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A Research Report for
Westinghouse Hanford Company

WATER LEVEL MEASUREMENTS FOR MODELING HYDRAULIC PROPERTIES IN THE 300-FF-5 AND 100 AGGREGATE AREA OPERABLE UNITS

M. D. Campbell
W. J. McMahon
K. R. Simpson

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Pacific Northwest Laboratory
Richland, Washington 99352

Summary

Pressure transducers connected to dataloggers were used to measure ground and river water elevations simultaneously and hourly at 35 locations in the 300-FF-5 Operable Unit and 16 locations in the 100 Aggregate Area Operable Unit on the Hanford Site. Water temperatures were also measured at 12 of these locations.

Absolute water level accuracy is uncertain but is believed to be within ±0.1 ft. Factors affecting accuracy include the quality of topographic surveys, instrument calibrations, and steel tape measurements. Measurement precision alone appears to be within ±0.02 ft, and probably better. Steel tape measurements are read within ±0.01 ft. Survey error is variable with distance from the reference, but likely less than ±0.07 ft. Periodic measurement system checks and calibration in situ helped ensure precision by including the entire measurement system in accounting for ambient physical conditions without instrument removal from the test site. Some of the data were used in the Ferris Model to estimate aquifer hydraulic properties and project relationships between river and well responses.

Based on data from the 300-FF-5 Operable Unit network, groundwater in the shallow unconfined aquifer apparently flowed toward the river until it entered a zone of much greater transmissivity. Hydraulic gradient attenuation resulted from the greater transmissivity of the zone, which apparently runs parallel to the river. An upward protrusion from the Ringold Formation, which bounds the channel and separates it from the river, impeded groundwater access to the river. The flow was thus redirected southeastward, exiting the 300-FF-5 Operable Unit.

Two factors that could influence the interpretation of the water flow behavior beneath the 300 Area are inter-aquifer communication and pumping. Inter-aquifer communication, either by means of natural fissures in the aquitards or because of faulty well drilling, completion, and/or sealing activities, could have resulted in leakage, according to the hydraulic gradient of potential. The leakage could cause local hydraulic mounding or depression. Thus, certain well water level measurements, impacted by the presence of a mound or depression, may lead to incorrect conclusions about the overall shape of the water table. Pumping could also produce local depressions, introducing the same sort of interpretive errors.

Graphic review of data confirmed its continuity and suggested relationships between measurement points. The automatic monitor system acquired data from the dynamic river/aquifer system simultaneously, frequently, and economically with a quality suitable for computer model calibration and testing, which fulfills the purpose of collecting the data.

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1.0 Introduction

Water elevation measurement was authorized under the 300-FF-5 Operable Unit Remedial Investigation/Feasibility Study (RI/FS) Work Plan (DOE/RL 89-14) and was initiated in FY 1991 and continued to present. Phase 1 Remedial Investigation Task 4C - Hydraulic Properties - called for measurements of aquifer and river water levels. Similar requirements were specified for the 100 Aggregate Area Operable Unit. These areas are shown in Figure 1.

1.1 Background

Hanford Site unconfined aquifer hydraulic properties and hydraulic head gradients control the rate of contaminant migration to the Columbia River. This task is to measure water elevations for computer model calibration and testing. When calibrated, the computer model can simulate interactions between the aquifer and the Columbia River and show possible consequences of remediation. To fulfill these requirements, the data must distinguish driving forces during water level fluctuations. The first problems to be addressed were 1) how frequently must water levels be measured to show hydraulic gradients acting on and in the aquifer, 2) how much resolution of amplitude is necessary, and 3) how frequently and where must water temperatures be measured.

Contaminant migration from the aquifer to the river and dilution of aquifer water by the river, as river water intrudes into the aquifer, depends on aquifer hydraulic properties, on the rate and magnitude of the water level changes, and to some degree on thermal gradients operating in the aquifer/river system. To measure these water level changes, Westinghouse Hanford Company (WHC) and Pacific Northwest Laboratory[a] (PNL) installed an automated monitor network on the Hanford Site. The network now monitors water levels at 51 locations and water temperatures at 12 locations hourly in the 300 and 100 Areas. Within the 300-FF-5 Operable Unit alone, simultaneous measurements of water levels at 34 wells and 1 river location are measured each hour to show rates and magnitudes of water level changes. Automated data collection was selected as the only feasible method of collecting the simultaneous data and the only economical method of satisfying the frequency requirement.

The monitor network now comprises 34 radiotransceivers and 30 automatic datalogging systems that collect and store the data for automatic retrieval by radio telemetry into a computer for storage and processing. The main computer is with the base station for the telemetry network, located at 740 Stevens Center in North Richland. A backup computer and base station are located in the Sigma 5 building.

(a) PNL is operated for the U.S. Department of Energy by Battelle Memorial Institute.

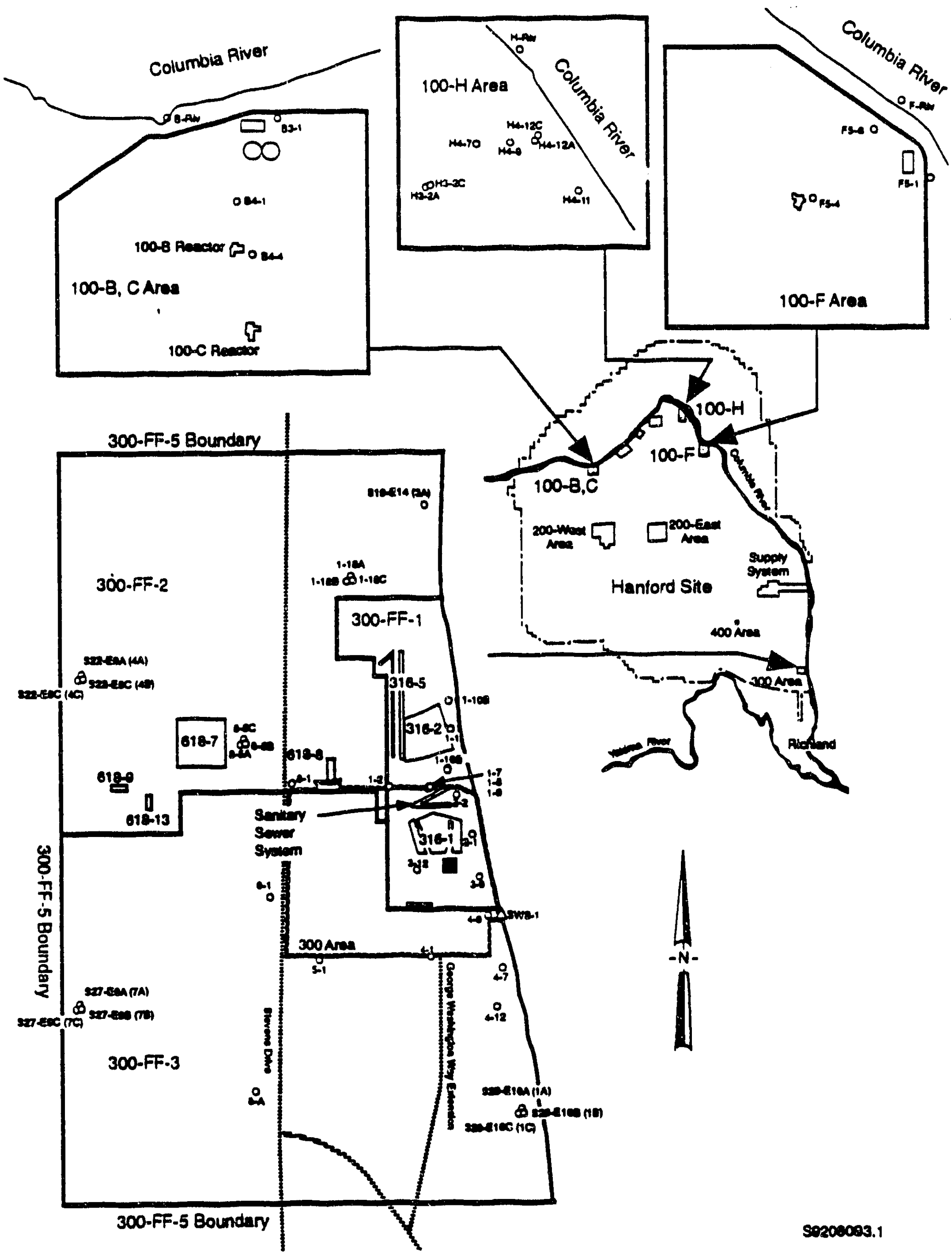

Figure 1. Network Monitor Station Locations

Network components were checked for conformance to specifications and tested or calibrated in the laboratory. Monitor stations were installed at wells and river locations identified by modelers as most likely to yield data required for calibration and testing of the computer mathematical models. Two types of models were to be used: 1) a river-normal wave propagation model and 2) a mass and thermal transport model.

1.2 Purposes and Data Requirements of This Project

Presented in this report are a summary of station installation, examples of data being collected, with graphs of water levels and temperature, a summary of data quality, and an interpretation of some of the data. All the data are for calibrating and testing computer models for use in waste site remediation alternative assessment.

Several remediation alternatives have been proposed for contaminated sites within the 300-FF-5 and 100 Aggregate Area Operable Units. These remediation alternatives may be evaluated through use of computer models. Aquifer performance assessment by computer models requires careful calibration of the models using site-specific data. Subsequent data may then be used for model validation. Providing these two data sets for computer calibration and validation is the purpose of this project.

Two types of data are required: 1) water elevations in several wells and river locations, and 2) temperatures in the river and in wells aligned parallel and normal to the river. The water elevations provide the basis for constructing flow nets and hydraulic gradients. The temperatures reveal to some degree the interactions between the river and the connected aquifer. Both mass and heat transfer are included in the PORFLO-3 Model (Runchal and Sagar 1989), while the Ferris Model (Ferris 1952) uses only the water elevations.

Some computer models impose more stringent requirements than others on certain aspects of the data. The Ferris Model, for example, assumes that the geologic media are porous and uniform, that the aquifer is normal to river, that the water-surface and pressure drops are immediate and proportional, and that flow is one-dimensional and fully penetrating into the aquifer. If these assumptions were reasonably met in the aquifer being monitored, then water elevation changes as small as 0.001 ft could be required to define wave propagation distances with an accuracy of 100 ft. While this magnitude is measurable, the hourly measurements selected to capture wave crests could not reliably identify the time of wave front passage.

While the Ferris Model assumptions may not be met in the Hanford aquifer, the model is nevertheless useful in discovering needed measurement precision; and it may be helpful in understanding aquifer/river interactions, as discussed later. There is no data requirement specifying accuracy or frequency, but accuracy of model output is limited to the accuracy of the measured data. The hourly data frequency mentioned previously appears to be adequate to define significant water level fluctuations, although it may not capture wave front propagation through the aquifer.

The PORFLO-3 Model assumes that fluids are incompressible, that gas and liquid flow are independent, that hydraulics are non-hysteretic, that the matrix is rigid and porous, and that solute does not affect water flow. However, none of this nor any other information revealed the model's requirements for accuracy or frequency. Modelers at WHC estimated that water elevations accurate within ±0.1 ft would be adequate for this model and that hourly frequency would be useful for model testing. Daily average values would be needed for calibration, extending over an annual cycle. Apparently, both frequency and accuracy of water level measurements are adequate to meet such model requirements.

The most recently monitored wells have at least 5 months of data in the database to calibrate the models. Up to 18 months of data are available from the first eight wells monitored. The remaining well and river stage measurements range between these two extremes.

1.3 Structure of this Report

Materials and methods are presented with enough detail to repeat the work if necessary. The structure and installation of monitor stations are discussed, with details about the component position and arrangement. Field quality tests and calibration are discussed next, followed by descriptions of water level and temperature data collected and model requirements. Data quality tests are discussed, with enough review of model characteristics to understand the significance of measurement frequency and precision. Finally, results of tests and measurements and their significance and uses are presented and discussed, and conclusions are presented.

2.0 Materials and Methods

Automated water level monitor stations comprise one pressure transducer for each water level measured by a station, a datalogger, a radio frequency (RF) modem, a frequency modulated (FM) radio transceiver with antenna and connecting cables, a power supply consisting of one large and one small lead-acid battery with a solar panel recharging unit, and a tripod to support the antenna and other components.

Data are recovered by a base station that comprises a computer linked through an RF modem to an FM radio transceiver with a roof-mounted, omnidirectional antenna. Two repeater stations are required for the Hanford Site: one atop the highest building in the 300 Area, the other on the east end of Gable Butte.

2.1 Station Installation and Calibration

Twenty-three stations were installed in the 300-FF-5 Operable Unit. These 23 stations monitor 34 wells and 1 river location, with 25 of the wells brought on line since the beginning of FY 1992. The other stations were installed between June and October of 1991. Fifteen stations were installed in the 100 Aggregate Area Operable Unit, equipped as were the stations in the 300 Area (See Appendix A for Well Identification). Eleven stations monitor wells; one station monitors a river seep; and three stations monitor river water levels in the 100-B, -H, and -F Areas. Ten of the 15 stations were installed during September 1991. The B-River station was installed during February 1992. The other four stations were installed since October 1992.

2.1.1 Monitor Installation

Each monitor system was mounted on a mast that was fastened to either a well post or a tripod near the well site or river, as shown in Figure 2.

The masts were either 5 or 10 ft long. The 5-ft mast was used for the tripod; the 10-ft mast was used with the well post. A coaxial cable was attached to the antenna, and the antenna was clamped to the 1-1/4-in. galvanized pipe mast. A copper ground cable and rod were installed near, and attached to, each antenna mast pipe. The mast was clamped to the well post. A weather shelter was clamped onto the mast with the door facing north. The solar panel was clamped onto the mast opposite the weather enclosure, facing south at an inclined angle of 23° above the horizon, to present a normal face to the winter sun. The large battery box was clamped onto the mast with the top about 6 in. below the weather shelter. An electrical cable was connected between the large battery and the power panel inside the weather enclosure. The antenna coaxial cable was inserted into the weather shelter and attached to the radio.

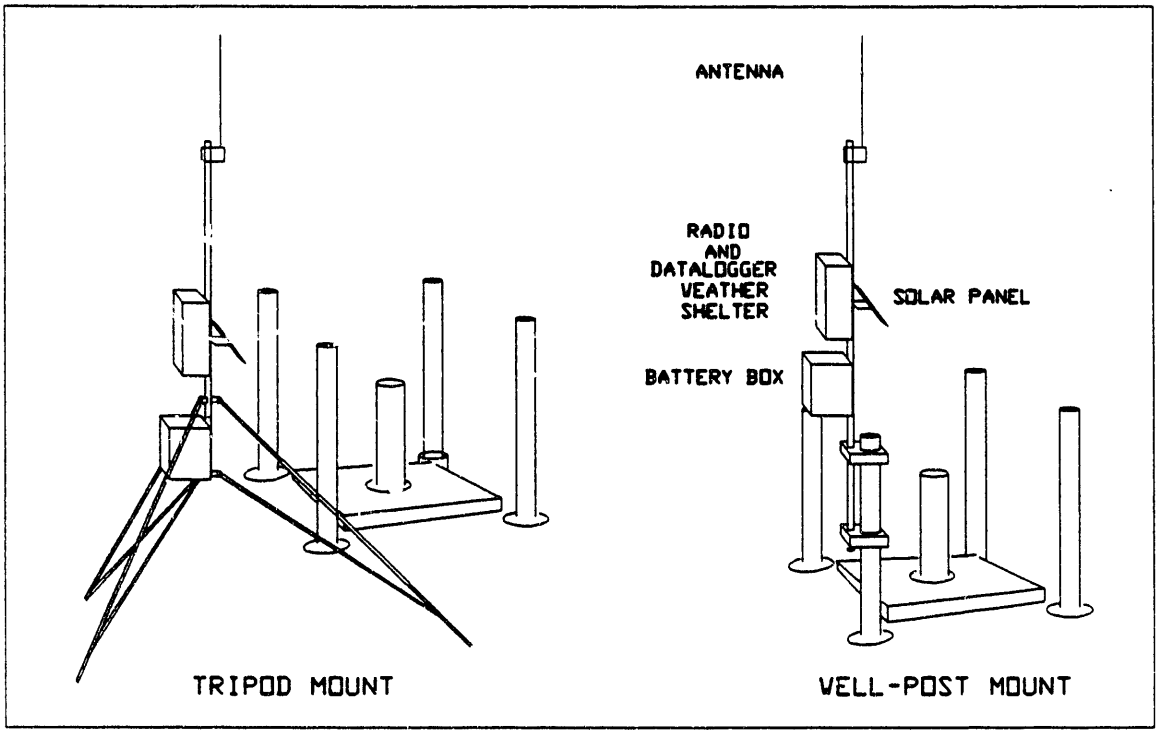

Figure 2. Two Types of Station Installations

2.1.2 Transducer Installation

Because wells within the 300-FF-5 Operable Unit were sampled for water quality, special cleaning and handling of all components placed inside each well were required. A mounting bracket was installed in each well about 1 ft below the top of casing (ToC). A short length (2 to 10 ft) of 3/8-in. pipe was fastened to a 3/8 x 1-in. reducer to form an in situ calibrator, as shown in Figure 3.

The transducer cable was inserted in and drawn through the 3/8-in. pipe and through a compression fitting and lowered into the water. The cable was then drawn through another compression fitting in the well casing, mounted about 18 in. below ToC, and connected to the datalogger. The datalogger was turned on and programmed, using the program found in Appendix B of this report. With the datalogger set on a 5-s scan interval, the transducer was adjusted in the water until the desired reading appeared on the datalogger display. The free compression fitting on top of the in situ calibrator was then secured to the cable to support the transducer. The cable was adjusted to allow about 1 ft free vertical movement of the short pipe, with the cable looped downward to exit the well casing through the other compression fitting. The cable was then secured in the exit fitting. A steel tape reading of water level from the ToC was recorded, along with the average of six datalogger readings taken at the same time.

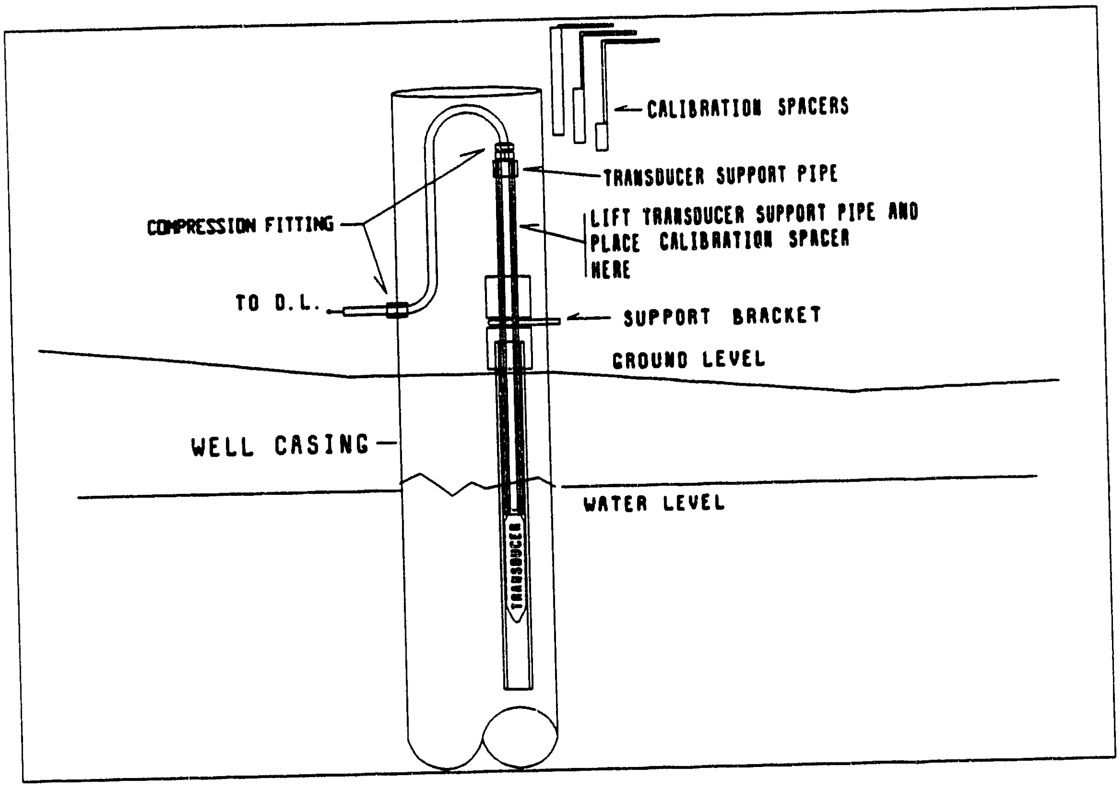

Figure 3. In Situ Calibrator for Pressure Transducers

Each field station serves one to three wells or a river station. Periodic field tests helped assure data continuity and quality. Three processes were used: 1) simultaneous steel tape and datalogger measurements were made; 2) battery voltages were recorded as evidence of adequate power supply to avoid failure; and 3) measurement systems were calibrated in situ.

2.1.3 Paired Tape and Datalogger Readings

Well water levels below ToC were measured monthly using a calibrated steel tape, while simultaneously recording an average of six datalogger measurements. Steel tape readings were duplicated whenever paired reading sets disagreed with previous paired reading sets. Battery voltages were also measured monthly to detect potential power supply failures without data loss.

2.1.4 Transducer In Situ Calibration

The in situ calibrator has a transducer suspended from it, as shown in Figure 3. The calibrator facilitates system recalibration without removing the transducer from the well or disconnecting the datalogger. The transducer is submerged 1 to 5 ft in the water, with the cable extending up inside the well, through the top of the in situ calibrator, and out through the side of the well casing to the datalogger. The cable has a small loop just inside the well casing to permit a vertical displacement of the transducer for inserting a calibrated standard spacer during in situ calibration.

Calibration is presented and discussed in detail by Campbell and Newcomer (1992) and is only briefly summarized here. Calibration requires about 4 min, with a datalogger scan interval of 3 s to provide a sufficient sample for valid data processing at the 1% confidence level. The two test positions were 1) the normal resting position before and after displacement, and 2) the vertically upward displaced position (using a standard spacer).

The purpose of calibration in situ was to obtain a calibration factor to relate the voltage ratio displayed by the datalogger to the change in water level without disconnecting or removing equipment from its operating position. The factor multiplied by a datalogger reading yields water depth. Once converted and appended properly to steel tape measurements, transducer readings may be converted to water elevations.

2.2 Data Requirements and Quality Assurance

Accurate and frequent data from one annual cycle are considered necessary for model calibration and preliminary model testing. The U.S. Environmental Protection Agency (EPA 1986) suggested ±0.01 ft accuracy for water level measurement. Accuracy depends on elevation survey and on datalogger and pressure transducer resolution. Measurement frequency must identify maximum and minimum water elevations within the shortest significant cycle. Measurements of Columbia River water fluctuations revealed significant cycles as short as 4 h, but daily cycles were more common. Hourly measurement frequency was selected because maximum and minimum water levels could be detected with a resolution of ±0.1 ft, which was also the resolution of the datalogger range.

In addition to detecting maximum and minimum water levels reliably, data frequency need depends on the mathematical models used and on whether they are for calibration or simulation testing. The Ferris Model, for example, requires readings frequent enough to capture maximum and minimum river stages, which the 1-h measurement does. However, the hourly measurement is not frequent enough to capture wave front passage at any given well. The modelers at WHC estimated that the PORFLO-3 Model may be adequately calibrated from daily average data extended over an annual cycle. Interest was expressed, however, in model test data of higher frequency. Apparently the hourly data frequency will be adequate.

Data quality was checked in four ways. All data were checked visually for consistency and continuity. Paired measurements made by steel tape and datalogger were compared over time to assess reading variations. Data with similar variations were paired and their ratio plotted to show discontinuities. Finally, where questionable values in data appeared, in situ calibration was done. Each of these will be described.

2.2.1 Visual Check of Data

Each week, data were downloaded from the datalogger to the computer, either by radio telemetry or by audio cassette tape recorder. In both cases, files were scrolled on the computer screen to check for data consistency and continuity. Data fluctuations were clearly apparent, as were data breaks. When very rapid changes occurred or when discontinuities were apparent, other tests were used to confirm data quality.

2.2.2 Paired Steel Tape and Datalogger Readings

A change in water level measured by steel tape should equal the change in datalogger readings multiplied by a calibration factor, according to the following equation.

$$T_1 - T_2 = f(DL_1 - DL_2) \qquad (1)$$

where T_1 and T_2 are steel tape readings 1 and 2, f is the calibration factor for the transducer, and DL_1 and DL_2 are datalogger readings 1 and 2. This test is done each month and when data are questionable.

2.2.3 Difference Tests

If proximate wells in a common aquifer are not being pumped, the difference in their water elevations remains nearly constant. When the difference becomes erratic, some monitor component failure may be indicated. Changes can easily be detected, either visually or by computer processing of data. If transducers or dataloggers fail to a significant degree, the difference test usually detects the consequent data deviation. Also, fluctuations about the mean value may be compared to detect transducer drift.

2.2.4 In Situ Calibration

Occasionally, data are disparate without apparent cause. When such data are found, field calibration may be done in situ. This in situ calibration process was fully described by Campbell and Newcomer (1992). This process yields a new calibration factor for the pressure transducer. Then, a simple data difference test, like the one described above, usually shows the point in the data stream where the new calibration factor should be applied.

2.3 Field Measurements

Thirty-five water levels and seven temperatures were recorded each hour in the 300-FF-5 Operable Unit. Fourteen water levels and eight temperatures were also recorded each hour in the 100 Aggregate Area Operable Unit.

2.3.1 Water Level Measurements

The water level measurements were recorded as volt ratios. Each datalogger reading consists of the following transducer voltages: [(output x 1000) / input]. The following equation is required to convert the datalogger reading into elevation relative to mean sea level (MSL) elevation:

$$E_{MSL} = E_{ToC} - T + (DL - DL_T) \times F \qquad (2)$$

where E_{MSL} = elevation relative to MSL
E_{ToC} = surveyed elevation at top of the well casing
T = steel tape measurement
DL = ambient datalogger reading
DL_T = datalogger reading taken with the tape reading
F = the calibration factor for the transducer.

All pressure transducer readings were preserved as volt ratios. Calibration factors were not stored with raw data. Raw data were preserved in computers in two separate locations, readily accessible for processing.

River and Aquifer Measurements

Resolution differed between river and aquifer measurements because of the wider datalogger range required by the larger river fluctuations, as shown in Table 1. The river changed as much as 8 ft/d, while aquifer water levels rarely varied as much as 3 ft/d. The large fluctuations in river stage required use of the least sensitive datalogger range to prevent overranging. Consequently, range 25 was selected for river stage measurements. This range has a precision of about ±0.1 ft.

While most well water levels fluctuated daily so little that the most sensitive datalogger range could be used, their annual water level fluctuation was large enough to require a less sensitive datalogger range. Therefore, sensitivity was sacrificed for data continuity. The transducers were installed about 1 ft below the expected annual minimum water level. Range 24 was selected to satisfy the ±0.01-ft resolution desired and yet accommodate the several feet of annual fluctuation common in the aquifers. These constraints resulted in transducer submergence 5 to 7 ft deep during some parts of the year and 0 to 1 ft deep during other parts of the year.

Measurement Range and Resolution

The datalogger resolves voltage changes as small as 0.33μv on its most sensitive range, which corresponds with 0.0001 ft of water elevation change. However, the most sensitive datalogger range cannot be used in the field because of water level fluctuation beyond its range. Both voltage and depth resolution are displayed in Table 1.

2.3.2 Temperature Measurements

Temperatures were measured by copper/constantan thermocouples enclosed in and electrically isolated from 1/4-in. stainless steel tubes. The 10-ft long tube was crimped to seal the bottom end. The thermocouple wire was inserted about 5 ft into the tube, and the top end of the tube was crimped to hold onto the thermocouple wire-mesh jacket. The top end of the tube was then wrapped with plastic tape to seal against moisture intrusion.

The tube with the thermocouple fastened in it was suspended in the water to a depth of 5 ft. The opposite end of the wire was threaded through an exit hole in the well casing and connected to the datalogger. The datalogger was programmed to measure temperature with a different input code to facilitate data sorting. River temperature was measured only at SWS-1, with similar equipment.

Table 1. Datalogger Range and System Resolution, Assuming Calibration Factor of 0.93 ft/volt-ratio

Range		Sensitivity	System Resolution
Code	(mv)	(mv)	(ft)
21	2.5	0.00033	0.0001
22	7.5	0.00100	0.0003
23	25.0	0.00333	0.0012
24	250.0	0.0333	0.012
25	2500.0	0.333	0.12

3.0 Results and Discussion

Examples of laboratory and field tests, measurements, and problems are presented and discussed in this section. Water levels and temperatures measured hourly captured high and low water elevations and water temperatures. Temperatures were measured parallel and normal to the river. Initial selection of the hourly measurement frequency was based on experience from measuring fluctuations at 15-min intervals in some sample wells over a period of years. The hourly measurement frequency, for groundwater modeling purposes, was based on the need to identify maximum and minimum water levels within ±0.01 ft when the wave period is 4 h.

3.1 Results from Initial Tests of Equipment

Laboratory test results from dataloggers and transducers revealed their general suitability for use in the field. Accuracy and precision were demonstrated for the intended mode of use. Component results are reported separately.

The datalogger tests demonstrated errors in each of the five ranges for the 20 dataloggers tested. Results are shown in Table 2. The number below each column approximates the equivalent error in feet of water represented by the largest datalogger deviation in the column. These data were taken as direct voltage readings and as such represent the worst-case error expected from any datalogger. In use, ratios of output-to-excitation voltages tend to reduce or eliminate error.

Initially, transducers functioned properly in both normal and over-range modes. Subsequently, 12 transducers failed. Ten of the failures apparently resulted from improper electrical contact between the transducer body and the electrical wiring. Figure 4 shows the transducer configuration and cause of failure. The other two transducers failed for reasons unknown. The manufacturer modified the design to correct the problem and repaired or replaced the faulty transducers. Many of the transducers used were outside manufacturer's specified tolerance because of hysteresis. Recalibration at the factory showed no observable problem with the four transducers they retested. However, they used compressed air where we used distilled water. Capillarity of water in the transducer access holes should be 0.017 ft. It thus appears that the medium of calibration may have been responsible for the unexpected variations.

Radio transceivers were checked, and two were adjusted. Antennas shipped initially were incorrect and had to be replaced. The RF modems were programmed with call identification that matched the station number. Other support equipment was acceptable and required only adjustment. When all adjustments were complete, stations were assembled, excluding transducers, and functionally tested by radio telemetry. All stations performed acceptably.

Table 2. Datalogger Calibration Showing Deviations in Millivolts for Five Ranges

Station Number	Range 21	Range 22	Range 23	Range 24	Range 25
106	0.0005	0.0024	0.0028	0.0195	-0.0551
107	0.0002	0.0005	-0.0011	0.0002	-0.1043
108	0.0001	0.0006	-0.0018	-0.0055	-0.0000
109	-0.0004	-0.0006	-0.0016	-0.0179	0.0376
110	0.0002	-0.0003	0.0007	-0.0052	0.0103
111	0.0001	0.0005	0.0019	0.0269	0.0024
112	0.0006	0.0020	0.0058	0.0415	0.0070
113	0.0004	0.0009	0.0030	0.0247	0.0402
114	0.0001	-0.0003	-0.0008	0.0001	-0.0145
115	-0.0001	-0.0002	0.0024	0.0085	0.0040
116	-0.0000	-0.0003	0.0005	0.0052	-0.0393
120	-0.0008	-0.0018	-0.0043	-0.0216	0.0339
121	-0.0002	-0.0010	0.0010	-0.0020	0.0135
122	-0.0004	-0.0013	-0.0035	-0.0473	0.1083
123	-0.0002	-0.0006	-0.0019	-0.0142	-0.0188
124	-0.0002	-0.0013	-0.0036	-0.0226	0.0529
125	0.0005	0.0010	0.0025	0.0108	0.0063
126	0.0004	0.0005	0.0019	0.0046	-0.1298
127	-0.0007	-0.0005	-0.0017	0.0031	0.0087
128	-0.0001	-0.0003	-0.0021	-0.0087	0.0368

3.1.1 Initial Monitor System Tests

All monitor systems functioned according to design. Radio telemetry operated in the store-and-forward mode. Dataloggers seemed to operate interchangeably over all ranges, but, as described in 2.3.1, well dataloggers were set on range 24, with 2500 mv excitation, and river stations were set on range 25.

Field data are now being recovered exclusively by radio telemetry and are backed up on two separate databases.

3.1.2 Results from Field Calibration and Crosschecks

Three processes were employed to assure proper calibration and continuous data quality. The first was in situ calibration. The second was simultaneous reading of water levels by steel

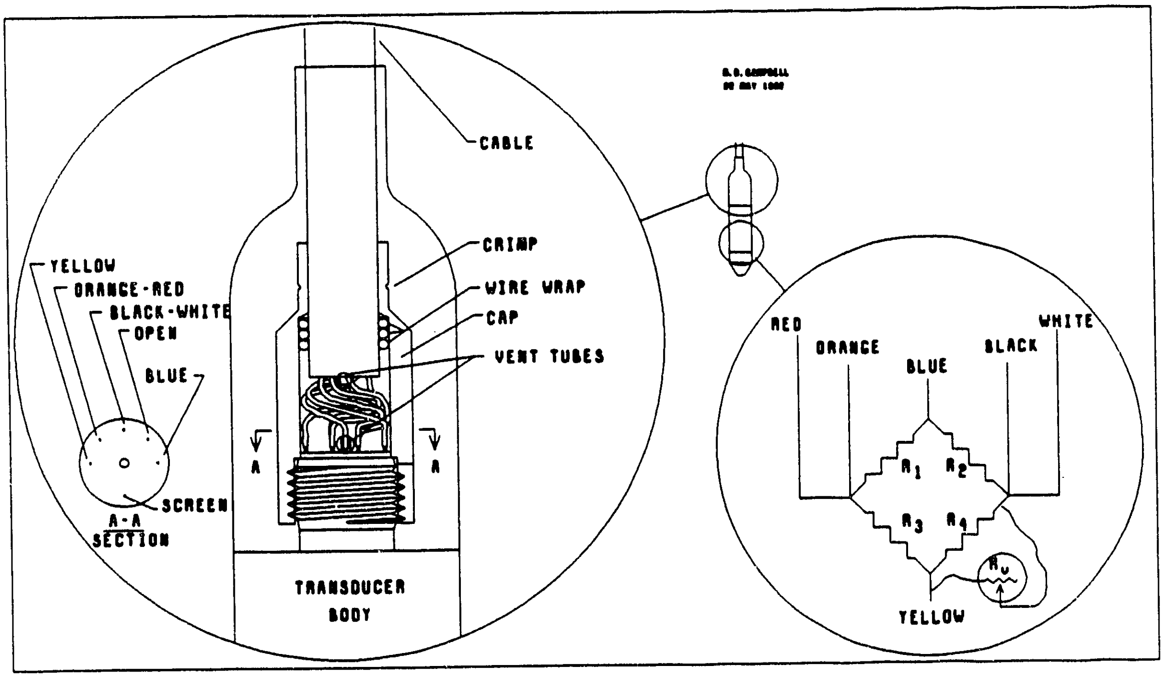

Figure 4. Transducer Configuration

tape and datalogger. Each of these two is discussed in turn. The third process was computer plotting of data from adjacent wells. This process is simple and is mentioned later.

Results from In Situ Calibration

In situ calibration, by temporarily displacing a transducer, was done several times in the first few wells monitored to refine the technique. A set of 20 readings at 3-s intervals constitutes a suitable basis for 1% statistical confidence level. Well recovery following transducer displacement required about 30 s. Thus, to obtain 20 useful readings, 30 readings were taken before displacement, followed by 30 readings during displacement, and 30 readings following return to the original position. Prestructured programs were prepared to process the data collected during field calibration. The in situ calibration process was presented and discussed in detail by Campbell and Newcomer (1992).

Examples of calibration factors obtained from in situ calibration are shown in Table 3.

Standard deviations show that the calibration procedure is acceptable, because precision is more than four times greater than that required of the water level measurement. Water level recovery and natural water level changes were properly considered.

Table 3. Calibration Factors Obtained by In Situ Calibration

	Well Number					
	1-8	1-9	1-16B	1-18A	1-18B	1-18C
Factor[(a)]	0.9242	0.9145	0.9290	0.9276	0.9056	0.9069
	0.9245	0.9134	0.9249	0.9318	0.9061	0.9056
	0.9251	0.9140	0.9291	0.9259	0.9048	0.9074
	0.9235	0.9168	0.9278	0.9264	0.9092	0.9087
Average	0.9243	0.9146	0.9277	0.9279	0.9064	0.9071
S.D.	0.00057	0.00128	0.00169	0.00232	0.00166	0.00111

(a) Units in ft/volt ratio.

Results from Steel Tape and Datalogger Measurements

Crosschecking datalogger with steel tape measurements helped identify errors. Errors have been traced to well casing extension, misread tape, transducer movement, transducer failure, and datalogger wiring panel failure. Table 4 shows normal and erroneous tape and datalogger reading sets. Well casings were extended upward approximately 1 ft when some of the older wells were renovated. When the work was done, a time lag occurred before resurvey records were available; so the water elevations, incorrect for a time, are now correct.

Steel tape measurements are commonly accepted as the standard. Tape reading accuracy depends on technique, individual observation, and weather conditions. For example, the tape may be lodged on an obstacle rather than being suspended straight into the water. Detection of this problem depends on the observer's sense of feel. Furthermore, whether the wet line across the tape scale resulted from normal water submergence or from contact with a condensing surface is also a matter of observer judgment, based on feel. Repeated measurements in wells revealed errors ranging from near zero up to 10 ft. Errors were more difficult to discover and resolve in wells having large pumps, hanging wires, or restricted access. These difficulties were amplified by large amounts of condensation near the top of the well casing, especially during cold weather. Nevertheless, repeated attempts were made to verify the reliability of steel tape readings within 0.01 ft. When disagreement exists between steel tape and transducer readings, and the transducer readings are continuous and consistent, steel tape readings should be questioned and proven by replicated remeasurement.

Transducer errors are of three kinds: 1) slippage through the support fitting, 2) electrical short circuit, and 3) other electrical failure. The first kind of error invariably results in a class 2 error discussed later and shown as a negative variance in Table 4. The second kind of error, also shown in Table 4, is large and variable. The third kind of error has been a non-changing transducer output and has been detectable during pre-installation calibration tests.

Table 4. Paired Sets of Tape and Datalogger Readings

WELL/ DATE	Time	Tape	DLRdg.	Relative Change (ft)	Absolute Change (ft)	Problem
(1-7)						
399-1-7						
1-9-92	1450	42.48	3.4295		0.05	
2-5-92	1038	43.95	1.9163	-0.06	-0.01	
3-5-92	1433	43.68	2.1911	0.01	0.00	
4-8-92	904	43.59	9.7679	Bad XD	-6.96	
4-21-92	1335	44.45	4.792	Replaced		
6-3-92	742	42.23	7.2562	-0.07	0.01	
7-2-92	740	42.37	7.1209	-0.01	0.00	
8-7-92	713	44.21	5.1349	0.01	0.01	
9-9-92	743	44.67	4.6284	0.01	0.02	
10-8-92	725	44.47	4.8486	-0.00	0.01	
11-10-9	937	44.3	5.0319	-0.00	0.01	
12-8-92	911	42.4	7.0938	-0.02	-0.00	
(7A)						
S27-E9A						
12-9-91	1154	42.31	3.4800		0.07	
2-5-92	1352	42.42	3.4664	-0.10	-0.02	Rng.25>24
3-5-92	1508	42.48	3.3476	0.05	0.03	
4-7-92	1027	42.67	3.2126	-0.06	-0.04	
5-5-92	1343	42.74	3.0973	0.04	0.00	
6-2-92	955	42.64	3.2018	0.00	0.00	
6-30-92	1001	42.5	4.5183	-1.08	-1.08	ftg.slp
7-8-92	755	42.46	3.4773	1.01	-0.07	adj.ftg.
8-6-92	858	42.46	3.4721	0.00	-0.07	
9-9-92	711	42.61	3.2849	0.02	-0.04	
10-8-92	1238	42.68	3.1596	0.05	0.00	
11-10-9	1015	42.76	3.0818	-0.01	-0.01	
12-9-92	1120	42.76	3.0633	0.02	0.01	
(2-2)						
399-2-2						
9-16-92	1145	36.35	4.9659		0.00	
10-8-92	746	36.41	5.0153	-0.11	-0.11	
11-10-9	817	36.24	5.2036	-0.01	-0.11	
12-8-92	925	34.3	7.3153	-0.02	-0.13	

WELL/ DATE	Time	Tape	DLRdg.	Relative Change (ft)	Absolute Change (ft)	Problem
(1A)						
S29-E16A						
12-9-91	1300	38.65	1.9362		0.18	
1-9-92	1320	37.22	3.8282	-0.33	-0.15	Rng.25>24
2-5-92	1517	38.66	2.1188	0.15	-0.00	
3-5-92	1029	38.39	2.4014	0.01	0.00	
4-8-92	648	37.95	2.8945	-0.02	-0.01	
5-5-92	1428	37.46	3.4066	0.01	0.00	
6-2-92	1250	36.99	3.9249	-0.01	-0.01	
6-30-92	1231	36.82	3.8166	0.27	0.26	chng.chn.ord
7-8-92	928	39.47	1.1292	Adj.	0.00	ftg.adj.
8-6-92	932	38.99	1.5066	0.13	0.13	
9-9-92	549	39.09	20.7060	Replace	Went bad day 249	
9-17-92	907	38.44	4.9407	0.00	0.00	
10-8-92	635	38.81	4.5293	0.01	0.01	
11-10-9	1052	38.54	4.8137	0.01	0.02	
12-9-92	921	36.82	6.6863	-0.02	-0.00	
(1-10B)						
399-1-10B						
1-24-92	1351	32.97	5.2823		0.11	
2-5-92	1219	33.70	4.5796	-0.08	0.04	
3-5-92	1310	33.35	4.9636	-0.01	0.03	
4-8-92	811	32.95	5.4254	-0.03	-0.00	
5-6-92	756	31.94	6.5104	0.00	0.00	
6-3-92	728	31.67	6.815	-0.01	-0.01	
7-2-92	716	32.17	6.2674	0.01	-0.00	
8-7-92	733	43.73	4.4183	-9.84	-9.84	tp.rd.err
9-9-92	1236	34.09	4.1024	9.93	0.09	
10-8-92	805	34.11	4.1021	-0.02	0.07	
11-10-9	836	33.61	4.6649	-0.02	0.05	
12-8-92	933	31.72	6.7429	-0.04	0.00	
(5-1)						
399-5-1						
8-13-92	808	53.91	4.8994		0.00	
9-9-92	605	54.55	4.2434	-0.03	-0.03	
10-8-92	654	54.41	4.4125	-0.02	-0.05	
11-10-9	1138	54.3	4.5452	-0.01	-0.06	
12-9-92	940	52.53	6.4519	-0.00	-0.06	

3.1.3 Precautions and Sources of Error

Two classes of errors are evident in Table 4. A class 1 error is positive and results if a steel tape or datalogger reading is too small. Condensate wetting of a steel tape is a typical cause of class 1 error. A class 2 error is negative and results if a steel tape or datalogger reading is too large. Transducer cable slippage and steel tape hang-up are typical causes of class 2 errors. Aquifer adjustment delay and wind cause both classes of error. Incorrect field survey or well casing modifications may also cause either class of error if the survey occurs during a test period, as it has three or four times in the past year. Usually, however, survey errors affect only the measurement accuracy and not the precision. Well pumping or slug testing that occur near the time of the tape and datalogger test make it necessary to read both tape and datalogger average simultaneously. Gradual relaxation of the transducer cable into the well causes a class 1 error, but it is usually small. Transducer hang-up on a pump or other obstruction in the well causes a class 1 error if it occurs before tape reading and then slips deeper into the water afterward. If reversed, it can cause a class 2 error. Because pump crews frequently remove or adjust pumps, this cause of error is relatively common. In all these causes of error, the error detection is simplified by plotting differences between simultaneous water elevations in similar wells. Departures from a trend line are cause for calibration recheck.

Monitor System Errors

Another type of error is associated with changes in datalogger range. As previously shown, the prospect of error increases with increasing range. Inasmuch as the resolution of datalogger range 25 is ±0.12 ft, it would be possible to experience a 0.2-ft error when switching range from 25 to 24. This error was observed and forms the basis for leaving wells on range 24 and river stations on range 25. Of course, averaging reduces the error, too, which is why the average from six readings is used when steel tape and datalogger readings are paired.

Physical System Errors

Because elevations are used as the basis of water level comparison, topographic surveys are used to measure the MSL ToC elevation at each well. The accuracy of the topographic survey is normally related to the distance from the well to the reference. A recent discussion with the current surveying contractor revealed that none of the wells in the network should have plane survey errors larger than ±0.06 ft.

Errors from Equipment Service and Maintenance

It is possible for transducers to produce errors as a result of plugged air vent tubes. Water, debris, or a compressed cable can also cause this type of error. Each cable is checked visually each month to ascertain its condition. The vent tubes are checked, and a dry desiccant is placed in the vented enclosure to keep air vents clean and dry.

If monitor system battery voltage drops below 10.5, directly measured voltages increase. This cause of error is most likely where solar panels fail to recharge the lead-acid battery.

Error Detection

Errors in the data were most often detected through field observation of a problem or potential problem. For example, a pump support plate resting on a cable or a frozen atmospheric vent tube or a low battery voltage was considered sufficient grounds for a data inspection. Other things, such as slipped or loose fittings or observed well pumping or renovation were cause for error checks. With all these observations, including the routine maintenance and service checks, there is reason to accept the quality of the data proven against the standards reported as representative of the respective Operable Units and suitable for either calibration or testing of the computer models.

3.2 Field Data

Data are continuous for several well and river water elevations since autumn 1991 in the 300-FF-5 and 100 Aggregate Area Operable Units. Thus, a limited amount of data for an annual cycle are accessible to modelers for calibration of PORFLO-3. The data were standardized and quality assured by supporting measurements. For example, the top of each well casing was surveyed for its relation to MSL, as were the SWS-1 river stage scale and the other river stations. The transducer readings were referenced to MSL by steel tape measurements from the tops of well casings to the water level for a particular transducer reading.

Data were stored by calendar year and quarter in the databases. Quarter 3, 1992 and earlier data are stored in two types of files: 1) *.WQ1 files for wells F5-4, F5-6, F5-1, B4-4, B4-1, B3-1, and 2) *.DAT files for all other well and river stations. All data collected during quarter 4, 1992 and thereafter are stored as *.DAT text files. The *.DAT files require import into a spreadsheet or parsing when read in as a text file.

3.2.1 Water Level Measurements

In general, the data show the largest water level fluctions near the river, with well 399-4-7, for example, varying about 2.5 ft/d. Wells 399-1-18A, B, and C appear to be hydraulically connected, resulting in similar water elevations and fluctuations. Wells farthest from the river show no short-term fluctuation but do show long-term variations that correspond to river fluctuations. Superimposed on the long-term river-induced variations are what appear to be seasonal variations resulting from aquifer recharge unrelated to the river. Wells within the high frequency detection distance limit do not show high frequency variations. The cause is unclear, though it may be dominance of flow parallel to the river over attenuation associated with the distance from the river. The cause may also be anisotropy of the aquifer matrix.

All data require conversion to feet and then to other units if desired, because calibration was in feet. Equation (2) may be used for this conversion. Once converted, comparisons are possible, such as the river stage shown in Figure 5. Each river station is shown with its Hanford River Mile (HRM) location. The periodic fluctuation of the water elevation at all four river stations suggests a sinusoidal quality that may be helpful in evaluating hydraulic characteristics of the adjoining aquifer.

The river fluctuations in Figure 5 show similarity of river stage changes at stations 100-B, 100-H, and 100-F. However, stage response at SWS-1 is greatly attenuated and slightly different. This stage response difference is most likely related to the McNary pool's influence on SWS-1 and not on the others. The McNary pool operates between a minimum of 335 ft and a maximum of 340.5 ft MSL. During October and November of 1992, the average difference between water elevations at SWS-1 and that at McNary Dam was 3.7 ft. While the average river slope from 100-B to SWS-1 was 1.2 ft/mi, it was approximately 0.1 ft/mi between SWS-1 and McNary Dam. It is not surprising, therefore, to find significant attenuation of river fluctuations at SWS-1 compared with those farther up river. Typical attenuation is shown rather clearly in Figures 6a and 6b, where stage is normalized to show only the variation about the mean for all four river stations.

Figure 6b displays the points at which hourly measurements were made and seems to justify selection of the measurement frequency by demonstrating capture of the extreme variations. It is apparent from Figure 6b that the lag in beginning river rise was only 3 h from 100-B to the 300 Area. However, the lag in river crest was 7 h. It seems reasonable to conclude that this difference in time of 4 h resulted in the necessary gradient, expressed as increased river slope, to move the water downstream. If this is true, the river slope increase would range from about 0.24 ft/mi at 100-B to 0.04 ft/mi at the 300 Area.

After examining river stage and fluctuation, it seems appropriate to examine interactions between the river and the adjoining aquifer. Data from several wells parallel to the river in the 300 Area were plotted. These data are shown in Figure 7 (a through f). Apparently, well water elevations vary with the river. Attenuation is evident as expected in these wells. The water elevation difference between wells indicates approximately a 1-ft/mi slope along the river during March 1992. The river slope is not uniform along its Hanford reach, not even along the 300-FF-5 Operable Unit boundary. Nevertheless, an estimated adjustment was applied to river data shown in Figure 7 to clarify graphically the relation between well water fluctuation and nearby river water fluctuation. Figure 7a shows water levels in five wells and the river at SWS-1. Figure 7b shows well S19-E14, with river fluctuation measured at SWS-1 adjusted up 1.38 ft to compensate for river slope. Figure 7c shows well 399-1-1 (labeled 3-1-1 in the graph), with the river fluctuation from SWS-1 adjusted upward 0.58 ft to compensate for river slope. Likewise, the river elevation at SWS-1 was adjusted to compensate for river slope so that the river water level nearest each well would be most closely approximated.

Well 399-4-12, which was near Well 399-4-7, was pumped continuously but at a varying rate to supply water to the fish tanks in the 300 Area. The outflow observed was approximately 1 M gal/d. Figure 8 shows the water level fluctuations about their mean value, which includes the influence of pumping Well 399-4-12.

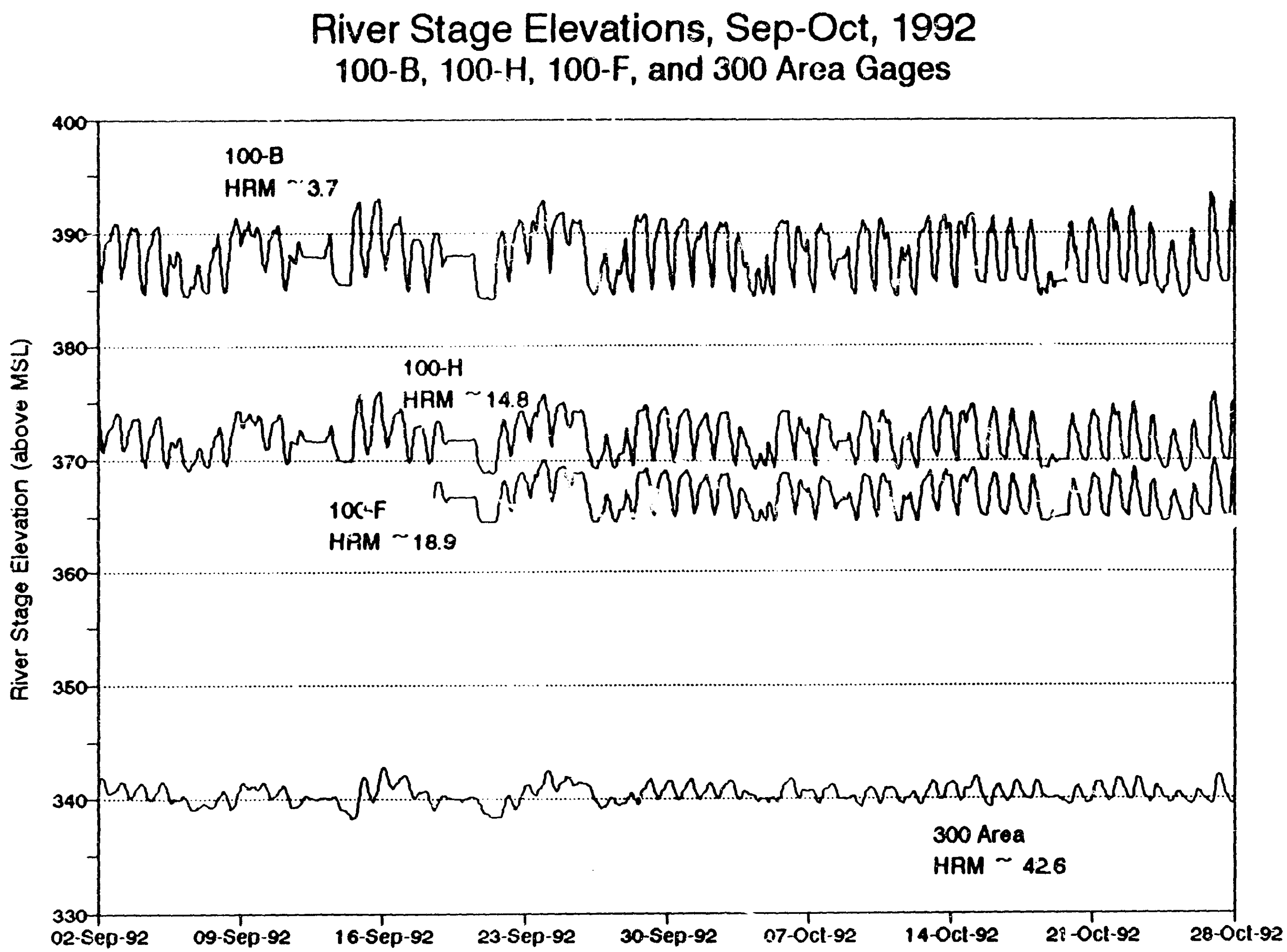

Figure 5. River Stage at Four River Stations

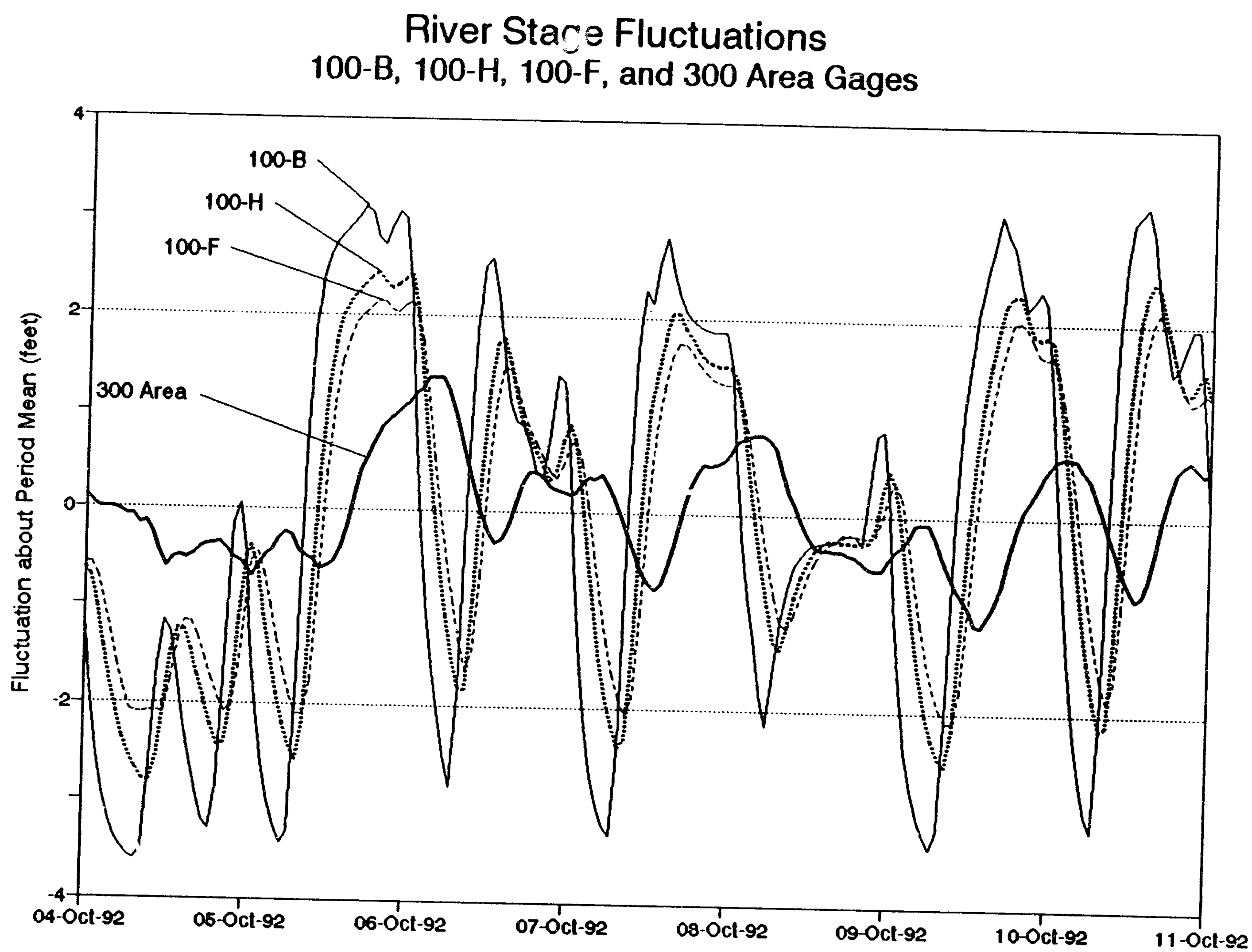

Figure 6. Water Level Fluctuations at Four River Stations (a) One Week

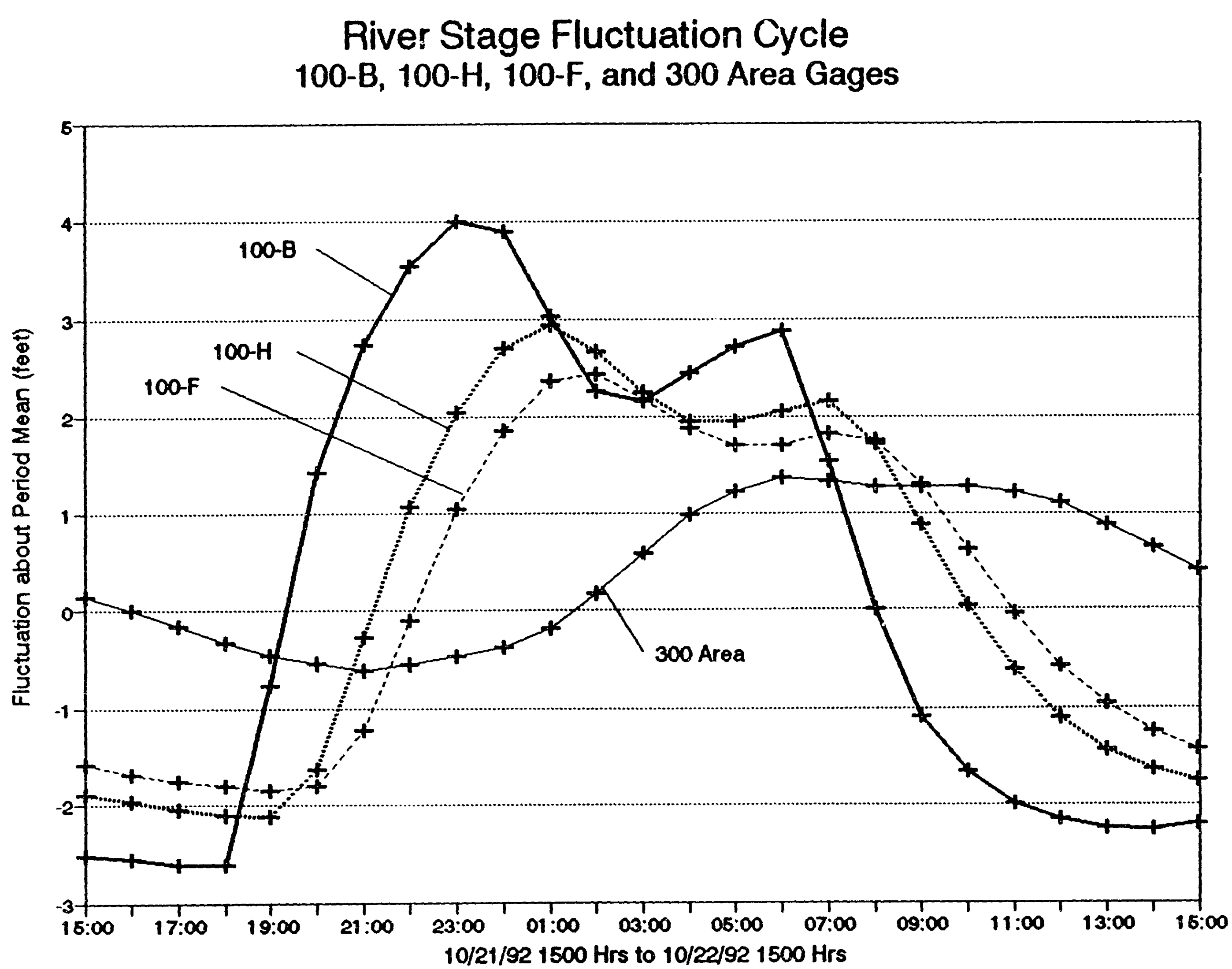

Figure 6 (Contd). Water Level Fluctuations at Four River Stations (b) One Day

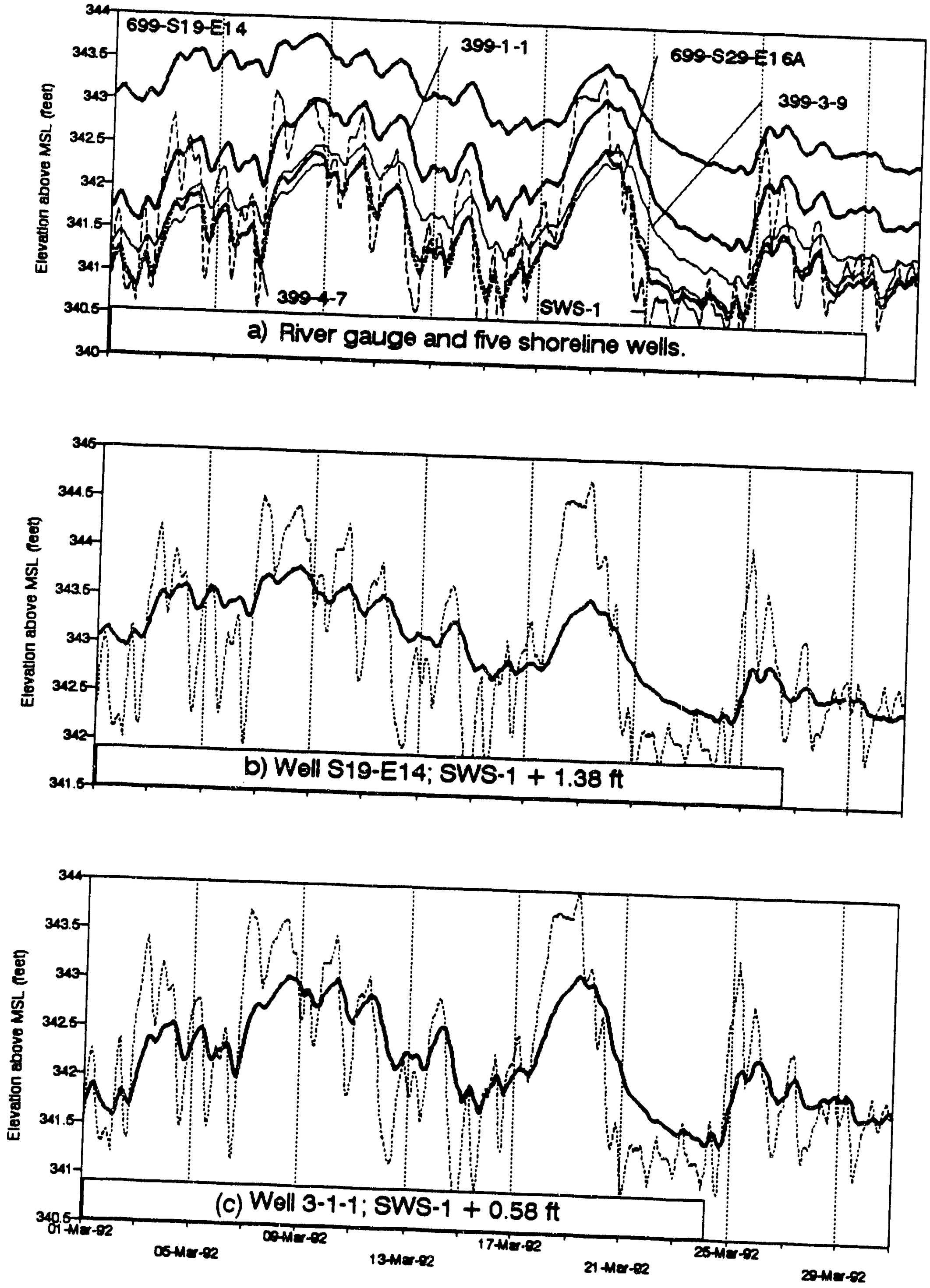

Figure 7. River Stage and Water Elevations in five Wells (The dotted line shows river elevation adjusted for newest proximity). (a) All Five Wells (b) Well S19-E14 (c) Well 3-1-1

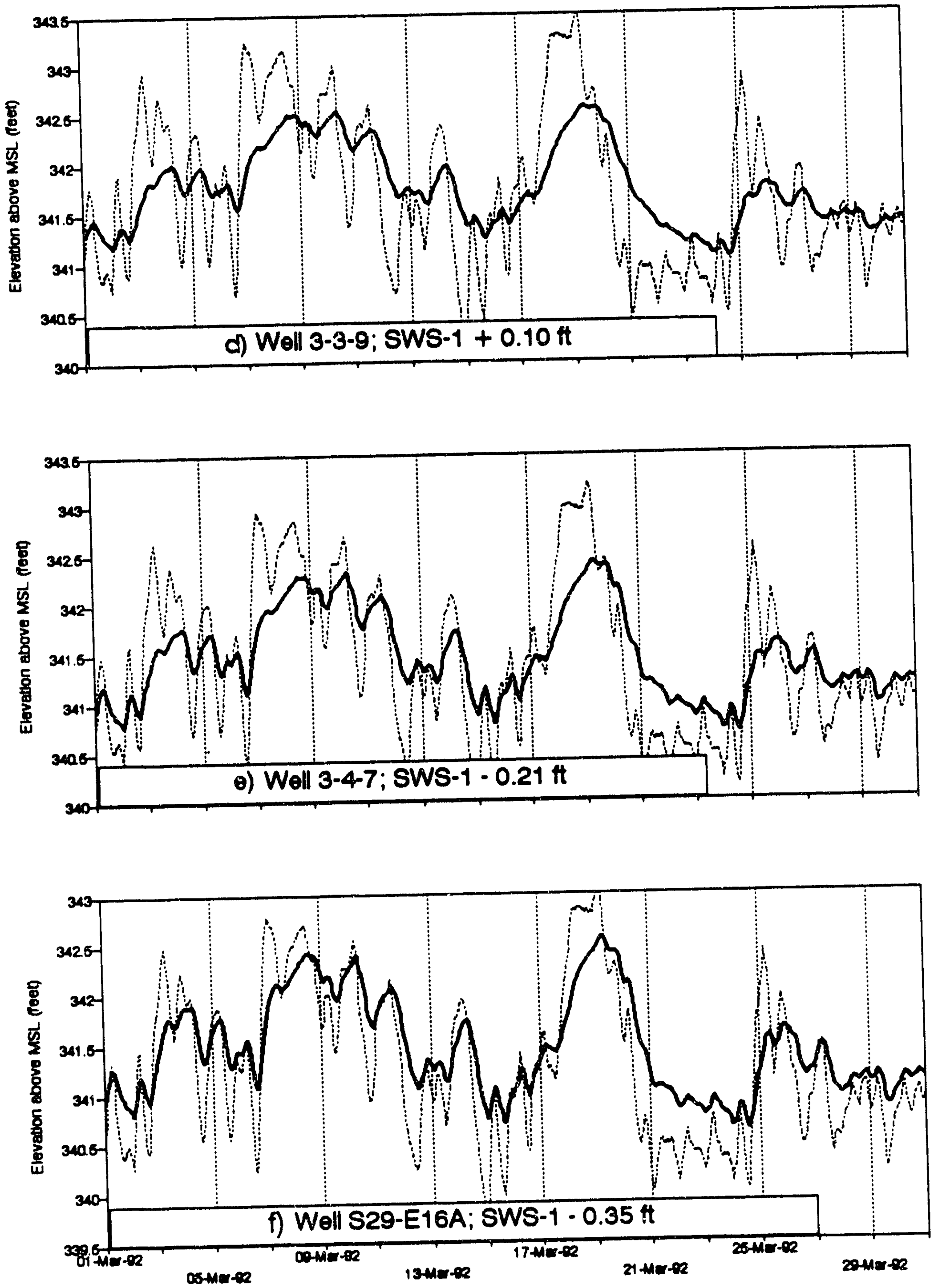

Figure 7. (Contd.) River Stage and Water Elevations in Five Wells (The dotted line shows river elevation adjusted for nearest proximity). (d) Well 3-3-9 (e) Well 3-4-7 (f) Well S29-E16A

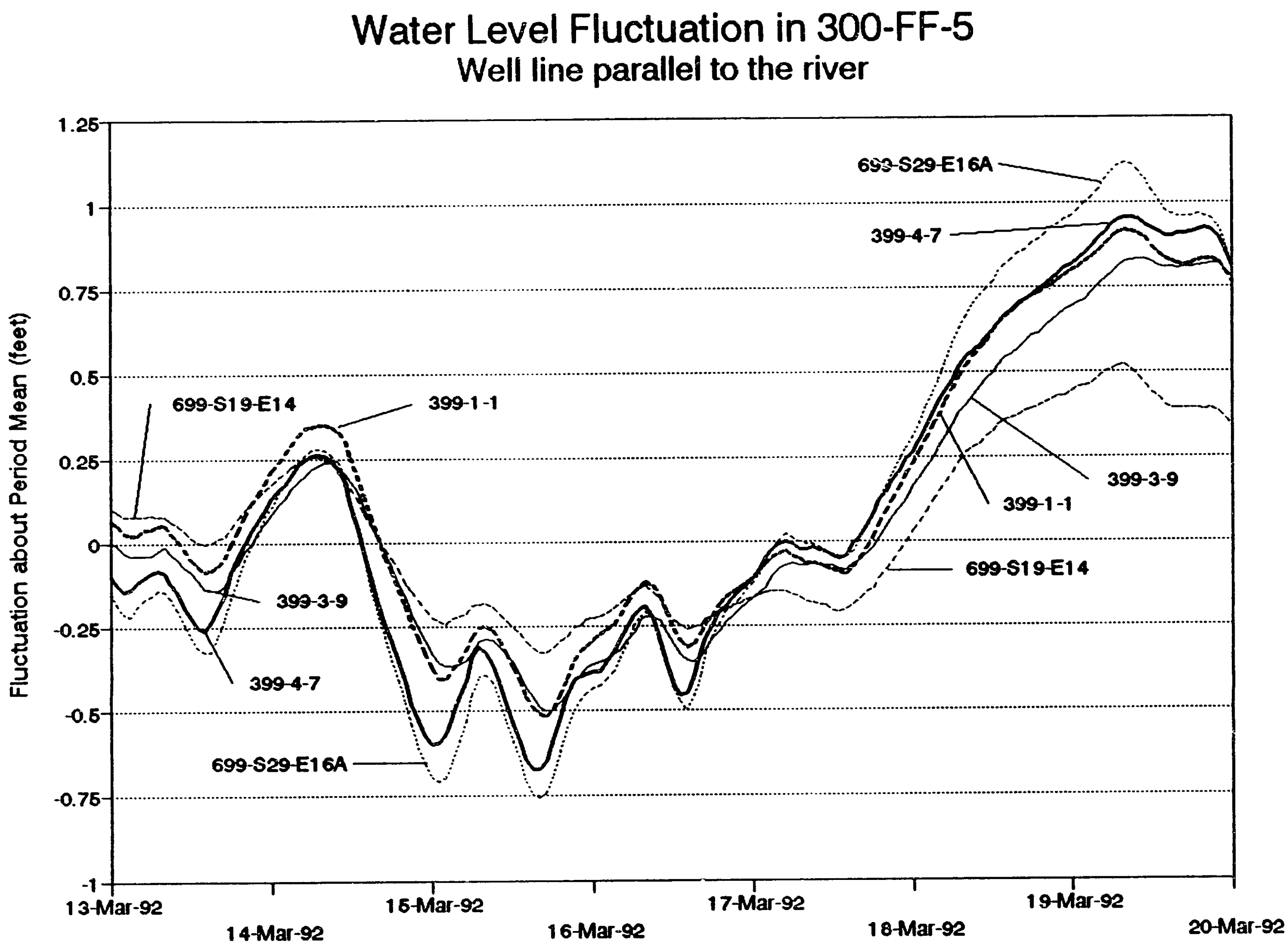

Figure 8. Water Level Fluctuation in Wells Parallel to the River

Figure 9 shows water elevations in wells aligned normal to the river. Clearly, wells near the same elevation as the river fluctuate with the river, but with the expected time delay and attenuation. Well 699-S27-E9A is not responsive to river fluctuation. Among the other wells depicted, well 399-6-1 is farthest from the river and shows the longest cycle response period. Well 399-3-12 is next and is about half as far as 399-6-1 from the river. Well 399-3-9 is nearest the river and shows the greatest response to the river influence, as expected. Figure 10 shows the water fluctuations about their mean values even more clearly. Again, there is no indication that well 699-S27-E9A is responding to river fluctuation. This fluctuation attenuation with distance will be discussed later in connection with an example using the Ferris Model.

Wells in the 100 Aggregate Area Operable Unit also show variation with the river. In the 100-B Area, for example, the river fluctuated about 9 ft/d. This fluctuation produced about 1.5 ft of change in well B3-1, which lies about 400 ft from the river (see Figure 11). Well B4-1 at 1970 ft from the river and well B4-4 at 3150 ft from the river showed only slight long-term variations with the river.

Water elevations in the 100-H Area aquifer seem to respond to river fluctuations reasonably well, as shown in Figure 12. As expected, there is a damping and delaying effect from the aquifer matrix. Unlike the 100-B Area wells, the 100-H Area wells more closely match and follow the water elevation at the river. It is also interesting to note that the magnitude of river fluctuation is slightly less at the 100-H Area than it is at the 100-B Area. Both Figures 12 and 6 show this quality.

Water elevations in the 100-F Area aquifer also respond to river fluctuations, but to an even greater degree than 100-H or 100-B areas, and farther inland. Although the 100-F Area river stage monitor came on line after August, Figure 6 shows that the 100-H Area river stage closely approximated that at 100-F Area in magnitude and timing. Figure 13 shows water elevations in 100-F Area wells.

We used the Ferris Model with some of the data to estimate aquifer hydraulic properties and to evaluate water level relationships among wells. The monitor network logged data that show the river's influence on the adjacent shallow unconfined aquifer. Figure 9 shows water elevations during March 1992 at river station SWS-1 and a series of wells approximately normal to the river. The distance from each well to the river is provided in Table 5.

Groundwater response to diurnal river fluctuations appeared to be limited to wells 399-3-9 and 399-3-12, or about 1200 ft inland from the river bank. Beyond that, the daily fluctuations were damped out; water elevation in well 399-6-1 responded to overall river stage trends, but

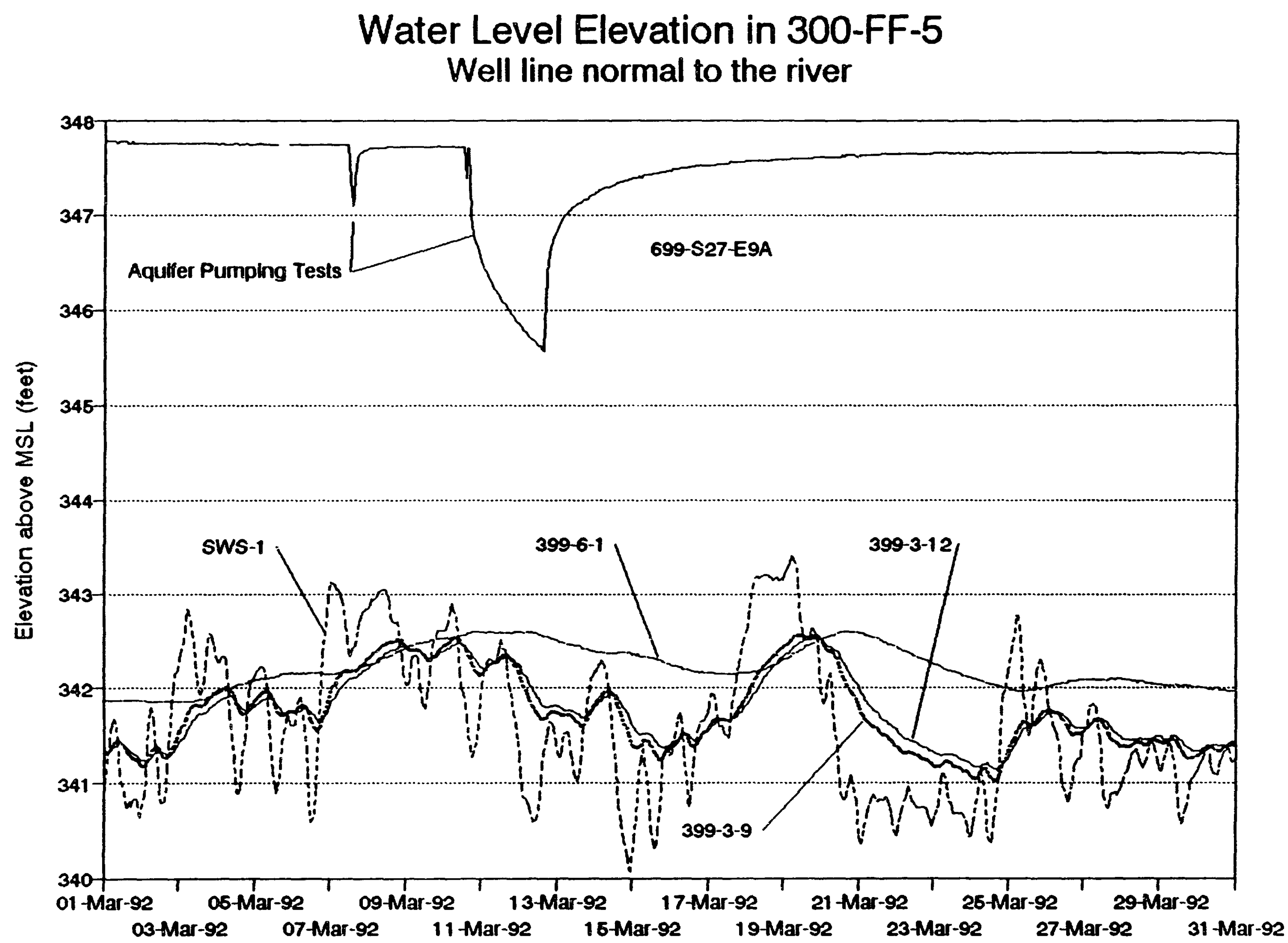

Figure 9. Water Elevations in Wells Aligned Normal to the River

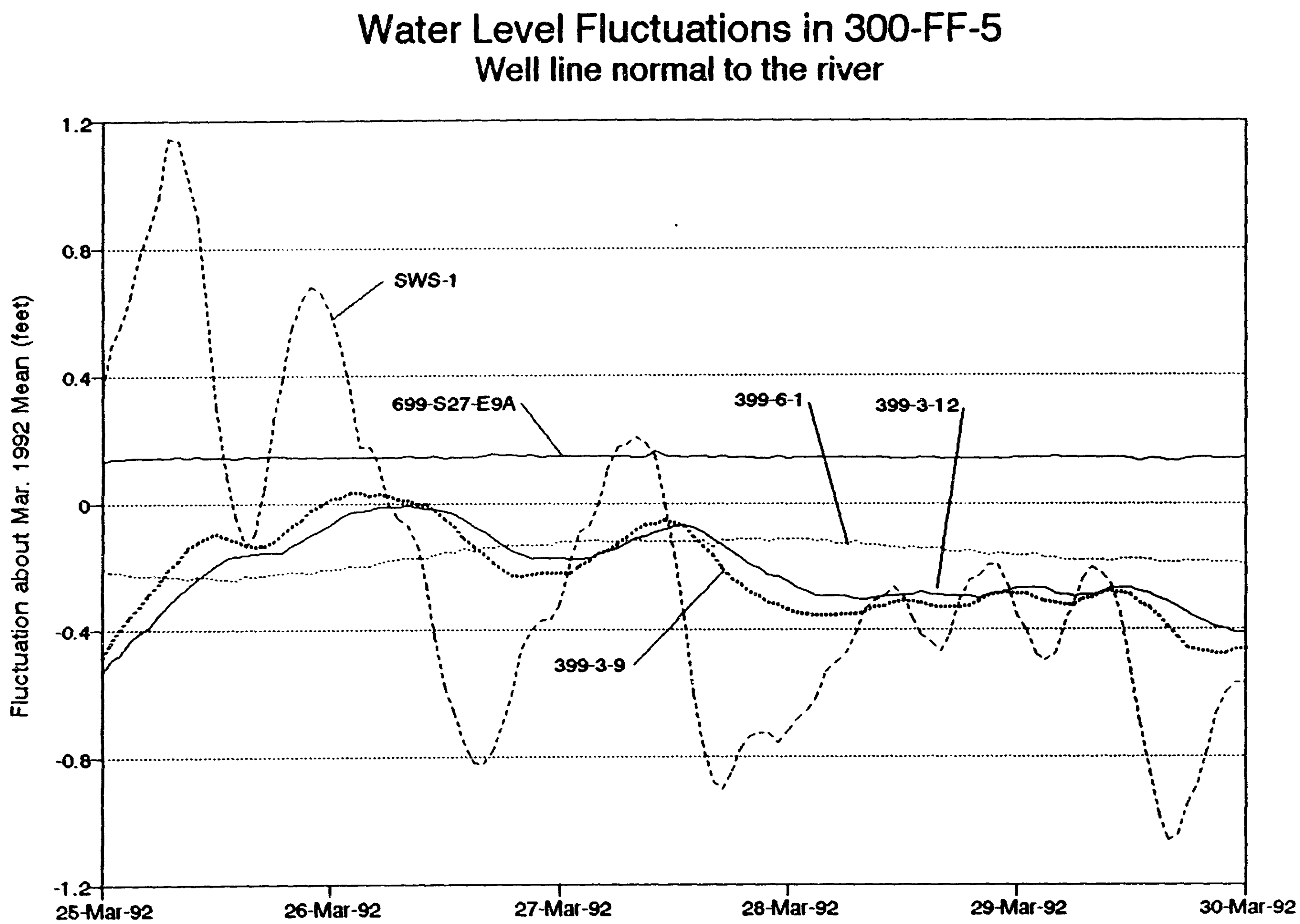

Figure 10. Water Level Fluctuation in Wells Normal to the River

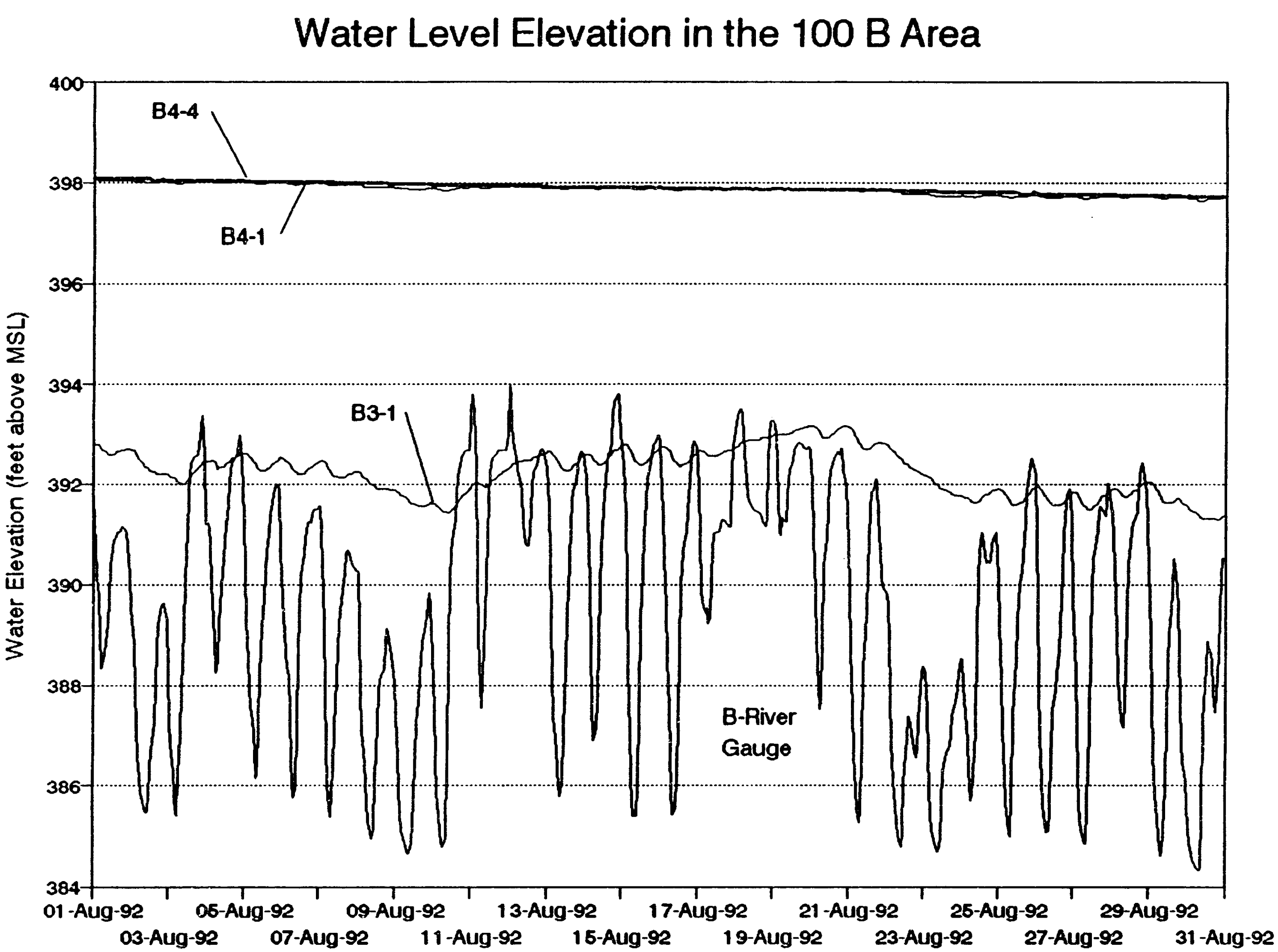

Figure 11. Water Elevations in the 100-B Area

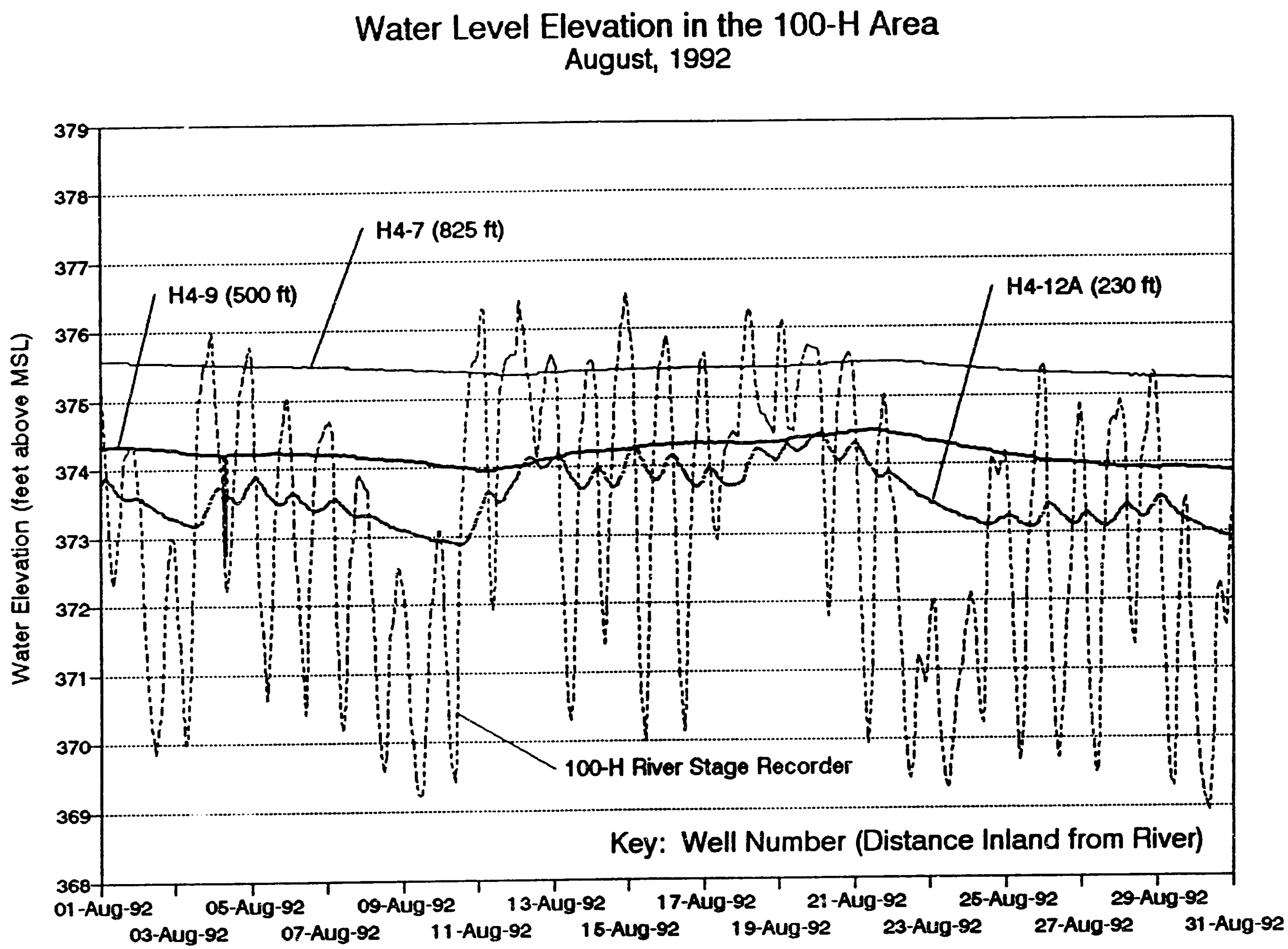

Figure 12. Water Elevations in the 100-H Area

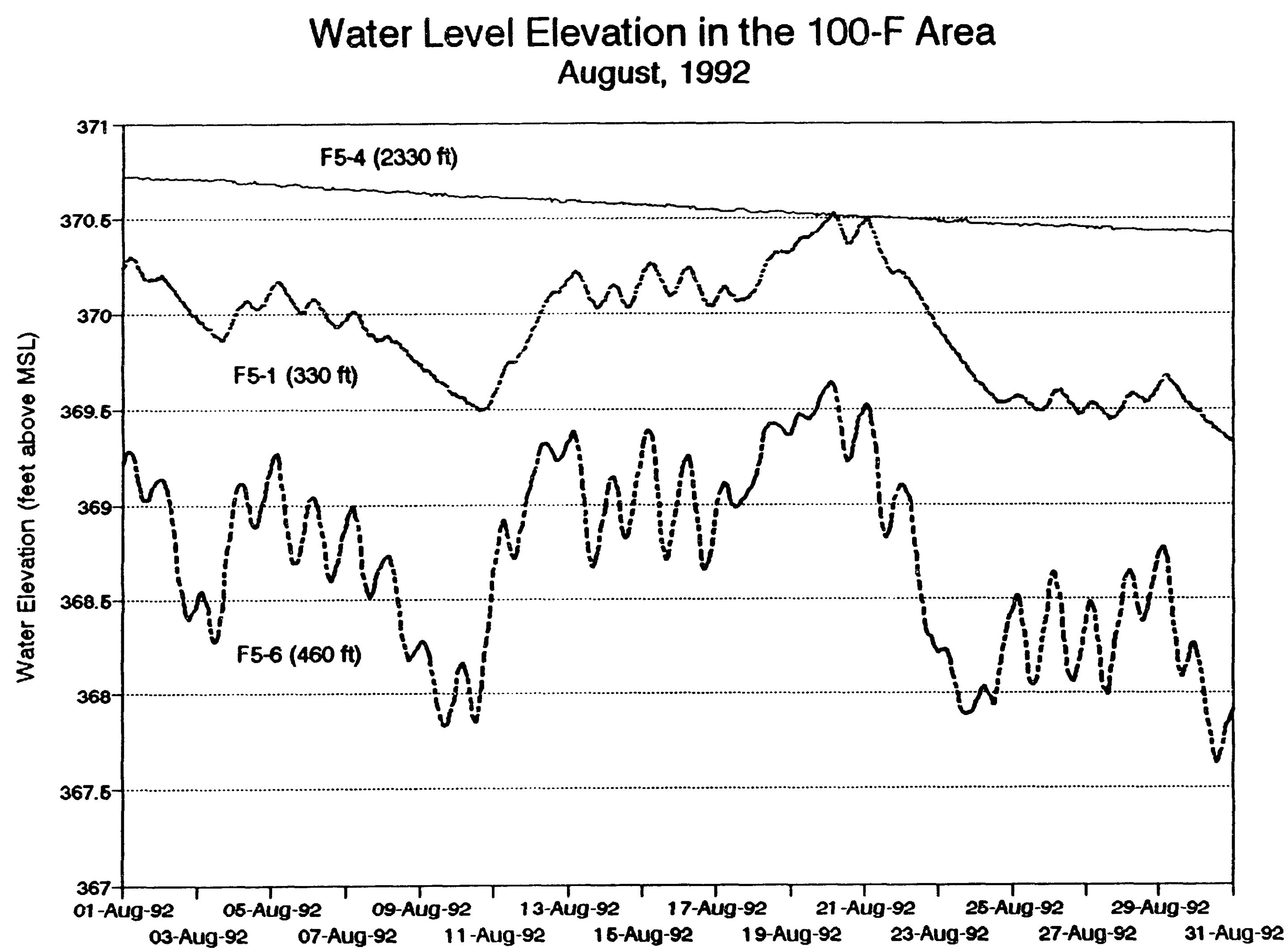

Figure 13. Water Elevations in the 100-F Area

Table 5. Mean Water Elevations and Distances from the River for the Series of Wells Running Normal to the River

Well	Distance from River[a] (ft)	Mean Water Level Elevation (March 1992) (ft above MSL)[b]
SWS - 1 (River)	0	342.03
399-3-9	260	341.74
399-3-12	1210	341.76
399-6-1	3460	342.21
699-S27-E9A	6100	347.51

(a) Note: The distance from the river was determined by subtracting the Lambert NAD '83 easting coordinate of SWS-1 from the easting coordinate of each well.
(b) Note: Elevation readings taken on an hourly basis.

not to individual fluctuations. Data from well 699-S27-E9A (about 6100 ft from the river) exhibited no discernable response to any river influences.

The monitor network has also provided information to help describe groundwater flow paths. Surprisingly, Figure 9 fails to show a definitive flow direction between the river and the two wells nearest the river (399-3-9 and 399-3-12). Flow appeared to occur from well 399-6-1 toward those two wells, but its ultimate destination cannot be deduced readily. In fact, comparison of the monthly elevation means (see Table 5) indicates that the water table nearly flattened between wells 399-3-9 and 399-3-12. Because the largest hydraulic difference along the line existed between wells 699-S27-E9A and 399-6-1, and the groundwater did not accumulate in the area, at least one of the following circumstances must have been true.

1. The transducer equipment failed to operate properly.
2. The well ToC survey elevations were in error.
3. The groundwater away from the river was not hydraulically connected to the groundwater near the river.
4. The aquifer material near the river was greatly more transmissive than that farther away.
5. The groundwater near the river travelled in a path parallel to the river.
6. The groundwater exited vertically from the unconfined aquifer to another aquifer or reservoir.
7. The groundwater was removed mechanically.

The plausibility of each of these seven items will be discussed.

(1) All transducer equipment was calibrated and tested before installation. Upon installation, the transducer readings were correlated with steel tape measurements referenced to the well ToC. Confirmatory steel tape readings were taken at monthly intervals to ensure that the transducer continued to operate satisfactorily. This information provided no indication of transducer malfunction.

(2) The ToC elevations were surveyed in 1992 using NGVD,29 as the vertical datum. A recheck of five wells, including 399-3-12, held to the original surveys. No significant error in the ToC surveys has been detected, though the river stage scale had slipped down 0.4 ft.

(3) Reports documenting the geology of the 300 Area (Swanson et al. 1992; Schalla et al. 1988; and Lindberg and Bond 1979) provided no evidence of a geologic irregularity capable of causing such a significant hydrologic disruption. Given the large number of borehole and geologic summary reports and the detailed geologic mapping of the area, it is unlikely that such an irregularity escaped detection.

(4) Lindberg and Bond (1979) described an erosional low in the Ringold formation, parallel to the river, about 10 to 15 ft deep and 2000 ft wide, and filled with highly permeable Pasco gravel. Subsequent reports detailing the 300 Area hydrology (e.g., Swanson et al. 1992) confirmed that the upper fluvial deposits of the Ringold Formation tended to form wide, shallow channels. An upward protrusion of the Ringold Formation bounds the highly permeable zone near the river and isolates the gravel from the river. At the river shore, the water table passes through the upward protruding, less permeable aquitard connecting the inland aquifer to the river. Except for this type of highly permeable zone, the water table in the 300 Area is contained entirely within the Ringold Formation.

Hydrologic testing results in the 300 Area also showed evidence that the shallow unconfined aquifer resides in different units. Field tests performed in five wells (399-1-13, 399-1-18A, 399-1-14, 399-1-10, and 399-1-16A) near the river were reviewed by Spane in 1991 (see Appendix C). He showed that the transmissivity of the shallow unconfined aquifer near the river varied over three orders of magnitude (10^4 to 10^6 ft^2/d). Field tests performed at well 699-S27-E9A (McMahon and Peterson) yielded transmissivity results around 4000 ft^2/d. While some variability in field testing results is always expected, even within highly homogeneous porous media, a three or four order of magnitude variation indicates definite changes in the aquifer composition and/or structure.

(5) To investigate whether substantial flow occurred parallel to the river, March water level data from another line of wells, 399-1-1, 399-3-9, 399-4-7, and 699-S29-E16A, were analyzed (see Figure 7). All of the wells along this line are located near the river (within 450 ft of the river bank). Examining the figure shows that the hydraulic gradient was directed southward from well 399-1-1 toward 399-3-9, and southward from there toward well 399-4-7. South of that, the gradient flattened; the flow direction between 399-4-7 and 699-S29-E16A was indistinguishable

Table 6. Mean Water Elevations and Distances from Well 699-S29-E16A for the Series of Wells Parallel to the River

Well	Distance from 699-S29-E16A[a] (ft)	Mean Water Elevation (March 1992) (ft above MSL)[b]
399-1-1	6090	342.23
399-3-9	3890	341.74
399-4-7	2500	341.45
699-S29-E16A	0	341.45

(a) Note: Well 699-S29-E16A was chosen as an arbitrary reference. The distance was determined by subtracting the Lambert NAD '83 northing coordinate of each well from the northing coordinate of 699-S29-E16A.
(b) Note: Elevation readings taken hourly.

[less than 0.01 ft (see Table 6)]. If groundwater flow travelled parallel to the river, it must have occurred farther inland, perhaps in the vicinity of the George Washington Way Extension road, which places it in the pathway of the highly transmissive zone described in item (4). Otherwise, the groundwater did not appear to travel southward out of the 300 Area.

(6) Vertical movement of groundwater could have occurred through either natural or man-made connections between aquifers. During March, the water level elevation at various pairs of clustered wells (screened in the deep and shallow portions of the unconfined aquifer) displayed an upward gradient. The average difference (during March) ranged from about 0.01 ft (at the 699-S29-E16 cluster) to about 1.4 ft (at the 699-S27-E9 cluster, prior to the aquifer testing performed in March). In addition to this, the confined aquifer maintained a hydraulic head about 25 ft greater than the unconfined aquifer. If connections existed between the aquifers, either because of natural faults in the aquitard material or because of well drilling and construction activities, water may have seeped upward. Although unlikely, the upward movement of the water could have caused localized mounding, which might have skewed regional scale evaluations of the groundwater flow direction.

(7) Pumping has been reported in well 399-4-12 for the fish tank activities conducted just outside the 300 Area boundary. At this time, the volume of water removed may be as much as 1 M gal/d, with the exact amount and timing currently unknown.

Based on the preceding discussion, the groundwater distant from the river but within the shallow unconfined aquifer apparently flowed toward the river until it reached the zone of higher transmissivity parallel to the river, which caused most of the hydraulic gradient to attenuate. The Ringold aquitard, which bounds the highly transmissive zone and separates it from the river, impeded groundwater access to the river.

3.2.2 Temperature Measurements

Figures 14 through 17 show river temperatures in the Columbia River and in 10 wells for the period April through November 1992. The river temperature was not consistently measured during low flow periods because of an electronic ground-loop problem. However, each point plotted in Figures 14 and 15 represents the average of 100 measurements. Apparently, river water varied 34°F (between 38 and 72°F) over the season shown.

Water temperatures for five of the wells are shown in Figure 14. The other five well temperatures are shown in Figure 15. Well 399-6-1 had an invariant temperature near 61°F for the entire period shown. Temperatures in well 399-4-7 varied between 61 and 63°F over the interval, with temperature swings opposite the river. Temperatures in well 399-2-1 varied between 63 and 68°F over the interval, with a pattern similar to that of well 399-4-7. Wells H4-7 and H4-9 varied from about 64 to 65°F in a path apparently unrelated to the river temperature. Temperatures in wells H4-12A, F5-4, and F5-1 varied together about 1°F, near 64°F, and opposite the river. Temperatures in wells F5-6 and B3-1 remained nearly constant over the period, with F5-6 near 71°F and well B3-1 near 75°F.

Figures 16 and 17 show temperatures plotted as frequency distributions. These plots give a different impression than the straight temperature/time plots. Both figure 16 and 17 show nearly single mode water temperatures. However, a very slight modal deviation appears at the base of all wells except H4-7 and H4-9. Strong bimodality is evident in well 399-2-1, as shown in Figure 17.

The distinct temperature difference between well B3-1 in the 74 to 76°F range and well F5-1 in the 62 to 64°F range is an unaccounted anomaly. Most of the well temperatures are similar to those in F5-1, while F5-6 and B3-1 are distinctly different. Well 399-2-1 apparently has a temperature opposite that expected from river influence if water displacement was horizontal.

3.3 Data and Model Interactions

A hydraulic diffusivity of 3×10^6 was selected, based on the work of McMahon and Peterson (1992), to represent the aquifer and was input with other data into the Ferris Model to generate a line parallel to the river to denote a predictable wave amplitude corresponding to a given period. For example, a wave amplitude of 1 ft and a period of 1 d propagates a wave nearly 1700 ft before reaching 1% amplitude, which is the detection limit of 0.01 ft. The same wave propagates almost 4400 ft if the period is 7 d. Similarly, it should be possible to inquire for a unit amplitude what period pairs with the 1% line to reach a given distance in a given period, so that for a given oscillation frequency, a maximum detection distance may be

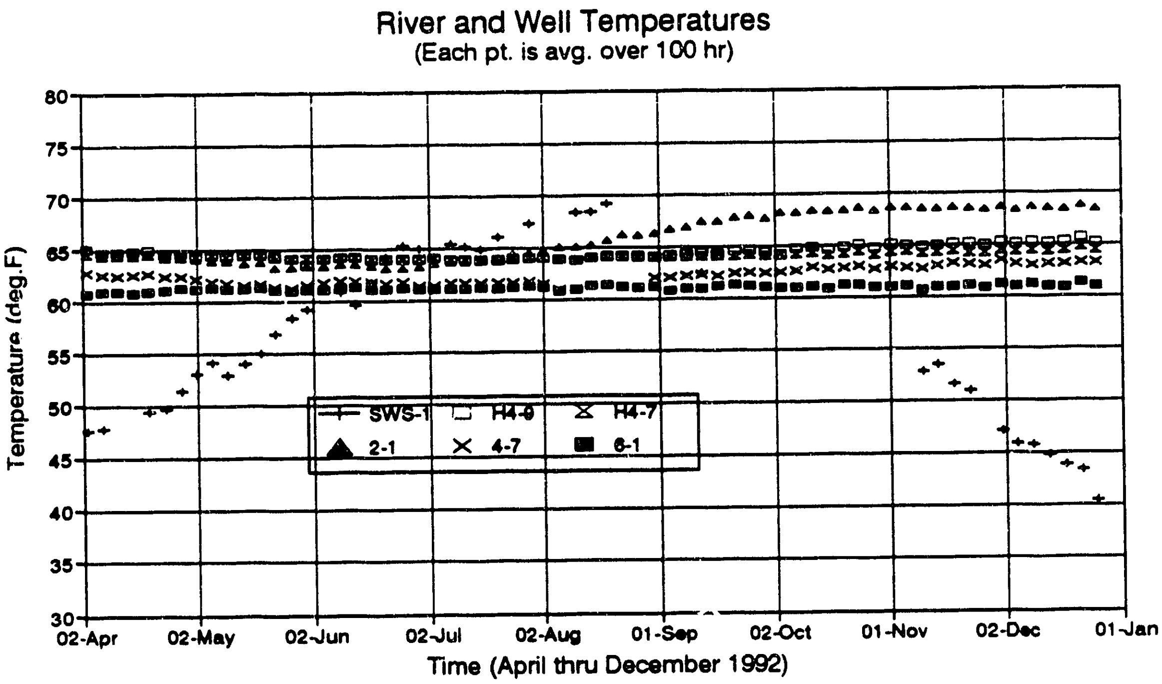

Figure 14. River and Well Temperatures--April-December 1992

calculated and tested. Such a plot is shown in Figure 18, where either the period or the distance is selected and the other is deduced from the log-log graph.

As aquifer fluctuations are related to river fluctuations that are sinusoidal through the Ferris Model, it is possible to characterize aquifer hydraulics, as in Figure 18. After looking at river data to estimate the period of the fluctuation to be investigated, one may enter the log-log graph using the chosen period and find the expected aquifer wave travel amplitude and distance. For example, a river stage cycle of 10 ft/d would propagate inland with a 1-ft amplitude wave reaching about 800 ft, a 0.1-ft amplitude wave reaching about 1500 ft, and a 0.01-ft amplitude wave reaching about 2500 ft. Similarly, a river cycle with a 10-ft amplitude over 10 d would propagate inland with a 1-ft amplitude wave reaching about 2500 ft, a 0.1-ft amplitude wave reaching about 5000 ft, and a 0.01-ft amplitude wave reaching about 8000 ft, all in a level plane. This process may be used to map detection limits from river influence on an aquifer.

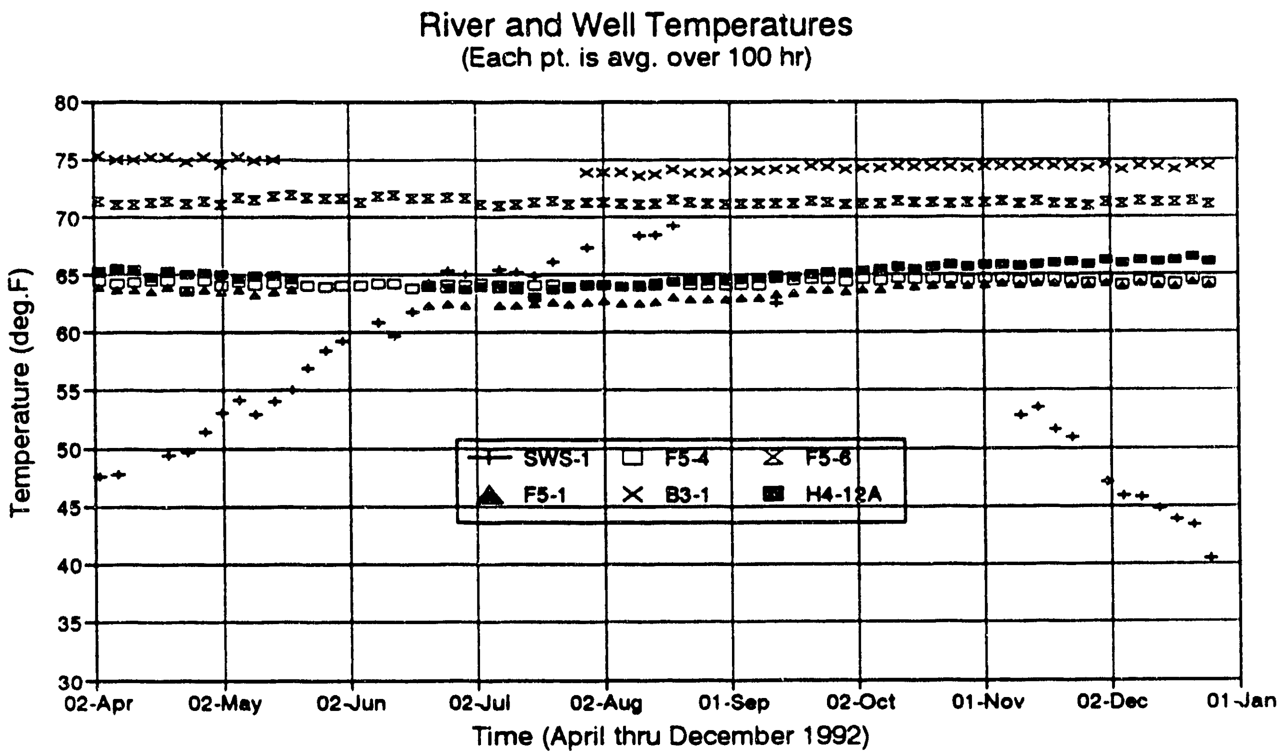

Figure 15. River and Well Temperatures--April through December 1992

Figure 19 shows the 300-FF-5 Operable Unit with two detection-limit lines drawn parallel to the river shore line. These 1-d detection-limit lines show the 10% and 1% wave amplitude penetration for any river wave with a 1-d period.

3.3.1 Data Attributes

Apparently, the high resolution of water levels in wells is warranted for the study areas because of the amplitude of river fluctuation and the distances from the river to the wells. However, passage of the propagating wave front could go undetected by the hourly scan, especially near the monitor system resolution limit.

Quality

Datalogger precision appears to be more important in the Ferris Model than accuracy of the MSL elevation. The datalogger precision is not the only factor that affects precision of the measurements, however. Other factors, such as transducer cord stretching, transducer mount slippage, or transducer circuit electrical resistance changes affect measurement precision, though not resolution.

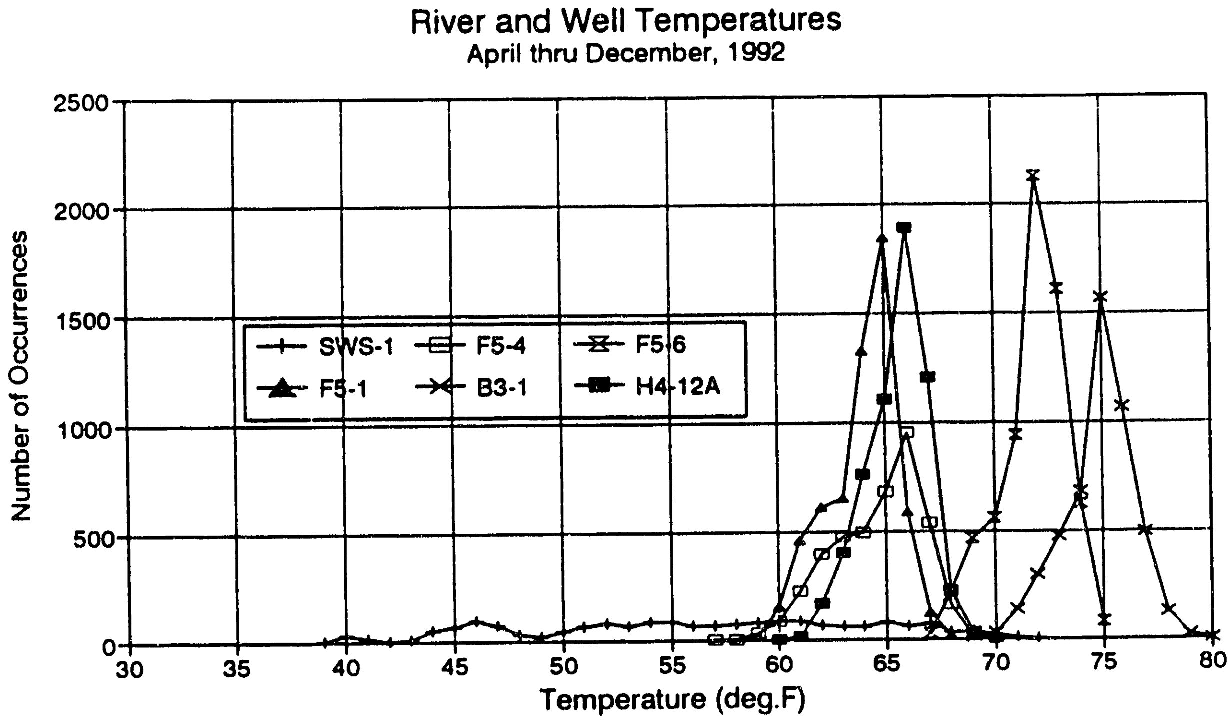

Figure 16. Occurrences of River and Well Temperatures--April through December 1992

Frequency

The hourly measurement frequency appears inadequate for detecting the exact time at which a wave crest passes a well. However, detection of wave crest passage would require collection of far more data or a change in the way the data are collected that would allow delayed data testing and exclusion. Perhaps more importantly, the PORFLO-3 Model to be used for remedial investigation modeling would likely not benefit from more frequent data; and the model may be calibrated using data now available.

3.3.2 Topographic Sequences of Water Surfaces

Modelers from WHC used the water level data collected from this project to prepare an animated-sequence, topographic plot. The plot caused concern over possible well casing survey errors surrounding well 399-4-7. A re-survey revealed no errors. However, other information then emerged that explained the unusual sink characteristic associated with well 399-4-7. Apparently, well 399-4-12, which is near well 399-4-7, is pumped continuously but at a variable rate. Pump discharge rate reaches up to 1 M gal/d, with corresponding discharge to the river slightly downstream from well 399-4-7. Not surprisingly, therefore, the area near well 399-4-7 appeared as a sink on the topographic plot. Two other important discoveries were

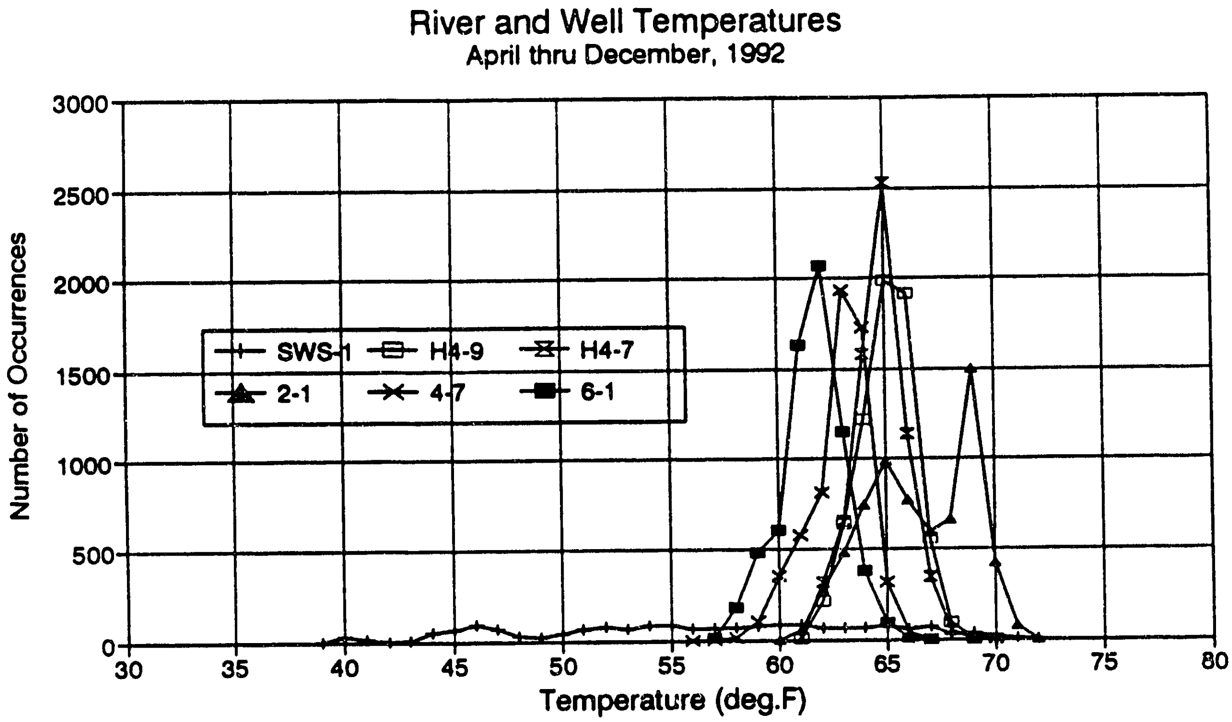

Figure 17. Occurrences of River and Well Temperatures--April through December 1992 for Well 399-4-7.

made from this animated sequence. First, more wells were desirable, as demonstrated when data were missing from wells S27-E9A and S22-E9A, causing dramatic shifts in the topographic sequence. Second, interaquifer leaks near wells 399-1-18C and 399-1-16B may be perturbing natural water movement in the highly transmissive zone in the 300-FF-5 Operable Unit, giving an incorrect picture regarding the source of upgradient water input and river-aquifer interactions.

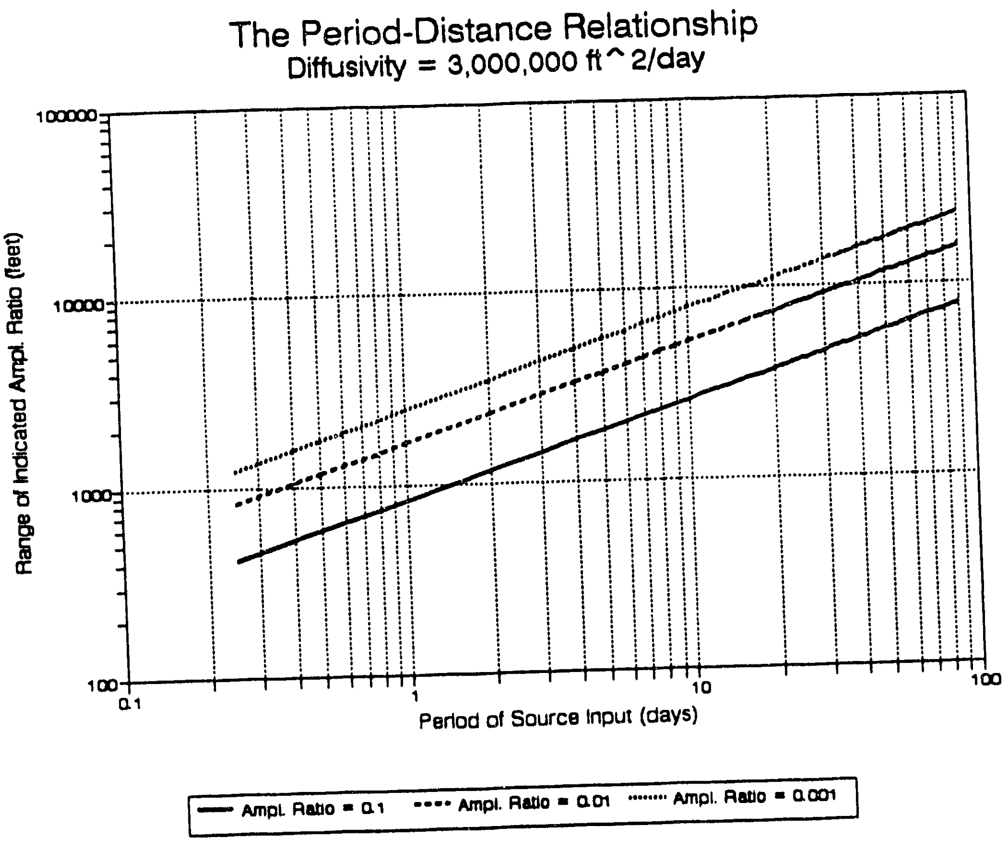

Figure 18. Aquifer Wave Propagation Graph of Distance vs Period

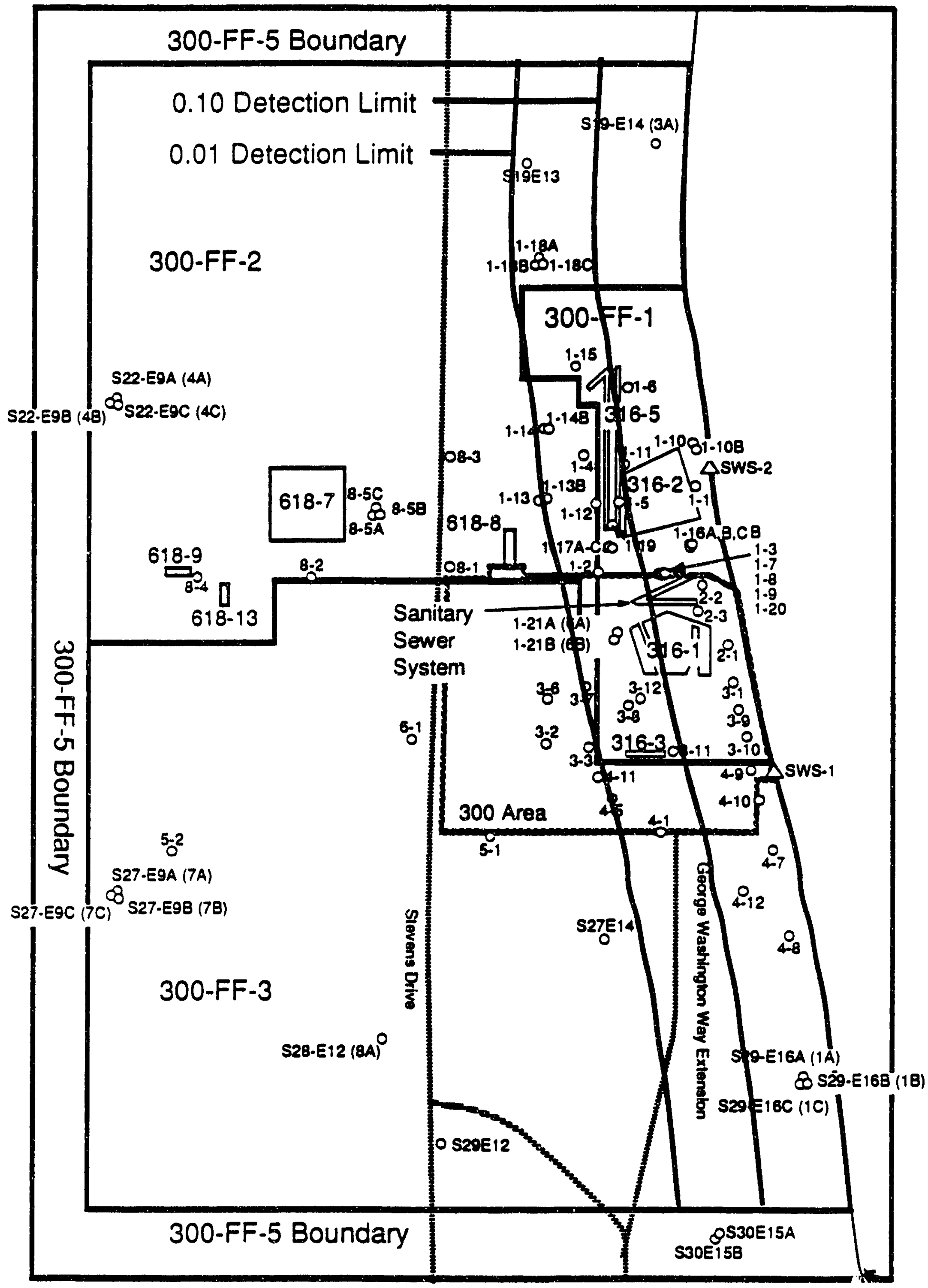

Figure 19. The 10% and 1% Detection Limit Lines for 1-d Wave Cycle (not to scale)

4.0 Conclusions

Automatic measurement and telemetry of water levels in wells have been efficient and reliable in obtaining hourly aquifer water level data for site characterization and remediation. Simple error detection and correction processes are important factors in data reliability. These simple processes include in situ calibration of pressure transducers, periodic steel tape and datalogger paired readings, data difference tests, and visual data checking.

Absolute accuracy of the method is unknown, partly because steel tape measurements, long accepted as the standard, have proven insufficiently reliable and partly because survey errors are uncertain. Monitor system precision appears to be within ± 0.02 ft, and possibly better. In situ calibration takes into account liquid physical property effects that influence hydraulic driving forces, including temperature, density, depth, solutes, and multi-phase systems. Also, accurate recalibration is possible without removal from the test well.

Some of the data were used in the Ferris Model to estimate aquifer hydraulic properties and to project relationships between river and well responses. Two factors that could have influenced the interpretation of the water flow behavior beneath the 300 Area are inter-aquifer communication and pumping. Inter-aquifer communication, either by means of natural fissures in the aquitards or because of faulty well drilling, completion, and/or sealing activities, could have resulted in leakage according to the hydraulic gradient of potential. The leakage would cause either local hydraulic mounding or receding to occur. Thus, certain well water level measurements, impacted by the presence of a mound or depression, may have fostered incorrect deductions about the overall shape of the water table. Pumping could have also produced local depressions, introducing the same sort of interpretive errors as just described.

When modelers from WHC prepared the animated-sequence, topographic plots, the plots caused concern over possible sources of errors. Surveys, missing data, unknown sinks, and aquitard perforation were among the most prominent concerns. Re-survey confirmed correct casing reference elevation. Missing data without model constraint caused gross distortions in topography, thus confirming the need for all perimeter data points. Continuous pumping of well 399-4-12 at a high rate accounted for otherwise unexplainably low water surface in the aquifer. Aquifer interlayer perforations associated with wells 399-1-18A and 399-1-16B may account for the unexpected inland flow direction parallel to the river.

Nevertheless, data gathered by the present monitor system appears suitable to calibrate and test computer models used to evaluate remediation options for aquifers beneath the Hanford Site.

5.0 References

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Appendix A

Well Identification

Appendix A

Well Identification

WELL IDENTIFICATION

INFORMAL	FORMAL	INFORMAL	FORMAL
1A,B,C	699-S29-E16A,B,C	4-1	399-4-1
3A	699-S19-E14	4-7	399-4-7
4A,B,C	699-S22-E9A,B,C	4-9	399-4-9
5A,B,C	399-8-5A,B,C	4-12	399-4-12
7A,B,C	699-S27-E9A,B,C	5-1	399-5-1
8A	699-S28-E12	6-1	399-6-1
1-1	399-1-1	8-1	399-8-1
1-2	399-1-2	B3-1	199-B3-1
1-7	399-1-7	B4-1	199-B4-1
1-8	399-1-8	B4-4	199-B4-4
1-9	399-1-9	F5-1	199-F5-1
1-10B	399-1-10B	F5-4	199-F5-4
1-16A,B,C	399-1-16A,B,C	F5-6	199-F5-6
1-18A,B,C	399-1-18A,B,C	H3-2A,B,C	199-H3-2A,B,C
2-1	399-2-1	H4-7	199-H4-7
2-2	399-2-2	H4-9	199-H4-9
3-9	399-3-9	H4-11	199-H4-11
3-12	399-3-12	H4-12A,B,C	199-H4-12A,B,C

Appendix B

Datalogger Program

Appendix B

Datalogger Program

* 1 A 3600 A			This sets 3600-s scan time (1 hour)
P	10		
	1	5	Location to display battery voltage
P	78		Precision
	1	1	High Precision
P	9		6-Wire Voltage Bridge with Excitation
	1	1	Reps (add 1 for each transducer connected)
	2	25	Excitation Range
	3	24	Bridge Measurement Range (25 for river stations)
	4	1	Input Channel
	5	1	Excitation Channel
	6	2500	Excitation Millivolts
	7	1	Location to store
	8	1	Multiplier
	9	0	Offset
P	86		Do
	1	10	Set Flag 0 High
P	77		Real Time
	1	110	Day:Hr:Min
P	70		Sample
	1	1	Reps (add 1 for each transducer connected)
	2	1	Location
P	17		Panel Temperature
	1	2	Location to store
P	14		Thermocouple Temperature
	1	1	Replications
	2	21	Range 1 with 60 Hz rejection
	3	5	Input Channel (where thermocouple is connected)
	4	1	Thermocouple Type (1 is for Cu/Con)
	5	2	Reference Location (same as P17 step 1)
	6	3	Location to store
	7	1.8	Multiplier (change C to F degrees)

	8	32	Offset (change C to F degrees)
P	86		Do
	1	10	Set Flag 0 High
P	70		Sample
	1	1	Reps (add 1 for each transducer connected)
	2	3	Location to store

Appendix C

Pumping Test Analysis Report

Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509) 376-8329

August 13, 1991

Craig Swanson
Westinghouse-Hanford
Geosciences Group
450 Hills Room 60
MS#H4-56
Richland, Washington 99352

Dear Craig:

Evaluation of Pumping Test Analyses Reported in Schalla, et al. (1988)

In support of the FF5-300 Area site characterization program, I have reviewed the results of 13 pumping tests reported in Schalla, et al. (1988). The purpose of this review is to provide a qualitative evaluation of the uncertainty associated with the pumping test derived transmissivity values. The evaluation results will be used for planning the level and location of future hydraulic characterization within the FF5-300 Area. For the most part, the hydraulic property estimates obtained fall within the range previously reported for the unconfined aquifer across the Hanford Site. A quick review of the reported test results are included in this letter report for each individual well site, and are summarized in Table 1.

As a basis for some of the review comments, a background discussion is provided that outlines some of the analytical procedures employed in Schalla, et al. (1988) and utilized in the review. It should be noted that the review comments contained in this letter report are intended to indicate qualitatively the level of uncertainty associated with the hydraulic properties that are reported in Schalla, et al. (1988) for the individual pumping test results.

Sincerely,

Frank A. Spane, Jr.

Frank A. Spane, Jr., Ph.D.
Staff Scientist

FAS:go

Attachment

cc: Ron Jackson
Tony Knepp
Reed Simpson

Background Discussion

The analyses presented in Schalla, et al. (1988) rely primarily on semi-log straight-line solutions and log-log type curve matching procedures. The pumping test analyses are complicated in some cases by: recharge boundary effects and water-level fluctuations induced by the Columbia River, wellbore storage (especially for intermediate and lower transmissivity test intervals), and pumping rate variations. The results reported in Schalla et al. (1988) rely on several qualitative equation relationships (e.g., Schafer 1978, Hargis, 1979) to determine when formation responses have been established (i.e., when wellbore storage effects are not important) and visual examination for detecting the presence of boundaries. While these methods are accepted procedures for analyzing pumping test results, they are not very accurate or definitive for establishing the proper data set for analysis.

Since the reported analyses depend primarily on semi-log straight line solutions, it is important that the analyses be applied correctly, for that portion of the pumping test data for which it is valid (i.e., homogeneous formation - radial flow conditions). A recently developed method that has been used quite extensively in the petroleum industry to help identify various formation responses (i.e., homogeneous vs. heterogeneous formation) and flow conditions (wellbore storage, radial flow, boundaries, etc.), is the use of pressure derivatives. When plotted in log-log format in combination with the traditional pressure change vs. time plot, the pressure derivative response curve can be used diagnostically to identify the presence of wellbore storage and boundaries, and to precisely indicate the establishment of radial flow conditions, for which straight-line solutions are appropriate.

To illustrate the use of pressure derivative log-log diagnostic plots, Figure 1 shows the response of a combined traditional pressure change versus time and pressure derivative plot for: (1) a homogeneous formation with wellbore storage, and (2) a homogeneous formation with wellbore storage and a recharge boundary effect. The axes in Figure 1 are represented by dimensionless drawdown versus dimensionless time. For the arbitrarily selected formation/wellbore conditions (i.e., CD = 1e+7), the pressure derivative plot clearly shows the presence of wellbore storage in early time by its characteristic "hump" pattern. Radial flow conditions are established (and straight-line solutions valid) when the pressure derivative line is horizontal (i.e., at a value of 0.5).

When boundaries are present, the pressure derivative plot clearly indicates its presence by a marked departure from the homogeneous formation plot response. In this case, recharge is indicated by the significant decline pattern (from the homogeneous formation response) occurring at a dimensionless time of approximately 1E+8. As shown in Figure 1, the presence of a recharge boundary in the traditional pressure change vs. time plot is difficult to distinguish, and is denoted by only a subtle departure from the homogeneous formation response. This is in marked contrast with the pressure derivative plot, where a recharge boundary response is equal to 0.

Figures 2 and 3 show the predicted response patterns for (1) a homogeneous formation : T = 100 ft2/d and S = 10-3), and (2) the same formation with a recharge boundary exhibited at a time of approximately 25 minutes. It should be noted that the hydrologic properties selected are similar to those exhibited for the lower Ringold Formation in the 300 Area. As indicated in Figure 2, radial flow conditions are not established until about 150 minutes into the test; therefore, a straight-line analysis would not provide valid results for data prior to this time point. The presence of the recharge boundary is clearly denoted in the pressure derivative plot after approximately 25 minutes.

Figure 3 shows the semi-log plot that would be commonly used for straight-line analysis of the pumping test drawdown data. As indicated, the straight line plot for the homogeneous case approaches the true straight-line portion of the plot (i.e., for time data greater than 150 minutes) in a curvi-linear fashion. Drawdown data that would be erroneously "force fit" with a straight-line solution immediately before the recharge boundary becomes evident, would provide a hydraulic property estimate that was actually lower than actual formation conditions.

In summary, pressure derivative analysis of pumping test results can be used to:

- diagnostically determine formation response (homogeneous vs.heterogeneous) and boundary conditions (recharge or discharge) that are evident during the test,
- determine when radial flow conditions are established and, therefore, when straight-line solution analysis of drawdown data is valid, and
- can be used in log-log type-curve matching to determine hydraulic properties for test data exhibiting wellbore storage effects and boundary conditions.

Pumping Test Evaluations

Well 399-1-13

The pumped well is screened primarily in the Hanford Formation, with a minor underlying section of Ringold Formation also present. The reported test result of 110,000 ft^2/d is based on the analysis results of a 136 minute pumping test which was conducted at an average pumping rate of 660 gpm. The analysis provided in Schalla, et al. (1988) appears appropriate, with the straight-line analysis of the drawdown data appearing to be most representative of actual test formation conditions (i.e., not affected by non-formational factors such as river fluctuations, wellbore storage, etc.)

Well 399-1-18A

The test well is screened primarily in an upper section of Ringold Formation immediately below the unsaturated Hanford Formation. The test analysis result of 1,000,000 ft^2/d is based on the analysis of a 120 minute pumping test that was conducted at an average pumping rate of 680 gpm. The straight-line drawdown analysis contained in Schalla, et al. (1988) appears appropriate. However because of the extremely slight drawdown recorded during the short-duration pumping test and the fact that the recovery phase data were not analyzable, a level of uncertainity exists with respect to the actual transmissivity of the test interval. Until additional analyses can be performed, the transmissivity value of 1,000,000 ft^2/d is considered to be qualitatively acceptable. The assigned value for hydraulic conductivity of 50,000 ft/d is also considered to be highly uncertain, since it is based on an arbitrarily selected aquifer thickness of 20 ft.

Well 399-1-14

The pumped well is screened in a lower section of the Hanford Formation, directly above the underlying Ringold Formation. The pumping test was conducted for a period of 420 minutes at an average pumping rate of 565 gpm. The reported transmissivity value of 190,000 ft^2/d is based on averaging the straight-line analysis results of test data obtained during the recovery phase with separate pressure transducer and electric water-level indicator systems. Data obtained during the drawdown phase were not analyzed because of induced variability in the data set caused by non-uniform pumping rates, river fluctuations, and possible well development that occurred during the pumping phase.

Although the recovery analyses reported by Schalla, et al. (1988) provide comparable transmissivity estimates, the fact that the recovery curves displayed slightly different patterns and that different time data sets were analyzed (i.e., obtained with the two recording equipment systems) suggests some uncertainty in the cited average transmissivity value.

Well 399-1-10

The test well is screened in an upper section of the Ringold Formation, immediately below the unsaturated Hanford Formation. The pumping test was conducted for a period of 240 minutes at an average pumping rate of 634 gpm.

The reported transmissivity value of 200,000 ft^2/d is based on the average of the straight-line analysis of drawdown and recovery water-level data phases. The straight-line analysis results, however, exhibit considerable divergence, with the recovery phase analysis yielding an estimate of 260,000 ft^2/d versus a value of 110,000 ft^2/d obtained from the drawdown phase.

Because of the transmissivity estimate differences obtained from the drawdown and recovery phases, the possible effects induced by pump test equipment and external stress factors (i.e., Columbia River fluctuations) that occurred during the test, a moderate level of uncertainty for the assigned average transmissivity value of 200,000 ft^2/d is warranted.

Well 399-1-18B

The pumped well is screened in a lower section of the Ringold Formation, immediately above the M3 layer. The transmissivity value of 100 ft^2/d, reported in Schalla, et al. (1988), is the average value obtained from the straight-line analysis and Theis log-log curve match of the drawdown phase of the pumping test. The pumping test was conducted for a duration of 480 minutes, at an average pumping rate of approximately 4 gpm. The drawdown phase analysis was complicated by fluctuations and adjustments to the pumping rates. The straight-line solution was applied to analyzing drawdown data between 200 and 480 minutes, following the last major adjustment in flowrate. Recovery water-level data were not analyzed, due to river fluctuation effects.

The adjustments of flowrate that occurred during the drawdown phase, as well as the impact that nearby river fluctuations had on observed water levels suggests a moderate level of uncertainty in the reported transmissivity for this test section. In addition the reported hydraulic conductivity value of 1.9 ft/d is also considered to be uncertain, since it is based on an arbitrarily assigned aquifer thickness of 53 ft.

Well 399-1-18C

The test well is screened in lowest section of the Ringold Formation, directly above the Goose Island basalt flow. The transmissivity value of 90 ft^2/d, reported in Schalla, et al. (1988), is the average value obtained from the straight-line analysis of the drawdown and recovery phases, and log-log type curve matching of the drawdown phase.

An independent pressure derivative analysis of the drawdown and recovery pumping test data by the reviewer indicated that a "recharge" boundary was encountered prior to radial flow conditions being established for both phases of the test (note: the early stages of delayed yield/unconfined aquifer response and confined aquifer leakage also produce a "recharge" boundary response in pressure derivative plots). Therefore, the straight-line analyses presented in Schalla, et al. (1988) for this pumping test are not valid and should not be utilized for characterization of the hydrogeologic unit.

Well 399-1-17B

The pumping well is screened in a Ringold Formation section that is immediately above a mud layer (M3 Layer?). The transmissivity value of 900 ft^2/d that is reported in Schalla, et al. (1988) for this interval, represents the average value obtained from the straight-line analysis of the drawdown and recovery phases, and log-log type curve matching of the drawdown phase.

As for the previous well test, an independent pressure derivative analysis of the drawdown and recovery pumping test data by the reviewer indicated that a "recharge" boundary was encountered prior to radial flow conditions being established for both phases of the test. Therefore, the straight-line analyses presented in Schalla, et al. (1988) for this pumping test are inappropriate and should not be utilized for characterization of the hydrogeologic unit.

Well 399-1-17C

The pumping well is screened in the lowest section of the Ringold Formation section that is immediately above the underlying Martindale basalt flow. The transmissivity value of 1300 ft^2/d that is reported in Schalla, et al. (1988) for this interval, represents the average value obtained from the straight-line analysis of the drawdown and recovery phases, and log-log type curve matching of the drawdown phase.

As for the previous two well test reviews, an independent pressure derivative analysis of the drawdown and recovery pumping test data indicated that a recharge boundary or delayed yield response condition was encountered prior to radial flow conditions being established for both phases of the test. Therefore, the straight-line analyses presented in Schalla, et al. (1988) for this pumping test are inappropriate and should not be utilized for characterization of the hydrogeologic unit.

In addition the reported hydraulic conductivity value of 260 ft/d is also considered to be uncertain, since the actual zone(s) thickness that is contributing during pumping (i.e., from the flow top and Ringold sediment) is not known with a high degree of precision.

Well 399-1-16C

The pumping well is screened in the lowest section of the Ringold Formation section that is immediately above the underlying Martindale basalt flow. The transmissivity value of 90 ft^2/d that is reported in Schalla, et al. (1988) for this interval, represents the straight-line analysis of the recovery phase. The drawdown data analyzed in Schalla, et al. (1988) yielded a transmissivity value that was nine times lower than the recovery value. It was not included, however, in the assigned transmissivity estimate for the test interval due to erratic drawdown water-level data caused by pumping rate variations.

An independent pressure derivative analysis of the drawdown data confirms the erratic behavior during this phase. It also indicates that radial flow conditions were not established prior to termination of the pumping test; thereby, rendering any straight-line analysis of drawdown or recovery phase data as invalid. The pressure derivative analysis of the recovery phase data also indicates that the river fluctuation dynamics induced an overwhelming effect on recovery pumping test data, which would also invalidate the analysis contained in Schalla et al. (1988) for formation properties.

Based on the review evaluation, the reported transmissivity value 90 ft^2/d should be considered to be inappropriate and not be included in assessing the transmissivity of this hydrogeologic unit.

Well 399-1-16B (Observation Well 399-1-16D)

The pumping well (16B) and observation well (16D) are screened in a section of the Ringold Formation, immediately above an areally extensive mud layer (M3?). Two pumping tests were performed; the first at a pumping rate of 12 gpm over a test period of 800 minutes, and the second at 20 gpm over a test duration of 300 minutes. Transmissivity values of 130 ft^2/d and 170 ft^2/d are reported in Schalla, et al. (1988) for this interval for the two tests. The transmissivity values are based on log-log and straight-line analysis results of drawdown phase data and straight-line analysis of recovery phase data obtained from the observation well (16D). Schalla, et al. (1988) report that test data obtained from the pumping well (16B) were influenced both by wellbore storage and recharge boundary (i.e., the Columbia River) effects, and could not be analyzed.

An independent pressure derivative analysis of drawdown and recovery data for the pumping well confirms the presence of wellbore storage and recharge boundary effects, and the conclusion that the data are not analyzable. Pressure derivative analysis of drawdown and recovery data obtained at the observation well (16D) also confirms the same response characteristics, and indicates that radial flow conditions were not established prior to encountering the recharge boundary. This indicates that the reported transmissivity values of 130 ft^2/d and 170 ft^2/d are inappropriate and should not be included in assessing the transmissivity of this hydrogeologic unit.

Well 399-1-16A

The pumping well is screened in the uppermost saturated section of the Ringold Formation. The transmissivity value of 10,000 ft^2/d that is reported in Schalla, et al. (1988) for this interval, represents the average of the log-log and straight-line analysis results of the drawdown data phase. The recovery data analyzed in Schalla, et al. (1988) indicated that recharge boundary and river fluctuations that occurred during this phase prevented an accurate estimate of transmissivity being obtained. It was not included, however, in the assigned transmissivity estimate for the test interval.

An independent pressure derivative analysis of the recovery data confirms the presence of the recharge boundary and river fluctuation effects. The pressure derivative analysis of the drawdown phase data also indicates the presence of the recharge boundary, but also indicates the absence of wellbore storage and the establishment of radial flow conditions prior to interception of the boundary. This indicates that the test data are analyzable with straight-line analysis procedures. The straight-line analysis result contained in Schalla et al. (1988) for transmissivity (i.e., 15,000 ft^2/d) is considered to be an appropriate estimate for the test interval.

Well 399-1-9

The pumping well is screened in the lowest section of the Ringold Formation section that is immediately above the underlying Martindale basalt flow. The transmissivity value of 60 ft^2/d that is reported in Schalla, et al. (1988) for this interval, represents the straight-line analysis of the recovery data phase. The drawdown data analyzed in Schalla, et al. (1988) indicated the presence of extended wellbore storage effects and, therefore, were not included in the average transmissivity assigned for the test interval. The effects of wellbore storage were also recognized in Schalla et al. (1988) as affecting the straight-line analysis results. The cited value of 60 ft^2/d was, therefore, considered to be questionable by Schalla, et al. (1988).

An independent pressure derivative analysis of the recovery data confirms the presence of wellbore storage and indicated that radial flow conditions were not established prior to termination of recovery data collection. The straight-line analysis of the recovery phase data, therefore, is invalid.

In addition the reported hydraulic conductivity value of 6 ft/d is also considered to be uncertain, since the actual zone(s) thickness that is contributing during pumping (i.e., from the flow top and Ringold sediment) is not known with a high degree of precision.

Based on the review evaluation, the reported transmissivity value 60 ft^2/d should be considered to be highly questionable (as also indicated in Schalla, et al., 1988), and not be included in assessing the transmissivity of this hydrogeologic unit.

Summary

The evaluation of the pumping test results reported in Schalla, et al. (1988) is summarized in Table 1. The review evaluation comments are designed to provide a qualitative indication of the level of uncertainty associated with the reported (pumping test derived) transmissivity values. As an approximate means of quantifying the level of uncertainty, the following generalizations are provided:

Uncertainty Designation	Transmissivity Uncertainty
Slight	Within a factor of 3
Moderate	Within a factor of 10
High	Greater than a factor of 10

As indicated, nearly half the reported values have an invalid or high level of uncertainty evaluation designation. The lowest level of uncertainty is ascribed to the higher transmissive sections within the Hanford and upper Ringold Formations.

As indicated previously, factors contributing to the uncertainty of the pumping test results included the recharge boundary effects and stage fluctuations induced by the neighboring Columbia River, delayed yield/unconfined aquifer response, confined aquifer leakage, variable pumping discharge rates, etc.

Reference

Schalla, R., (14 co-authors), 1988, Interim Characterization Report for the 300 Area Process Trenches, Pacific Northwest Laboratory, PNL-6716, Richland, Washington.

Table 1. Pertinent Information Reported in Schalla, et al. (1988) for Pumping Test Results in the FF-5/300 Area.

Well Designation	Representative Test Formation*	Reported Transmissivity (ft2/d)	Review Evaluation
399-1-13	Hanford (U.Ring)	110,000	Acceptable Value
399-1-18A	Upper Ringold	1,000,000	Slight Level of Uncertainty
399-1-14	Hanford	190,000	Slight Level of Uncertainty
399-1-10	Upper Ringold	200,000	Moderate Level of Uncertainty
399-1-18B	Ringold	100	Moderate Level of Uncertainty
399-1-18C	Lower Ringold/Basalt	90	Invalid Value
399-1-17B	Ringold	900	Invalid Value
399-1-17C	Lower Ringold/Basalt	1,300	Invalid Value
399-1-16C	Lower Ringold/Basalt	90	Invalid Value
399-1-16D	Ringold	130	Invalid Value
399-1-16D	Ringold	170	Invalid Value
399-1-16A	Upper Ringold	10,000	Acceptable Value
399-1-9	Lower Ringold/Basalt	60	High Level of Uncertainty

* The designation of "upper" and "lower" Ringold Formation refers to the position of the test section within the Ringold Formation underlying the FF5-300 Area, and has no formational member connotation.

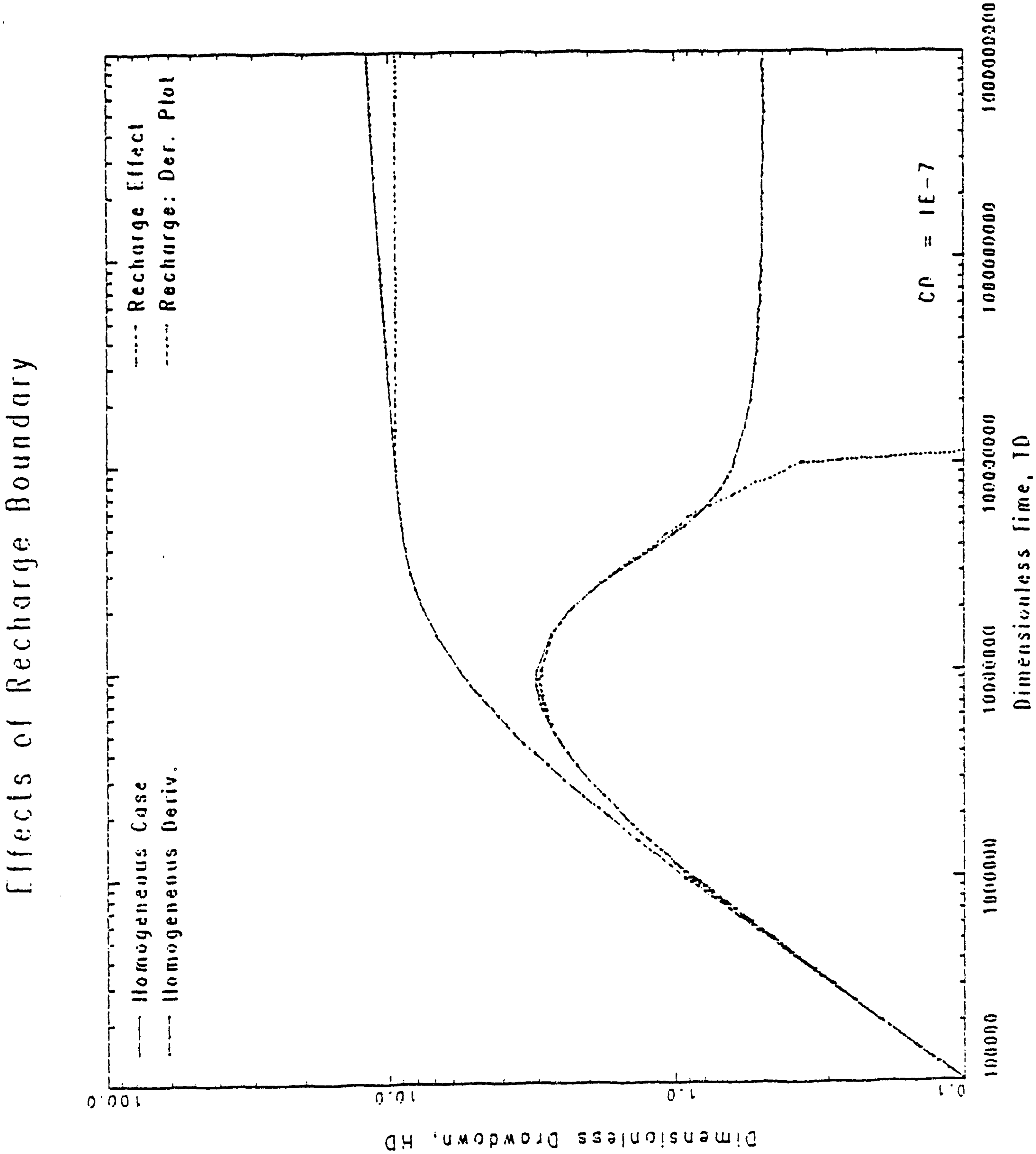
Effects of Recharge Boundary
Homogeneous Case
Homogeneous Deriv.
Recharge Effect
Recharge: Der. Plot
CD = 1E-7
Dimensionless Time, TD
Dimensionless Drawdown, HD
100000
1000000
10000000
100000000
1000000000
10000000000
0.1
1.0
10.0
100.0

Figure 1.

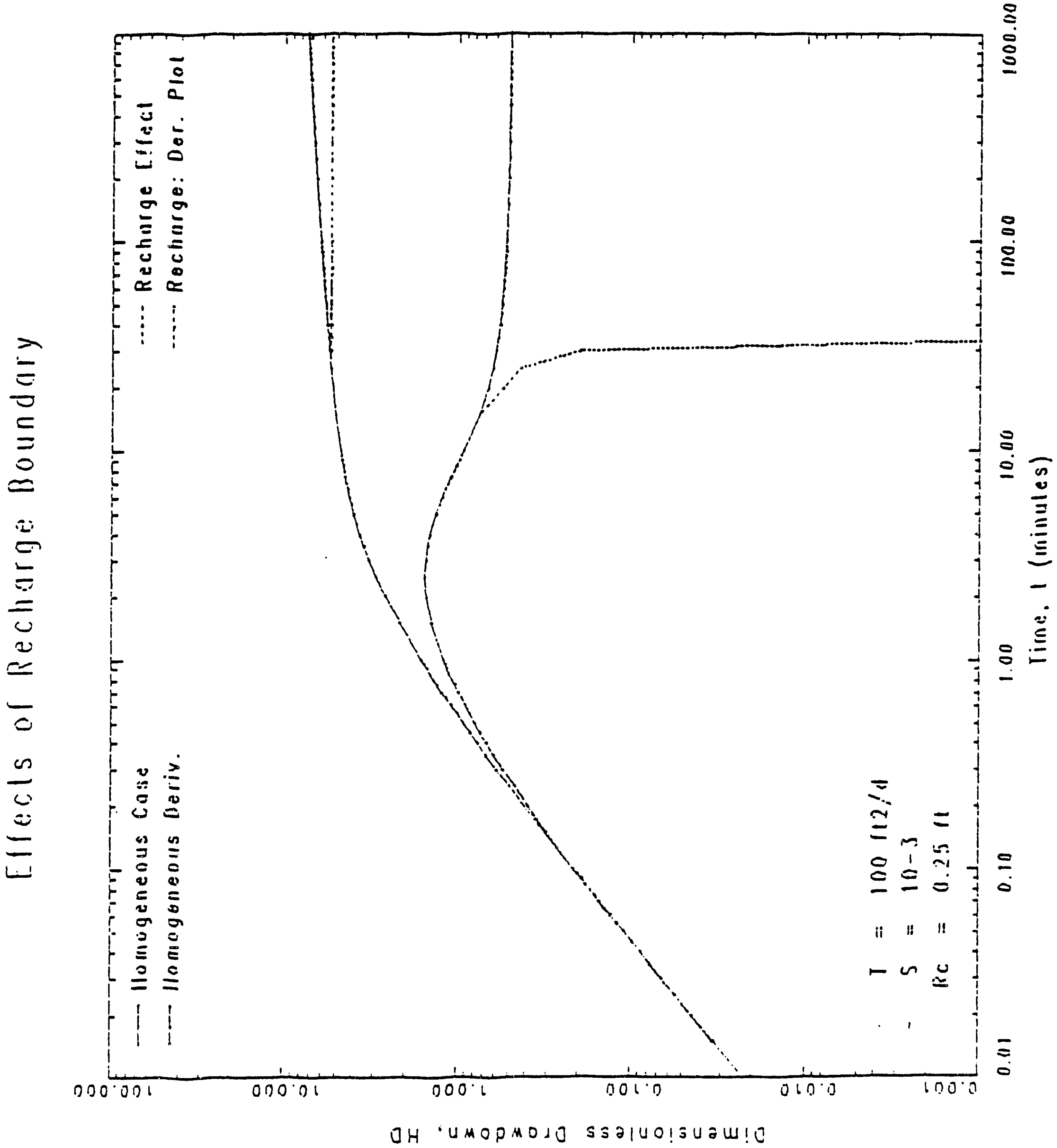
Effects of Recharge Boundary
Homogeneous Case
Homogeneous Deriv.
Recharge Effect
Recharge: Der. Plot
T = 100 ft2/d
S = 10-3
Rc = 0.25 ft
Time, t (minutes)
0.01
0.10
1.00
10.00
100.00
1000.00
Dimensionless Drawdown, HD
0.001
0.010
0.100
1.000
10.000
100.000

Figure 2.

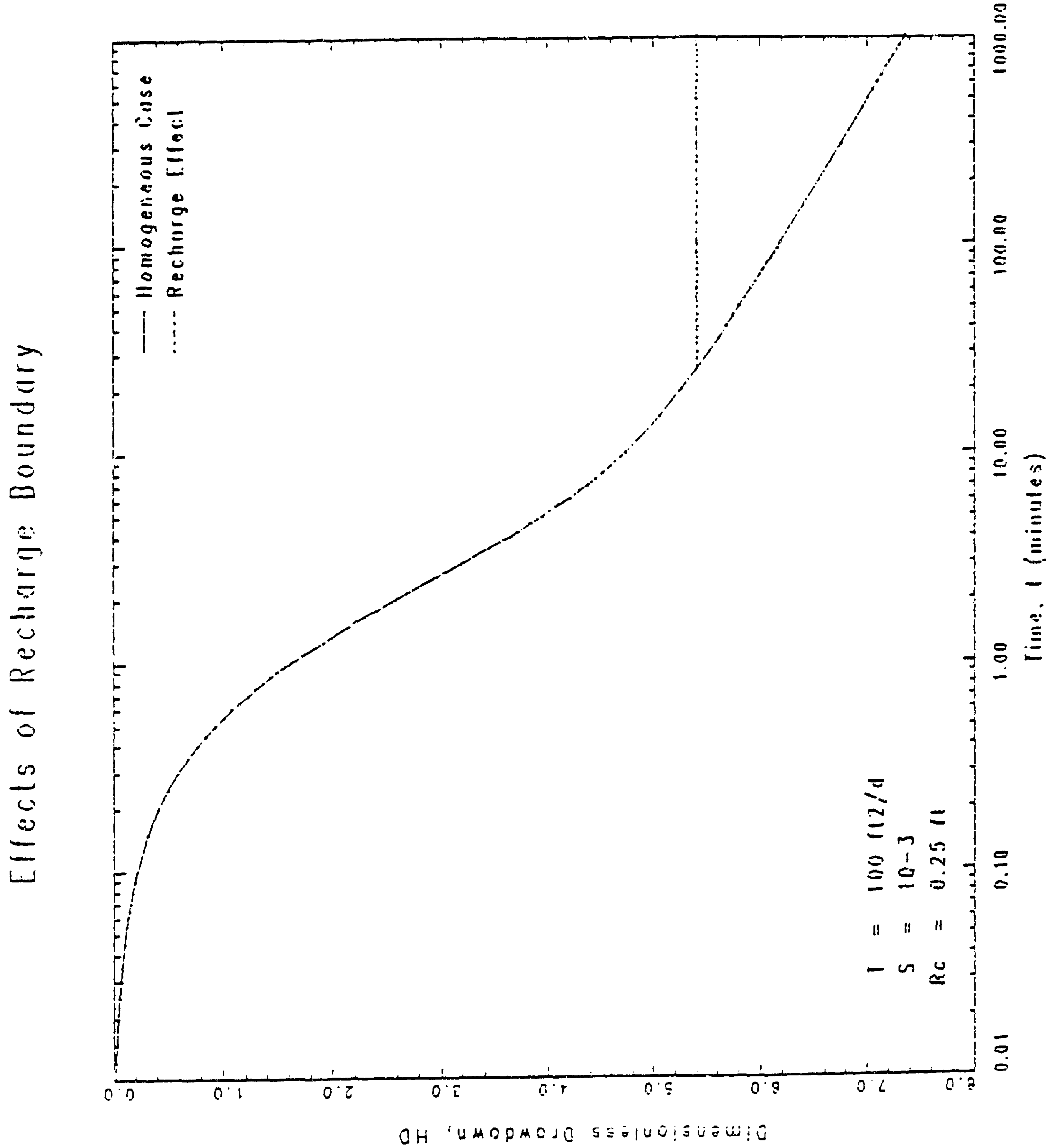
Effects of Recharge Boundary
Homogeneous Case
Recharge Effect
T = 100 ft2/d
S = 10-3
Rc = 0.25 ft
Time, t (minutes)
Dimensionless Drawdown, HD
0.01
0.10
1.00
10.00
100.00
1000.00
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0

Figure 3.

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