the conduits allows for preferential flow directions to change locally in response to position of the conduits. Nevertheless, the large scale, dominant flow direction in the Cmn is along strike, and hydrologic communication along dip, perhaps along bedding planes, occurs in several of the locations studied.

INTRODUCTION

Several waste disposal sites are located adjacent to the karstic Cambrian Maynardville Limestone (Cmn), and on the Cambrian Copper Ridge Dolomite (Ccr), at the Department of Energy Y-12 Plant on the Oak Ridge Reservation (ORR) in Oak Ridge, TN. The Cmn is the upper member of the Conasauga Group and the Ccr is the lower member of the Knox Group. The study area in this report is near the Y-12 Plant in the lower Knox Group which forms Chestnut Ridge, and the upper Conasauga Group which occurs in Bear Creek Valley (BCV) (see Fig. 1).

Several concepts pertaining to the distribution, connectivity, nature, and extent of the conduit system at the Y-12 Plant require refinement. Results from a recent drilling project appear in Shevenell et al. (1992). The geochemical characteristics of the groundwaters as they relate to identifying quick flow zones through fractures and conduits have previously been evaluated (Shevenell, 1994). Detailed lithologic descriptions, diagenetic interpretations, and evaluation of secondary porosity development are documented in Goldstrand (in press) and Goldstrand et al. (in prep.). Statistical analyses on the conduit distributions have been conducted to determine if the probability of conduit occurrence can be reliably predicted based on the distribution of known conduits encountered during drilling activities. This type of analysis was found to be of limited value at the Y-12 Plant, likely due to insufficient data and the complexities of the hydrogeology of the area (Shevenell and Beauchamp, 1994). The ultimate objective of the overall studies of the Cmn is to characterize the hydrology of the karst aquifers and to identify the generalized configuration of the conduit systems and portions subject to a significant quick flow component (i.e., higher hydraulic conductivity zones). The resultant conceptual model will be useful in constructing numerical models to be used to predict probable flow paths and times.

The purpose of conducting cross borehole tests at Picket wells in the Cmn (see Shevenell et al., 1992 for the definition of "Picket"; Fig. 2) is to determine the directions in which conduits may be interconnected in different portions of the karst aquifer. Rapid fluid velocities and locally high hydraulic conductivities are associated with cavity occurrence. Knowledge of the distribution and interconnections of cavities can be useful in conducting groundwater flow modeling and predicting possible, preferential flow paths. It is noted that tests which result in no response in monitored wells are inconclusive. No responses may be a result of poor hydrologic communication, or simply that insufficient volumes of water were introduced into the system to produce a response in particular locations in the aquifer.

BACKGROUND

To effectively evaluate groundwater and surface water contamination and contaminant migration from waste sites at the Y-12 Plant, a Comprehensive Groundwater Monitoring Plan was developed to guide monitoring of surface water and groundwater quality at the Y-12 Plant (Geraghty and Miller, 1990). The Cmn, which underlies the southern portion of BCV, is considered to be the primary pathway for groundwater leaving the Y-12 Plant (King and Haase, 1988). Because water in the Cmn interacts with that in the Ccr, some of the cavities in each formation were investigated during cross-borehole testing.

Over 800 water producing zones have been identified in the Cmn and Ccr, and additional zones continue to be encountered as drilling proceeds. Of these 800 water zones, 36% have been identified as cavities (noted by an obvious drop in the drill string during drilling). A large percentage (66%) of wells which have been drilled in carbonate units (Cmn and Ccr) at the Y-12 Plant have encountered at least one cavity (Shevenell and Beauchamp, 1994) indicating that cavities are pervasive throughout the site. Note that additional wells have been and continue to be drilled which encounter cavities.

PROCEDURE

The cross borehole tests are best suited to the summer months when there is less potential for interference in the data signal from storm events. If a significant storm were to occur during a test, it would be necessary to re-run the test because the storm signal would likely overwhelm the artificial signals. Hence, the tests were conducted between August and November when rainfall is lower and water demand from vegetation is higher. Rapid water level responses are expected in conduits, in comparison to those in the more diffuse flow portion of the aquifer. Because conduit systems have little hydraulic resistance in comparison to porous media, introduced water will drain quickly. The much lower hydraulic conductivity porous media portion of the system responds more slowly to transient events, and does not remain in phase with the conduit system (White, 1988). The fractured portions of the system are intermediate in hydraulic conductivity between the conduits a matrix portions of the system. The lag time between the injection, and the response at a monitoring well is the time necessary to transmit the pressure pulse through conduits, fractures and matrix intervals and not the time for water to move between the two points. Note that the rock matrix on the ORR is believed to contain microscopic and larger mostly disconnected pores and vugs that do not completely drain under the influence of gravity. When the matrix or porous media portion of the aquifer is referenced in this report, it is assumed that this portion of the aquifer system is composed pores, small fractures and vugs that are not included in the categories represented by rapid drainage through open conduits or the larger fractures in the system.

For each test, deionized (DI) water was injected into a source well from a tank truck containing ≈3000 gallons. A flow meter was installed on the hose from the tank truck along with a gate valve to be used to adjust flow rates. During all of the cross bore hole tests, DI water was injected into one well in a Picket area, rather than pumping water from the well, because injection should produce a sharper, more instantaneous pulse in the aquifer. During the first test, water was introduced into GW-684 (Picket A) under gravity feed. In this test, a stilling well was installed in the source well prior to initiation of the testing. The stilling well was a 2-in PVC pipe clamped to the steel well casing of the source well, and the pressure transducer was placed inside the stilling well. The purpose of the stilling well was to minimize turbulence in the well bore during fluid injection so that the pressure transducer did not become damaged.

During the second test at Picket A, water was injected into the source well under pressure. Tests at all other Pickets were conducted by injecting water under pressure because a more rapid, sharper injection pulse could be obtained. Injection pressures between 30 and 80 psi were used during the various tests which is equivalent to 60 and 185 ft of head. In order to inject water under pressure into the source wells, a short length of threaded steel casing was welded to the well head of each source well. Threaded 7-in or 4-in to 2-in reducers were then installed on each well head and attached to piping which connected the tanker truck to a portable gasoline pump, and ultimately to the well head.

Pressure transducers were installed in up to 10 monitor wells, and Hydrolab probes, measuring temperature and specific conductance, were installed in up to five monitor wells surrounding a source well. All data logger times were set at the same time, or as close as practicable, in order that responses from different wells could be directly compared. Numbers were assigned to all Hydrolab probes, pressure transducers and data loggers, and probes matched up with specific data loggers. When installing probes, Hydrolab probes were installed first, and pressure transducers second to avoid transducer probe damage by the larger Hydrolab probe.

In general, pressure transducers were placed ≈2 to 4 ft below the static water level, and the depths at which these were placed are noted in the discussions below. Hydrolab probes were placed at the depth of the completion intervals in each of the wells for which temperature and specific conductance (SC) measurements were desired. The maximum depth of deployment of the Hydrolab probes was 300 ft. When the probes were installed into or removed from a well, they were checked for proper operation and calibration, and recalibrated if necessary. Each time data logger systems were set up or removed from a well, the batteries were checked, and the water levels were field checked with an electronic water level indicator. The pressure transducer and Hydrolab probes were decontaminated each time they were moved into different wells. Pressure transducers were removed from the borehole first, and the Hydrolab probes removed second. The probes were washed with a laboratory detergent, rinsed with tap water, and then rinsed with DI water and dried. Cables were wiped dry as they were retrieved from the wells.

The data loggers were programmed to include the well identification number and elevation for each well monitored. The readings on pressure transducers were scanned every 15 seconds and recorded every 1 min during the first ≈500 min of the test, and scanned every 15 sec and recorded every 2 min for the remainder of the test. The pressure measurements were automatically converted into water level above mean sea level and recorded in the data logger file. The minimum, maximum, and instantaneous water level measurements were also recorded. The measurements from the Hydrolab probes were recorded each time the pressure was recored, though no minimum and maximum scans were possible from these probes. The data loggers in the monitored wells were operational for ≈48 hours after each injection. Field notes from the tests included well number, static water level, date, time, transducer depth below top of casing (or elevation above mean sea level), Hydrolab depth or elevation, notes on calibration (transducer water level versus manually measured water level), battery conditions, weather, the identification number of the data logger, transducer and Hydrolab assigned to the particular well, volume of water added as a function of time, and pressure of injection.

The specific depths at which probes were placed in each of the wells monitored is listed in the Picket descriptions below. The locations of the Picket wells, and their radial distances from their respective injection wells are listed in Table 1. North and East are in Y-12 coordinates in feet, and 'Distance' indicates the radial distance between the injection and monitor wells in this table. In this section, the Pickets are listed in order of their location from west to east (Picket W, Picket A, Picket B, Picket C, and Picket J).

Picket W

GW-713 (TD=315.2 ft) was used as the injection well in the first test at Picket W to determine the degree to which strata-bound permeability may be important. Three wells (GW-711, GW-713 and GW-714) intersected zone 4 of the Cmn (Cmn-4), and the test was used to evaluate hydraulic connection between the zones (location maps and cross sections are referenced in the RESULTS section). During Test 1, water was injected into GW-713 at pressures between 30 and 35 psi for 40 min. on 8/25/93, over which time only 178 gallons were injected into the well (i.e., ≈4.4 gpm). Such slow injections could not be expected to produce a sharp pressure pulse. Hence, a second test was run by injecting water into GW-712 (TD=457.5 ft), which was noted to produce a greater amount of water than GW-713 during well development procedures. Water was injected into GW-712 at pressures between 50 and 82 psi for 41 min. on 8/30/93, over which time only 443 gallons were injected into the well (ie. ≈10.8 gpm). Due to the slow pumping rates in each well, rapid conduit type responses could not be expected to be detected in the surrounding wells at Picket W. Zones tapped by these two wells are clearly slow flow water zones.

The following wells in the Picket W area were instrumented with pressure transducers and Hydrolab probes:

GW-710 (TD=744.5 ft; WL = 68.95 ft, both tests): 10 psi transducer depth = 75 ft.

GW-711 (TD=666.2 ft; WL = 64.83 ft, first test, 67.33 ft, second test): 10 psi transducer depth = 70 ft.

GW-712 (TD=457.5 ft; WL = 35.0 ft, first test): 10 psi transducer depth = 35 ft.

GW-713 (TD=315.2 ft; WL = 38.48 ft, second test): 10 psi transducer depth = 43 ft; Hydrolab = 300 ft when GW-712 is used as an injection well.

GW-714 (TD=145 ft; WL = 31.28 ft, first test, 30.91 ft, second test): 10 psi transducer depth = 35 ft; Hydrolab = 140 ft.

GW-715 (TD=43.1 ft; WL = 29.76 ft, first test, 29.84 ft, second test): 10 psi transducer depth = 35 ft; Hydrolab = 40 ft.

Picket A

GW-684 (TD=128.4 ft) was used as the injection well because a 2-ft cavity is known to be present within the completion interval of this well (Location maps and cross sections can be found in the RESULTS section). Hence, it was expected that the well would accept sufficient water for a sharp injection pulse to be produced. During measurements in Picket A, it was also desirable to monitor the SS-5 spring because an increase in turbidity was noted in the spring during drilling of GW-684 (Shevenell, et al., 1992). Water level variations in the SS-5 spring were measured using an Isco sampler. During the first test at this Picket, a total of 2855 gallons of water from the tanker truck were injected into GW-684 on 8/3/93 over a 41 min. interval (≈70 gpm). Questionable responses in the surrounding monitored wells were obtained during the first test and it was decided to attempt another test by injecting water under pressure in order to increase the rate at which water was introduced into the aquifer. During the second test, DI water was injected into GW-684 at a pressure of 40 psi for 15.75 min. on 8/11/93, over which time 2775 gallons were injected into the well (i.e., ≈176 gpm). Hence a much sharper pressure pulse was obtained during the second test.

The following wells in the Picket A area were instrumented with pressure transducers and Hydrolab probes:

GW-054 (TD=37.2 ft; WL = 11.63 ft, first test, 11.0 ft second test): 5 psi transducer depth = 20 ft.

GW-056 (TD=55.2 ft; WL = 8.01 ft, first test, 7.73 ft, second test): 5 psi transducer depth = 12 ft.

GW-057 (TD=22.8 ft; WL = 6.56 ft, first test. 6.21 ft, second test): 10 psi transducer depth = 10 ft.

GW-058 (TD=44.2 ft; WL = 24.6 ft, first test): 5 psi transducer depth = 30 ft.

GW-059 (TD=24.8 ft; WL = 24.78, first test): 10 psi transducer depth 24.7 ft.

GW-060 (TD=49.8 ft; WL = 17.72, first test): 10 psi transducer depth = 25 ft.

GW-061 (TD=24.6 ft; WL = 17.92, first test): 10 psi transducer depth = 25 ft.

GW-651 (TD=52.0 ft; WL = 10.2 ft, first test): 10 psi transducer depth = 15 ft.

GW-683 (TD=196.8 ft (in the Copper Ridge Dolomite); WL = 89.0, first test, 88.9 ft, second test): 10 psi transducer depth = 93 ft. ft; Hydrolab = 190 ft.

GW-684 (TD=128.4 ft; WL = 15.6 ft, first test,): 10 psi transducer depth = 20 ft.

GW-685 (TD=138.3 ft; WL = 8.6 ft, first test, 8.3 ft, second test): 5 psi transducer depth = 12 ft; Hydrolab = 130 ft.

GW-728 (WL = 23.4 ft, first test, 22.91 ft, second test): 10 psi transducer depth = 27 ft.

Picket B

GW-706 (TD=182.5 ft) was used as the injection well in order to evaluate possible hydraulic connections to zones located both along dip (i.e., GW-704) and across strata (i.e., GW-694 and GW-703; Location maps and cross sections can be found in the RESULTS section). During measurements in Picket B, it was desirable to monitor a nearby spring (the SS-4 spring) in order to determine if there was a hydraulic connection between the spring and the source well. Although this spring was monitored, the digital data were lost, and only the strip chart recording is available. Deionized water was injected into GW-706 at pressures between 62 and 65 psi for 40 min on 11/3/93, over which time 2960 gallons were injected into the well (i.e., ≈74 gpm).

The following wells in the Picket B area were instrumented with pressure transducers and Hydrolab probes:

GW-621 (TD=40.5 ft; WL = 17.99 ft): 10 psi transducer depth = 21 ft; Hydrolab = 37 ft.

GW-694 (TD=204.5 ft; WL = 29.56 ft): 10 psi transducer depth = 33 ft; Hydrolab = 202 ft.

GW-695 (TD=62.4 ft (in the Copper Ridge Dolomite); WL = 29.73 ft): 10 psi transducer depth = 33 ft; Hydrolab = 60 ft.

GW-703 (TD=182 ft; WL = 44.64 ft): 10 psi transducer depth = 49 ft; Hydrolab = 170 ft.

GW-704 (TD=256 ft; WL = 35.06 ft): 10 psi transducer depth = 39 ft; Hydrolab = 250 ft.

GW-705 (TD=307 ft; WL = 28.04 ft): 5 psi transducer depth = 32.

Picket C

GW-724 (TD=301.6 ft) was used as the injection well at Picket C in order to evaluate the possibility of along strata hydraulic connection between GW-724 and GW-725, GW-736 and GW-737 (location maps and cross sections can be found in the RESULTS section). Also, numerous cavities were identified at shallower depths in the vicinity of GW-724. Note that the natural water level in all wells at Picket C, except GW-062 and GW-063, are higher than in the injection well. However, the depth and stratigraphic location of GW-724 is appropriate for evaluating hydraulic communication between the GW-724 well and GW-725, GW-736, GW-737, and GW-723. Deionized water was injected into GW-724 at a pressure of 50 psi for 22 min. on 9/21/93, over which time 2930 gallons were injected into the well (ie. ≈133 gpm).

The following wells were instrumented with pressure transducers and Hydrolab probes during the test:

GW-066 (TD=16.5 ft; WL = 10.49 ft): 5 psi transducer depth = 15 ft.

GW-723 (TD=444.5 ft; WL = 76.79 ft): 5 psi transducer depth = 81 ft.

GW-725 (TD=142.5 ft; WL = 14.86 ft) 10 psi transducer depth = 19 ft; Hydrolab = 135 ft.

GW-736 (TD=102.5 ft; WL = 13.66 ft) 10 psi transducer depth = 18 ft; Hydrolab = 95 ft.

GW-737 (TD=89.5 ft; WL = 13.6 ft) 10 psi transducer depth = 18 ft; Hydrolab = 85 ft.

GW-738 (TD=87.5 ft; WL = 31.07 ft) 10 psi transducer depth = 35 ft; Hydrolab = 80 ft.

GW-739 (TD=320 ft; WL = 77.82 ft): 5 psi transducer depth = 81 ft; Hydrolab = 300 ft.

GW-800 (TD=35 ft; WL = 21.18 ft): 5 psi transducer depth = 25 ft.

Picket J

Cross borehole testing was conducted two separate times because only 10 wells could be monitored during any given test, and there are more than 10 wells in this Picket area (location map and cross sections can be found in the RESULTS section). GW-734 was selected for use as the injection well because it intersects a large cavity and it was believed that this well would accept injected water more rapidly than would other wells in the Picket area. Four zones in each of two multiport wells (GW-722 and GW-131; Dreier et al., 1993) were monitored during the tests. During the first test at Picket J, DI water was injected into GW-734 at pressures between 45 and 50 psi for 17 min. on 9/29/93, over which time 2803 gallons were injected into the well (i.e., ≈165 gpm). During the second test on 10/6/93, water was also injected into GW-734 at pressures between 45 and 50 psi for 17 min., over which time 2910 gallons were injected into the well (ie. ≈171 gpm).

The following multiport zones were monitored: GW-722-10, -17, -22, -32, and -33, and GW-131-04, -24, -28, and -32. These zones were selected in order to maximize the likelihood of detecting a response during the test. It is assumed that zones in the same stratigraphic horizon or at the same elevation as the source well, or zones showing high hydraulic conductivities would be the most likely zones to experience a response during testing. All GW-131 zones showed relatively high hydraulic conductivities during recent conductivity testing (hydraulic conductivities of zones 4, 24, 28, and 32 are 1.5×10^{-3}cm/s, 8.6×10^{-4}cm/s, 1.9×10^{-4}cm/s, and 2.9×10^{-3} cm/s, respectively; R. Dreier, pers. comm., August, 1993). Zones GW-722-32 (elevation = 846.7 ft) and GW-722-33 (elevation 866.7 ft) were selected because they monitor the same elevation interval as does GW-734 (elevation = 833 to 877 ft), and solution cavities were noted in both zones in GW-722. GW-722-17 monitors the same stratigraphic interval as GW-131-04 and both were monitored during the tests. Also, major fractures are located within zones GW-722-10 and -22 (Dreier, pers. comm, August, 1993). The zones in GW-131 and GW-722 were monitored during both cross-borehole tests conducted at Picket J.

During the first test, the following wells in the Picket J area were instrumented with pressure transducers:

GW-131-04, -24, -28, and -32 (instrumented with Westbay pressure probes at depths of 1003 ft, 458 ft, 376 ft, and 259 ft, respectively).

GW-151 (TD=96.5 ft, WL = 15.1 ft, second test): 10 psi transducer depth = 19 ft.

GW-167 (TD=30.1 ft, WL = 29.35, first test): 5 psi transducer depth = 32 ft.

GW-168 (TD=135.4 ft, WL = 30.63 ft, second test): 5 psi tramsducer depth = 34 ft.

GW-220 (TD=44.7 ft; WL = 16.06 ft, first test): 10 psi transducer depth = 19 ft; Hydrolab = 40 ft.

GW-603 (TD=75.2 ft; WL = 59.4 ft, first test): 10 psi transducer depth = 63 ft; Hydrolab = 70 ft.

GW-604 (TD=112.4 ft; WL = 59.53 ft, first test): 10 psi transducer depth = 63 ft; Hydrolab = 105 ft.

GW-722-10, -17, -22, -32, and -33 (instrumented with Westbay pressure probes at depths of 500 ft, 385 ft, 313 ft, 107 ft, and 87 ft, respectively).

GW-733 (TD=256 ft; WL = 57.22 ft, first test): 5 psi transducer depth = 61 ft.

GW-735 (TD=78.1 ft,WL = 22.47 ft, first test, 23.0 ft, second test): 10 psi transducer depth = 26 ft; Hydrolab = 78 ft.

GW-744 (TD=69.5 ft, WL = 7.08 ft, second test): 5 psi transducer depth = 11 ft.

GW-745 (TD=32.7 ft; WL = 6.0 ft, first test): 5 psi transducer depth = 9 ft.

GW-747 (TD=82.5 ft; WL = 6.06 ft, second test): 5 psi transducer depth = 10 ft.

GW-748 (TD=27 ft; WL = 6.63 ft, first test): 5 psi transducer depth = 10 ft; Hydrolab = 25 ft.

GW-750 (TD=72.4 ft; WL = 11.71 ft, first test, 13.14 ft, second test): 10 psi transducer depth = 15.85 ft; Hydrolab = 70 ft.

During the second test, the following wells in the Picket J area was instrumented with pressure transducers:

GW-131-04, -24, -28, and -32 (instrumented with Westbay pressure probes at depths of 1003 ft, 458 ft, 376 ft, and 259 ft, respectively).

GW-150 (TD=11.7 ft, WL = 14, 14.2, 14.2): 5 psi transducer depth = 16 ft; Hydrolab = 9 ft.

GW-151 (TD=96.5 ft, WL = 15, 15.2, 15.6): 5 psi transducer depth = 18 ft; Hydrolab = 90 ft.

GW-722-10, -17, -22, -32, and -33 (instrumented with Westbay pressure probes at depths of 500 ft, 385 ft, 313 ft, 107 ft, and 87 ft, respectively).

GW-734 (TD=103 ft; WL = ?, 39.9, 35.9): 10 psi transducer depth = 50 ft.

GW-735 (TD=79.2 ft,WL = 23, 23.6, 19.8): 10 psi transducer depth = 26 ft.

GW-744 (TD=67 ft; WL = 7, 7.1, 5.5): 5 psi transducer depth = 9 ft; Hydrolab = 65 ft.

GW-747 (TD=79.2 ft WL = 6, 9, 3.2): 10 psi transducer depth = 13 ft; Hydrolab = 75 ft.

GW-750 (TD=72.4 ft; WL = 13, 13.5, 8.1): 5 psi transducer depth = 15 ft.

RESULTS

Results of the cross borehole tests are discussed below, with the westernmost Picket (W) being discussed first, and the easternmost (J) last. Plots for only those wells showing water level responses are included in this report. Note that only two of the wells which showed a pressure response had an accompanying response in temperature and specific conductance suggesting that zones with water level responses may be hydrologically connected, but that generally, either no water from the injection wells actually reached the monitor wells during the tests, or the injected water was sufficiently diluted with aquifer water that it was not detected.

Diagnostic plots were constructed and evaluated for each of the wells showing water level responses with their water level rises being assumed analogous to drawdown. Drawdown (s) in this context is actually the difference between the starting water level at time t = 0 and the water level in the monitored well as it increases during the test ("draw-up"). Earlier work by Smith and Vaughn (1985) on the ORR shows that diagnostic plots can be used to determine if the well responses during a pumping test are indicative of radial flow, or linear flow to a wellbore as would occur in fracture dominated systems. Smith and Vaughn (1985) show that if the graphs of drawdown versus the log of the pumping time is not a straight line, but the graph of drawdown versus $t^{1/2}$ does forms a straight line, then it is likely that flow to the wellbore is linear. Hence, drawdown (s) versus log(t) and $t^{1/2}$ were plotted for all wells to determine if there were indications of linear flow. In addition, log(t) versus the log(s) was plotted for each well. Based on work by Gringarten (1982), the slope of a log versus log plot is also diagnostic. A slope of 1 indicates wellbore storage effects, whereas slopes of 0.5 and 0.25 suggest the wellbore taps a high or a low hydraulic conductivity fracture, respectively. In addition, two parallel slopes on a semilogarithmic plot of time versus drawdown is indicative of either a damaged well or a fissured reservoir with large blocks (Gringarten, 1982). Table 2 summarizes the features of the diagnostic plots for the wells in the five Pickets. In the interest of brevity, none of these plots are included in this report, yet an example of these types of plots is illustrated in Fig. 3 using data from GW-711, test 1. The log(t) versus s plot shows that the initial curve is not linear, yet it is when plotted as $\sqrt{t}$ versus s indicating there is probably linear flow to the well bore through fractures (based on Smith and Vaughn, 1985). Two slopes are observed on the log-log plot, the first with a slope of 0.91, which is indicative of well bore storage effects during early times, and the second slope of 0.6 is indicative that the well may tap a high conductivity fracture. In this well it is reasonable to have the effects of well bore storage because it is a deep (666 ft) well with considerable storage.

Picket W

Although numerous cavities were encountered during drilling activities at Picket W, most of the wells in the Picket are quite deep, and only one (GW-715) is completed within a cavity. Hence, rapid responses between source and monitor wells after fluid injection was not expected. However, the cross borehole tests allowed evaluation of the non-conduit aquifer characteristics in the zones monitored by the wells in this Picket. Table 3 lists selected data from the injection tests at all five pickets and indicates which wells showed a water level response to the injections. Figs. 4 through 10 show water level responses in the monitor wells as a result of injection into either GW-713 or GW-712. Figs. 11 and 12 show the locations of the wells used in the Picket W tests, and the possible hydrologic connections between the wells inferred from the results of the tests.

The wells GW-710, GW-711, and GW-714 exhibited slow water level responses during injection tests in both GW-712 and GW-713 (Figs. 4, 5, 7, 8, 9, and 10). The same time intervals were used for obtaining water levels in all wells, and the differences in the "steps" between wells (e.g., Fig. 4 versus Fig. 5) are a result of the monitored water level changes and not the time intervals. Larger apparent steps are illustrated in Fig. 4 than in Fig. 5 because changes on the order of hundredths of a foot are shown in Fig. 4 whereas Fig. 5 illustrates changes on the order of tenths of a foot. Gradual changes in water level occur in these wells, perhaps changing by < 0.01 feet between time steps. These small changes are not depicted by a smooth curve because the measured water levels are rounded to two significant figures.

Water level increases were observed in GW-712 during injection into GW-713, and in GW-713 during injection into GW-712 (Fig. 6). Much greater water level increases where seen when flow was with the hydrologic gradient (GW-712 to GW-713), rather than against the gradient (GW-713 to GW-712). Note that two small water level increases occur at the end of the recorded interval at these wells, and all other wells in Picket W, during both tests. These small increases and decreases occur in intervals approximately 12 hours apart and suggest the wells are responding to earth tides. Given that the aquifers on the ORR are considered to be increasingly confined with depth (Solomon et al., 1992; Moore and Toran, 1992), the water level fluctuations in these well may suggest partial confinement. Data from ambient monitoring of water levels also shows twice daily peaks for these wells.

Picket W wells exhibit the slowest water level responses of any of the wells monitored, due in part to the generally greater distances between injection and monitor wells, but more importantly, due to the nature of flow at Picket W. Responses at other pickets (see below) show karst behavior in that responses in monitor wells are quite rapid with peak water levels being observed within a few minutes of cessation of injection. Peak water levels in Picket W wells, however, occur long after cessation of injection (23 to 601 min) suggesting a relatively slow pressure build-up in a fractured system with low storage.

Diagnostic plots for the Picket W wells often suggest linear flow in this portion of the aquifer (Table 2), indicating that flow between these wells may be fracture dominated. Note that the digital files for GW-714 (first test), and GW-711 (second test) were inadvertently lost, and diagnostic plots are not available for them. Flow through relatively high hydraulic conductivity (K) fracture(s) is indicated by the diagnostic plots, yet this seems unlikely given the long recession curves for all the monitor wells. These long curves show that pressures dissipate slowly as would be the case in lower hydraulic conductivity portions of the aquifer. However, the diagnostic plots also indicate a fissured reservoir with large blocks which is reasonable at this Picket. Wellbore storage effects during early time data are indicated in both GW-710 and GW-711, which is not surprising given that these two wells have 7 inch bores to depths of 666 and 745 ft. Based on the responses in the Picket W wells, and diagnostic plots, low K, interconnected fractures (networks) appear to occur between the wells, possibly allowing relatively slow flow over the depth interval of 145 to 745 ft.

Slow flow between these wells is reasonable when the chemistry of the waters are considered. The deep wells GW-710 and GW-711 have TDS between approximately 2500 and 4900 mg/L, whereas the shallower wells have TDS between about 320 and 450 mg/L. Deeper wells show evidence for interaction with the underlying brine and have Na and Ca as major cations, with $SO_4 \geq Cl >> HCO_3$. GW-712 has water with $Ca \approx Na$ and $SO_4 > HCO_3 >> Cl$. The shallowest wells (GW-714 and GW-715) have $Ca > Mg \approx Na$ and $HCO_3 >> SO_4$, with varying amounts of Cl. Hence shallow and deep zones are clearly different water types with the shallower zones experiencing more active flushing. Recharge to the deeper zones must be slow based on the high TDS, and water chemistry indicating mixing with a Na-Cl brine. The slow responses between the wells during cross borehole testing are consistent with the observed chemistry of the waters. It is improbable that water from the injection wells actually flowed to the deeper wells during the tests. The pressure responses observed reflect the slow pressure build up and dissipation in the low K portions of the Cmn.

Picket A

Because the first test at Picket A was conducted by gravity feeding water into GW-684, the injection well was monitored for the pressure response throughout the test. Hence, this test allowed for the estimation of transmissivity in the vicinity of GW-684. The hydraulic conductivity estimated from the Hvorslev method (Hvorslev, 1951) is 0.229 m/d, whereas the Theis recovery method (Theis, 1935) indicates a transmissivity of 34.5 m^2/d. During this test, the water level was maintained at a nearly constant elevation in order to avoid overflowing the well. In order to maintain this level, the flow rate needed to periodically be adjusted, and flow rates between ≈65 and 125 gpm were recorded. Hence, this well does not accept a constant volume of water, but undergoes surging (turbulent, transient flow near the wellbore). This behavior was also observed in the conduit well GW-734 (see Picket J discussion).

Table 3 lists selected data from the injection tests at all five pickets and indicates which wells showed a response to the injections. Fig. 13 shows water level responses in the SS-5 spring as a result of injection into GW-684 during the first test, whereas Figs. 14 and 15 show water level responses as a result of injection into GW-684 during the second test. Figs. 16 and 17 show the locations of the wells used in the Picket A tests, and the possible hydrologic connections between the wells inferred from the results of the tests.

During the first test, a small (≈ 0.051 ft), yet clear response was observed in the SS-5 spring (Fig. 15), as was expected given that increased turbidity in the spring was noted during drilling of GW-684 (Shevenell et al., 1992). The water level response began within 1 to 2 min. following initiation of injection and began to decline at the same time that injection was terminated in the well. Hence, a clear hydrologic connection was established between the injection well and this spring. The second test at Picket A produced a similar response.

No clear water level, temperature, or SC responses were observed in any of the monitor wells during the first test. Possible responses were observed in two of the wells, however. A 0.1 ft response to water injection in GW-684 may have occurred in GW-683 during the injection, although it is unclear if this signal is merely noise. A spike of 0.1 ft was also recorded in GW-685 which lasted 12 min. and began 11 min. after fluid injection was initiated at GW-684. These 0.1 ft water level responses were not considered significant because a similar 0.1 ft response was recorded in GW-057 12 min. before the test began. These responses suggested the possibility of hydrologic communication between the injection and two monitor wells, yet the test proved inconclusive. Hence, a second test was designed in which water would be injected under pressure at a higher flow rate than could be obtained from a gravity feed in hopes that more definitive responses would be obtained.

The only well in which a response was observed in the second test at Picket A was GW-683 which exhibited about a 0.13 ft maximum increase in water level only 0.25 minutes following cessation of injection. Also, the water level began to rise almost immediately (<1 min) after injection began suggesting a direct connection between the injection and monitor well via a conduit or fracture. The water level receded rapidly (within 40 min) suggesting rapid draining of the karst feature. Many of the other wells probably showed no response to injection because they are located at too great a distance from the source well (up to 1870 ft away, Table 1).

Picket B

Clear responses to injection in GW-706 were observed in several wells in Picket B (GW-621, GW-694, GW-695, and GW-704), and a questionable response was observed in GW-703. Possible responses in temperature and SC were noted in two of the wells (GW-621 and GW-694; see Table 4). The SS-4 spring showed a peak water level response of 0.058 ft at the precise time that injection ceased, and the water level began to rise upon initiation of injection suggesting a hydrologic connection with the injection well which is located along strike. However, no digital data are available because the data were inadvertently deleted from the logging unit before they could be retrieved. Table 3 lists selected data from the injection tests at all five pickets and indicates which wells showed a water level response to the injections. Figs. 18 through 24 show water level responses in the monitor wells and possible temperature and SC responses in GW-621 and GW-694. Figs. 25 and 26 show the locations of the wells used in the Picket B test, and the possible hydrologic connections between the wells inferred from the results of the tests.

Water level responses in GW-621, and GW-694 were quite sharp, with water levels beginning to rise 1 to 2 min after the start of injection. The responses suggest the completion zones in theses wells are connected to the injection well via fractures or conduits. The steady decrease in water level in GW-621 (and GW-703) is believed to be a result of transducer drift, yet the water level rises in response to the injection are still quite clear. Much slower responses and longer recession curves were observed in the GW-695, GW-703 and, perhaps, GW-704 wells. This suggests a less direct connection between these wells and GW-706 and a slower pressure build-up expected in portions of the aquifer which are not subject to quick flow. Although the GW-704 well showed a rapid initial response to the injection (Fig. 24), the delay time to the peak water level, and the length of the recession curve (Table 3) suggest a slowly dissipating pressure pulse, likely dominated by flow through non-conduit portions of the aquifer.

Although the changes in temperature and SC in GW-621 are not distinct, those in GW-694 show an abrupt increase in both parameters followed by a sharp decrease. Due to the timing of these changes shortly following fluid injection into GW-706, temperature and SC likely increased in GW-694 due to fluid flow from GW-706. However, this interpretation is not considered definitive because of the nature of the plot which shows that the pre-injection temperature and SC are not equal to the post-injection values. Instead, a distinct drop in the baseline occurred such that the stabilized post-injection temperature and SC are ≈0.04 °C and 94 μmhos/cm lower than the pre-injection values.

Both the water level changes and the temperature and SC data suggest that GW-621 and GW-694 may be connected to GW-706 through fractures or conduits (i.e., open flow paths), and that rapid flow between these wells may be expected. This conclusion is also supported based on the information obtained from diagnostic plots (Table 2). These data suggest that there is linear flow to both of these wells, which are located ≈115 ft from GW-706, and that both tap relatively high hydraulic conductivity fractures.

Picket C

Clear responses to injection in GW-724 were observed in several wells in Picket C (GW-066, GW-725, GW-736, GW-737, GW-738, and GW-739; see Table 3). Figs. 27 through 32 show water level responses in the monitor wells as a result of injection into GW-724. Figs. 33 and 34 show the locations of the wells used in the Picket C test, and the possible hydrologic connections between the wells inferred from the results of the tests.

Water level responses in some of the monitoring wells had a long delay to the peak water level, and a very long recession curve, although several exhibited rapid initial responses to injection (GW-725, GW-736, and GW-737). GW-725 is the only well at Picket C which showed a response suggestive of quick flow conditions between it and the injection well (Fig. 28). In all other wells the pressure pulse dissipates very slowly suggesting that flow between these wells and the injection well is dominated by the slower flow, non-conduit portion of the aquifer. Note that GW-725 likely showed an increase in SC during the test, but the Hydrolab apparently stopped logging during the critical time of the test. SC increased from 930 to 956 μmhos/cm 16 min after injection began, with SC beginning to rise only 2 min after initiation of injection. The SC had a value of 999 μmhos/cm at 195 min, and this value is clearly on the recession portion of the curve, yet the maximum value, and the time at which this occurred is unknown. Temperature may have also risen slightly during the test. Given that DI water was injection, one would expect SC to decrease in a well if water flow occurs between the injection and monitoring well. However, an increase apparently occured and this may be the result of entrainment of some rust particles from the interior of the water truck tank. In spite of some missing data in temperature and SC, it appears that water flowed from the injection well to GW-725 during the test.

Diagnostic plots suggest the possibility that the water level responses in all Picket C monitor wells are influenced by wellbore storage effects (Table 2). Linear flow from GW-724 to GW-725, GW-736 and GW-737 is suggested, with low hydraulic conductivity fractures expected between GW-724 and and GW-736 and GW-737. This is reasonable given the slow dissipation of the pressure pulse observed in these wells.

Picket J

Prior to conducting cross borehole testing at Picket J, a step injection test was attempted at GW-734 to determine if sufficient water could be introduced into the wellbore by gravity feeding the water. During this test, water in GW-734 repeatedly surged with water levels dropping rapidly followed by rapid increases in water level and overtopping of the well bore. These effects occurred even though relatively constant injection rates were used. Surging occurs in other wells which also intersect conduits. Most of the cavities contain mud on their walls, or appear to be mud filled. It is believed that surging occurs when the well area is stressed by pumping, and mud clots are periodically dislodged, and then become lodged in smaller conduit openings, thus temporarily reducing the flow until sufficient pressure builds up to dislodge the mud. The step injection tests were, therefore, not useful for the purpose intended due to this surging, inability to maintain a constant flow rate without surging, and the overflowing of the well.

During the two injection tests at Picket J, clear water level responses were observed in five multiport water zones or wells as a result of injecting water into GW-734 (Table 3). Figs. 35 through 42 show water level responses in the monitor wells and zones as a result of injection into GW-734. Figs. 43 and 44 show the locations of the wells used in the Picket J test, and the possible hydrologic connections between the wells inferred from the results of the tests.

Sharp, rapid water level responses were noted in GW-735, GW-722-32 and GW-722-33 during both tests suggesting quick flow between these wells and GW-734. Conduits are known to be located in GW-734, GW-722-32, and GW-722-33 at approximately the same elevations (Shevenell, et al., 1992), and the cross borehole tests verify that these conduits are hydrologically connected. Water level responses were also observed in GW-167 and GW-168, located along geologic strike of GW-734. However, the peak water level in each of these wells occurred long after (203 to 73 min) cessation of injection, and both have relatively long recession limbs (1636 and 881 min). Diagnostic plots (Table 2) indicate that these wells may be completed in high hydraulic conductivity fractures, yet the timing of the water level responses appears to be more consistent with lower hydraulic conductivities. Given the exceedingly long times for peak water levels to be observed in GW-167, a direct hydrologic connection between this well and GW-734 is questionable. It is possible that the injected water caused a small water level rise between GW-734 and GW-167 which dissipated slowly in the downgradient direction (toward GW-167) though poorly permeable zones, rather than water actually being transmitted through fractures toward GW-167.

DISCUSSION

No definitive changes in SC and T were seen at any of the wells, except for possible changes at GW-621 and GW-694, and GW-725 and GW-734 where important data are missing. Cross borehole tests were successfully used to identify hydrologic connections between some monitor wells. Whereas some responses were very rapid and suggestive of quick flow through conduits, other responses showed very slow pressure dissipation reflective of lower hydraulic conductivities. It should be recognized, however, that results of this nature are not conclusive. It is possible that no response may have been noted in some wells in which there was a hydrologic connection to the injection well. If the connection were a large conduit, it is possible that insufficient water may have been introduced into the injection well to produce an observable response in the monitor well. In addition, some wells may have been located at too great a distance from the injection well for responses to be noted. In general, quick flow responses were observed in wells located within ≈250 ft of the injection well. However, slower flow responses were seen at radial distances of up to 592 ft (Picket W).

In an attempt to estimate the differences in hydraulic conductivities between the water zones tested, transmissivities (T), hydraulic conductivities (K), and storage coefficients (S) were estimated based on the acquired water level data. Theses types of data were not specifically collected for the purpose of determining these parameters. Because water was injected under pressure, the injection/pumping rates needed to solve radial flow to a well are exaggerated over what the formation would actually accept under natural conditions. However, an attempt to use data on the 'draw up' curve in a relative sense was made for the purpose of comparison of T and S values along BCV.

The computer program AQTESOLV (Duffield and Rumbaugh, 1991) was used to estimate T or K and S from several standard models: (1) Theis confined and unconfined aquifer solutions (Theis, 1935), (2) Cooper-Jacob confined and unconfined aquifer solutions (Cooper and Jacob, 1946), (3) Theis recovery test solution (Theis, 1935), and (4) fractured aquifer test solution (Moench, 1984). Because the aquifers on the ORR are unconfined at shallow depths, and become increasingly confined at deeper levels, yet appear to be hydrologically connected throughout these depths (Solomon et al., 1992), both confined and unconfined aquifer test solutions were utilized for comparison.

Table 5 lists the relevant parameters used in these models. Injection rates were calculated based on the total volume flow into each injection well and the total injection time. Saturated thicknesses were estimated by subtracting the depth of the shallowest from the deepest well completion interval in a Picket which showed water level responses during the tests. Hence, at Picket W, both GW-714 and GW-710 showed water level changes during the test and the vertical distance between these zones is 599.5 ft. The total saturated thicknesses are likely to be larger than those noted on Table 5, but will not be less because the determination of thickness is based on known hydrologic responses over a particular depth interval. For instance, no responses would have been observed during these short tests in the deeper zones if they were part of a lower, confined aquifer. Actual aquifer thicknesses vary with location, and are largely unknown, but the aquifers on the ORR are known to become increasingly confined with depth (Solomon et al., 1992).

The fracture spacing was calculated based on drilling results from each, individual picket. The total number of fractures and cavities encountered in each well was divided into the total thickness penetrated by the wells. Note that at most Pickets, the shallower wells have smaller spacings between fractures than the deeper wells. It has been recognized in other wells on the ORR that fracture spacing increases with increasing depth (Solomon et al., 1992), and the spacings noted on Table 5 also reflect this trend.

Tables 6 and 7 list the results of the aquifer test models. In addition, a new method was utilized to estimate aquifer parameters in order to determine the degree to which the values in Tables 6 and 7 reflect reality. This method is applicable to wells intersecting conduits whose recession curves show three separate slopes representative of drainage from conduits, fractures, and matrix intervals. This method is described in detail in Shevenell (in press).

Table 6 lists results from the fractured aquifer test solution (Moench, 1984), and all are clearly unreasonable and unreliable results. In many cases, the standard error is greater than the calculated values for the storage coefficients. Hydraulic conductivities appear too high, and storage coefficients too low. The inaccuracy of the Moench model in predicting aquifer parameters can be attributed to several factors. First, the Moench model requires a fully penetrating well, and none of the wells are fully penetrating. The elevated pumping rates used in the tests also contribute significantly to the erroneous values. Other factors contributing to errors could be that the fracture spacing and aquifer thicknesses selected are not representative of the particular areas modeled and that the model is inappropriate to analyze the data collected.

The other aquifer test models (Theis, Copper-Jacob, Theis Recovery) show smaller standard errors in calculated T and S values, yet all T and S values appear too large, likely as a result of the elevated injection rates and pressures, and hence water level changes, used during the tests. In addition, saturated thicknesses selected for the Pickets may not be realistic, resulting in additional errors in the solutions. The same trends in relative T between the pickets are observed with this data, with Picket W having the lowest values as expected. Note that all models, including the Theis recovery method, yield similar results for calculated T and S at each of the pickets. Clearly, the elevated injection rates and pressures used during these tests results in elevated calculated values of T and S using the Theis recovery method as well.

The observation that the T and S values are elevated can be confirmed with values estimated using slopes of the recession curves. Table 8 lists estimated values for T of the continuum which includes contributions of conduits, fractures and matrix intervals. The utility of this method is demonstrated in Shevenell (in press), and in Table 8. This table shows separate calculations for GW-735 for which data from hydrographs as well as injection tests were available. The first two listings (GW-735-1, GW-735-2) are results based on the recession slopes obtained during cross borehole testing, and the next three entries are results from hydrographs obtained during ambient water level monitoring. Very similar results are obtained using both types of data indicating that this method of estimating T is not controlled by the elevated pumping rates in the injection tests as are the other methods employed in Tables 6 and 7. Optimally, to use this new method, three separate slopes must be identifiable on the recession limb, and this was only the case in eight of the monitored wells (or spring). Comparing these eight values in Table 8 to those in Table 7 shows that the more traditional methods of calculating T and S overestimate T by about three orders of magnitude. Hence, data from cross borehole tests conducted under elevated pressures are not suitable input to traditional aquifer test models. However, the recession curves may be used to estimate the continuum T from the method using separate slopes of the recession curve.

Data from Table 7 and 8 from Picket B are compared to evaluate if data in Table 7 can be used in a relative sense. Data from Table 7 indicate that the T associated with the GW-704 data is greater than that in GW-694, which are both greater than that in GW-695. However, data from Table 8 indicate that the T associated with the GW-694 data is greater than that in GW-704, which are both greater than that in GW-695. Hence, the two methods do not agree, and the larger data set in Table 7 can not be used to determine the locations of higher T zones. However, general trends appear reasonable and show that the deep wells in Picket W have lower T than wells in the other pickets, which are more representative of conduit flow in BCV.

In order to evaluate preferential quick flow directions, a summary of possible flow paths between injection and monitor wells is made based on the location of completion zones relative to one another. Table 9 lists the Cmn zone of each completion interval, and the location of the monitor well in relation to the injection well as a function of strike, dip and elevation. Several observations can be made from the data in this table. The following observations do not include Picket W which is not in an area representative of quick flow in BCV. Most wells located at different elevations, perpendicular to strike and across strata from the injection well do not show a hydrologic response to the injection, even at distances <200 ft. Only one well in this category (GW-703) showed a response, and it was fairly weak. When wells are located at the same elevations (at depths <150 ft), rapid responses are generally seen, even when the monitor well is located across strata and perpendicular to strike. Relatively rapid responses suggestive of quick flow are also seen regularly when zones are along dip with one another, regardless of whether they are along strike, perpendicular to strike or at some angle to strike. Rapid responses can also be expected in directions that are both along strike and dip, yet only one example of this situation occurs in the data set (GW-168). Very slow, or no responses were observed in the along strike, across strata category (ie. GW-705, GW-167). Considering Picket W only, more rapid flow appears to occur along strike, although none of the responses exhibited quick flow characteristics. Except for Picket W in which the injection wells were not completed in cavities, all monitor wells noted to contain cavities in their completion intervals showed a response to injection. Many water zones showed no response (Table 9) in Pickets A, B, C, and J in which the injection wells were either completed in cavities or water producing fractures. In these settings, pressure pulses are able to dissipate rapidly, and hence insufficient time may be available for water zones which are not directly connected to the injection well cavity or fracture to exhibit a response. Hence, the zones noted with fractures or cavities showed the quickest responses to injection, as expected. This is true except for GW-703. This well is located perpendicular to strike and across strata from GW-706 suggesting, again, that conduits are probably not well connected in this direction. In summary, rapid fluid velocities can be expected along dip through cavities and fractures, and at shallow depths in all lithologies and at various angles to strike. The along dip hydrologic connections appear to be most prominent within zone 2.

CONCLUSIONS AND RECOMMENDATIONS

Cross borehole testing was successfully used to identify hydrologic communication between individual wells in both the quick flow and slower flow regimes. Rapid water level rises and recessions are observed in the quick flow areas, whereas slower, diffuse flow is characterized by long responses showing broad curves for water level rise and fall. Picket W, where wells are generally deep and are not completed in cavities, showed the slowest water level responses of any of the Pickets tested. The best evidence for quick flow behavior was obtained at Picket J (between GW-734 and GW-722-32 and GW-722-33) and at Picket A (between GW-684 and GW-683 and the SS-5 spring). The rapid water level responses to injection were expected at these locations based on previous drilling data. The monitored zones in the three wells in Picket J occur at nearly the same elevations, and all three zones contain cavities. Hence, a direct hydrologic connection was not surprising. Similarly, at Picket A, increased turbidity occurred in the SS-5 spring during drilling of both GW-683 and GW-684 indicating the wells were hydrologically connected to the spring. No other wells in Picket A showed hydrologic communication with the injection well, and hence, very little additional information was obtained with the use of the cross borehole testing. Evidence for quick flow between injection and several monitor wells was also observed at Pickets B and C. Significant quick flow can therefore be expected throughout BCV, yet the directions of this flow may vary locally from site to site.

The cross borehole testing was useful in identifying general trends in the directions in which quick flow may be more dominant. Quick flow is common at shallow depths (<150 ft) in all directions, and this supports the observations of cavity occurrence during drilling, and lithologic observations in core which both indicate significant secondary porosity and cavity development at these shallow depths, with significantly fewer karst features at deeper levels. Rapid fluid velocities can also be expected along dip, in all lithologies and at various angles to strike. The along dip hydrologic connections are more prominent within zone 2. Hence, in any hydrologic modeling of this aquifer, considerably higher hydraulic conductivities should be assigned to the shallow (<150 ft) depths when modeling a large scale problem. Smaller scale problems should take into account the higher hydraulic conductivities expected in along strike and dip directions.

The results of this study support conclusions made from previous studies in the Cmn. Significant conduit development occurs in the shallow depths and the conduits are likely to be well interconnected. The possible anastomotic pattern of the conduits allows for preferential flow directions to change locally in response to position of the conduits. Nevertheless, the large scale, dominant flow direction in the Cmn is along strike, and hydrologic communication along dip, perhaps along bedding planes, occurs in several of the locations studied. The data presented here support previous assumptions, data, and conclusions. Other tests which could provide additional insight into the flow system should also be conducted, although these other tests do not provide information of the directional permeability characteristics of the aquifer. For instance, analysis of well and spring hydrographs collected from ambient monitoring will provide evidence of quick flow, slow flow, degree of confinement, assistance with a water balance, and perhaps, an estimate of the continuum transmissivity near the well bore.

ACKNOWLEDGMENTS

We wish to thank W. Kevin Jago for useful discussions and assistance during this work. We also thank C. Rightmire for providing thorough review comments on the manuscript.

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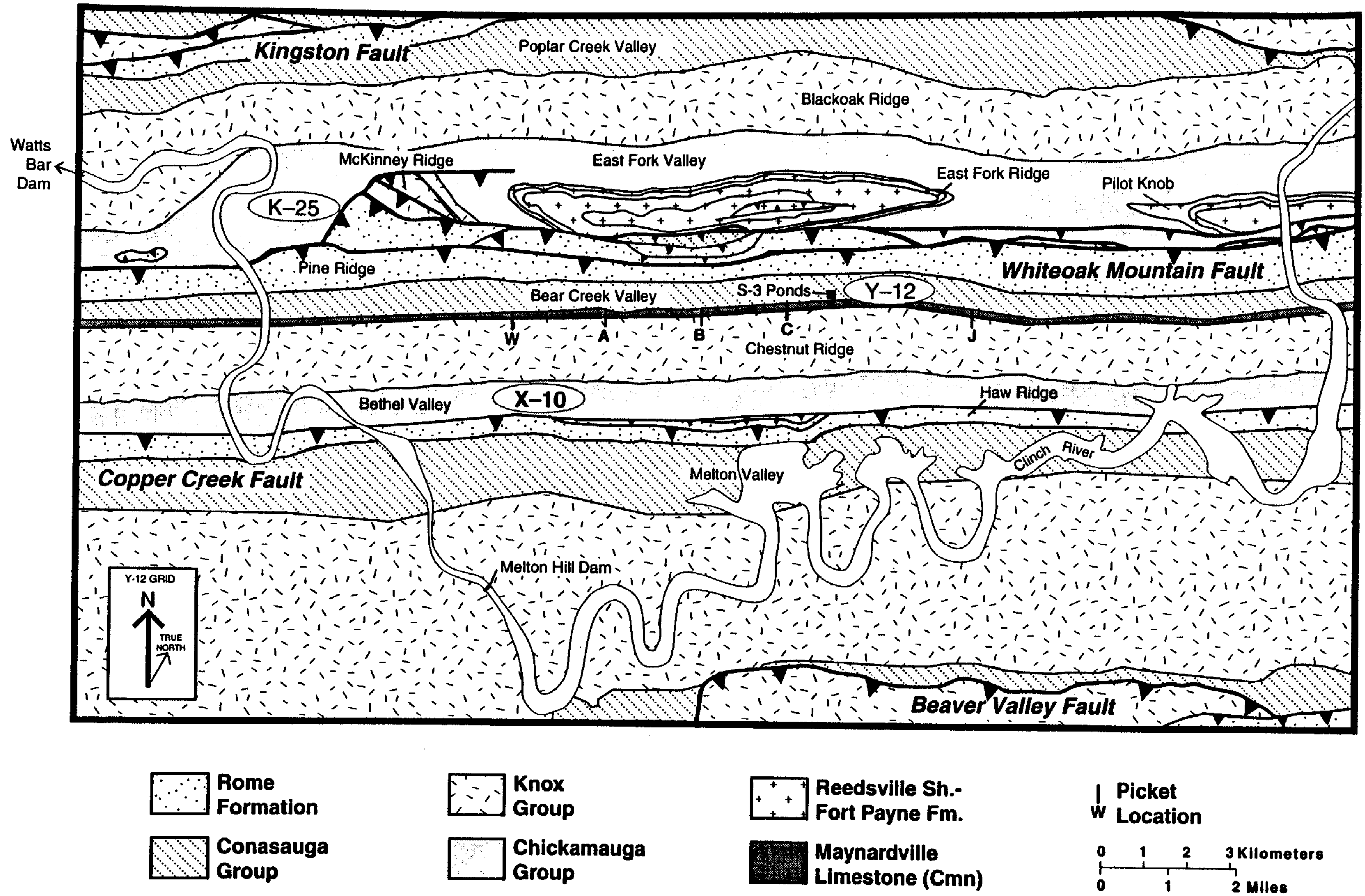

Figure 1. Generalized Geologic Map of the Oak Ridge Reservation. (Modified from Hatcher et al. 1992)

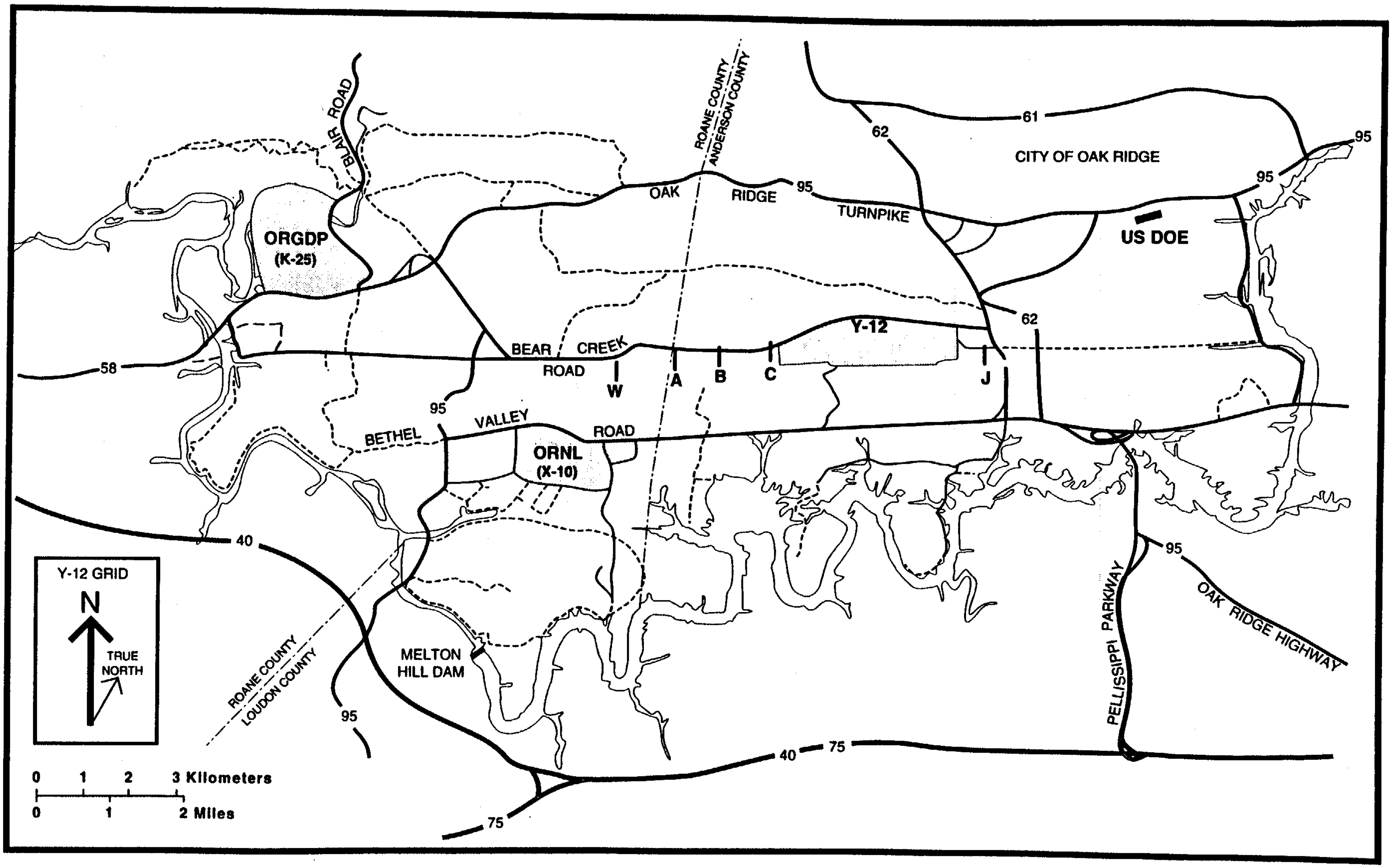

Figure 2. General locations of the Cmn Pickets at the Y-12 Plant.

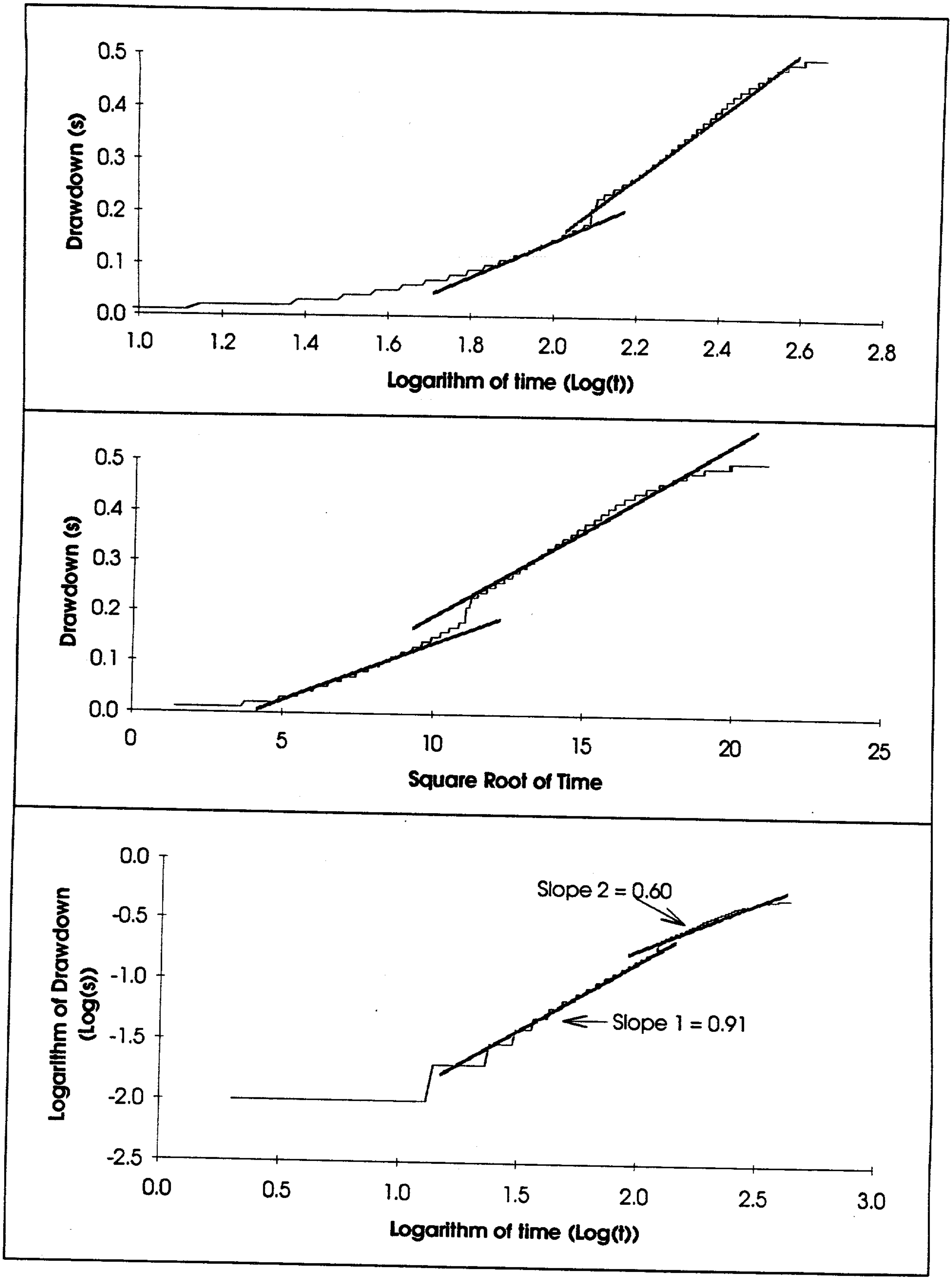

Figure 3. Examples of types of plots used in diagnosing the water level rises ("draw-up") for each well. The plots here are for GW-711 from the first cross-borehole test. Diagnostic plots were used to evaluate fracture flow at all wells discussed in this report.

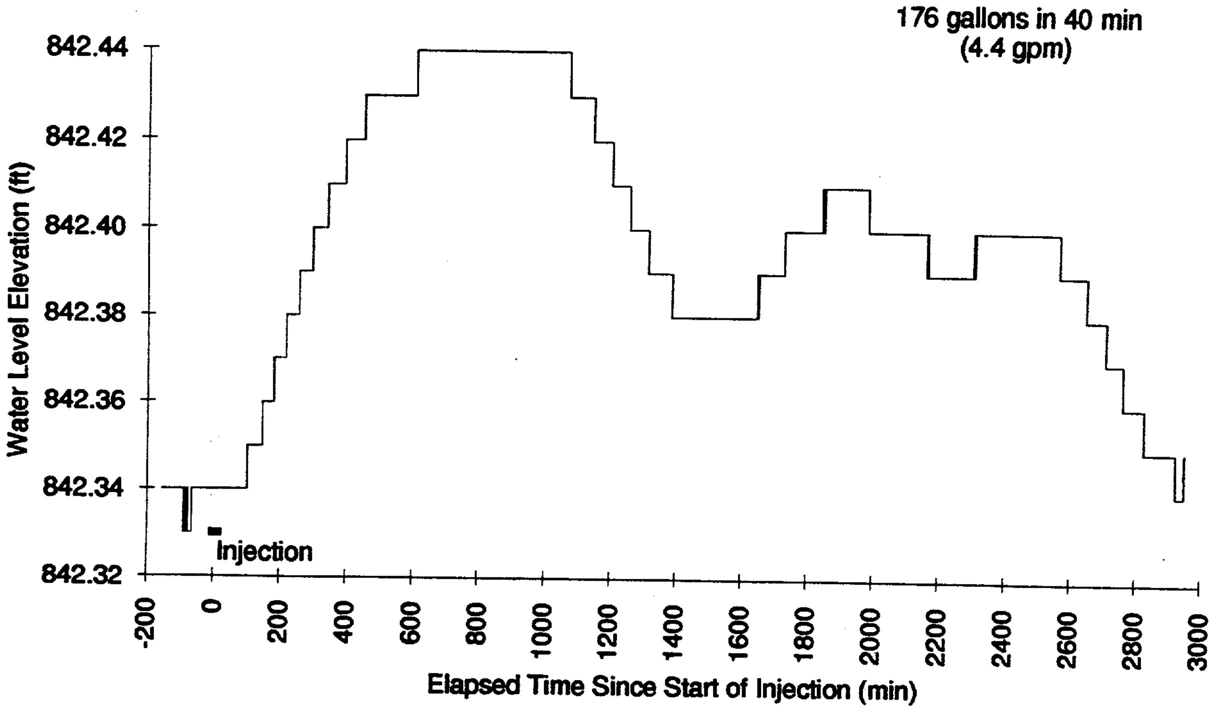

Figure 4. Water level elevation in GW-710 versus elapsed time since injection into GW-713, first test. (Picket W)

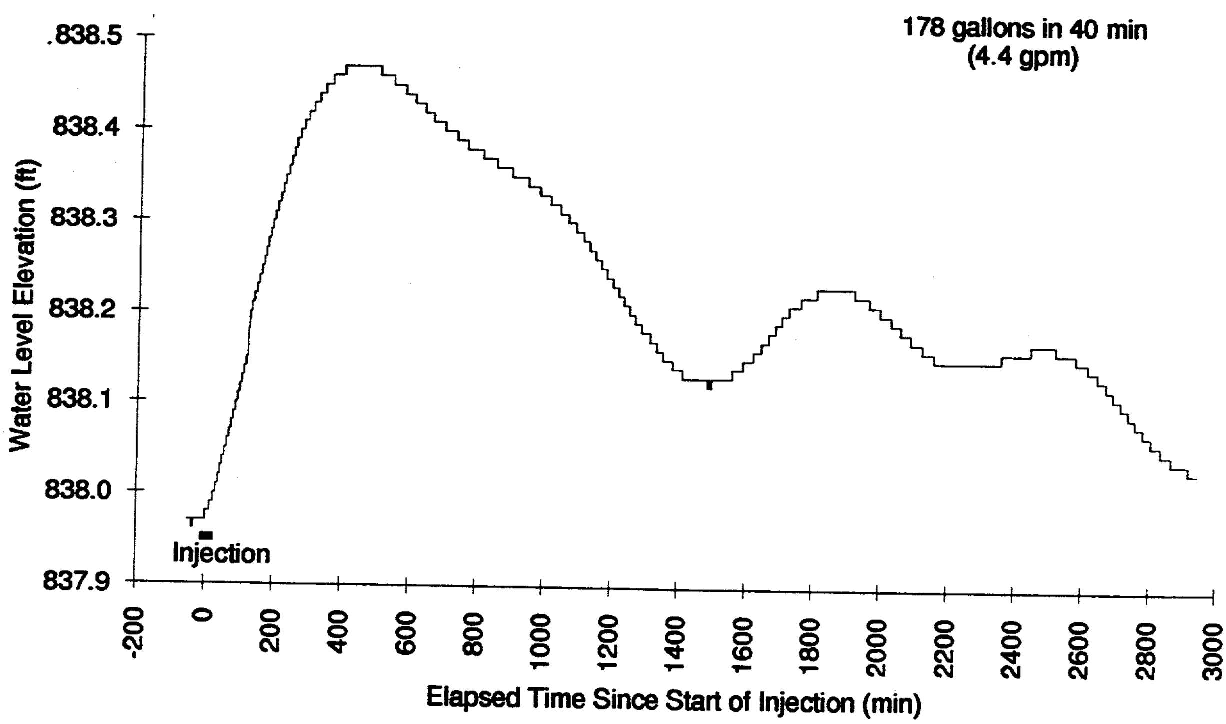

Figure 5. Water level elevation in GW-711 versus elapsed time since injection into GW-713, first test. (Picket W)

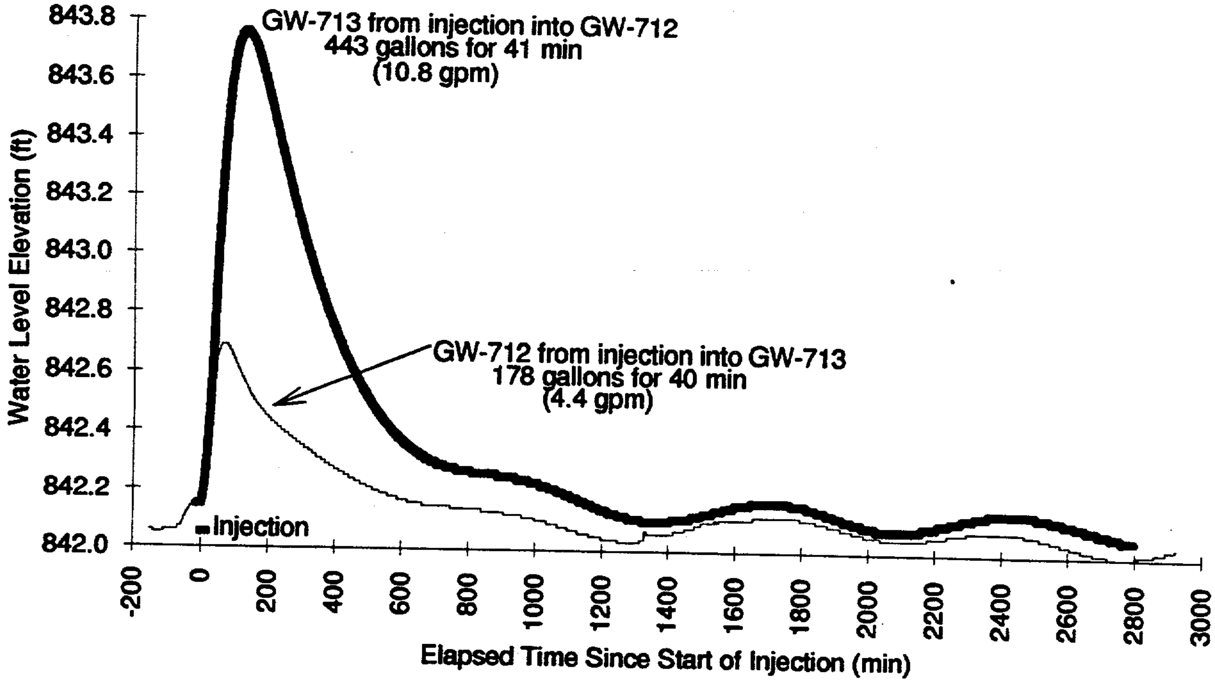

Figure 6. Water level elevation in GW-712 and GW-713, first and second tests. (Picket W)

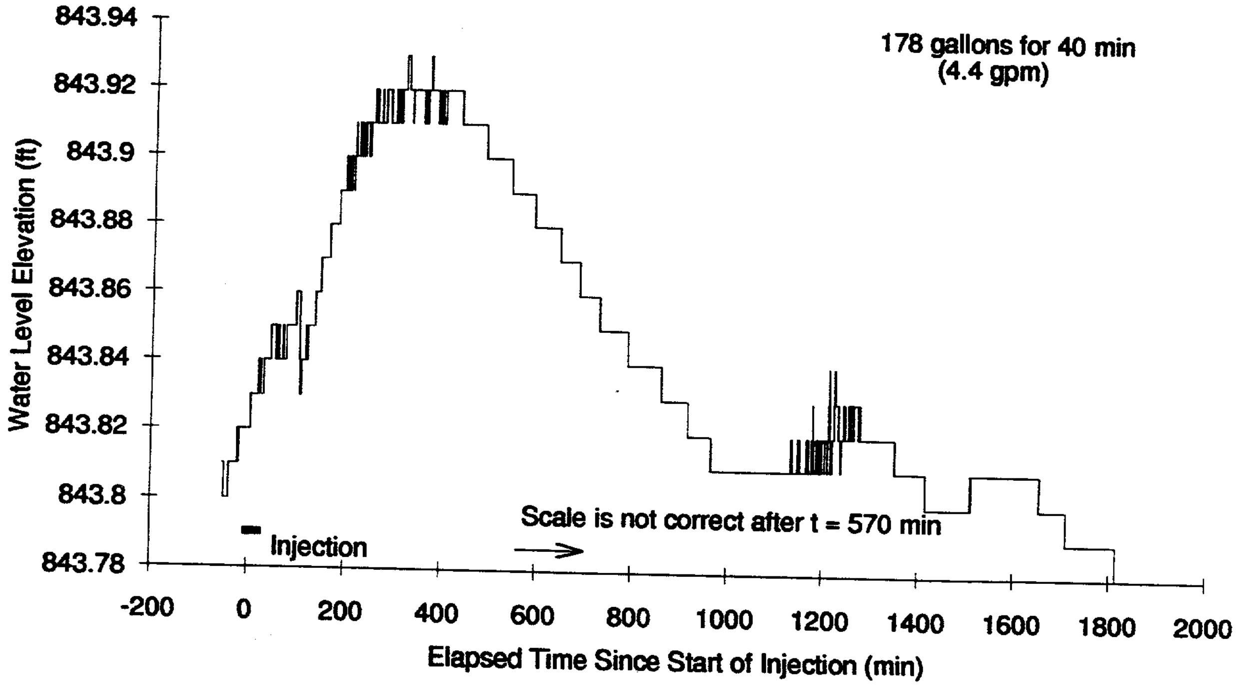

Figure 7. Water level elevation in GW-714 versus elapsed time since injection into GW-713, first test. (Picket W)

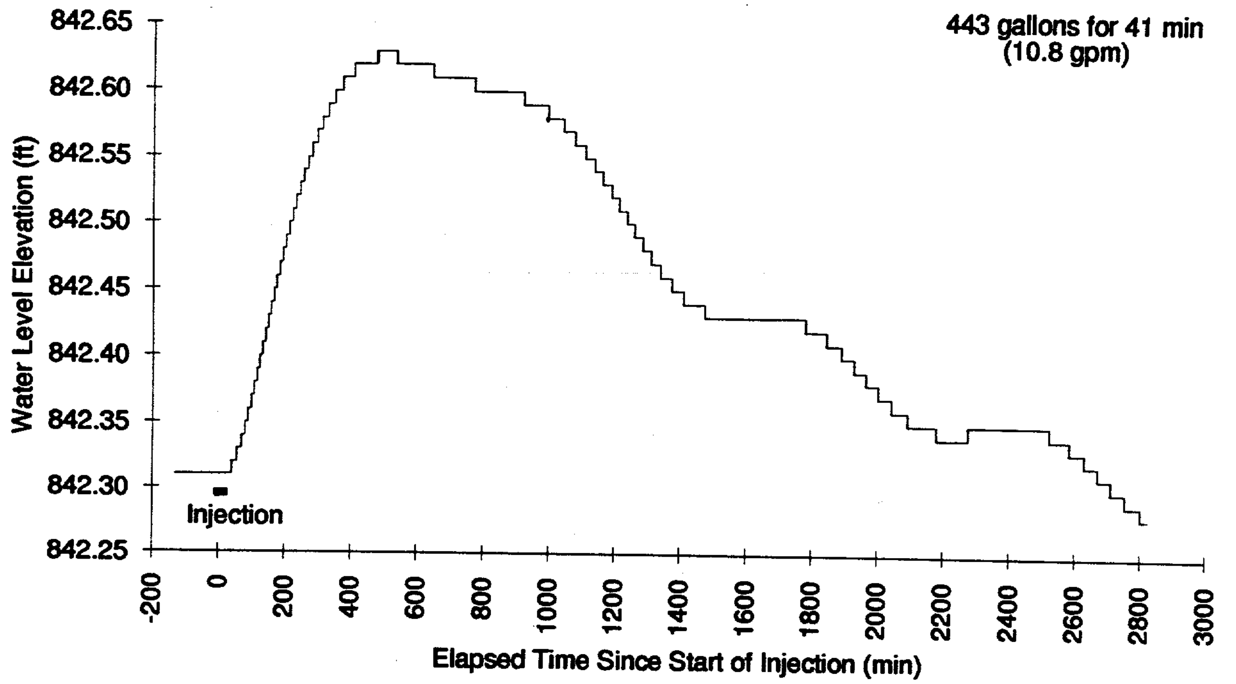

Figure 8. Water level elevation in GW-710 versus elapsed time since injection into GW-712, second test. (Picket W)

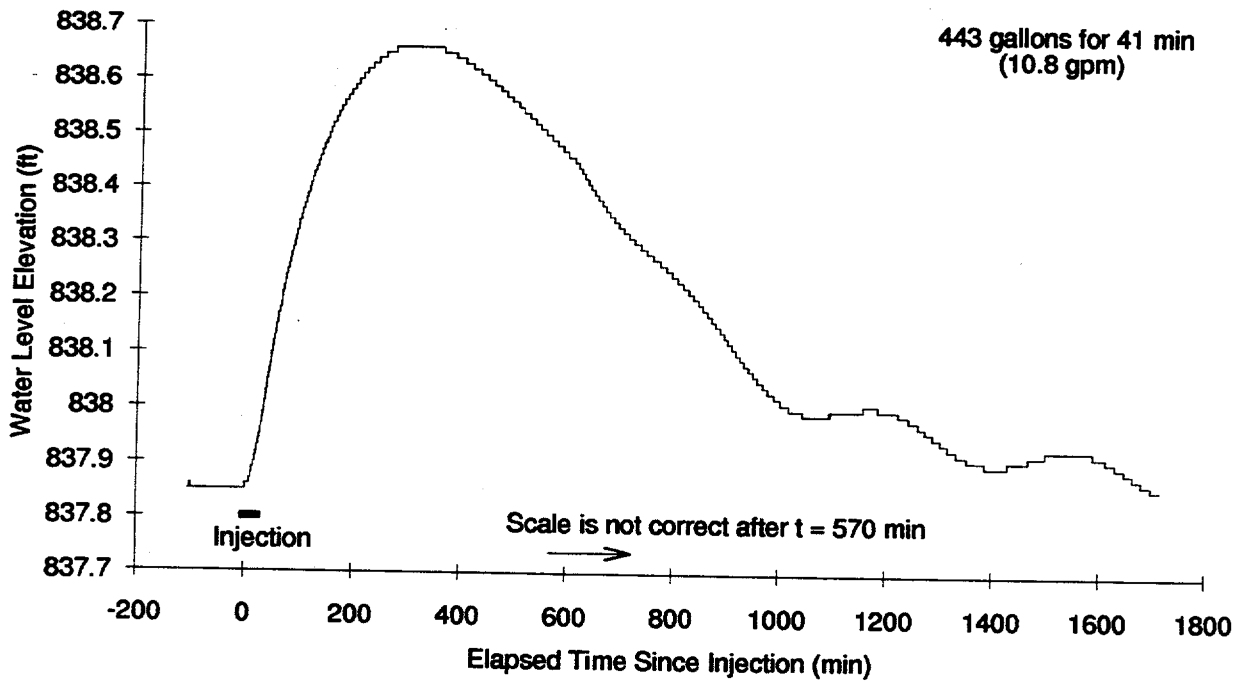

Figure 9. Water level elevation in GW-711 versus elapsed time since injection into GW-712, second test. (Picket W)

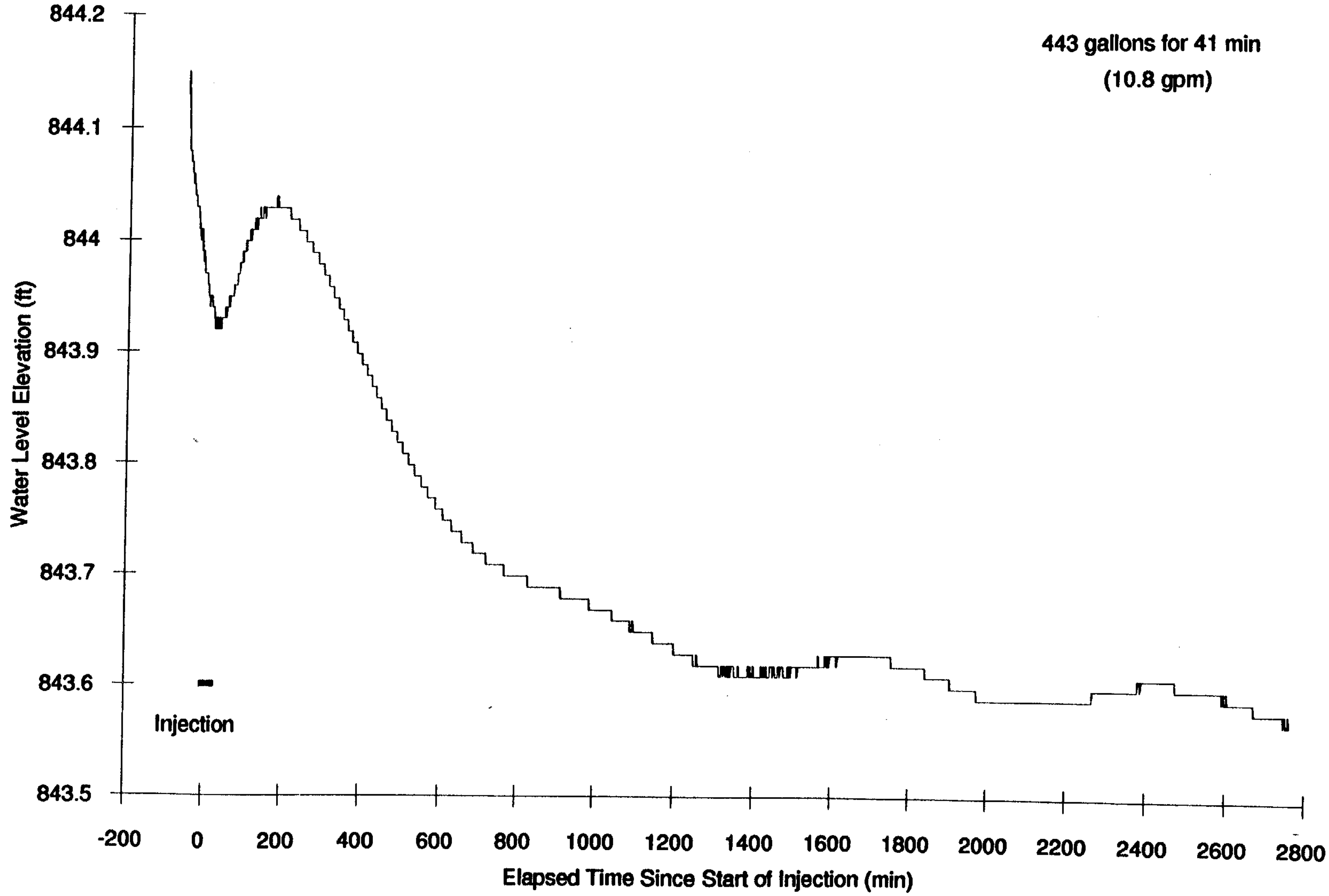

Figure 10. Water level elevation in GW-714 versus elapsed time since injection into GW-712, second test. (Picket W)

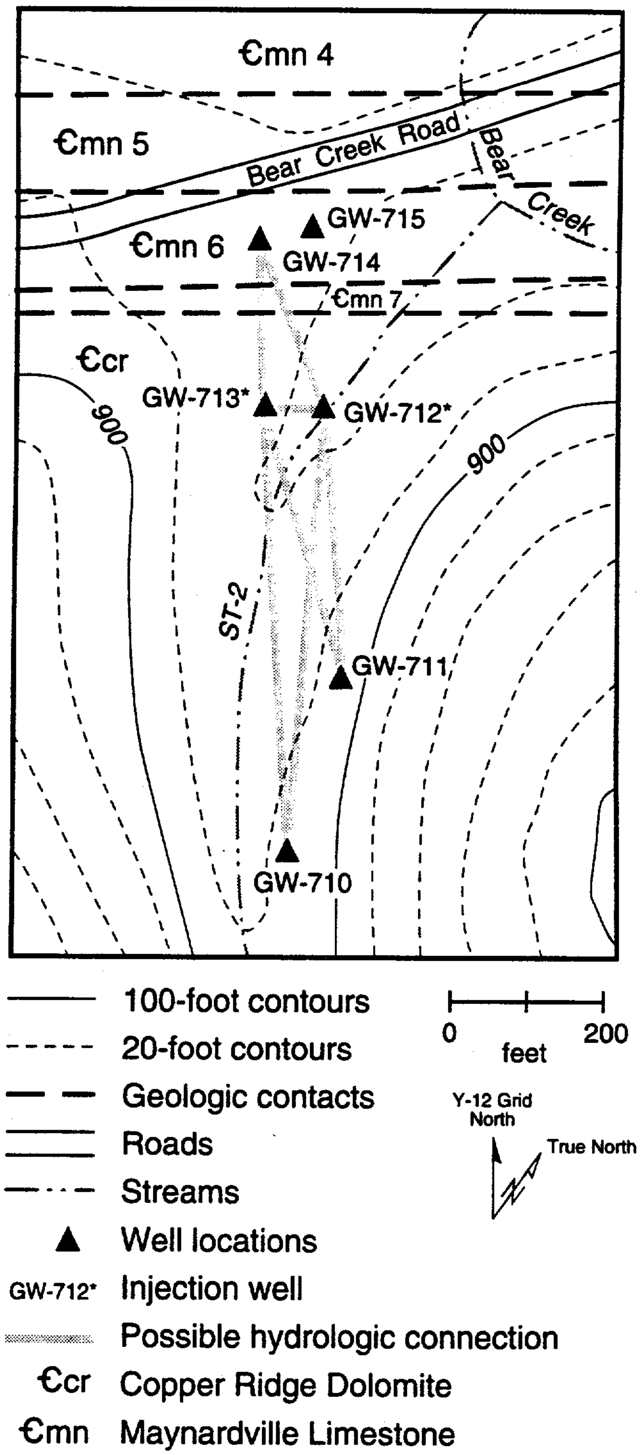

Figure 11. Map of the Picket W area showing locations of injection wells (modified from Shevenell et al., 1992).

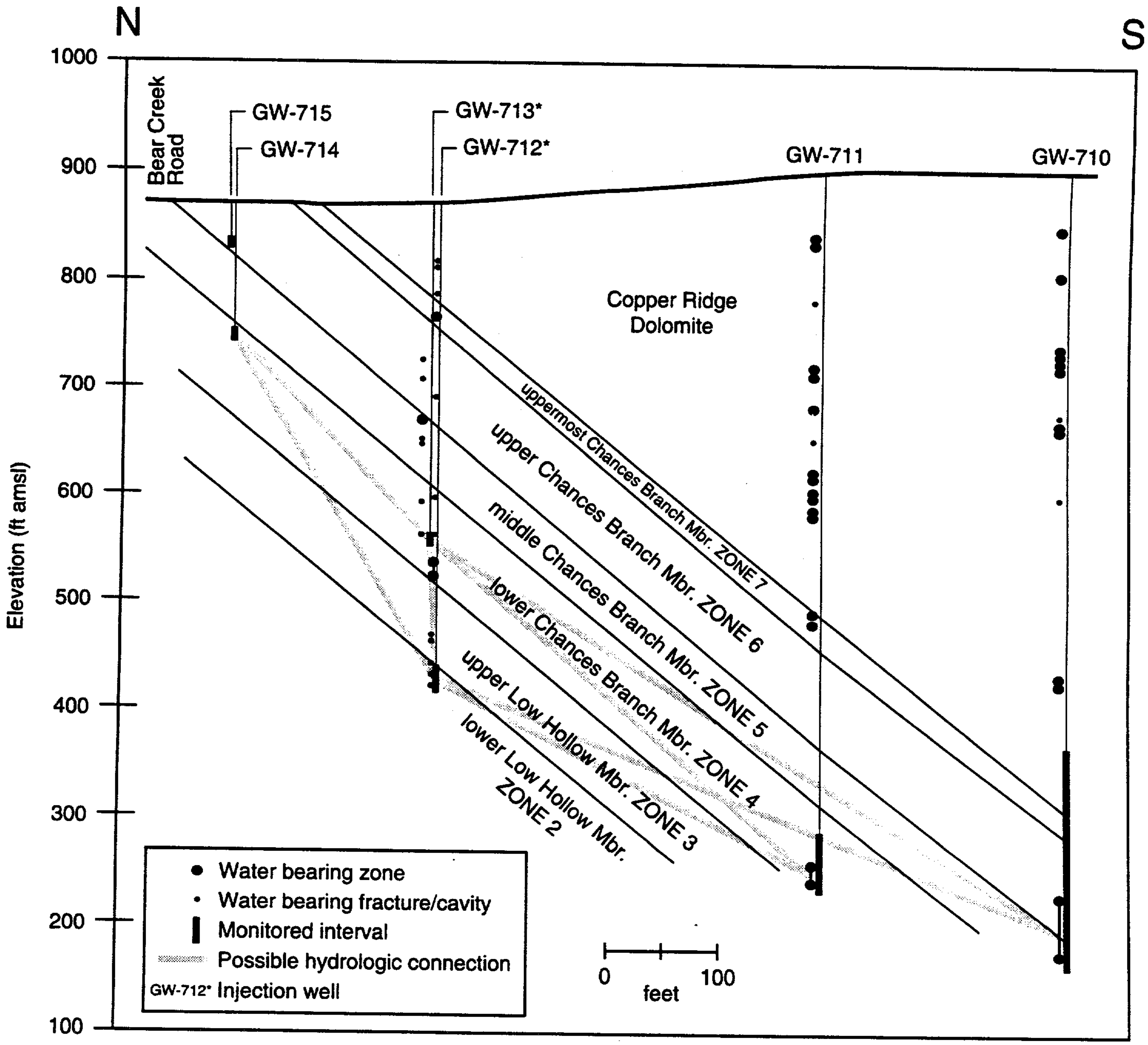

Figure 12. Cross-section at Picket W showing well locations (modified from Shevenell et al., 1992).

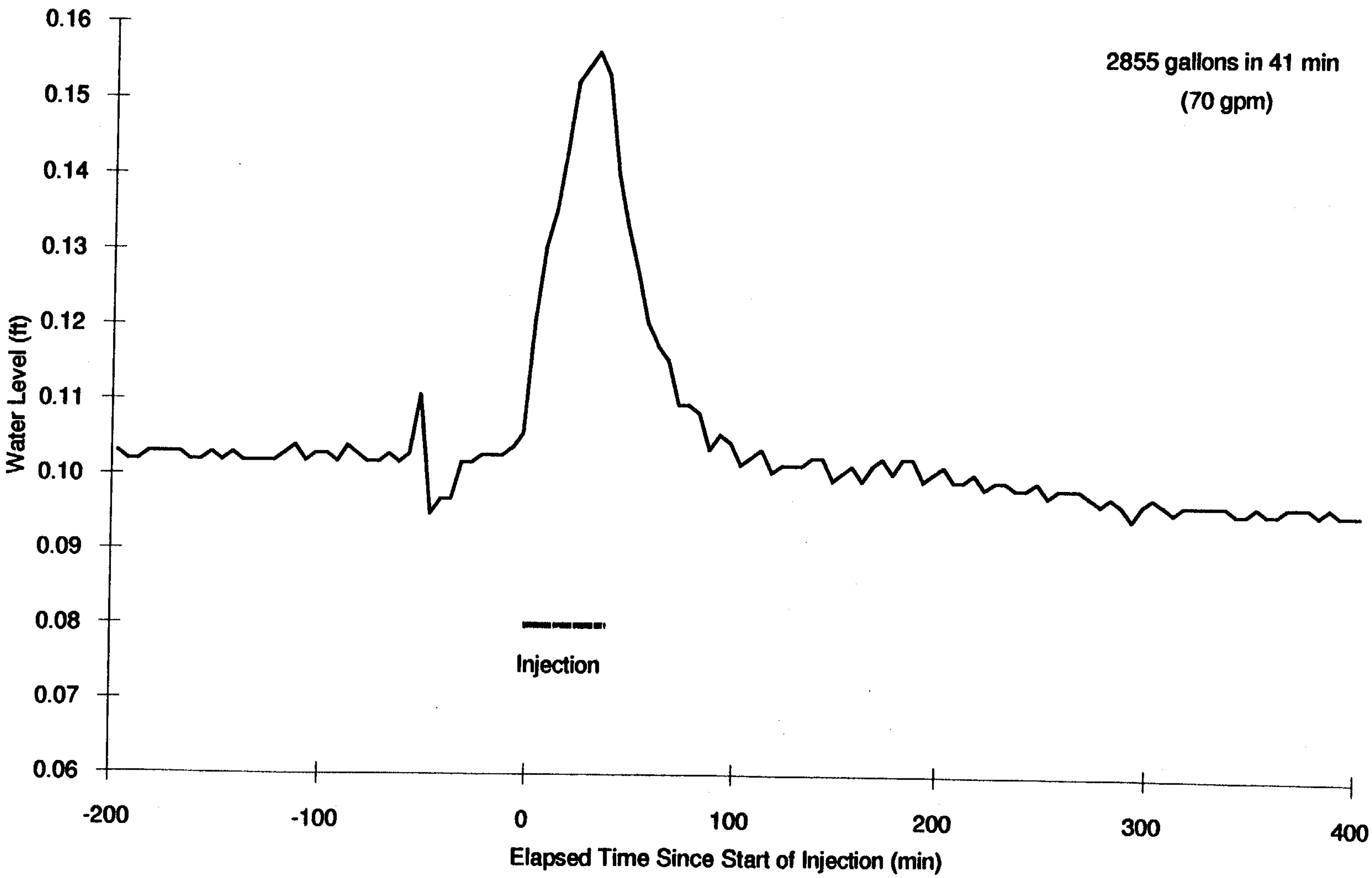

Figure 13. Water level response in the SS-5 spring versus elapsed time since injection into GW-684, first test. (Picket A)

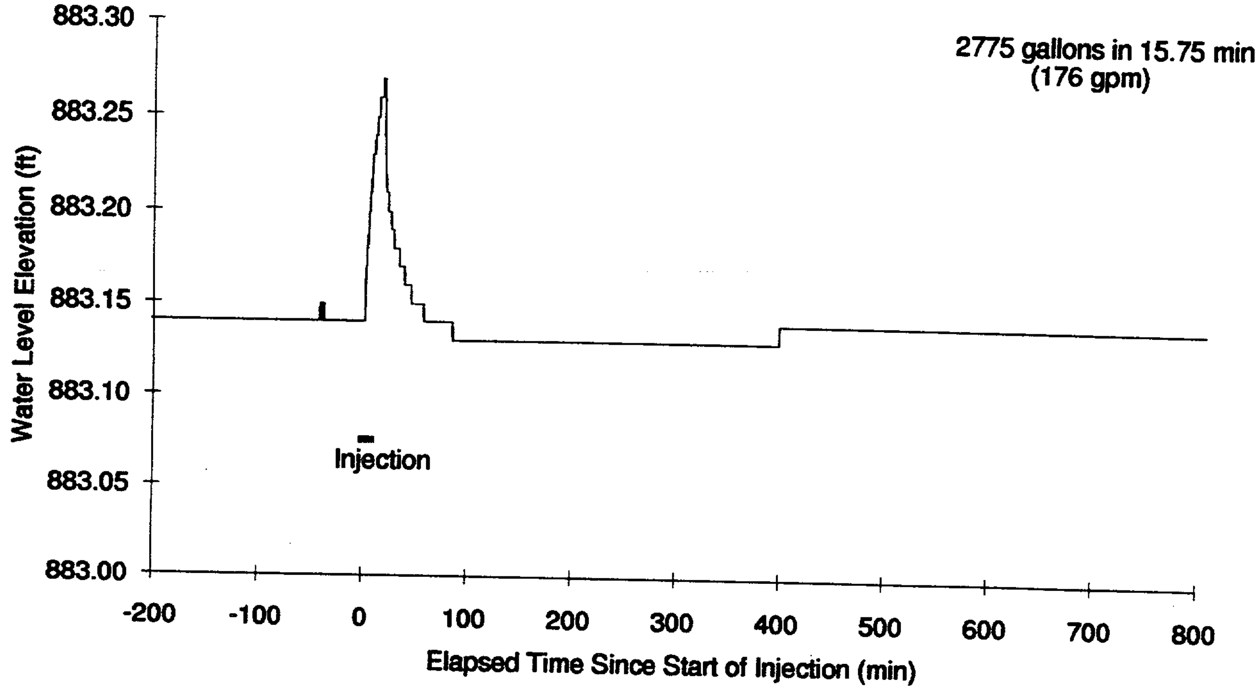

Figure 14. Water level elevation in GW-683 versus elapsed time since injection into GW-684, second test. (Picket A)

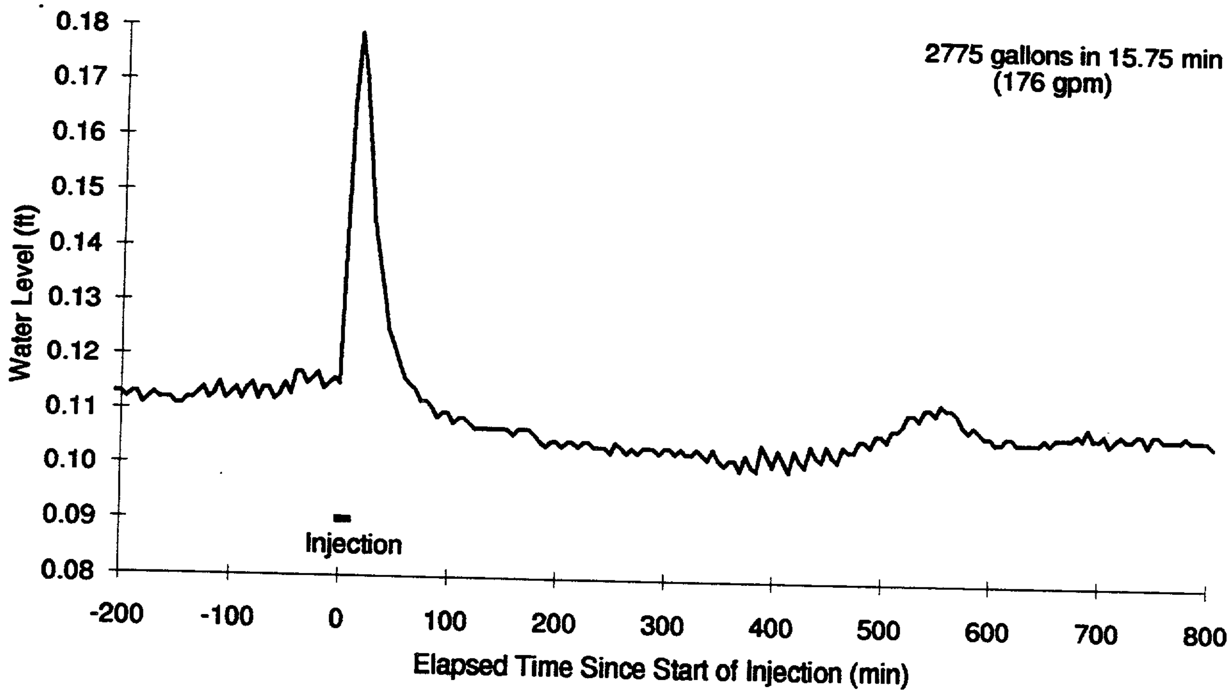

Figure 15. Water level response in the SS-5 spring versus time since injection into GW-684, second test. (Picket A)

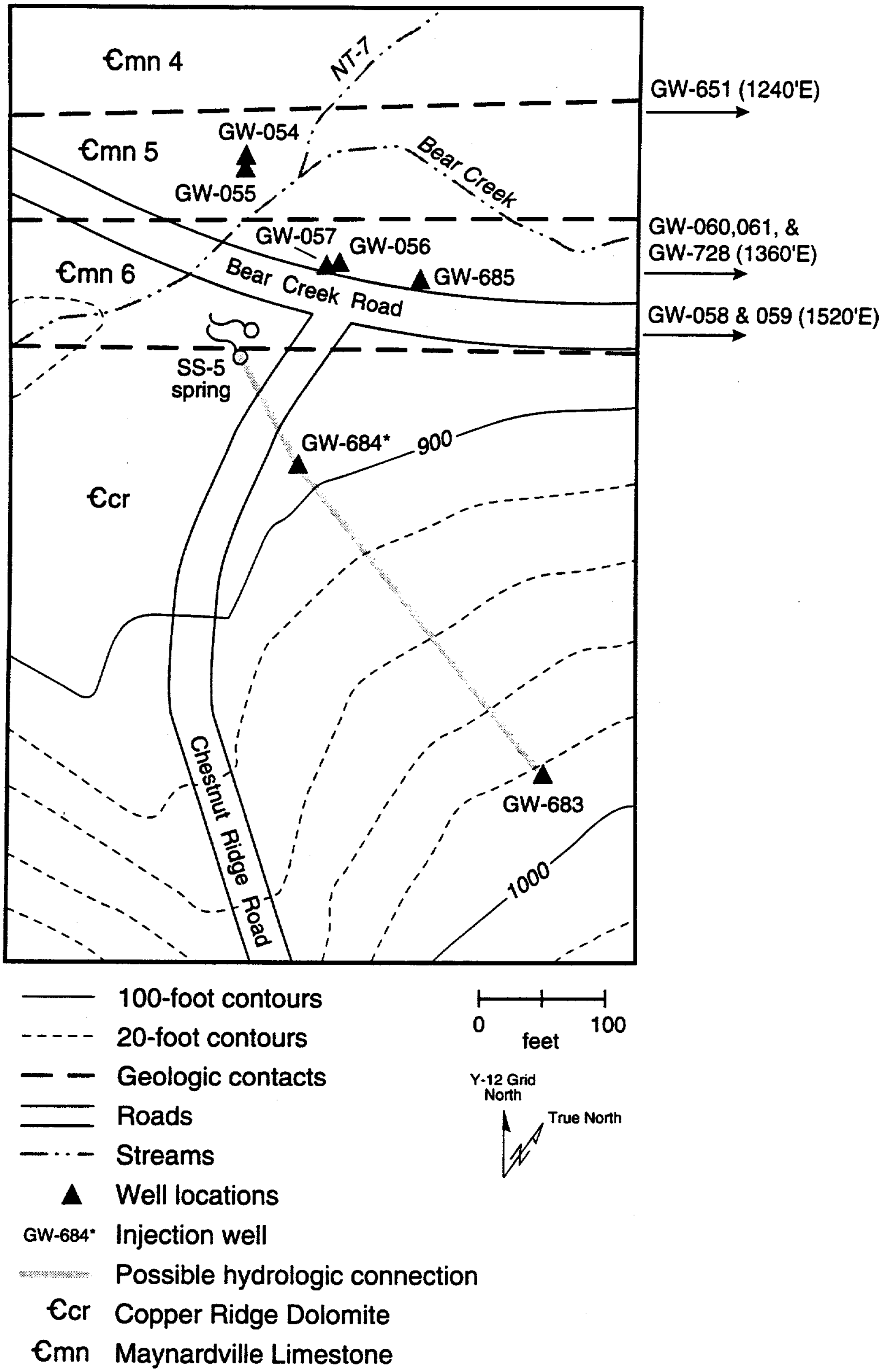

Figure 16. Map of the Picket A area showing the location of the injection well and the SS-5 spring (modified from Shevenell et al., 1992).

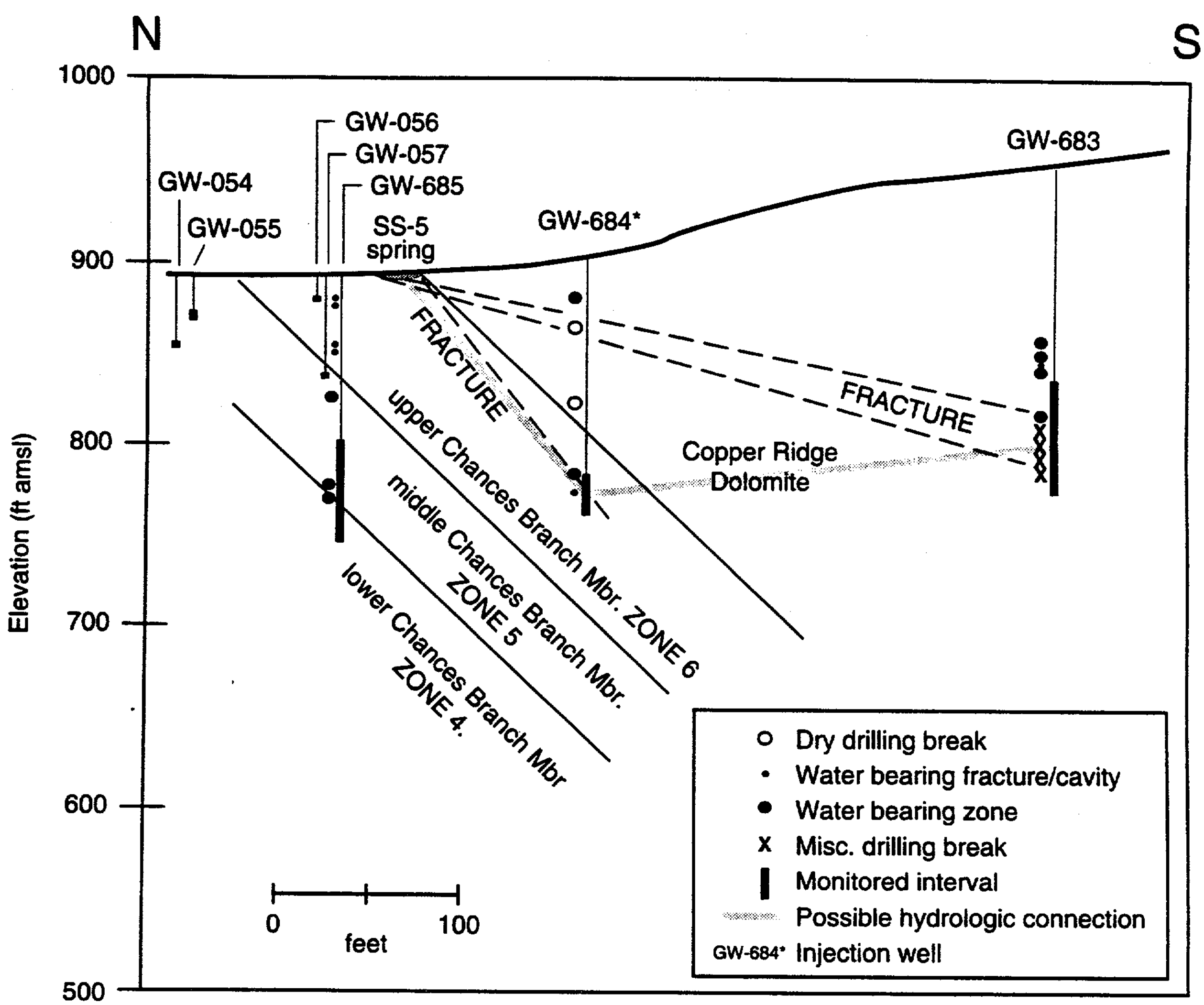

Figure 17. Cross-section at Picket A showing well locations and possible connections to the SS-5 spring (modified from Shevenell et al., 1992).

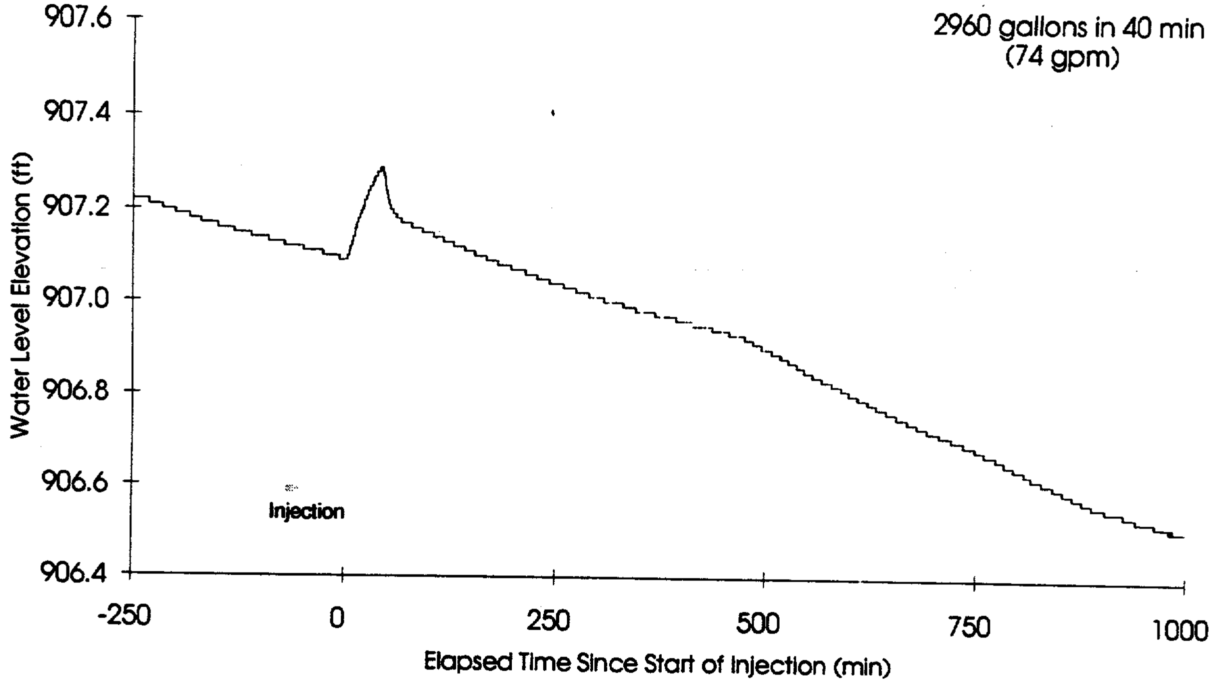

Figure 18. Water level elevation in GW-621 versus elapsed time since injection into GW-706. (Picket B)

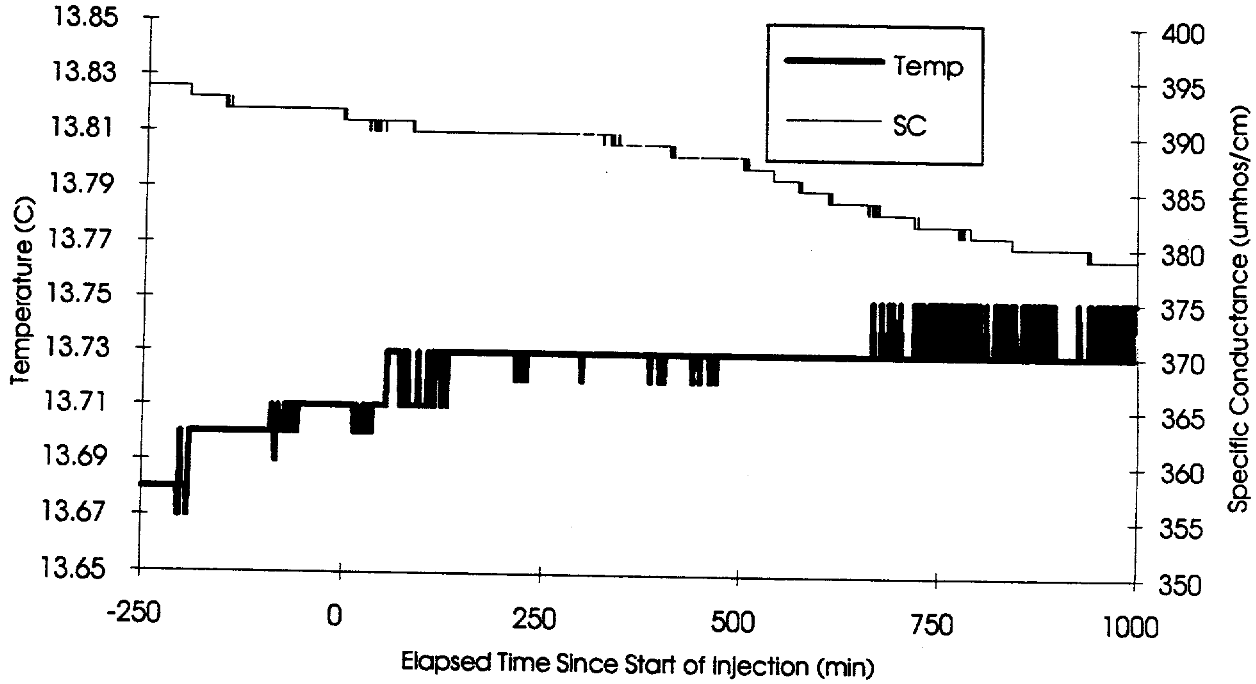

Figure 19. Temperature and specific conductance in GW-621 versus time since injection into GW-706. (Picket B)

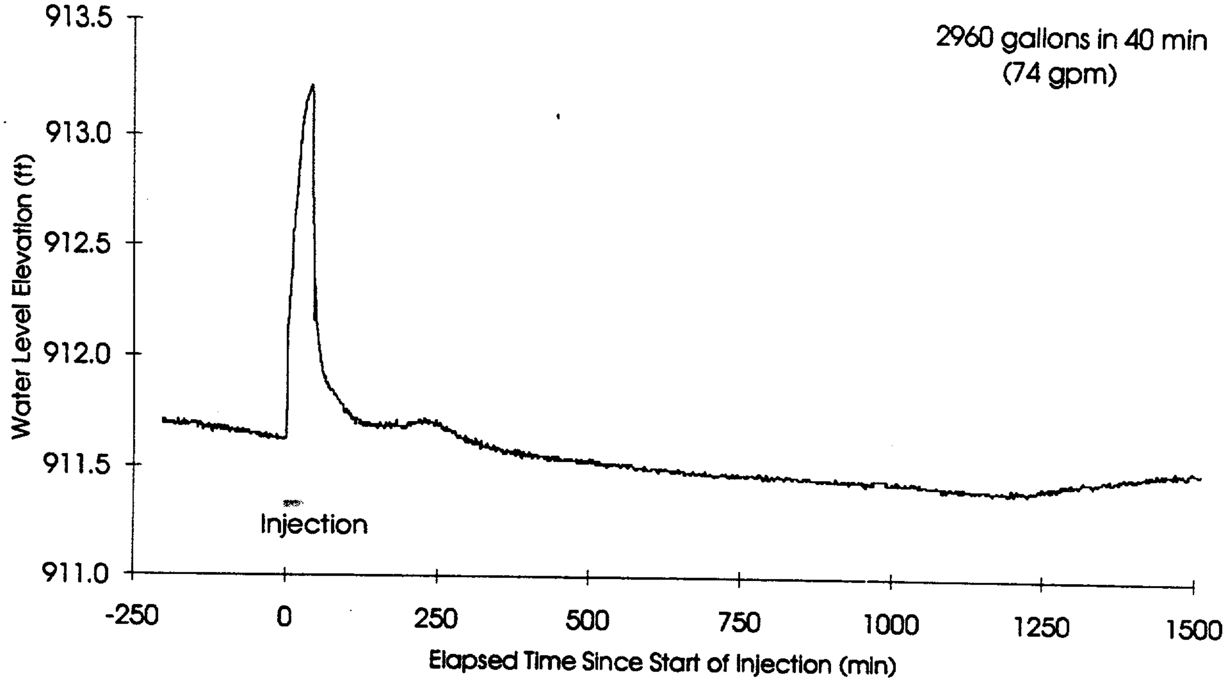

Figure 20. Water level elevation in GW-694 versus elapsed time since injection into GW-706. (Picket B)

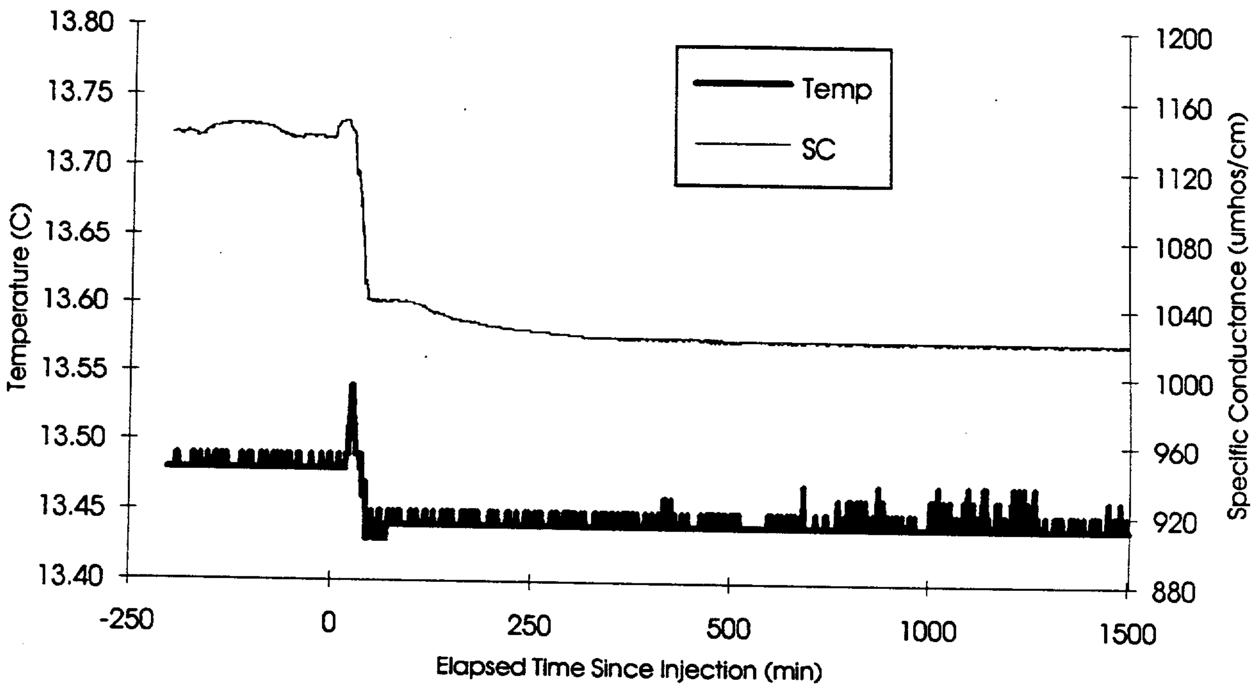

Figure 21. Temperature and specific conductance in GW-694 versus time since injection into GW-706. (Picket B)

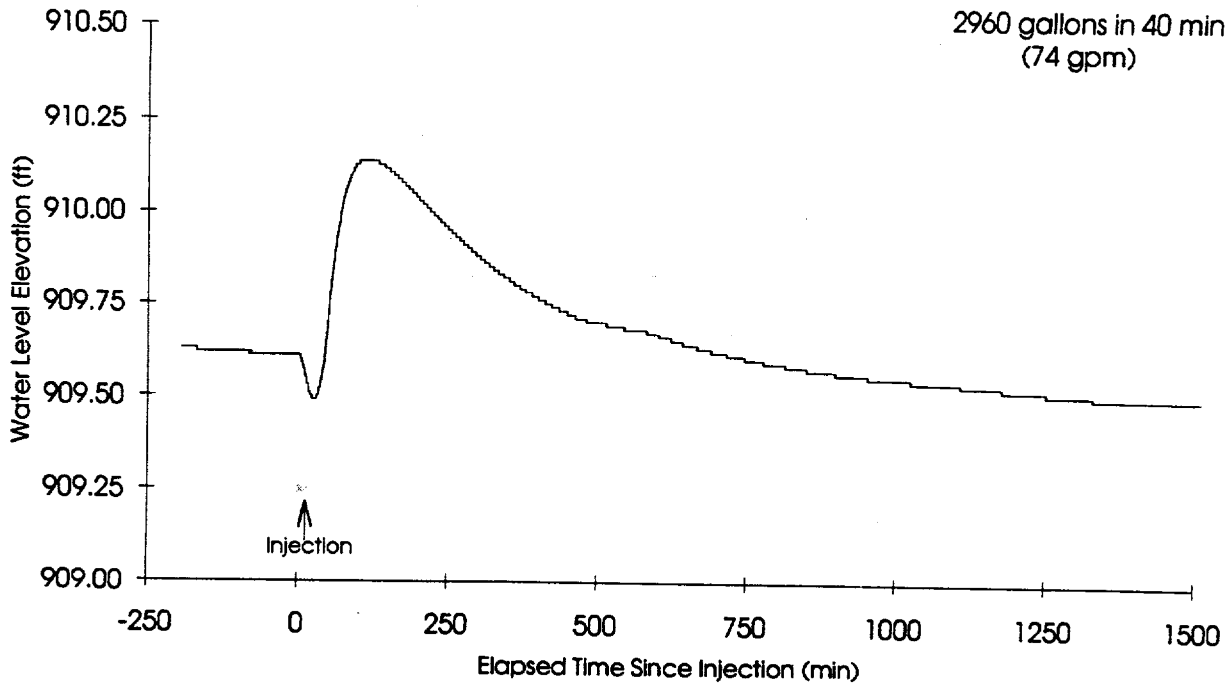

Figure 22. Water level elevation in GW-695 versus elapsed time since injection into GW-706. (Picket B)

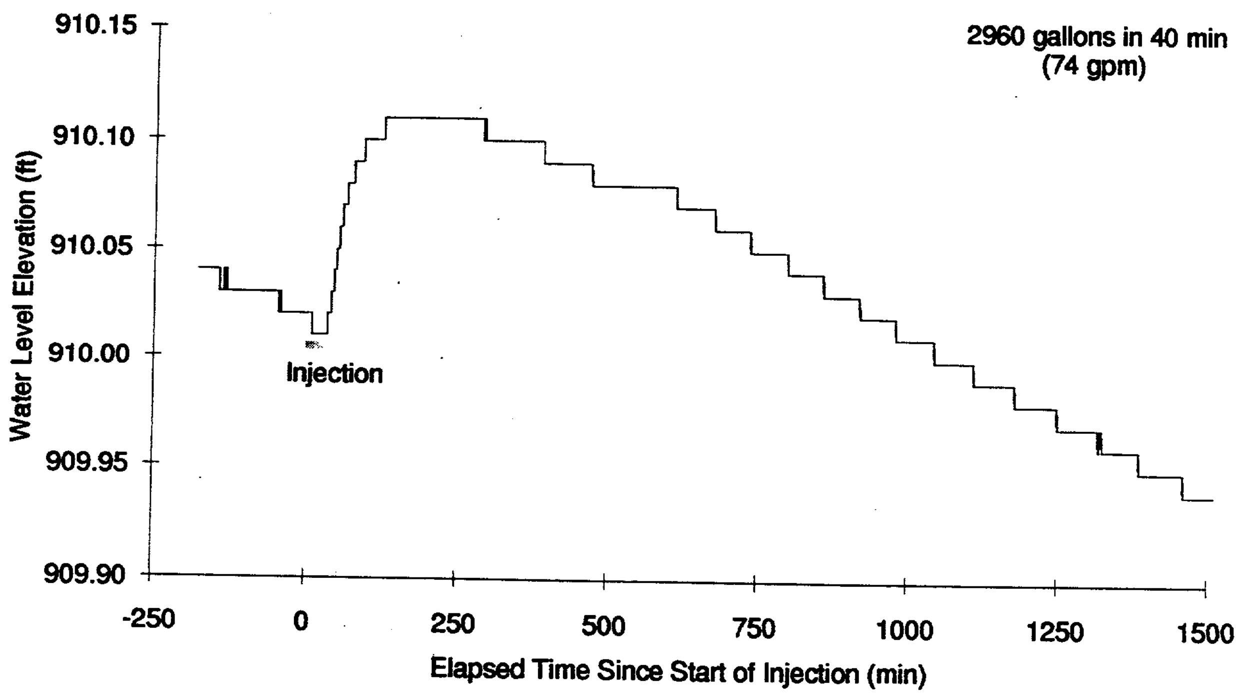

Figure 23. Water level elevation in GW-703 versus elapsed time since injection into GW-706. (Picket B)

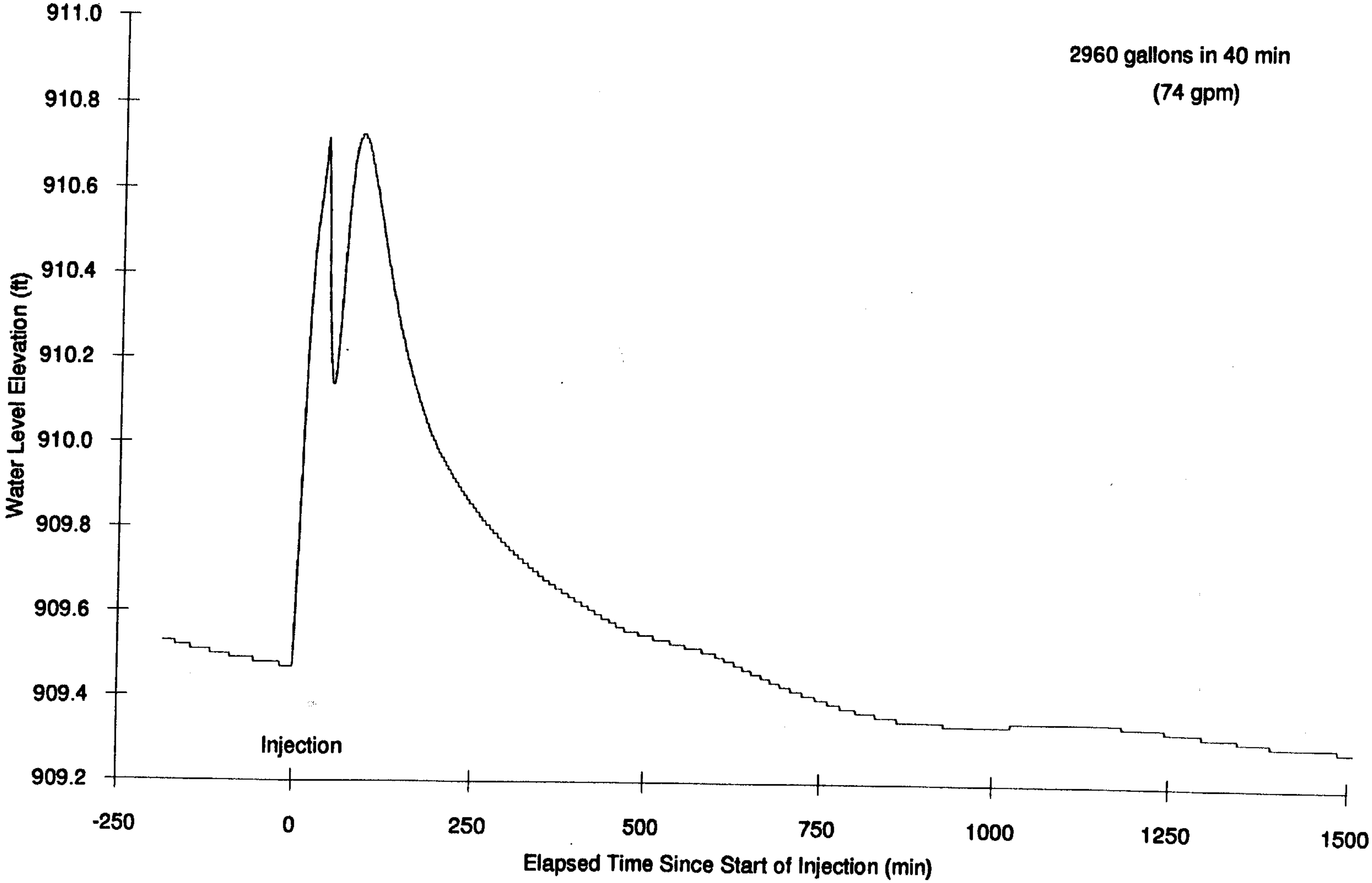

Figure 24. Water level elevation in GW-704 versus elapsed time since injection into GW-706. (Picket B)

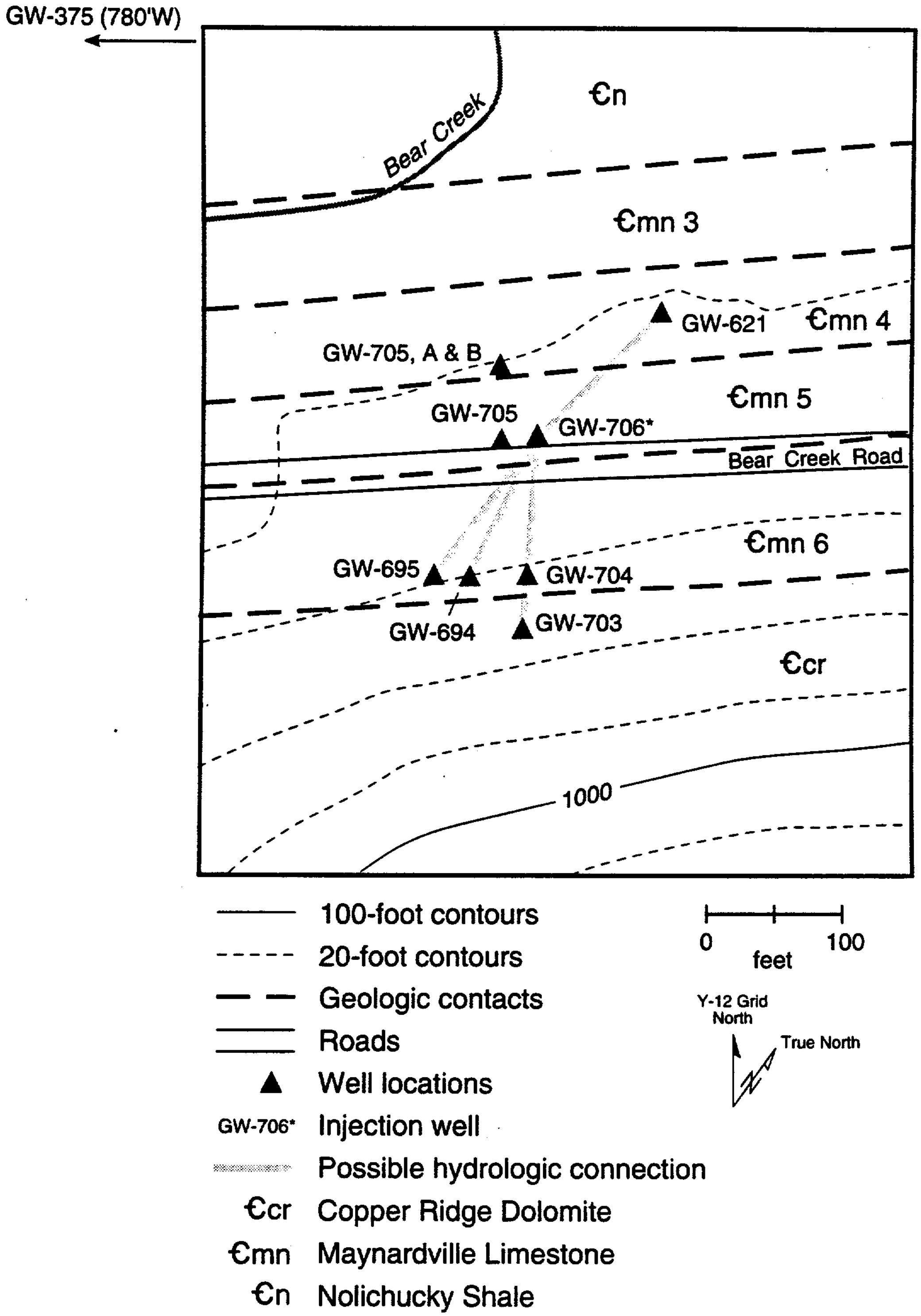

Figure 25. Map of the Picket B area showing the location of the injection well and the SS-4 spring (modified from Shevenell et al., 1992).

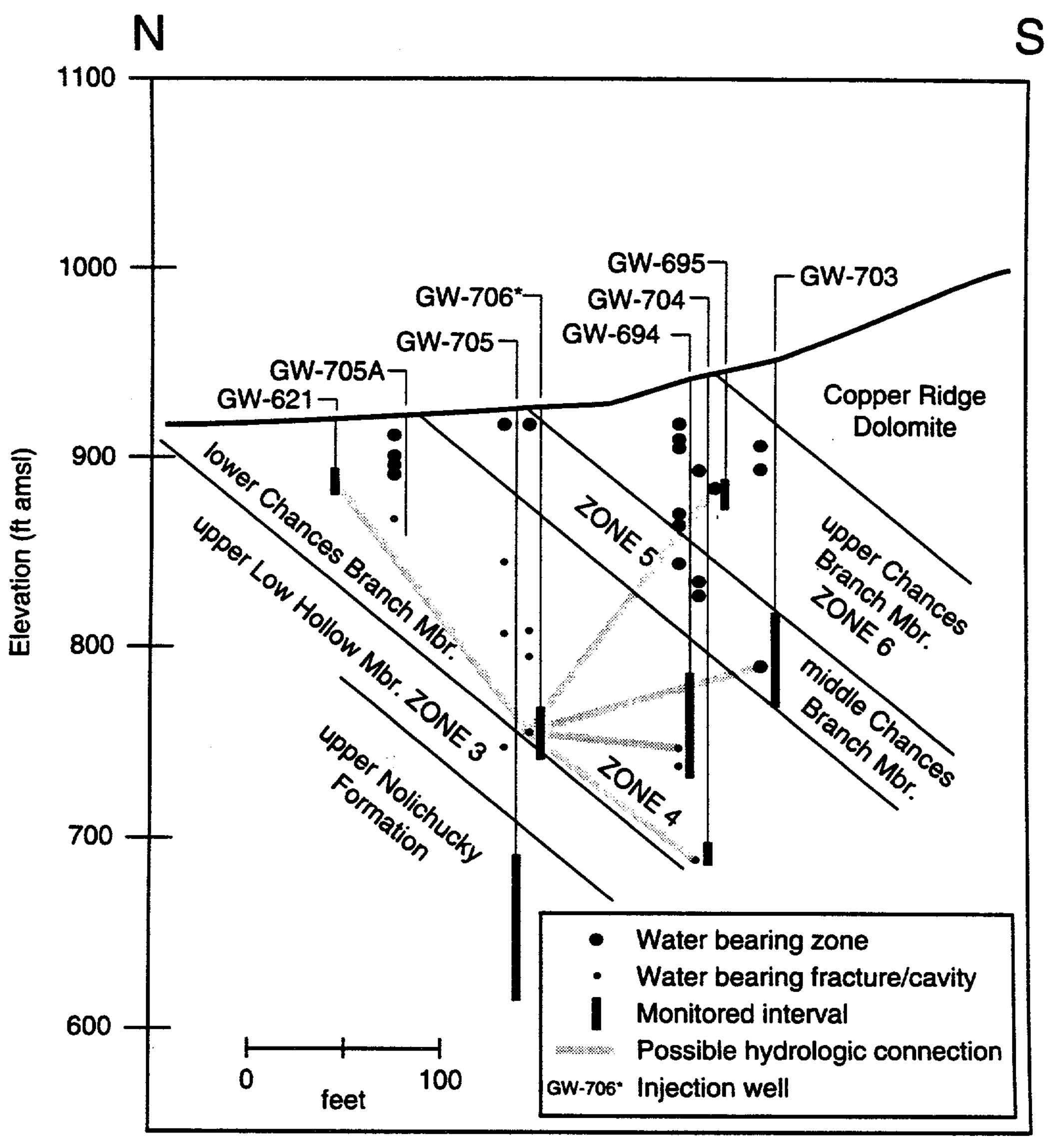

Figure 26. Cross-section at Picket B showing well locations (modified from Shevenell et al., 1992).

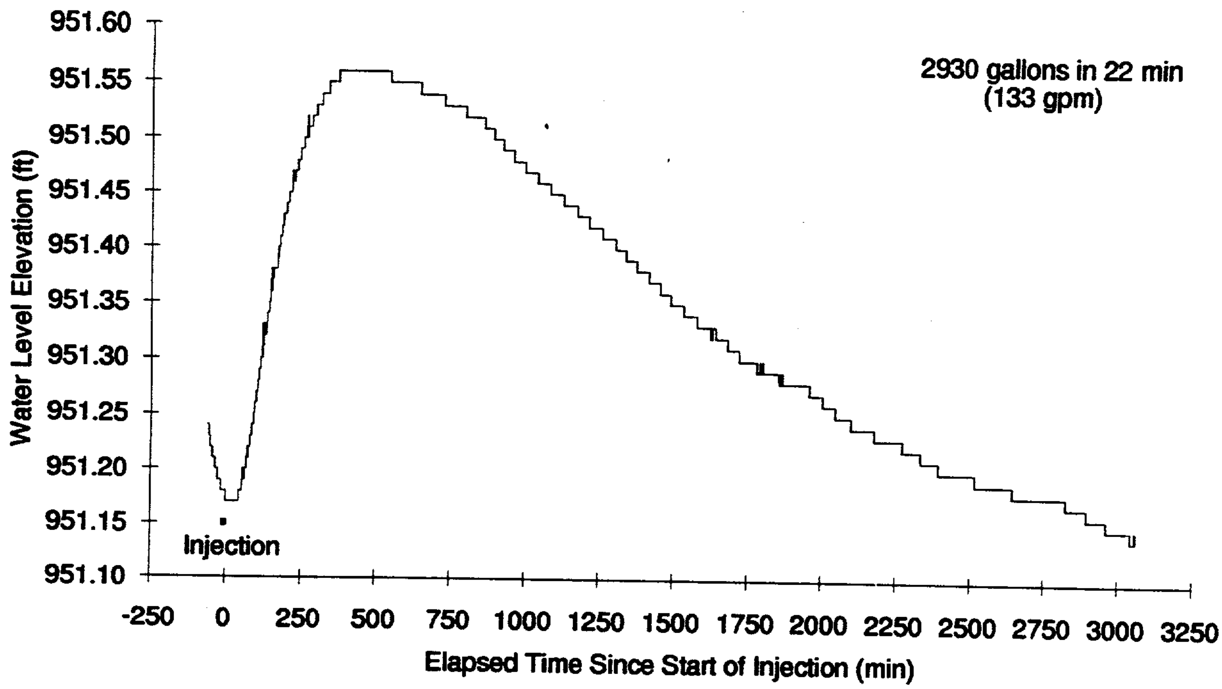

Figure 27. Water level elevation in GW-066 versus elapsed time since injection into GW-724. (Picket C)

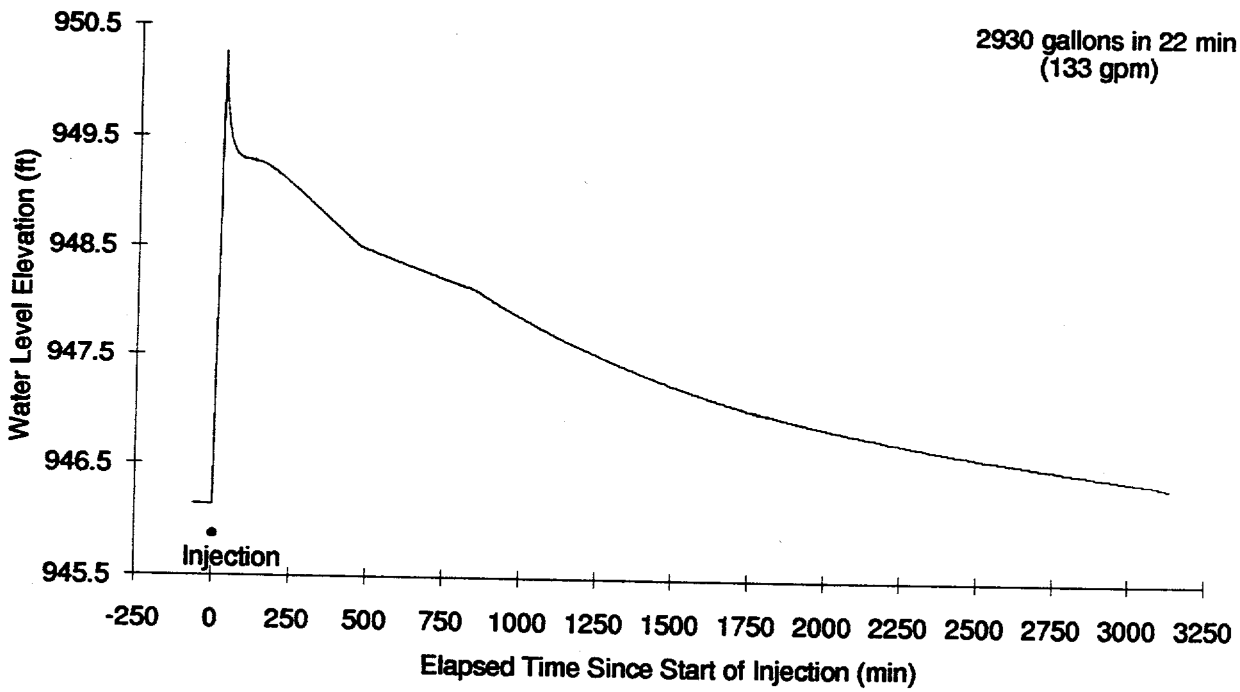

Figure 28. Water level elevation in GW-725 versus elapsed time since injection into GW-724. (Picket C)

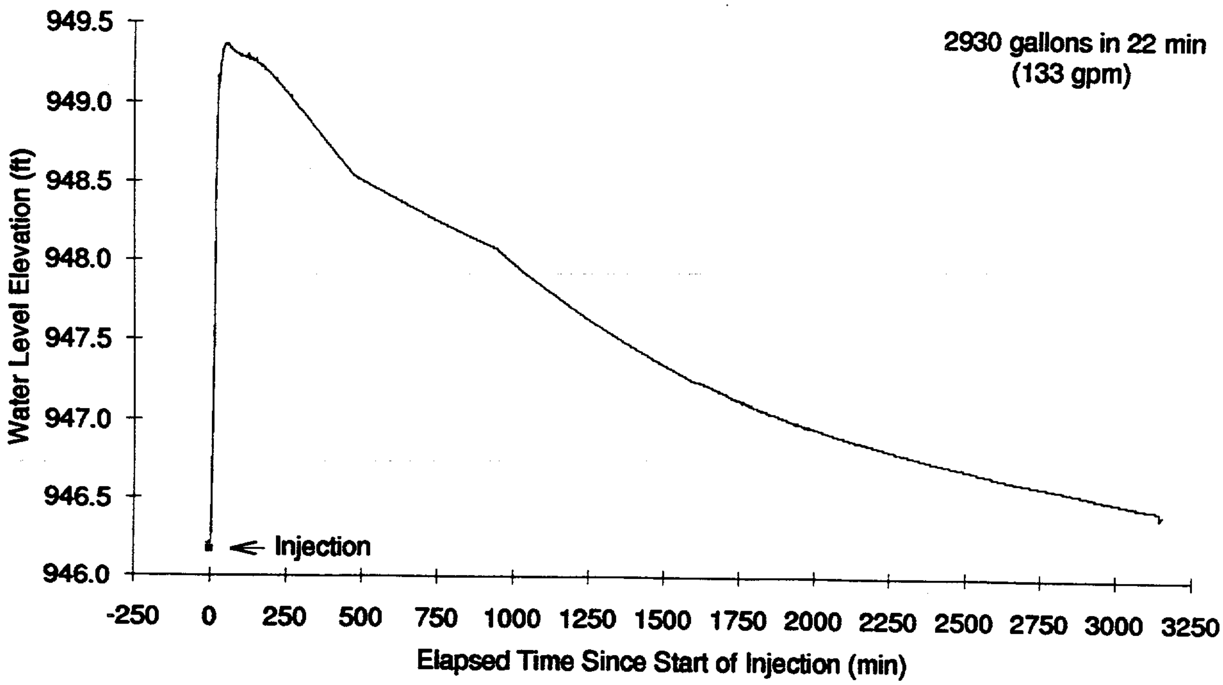

Figure 29. Water level elevation in GW-736 versus elapsed time since injection into GW-724. (Picket C)

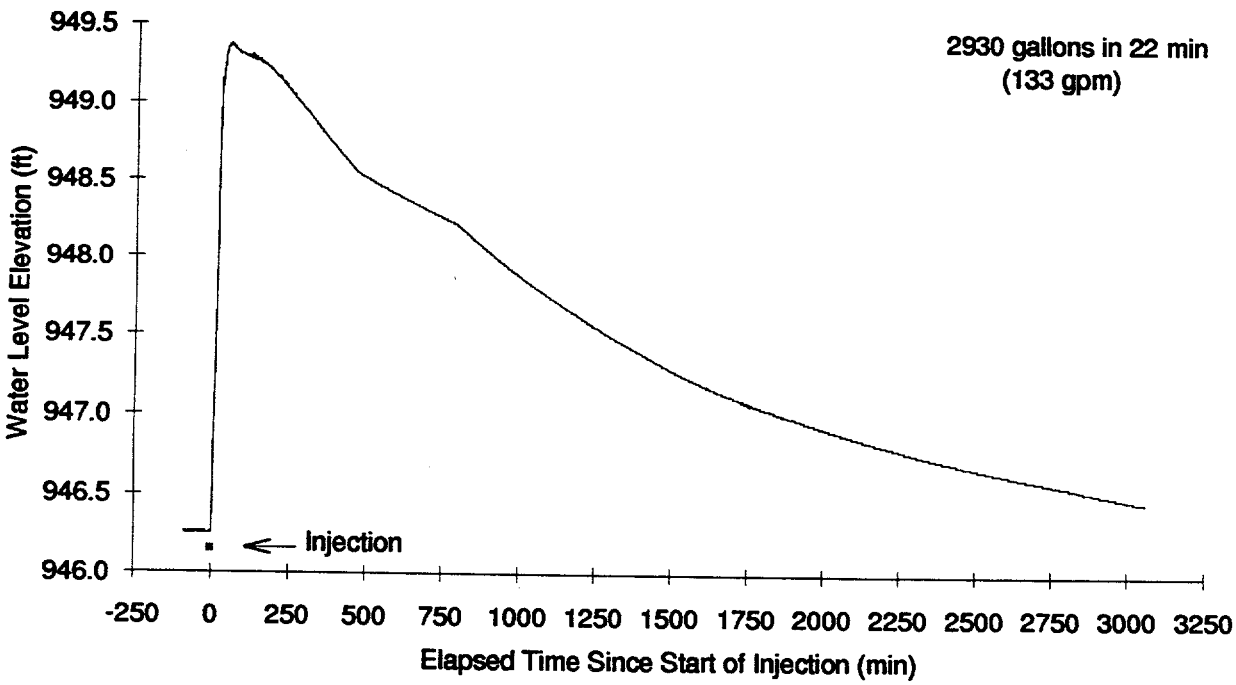

Figure 30. Water level elevation in GW-737 versus elapsed time since injection into GW-724. (Picket C)

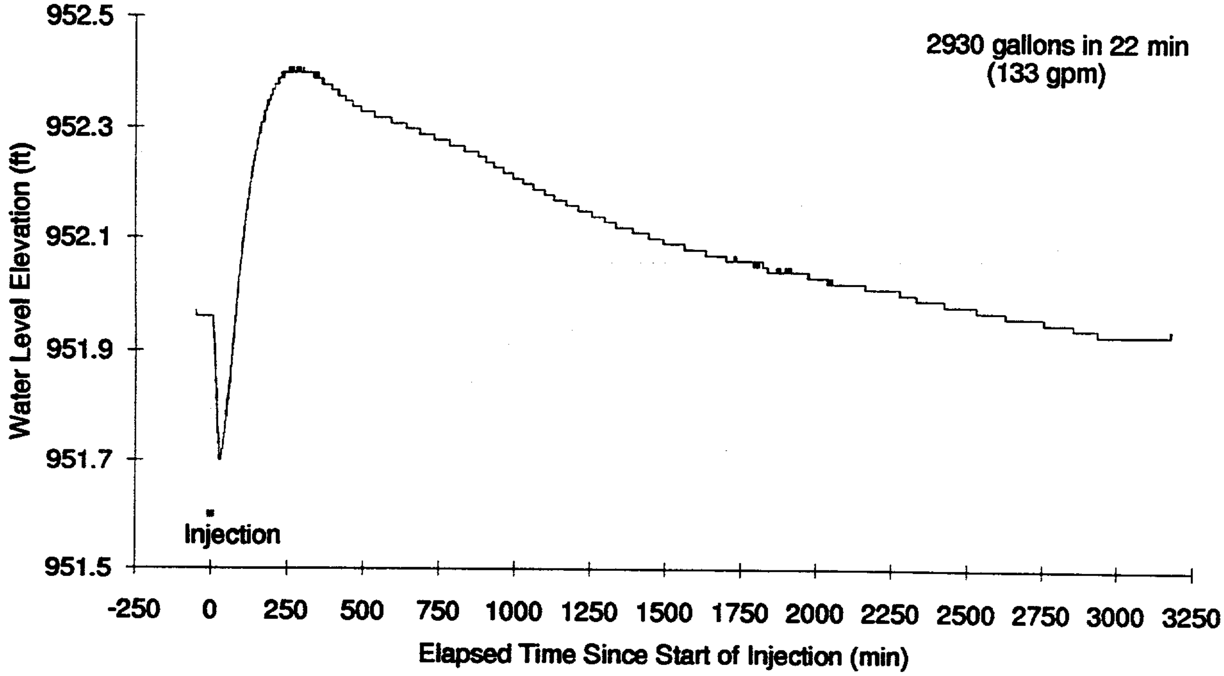

Figure 31. Water level elevation in GW-738 versus elapsed time since injection into GW-724. (Picket C)

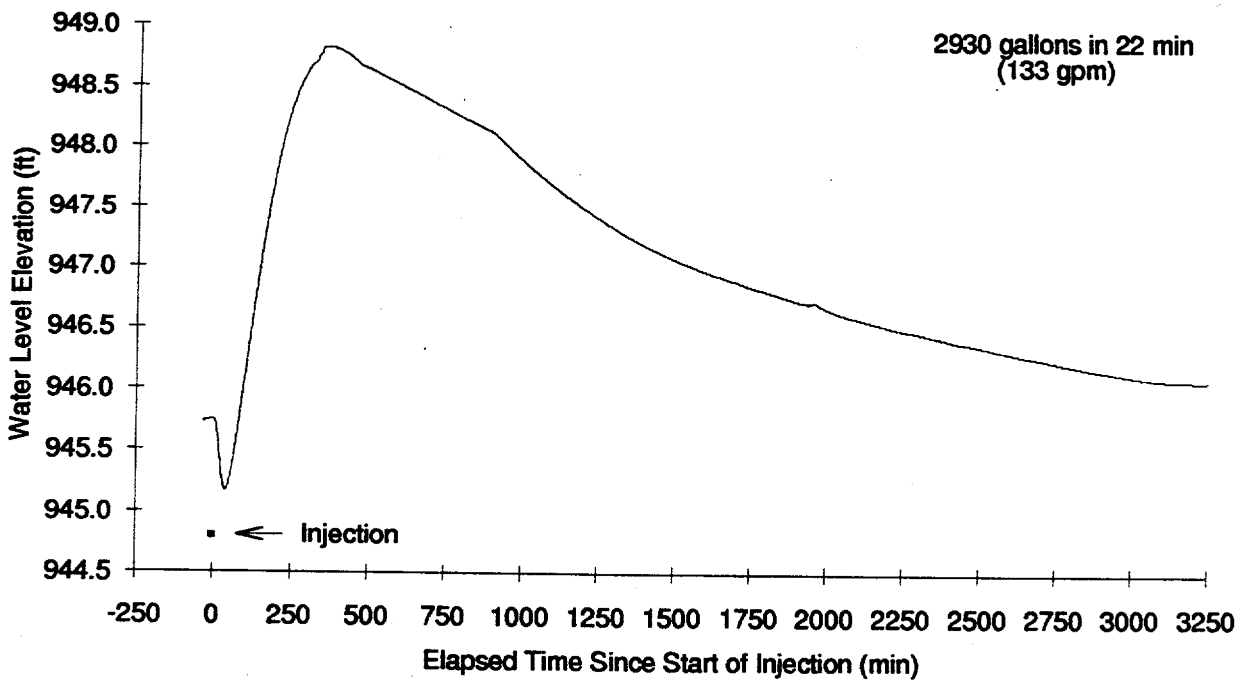

Figure 32. Water level elevation in GW-739 versus elapsed time since injection into GW-724. (Picket C)

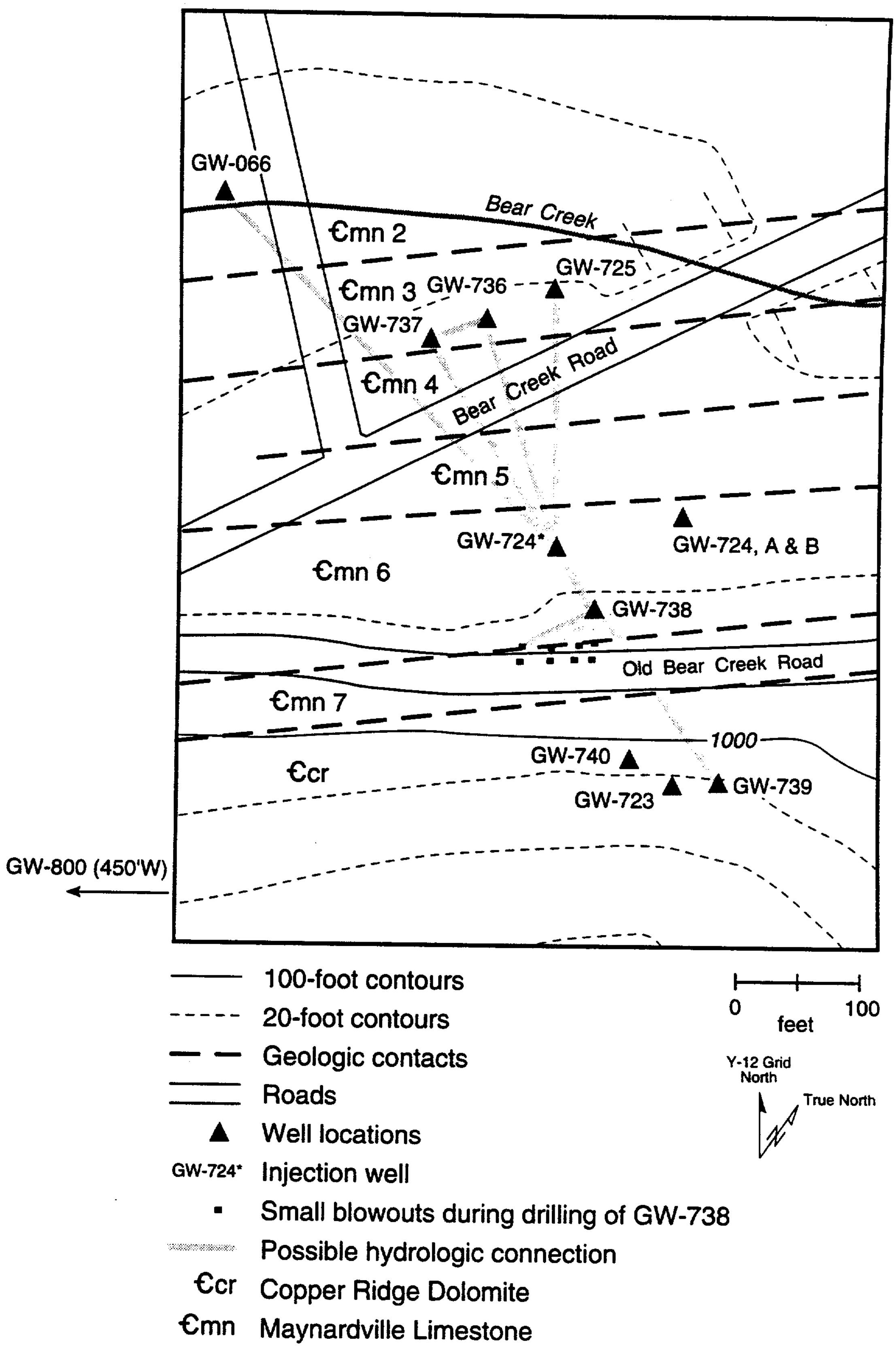

Figure 33. Map of the Picket C area showing the location of the injection well (modified from Shevenell et al., 1992).

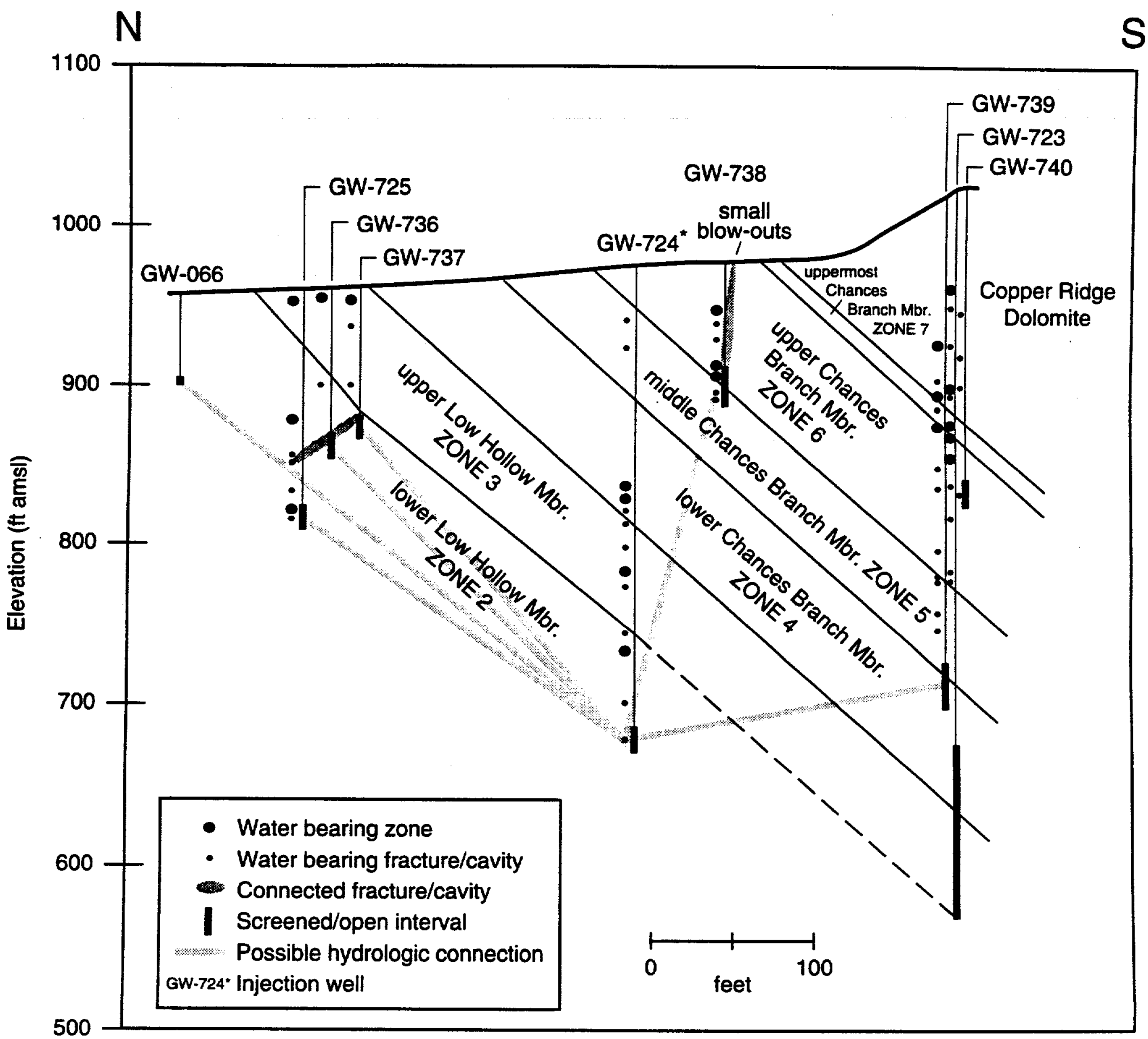

Figure 34. Cross-section at Picket C showing well locations (modified from Shevenell et al., 1992).

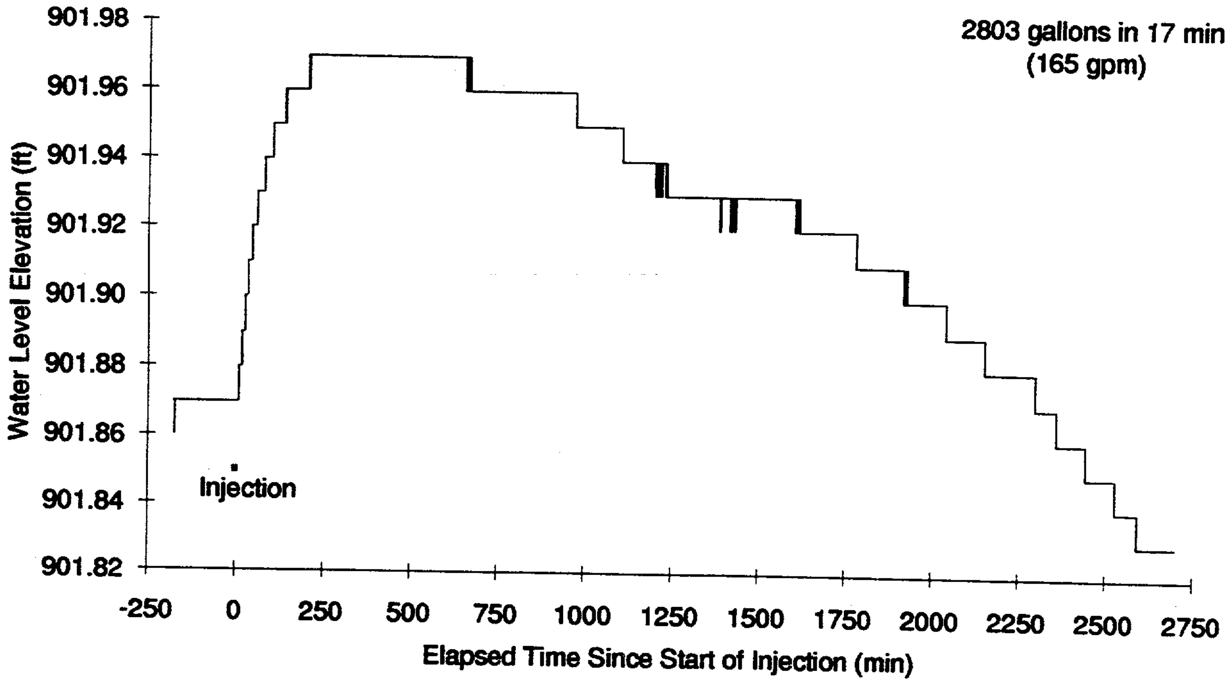

Figure 35. Water level elevation in GW-167 versus elapsed time since injection into GW-734, first test. (Picket J)

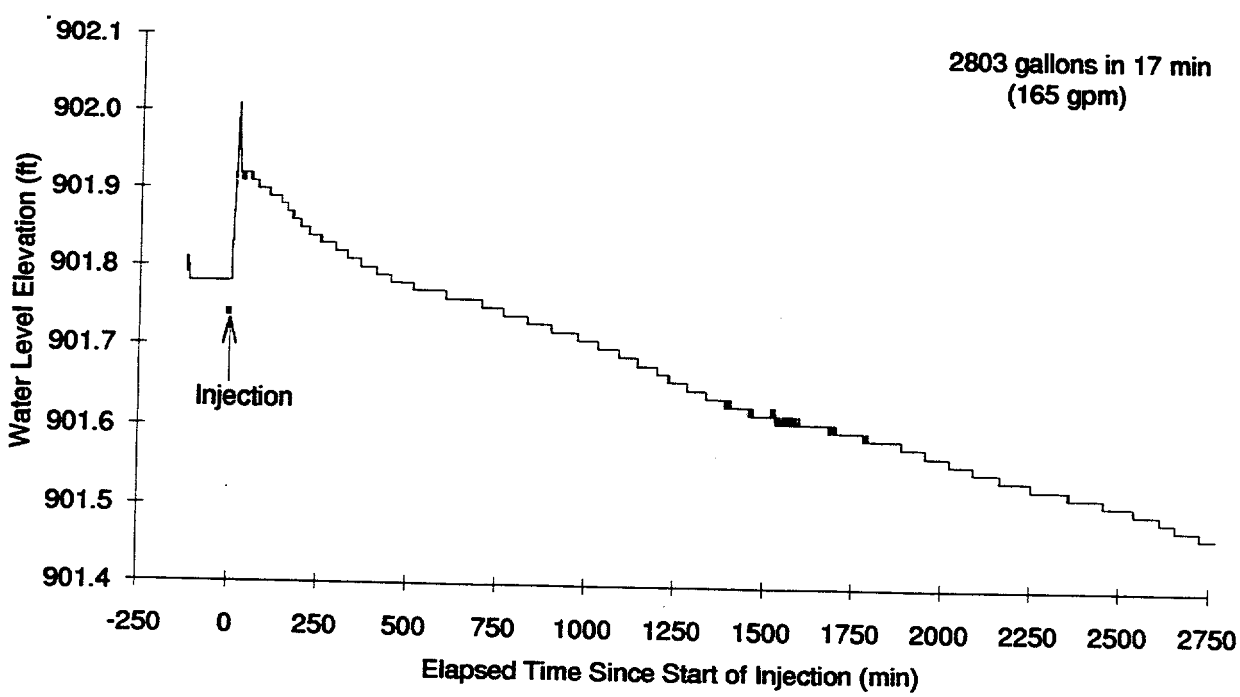

Figure 36. Water level elevation in GW-735 versus elapsed time since injection into GW-734, first test. (Picket J)

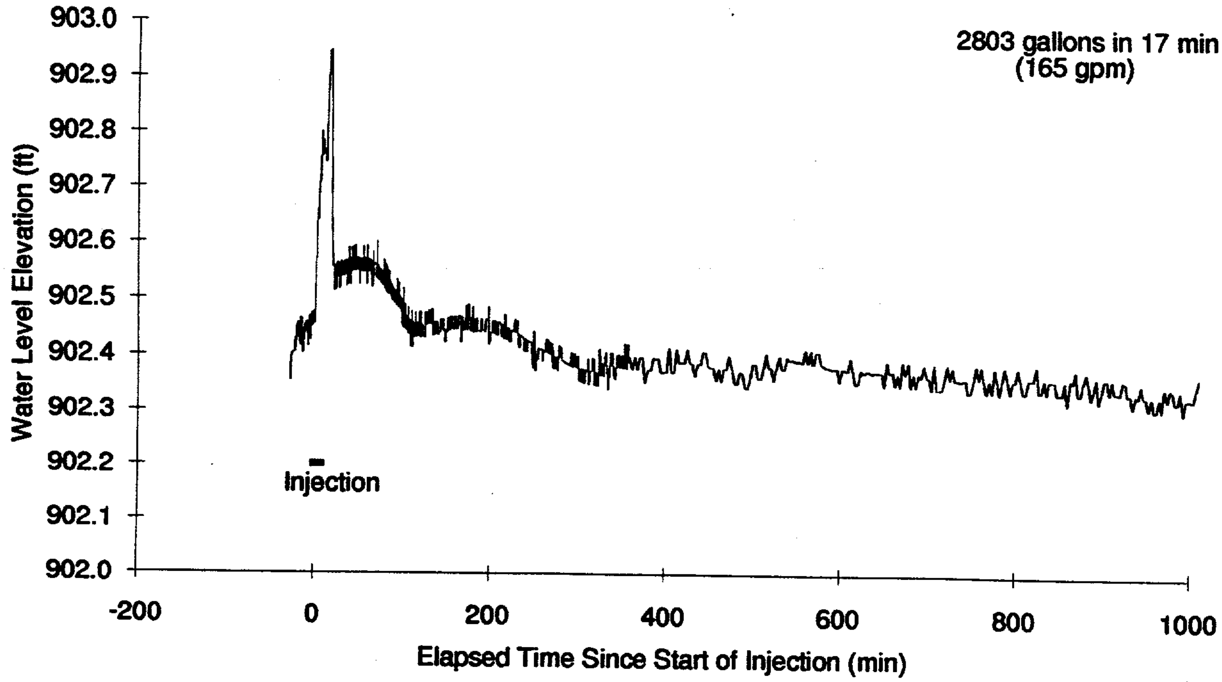

Figure 37. Water level elevation in GW-722-32 versus elapsed time since injection into GW-734, first test. (Picket J)

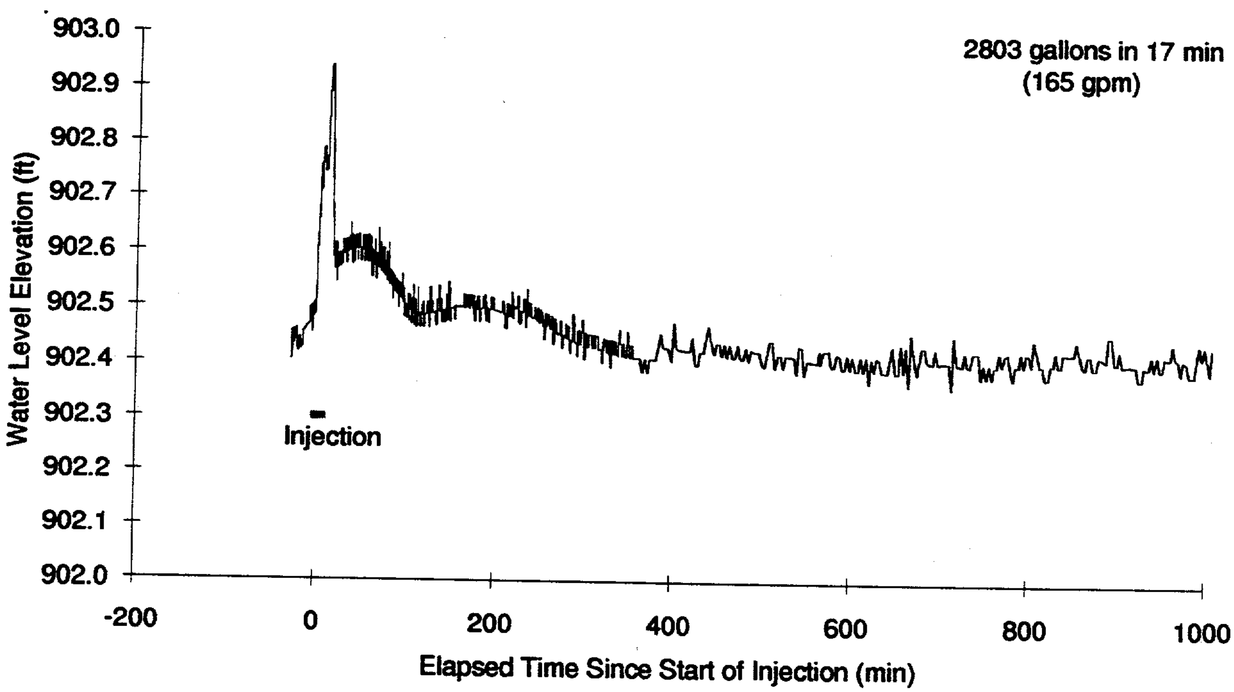

Figure 38. Water level elevation in GW-722-33 versus elapsed time since injection into GW-734, first test. (Picket J)

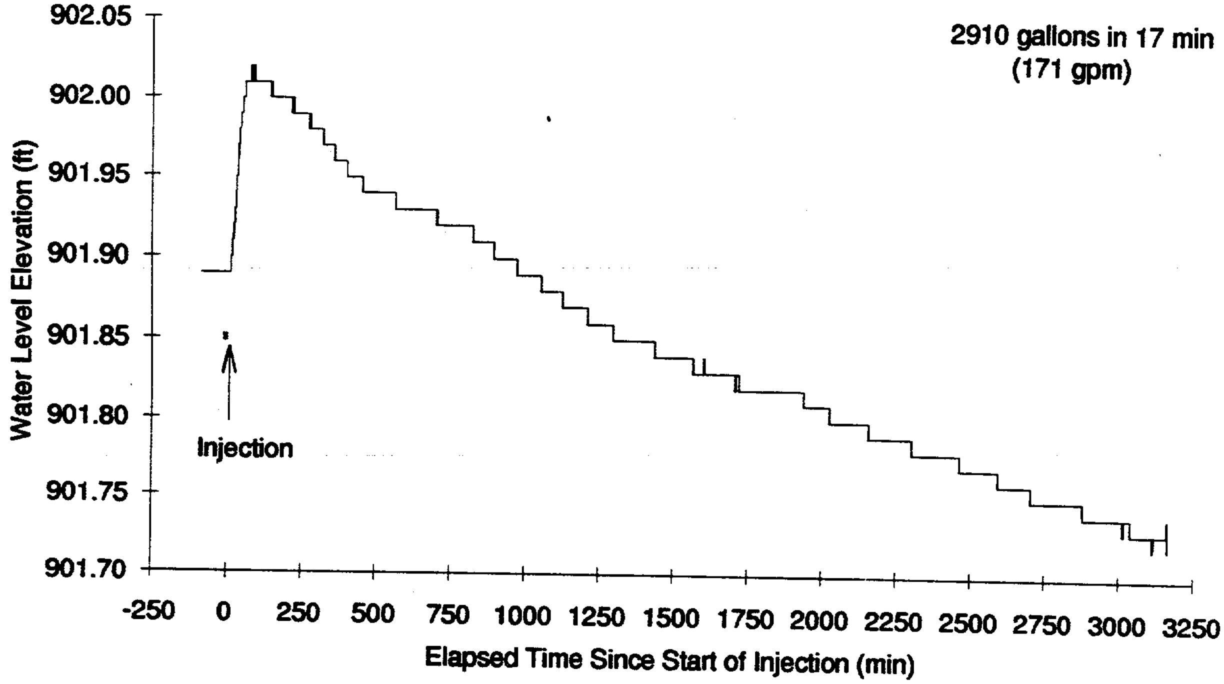

Figure 39. Water level elevation in GW-168 versus elapsed time since injection into GW-734, second test. (Picket J)

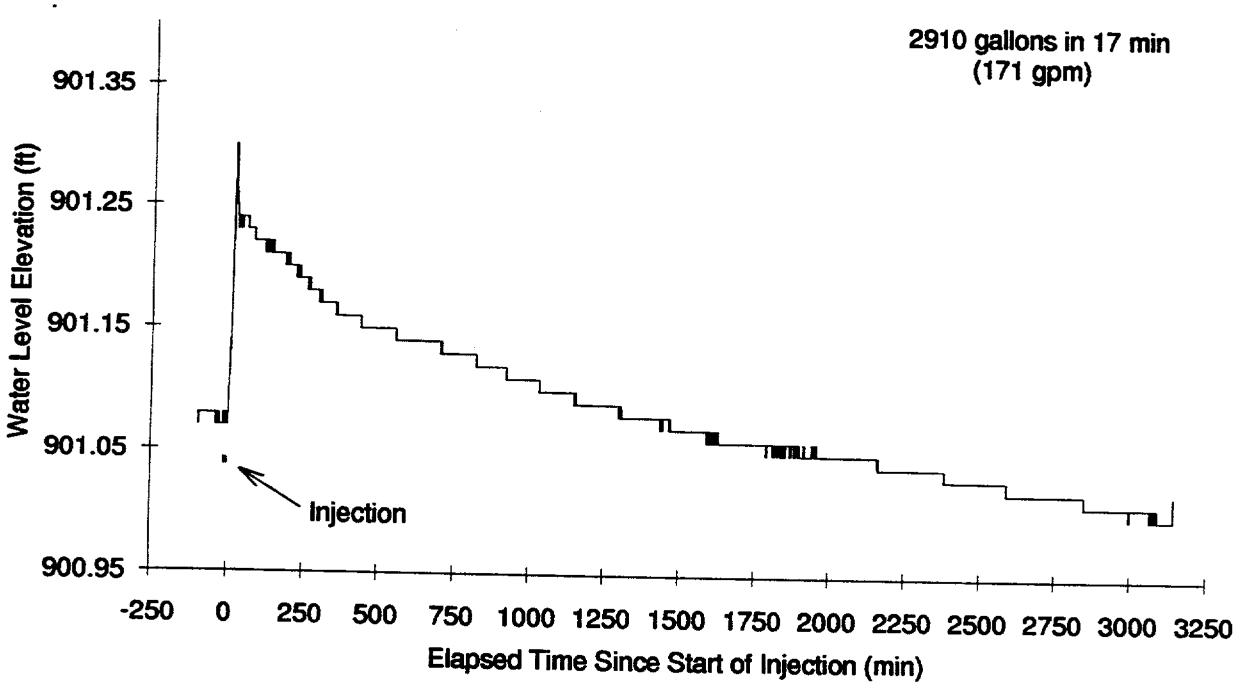

Figure 40. Water level elevation in GW-735 versus elapsed time since injection into GW-734, second test. (Picket J)

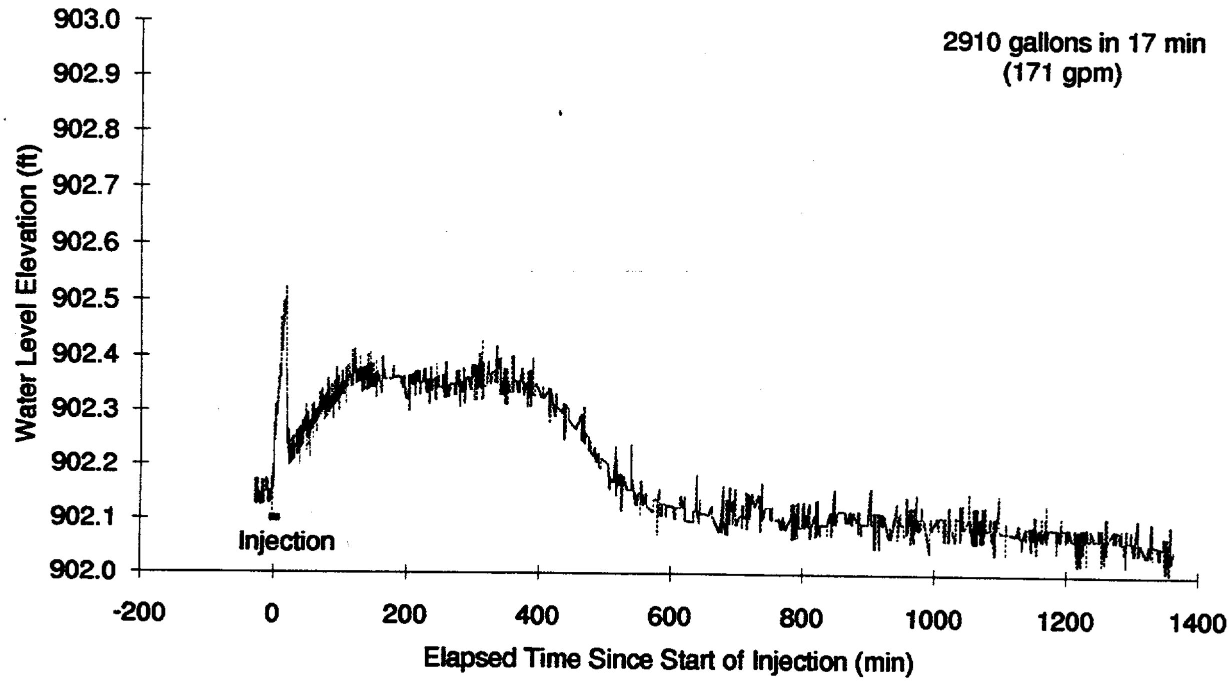

Figure 41. Water level elevation in GW-722-32 versus time since injection into GW-734, second test. (Picket J)

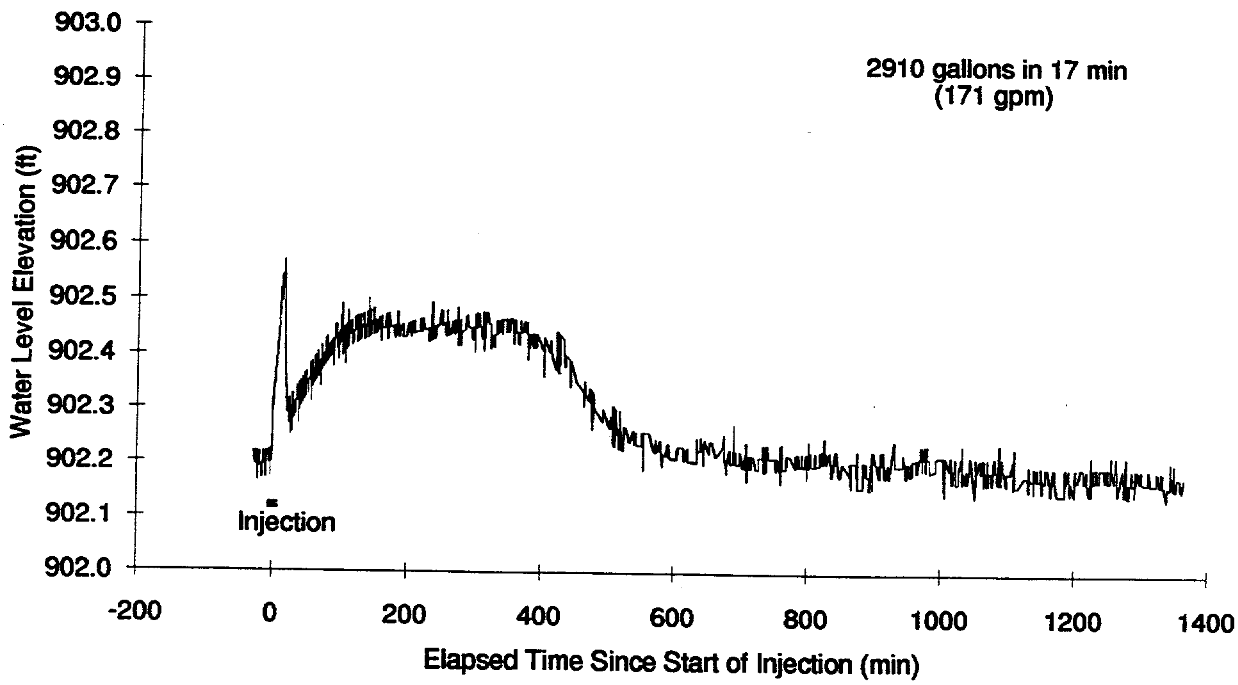

Figure 42. Water level elevation in GW-722-33 versus time since injection into GW-734, second test. (Picket J)

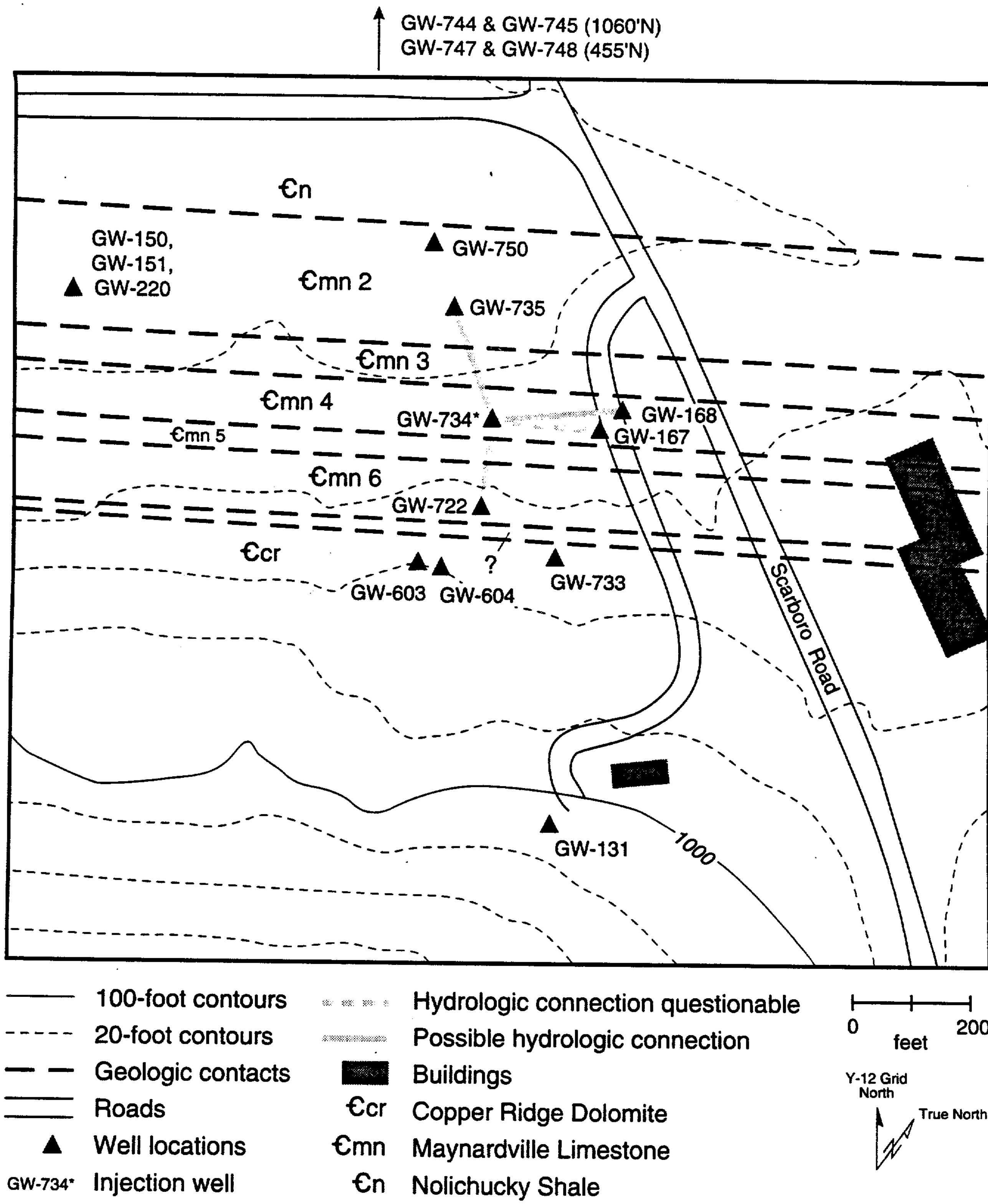

Figure 43. Map of the Picket J area showing the location of the injection well (modified from Shevenell et al., 1992).

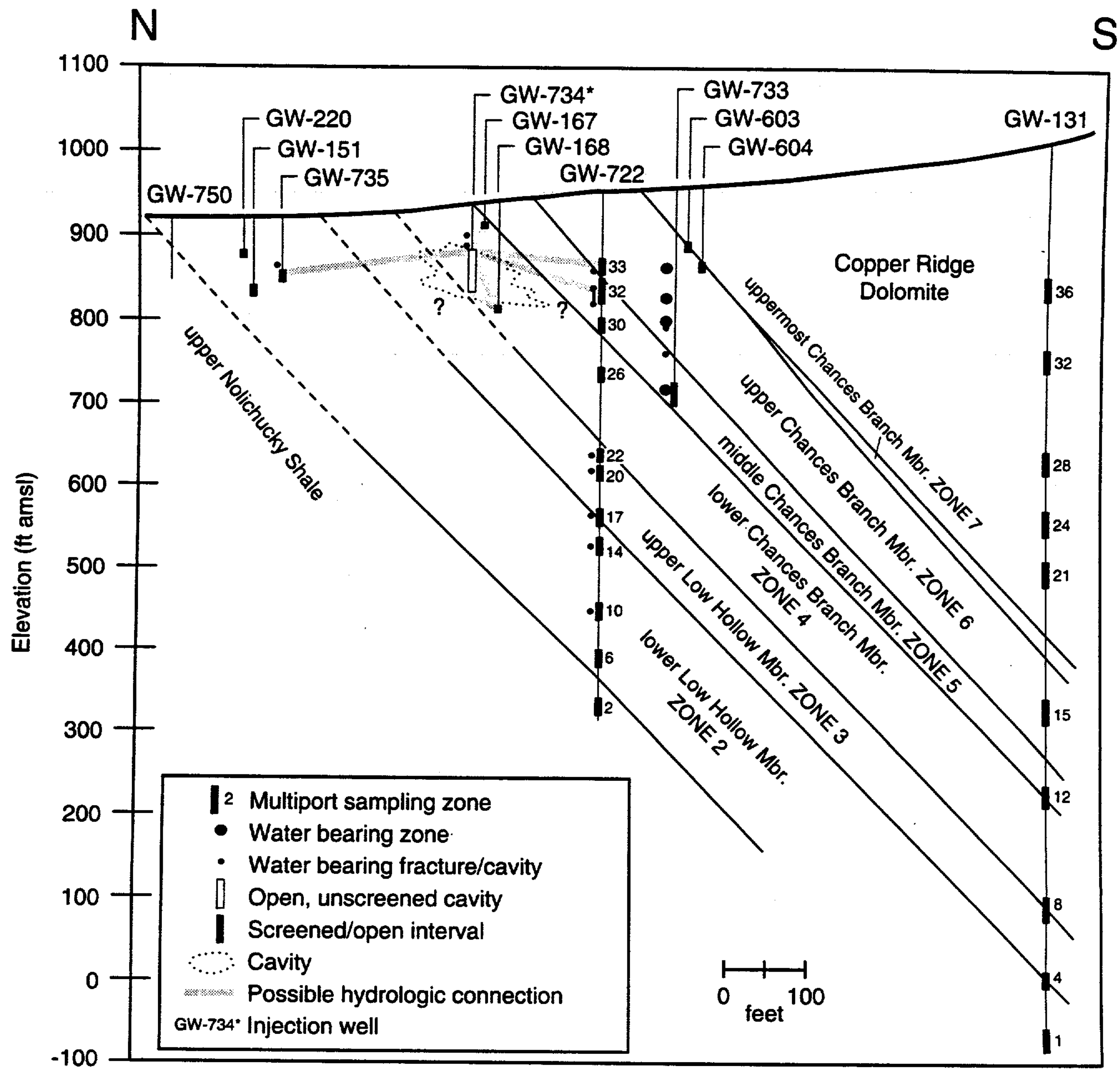

Figure 44. Cross-section at Picket J showing well locations (modified from Shevenell et al., 1992).

Table 1. Listing of coordinates and distances between injection and monitor wells.

Well	North (ft)	East (ft)	Elev. (ft)	TD (ft)	Elev TD (ft)	Distance (ft)	Distance (m)
Picket W - Inject in GW-713							
GW-710	27645	36471	908.0	744.5	163.5	592.0	180.4
GW-711	27873	36535	902.0	666.2	235.8	376.9	114.9
GW-712	28233	36507	873.6	457.5	416.1	72.6	22.1
GW-713	28236	36434	877.8	315.2	562.6	0.0	0.0
GW-714	28422	36435	872.3	145.0	727.3	186.1	56.7
GW-715	28425	36453	872.2	43.1	829.1	190.0	57.9
Picket W - Inject in GW-712							
GW-710	27645	36471	908.0	744.5	163.5	588.6	179.4
GW-711	27873	36535	902.0	666.2	235.8	360.8	110.0
GW-712	28233	36507	873.6	457.5	416.1	0.0	0.0
GW-713	28236	36434	877.8	315.2	562.6	72.6	22.1
GW-714	28422	36435	872.3	145.0	727.3	202.7	61.8
GW-715	28425	36453	872.2	43.1	829.1	199.9	60.9
Picket A - Inject in GW-684 (1st test)							
GW-054	28823	41295	889.8	40.0	849.8	304.2	92.7
GW-056	28698	41384	886.7	55.2	831.5	176.1	53.7
GW-057	28688	41380	886.8	25.0	861.8	165.6	50.5
GW-058	28715	43211	909.7	45.2	864.5	1867.2	569.1
GW-059	28702	43215	909.8	27.0	882.8	1869.9	569.9
GW-060	28931	43047	900.5	50.0	850.5	1741.6	530.8
GW-061	28917	43048	900.8	25.0	875.8	1739.3	530.1
GW-651	29043	42535	900.1	52.0	848.1	1290.2	393.3
GW-683	28282	41552	969.5	197.5	772.0	313.8	95.6
GW-684	28525	41354	895.5	129.6	765.9	0.0	0.0
GW-685	28667	41448	889.3	138.3	751.0	171.2	52.2
GW-728	28774	43010	907.0	308.3	598.7	1674.9	510.5
SS-5 spring	28525	41304	885.0	--	--	50.0	15.2
Picket A - Inject in GW-684 (2nd test)							
GW-054	28823	41295	889.8	40.0	849.8	304.2	92.7
GW-055	28811	41296	889.5	20.6	868.9	292.2	89.1
GW-056	28698	41384	886.7	55.2	831.5	176.1	53.7
GW-057	28688	41380	886.8	25.0	861.8	165.6	50.5
GW-683	28282	41552	969.5	197.5	772.0	313.8	95.6
GW-684	28525	41354	895.5	129.6	765.9	0.0	0.0
GW-685	28667	41448	889.3	138.3	751.0	171.2	52.2
GW-728	28774	43010	907.0	308.3	598.7	1674.9	510.5
SS-5 spring	28581	41301	883.1	--	--	77.1	23.5
Picket B - Inject in GW-706							
GW-621	29023	45033	923.1	43.0	880.1	117.8	35.9
GW-694	28845	44893	938.6	204.5	734.1	113.4	34.6
GW-695	28845	44868	937.2	62.6	874.6	126.5	38.6
GW-703	28806	44931	951.8	182.0	769.8	140.7	42.9
GW-704	28845	44935	942.0	256.0	686.0	102.1	31.1
GW-705	28945	44916	925.0	307.0	618.0	27.7	8.4
GW-706	28946	44944	925.8	182.5	743.3	0.0	0.0

Well	North (ft)	East (ft)	Elev. (ft)	TD (ft)	Elev TD (ft)	Distance (ft)	Distance (m)
Picket C - Inject in GW-724							
GW-066	29513	48677	957.3	55.8	901.5	447.6	136.4
GW-723	29006	49089	1019.3	444.5	574.8	213.3	65.0
GW-724	29198	48995	976.6	301.6	675.0	0.0	0.0
GW-725	29405	48989	958.3	142.5	815.8	207.3	63.2
GW-736	29381	48936	957.6	105.0	852.6	192.1	58.6
GW-737	29365	48890	957.5	89.5	868.0	197.2	60.1
GW-738	29150	49026	980.4	90.1	890.3	57.3	17.4
GW-739	29010	49126	1020.7	320.0	700.7	229.2	69.9
GW-740	29027	49055	1017.0	190.0	827.0	181.4	55.3
GW-800	28982	48260	961.4	35.0	926.4	766.1	233.5
Picket J - Inject in GW-734 (1st test)							
GW-131-04	27989	65059	1008.4	1003.0	5.4	702.6	214.2
GW-131-24	27989	65059	1008.4	458.0	550.4	702.6	214.2
GW-131-28	27989	65059	1008.4	376.0	632.4	702.6	214.2
GW-131-32	27989	65059	1008.4	259.0	749.4	702.6	214.2
GW-167	28661	65146	929.7	30.1	899.6	204.1	62.2
GW-220	28949	64225	912.7	45.2	867.5	766.0	233.5
GW-603	28430	64803	959.4	75.2	884.2	288.3	87.9
GW-604	28437	64837	959.5	112.4	847.1	267.0	81.4
GW-722-10	28532	64926	951.0	500.0	451.0	151.0	46.0
GW-722-17	28532	64926	951.0	385.0	566.0	151.0	46.0
GW-722-22	28532	64926	951.0	313.0	638.0	151.0	46.0
GW-722-32	28532	64926	951.0	107.0	844.0	151.0	46.0
GW-722-33	28532	64926	951.0	87.0	864.0	151.0	46.0
GW-733	28447	65057	955.7	256.5	699.2	261.2	79.6
GW-734	28682	64943	937.4	103.5	833.9	0.0	0.0
GW-735	28867	64872	921.3	83.0	838.3	198.2	60.4
GW-745	30278	64309	904.3	33.0	871.3	1717.3	523.4
GW-748	29741	64579	918.9	29.5	889.4	1119.6	341.2
GW-750	28975	64835	916.0	75.7	840.3	311.7	95.0
Picket J - Inject in GW-734 (2nd test)							
GW-131-04	27989	65059	1008.4	1003.0	5.4	702.6	214.2
GW-131-24	27989	65059	1008.4	458.0	550.4	702.6	214.2
GW-131-28	27989	65059	1008.4	376.0	632.4	702.6	214.2
GW-131-32	27989	65059	1008.4	259.0	749.4	702.6	214.2
GW-151	28958	64232	913.1	96.5	816.6	762.7	232.5
GW-168	28699	65167	929.5	135.4	794.1	224.6	68.5
GW-722-10	28532	64926	951.0	500.0	451.0	151.0	46.0
GW-722-17	28532	64926	951.0	385.0	566.0	151.0	46.0
GW-722-22	28532	64926	951.0	313.0	638.0	151.0	46.0
GW-722-32	28532	64926	951.0	107.0	844.0	151.0	46.0
GW-722-33	28532	64926	951.0	87.0	864.0	151.0	46.0
GW-734	28682	64943	937.4	103.5	833.9	0.0	0.0
GW-735	28867	64872	921.3	83.0	838.3	198.2	60.4
GW-744	30282	64324	905.1	69.5	835.6	1715.6	522.9
GW-747	29730	64570	918.3	82.5	835.8	1112.4	339.0
GW-750	28975	64835	916.0	75.7	840.3	311.7	95.0

Table 2. Summary of diagnostic plots for monitor wells.

	Log (s) versus Log (t)					Log (t) vs s	sqrt(t) vs s	Linear Flow	Radial Flow	Hi K Fracture	Low K Fracture	Fissured Res. with large blocks	Wellbore Storage
	Slope 1	R^2	Slope 2	R^2	Comment								
Picket W - first test													
GW-710	0.77	0.97				linear	linear	Y(?)	Y(?)	Y			P
GW-711	0.91	0.92	0.60	0.93		2L	2L,P	Y		Y			Y
GW-712	1.15	0.99				3L	curved	Y				Y	Y
GW-714	Files lost												
Picket W - second test													
GW-710	1.92	0.98	0.61	0.94		S, LS	S, LS	Y(?)	Y(?)	P			Y
GW-711	Files lost												
GW-713	1.42	0.98	0.60	0.95		S	S	?	?	Y			Y(?)
GW-714	No straight lines; noisy data												
Picket A - second test													
SS-5	0.94	0.98			3L	3L	3L	Y(?)					
Picket A - second test													
GW-683	0.54	0.99			linear	convex up	linear	Y		Y			
SS-5	0.26	0.30	6.20	0.84	erratic,2L	2L	2L	Y(?)			Y(?)		
Picket B													
GW-621	1.19	0.87	0.88	0.99	curved	convex up	linear	Y		Y(?)			P
GW-694	0.52	0.99			erratic	3 slopes	linear	Y		Y			
GW-695	6.21	0.88	0.94	0.94	convex up	convex down	convex down	?	?				P
GW-703	3.83	0.90	0.55	0.83		steps up	steps up	?	?	Y			?
GW-704	0.90	0.98			2 peaks	convex up	convex down	?	?				P

	Log (s) versus Log (t)												
	Slope 1	R^2	Slope 2	R^2	Comment	Log (t) vs s	sqrt(t) vs s	Linear Flow	Radial Flow	Hi K Fracture	Low K Fracture	Fissured Res. with large blocks	Wellbore Storage
Picket C													
GW-066	2.89	0.96	0.88	0.95	curved	S	S	?	?				P
GW-725	2.65	0.98	1.09	0.99	curved	convex up	linear	Y	N				P
GW-736	1.17	0.99	0.15	0.96	2L	convex up	2L	Y	N		Y		Y
GW-737	1.20	0.98	0.12	0.89	2L	convex up	2L	Y	N		Y		Y
GW-738	8.58	0.88	1.00	0.87	curved	convex down	convex down	?	?				P
GW-739	14.30	0.86	1.24	0.87	curved	S, LS	S, LS	?	?				P
Picket J - first test													
GW-167	0.68	0.94			steps	steps	steps	?	?	Y			
GW-722-32					erratic								
GW-722-33	0.46	0.88			erratic	convex up	convex up	?	?	Y			
GW-735	1.25	0.99			linear	convex up	linear	Y	N	?			P
Picket J - second test													
GW-168	1.92	0.98	0.45	0.86	convex up	steps, S	steps, S	?	?	Y			P
GW-722-32	0.66	0.87			erratic	convex up	convex up	?	?	Y			
GW-722-33	0.83	0.94			erratic	convex up	linear	Y	N	P			P
GW-735	1.32	1.00			linear	convex up	2L	Y(?)					P

Note: Y (yes) and N (no) indicate the likely features of the flow system. P indicates there is a possibilty of the feature.
S = a slight S curve for the plot; LS indicates a linear segment occurred in the S curve
2L inidcates 2 linear segments occured on the plot
2L,P inidcates 2 linear segments with parallel slopes occured on the plot

Table 3. Listing of responses in monitor wells from the injection tests.

Well	Distance (ft)	WL Response	Delay to Start (min)	Delay to Peak (min)	Maximum Change (ft)	Elev. Max WL (ft)	Duration Peak (min)	Duration Recession (min)
Picket W - Inject in GW-713								
GW-710	592.0	Y	101	601	0.10	842.44	462	1860
GW-711	376.9	Y	2	395	0.50	838.47	107	913 (?)
GW-712	72.6	Y	0	58	0.52	842.69	17	547
GW-713	0.0	–						
GW-714	186.1	Y	5	320	0.11	843.93	5	641
GW-715	190.0	?	-137	194	0.06	845.02	550	686
Picket W - Inject in GW-712								
GW-710	588.6	Y	41	466	0.32	842.63	61	1651
GW-711	360.8	Y	1	272	0.81	838.88	89	1354 (?)
GW-712	0.0	–						
GW-713	72.6	Y	1	119	1.61	843.76	14	1037
GW-714	202.7	?	39	176	0.07	843.97	3	119
GW-715	199.9	N						
Picket A - Inject in GW-684 (1st test)								
GW-054	304.2	N						
GW-056	176.1	N						
GW-057	165.6	N						
GW-058	1867.2	N						
GW-059	1869.9	N						
GW-060	1741.6	N						
GW-061	1739.3	N						
GW-651	1290.2	N						
GW-683	313.8	N (?)						
GW-684	0.0	–						
GW-685	171.2	N						
GW-728	1674.9	N						
SS-5 spring		Y	2	33	0.05		5 (?)	60
Picket A - Inject in GW-684 (2nd test)								
GW-054	304.2	N						
GW-055	292.2	N						
GW-056	176.1	N						
GW-057	165.6	N						
GW-683	313.8	Y	1	16	0.13	883.27	1	40
GW-684	0.0	–						
GW-685	171.2	N						
GW-728	1674.9	N						
SS-5 spring		Y	2 (?)	14	0.06		1 (?)	50
Picket B - Inject in GW-706								
GW-621	117.8	Y	2	40	0.20	907.29	3	124
GW-694	113.4	Y	<1	39	1.59	913.22	<1	257
GW-695	126.5	Y	36	99	0.53	910.14	31	586
GW-703	140.7	Y (?)	36	127	0.09	910.11	164	631
GW-704	102.1	Y	2	76	1.25	910.70	24	414
GW-705	27.7	N						
GW-706	0.0	–						

Well	Distance (ft)	WL Response	Delay to Start	Delay to Peak	Maximum Change	Elev. Max WL (ft)	Duration Peak	Duration Recession
Picket C - Inject in GW-724								
GW-066	447.6	Y	43	365	0.38	951.56	171	2108
GW-723	213.3	N						
GW-724	0.0	–						
GW-725	207.3	Y	2	23	4.12	950.26	<1	>3111
GW-736	192.1	Y	2	46	3.16	949.37	11	>3099
GW-737	197.2	Y	2	51	3.13	949.37	1	>3006
GW-738*	57.3	Y	28	249	0.45	952.41	47	2328
GW-739+	229.2	Y	42	348	3.07	948.82	36	>2872
GW-800	766.1	N						
Picket J - Inject in GW-734 (1st test)								
GW-131-04	702.6	N						
GW-131-24	702.6	N						
GW-131-28	702.6	N						
GW-131-32	702.6	N						
GW-167	204.1	Y (?)	6	203	0.10	901.97	527	1636
GW-220	766.0	N						
GW-603	288.3	N						
GW-604	267.0	N						
GW-722-10	151.0	N						
GW-722-17	151.0	N						
GW-722-22	151.0	N						
GW-722-32	151.0	Y	0.25	14.5	0.45	902.95	1.75	8.5
GW-722-33	151.0	Y	0.25	14.25	0.46	902.94	1.75	5.5
GW-733	261.2	N						
GW-734	0.0	–						
GW-735	198.2	Y	3	18	0.23	902.01	<1	431
GW-745	1717.3	N						
GW-748	1119.6	N						
GW-750	311.7	N						
Picket J - Inject in GW-734 (2nd test)								
GW-131-04	702.6	N						
GW-131-24	702.6	N						
GW-131-28	702.6	N						
GW-131-32	702.6	N						
GW-151	762.7	N						
GW-168	224.6	Y	11	73	0.13	902.02	14	881
GW-722-10	151.0	N						
GW-722-17	151.0	N						
GW-722-22	151.0	N						
GW-722-32	151.0	Y	0.25	12.3	0.30	902.50	4.17	9.67
GW-722-33	151.0	Y	0.25	16.22	0.30	902.57	0.25	7.75
GW-734	0.0	–						
GW-735	198.2	Y	3	19	0.23	901.30	1	1418
GW-744	1715.6	N						
GW-747	1112.4	N						
GW-750	311.7	N						

* Initial decrease in water level began at 4 minutes and continued until 27 minutes.

\+ Initial decrease in water level began at 4 minutes and continued until 49 minutes.

Table 4. Wells in which a response in temperature and specific conductance were observed.

Well	Water Level			Temperature			Specific Conductance		
	Delay to Start (min)	Delay to Peak (min)	Maximum Change (ft)	Delay to Start (min)	Delay to Peak (min)	Maximum Change (C)	Delay to Start (min)	Delay to Trough (min)	Maximum Change (umhos/cm)
Picket B - Inject in GW-706									
GW-621	2	40	0.02	54	834	0.04	27	1984	14
GW-694	<1	39	1.60	1	25	0.06	19	44	94

Note: Changes in temperature and specific conductance (SC) are inconclusive.

Table 5. Injection and hydrologic parameters for the Pickets.

Well	Pumping Rate (gpm)	Pumping Time (min)	Pumping Pressure (psi)	Saturated Thickness (ft)	Fracture Spacing* (ft)
Picket W					
Inject in GW-713 (1st test)	4.4	30-35	40	599.5	
Inject in GW-712 (2nd test)	10.8	41	50-82	599.5	
(for GW-710 & GW-711)					70.5
(for GW-712 through GW-715)					23.5
Picket A					
Inject in GW-684 (1st test)	70	41	atmos.	103.4	24.2
Inject in GW-684 (2nd test)	176	15.75	40	103.4	24.2
Picket B					
Inject in GW-706	74	40	62-65	213	
(for GW-621, GW-694 & 695)					34.1
(for GW-703)					60.7
(for GW-704)					85.3
Picket C					
Inject in GW-724	133	22	50	275	27
Picket J					
Inject in GW-734 (1st test)	165	17	45-50	325	
Inject in GW-734 (2nd test)	171	17	45-50	325	
(for shallow wells)*					8.8
(for GW-722)					44.6
(for GW-733)					32

Note, shallow wells include the following: GW-167, GW-168, GW-734, GW-735, GW-750, and GW-604.
* This refers to the conductive fracture spacing; these values do not include fractures which were not observed to produce water during drilling

Table 6. Theis recovery, and unconfined and confined aquifer test solutions.

		Unconfined Aquifer Theis	Unconfined Aquifer Cooper-Jacob	Confined Aquifer Theis	Confined Aquifer Cooper-Jacob	Theis Recovery	Average*
Picket W - 1st Test							
GW-710	T(ft²/min)	9.11E-01	1.74E+00	9.11E-01	1.74E+00	1.64E+00	1.39E+00
	Std. Error	1.26E-02	3.41E-02	1.25E-02	3.41E-02	9.49E-02	4.37E-01
	S	4.68E-04	2.18E-04	4.68E-04	2.18E-04		3.43E-04
	Std. Error	4.64E-06	6.61E-06	4.64E-06	6.61E-06		1.44E-04
GW-711	T(ft²/min)	1.35E-01	2.98E-01	1.35E-01	2.98E-01	5.04E-03	1.74E-01
	Std. Error	1.33E-03	6.34E-03	1.33E-03	6.34E-03	7.64E-05	1.25E-01
	S	2.14E-04	1.04E-04	2.14E-04	1.04E-04		1.59E-04
	Std. Error	1.00E-06	2.90E-06	1.00E-06	2.90E-06		6.34E-05
GW-712	T(ft²/min)	1.20E-01	2.72E-01	1.20E-01	2.72E-01	1.28E-01	1.83E-01
	Std. Error	2.45E-03	1.44E-01	2.45E-03	1.44E-02	4.29E-03	8.19E-02
	S	8.78E-04	4.50E-04	8.78E-04	4.50E-04		6.64E-04
	Std. Error	7.10E-06	2.77E-05	7.09E-06	2.77E-05		2.47E-04
Picket -2nd Test							
GW-710	T(ft²/min)	4.21E-01	7.19E-01	4.21E-01	7.18E-01	2.45E-01	5.05E-01
	Std. Error	5.57E-03	5.97E-03	5.56E-03	5.97E-03	1.21E-02	2.08E-01
	S	4.31E-04	2.87E-04	4.31E-04	2.68E-04		3.54E-04
	Std. Error	1.83E-06	1.57E-06	1.83E-06	1.57E-06		8.92E-05
GW-713	T(ft²/min)	8.61E-02	2.12E-01	8.59E-02	2.12E-01	1.12E-01	1.42E-01
	Std. Error	1.99E-03	8.85E-03	1.99E-03	8.86E-03	3.95E-03	6.53E-02
	S	1.41E-03	7.06E-04	1.41E-03	7.05E-04		1.06E-03
	Std. Error	1.14E-05	3.52E-05	1.14E-05	3.52E-05		4.05E-04
GW-714	T(ft²/min)	5.86E-01	1.53E+00	5.86E-01	1.53E+00	5.53E+00	1.95E+00
	Std. Error	6.12E-02	4.54E-02	6.12E-02	4.54E-02	5.36E-01	2.05E+00
	S	7.29E-03	5.92E-03	7.28E-03	5.91E-03		6.60E-03
	Std. Error	2.86E-04	8.03E-05	2.86E-04	8.03E-05		7.91E-04
Picket A - First Test							
SS-5 spring	T(ft²/min)	3.83E+01	3.83E+01	3.83E+01	3.83E+01	5.73E+00	3.18E+01
	Std. Error	4.10E+00	4.09E+00	4.09E+00	4.08E+00	2.17E-01	1.46E+01
	S	9.66E-05	9.61E-05	9.69E-05	9.64E-05		9.65E-05
	Std. Error	6.42E-05	6.36E-05	6.43E-05	6.38E-05		3.19E-07
Picket A - Second Test							
GW-683	T(ft²/min)	3.90E+01	4.81E+01	3.89E+01	4.81E+01	3.88E+01	4.26E+01
	Std. Error	2.01E+00	2.51E+00	2.01E+00	2.01E+00	1.37E+00	5.05E+00
	S	1.10E-03	7.59E-04	1.10E-03	7.59E-04		9.29E-04
	Std. Error	7.32E-05	6.00E-05	7.32E-05	6.11E-05		1.96E-04

		Unconfined Aquifer Theis	Unconfined Aquifer Cooper-Jacob	Confined Aquifer Theis	Confined Aquifer Cooper-Jacob	Theis Recovery	Average*
SS-5 spring	**T(ft²/min)**	5.52E+01	5.55E+01	5.51E+01	5.54E+01	1.26E+01	4.68E+01
	Std. Error	1.18E+00	1.12E+00	1.18E+00	1.12E+00	3.42E-01	1.91E+01
	S	9.47E-04	9.24E-04	9.49E-04	9.26E-04		9.37E-04
	Std. Error	7.76E-05	7.13E-05	7.76E-05	7.12E-05		1.34E-05
Picket B							
GW-621	**T(ft²/min)**	5.92E+00	1.07E+01	5.92E+00	1.07E+01	1.11E+01	8.85E+00
	Std. Error	1.43E-01	4.66E-01	1.43E-01	4.66E-01	3.30E-01	2.68E+00
	S	1.01E-02	6.04E-03	1.01E-02	6.03E-03		8.08E-03
	Std. Error	1.12E-04	2.49E-04	1.12E-04	2.49E-04		2.36E-03
GW-694	**T(ft²/min)**	1.53E+00	1.56E+00	1.55E+00	1.83E+00	2.03E+00	1.70E+00
	Std. Error	9.32E-02	4.81E-02	4.80E-02	5.38E-02	6.57E-01	2.21E-01
	S	4.61E-04	4.50E-04	4.50E-04	3.18E-04		4.20E-04
	Std. Error	5.84E-05	2.34E-05	2.34E-05	1.81E-05		6.79E-05
GW-695	**T(ft²/min)**	4.78E-01	1.25E+00	4.77E-01	1.25E+00	2.77E+00	1.25E+00
	Std. Error	6.00E-02	3.44E-02	5.98E-02	3.42E-02	1.40E-01	9.34E-01
	S	8.50E-03	6.89E-03	8.48E-03	6.88E-03		7.69E-03
	Std. Error	0.000401	8.99E-05	4.01E-04	8.98E-05		9.31E-04
GW-703	**T(ft²/min)**	7.389	1.17E+01	7.39E+00	1.17E+01	2.63E+01	1.29E+01
	Std. Error	7.05E-01	4.22E-01	7.05E-01	4.21E-01	2.24E+00	7.82E+00
	S	5.89E-02	4.23E-02	5.89E-02	4.23E-02		5.06E-02
	Std. Error	9.03E-04	5.10E-04	9.03E-04	5.10E-04		9.59E-03
GW-704	**T(ft²/min)**	3.04E+00	3.12E+00	3.02E+00	3.11E+00	1.21E+00	2.70E+00
	Std. Error	3.50E-01	2.79E-01	3.48E-01	2.77E-01	4.09E-02	8.34E-01
	S	7.38E-04	6.69E-04	7.40E-04	6.70E-04		7.04E-04
	Std. Error	2.25E-04	1.58E-04	2.25E-04	1.58E-04		4.04E-05
Picket C							
GW-066	**T(ft²/min)**	3.83E+00	6.39E+00	3.83E+00	6.38E+00	5.19E+00	5.12E+00
	Std. Error	7.15E-02	3.54E-02	7.14E-02	3.54E-02	3.16E-01	1.28E+00
	S	6.52E-03	4.52E-03	6.52E-03	4.52E-03		5.52E-03
	Std. Error	2.94E-05	1.29E-05	2.93E-05	1.29E-05		1.16E-03
GW-725	**T(ft²/min)**	3.94E-01	8.04E-01	3.89E-01	8.00E-01	5.05E-01	5.78E-01
	Std. Error	9.01E-03	4.46E-02	9.12E-03	4.47E-02	2.13E-02	2.09E-01
	S	1.93E-04	1.22E-04	1.92E-04	1.21E-04		1.57E-04
	Std. Error	1.14E-06	4.88E-06	1.15E-06	4.89E-06		4.10E-05
GW-736	**T(ft²/min)**	9.05E-01	1.16E+00	8.96E-01	1.16E+00	5.82E-01	9.41E-01
	Std. Error	5.19E-02	3.81E-02	5.13E-02	3.78E-02	2.83E-02	2.39E-01
	S	2.94E-04	2.03E-04	2.93E-04	2.03E-04		2.48E-04
	Std. Error	1.61E-05	7.87E-06	1.60E-05	7.82E-06		5.21E-05

		Unconfined Aquifer		Confined Aquifer			
		Theis	Cooper-Jacob	Theis	Cooper-Jacob	Theis Recovery	Average*
GW-737	T(ft²/min)	1.03E+00	1.24E+00	1.02E+00	1.23E+00	5.76E-01	1.02E+00
	Std. Error	5.94E-02	4.15E-02	5.88E-02	4.11E-02	2.72E-02	2.71E-01
	S	2.56E-04	1.87E-04	2.56E-04	1.86E-04		2.21E-04
	Std. Error	1.74E-05	8.38E-06	1.72E-05	8.30E-06		4.03E-05
GW-738	T(ft²/min)	2.14E+00	3.77E+00	2.13E+00	3.76E+00	4.09E+00	3.18E+00
	Std. Error	1.08E-01	5.37E-02	1.08E-01	5.36E-02	2.09E-01	9.62E-01
	S	2.42E-01	1.75E-01	2.42E-01	1.75E-01		2.09E-01
	Std. Error	2.11E-03	8.97E-04	2.11E-03	8.96E-04		3.88E-02
GW-739	T(ft²/min)	3.40E-01	6.23E-01	3.36E-01	6.19E-01	5.92E-01	5.02E-01
	Std. Error	1.04E-02	3.74E-03	1.02E-02	3.67E-03	2.70E-02	1.50E-01
	S	3.11E-03	2.23E-03	3.09E-03	2.22E-03		2.66E-03
	Std. Error	1.67E-05	5.53E-06	1.67E-05	5.47E-06		5.07E-04
Picket J - First Test							
GW-167	T(ft²/min)	4.72E+01	5.79E+01	4.71E+01	5.79E+01	6.02E+01	5.41E+01
	Std. Error	7.89E-01	7.41E-01	7.88E-01	7.41E-01	1.23E+01	6.38E+00
	S	3.89E-02	2.73E-02	3.89E-02	2.73E-02		3.31E-02
	Std. Error	8.00E-04	5.08E-04	8.00E-04	5.08E-04		6.65E-03
GW-722-32	T(ft²/min)	1.53E+01	2.14E+01	1.53E+01	2.14E+01	7.37E-01	1.48E+01
	Std. Error	1.08E+02	1.70E+00	1.80E+00	1.70E+00	4.81E-02	8.46E+00
	S	1.02E-03	6.36E-04	1.02E-03	6.35E-04		8.27E-04
	Std. Error	1.14E-04	6.71E-05	1.14E-04	6.71E-05		2.21E-04
GW-722-33	T(ft²/min)	1.53E+01	2.14E+01	1.53E+01	2.14E+01	6.41E-01	1.48E+01
	Std. Error	1.80E+00	1.70E+00	1.80E+00	1.70E+00	4.70E-02	8.50E+00
	S	1.02E-03	6.36E-04	1.02E-03	6.35E-04		8.27E-04
	Std. Error	1.14E-04	6.71E-05	1.14E-04	6.71E-05		2.21E-04
GW-735	T(ft²/min)	6.67E+00	1.52E+01	6.67E+00	1.52E+01	1.67E+01	1.21E+01
	Std. Error	5.69E-01	1.16E+00	5.69E-01	1.16E+00	9.17E-01	4.99E+00
	S	4.08E-03	2.80E-03	4.08E-03	2.80E-03		3.44E-03
	Std. Error	6.36E-05	1.12E-04	6.37E-05	1.12E-04		7.39E-04
Picket J - Second Test							
GW-168	T(ft²/min)	1.52E+01	2.47E+01	1.52E+01	2.47E+01	3.96E+01	2.39E+01
	Std. Error	9.01E-01	5.81E-01	9.01E-01	5.81E-01	5.31E+00	1.00E+01
	S	1.94E-02	1.34E-02	1.94E-02	1.34E-02		1.64E-02
	Std. Error	3.04E-04	1.66E-04	3.04E-04	1.66E-04		3.44E-03
GW-722-32	T(ft²/min)	1.03E+01	2.10E+01	1.03E+01	2.10E+01	1.73E+00	1.29E+01
	Std. Error	1.20E+00	2.09E+00	1.20E+00	2.09E+00	1.44E-01	8.21E+00
	S	3.69E-03	2.03E-03	3.69E-03	2.03E-03		2.86E-03
	Std. Error	1.73E-04	2.18E-04	1.73E-04	2.18E-04		9.59E-04

		Unconfined Aquifer Theis	Unconfined Aquifer Cooper-Jacob	Confined Aquifer Theis	Confined Aquifer Cooper-Jacob	Theis Recovery	Average*
GW-722-33	**T(ft²/min)**	9.20E+00	2.20E+01	9.19E+00	2.20E+01	1.92E+00	1.29E+01
	Std. Error	5.80E-01	1.72E+00	5.79E-01	1.72E+00	1.42E-01	8.86E+00
	S	4.18E-03	1.91E-03	4.18E-03	1.91E-03		3.05E-03
	Std. Error	1.10E-04	2.08E-04	1.10E-04	2.08E-04		1.31E-03
GW-735	**T(ft²/min)**	5.03E+00	1.56E+01	5.02E+00	1.56E+01	1.43E+01	1.11E+01
	Std. Error	5.34E-01	1.50E+00	5.34E-01	1.50E+00	7.33E-01	5.57E+00
	S	4.44E-03	3.22E-03	4.44E-03	3.22E-03		3.83E-03
	Std. Error	1.12E-04	1.65E-04	1.12E-04	1.65E-04		7.04E-04

Picket A - First Test
Slug test results from GW-684

		Bower-Rice+		Cooper (confined)
GW-684 (Slug Test)	K (ft/min)	7.06E-03	**T(ft²/min)**	3.14E-03
	Std. Error	4.83E-05	Std. Error	4.34E-01
	T(ft²/min)	7.30E-01	S	1.00E-08
			Std. Error	2.41E-05

* Average was calculated using results of all methods, both confined and unconfined.

* assuming an unconfined aquifer

Table 7. Aquifer test solutions for Moench fracture analysis.

		K (ft/min)	Ss	K' (ft/min)	Ss'
Picket W - First Test					
GW-710-1		1.72E-03	3.97E-07	5.21E-03	3.93E-07
	Std. Err	1.76E-04	2.24E-04	6.54E+00	2.24E-04
GW-711-1		2.97E-04	2.15E-07	4.79E-04	8.67E-08
	Std. Err	3.16E-05	4.58E-07	3.24E-01	4.29E-07
GW-713		2.12E-04	2.15E-06	1.52E+02	1.00E-08
	Std. Err	1.01E-05	3.10E-05	6.02E+06	3.08E-05
Picket W - Second Test					
GW-710-2		7.78E-04	3.94E-07	7.16E+02	3.39E-07
	Std. Err	4.22E-05	9.55E-05	1.50E+06	9.55E-05
GW-712		3.61E-04	1.00E-08	2.76E-04	6.84E-07
	Std. Err	4.11E-04	5.80E-07	9.14E-02	1.43E-06
GW-714-2		3.62E-02	4.61E-08	8.90E+02	4.61E-08
	Std. Err	6.99E-01	1.08E-01	1.80E-02	1.08E-01
Picket A					
GW-683		3.37E-01	4.75E-06	4.80E+04	7.61E-06
	Std. Err	6.85E-02	5.34E-01	5.94E-03	5.35E-01
Picket B					
GW-621		2.51E-02	3.21E-06	4.86E-01	4.68E-05
	Std. Err	1.96E-02	1.67E-04	5.50E+02	2.09E-04
GW-694		6.25E-03	9.80E-07	1.83E-03	1.75E-06
	Std. Err.	6.35E-04	3.63E-07	1.13E-01	7.47E-07
GW-695		1.08E-01	1.19E-08	1.25E+03	1.19E-08
	Std. Err	2.54E+00	3.30E-02	1.51E-01	3.30E-02
GW-703		7.91E-01	1.21E-08	1.17E+04	1.21E-08
	Std. Err	9.29E+00	2.42E-02	2.11E-02	2.42E-02
GW-704		1.78E-02	1.32E-06	3.11E+03	3.18E-07
	Std. Err	4.22E-03	5.13E-04	1.93E-01	5.11E-04
Picket C					
GW-066		1.42E-02	1.41E-05	6.37E+03	9.48E-06
	Std. Err	8.03E-04	9.90E-05	1.32E+07	9.88E-05

		K (ft/min)	Ss	K' (ft/min)	Ss'
GW-725		1.49E-03	9.48E-08	7.99E-04	5.70E-07
	Std. Err	3.20E-04	9.14E-05	2.76E-01	9.19E-05
GW-736		3.30E-03	5.60E-07	1.06E+03	4.87E-07
	Std. Err	4.17E-04	1.28E-03	5.65E+07	1.28E-03
GW-737		1.23E-03	2.48E-07	1.23E-03	2.64E-06
	Std. Err	9.80E-03	2.24E-06	1.22E+00	1.59E-05
GW-738		1.72E-01	2.19E-07	3.76E+03	2.19E-07
	Std. Err	1.07E+00	2.64E-01	1.15E-01	2.64E-01
GW-739		1.35E-03	2.14E-06	6.18E+02	8.60E-06
	Std. Err	1.78E-04	6.67E-05	2.70E+06	6.68E-05
Picket J - First Test					
GW-167		1.45E-01	4.32E-05	5.78E+04	6.63E-05
	Std. Err.	4.67E-03	1.14E+00	3.54E-03	1.14E+00
GW-722-32		3.97E-02	1.86E-06	2.14E+04	1.88E-06
	Std. Err	1.40E-02	1.07E-01	2.57E-02	1.07E-01
GW-722-33		4.95E-02	1.68E-06	2.00E+04	1.64E-06
	Std. Err	1.13E-02	1.85E-01	3.71E-02	1.85E-01
GW-735		1.52E-02	3.26E-06	1.52E-02	9.67E-06
	Std. Err	2.36E-02	1.12E-04	2.51E+01	1.09E-04
Picket J - Second Test					
GW-168		4.77E-02	3.34E-05	2.47E-02	2.61E-05
	Std. Err	5.40E-03	2.08E-01	5.09E+05	2.08E-01
GW-722-32		2.81E-02	7.62E-06	2.10E-02	4.45E-06
	Std. Err	4.58E-02	6.67E-03	7.46E+01	6.68E-03
GW-722-33		2.77E-02	1.24E-05	2.20E-02	6.16E-07
	Std. Err	2.57E-02	1.18E-04	1.15E+02	1.07E-04
GW-735		1.55E-02	8.29E-06	1.56E-02	5.54E-06
	Std. Err	7.97E-03	6.65E-05	2.90E+01	6.67E-05

K = hyd K of fissure system
K' = hyd K of block system
Ss = Ss of fissure system
Ss' = Ss ofblock system

Table 8. Calculated transmissivity based on the three-slope recession method.

	T1/Sy1	T2/Sy2	T3/Sy3	Sy1	Sy2	Sy3 (assumed)	T (m^2/d)	Saturated Thickness (m)	K (m/d)
Picket W									
No suitable slopes observed for use with this method									
Picket A									
GW-683	63.7	8	4.2	2.00E-04	1.60E-03	3.00E-03	1.7	31.52	0.05
SS-5-1	1.3	1.1	0.5	1.10E-03	1.30E-03	3.00E-03	0.18	31.52	0.01
SS-5-2	1.8	1.1	0.3	4.75E-04	8.03E-04	3.00E-03	0.12	31.52	0.00
Picket B									
GW-694	1142	313	101	2.65E-04	9.65E-04	3.00E-03	40.5	64.9	0.62
GW-695	157	58	10	1.95E-04	5.27E-04	3.00E-03	4.1	64.9	0.06
GW-704	725	141	14.5	5.98E-05	3.09E-04	3.00E-03	5.8	64.9	0.09
Picket C									
GW-725	1484	119	90	1.82E-04	2.27E-03	3.00E-03	36.2	83.8	0.43
GW-738	108	9.8	3.8	1.04E-03	1.15E-03	3.00E-03	1.5	83.8	0.02
GW-739	39	14.5		1.11E-03	3.00E-03		5.8	83.8	0.07
Picket J									
GW-735-1	2709	87	54	6.00E-05	1.88E-03	3.00E-03	21.8	99.1	0.22
GW-735-2	2449	24	29	3.60E-05	3.66E-03	3.00E-03	11.8	99.1	0.12
GW-735 - from storm hydrographs									
1994 - 1	9047	5118		1.32E-03	*2.34E-03*		26.7	99.1	0.27
1994 - 2	9710	7668	5992	1.85E-03	2.34E-03	3.00E-03	40.1	99.1	0.40
1994 - 3B	11841*	12144*		0.0024*	*0.00234**		63.4	99.1	0.64
Ave:	9379	6393	5992	1.59E-03	2.34E-03				**0.44**
+-	469	1803		3.75E-04	0.00E+00				0.19

The Sy2 value in italics is the average value calculated from recesion curves containing 3 slopes from other storms at the same well.

* indicates questionable results. Values were not used in the calculation of averages.

Table 9. Summary of hydrologic connections noted during injection tests.

	Distance (ft)	T (m^2/d)	Relative Quick flow	Along Strike	Perp. to Strike	Along Dip	Across Strata	Same Elev	Zone	Water+
Picket W - First Test (from Cmn-4)										
GW-710	592		4		Y		Y		Ccr - 5	N
GW-711	377		3		Y	Y			4	W
GW-712	73		1	Y			Y		2	W
GW-714	186		2		Y	Y			4	W
GW-715	190		No Res		Y		Y		6	C
Picket W - Second Test (from Cmn-2)										
GW-710	589		4		Y		Y		Ccr - 5	
GW-711	361		3		Y		Y		4	
GW-713	73		1	Y			Y		2	F
GW-714	203		2		Y		Y		4	
GW-715	200		No Res		Y		Y		6	
Picket A (from Cmn-6)										
GW-054	304		No Res		Y		Y		5	?
GW-055	176		No Res		Y		Y		5	?
GW-056	176		No Res		Y		Y		6	?
GW-057	166		No Res		Y		Y		5	?
GW-683*	314	1.7	1				Y	Y	Ccr	C
GW-685	171		No Res		Y		Y	Y	4 - 5	W
SS-5 spring*	50	0.15	2			Y			6	
Picket B (from Cmn-4)										
GW-621*	118		2			Y			4	C
GW-694*	113	40.5	1		Y			Y	4	F
GW-695	127	4.1	4				Y		6	W
GW-703	141		5		Y		Y		5	C
GW-704*	102	5.8	3		Y	Y			4	W
GW-705	28		No Res	Y			Y		Cn	N
Picket C (from Cmn-2)										
GW-066	448		6			Y			2	?
GW-723	213		No Res		Y			Y	3 - 4	W
GW-725*	207	36.2	1		Y	Y			2	F
GW-736	192		2			Y			2	F
GW-737	197		3			Y			2	C
GW-738	57	1.5	4				Y		5 - 6	C
GW-739	229	5.8	5				Y		4 - 5	W
GW-740	181		No Res				Y		3 - 4	F

	Distance (ft)	T (m^2/d)	Relative Quick flow	Along Strike	Perp. to Strike	Along Dip	Across Strata	Same Elev	Zone	Water+
Picket J (from Cmn-4)										
GW-167	204		5	Y			Y		4	?
GW-168	225		4	Y		Y			4	?
GW-603	288		No Res		Y		Y	Y	6	W
GW-604	267		No Res		Y		Y	Y	6	W
GW-722-32*	151		2		Y		Y	Y	5	C
GW-722-33*	151		1		Y		Y	Y	5 - 6	C
GW-733	261		No Res		Y		Y		5	W
GW-735*	198	32.8	3		Y		Y	Y	2	C
GW-750	312		No Res		Y		Y		2 - Cn	W

Relative Quick Flow: Ranking of response to cross borehole test in an individual picket.
1 = most rapid response in wells, 2 = slower response
+ water zone type noted in drilling records: W = diffuse flow water zone, F = fracture, C = cavity, N = none, ? = not reported.
*Good evidence for quick flow

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