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FIELD TESTS OF AUTOMATIC WATER-LEVEL MONITOR SYSTEMS: TECHNOLOGY DEVELOPMENT PROGRAM--SITE INVESTIGATION TECHNOLOGY PROJECT

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MASTER

SUMMARY

Groundwater in the aquifer beneath the Hanford Site contains radioactive and other contaminants from deposits in the overlying vadose zone. These contaminants flow with the groundwater into the Columbia River (Jaquish and Bryce 1989). The rate of contaminant movement toward the river depends on hydraulic gradients resulting from aquifer recharge by process water and other liquid waste. Historically, hydraulic gradients were deduced from water-level measurements made manually using steel tapes. These measurements were used to construct topographic, hydrologic maps on which contaminant plumes were plotted and from which flow toward the river was deduced. However, frequent or simultaneous measurements essential to proper site characterization and remediation under the Resource Conservation and Recovery Act; Comprehensive Environmental Response, Compensation, and Liability Act; and U.S. Environmental Protection Agency (EPA) have been either too costly or impossible. This investigation was authorized to identify technologies capable of meeting site characterization and remediation requirements with precision suitable to EPA. Therefore, we identified and tested available automatic monitoring systems for cost-effective and timely measurements of aquifer water levels.

We designed laboratory and field tests to reveal the monitoring system precision of ±1.5 mm (0.005 ft), as required by the EPA, over 1 year. The tests included compliance with qualifying specifications, assembly, installation, operation, and maintenance. Only 2 of 11 monitor systems we tested fully qualified.

Both monitor systems provided data within the 3-mm (±1.5-mm) limit over periods as long as 3 months. One monitor system provided acceptable data over 15 months. While all transducers continued to function over the 15-month period, two of them underwent significant offset, one of nearly 3 m (10 ft). The cause of offset is unknown but is thought to result from capillary occlusion by water vapor condensation. (The remedy for this would be ventilation of both the atmospheric compensation capillary tube and the electrical cable through a desiccator.)

We concluded that commercially available instrumentation is currently capable of measuring water levels within 3 mm over periods longer than 1 year without field maintenance or field visits following installation. We also concluded that water levels must be measured with desiccant-protected transducers supported on rods from the bottoms of the wells rather than suspended from cables. Frequency of measurements must be at least four times the natural frequency of the aquifer fluctuation to detect peak driving forces reliably. Reprogramming and system status monitoring, including battery voltage, can be done remotely, thus reducing on-site service.

Actual costs, based on the 175,000 measurements made over the past 15 months, including preparation of this report, were $2.34 per measurement, compared with $9 per measurement for manual measurements without a report. Equipment, installation, measurements, and data reduction cost about $0.21 per measurement. Projected costs, based on 150 wells and a 5-yr service life with automatic data processing, would be about $0.10 per measurement. Automatic water-level monitoring is estimated to be cost effective when measurements more frequent than one per week are required, or when simultaneous measurements are required.

CONTENTS

SUMMARY iii

1.0 INTRODUCTION 1

2.0 SYSTEM REQUIREMENTS 5

2.1 SITE CHARACTERISTICS 5

2.2 INSTRUMENT REQUIREMENTS 5

3.0 MATERIALS AND METHODS 7

3.1 MONITOR SYSTEMS 7

3.2 MONITOR SYSTEMS CALIBRATIONS 7

3.3 VOLT-RATIO REFERENCE 10

3.3.1 Radiotelemetry 10

3.3.2 Field Installation 11

3.4 DATA COLLECTION AND PROCESSING 13

4.0 RESULTS AND DISCUSSION 15

4.1 CALIBRATION RESULTS 15

4.2 INITIAL FIELD MEASUREMENT RESULTS 16

4.3 EXTENDED FIELD MEASUREMENT RESULTS 16

4.3.1 Equipment Performance 17

4.3.2 Data Quality Considerations 20

4.3.3 Costs 21

5.0 CONCLUSIONS AND RECOMMENDATIONS 23

6.0 REFERENCES 25

APPENDIX - FIELD TEST DATA A.1

FIGURES

1 Transducer Calibration Fixture 8

2 Millivolt Working Reference 11

3 Transducer Support Fixture for In-Well Monitoring 12

4 Transportable Monitoring System Support Fixture 12

5 Measurement Precision Demonstrated During Calibration 15

6 Temperature Dependance of Readings From a Pressure Transducers . . 16

7 Water-Level Fluctuation in Well 699-15-15A 17

8 Water-Level Fluctuation in Well 399-4-7 18

9 A Comparison Between Steel Tape and Automatic Measurements 18

1.0 INTRODUCTION

Groundwater in the aquifer beneath the Hanford Site contains radioactive and other wastes leached from deposits in the overlying vadose zone. These wastes flow with the groundwater into the Columbia River. According to Jaquish and Bryce (1989),

> The DOE operations on the Site have resulted in the production of large volumes of waste water that historically have been discharged to the ground through cribs, ditches, and ponds. These discharges have greatly influenced ground-water flow and contaminant movement in the unconfined aquifer beneath the Site. Approximately 2.42 billion L of liquid effluent in the 200 Areas were disposed to the ground during 1988, including process cooling water and water containing low-level radioactive and hazardous wastes.

The rate of contaminant movement toward the river depends on hydraulic gradients resulting from aquifer recharge by process water and other liquid waste. The hydraulic gradients were inferred from water-level measurements.

Historically, water levels were measured manually, using a steel tape, at a cost of about $9 per measurement, based on 60 measurements and 50 miles of travel per day. Although sufficiently accurate to satisfy U.S. Environmental Protection Agency (EPA) requirements of 3 mm (0.01 ft), manual measurements are very costly and cannot provide the simultaneous data essential to perform accurate aquifer analysis. In the absence of simultaneous measurements, modeling was used to simulate aquifer characteristics. However, administrators of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) rely on measurements instead of models for site characterization and remediation. The very costly manual measurements led to authorization of this work to find less costly technologies for future site characterization and remediation.

The objective of this study was to identify and evaluate at least two automatic monitoring systems that could provide higher quality information more frequently and at a lower cost. During FY 1988, Pacific Northwest

Laboratory (PNL)[a] personnel tested several monitoring systems in their laboratory and selected two monitoring systems for further testing in the field. Preparatory tests and calibration of equipment were done in a laboratory, where environmental conditions were only moderately variable. Once tested, the two types of systems were installed in the field. The field tests exposed the equipment to lightning, severe wind, rain, widely varying temperatures, invasion by insects and spiders, gnawing by rodents, and roosting and defecating by birds. The purpose of the field tests was to demonstrate measurement precision within 3 mm (0.01 ft) and reliability over an annual cycle of environmental conditions, with minimum maintenance. Data were retrieved by radiotelemetry and manually and processed by computer.

The cost of manually measuring water levels in the 500 wells now monitored at the Hanford Site is about $9 per measurement, based on measuring 60 wells and traveling 50 miles per day. Simultaneous measurements at least four times higher than the highest aquifer fluctuation frequency are required to characterize an aquifer without modeling. Manual measurements may suffice if modeling is an acceptable substitute for missing measurements and if measurements at once a week or less are needed. However, automatic data collection becomes cost-effective if simultaneous measurements are required to characterize aquifer performance or if two or more measurements per week are required. With fixed equipment cost and measurements made at 1-hour intervals, costs may be reduced from $9 per manual measurement to less than $0.20 per measurement. Automatic data collection can provide frequent and simultaneous readings, which could allow reduction in the number of wells measured without sacrificing needed information. Greater cost reductions may be possible from automating the well-monitoring process, as a result of improved efficiency and reliability in data handling. The estimate of $9 per measurement was for the field work only and did not include data handling.

This is the final report on field tests of automatic groundwater monitoring systems. This report includes the unpublished FY 1989 interim report which, with the subsequent field data, forms one contiguous test result.

(a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

While instrument accuracy was tested, accuracy of water-level measurements was beyond the scope of this task (water-level accuracy pertains to water elevation with respect to sea level and depends on a well-head survey with respect to an elevation reference standard).

2.0 SYSTEM REQUIREMENTS

During laboratory tests of several dataloggers and transducers, we developed a list of essential information and requirements needed to measure water levels in wells at the Hanford Site. The list included site characteristics and instrument requirements.

2.1 SITE CHARACTERISTICS

Hydraulic gradients beneath the Hanford Site that drive groundwater toward the Columbia River range from 0.1 m/km to about 14 m/km, as determined from water-table maps in Newcomer and McDonald (1990). Maximum water-level change is never expected to exceed 6 m in 3 months, and may not be more than 1 m in that interval. Groundwater levels near the river vary up to 1 m/d. Groundwater levels near disposal areas are disposal-volume dependent and may be greater than 1 m/d.

2.2 INSTRUMENT REQUIREMENTS

Measurement equipment precision must be within ±1.5 mm to measure gradients within 3 mm. The 6-m range of measurements with the ±1.5-mm resolution requires that the datalogger be able to resolve 1 part in 4000 from the transducer output. The datalogger must be capable of scanning transducers at intervals ranging as low as 0.1 s for early portions of recovery tests to several hours for transient monitoring and must be capable of storing at least 8760 data points (plus time and date) in a readily retrievable form.

The datalogger must be able to operate unattended on internal power for at least 3 months in an unprotected environment that is subject to temperatures ranging from -25° to +140° F, with humidity ranging from dry to 100% and condensing. In summary, the specifications required for the system are as follows:

- accuracy: 3 mm of water elevation
- precision/resolution: ±1.5 mm
- hysteresis/drift: ≤6 mm

- range of water head to be measured: ≥6 m
- size: ≤25.4 mm O.D. and ≤30 cm long
- power supply: ≥3 months of operation from a battery
- sample rate: ≤0.1 s
- data storage: ≥8760 data points with time and date
- durability: able to tolerate normal to rough handling during installation and servicing and to operate unattended for at least 3 months
- serviceability: capable of installation and routine field service by trained technicians, capable of data retrieval and battery change without interrupting data collection, capable of transducer replacement without power interruption or element damage
- versatility: adaptable to battery, solar, or municipal power supplies; capable of current, voltage, frequency, and pulse measurements; capable of data storage and retrieval (including radiotelemetry); tolerant of extreme environments with temperatures ranging from -25° to 140°F and humidity ranging from dry to 100% and condensing
- simplicity: able to be used by technicians without special training.

3.0 MATERIALS AND METHODS

3.1 MONITOR SYSTEMS

Four automatic monitoring and telemetry systems (two designated type A and two type B, each type qualified by tests made during FY 1988) were procured and calibrated. Each system consisted of a pressure transducer, a datalogger with a data storage unit, a power supply, and a radio transceiver. Precision, accuracy, hysteresis, and short-term drift were tested during calibration.

Both types of monitors were subjected to similar environments and were mounted on the field fixture the same way. Both monitors were powered by solar panels but of different size and manufacturers. Radiotelemetry was a similar style and the same type. Transducers were identical.

Two of the four automatic monitoring and telemetry systems, one type A and one type B, were installed at well 699-15-15A, and the other two were installed at well 399-4-7. Groundwater levels were measured at the two wells at high frequencies (10-s intervals) to define the amplitude and wavelength of the shortest water-elevation cycle in the aquifer. These data led us to select a 15-min scanning interval for each well. Duplicate water-level measurements to 3 mm (0.01 ft) were made periodically with a steel tape at each well for comparison with automatic measurements. A documented procedure was followed to measure water levels with a steel tape (PNL 1989).

3.2 MONITOR SYSTEMS CALIBRATIONS

The pressure transducer-datalogger systems were calibrated by fastening four of the transducers into the fixture and displacing them vertically in a water column. The calibration fixture is shown in Figure 1. Transducers were all of one type, the only type that qualified in all aspects of all the previous tests. Although pressure transducers are commonly checked on a deadweight tester, precise vertical displacement in water is also an accepted standard method for calibration. Water was selected for this task because it was simple, convenient, and accurate.

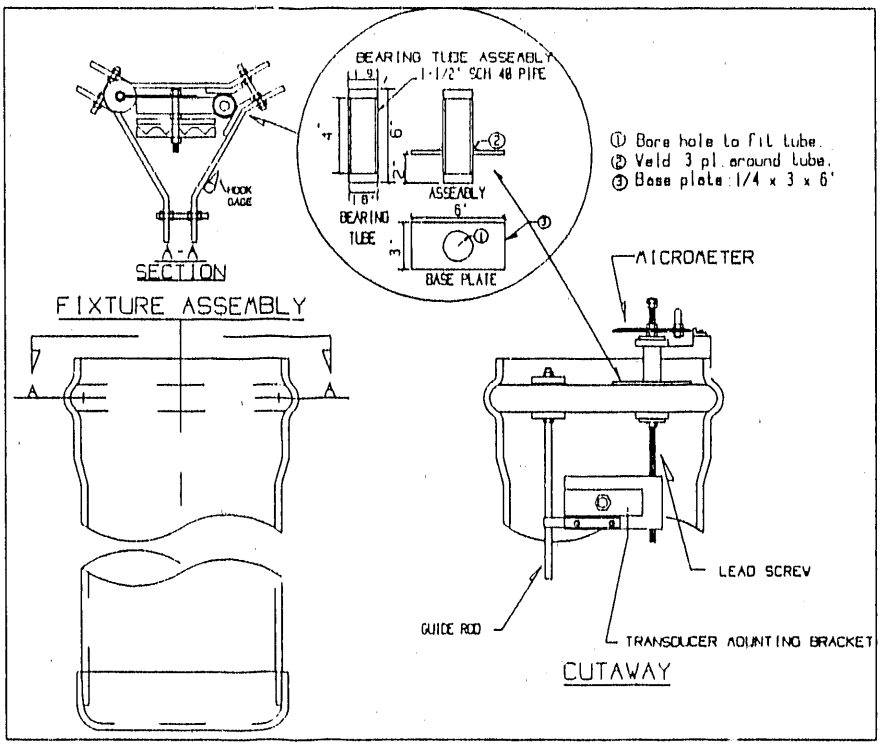


FIGURE 1. Transducer Calibration Fixture

The test and calibration tank and fixture shown in Figure 1 consisted of a PVC pipe that was 0.3 m (12 in.) in diameter and 1.5 m (5 ft) long, capped at the bottom end and filled with distilled water. The fixture frame was made from three 9.53- by 50.8-mm (3/8- by 2-in.) aluminum straps. A 19.05-mm-dia- by 182.88-mm-long (3/4-in.- dia- by 6-ft-long), stainless steel lead screw with 0.3937 threads/mm (10 threads/in.) was mounted in a bearing assembly that was fastened to the fixture frame. A round, flat micrometer dial was mounted on the top end of the lead screw. A 25.4- by 127- by 203.2-mm (1- by 5- by 8-in.) Teflon block was drilled, tapped, and mounted on the lower end of the lead screw. An aluminum mounting bracket to hold four pressure transducers was bolted to the Teflon block. A hook gage, used by the U.S. Weather Bureau to measure water depth in a Class A Evaporation Pan, was adjusted to the middle of its 10-cm range and fastened to the fixture frame, with the U-shaped hook suspended downward so its point could reach the water surface. The fixture assembly was mounted in the PVC pipe with the lead screw, hook-gage point, and transducer mounting bracket suspended down into the water.

Pressure transducers were fastened to the mounting bracket, with their cables suspended below them far enough to allow a 1-m (3-ft) submergence of the transducers in the tank of water. The water level was adjusted to bring it to the tip of the hook gage.

Micrometers on the hook gage and the lead screw were set to initial positions, and the readings were recorded. The water level was measured using the hook gage, and the value was recorded. The micrometer on the hook gage permitted direct readout of water level to 0.02 mm (0.000065 ft). The lead screw permitted vertical displacement of transducers in increments of 0.0254 mm (0.000083 ft).

The fixture qualified as a standard water column when filled with distilled water at a standard temperature with more than four times the precision needed for the measurements. This setup was used to test accuracy, precision, hysteresis, and drift in the automatic systems.

The pressure transducers had a six-wire, full-bridge configuration with differential voltage output. The full-range pressure was 17.25 kPa (2.5 psig) with an overranging factor of 10 for the two units with 61-m (200-ft) cables and 34.5 kPa (5 psig) with an overranging factor of 4 for the two units with 15-m (50-ft) cables. It was the overranging factor that allowed us to use the low-pressure range transducers for high precision and still measure a water-level change of 6 m (20 ft) when required.

Dataloggers were programmed and placed in operation, with transducers attached. The following instrument qualities were tested:

- transducer resolution, accuracy, hysteresis, and drift
- datalogger resolution, accuracy, and drift
- standard voltage measurement to separate datalogger errors from transducer errors
- measurement deviations from known values for each component.

Although the height of the water column in the PVC pipe provided a calibration range up to 1.3 m (4.5 ft or 2 psig), actual displacement was from 0 to 1 m (0 to 3.5 ft). Accuracy, precision, and hysteresis were tested.

Displacements by the lead screw were small enough to test the resolution of the dataloggers and the transducers (steps as small as 0.0254 mm [0.001 in.] were used). Transducer readings were adjusted by subtracting the known displacement value and treating the remaining difference as a deviation from that step. Thus, only the deviation from a step and not the length of the step itself was used to show the magnitude and direction of the errors. This process was followed on each of the pressure transducers and dataloggers.

Full-bridge voltage transducers received precisely regulated excitation voltage from the dataloggers. All transducers were monitored automatically on the most sensitive range possible on the attached datalogger. A ratio of output in millivolts to excitation in volts was recorded by type B dataloggers. Both output and excitation voltages were measured and recorded separately by type A dataloggers.

3.3 VOLT-RATIO REFERENCE

A millivolt working reference was prepared using a D-size alkaline cell and dropping resistors in series (shown in Figure 2). This millivolt reference was measured periodically during pre-installation tests using a digital multimeter with resolution to ±1 microvolt. During transducer tests, the millivolt reference was connected to the monitoring datalogger so a reference voltage could be measured every time the transducers were read. Deviations in these readings were then reduced to equivalent transducer units and subtracted from the deviations of the transducer to remove datalogger influence from the test. The millivolt working reference was again measured using the digital multimeter, which had calibration traceable to a national standard.

3.3.1 Radiotelemetry

Although all five radios were the same type and from the same manufacturer, and both were capable of "store-and-forward" operation, they were configured to operate differently. Radios with monitor A operated in the "store-and-forward" mode. Radios with monitor B operated in either "store-and-forward" mode or through a repeater.Radios were frequency tested and functionally checked before field installation by Boeing Computer Services,

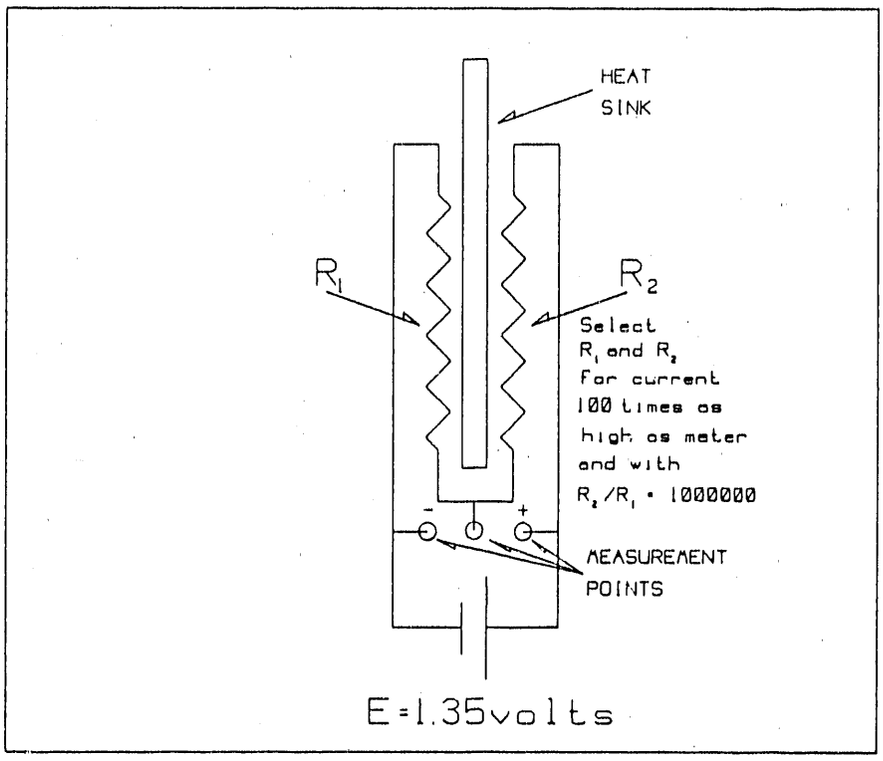


FIGURE 2. Millivolt Working Reference

Richland (BCSR), Radio Maintenance personnel. The radios were 5-watt, dual-channel, single-frequency, frequency modulation (FM) transceivers.

3.3.2 Field Installation

Following calibration, two well locations were selected, within a range of 15 miles to facilitate radiotelemetry. The wells were 4-7 in the 300 Area and 15-15A near the Wye Barricade. Two automatic data logging and telemetry systems were located at each well. Two pressure transducers were fastened to a fixture to maintain their constant position (shown in Figure 3) and lowered into each well.

Omnidirectional and bidirectional antennas were used. The antennas at the wells were mounted on 31.75-mm-dia (1.25-in.) galvanized steel pipe masts that were attached to a T base, as shown in Figure 4. They were positioned to provide a good radio frequency (RF) link with the base station. A radio base station and computer interface modem were installed in Sigma V to receive the data from the field. A radiotelemetry repeater was installed near the Fast

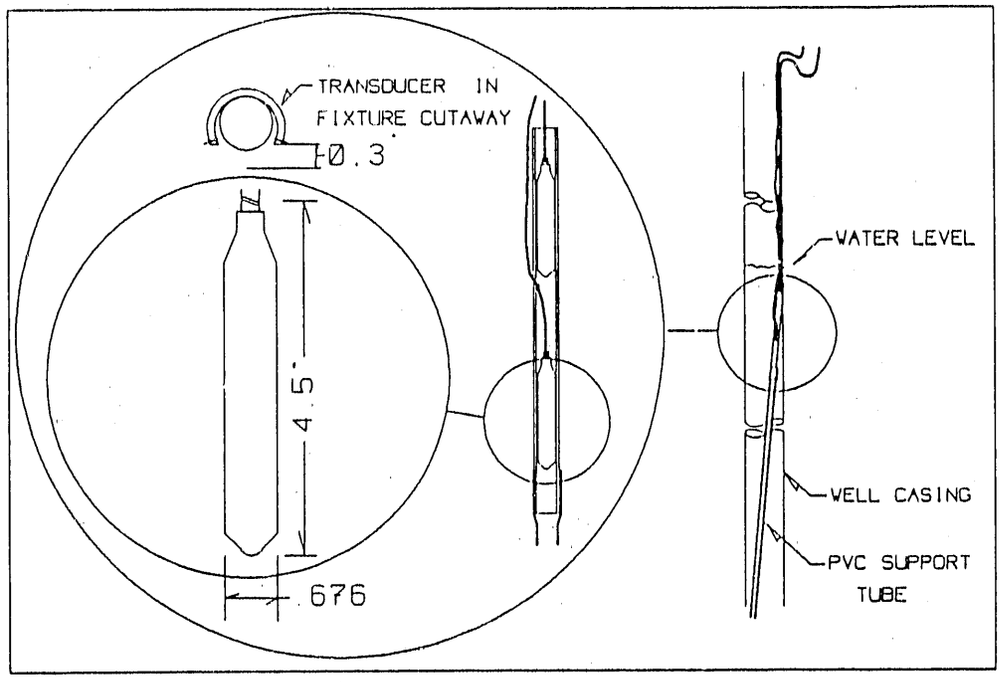


FIGURE 3. Transducer Support Fixture for In-Well Monitoring

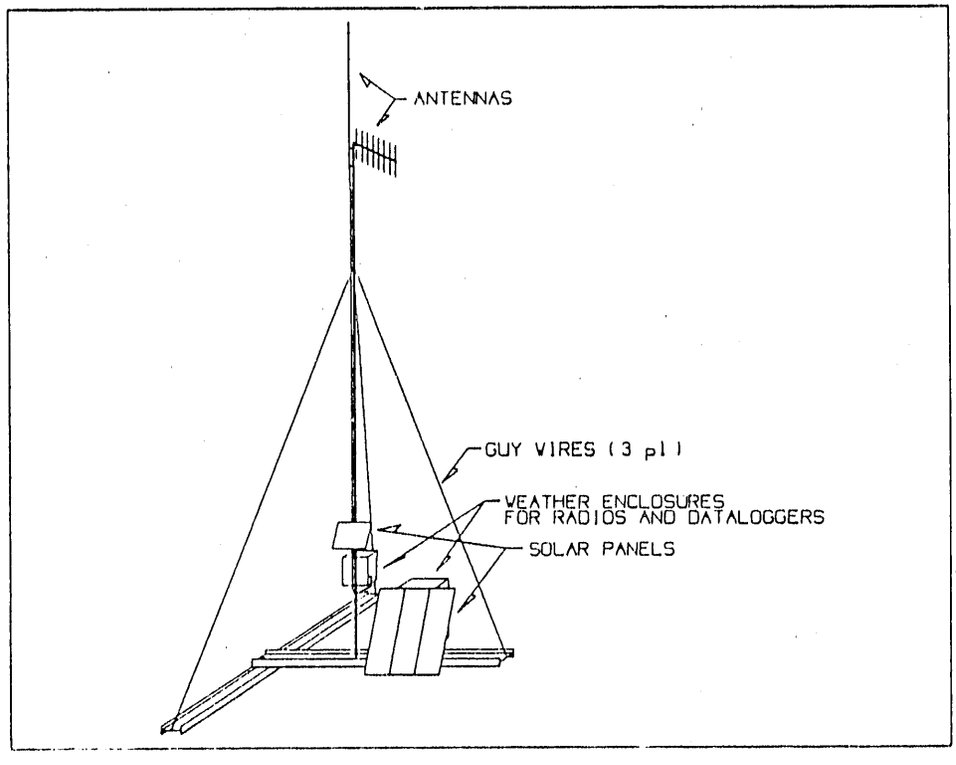


FIGURE 4. Transportable Monitoring System Support Fixture

Flux Test Facility (FFTF), between the base station and wells not within the line of sight necessary for radio communication.

Two sizes of solar panels were installed at each well, each feeding panel current through a voltage regulator into a deep-cycle, lead-acid battery. One solar panel was about 0.30 x 0.45 m (1 x 1.5 ft) and provided a nominal output of 7 watts. The other solar panel was made up of three sections, each about 0.30 x 1 m (1 x 3 ft), with a combined nominal output of 30 watts.

3.4 DATA COLLECTION AND PROCESSING

When the systems were assembled at the field sites, data collection began. Data were gathered at the well until the radiotelemetry system could transmit the data from the well to a central computer in the Sigma 5 building. Groundwater fluctuations were measured at 10-s and 15-min intervals to observe maximum fluctuation frequencies, compute the necessary measurement interval, and compare precision of transducers. The precision of the data was evaluated by comparisons with manual measurements taken by steel tape. The measurement precision of 3 mm (0.01 ft) was used as the target (EPA 1986).

All data had to be transformed from an ASCII text file to a spreadsheet file for processing. The spreadsheet processing consisted of assigning fractional-day values to each reading time and of calculating the depth to water from the top of the well casing, for comparison with steel tape measurements.

4.0 RESULTS AND DISCUSSION

Equipment tested and calibrated in the laboratory before field installation conformed to manufacturers' specifications. The temperature and voltage sensitivity, repeatability, and accuracy of dataloggers and transducers met system requirements discussed earlier, except the temperature/humidity requirements under versatility. Radiotelemetry systems performed according to vendor specifications.

4.1 CALIBRATION RESULTS

The measurement precision demonstrated during calibration indicated that the automatic measurement systems were capable of resolving water levels within ±1.5 mm (0.005 ft). The demonstrated precision is shown in Figure 5. The temperature dependence of the transducers is shown in Figure 6. Temperature compensation is adequate for variations up to 3°C and was not a problem in the 15 to 16°C aquifer tested (Eddy 1979).

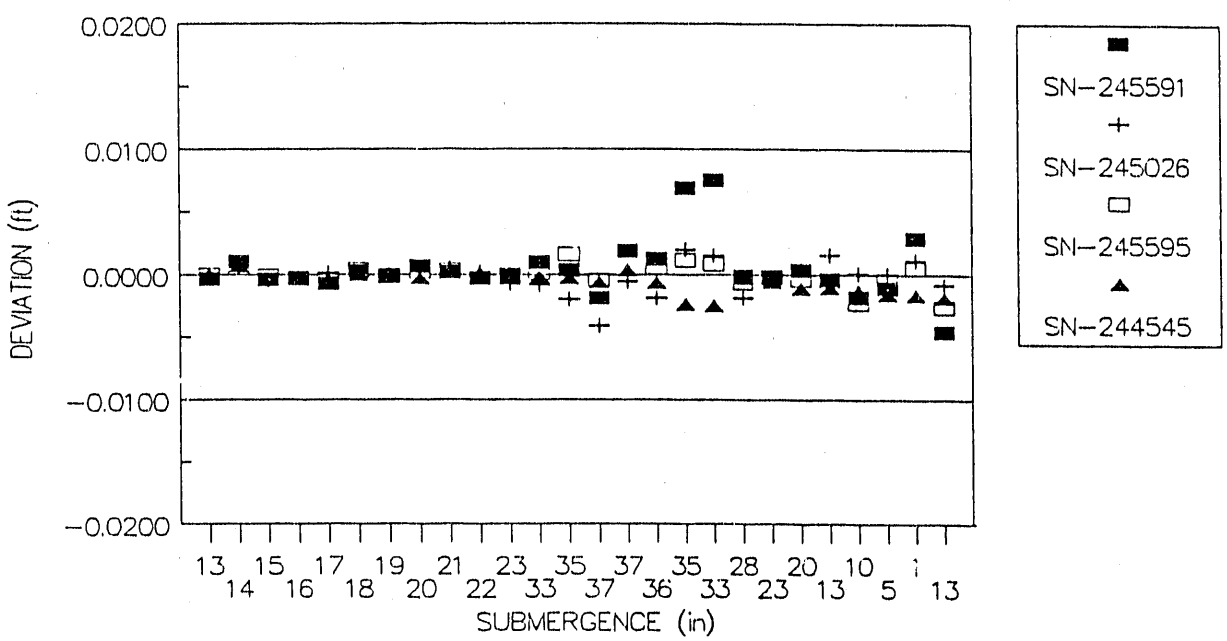


FIGURE 5. Measurement Precision Demonstrated During Calibration

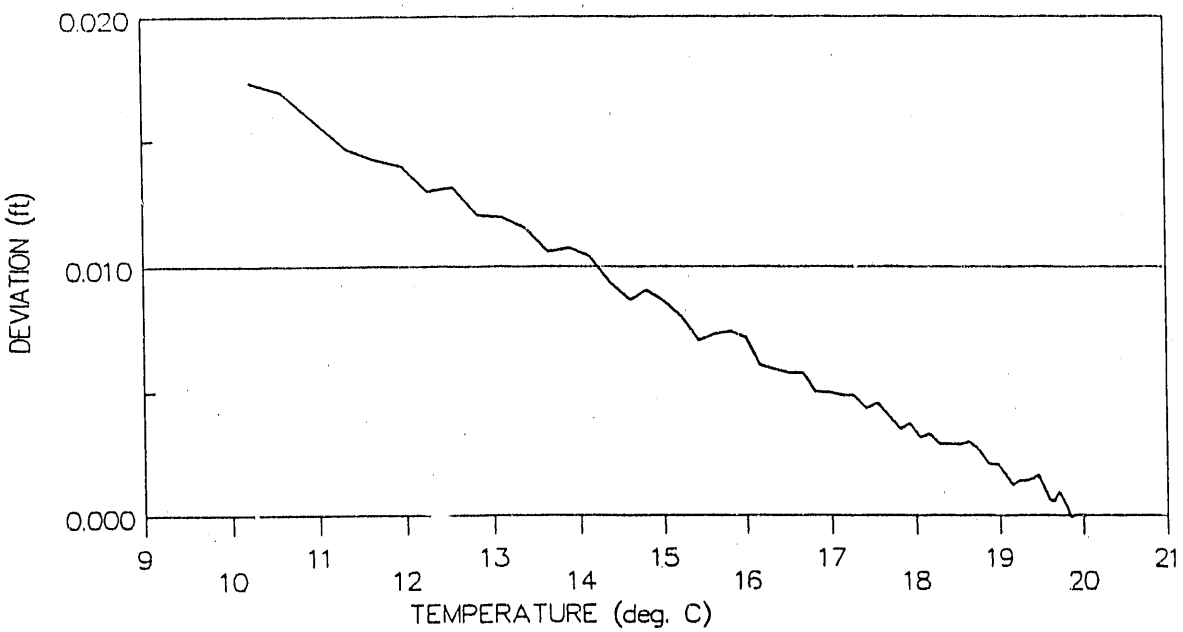


FIGURE 6. Temperature Dependance of Readings From a Pressure Transducer

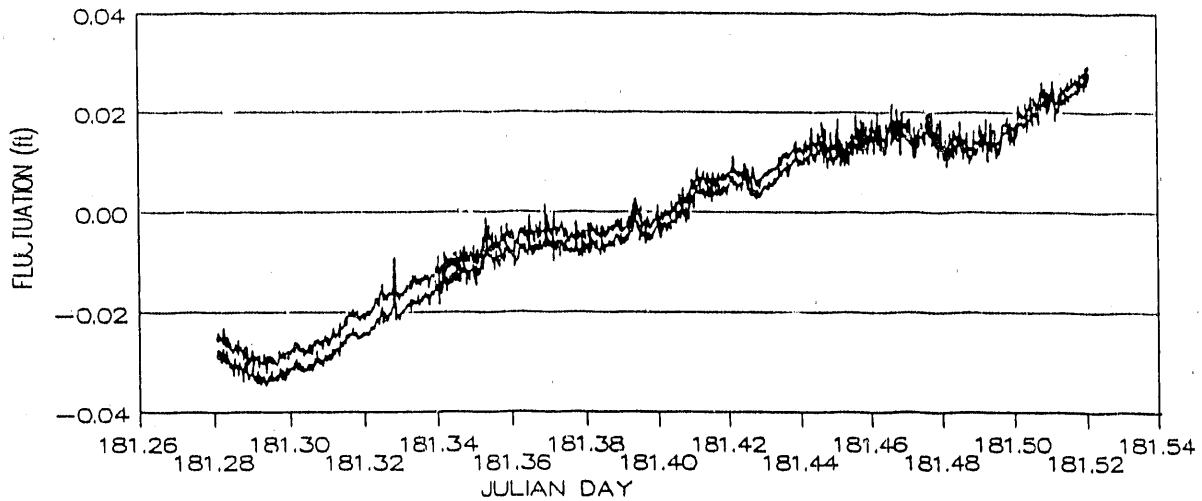
4.2 INITIAL FIELD MEASUREMENT RESULTS

Field measurements showed water-levels varying from 0.06 m (0.2 ft) to nearly 1 m (3 ft) (see Figures 7 and 8). To detect high and low points of fluctuation, for maximum driving force, we had to take at least four measurements (preferably more) per cycle. Thus, Figures 7 and 8 show that each well should be monitored about four times per day, since the cycles extended over a 1-day period. (Whether these fluctuations are hydrologically significant is beyond the scope of this investigation.)

The agreement between the steel tape measurements taken manually and the automatic measurements is displayed in Figure 9. The disparity is within the 3 mm (0.01 ft) range specified by EPA, until after the transducer offset occurred.

4.3 EXTENDED FIELD MEASUREMENT RESULTS

Field measurement graphs of water levels in wells 4-7 and 15-15A are presented in the Appendix. Results were broken into 30-day segments to improve data display, but the data were treated as a continuous set.



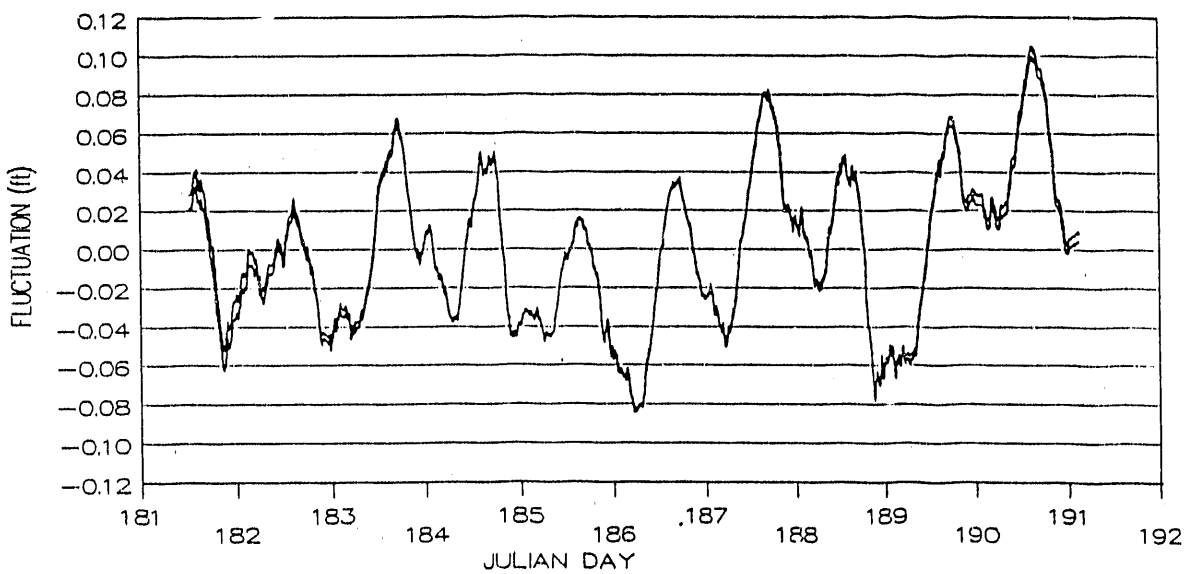


FIGURE 7. Water-Level Fluctuation in Well 699-15-15A (two transducers)

4.3.1 Equipment Performance

Monitor types A and B performed differently: Type A monitors logged transducer excitation and output voltages separately. Type B monitors logged the ratio of (output in millivolts)/(excitation volts).

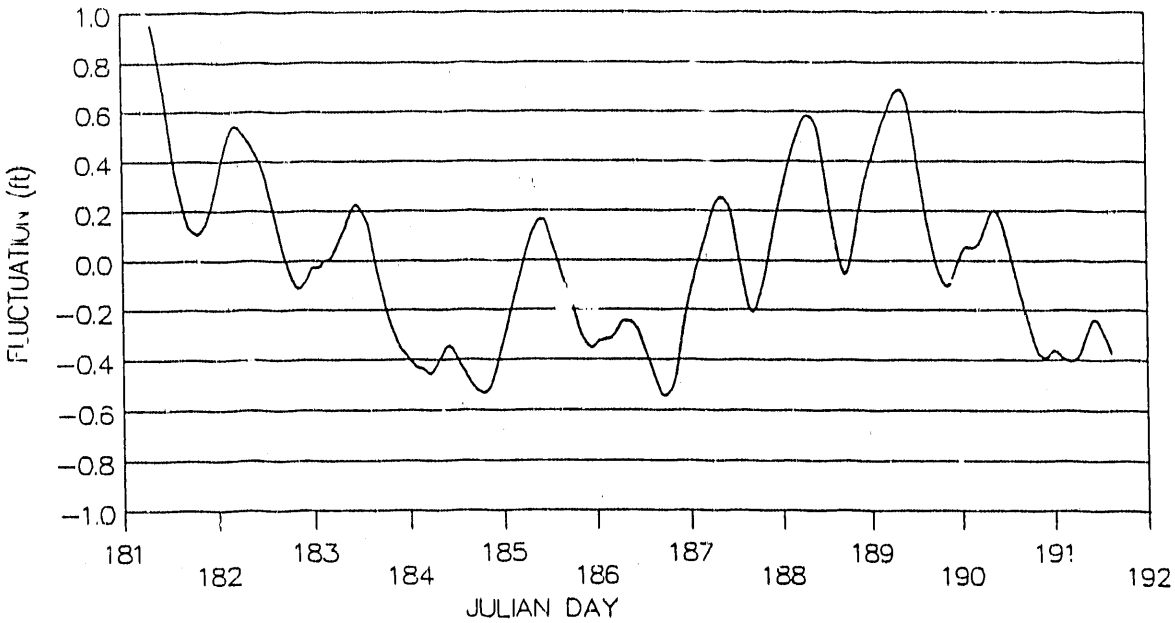


FIGURE 8. Water-Level Fluctuation in Well 399-4-7

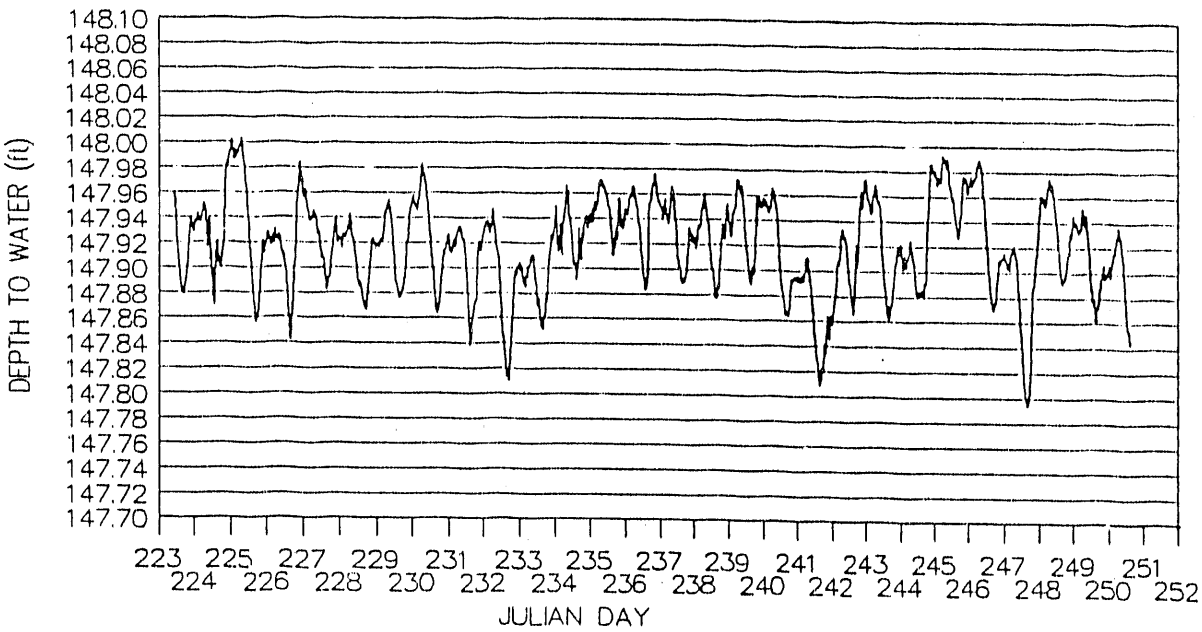


FIGURE 9. A Comparison Between Steel Tape and Automatic Measurements. Start: 147.96; End: 147.85.

4.3.1.1 Monitor A

Monitor A at well 15-15A failed initially, apparently because of an internal open circuit in the power supply line inside the datalogger. This problem was corrected on site by the vendor. The second failure was more complex: The internal open circuit occurred again, but the voltage regulator between the solar panel and the battery also failed, allowing the battery to discharge below a recoverable level.

Monitor A at well 4-7 failed initially as a result of voltage regulator failure. Data were recoverable, and the vendor replaced the voltage regulator. Cause of the second failure is still unreported by the vendor but was within the datalogger, making it unresponsive to computer interrogation. After the second failure, both dataloggers were returned to the vendor for evaluation and repair if needed.

4.3.1.2 Monitor B

Monitor type B at both wells performed according to manufacturer's specifications throughout the field test. Neither monitor required maintenance. Both type B power supplies worked properly, though one transmitter remained on long enough to drop battery voltage below 12 v.

4.3.1.3 Transducers

Two of the four transducers remained in tolerance over the entire field test; two did not. Displacement errors were detected on monitor B when the overrange indicator on the datalogger was noticed. A simple range selection change brought the transducer output within measurement range again. Data were lost during the overrange condition. However, an apparent displacement of nearly 3 m (10 ft) had occurred during the lost-data interval. Both initially and while monitor A was being repaired at well 15-15A, both transducers were connected to monitor B. The output from one of the transducers had not shifted, leaving us to conclude that calibration of the other had changed.

4.3.1.4 Radiotelemetry

Data recovery on site and by radiotelemetry conformed to manufacturer's specifications, except that one radio keyed on during a severe wind storm that broke the antenna. When that radio was turned off, all remaining systems resumed normal operations.

4.3.1.5 Manual Data Retrieval Equipment

Data retrieval from monitor A required a computer, whether on-site or by radiotelemetry. The 300-baud, data-transfer rate seemed slow, requiring about 30 min for 3000-datapoints. Data were retrieved from monitor B with computer by radiotelemetry or by direct connection, or manually by audio-cassette recorder. Manual retrieval was fastest, requiring about 3 min for 3000-datapoints. Manual data retrieval was used most frequently during the field tests because it allowed us to observe field conditions at least each month.

4.3.2 Data Quality Considerations

The data quality performance of pressure transducers was variable. Only 3 of 11 pressure transducers tested provided sufficiently precise data. Among the three, the one type best qualified was selected, though none met the condensing moisture tolerance requirement because of a lack of sealant or desiccant during manufacture, shipping, and use. Although all four transducers of the type selected functioned throughout the field test, data from two indicated sudden displacement. Excluding the apparent displacement in the two transducers, precision appeared acceptable. One possibility for the shift is that humidity caused the displacement. The pressure transducers were manufactured in warm, humid environments and were later installed in cold environments where condensate could form in the cable and in the vent tube, as evidenced during disassembly of two other failed transducers. The vent tubes are very small, and surface tension of the water forms a meniscus that moves under influences of gravity and pressure in the tube, causing a displacement error in the transducer output. The condensate inside the cable forms in like manner and may leak into the electronic circuitry and disable the transducer, causing premature failure. None of the transducers we tested or used had a sealant or a desiccant.

4.3.2.1 Application of Standard Calibrations

Pressure transducers calibrations (millivolts output)/(volts input) were between 0.427012/ft and 0.428891/ft. Both transducer and datalogger systems were within 0.025 mm which exceeds the reference standard by 15 times for a 3-mm (0.01-ft) precision requirement.

4.3.2.2 Cross Calibrations

Comparisons were made between transducer ratios in the two wells. When compensation was made for the zero offset and for the 127-mm (5-in.) vertical displacement between the transducers' mounting brackets, their values agreed. More importantly, changes in both transducer readings agreed with changes in steel tape readings within 1.5 mm, until the transducer offset, mentioned earlier, occurred.

4.3.2.3 Cause and Correction of Error

The cause of displacement errors in the two pressure transducers is currently unknown and will remain so until the transducers have been dismantled and analyzed by the manufacturer. All transducers are still functional but yield readings displaced from the initial calibrations. Discussion with the manufacturer also led us to believe that condensation in the vent tube of two of the transducers caused the displacement errors. All transducers will be removed from the wells and recalibrated and otherwise tested to ascertain the exact cause of the calibration shift.

4.3.3 Costs

Results from our cost analysis are compared with original cost estimates. Our original cost estimates were based on field system costs of $3000 each and a 5-yr lifespan, with less than $400 per yr maintenance. Based on the purchase of four complete systems and just over 15 months of field testing, the original projected costs seem possible but distributed differently.

4.3.3.1 Field Station Equipment and Manpower Costs

On a routine basis, we estimate that assembly and testing will require 2 man days per field station. There was no significant difference in required manpower or time between the two types of systems. Total installed cost for

the initial four field stations and the two base stations was about $27,000. Based on routine fabrication and installation, each field station should cost about $3500. Operating costs on monitor A would be prohibitive because of manpower. Monitor B required no maintenance of any kind. Monitor B was the lower cost system and was procured for just under $3000.

4.3.3.2 Data Retrieval and Processing Equipment and Manpower

Data retrieval and processing required a radiotelemetry base station, a computer with software. A spreadsheet software package capable of processing at least 6000 lines of data proved convenient (Note: Fewer lines require too much labor for setup and processing and was inefficient, unless the processing is automated). Manual data collection and processing consumed about 8 man hours per month to provide water levels from 5760 readings. This could be reduced to less than 1 hour by computer programming. Total base station costs averaged about $3500 for the two types of monitor systems. Monitor B base station cost just under $2000. Over 5 years, one base station would facilitate collection of 26-million datapoints at a datapoint cost of $0.02 each, including manpower.

The computer required 4 megabytes of RAM, to handle the data efficiently, and cost about $3500. This computer could collect and process data from about 150 field stations, each monitoring at 15-min intervals, if it were programmed to do so. Such service would yield nearly 52-million measured water levels during a 5-yr lifespan, at a cost of $0.01 per measurement. Thus, it appears that the minimum measurement costs would be $0.03 per measurement.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Precision, accuracy, hysteresis, and short-term drift of both type A and B automatic monitoring systems are acceptable. The measurement precision of 3 mm (0.01 ft), prescribed by the EPA, required calibration against a national standard with a precision of 0.75 mm (0.0025 ft). The actual calibration displacement precision was 0.0254 ± 0.00254 mm (0.000083 ± 0.0000083 ft) in a standard water column, thus satisfying the requirement. System measurement precision was within ±1.5 mm (0.005 ft), fully adequate to meet the EPA requirement. Temperature compensation in the pressure transducers was tested and was adequate over a 3°C range, sufficient for many well water applications.

Water levels fluctuated up to 5 mm (0.2 ft) daily in well 15-15A and up to 0.9 m (3 ft) daily in well 4-7. Automatic datalogging equipment was essential for reliable short-interval or simultaneous measurements. The reliability of the manual measurements seemed less consistent than automatic measurements but error was difficult to prove, although duplicate reading repeatability was within 3 mm (0.01 ft).

Data from two of the four transducers indicated an abrupt displacement. We believe the displacement was the result of water condensation in the vent tube. Every cable and vent tube need cryogenic stripping of water vapor during manufacture and shipment and use with a desiccant. The two type-B dataloggers performed acceptably and without maintenance or service for 15 months. The two type-A dataloggers failed twice and are now under investigation by the vendor. Both Type-A solar panel voltage regulators failed, possibly as a result of insufficient heat sinking. Radiotelemetry was satisfactory but slow.

6.0 REFERENCES

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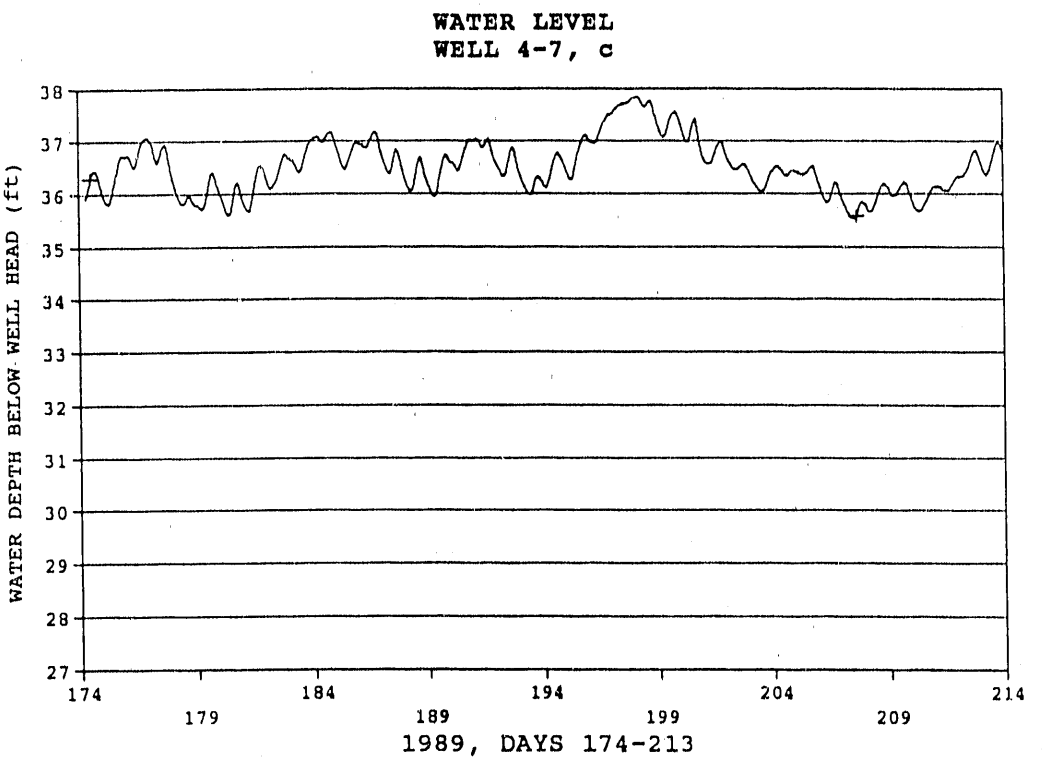
APPENDIX

FIELD TEST DATA

APPENDIX

FIELD TEST DATA

Data taken during field tests appear as graphs in the following pages. Datalogger readings were fit through one steel tape measurement (+) to assign transducer depth setting. Subsequent readings were connected end to end and allowed to deviate from tape readings to show a comparison between transducer and tape readings of the water levels. Precision appeared excellent until offset occurred. Graphs from well 399-4-7, monitor A and then B, are shown first, followed by graphs from well 699-15-15A, monitor A and then B.


WATER LEVEL
WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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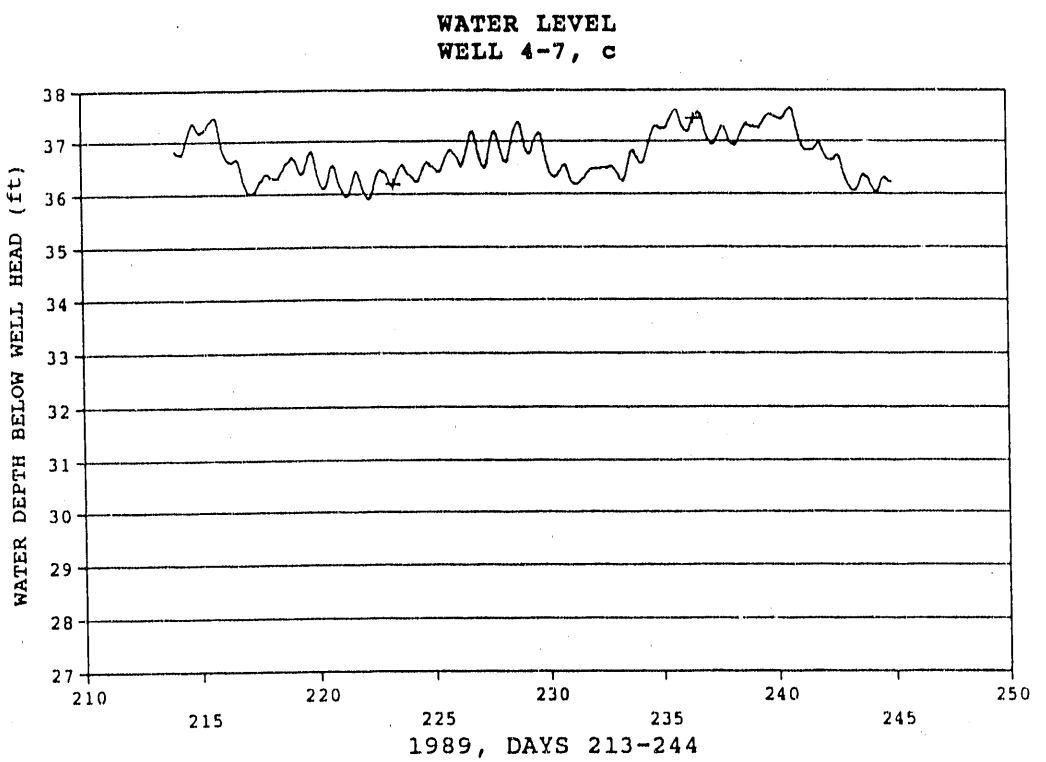
WATER LEVEL
WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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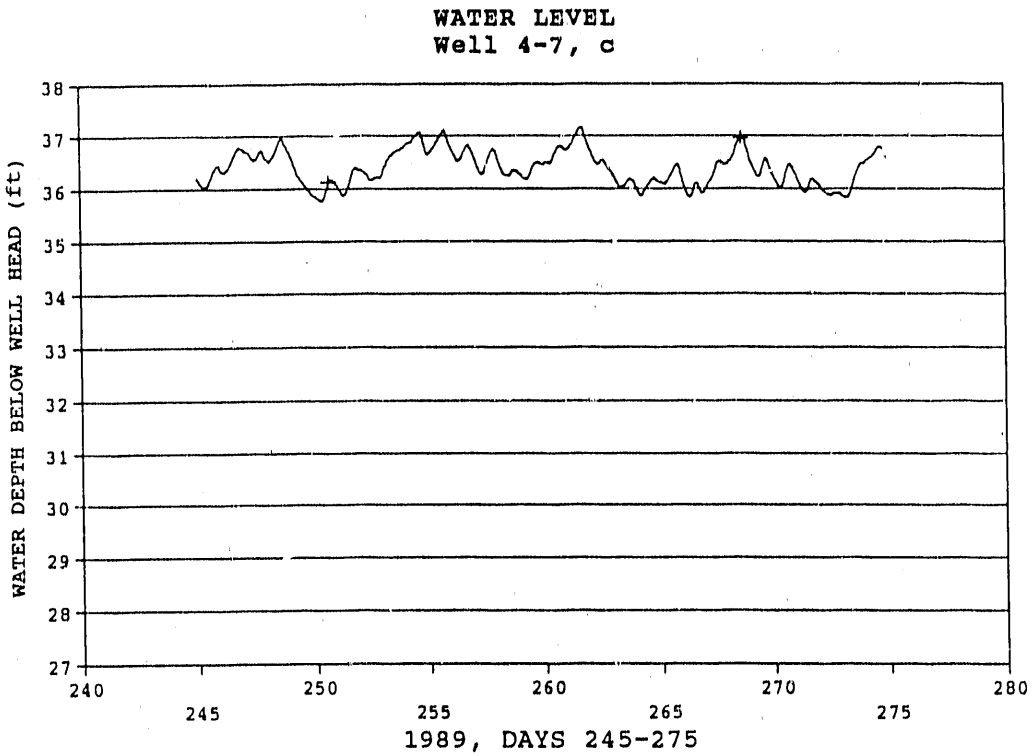
1989, DAYS 213-244


WATER LEVEL
Well 4-7, c
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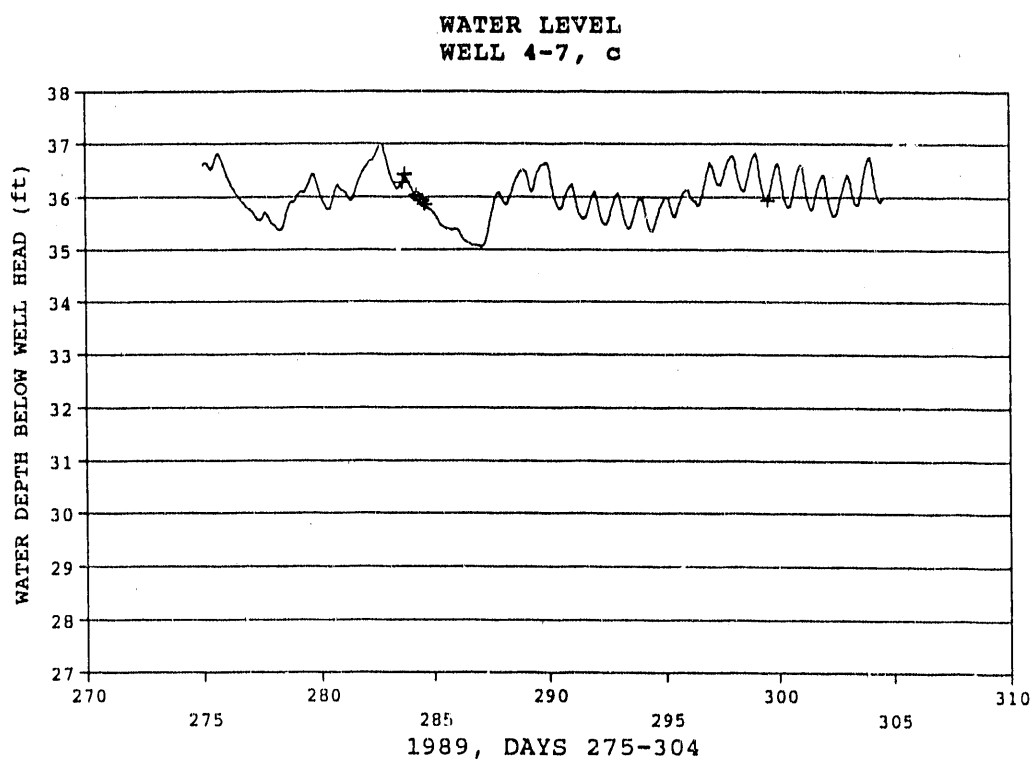
WATER LEVEL
WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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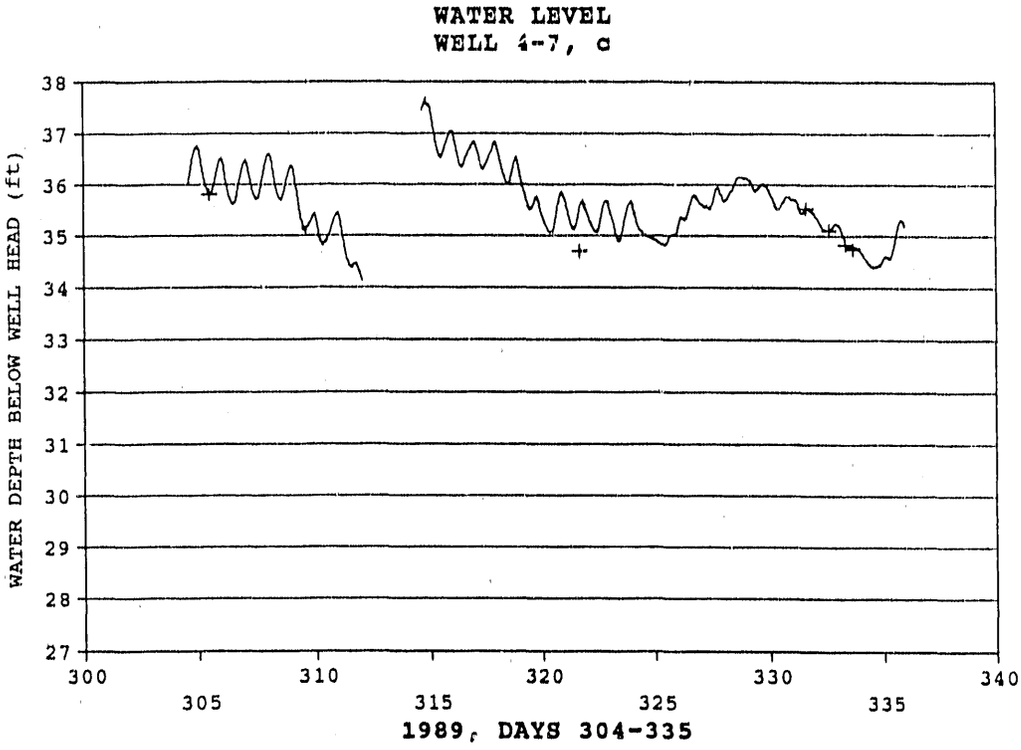
1989, DAYS 275-304


WATER LEVEL
WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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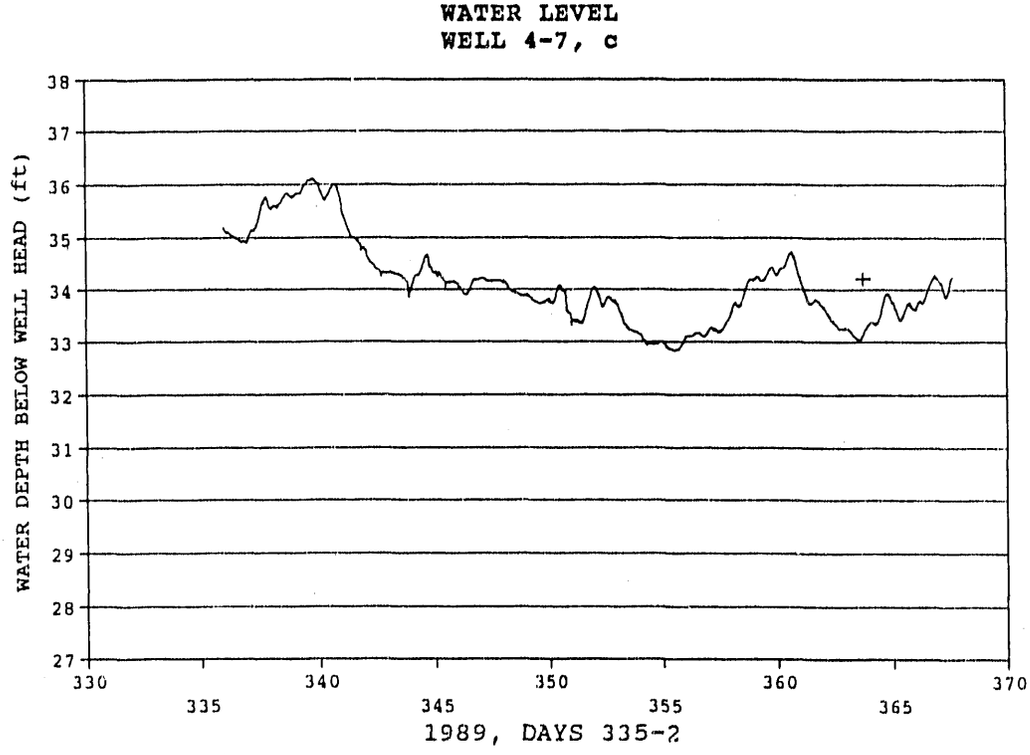
1989, DAYS 304-335


WATER LEVEL
WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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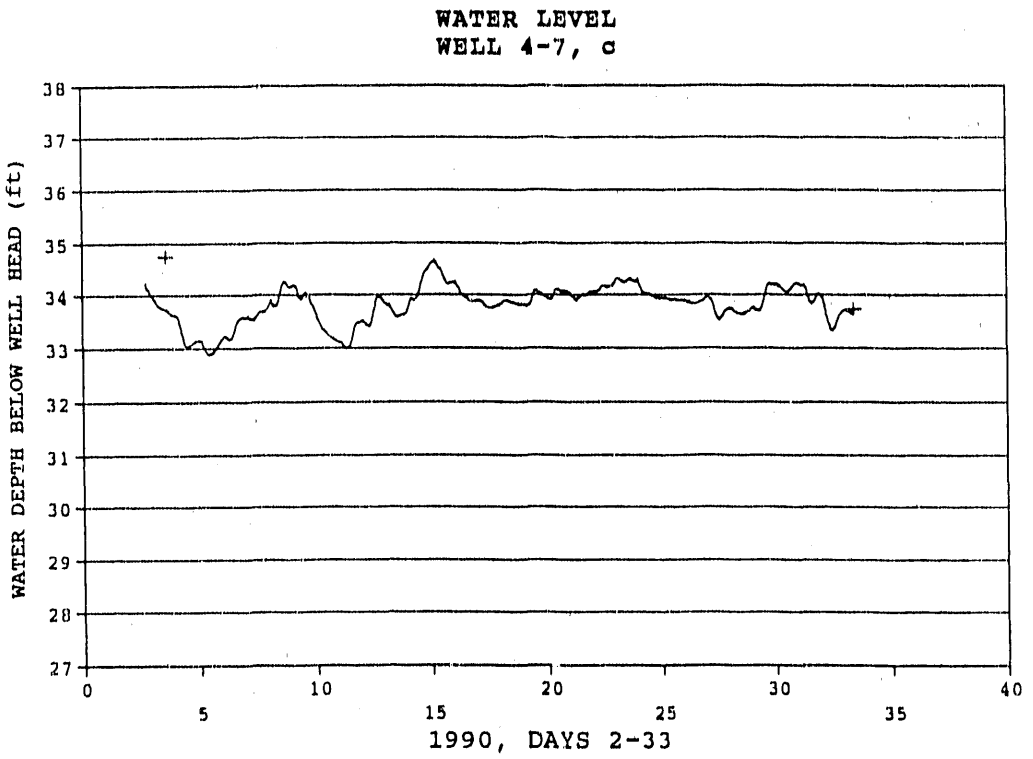
WATER LEVEL
WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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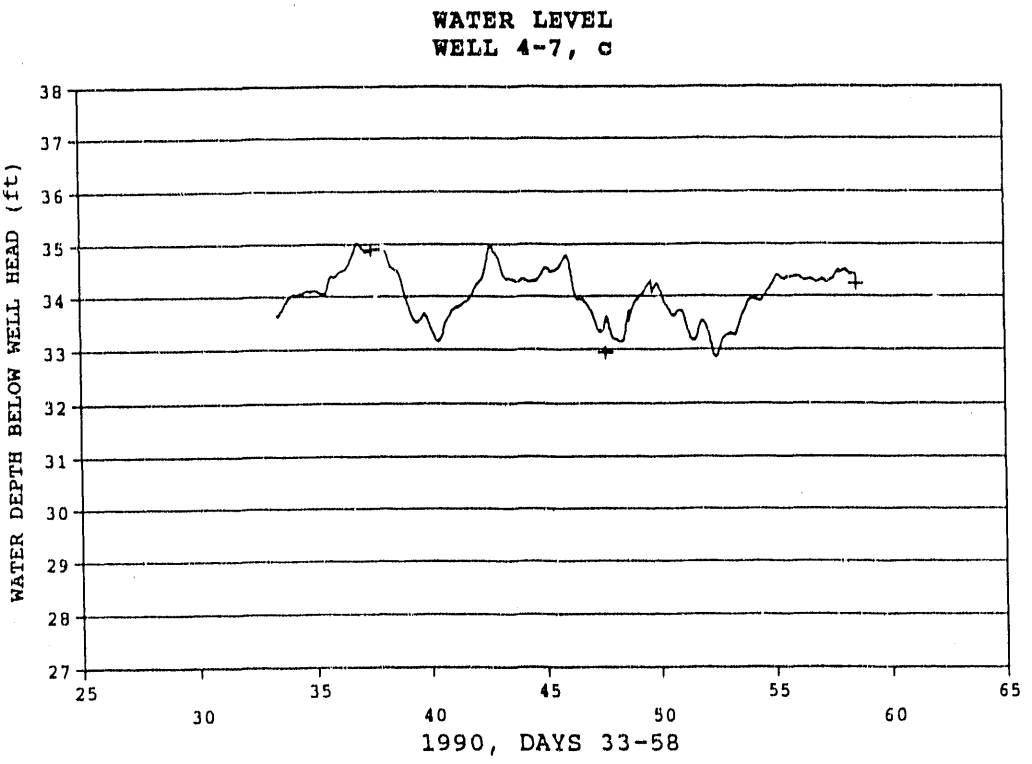
1990, DAYS 2-33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WATER DEPTH BELOW WELL HEAD (ft)
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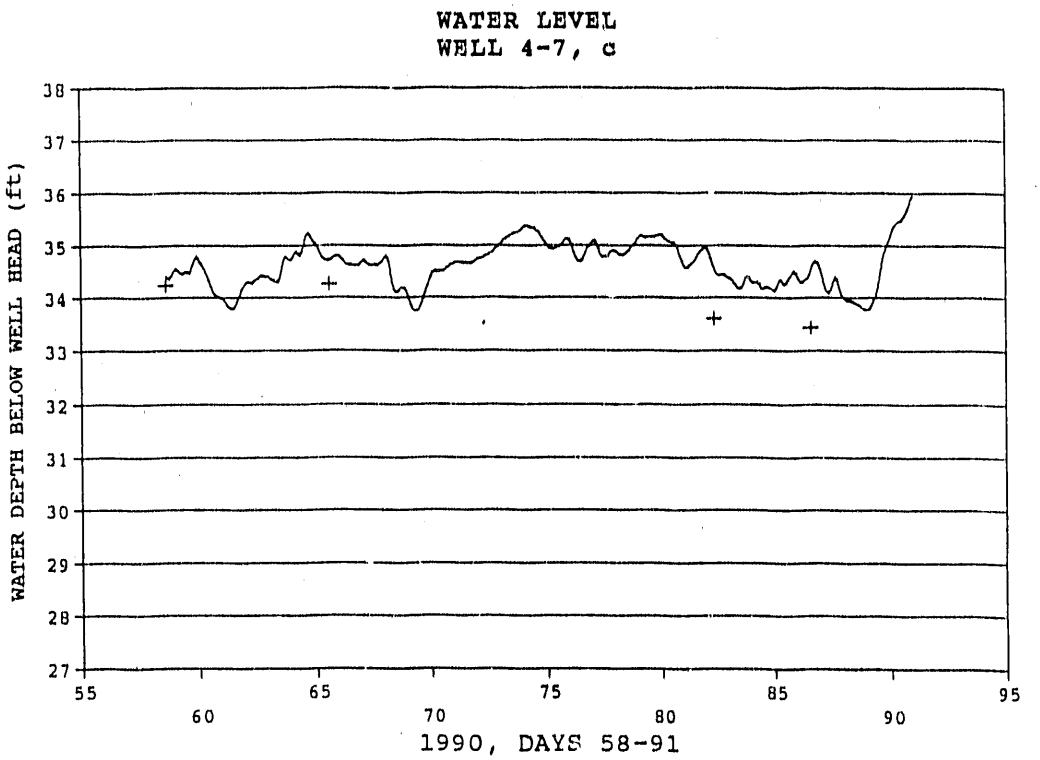
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WELL 4-7, c
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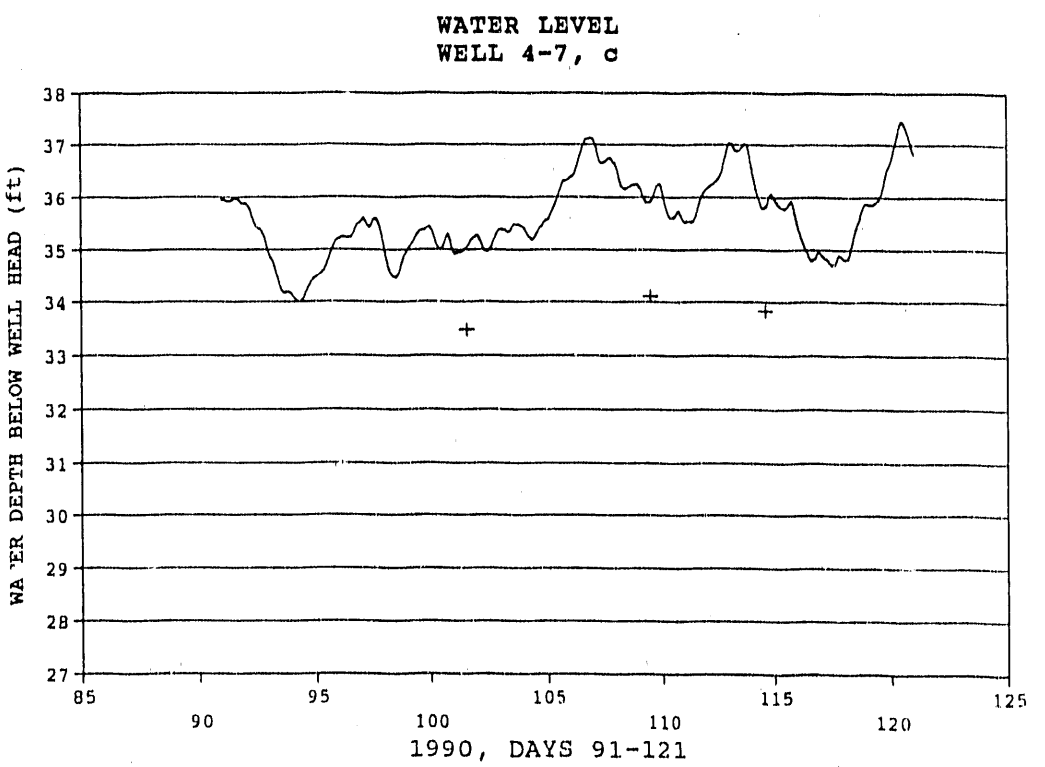
WATER LEVEL
WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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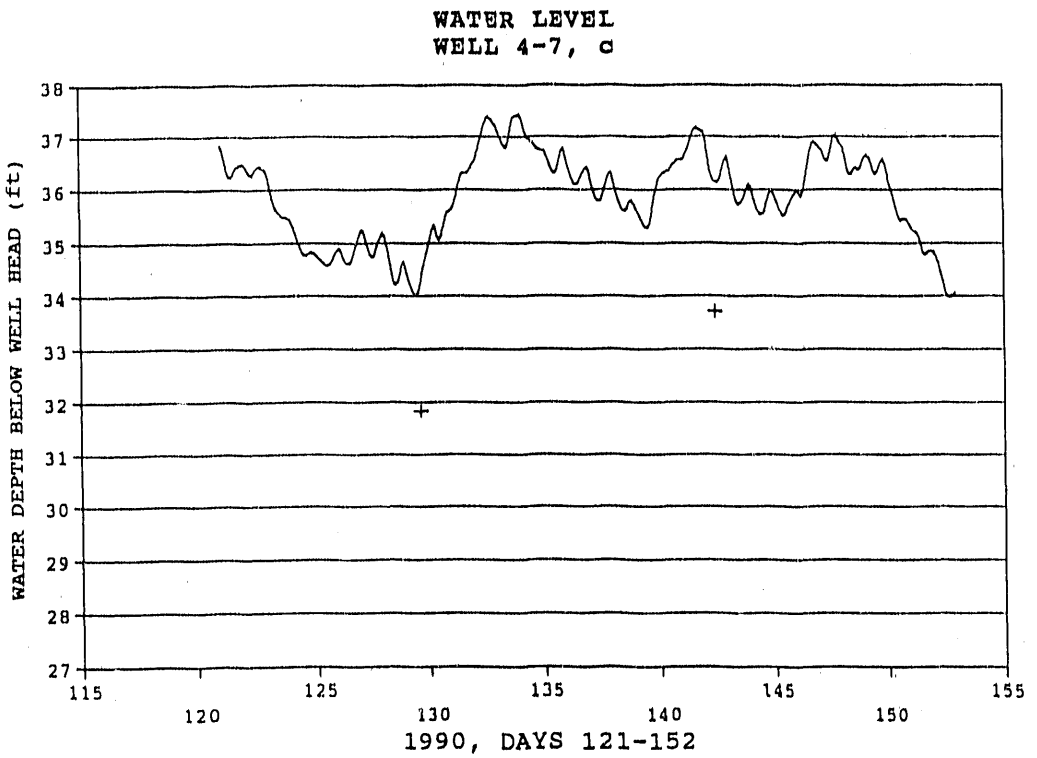
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WATER DEPTH BELOW WELL HEAD (ft)
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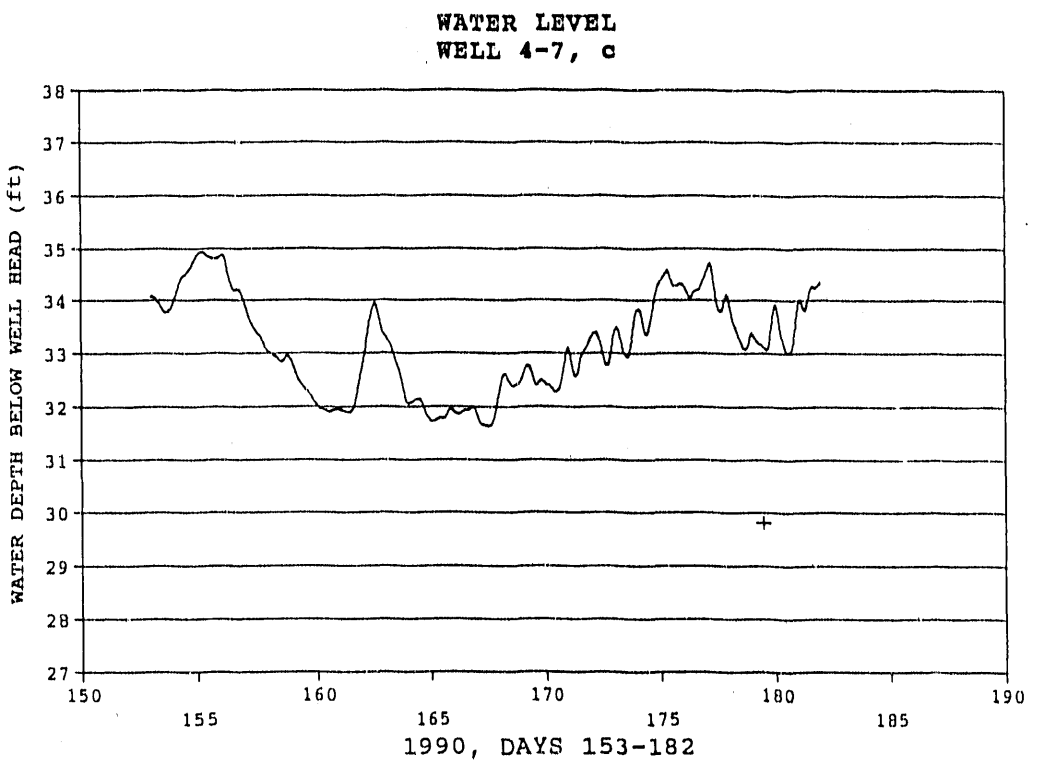
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WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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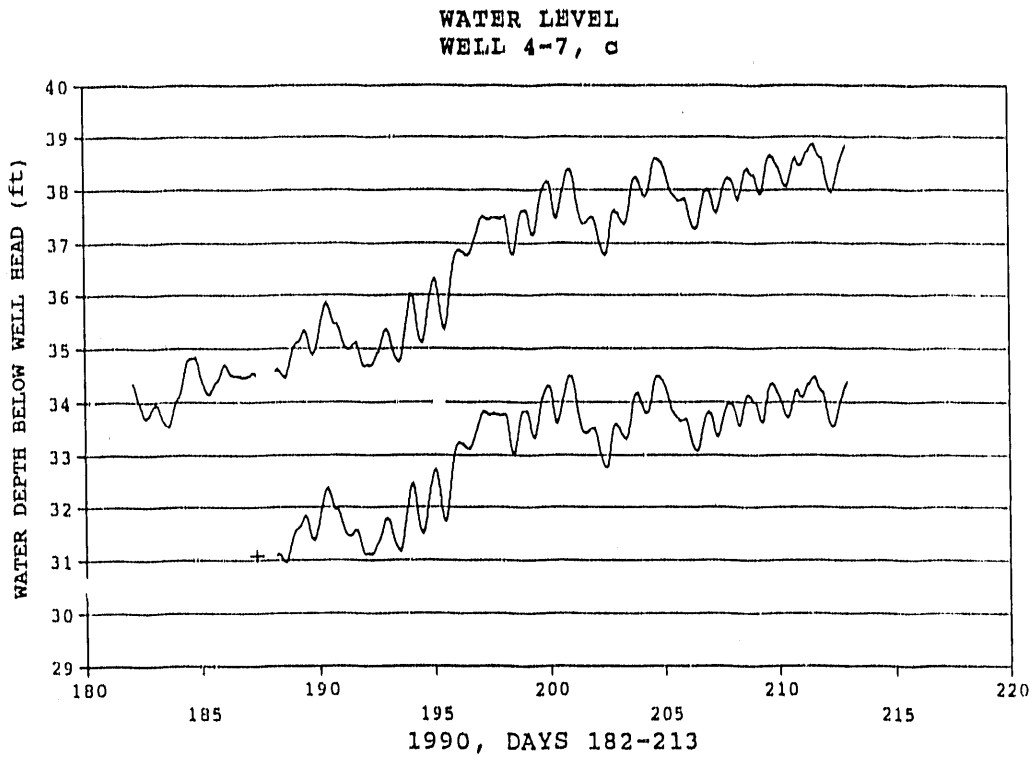
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WELL 4-7, c
WATER DEPTH BELOW WELL HEAD (ft)
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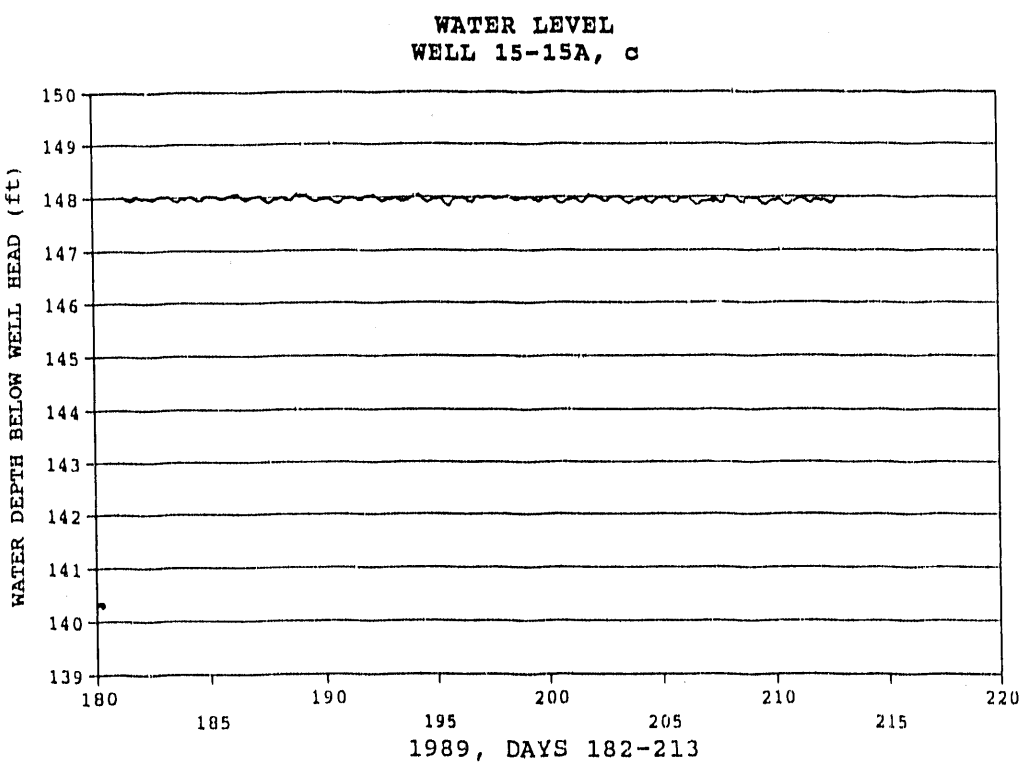
WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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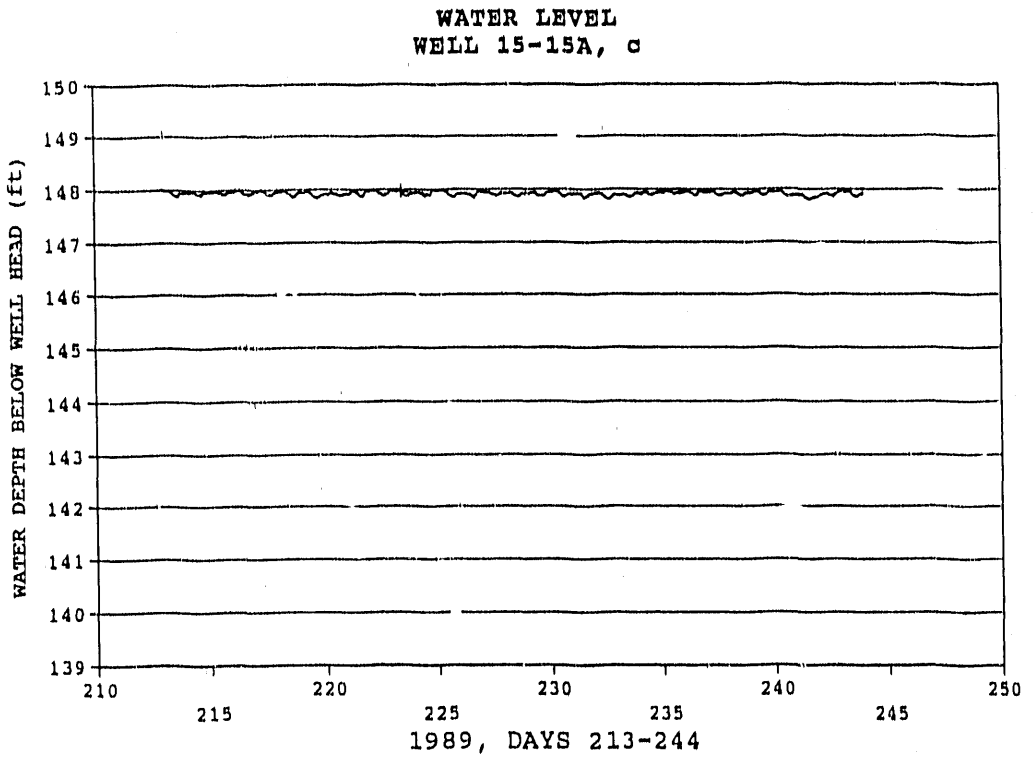
1989, DAYS 182-213


WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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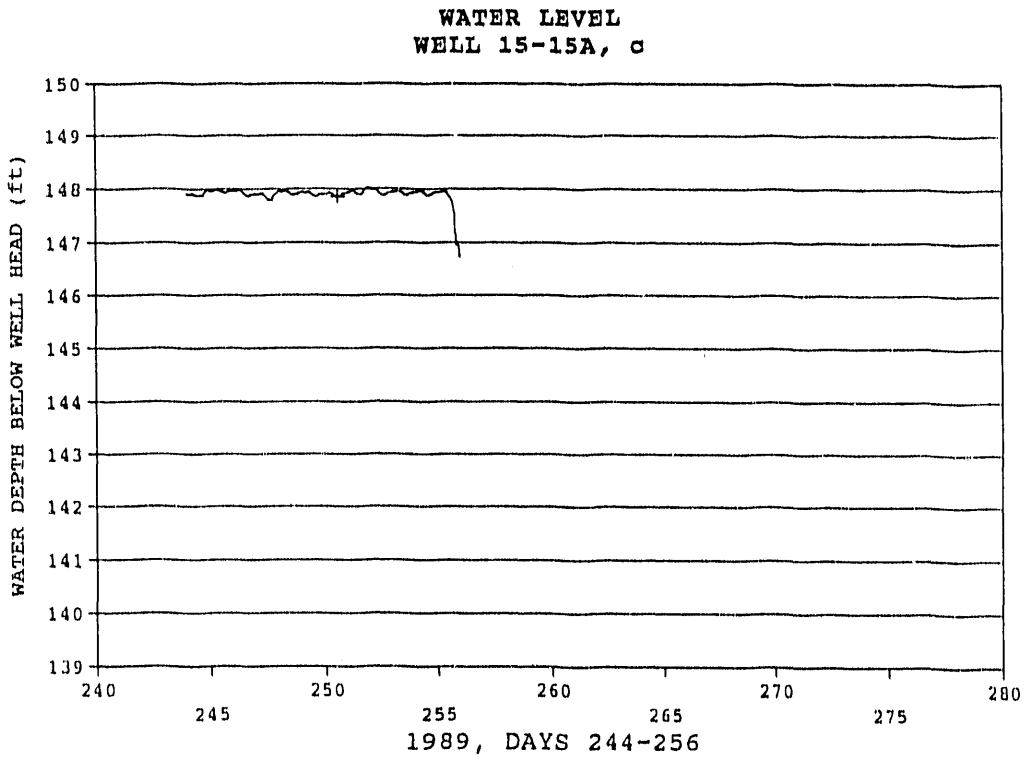
1989, DAYS 213-244


WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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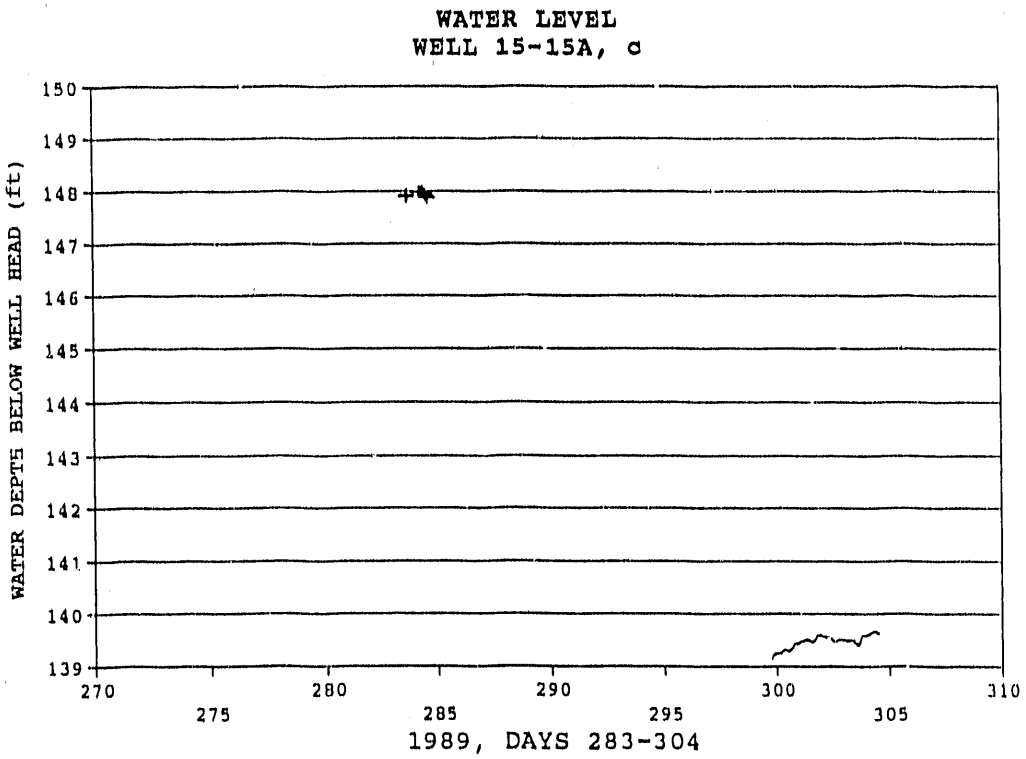
1989, DAYS 244-256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WELL 15-15A, c
WATER DEPTS BELOW WELL HEAD (ft)
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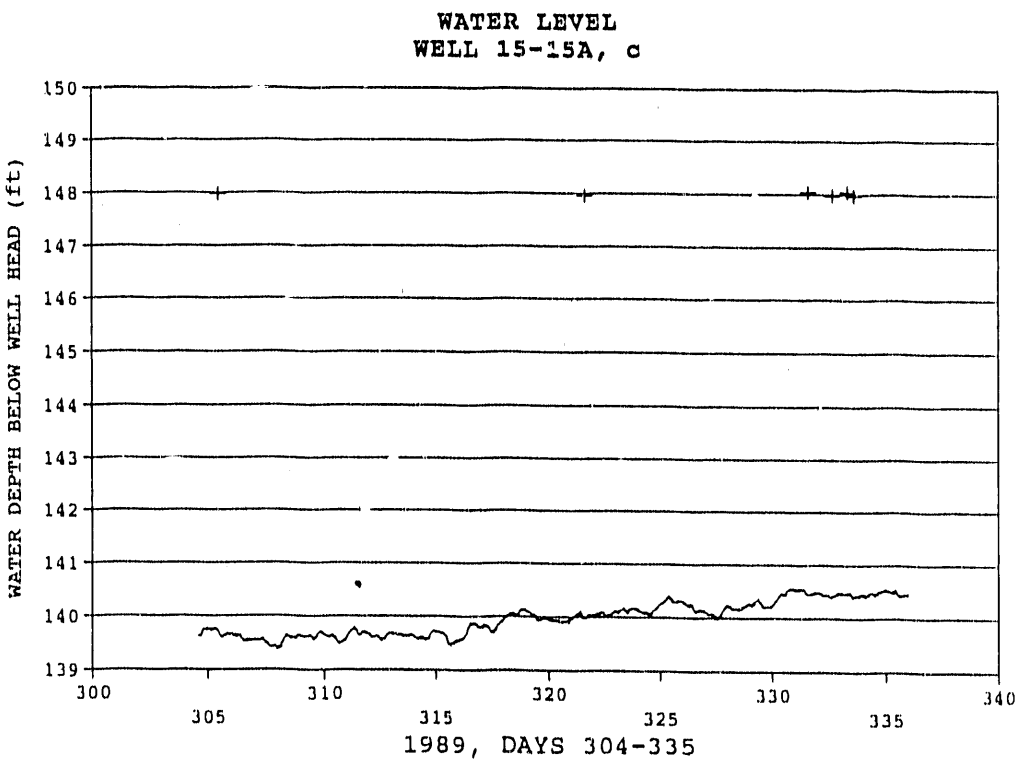
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WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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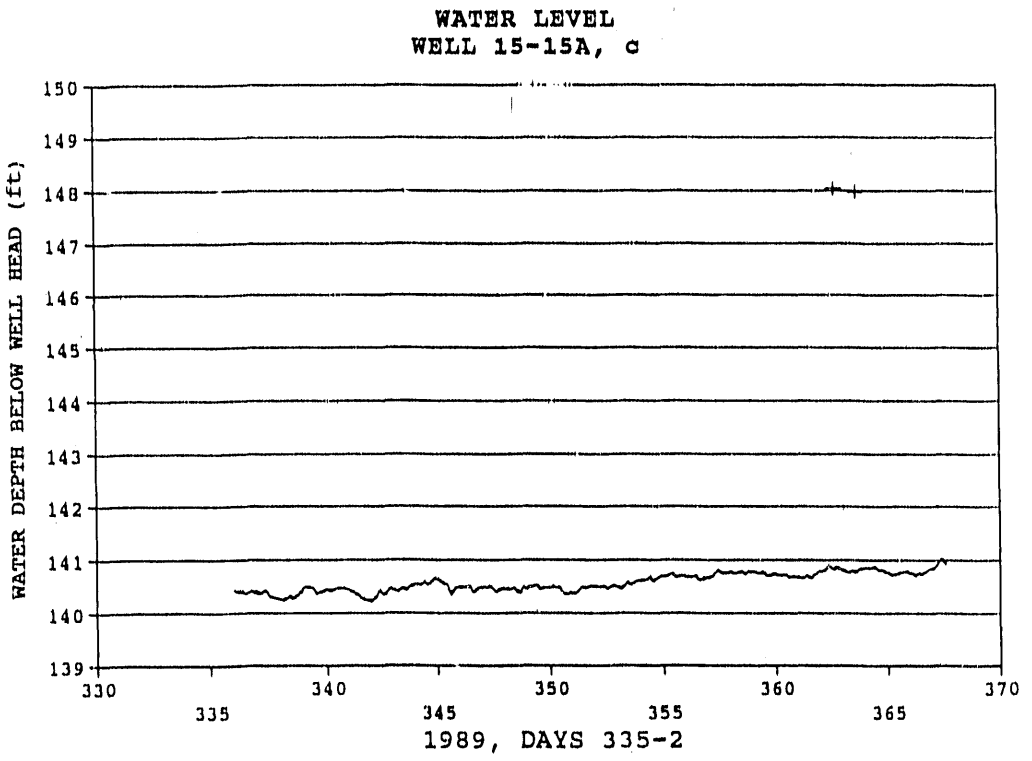
1989, DAYS 304-335


WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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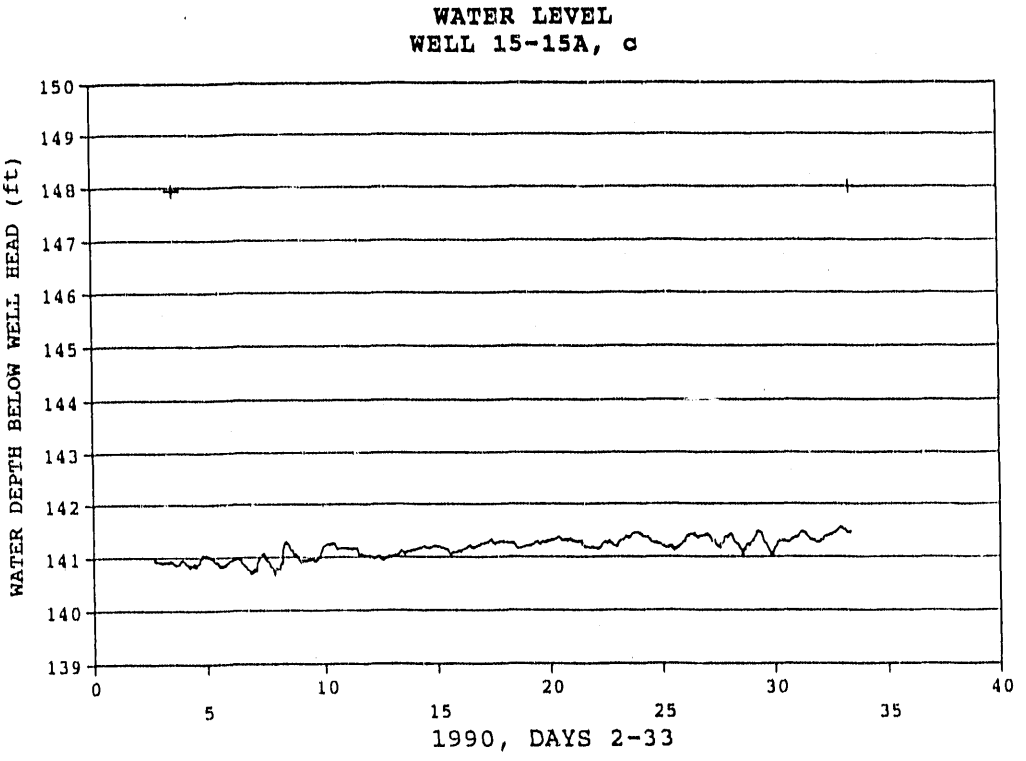
365
370
1989, DAYS 335-2


WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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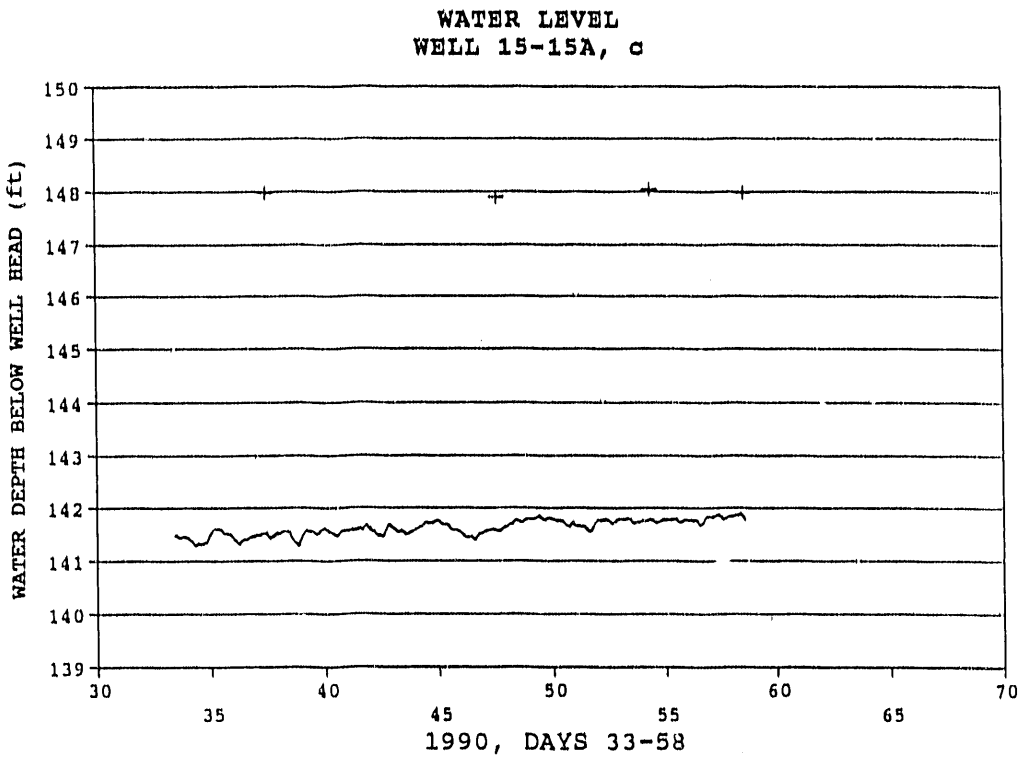
1990, DAYS 2-33


WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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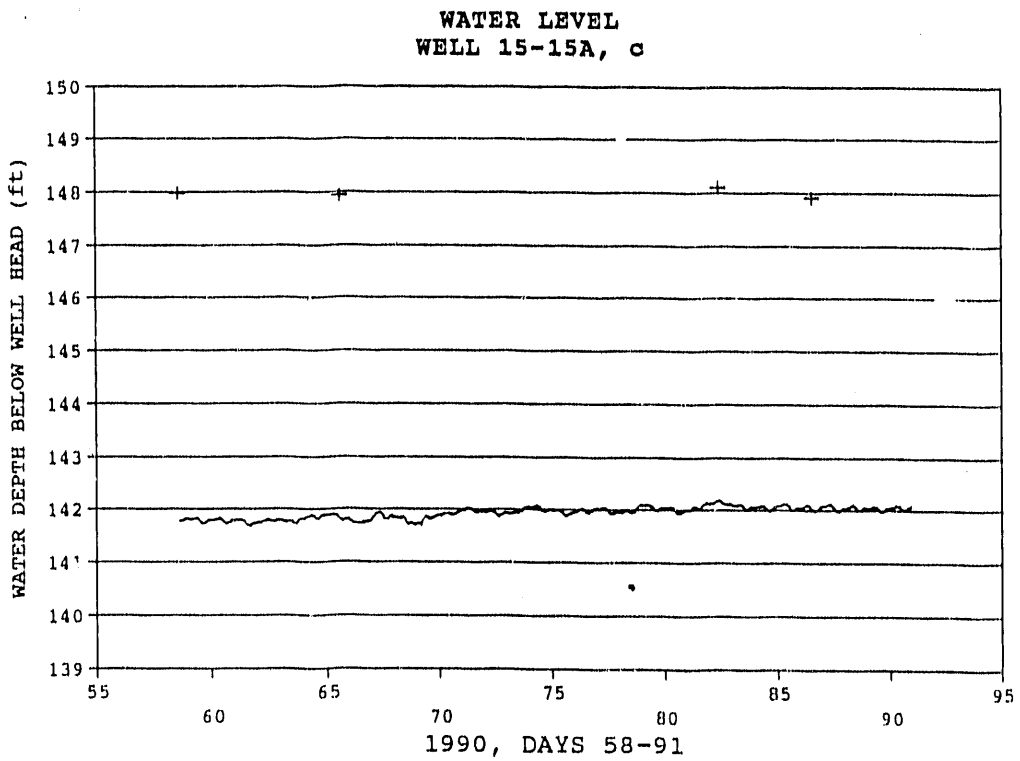
65
70
1990, DAYS 33-58


WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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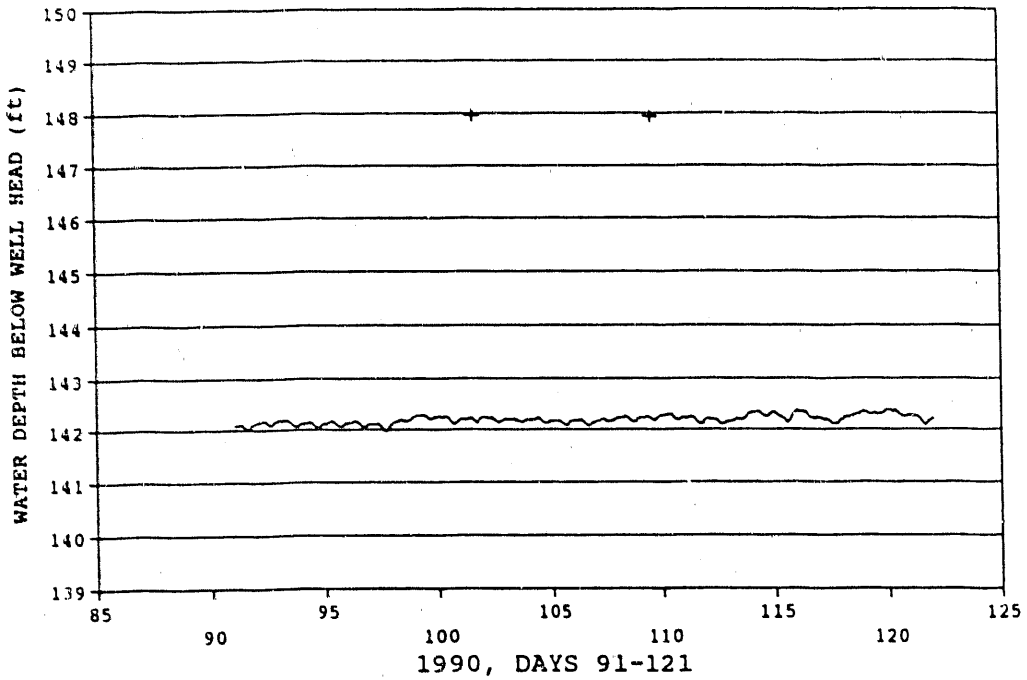
1990, DAYS 58-91

WATER LEVEL
WELL 15-15A, c



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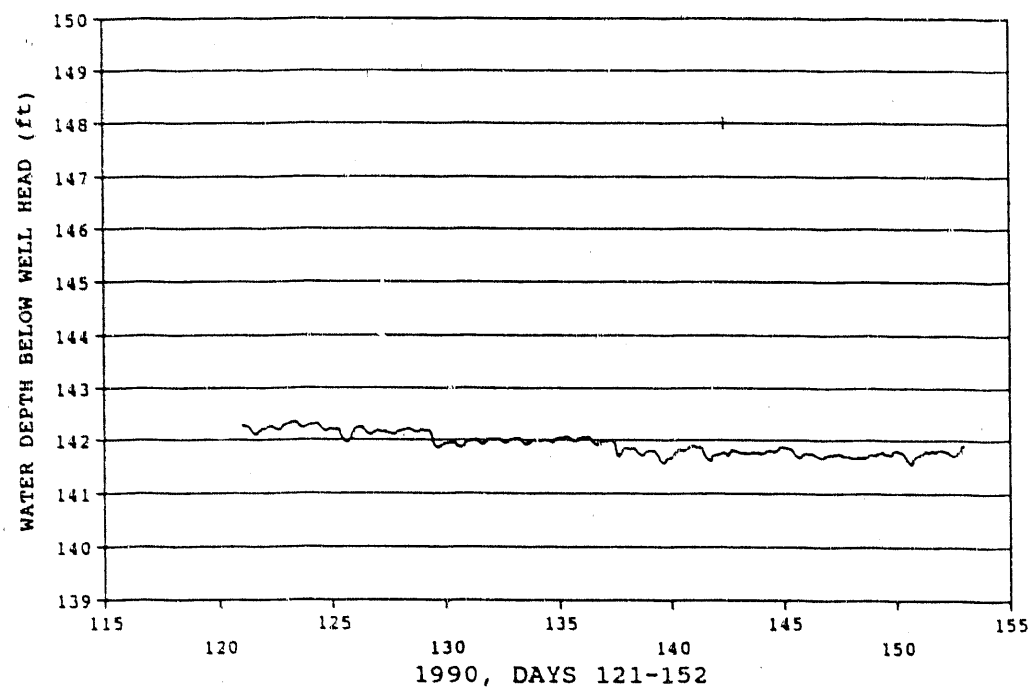
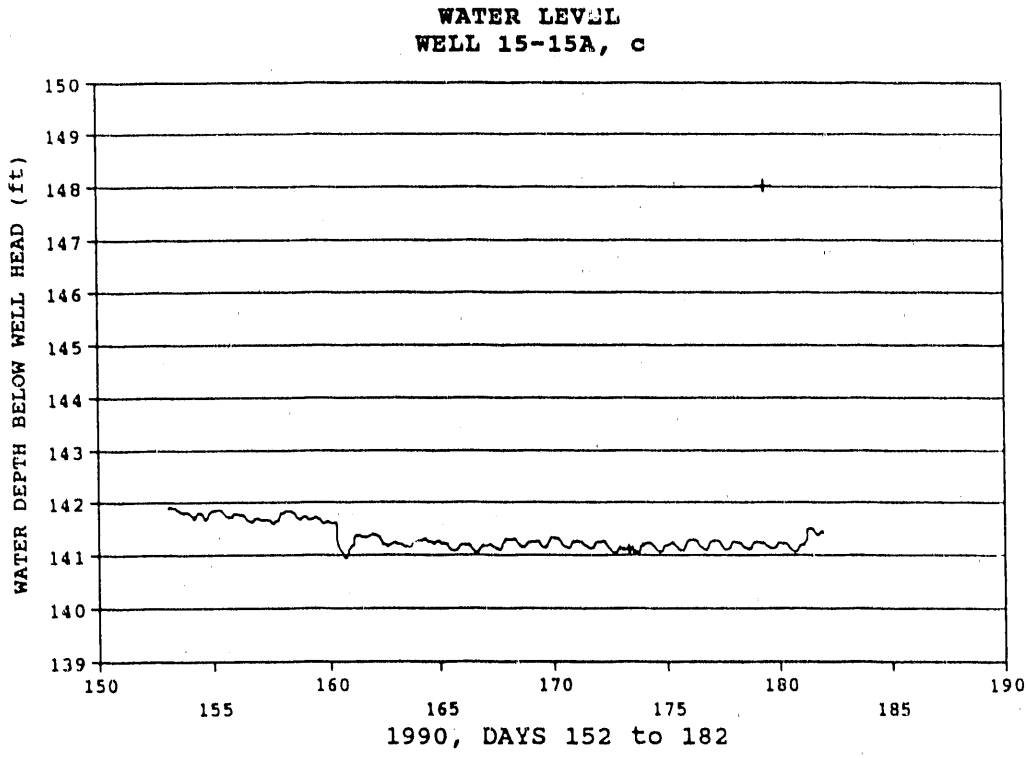
WELL 15-15A, c




WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
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148
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146
145
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155
160
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170
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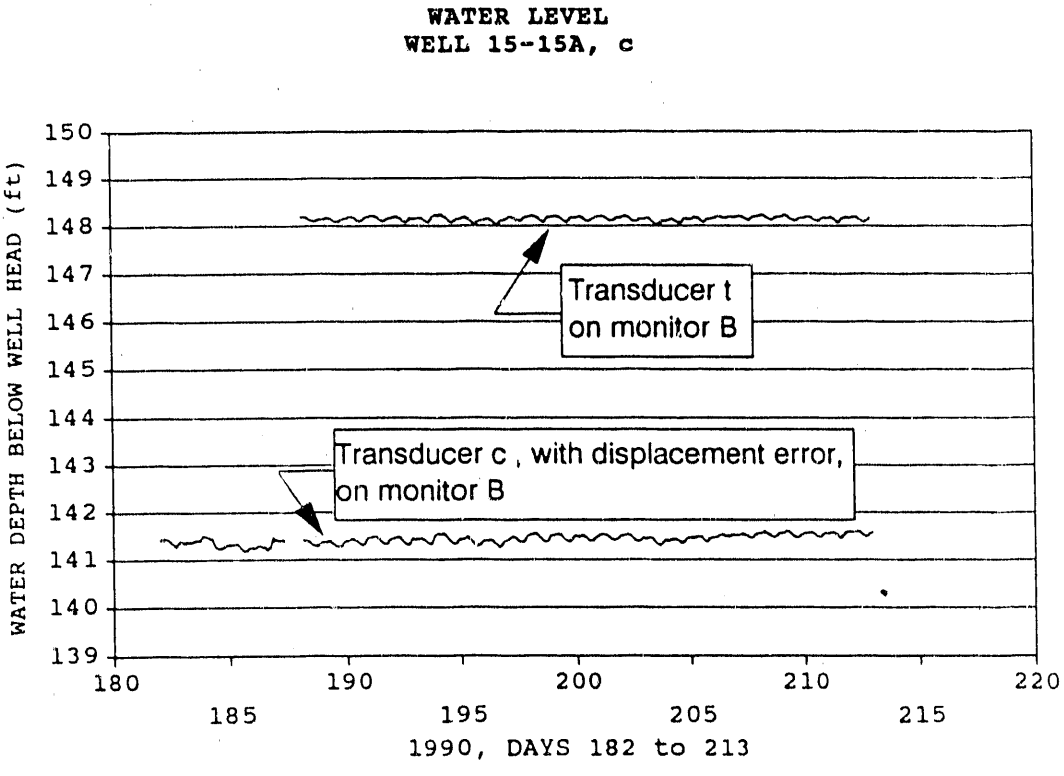
190
1990, DAYS 152 to 182


WATER LEVEL
WELL 15-15A, c
WATER DEPTH BELOW WELL HEAD (ft)
150
149
148
147
146
145
144
143
142
141
140
139
Transducer t
on monitor B
Transducer c , with displacement error,
on monitor B
180
185
190
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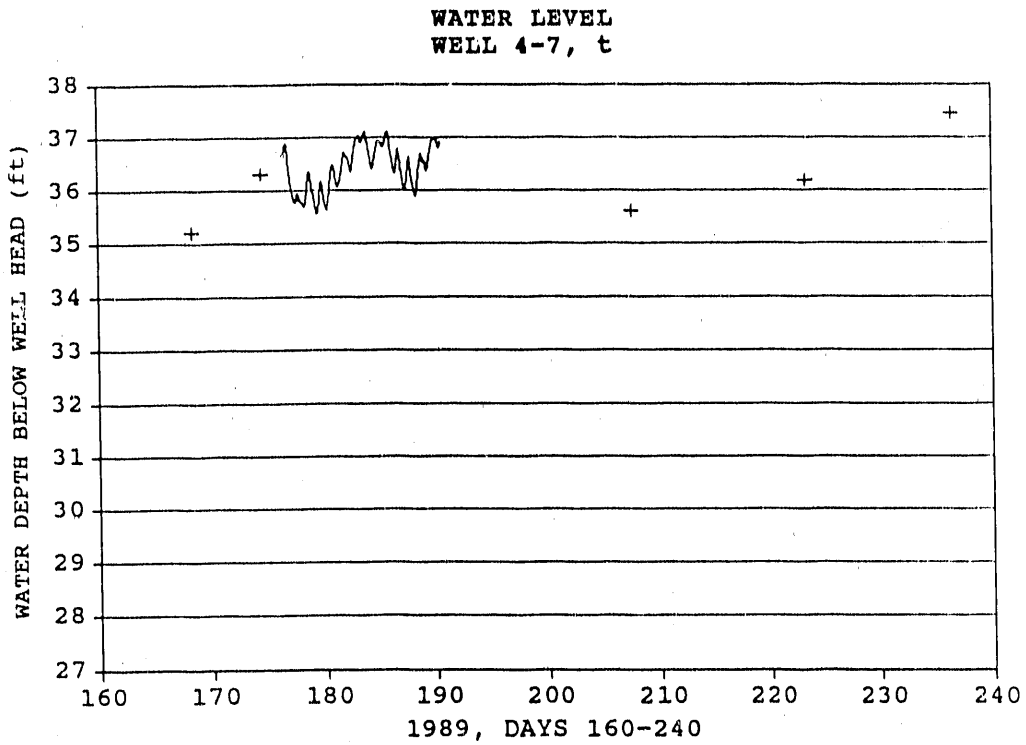
200
205
210
215
220
1990, DAYS 182 to 213


WATER LEVEL
WELL 4-7, t
WATER DEPTH BELOW WELL HEAD (ft)
38
37
36
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33
32
31
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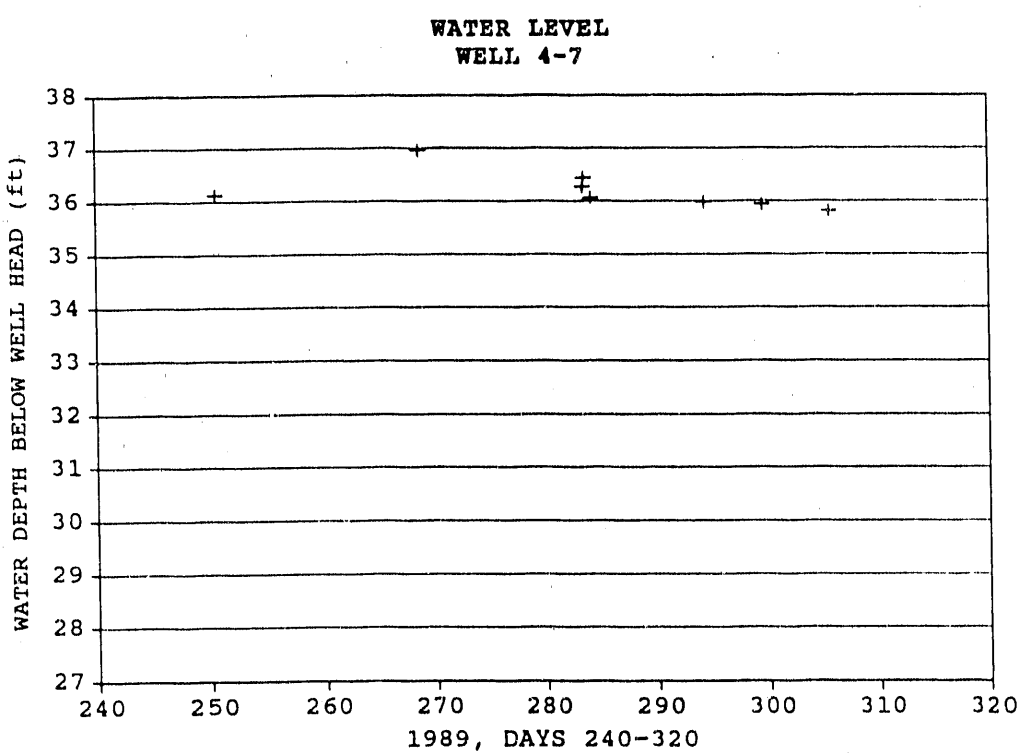
160
170
180
190
200
210
220
230
240
1989, DAYS 160-240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WELL 4-7
WATER DEPTH BELOW WELL HEAD (ft)
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310
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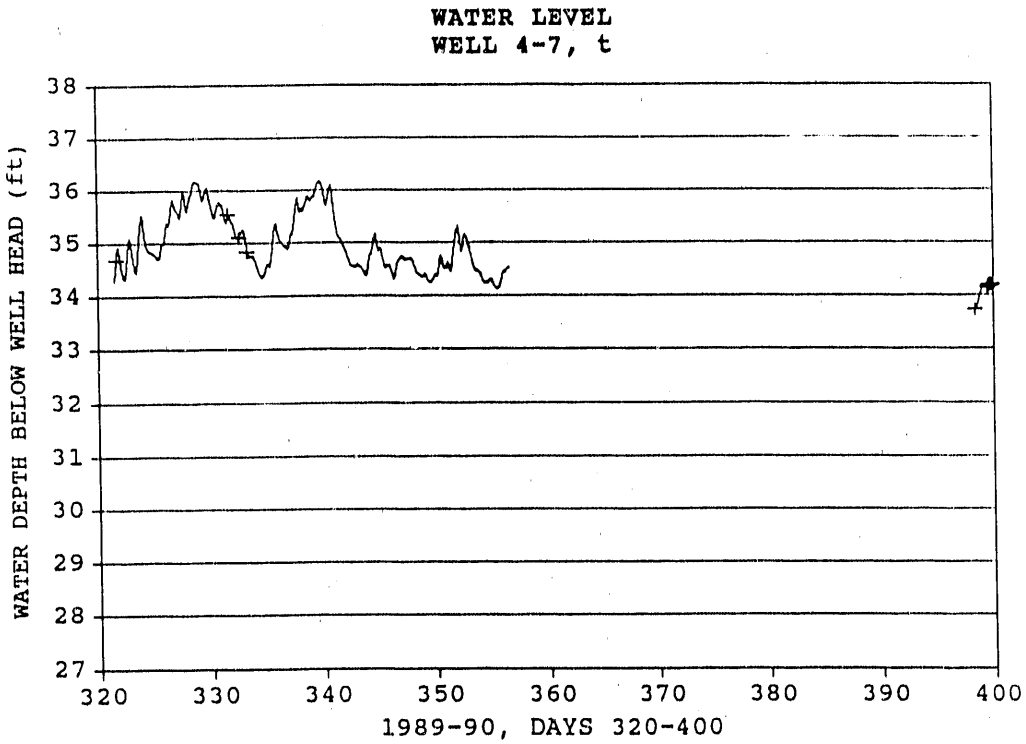
1989, DAYS 240-320


WATER LEVEL
WELL 4-7, t
WATER DEPTH BELOW WELL HEAD (ft)
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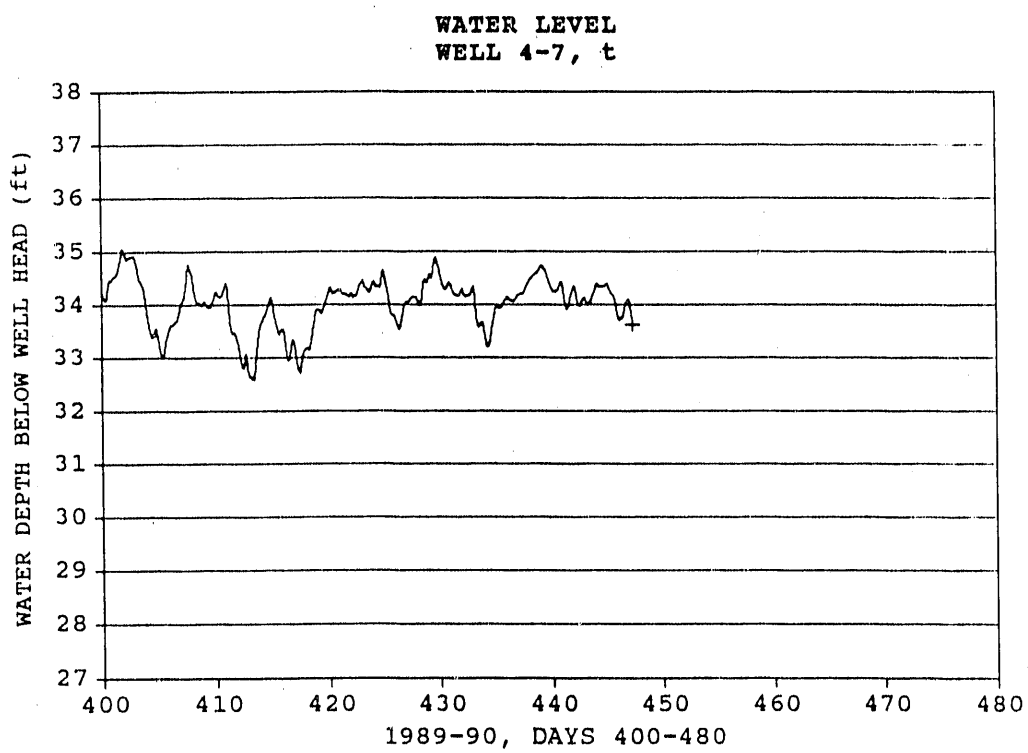
370
380
390
400
1989-90, DAYS 320-400


WATER LEVEL
WELL 4-7, t
WATER DEPTH BELOW WELL HEAD (ft)
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440
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460
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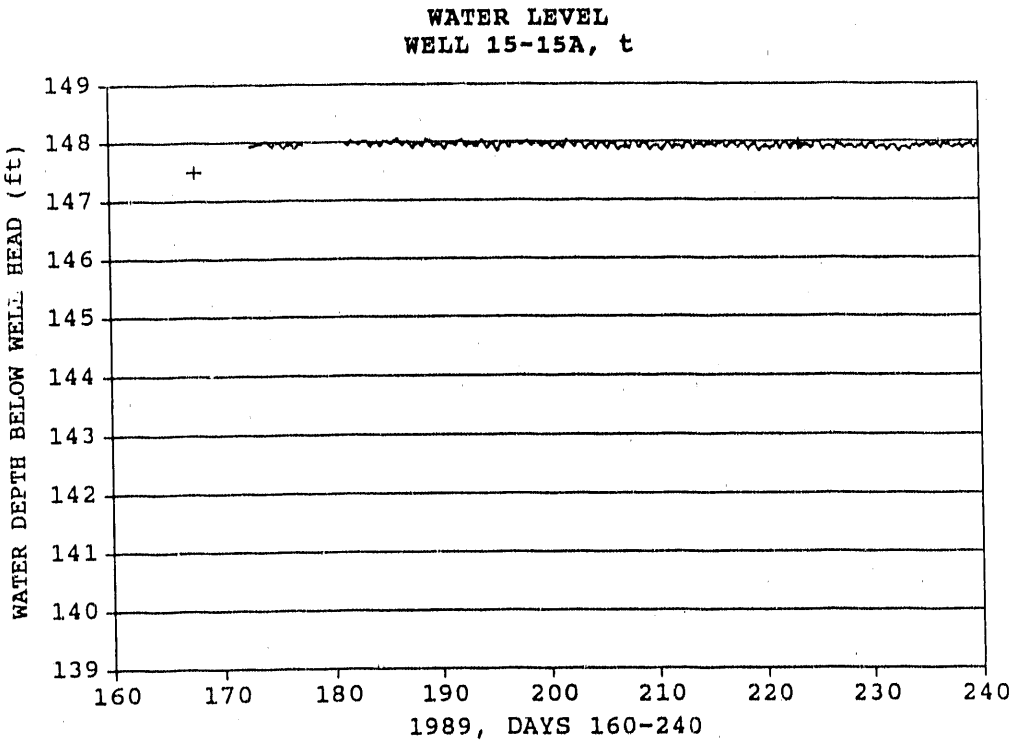
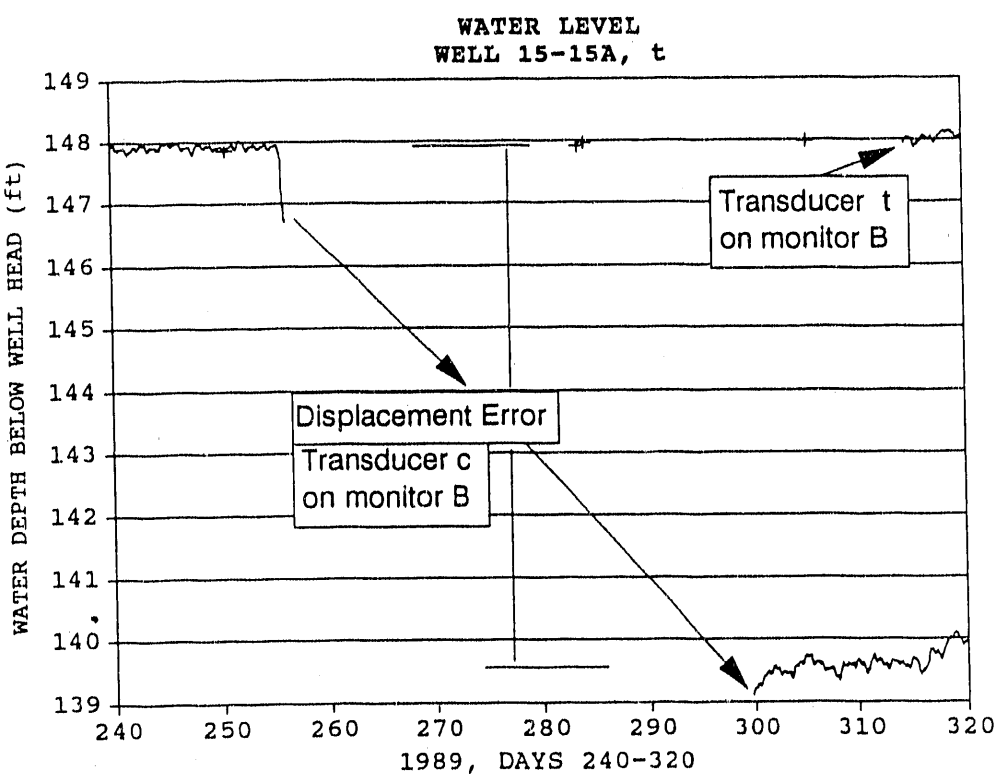
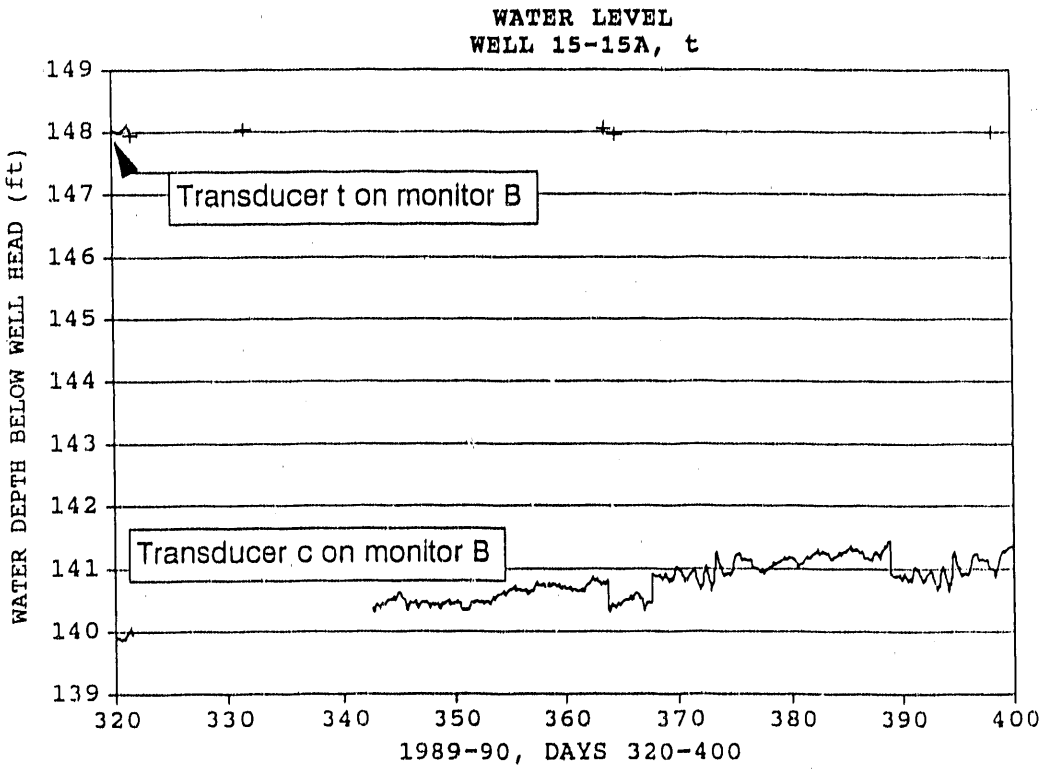
480
1989-90, DAYS 400-480


WATER LEVEL
WELL 15-15A, t
WATER DEPTH BELOW WELL HEAD (ft)
149
148
147
146
145
144
143
142
141
140
139
160
170
180
190
200
210
220
230
240
1989, DAYS 160-240


WATER LEVEL
WELL 15-15A, t
WATER DEPTH BELOW WELL HEAD (ft)
149
148
147
146
145
144
143
142
141
140
139
240
250
260
270
280
290
300
310
320
1989, DAYS 240-320
Transducer t
on monitor B
Displacement Error
Transducer c
on monitor B


WATER LEVEL
WELL 15-15A, t
WATER DEPTH BELOW WELL HEAD (ft)
149
148
147
146
145
144
143
142
141
140
139
Transducer t on monitor B
Transducer c on monitor B
320
330
340
350
360
370
380
390
400
1989-90, DAYS 320-400

END

DATE FILMED

12 / 18 / 90