145

Harding Lawson Associates

Engineers and Geoscientists

HYDROGEOLOGIC INVESTIGATION
WOHLER AQUIFER STUDY
SONOMA COUNTY, CALIFORNIA

HLA Job No. 1916,005.02

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF TABLES AND ILLUSTRATIONS

EXECUTIVE SUMMARY

The results of this investigation indicate that the study area shown on Plate 1 is suitable for water resources development by conjunctive use of the ground-water system and Russian River surface water supply. This conclusion is based on interpretation of the logs of the 16 borings drilled, evaluation of water-level data, analysis of the 3-day aquifer test performed, and review of previous reports.

The western portion of the 90-acre site, adjacent to the river, has surficial silts and clays generally less than 15 feet thick, with 50 to 70 feet of saturated sands and gravels beneath them. These sands and gravel comprise the aquifer. The eastern edge of the site, adjacent to the edge of the valley, has much thicker surficial silts and clays, and minimal saturated sand and gravel thickness.

On the basis of the aquifer test results, the following average aquifer parameters were calculated:

Transmissivity:	120,000 ft^2/day
Hydraulic Conductivity:	1,600 ft/day
Specific Yield:	0.23

These are consistent with results of previous tests conducted at the site of the nearby collector wells.

In spite of the high transmissivity of the aquifer, it is not areally extensive, being restricted to the river valley; hence ground-water storage and natural flow through the aquifer is limited. Therefore, as with the other systems in the vicinity, successful water resource development of this site must conjunctively use the Russian River surface water supply and the highly transmissive aquifer system.

The aquifer is capable of transmitting large quantities of water, and the Russian River can provide the water. The conjunctive development of these resources is limited by the ability to transfer surface water to the ground-water system. The presence of fine-grained materials on the bottom of the Russian River, and the prohibitions on removing these materials would limit a pumping system without recharge facilities to production of only an estimated 2,500 gpm (3.6 million gallons per day [mgd]) by induced filtration. Therefore, surface spreading of river water on the site would be necessary for significant water resource development. On the basis of conservative assumptions, an estimated 20,000 gallons per minute (gpm) (29 mgd) could be recharged on the site using a total of 40 acres of spreading basins. Seven conventional vertical wells installed on the site could then provide for production of about 20,000 gpm (29 mgd) from the aquifer. Using fewer than 40 acres of spreading basins would proportionately reduce the production capacity and the number of wells required.

On the basis of our analysis, the site appears to have the potential to provide significant conjunctive use of the surface water via the ground water system. Because the property is not suitable as is for production of more than a few thousand gallons per minute (a few million gallons per day), this would require extensive engineering and construction. In addition, development of this property, particularly the area adjacent to the river, would be subject to stringent, and possibly prohibitive, permitting requirements.

1.0 INTRODUCTION

In February 1988, the Sonoma County Water Agency (SCWA) contracted Harding Lawson Associates (HLA) to provide hydrogeologic consulting services for the SCWA Wohler Aquifer Study. The purpose of the study was to characterize the hydrogeology of the study area and to assess the water development potential of the property immediately upstream of the two existing collector wells at Wohler Bridge. This report summarizes the methodology, results, and conclusions of HLA's evaluation.

The study area is north of the Wohler Bridge, within the floodplain on the east bank of the Russian River (Plate 1). The area investigated is approximately 90 acres, extending from the eastern valley wall to the river. The area exhibits approximately 35 feet of topographic relief, with gentle slopes from the base of the eastern valley wall and steeper slopes at the river bank. A former gravel pit in the southeastern portion of the study area contains ponded water. Natural vegetation covers most of the study area, except the northeastern portion, which has undergone recent tilling. The local geology consists of alluvial deposits (unconsolidated clays, silts, sands and gravels) of variable thickness which overlie Jurassic and Cretaceous age bedrock. The sands and gravels comprise the aquifer investigated in this study. SCWA currently operates two radial collector wells located just downstream (south) of the study area (indicated as Caissons 1 and 2 on Plate 1). Together, these wells pump up to about 21,000 gpm (30 mgd) from these sands and gravels.

As described in HLA's proposal dated January 21, 1988, the work performed included:

- Reviewing available information and selecting Phase I exploratory boring/observation well locations
- Drilling eight exploratory borings to bedrock and installing 2-inch-diameter observation wells in the borings (Phase I)

- Reviewing Phase I exploratory boring and water-level data, and selecting test well and additional observation well locations
- Drilling and installing a 12-inch-diameter test well and seven additional 2-inch diameter observation wells (Phase II)
- Performing and analyzing a 3-day 2,500 gpm (3.6 mgd) aquifer test.
- Evaluating the ground-water production and recharge potential of the site
- Preparing this report.

HLA was contracted to provide technical consulting services for the project. Well drilling and construction, pump emplacement, and test pumping were performed by Weeks Drilling and Pump Company, which was under direct contract with SCWA.

2.0 GEOLOGIC AND HYDROLOGIC SETTING

The Russian River valley in the vicinity of the site ranges from less than 1,000 feet wide at Wohler Bridge to more than 3,000 feet wide at the bend in the river at the study site (Plate 1). Upstream of the site, the valley is more than a mile wide. A constriction in valley width generally results in higher energy river flow, and deposition of coarser, more permeable materials. This is evidenced at this site by the high hydraulic conductivities reported from aquifer tests on the collector wells, and confirmed by the aquifer test conducted for this study.

The aquifer at the site is composed of Quaternary alluvium and river channel deposits (*Cardwell, 1965*). These materials fill the valley cut into the surrounding bedrock by the river. On the northern and western side of the valley, Jurassic and Cretaceous rocks crop out. These consolidated sandstone, shale, chert, and metamorphic rocks (undifferentiated Franciscan and Knoxville Formation) are generally impermeable, except for local fractured zones. Cardwell (*1965*) has mapped the hill south and east of the valley as Plio-Pleistocene Merced Formation. This marine sandstone and claystone has generally low permeability and a limited areal extent. It is underlain by the undifferentiated Jurassic and Cretaceous rock described above.

Recharge to the alluvial aquifer is primarily by infiltration from the Russian River. Recharge from the surrounding bedrock is considered to be minor by comparison.

United States Geological Survey (USGS) river gauge data were reviewed for Gauging Station 11467000 (located at Hacienda Bridge, approximately 4 miles downstream of the study area). They are summarized below for the period 1940-1987.

Average discharge, 48-year record	=	2,362 cubic feet/second (cfs) (1,060,066 gpm; 1,526 mgd)
Maximum recorded discharge (2/18/86)	=	102,000 cfs (45,777,600 gpm; 65,920 mgd))
Minimum recorded discharge (5/6/77)	=	0.75 cfs (337 gpm; 0.5 mgd)

(Source: *Anderson et al., 1988*)

Currently, during a normal rainfall year, a minimum flow of 125 cfs (56,100 gpm; 81 mgd) is required to be maintained at the Hacienda Bridge gauge. During a dry year a minimum flow of 85 cfs (38,148 gpm; 55 mgd) is required, and during a critical year 35 cfs (15,708 gpm; 23 mgd) must be maintained (*State Water Resources Control Board, 1986*)

3.0 PREVIOUS INVESTIGATIONS

Previous investigations of the study area and adjacent property have been performed by Ranney Method Western Corporation (*Ranney, 1955, 1970 and 1975*) and Norcal Geophysical Consultants (*Norcal, 1987*). Ranney performed exploration and aquifer testing related to the collector wells south of the study area. Norcal conducted a geophysical investigation to assess subsurface lithologic variations (using electrical resistivity and seismic refraction methods), and hydrodynamic characteristics (using self-potential methods) of subsurface materials in the study area. On the basis of the geophysical surveys, Norcal mapped two channel-like features trending northeast-southwest through the study area. Norcal postulated that one or both of these features were zones of significant ground-water flow across the study area.

4.0 FIELD INVESTIGATION AND AQUIFER TESTING

Fifteen 2-inch-diameter, 50- to 70-feet-deep observation wells and one 12-inch-diameter, 103-feet-deep test well were installed to evaluate the geologic and hydrologic characteristics of the study area (Plate 2). A three-day aquifer test was conducted using these wells to evaluate aquifer properties in the study area.

4.1 Phase I - Exploratory Borings/Observation Wells

Between July 19 and July 28, 1988, eight exploratory borings were drilled to the unconsolidated alluvium/bedrock contact to characterize lithologies and thicknesses of the alluvium. Borings locations were selected largely on the basis of the Norcal study results. An observation well was installed in each boring (Wells TW-1 through TW-8). Lithologic logs and well completion diagrams are presented in Appendix A.

After well development, water levels were measured to determine the water table configuration and hydraulic gradient. Initial water-level measurements were conducted on July 26 and August 10, 11, 16, 18, and 19, 1988, during periods when the existing collector wells were pumped intermittently. These water-level data sets reflect the varying pumping schedules. Water-level data for all wells are presented in Appendix B.

4.2 Phase II - Test Well and Observation Wells

Evaluation of the materials observed during drilling the eight Phase I borings and the water-level data collected from the observation wells led to selection of locations for the test well (Well PW-1) and seven additional observation wells (Wells TW-9 through TW-15) . The test well was sited in the area of greatest thickness of aquifer material, as observed during Phase I drilling. The seven additional observation wells were located along two lines roughly perpendicular to each other, and trending generally perpendicular or parallel to the direction of ground-water flow (Plate 2). Six observation wells (TW-4, and TW-9 through TW-13) were located along the lines at distances of approximately 20, 50, and 100 feet from the pumping well to determine aquifer anisotropy and the effects of recharge from the river. An additional well (TW-14) was located on the eastern side of the pumping well to monitor for aquifer/bedrock boundary influence, if any. TW-15 was located near the river to monitor the river/aquifer relationship upgradient of the pumping well. Well completion diagrams and lithologic logs are presented in Appendix A.

4.3 Drilling Methodology and Well Construction Procedures

Exploratory drilling and well installation were observed by an HLA geologist, who logged the boreholes according to the Unified Soil Classification System (Plate A-17 in Appendix A), by inspection of the cuttings.

The 15 observation wells were drilled using a truck-mounted mud rotary rig, utilizing a 6-inch-diameter drill bit. The first 8 test borings (TW-1 through TW-8) were drilled to the bedrock contact, which varied in depth from 49.5 feet (TW-7) to 103 feet (TW-4) below ground surface. The second set of 7 observation well borings was drilled to a depth of 60 feet (approximately 20 feet below the water table). All 15 observation wells were completed with 2-inch-diameter Schedule 40 flush-joint threaded PVC blank and 0.020-inch factory-slotted well screen. Two centralizers were used on the screen in each well. The first 8 test borings were backfilled with Lonestar #3 sand from the bedrock contact to above the screened interval. The wells were sealed with a minimum of 20 feet of Portland cement. Above-grade locking covers were installed to secure the observation wells. Well completion details are shown on the boring logs in Appendix A. The elevation and horizontal location of each well were surveyed by SCWA.

On the basis of Phase I exploratory borings, HLA recommended the location, completion interval, slot and gravel pack sizes for the test well (PW-1). This well is located near TW-4, where the thickest interval of saturated sand and gravel was encountered. The test well was drilled to a depth of 110 feet using a truck-mounted mud rotary rig with an 18-inch-diameter drill bit. Conductor casing was set to a depth of 20 feet. The boring was logged using mud rotary cuttings, and the well was completed with 12-inch-diameter steel casing and steel wire-wrapped 0.050 inch slotted screen (Plate A-16, Appendix A). It was screened from 53 to 103 feet below ground surface. The annulus was packed with 3/8-inch pea gravel and the upper 20 feet were sealed outside the conductor casing with Portland cement. All wells were developed by repeated air lifting.

4.4 Aquifer Test Methodology

A three-day, constant-rate aquifer test was conducted to quantify aquifer properties and to characterize ground water/surface water interactions. Prior to the constant-rate test, a step-drawdown test was conducted to determine the discharge rate to be used during the constant-rate test. The aquifer testing was conducted by Weeks Drilling and Pump Company using a line shaft turbine pump. Twelve-inch-diameter aluminum pipe was connected to the pump discharge and used to convey the water to a holding pond approximately 1,200 feet south of the pumping well PW-1 (Plate 2). This location was selected to minimize any influence on water levels that might have resulted from infiltration of discharged water. An in-line velocity meter was used to monitor and control the discharge rate during the test.

Between September 9 and 16, 1988, the existing collector wells were continuously pumped at an average combined rate of about 20,000 gpm (about 30 mgd) to stabilize the ground-water flow system during the period of aquifer testing. Plots of discharge rates and water levels from the collector wells are included in Appendix B.

Pressure transducers and dataloggers were installed in the test well (PW-1), and observation wells TW-1, TW-2, and TW-15 on September 9, 1988, to collect continuous background water-level data to aid in aquifer test analyses. Hydrographs for these wells are included in Appendix B.

On September 12, 1988, the step-drawdown test was conducted. Discharge rates of 1,000, 1,500, 2,000, and 2,500 gpm (1.4, 2.2, 2.9, and 3.6 mgd) were sustained for a period of approximately one hour each, yielding pumping well drawdowns of approximately 4, 7, 14, and 18 feet, respectively. The step test was then stopped, allowing water levels to recover for 16 hours prior to measuring background water levels in the observation wells and starting the constant-rate test. Plate 3 shows water levels measured on September 13, 1988, immediately prior to initiation of the constant-rate pumping test.

The constant-rate pumping test was run for just over 72 hours, beginning at 8:56 a.m. on September 13, 1988, and ending at 9:20 a.m. on September 16. The discharge rate was 2,494 gallons per minute (about 3.6 mgd); no change in discharge rate was measured during the test.

Drawdown and recovery of water levels were monitored using hand measurements and pressure transducers. Observation Wells TW-4, TW-9, TW-10, TW-11, TW-12, TW-13, and TW-14, and the pumping well were monitored using calibrated pressure transducers (10 and 20 psi) with the time-drawdown data recorded on electronic dataloggers. Pressure transducer readings were recorded at logarithmically increasing intervals for the beginning of the pumping and recovery periods. During these beginning periods 109 measurements were recorded during the first 100 minutes. After these periods, measurements were recorded every 10 minutes. Plots of water levels from these wells during the background, drawdown, and recovery period are included in Appendix B. Water levels over time in all other observation wells were hand measured. Measurements were taken intermittently with approximately 20 measurements taken in each well during the pumping period. These data are presented Appendix B.

The Russian River was monitored to determine the effects of test pumping on the river stage. Two staff gauges were installed (Plate 2) and river levels were recorded intermittently with approximately 20 measurements taken during the test period. Hydrographs of the river stage are included in Appendix B. A staff gauge was also installed in the discharge pond to monitor storage or infiltration of the pumped water. Pond stage was recorded until the gauge became submerged.

Barometric pressure changes were monitored with a portable barograph. The data are included in Appendix B.

Discussion and analyses of the aquifer test results are presented in Section 5.3.

5.0 SITE HYDROGEOLOGY

5.1 Site Geology

The site is underlain by unconsolidated alluvial deposits of variable thickness which overlie shale bedrock of the Franciscan Formation. Plates 4 and 5 are generalized geologic cross sections through the site. The total thickness of unconsolidated sediments varies from a minimum of approximately 50 feet in the area of TW-7, to greater than 100 feet in the area of the pumping well. The bedrock surface observations correlate well with Norcal's interpretation of their seismic survey (Plate 7 in *Norcal, 1987*), with a north-south trending zone of thick sand and gravel in a bedrock trough crossing the site.

In general, sandy silts and sandy clays exist from the ground surface to depths up to 39 feet below the ground surface. Plate 6 shows the thickness of surficial silts and clays at each well location. These fine-grained materials are thickest in the areas closest to the eastern valley wall, as observed in Wells TW-7 and TW-8. In the area of the pumping well, the surficial silts are approximately 10 feet thick. Near the river, they are absent, having been eroded (or not deposited) by the river.

Beneath the fine-grained materials is a sand and gravel unit of variable thickness. This unit is over 90 feet thick in the area of the pumping well, decreasing to a minimum observed thickness of 8 feet in TW-8. Because the bedrock outcrops on the eastern valley wall, the edge of the sand and gravel aquifer is between the easternmost wells and the valley wall. The gravels exhibit a coarsening and thickening away from the canyon wall toward the main river channel. The sandy gravel is generally poorly sorted, with gravel diameters exceeding 2 inches.

The sand and gravel unit shows occasional clay lenses. These are most abundant in the area of TW-5, but absent in the immediate area of the pumping well (Plate 4). The sand and gravel layers generally coarsen downward, consistent with their river depositional origin.

The bedrock underlying the unconsolidated sediments is fractured gray shale.

5.2 Site Hydrology

Water-level measurements in the observation wells showed a downstream-sloping potentiometric surface. Plate 3 is a contoured water-level elevation map based on data collected immediately before the aquifer test began. The water-level configuration shows a variable hydraulic gradient direction, which roughly parallels the meander of the river. The magnitude of the horizontal hydraulic gradient between wells varies from 0.013 to 0.00015. Actual flow paths are locally influenced by the heterogeneity in aquifer transmissivity and therefore are not necessarily perpendicular to the ground-water-level contours shown.

The aquifer in the study area is unconfined, except along the southeastern edge (TW-7 and TW-8) where it is confined by the thick sequence of surficial silts and clays. The steeper gradient in this vicinity may reflect minor mountain-front recharge through this area of comparatively low transmissivity.

The approximate river elevations measured during this study were generally higher than ground-water elevations near the river, indicating that a gradient exists from the river to the ground-water system. The amount of infiltration from the river depends upon the magnitude of this gradient, as well as on the permeability of the materials on and beneath the river bottom. This interaction is further discussed in Section 6.

At the time of this investigation, the saturated thickness of the sand and gravel aquifer ranged from less than 10 feet along the east side of the study area, to about 70 feet in the vicinity of the test well. Assuming an average saturated sand and gravel thickness of 50 feet, an area of 90 acres, and a specific yield of 0.20, the aquifer beneath the site would be capable of storing about 300 million gallons of water.

5.3 Aquifer Test Results

5.3.1 Aquifer Test Data

The data collected during the aquifer test are included in Appendix B. Analyses of these data are presented in Appendix C and discussed below.

Staff gauge readings taken in the discharge pond following the step test and prior to the constant-rate test showed no measurable infiltration from this pond. Background data collected in the test well indicated constant water levels prior to the aquifer test. Barograph data (Plate B-18) indicate that little or no change in barometric pressure occurred during the pumping period. These measurements were verified with barometric data collected at the Sonoma County Airport, which are summarized below.

Date	10/13	10/14	10/15	10/16
Highest pressure	30.04	30.02	30.01	29.97
Lowest pressure	29.96	29.93	29.92	29.95

Source: Sonoma County Airport Control Tower

As would be expected in an unconfined aquifer, particularly with such small barometric pressure changes, no water-level response to barometric pressure was noted.

Water levels in the collector wells, and in Monitoring Well TW-1 showed fairly consistent declines prior to and during the aquifer test (Appendix B). This indicates that the discharge rate from the collector wells may have been exceeding their sustained yield. No effect of the collector well pumping was observed during background monitoring of the test well, and there was no discernible effect of the PW-1 constant-rate discharge test on the collector wells.

5.3.2 Aquifer Test Analysis

The primary purpose of an aquifer test is to quantify transmissivity and storativity, aquifer properties which govern the aquifer's water production capacity. Aquifer transmissivity is a measure of the amount of water that can be transmitted horizontally by the full saturated thickness of the aquifer under a unit hydraulic gradient. Transmissivity (T) is the product of the hydraulic conductivity (K) and the saturated thickness of the aquifer (b).

$$T = Kb$$

The storage coefficient (S) is the volume of water that an aquifer will absorb or expel from storage per unit surface area per unit change in head (*Fetter, 1980*).

Two methods were used to analyze the constant-rate aquifer test data to obtain values for T and S: the unconfined aquifer type-curve method (*Prickett, 1965*), and the residual drawdown method (*Theis, 1935*). Both methods assume homogeneous, isotropic, uniform aquifer conditions, and a fully penetrating pumping well discharging at a constant rate. Drawdown and recovery plots over time and calculation sheets are presented in Appendix B. The effects of partial penetration for the observation wells are assumed to be negligible as the screened intervals of the observation wells and pumping well overlap, and the vertical and horizontal hydraulic conductivities are believed to be similar.

At the end of the 72-hour pumping period, the pumping well had exhibited a maximum drawdown of 15.8 feet. Plate 8 shows the maximum drawdowns measured in each of the wells.

Analysis of the time drawdown data yielded fairly consistent aquifer transmissivity and storativity values, indicating no significant anisotropy. Table 1 summarizes the aquifer test results. Transmissivity values calculated from drawdown data prior to the influence of boundary effects ranged from 110,000 to 150,000 ft^2/day with a geometric mean of about 120,000 ft^2/day. These values reflect the highly permeable nature of the aquifer. Transmissivity values calculated from recovery data using the residual drawdown methods ranged from 140,000 to 250,000 ft^2/day. Because the recovery data were affected by recharge from the Russian River and the residual drawdown method is unable to distinguish this recharge, these values do not represent the actual aquifer transmissivity as accurately. No effect of the bedrock boundary was observed in the test data.

Calculated specific yields ranged from 0.14 to 0.32. The specific capacity for PW-1 during the test was 158 gpm/ft (2494 gpm/15.8 ft of drawdown).

5.3.3 Recharge Boundary Effects

Time-drawdown data for the monitoring wells exhibited late-time deviations from the theoretical type curves. These deviations are interpreted as ground-water recharge from the Russian River. Log-log time drawdown plots (Plates C-1 through C-5) show less drawdown after several hundred minutes than the unconfined aquifer type curve would predict. This effect was observed earliest in Wells TW-13 and TW-12 (closest to the river), occurring approximately 150 and 200 minutes after the start of pumping, respectively (Plates C-4 and C-3). Wells TW-4, TW-10, and TW-14 exhibited similar effects beginning at approximately 250, 350, and 550 minutes after initiation of pumping, respectively.

These deviations from theory indicate that the ground water and river systems are linked, such that high rates of ground-water pumpage and drawdown in the local area will result in some additional infiltration of surface water through the river bottom.

Plots of river stage over time, as monitored with two staff gauges (Plates 2 and B-17) did not reveal any significant river level reduction. Because the river discharge rate is much greater than the 2500 gpm (3.6 mgd) ground-water pumping rate, the induced infiltration of surface water to ground water could not be accurately recorded with staff gauges.

Time-drawdown data were analyzed using image well theory (*Ferris et al., 1962*) to investigate the degree of interconnection between the river and the aquifer system. By comparing the elapsed times for similar drawdowns to occur due to the pumping well and the theoretical image well, hydraulic distances from the observation wells to the image well were calculated (Calculation Sheets 1 through 5, Appendix C). Because the river is halfway between the image well and pumping well, the hydraulic location of the river can be estimated. When the river and aquifer are well connected, the hydraulic distance to river is the same as the physical distance to the river. Conversely, when the river and aquifer are not well connected, these distances are different. Hydraulic distances from observation wells to the image well ranged from 3,463 to 20,757 feet; the physical distance is about 500 feet. The wide variation in hydraulic distances coupled with the much greater hydraulic distances than physical distances to the river indicate that the river is not well connected to the aquifer. The poor connection is most likely caused by an accumulation of fine-grained material on the river bottom which restricts movement of water into the aquifer. Two additional methods of determining the hydraulic distance to aquifer boundaries were applied (*Moulder, 1963, and Rorabaugh, 1956*) and similar results were obtained.

5.4 Aquifer Yield

The safe yield of an aquifer system (assuming no vertical recharge) can be estimated by calculating the total ground-water discharge occurring through the aquifer under natural conditions. This underflow component can be calculated using Darcy's Law for ground-water flow:

$$Q = \frac{dh}{dl} Tw$$

where

Q = volumetric rate of discharge
T = aquifer transmissivity
w = width of aquifer
$\frac{dh}{dl}$ = hydraulic gradient component orthogonal to the cross-sectional area

As a conservative estimate, using a transmissivity of 110,000 ft^2/day, an aquifer width of 1650 feet, and a hydraulic gradient of 0.0067 ft/ft (see Plate 3 for location of profile used in calculation), this discharge is approximately 6,300 gpm (9.1 mgd).

$$Q = (110{,}000\ ft^2/day)\ (0.0067\ ft/ft)(1650\ ft)$$

$$Q = 1.2 \times 10^6\ ft^3/day \approx 6{,}300\ gpm = 9.1\ MGD$$

The ground-water system is clearly receiving substantial recharge from the river. This is evidenced by the yield of the existing collector wells, which exceeds the calculated ground-water underflow. It appears that the underflow contributes to the pumpage from the existing collector wells, and would not be available for production from wells in the study area.

6.0 DISCUSSION AND CONCLUSIONS

6.1 Ground-Water Production Potential

The sand and gravel aquifer in which the nearby existing collector wells are completed extends beneath the study area, and appears to be more than 50 feet thick under much of the area. This aquifer has a high transmissivity (more than 100,000 ft^2/day) and hydraulic conductivity (about 1,600 ft/day). However, it is not areally extensive, being restricted to the river valley; hence, ground-water storage and the natural ground-water flow through the aquifer is limited. As described in Section 5.4, the 6,300 gpm (9.1 mgd) underflow beneath the site appears to contribute to the yield from the existing collector wells. Therefore, the successful development of the water resources of this site must conjunctively utilize the ample surface water supplies of the Russian River and high transmissivity of the aquifer system. With the exception of induced infiltration, artificial recharge requires design, construction and operation of recharge facilities.

6.2 Artificial Recharge

Artificial recharge can increase the production of an aquifer basin by augmenting the ground water underflow. Without local artificial recharge of surface water, the Wohler aquifer could not sustain significant production. There are four general methods of artificial recharge:

1. Induced infiltration
2. Surface spreading
3. Recharge pits and shafts
4. Recharge wells

The applicability of each of these methods to the study area is discussed below.

6.2.1 Induced Infiltration

Induced infiltration is the method currently employed at the existing collector wells downstream of the site. Lowering the ground-water level by pumping increases recharge from a hydraulically connected river. The recharge rate is controlled by the river bottom permeability, the permeability and thickness of the materials (if any) between the river and the aquifer, the vertical hydraulic gradient between the river and the aquifer and the temperature of the recharge water. The river bottom permeability fluctuates seasonally due to clay and silt deposition during periods of reduced flow. Scarifying of the river bottom occurs naturally each winter seasons; in addition, Agency forces annually shave the top of a gravel bar nearby and then inundate the gravel bar under backwater when the Agency's inflatable dam is erected each spring. Induced infiltration at the study site could likely be enhanced by artificially scarifying the river bottom, however it is our understanding that such activities in the river would be prohibited by the Department of Fish and Game. A collector well(s) with radials beneath the river would increase the vertical hydraulic gradient beneath the river; however, the vertical gradient does not appear to be the limiting factor in inducing infiltration. The effect of temperature on the recharge rate is not expected to be large, and is not considered in the analyses in this study.

On the basis of the water level response in TW-2 prior to the constant-rate discharge test, it appears that the existing collector wells induce recharge from the Russian River as far upstream as Porter Creek. An estimated 2,500 gpm of induced infiltration could be achieved between Porter Creek and a point between TW-5 and TW-8 (this reach appears to be underlain by coarse aquifer material). This assumes a river bed area 2,200 feet long and 150 feet wide, and an infiltration rate of 1.5 feet/day.

One or two vertical wells placed near the river upstream of Porter Creek should be adequate for inducing infiltration along this reach (Plate 9).

6.2.2 Surface Spreading

Surface spreading involves recharge via flooding shallow ponds, ditches or irrigation systems over a substantial surface area. The recharge rate is controlled by the soil permeability and area of inundation. Much of the site appears to overlie thick aquifer material, and may be suitable for recharge ponds. The surficial silt and clay that blanket the site would limit the infiltration rate, and careful maintenance and operation of ponds would be required. However, if infiltration rates similar to those at Mirabel downstream of the study area could be attained significant quantities of water could be recharged.

6.2.3 Recharge Pits and Shafts

Recharge pits and shafts are excavated to penetrate low permeability materials overlying the aquifer to be recharged. Although the Wohler aquifer study site appears to be a candidate for this technique (i.e., there is a low permeability layer overlying the aquifer), pits and shafts are subject to rapid clogging, and are difficult and costly to rehabilitate.

6.2.4 Recharge Wells

Recharge wells are typically used to recharge deep aquifers. They are designed similar to production wells. Water recharged in wells generally requires treatment to remove fines to minimize clogging. Like pits and shafts, wells are subject to clogging and require periodic rehabilitation. Because of the high permeability and lack of continuous clay layers within the Wohler aquifer, and the shallow depth to water, wells would have no appreciable advantage over other recharge methods at the site.

6.3 Well Installation

The design spacing, location, and yield of wells on the property would depend on several factors, including the method, location and operation of artificial recharge, and the design and number of wells. With induced infiltration from the river, for example, wells should be placed parallel to the river and as near the river as possible to minimize drawdown (and pumping lift) in the wells. On the other hand, if infiltration ponds or recharge pits were constructed over the site, wells should be sited proximate to these facilities. Assuming adequate recharge, a properly designed production well could be expected to produce on the order of 5,000 gpm (7 mgd); this is based on the specific capacity of PW-1, an assumed drawdown of 25 feet, and a 20 percent increase in specific capacity due to a larger casing diameter (e.g., 18- or 24-inch) and production well design and development. For the options described below, we have assumed that each well would be pumped at rates of 2,500 to 3,500 gpm (3.6 to 5 mgd).

Although collector wells could be installed to create greater drawdown beneath the river, they do not appear to be advantageous for this application; vertical wells can create sufficient drawdown to induce river infiltration. The following are some of the considerations in selecting vertical wells over radial collector wells.

1. Vertical wells involve lower capital investment, and are less expensive and easier to maintain; they can also be installed as needed, thereby spreading out the expenditure of investment capital.

2. For a given discharge, a single vertical well has greater drawdown, and hence higher energy consumption than a single collector well. However, several vertical wells can be installed and maintained for the cost of one collector well; by apportioning the discharge over several vertical wells, the drawdown and energy costs are reduced.

3. Vertical wells allow more flexibility in operation.

6.4 Conjunctive Use Options

On the basis of this study the site appears to be hydrogeologically suitable for the conjunctive use of the surface water via the ground-water system. Two options for water resource development are described below: pumping vertical wells near the river to induce infiltration from the river, and installation and operation of surface spreading ponds and vertical wells.

6.4.1 Induced Infiltration by Pumping Vertical Wells

As described in Section 6.2.1 an estimated 2,500 gpm (3.6 mgd) could be induced to infiltrate from the Russian River by pumping one or two vertical wells placed on the property near the river. Plate 9 shows proposed locations for these wells. Although this system would not entail major construction on the site, a production capacity of 2,500 gpm (3.6 mgd) would not likely warrant purchase of the property.

6.4.2 Surface Spreading and Vertical Wells

On the basis of this study, surface spreading of Russian River water and pumping from several vertical wells should provide for conjunctive use of approximately 20,000 gpm (29 mgd). Plate 10 shows a general layout for the recommended system configuration. This configuration involves surface spreading with shallow ponds on approximately 80% of the 50 acres suitable for surface spreading, and pumping from 6 of 7 wells which fully penetrate the aquifer. The ponds are located in areas having generally less than 15 feet of surficial silt and clay, and more than 30 feet of saturated aquifer thickness. The wells are placed parallel to the river and along the area of greatest saturated aquifer thickness (>60 feet). A pond infiltration rate of 3.4 ft/day,* and a well capacity of about 3,500 gpm (5 mgd) were assumed for this configuration. It

---

* Based on half the estimated infiltration rate of 50 gpd/ft^2 (6.7 ft/day) for the Mirabel ponds.

was also assumed that one-third of the pond area and one well would be out of service at any given time, to allow for maintenance. The contribution of induced infiltration from the Russian River was assumed to be negligible; this contribution is expected to vary seasonally, and may reduce the need for pond operation and/or maintenance during some parts of the year.

If fewer than 40 acres were available for spreading basins, the infiltration and production capacities would be reduced in proportion to the reduction in spreading basin area. For example, if only 10 acres were utilized for spreading basins (e.g., the existing low area in the southeast corner of the site, which includes the pond shown on Plate 11), an estimated 5,000 gpm (7.2 mgd) could be recharged. Two vertical production wells could be installed adjacent to the pond to pump the recharged water. Plate 11 shows the proposed configuration for a 5,000 gpm (7.2 mgd) system. Alternatively, recharge from this area, without on-site pumping, might improve the production from the existing collector wells. However, the efficiency of the collector wells and/or the aquifer properties in the vicinity of the collector wells appear to be the limiting factor(s) in their production capacity.

If spreading basins and associated wells were constructed away from the river (that is, only on the eastern portion of the site), induced infiltration by pumping near the river, as described in Section 6.4.1, could provide up to an estimated 2,500 gpm (3.6 mgd) in addition to the amount recharged by the spreading basins.

System design should be preceded by pilot testing of surface infiltration and production well capacity.

7.0 REFERENCES

Anderson, S., K.L. Markham, W.F. Shelton, and L.F. Trujillo, 1988. Water Resources Data - California Water Year 1987, Vol. 2, USGS Water Data Report CA-87-2.

Cardwell, G.T., 1965. *Geology and Ground Water in Russian River Valley Areas and in Round, Laytonville and Little Lake Valleys, Sonoma and Mendocino Counties, California,* U.S. Geological Survey Water-Supply Paper 1548.

Ferris, J.G., Knowler, D.B., Brown, R.H., and Stallman, R.W., 1962. *Theory of Aquifer Tests,* U.S. Geological Survey Water Supply Paper 1536-E.

Fetter, C.W., 1980. *Applied Hydrogeology*, Merrill Publishing Co., p. 105.

Moulder, E.A., 1963. *Locus circles as an aid in the location of a hydrogeologic boundary,* in Benthall, Ray, *Shortcuts and special problems in aquifer tests*, U.S. Geological Survey Water Supply Paper 1545-C.

Norcal Geophysical Consultants, Inc., 1987. *Geophysical Survey of the Wohler Aquifer Study Area, Russian River, California*, a report prepared for the Sonoma County Water Agency. Job No. 87-165.01. September 14.

Prickett, T.A., 1965. *Type Curve Solution to Aquifer Tests Under Water Table Conditions, Groundwater*, vol 3, no 3, pp 025-634.

Ranney Method Western Corporation, 1955. *Report on Second Pumping Test, Hydrogeological Survey for Sonoma County Flood Control and Water Conservation District, Wohler Bridge Site, Santa Rosa, California.* October 31.

_________, 1970. *Report on Hydrogeological Survey, Sonoma-Marin Aqueduct, Sonoma County Water Agency, Santa Rosa, California.* September 14.

_________, 1975. *Report on Performance Tests, Ranney Collectors B-5 and C-1, Sonoma County Water Agency, Santa Rosa, California*, October 22.

State Water Resources Control Board, April 1986, Decision 1610.

Rorabaugh, M.I., 1956. *Ground-Water Resources of the Northeastern Part of the Louisville Area, Kentucky*, U.S. Geological Survey Water Supply Paper 1360-B.

Theis, C.V., 1935. *The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage,* Trans. Amer. Geophysical Union, 2, pp 519-524.

TABLE

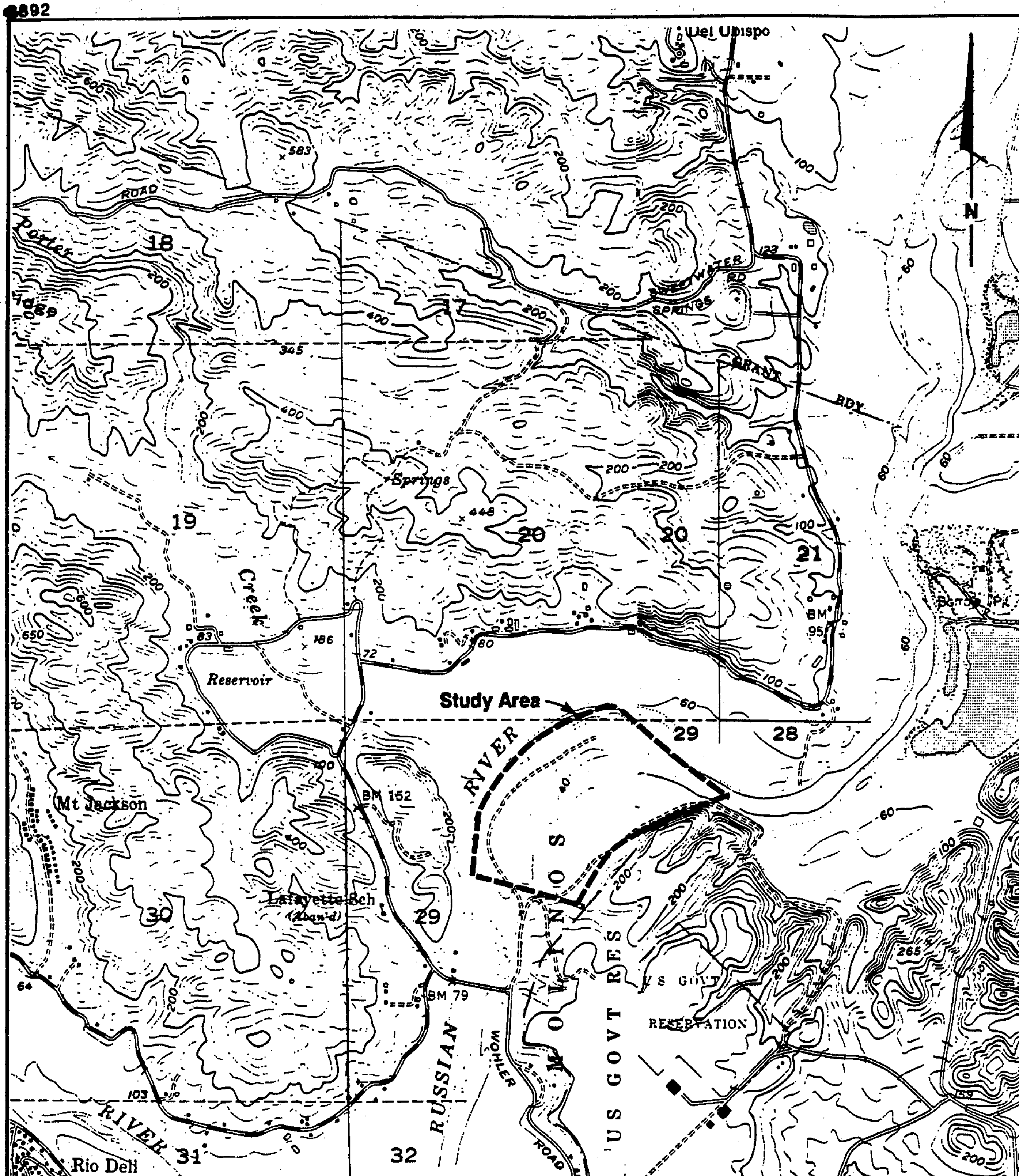
Table 1. Summary of Aquifer Test Results

Observation Well	Method of Analysis	Transmissivity (ft^2/day)	Hydraulic Conductivity (ft/day)	Storativity (dimensionless)	Specific Yield	Distance to Image Well (feet)
TW-4	Prickett	110,000	1,500	2.0×10^{-3}	0.78*	8,420
TW-4	Residual Drawdown	140,000	1,900			
TW-9	Residual Drawdown	190,000	2,500			
TW-10	Prickett	150,000	2,000	7.2×10^{-4}	0.14	20,304
TW-10	Residual Drawdown	150,000	2,000			
TW-11	Residual Drawdown	170,000	2,300			
TW-12	Prickett	110,000	1,500	2.3×10^{-3}	1.07*	3,463
TW-12	Residual Drawdown	190,000	2,600			
TW-13	Prickett	110,000	1,500	3.2×10^{-4}	0.32	20,757
TW-13	Residual Drawdown	250,000	3,400			
TW-14	Prickett	110,000	1,500	2.2×10^{-3}	0.61*	10,168
TW-14	Residual Drawdown	170,000	2,500			
Pumping Well	Residual Drawdown	170,000	2,200			

* These values are not representative of sand and gravel materials and are not used to characterize the hydrologic properties of the aquifer system.

ILLUSTRATIONS

6892



T. 8N., R. 9W
Source: U.S.G.S. quadrangle maps; Guerneville, photoinspected 1973 and Healdsburg, photorevised 1980

0 0.5 1
SCALE IN MILES

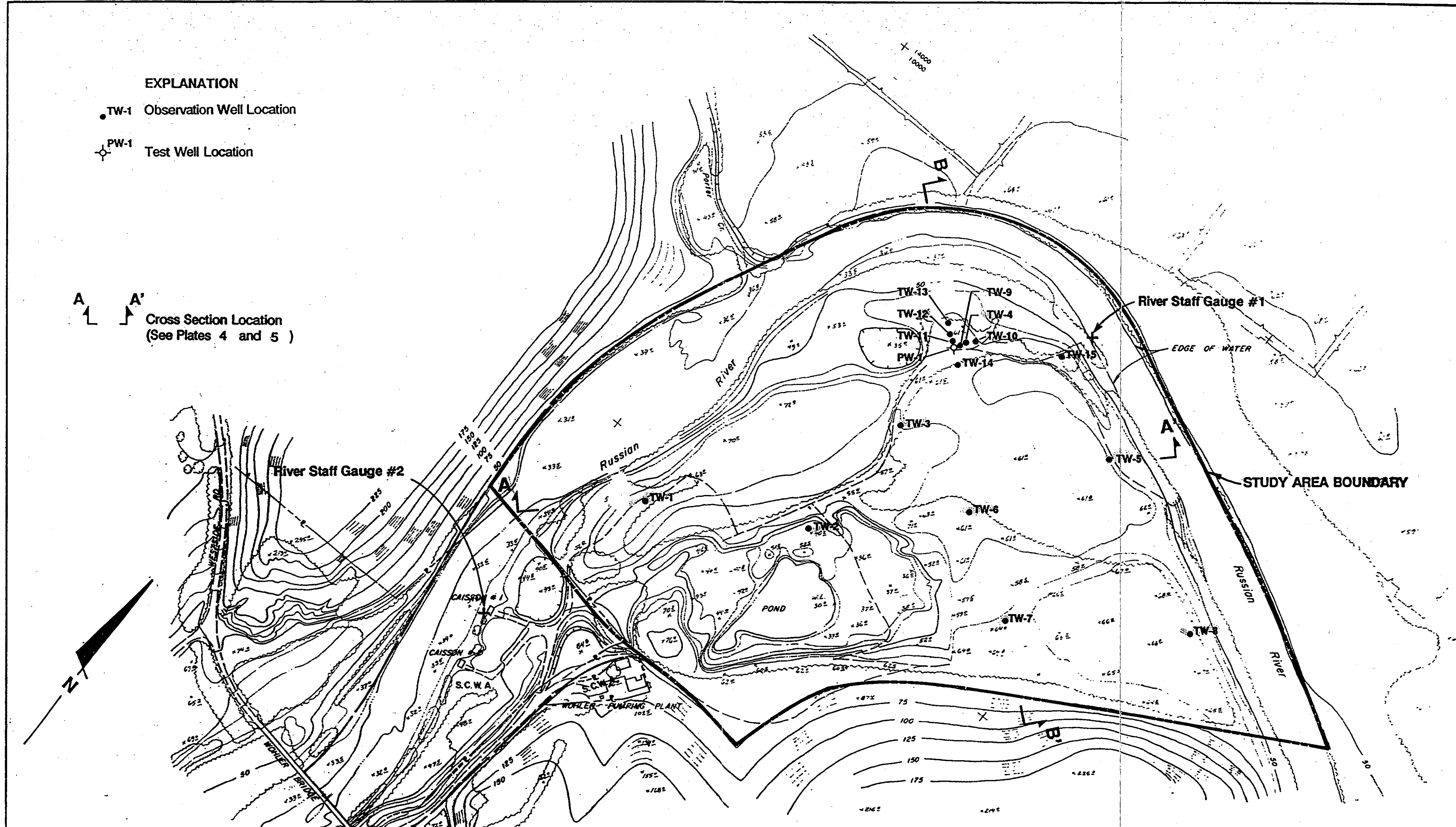
Harding Lawson Associates
Engineers and Geoscientists

Site Location Map
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
1

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
MOI	1916,005.02	TLW	10/88		

6738



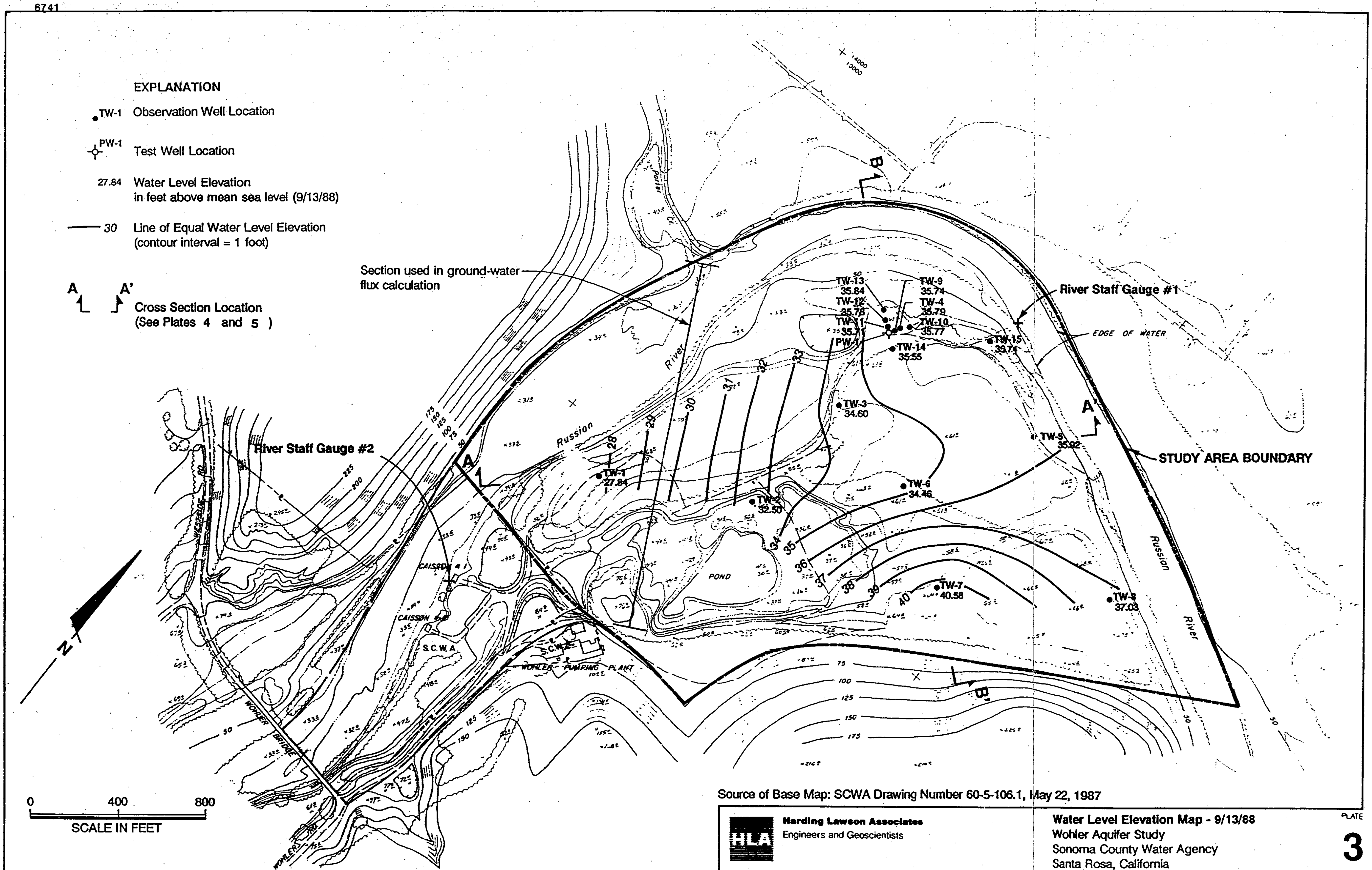
Source of Base Map: SCWA Drawing Number 60-5-106.1, May 22, 1987

HLA **Harding Lawson Associates** Engineers and Geoscientists	**Well Location Map** Wolher Aquifer Study Sonoma County Water Agency Santa Rosa, California	PLATE **2**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
AM	1916,005.02	TLW	10/88		

109463

6741

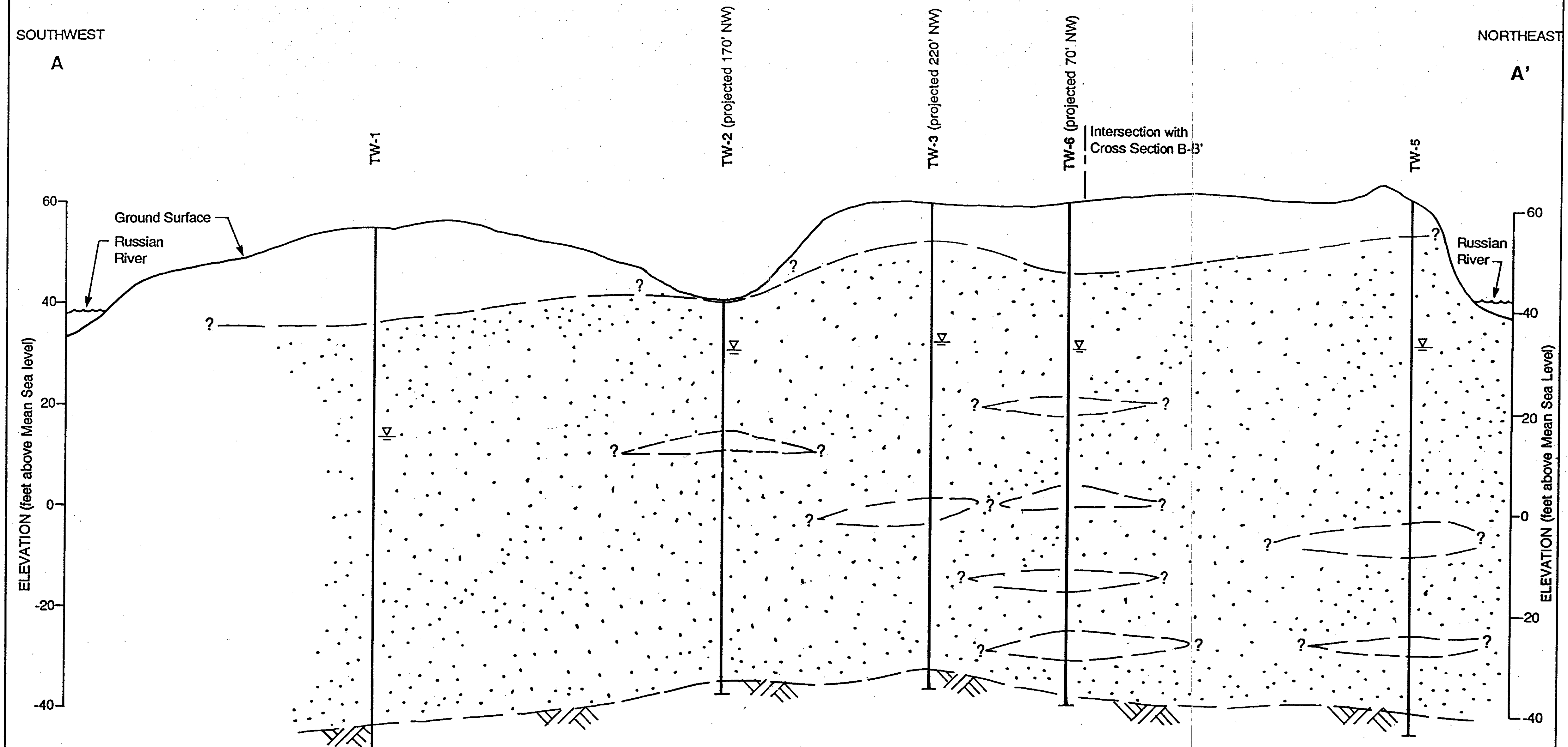


Source of Base Map: SCWA Drawing Number 60-5-106.1, May 22, 1987

Harding Lawson Associates Engineers and Geoscientists		Water Level Elevation Map - 9/13/88 Wohler Aquifer Study Sonoma County Water Agency Santa Rosa, California		PLATE 3
DRAWN AM	JOB NUMBER 1916,005.02	APPROVED TW	DATE 10/88	REVISED / DATE

109463

6745



EXPLANATION

Contact (queried where uncertain)

Silts and Clays

Sands and Gravels

Bedrock

Observation Well

9/13/88 Water level elevation

Bottom of hole

0 200 400

HORIZONTAL SCALE IN FEET

Vertical Exaggeration = 10x

Note: River level elevations are approximate

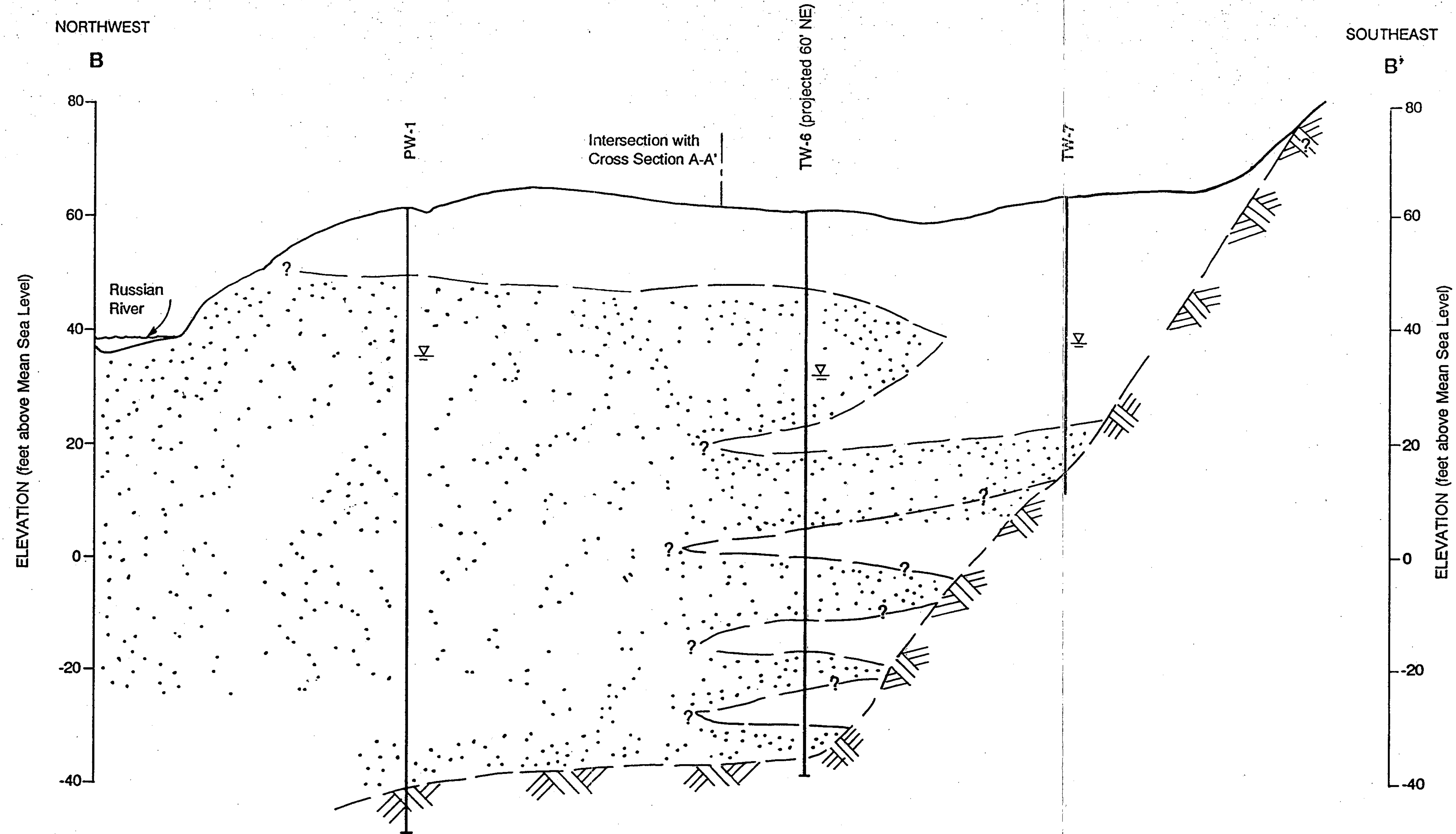
See Plate 3 for cross section location

Harding Lawson Associates
Engineers and Geoscientists

Generalized Geologic Cross Section A-A'
Wolher Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **4**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
EH	1916,005.02	TWJ	10/88		



0 200 400
HORIZONTAL SCALE IN FEET

Vertical Exaggeration = 10x

Note: River level elevations are approximate.

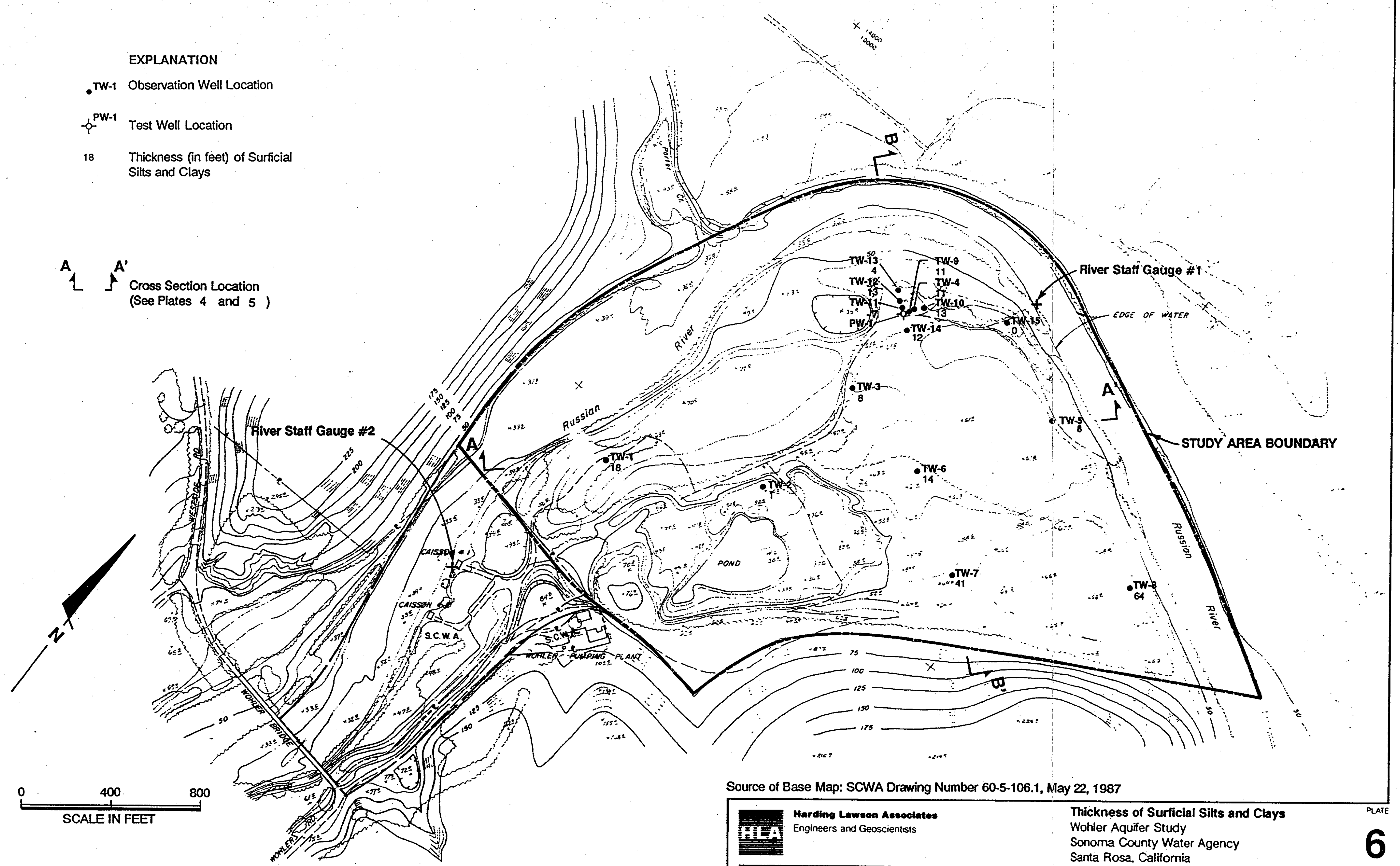
EXPLANATION

Contact (queried where uncertain)	Observation Well
Silts and Clays	9/13/88 Water level elevation
Sands and Gravels	
Bedrock	Bottom of hole

See Plate 3 for cross section location

HLA **Harding Lawson Associates** Engineers and Geoscientists		**Generalized Geologic Cross Section B-B'** Wolher Aquifer Study Sonoma County Water Agency Santa Rosa, California	PLATE **5**
DRAWN EH	JOB NUMBER 1916,005.02	APPROVED TLW	DATE 10/88	REVISED	DATE

6739

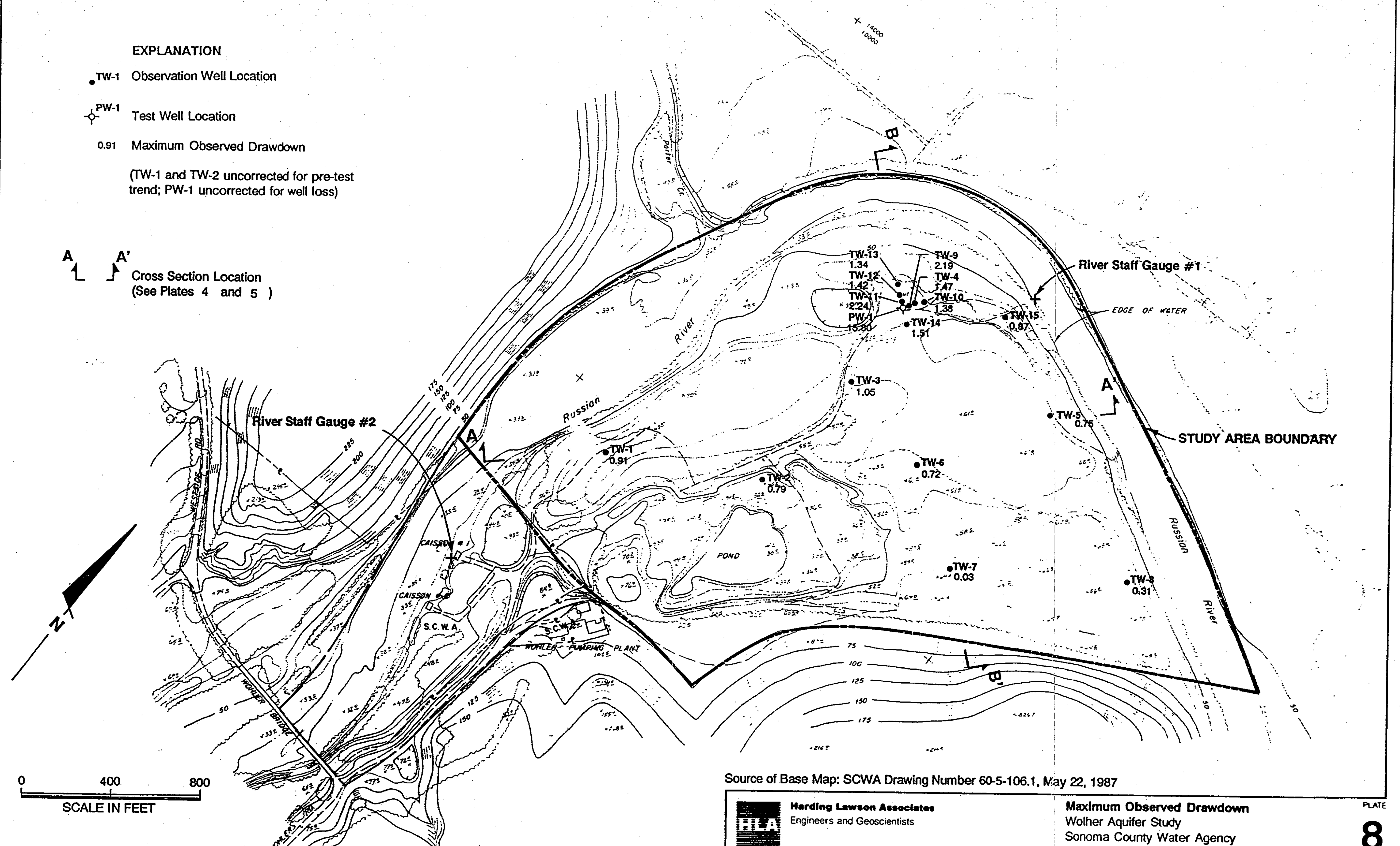


Source of Base Map: SCWA Drawing Number 60-5-106.1, May 22, 1987

Harding Lawson Associates Engineers and Geoscientists	**Thickness of Surficial Silts and Clays** Wohler Aquifer Study Sonoma County Water Agency Santa Rosa, California		PLATE 6
DRAWN AM	JOB NUMBER 1916,005.02	APPROVED	DATE 10/88	REVISED	DATE

109463

7022



Source of Base Map: SCWA Drawing Number 60-5-106.1, May 22, 1987

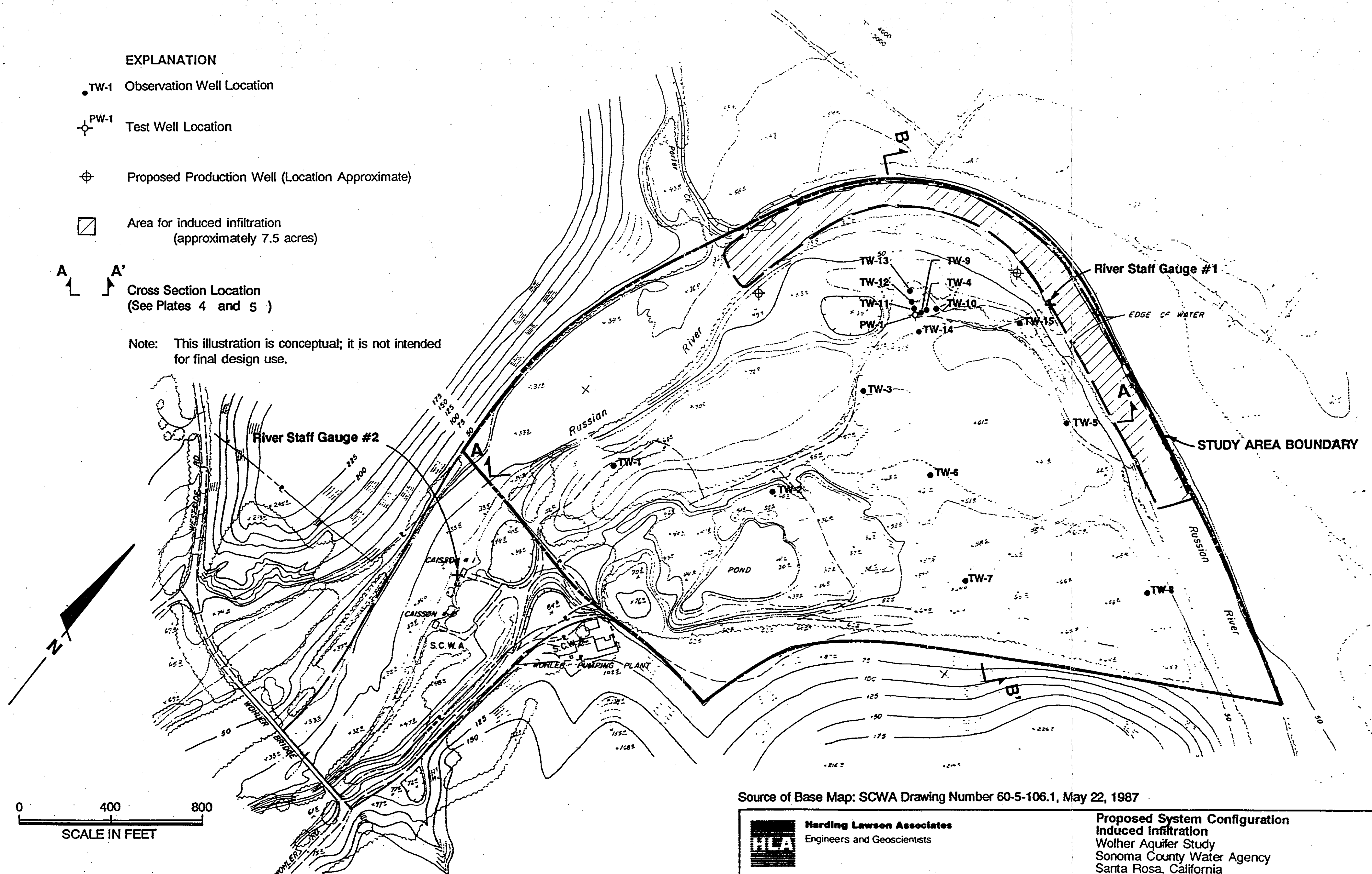
Harding Lawson Associates
Engineers and Geoscientists

Maximum Observed Drawdown
Wolher Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **8**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
AM	1916,005.02	TLW	10/88		

109463



Source of Base Map: SCWA Drawing Number 60-5-106.1, May 22, 1987

Harding Lawson Associates
Engineers and Geoscientists

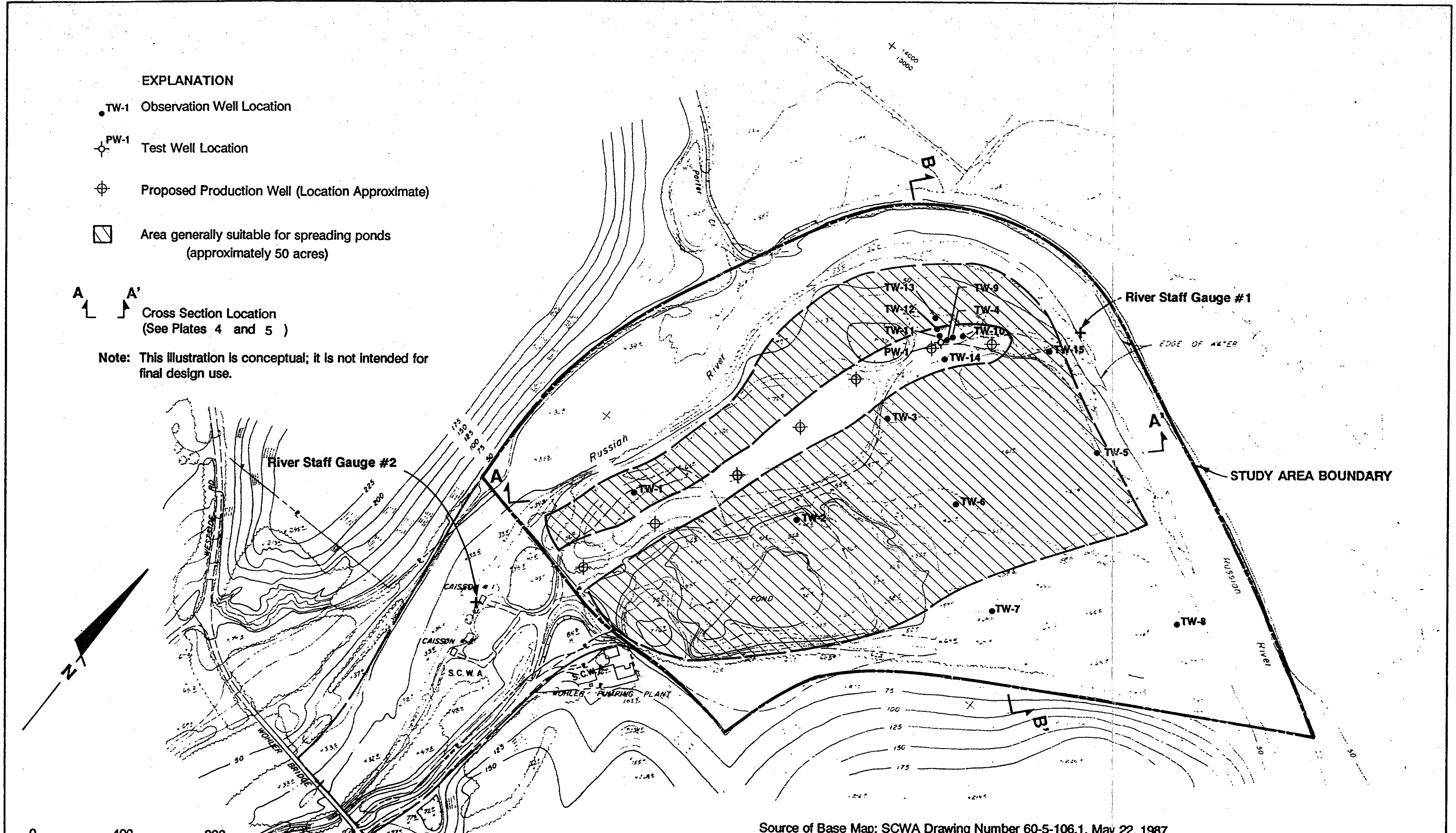
Proposed System Configuration
Induced Infiltration
Wolther Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **9**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
AM	1916,005.02	TWJ	10/88		

108463

7411



Source of Base Map: SCWA Drawing Number 60-5-106.1, May 22, 1987

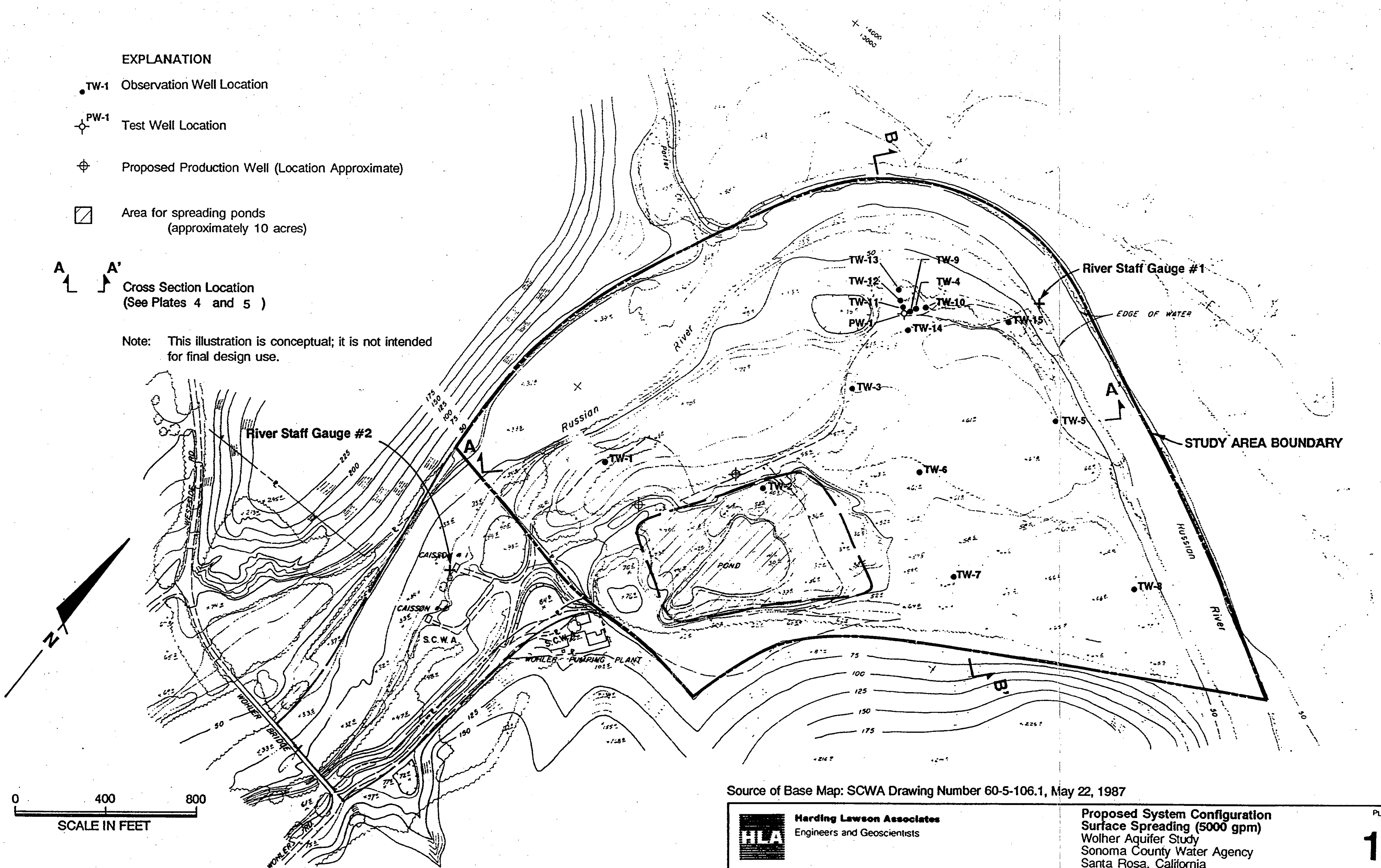
Harding Lawson Associates
Engineers and Geoscientists

Proposed System Configuration
Surface Spreading (20,000 gpm)
Wolher Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **10**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
AM	1916,005.02	RW	10/88		

109463



Source of Base Map: SCWA Drawing Number 60-5-106.1, May 22, 1987

Harding Lawson Associates
Engineers and Geoscientists

Proposed System Configuration
Surface Spreading (5000 gpm)
Wolher Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **11**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
AM	1916,005.02	TCW	10/88		

109463

Appendix A

LITHOLOGIC LOGS/WELL COMPLETION DETAILS

Appendix A

LITHOLOGIC LOGS/WELL COMPLETION DETAILS

6893

Top of PVC Casing
Elevation 69.14 ft

GROUND SURFACE

See below for Well Top Detail

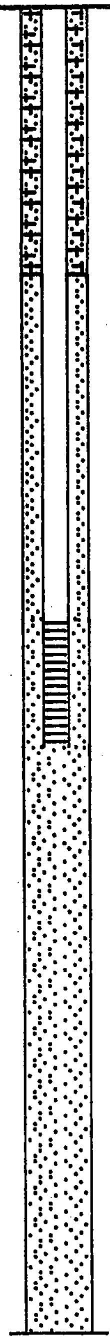
Blows/foot

Depth (ft)

Sample

Equipment Failing Mud Rotary

Elevation 67 ft Date 7/22/88



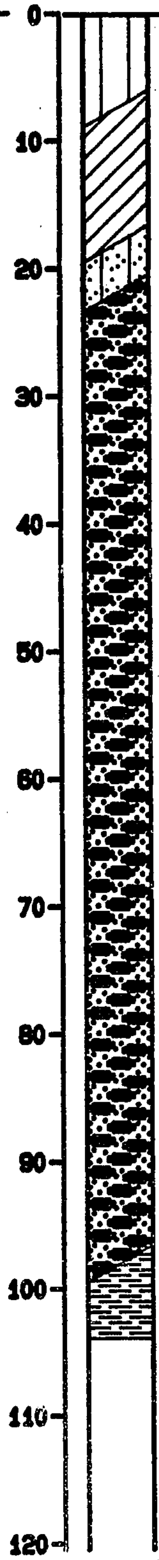
GROUT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 48 ft

SAND FILTER PACK
(size: Lonestar #3)
21 to 104 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
48 to 50 ft



BROWN SILT (ML) 10% fine- to medium-grained sand

BROWN SILTY CLAY (CL) trace fine-grained sand

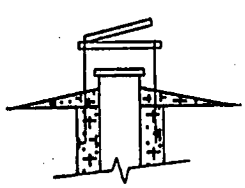
BROWN SILTY SAND (SM) fine-grained sand
coarse sand at 20 ft

GRAY SANDY GRAVEL (GW) 40% coarse sand

FRACTURED SHALE BEDROCK

bottom of boring at 104 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and
Environmental Services

Log of Boring and Well Completion Detail TW-1
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-1**

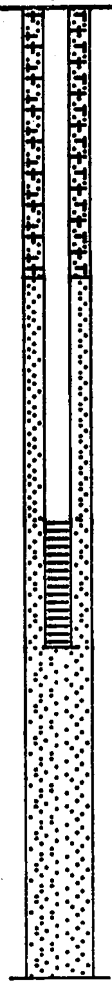
DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TW	10/88		

6894

Top of PVC Casing
Elevation 40.75 ft

Equipment Failing Mud Rotary
Elevation 39 ft Date 7/21/88

GROUND SURFACE | See below for Well Top Detail | Blows/foot | Depth (ft) | Sample



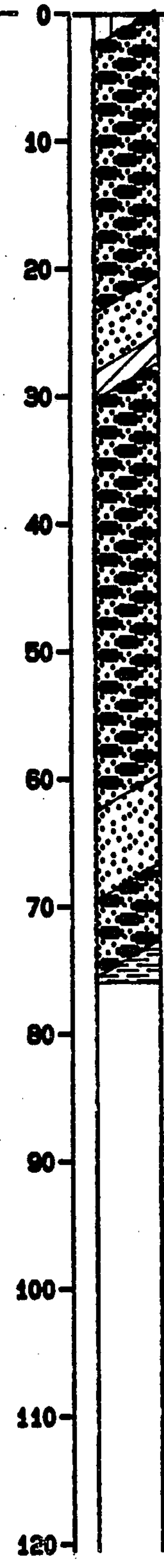
NEAT CEMENT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 40 ft

SAND FILTER PACK
(size: Lonestar #3)
21 to 76 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
40 to 50 ft



BROWN GRAVELLY SILT (ML)

GRAY SANDY GRAVEL (GW) 1" maximum diameter, 20% coarse-grained sand

GRAY SAND (SW) trace gravels and silt

BROWN SANDY CLAY (CL) 30% fine-grained sand

GRAY GRAVEL (GW) 1-1/2" maximum diameter

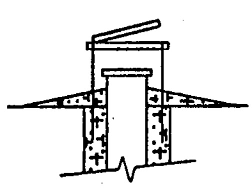
GRAYISH BROWN GRAVELLY SAND (SW) 40% gravel

GRAY SANDY GRAVEL (GW) 40% coarse-grained sand

FRACTURED BLACK SHALE BEDROCK

bottom of boring at 76 ft

Well Top Detail
Not to Scale



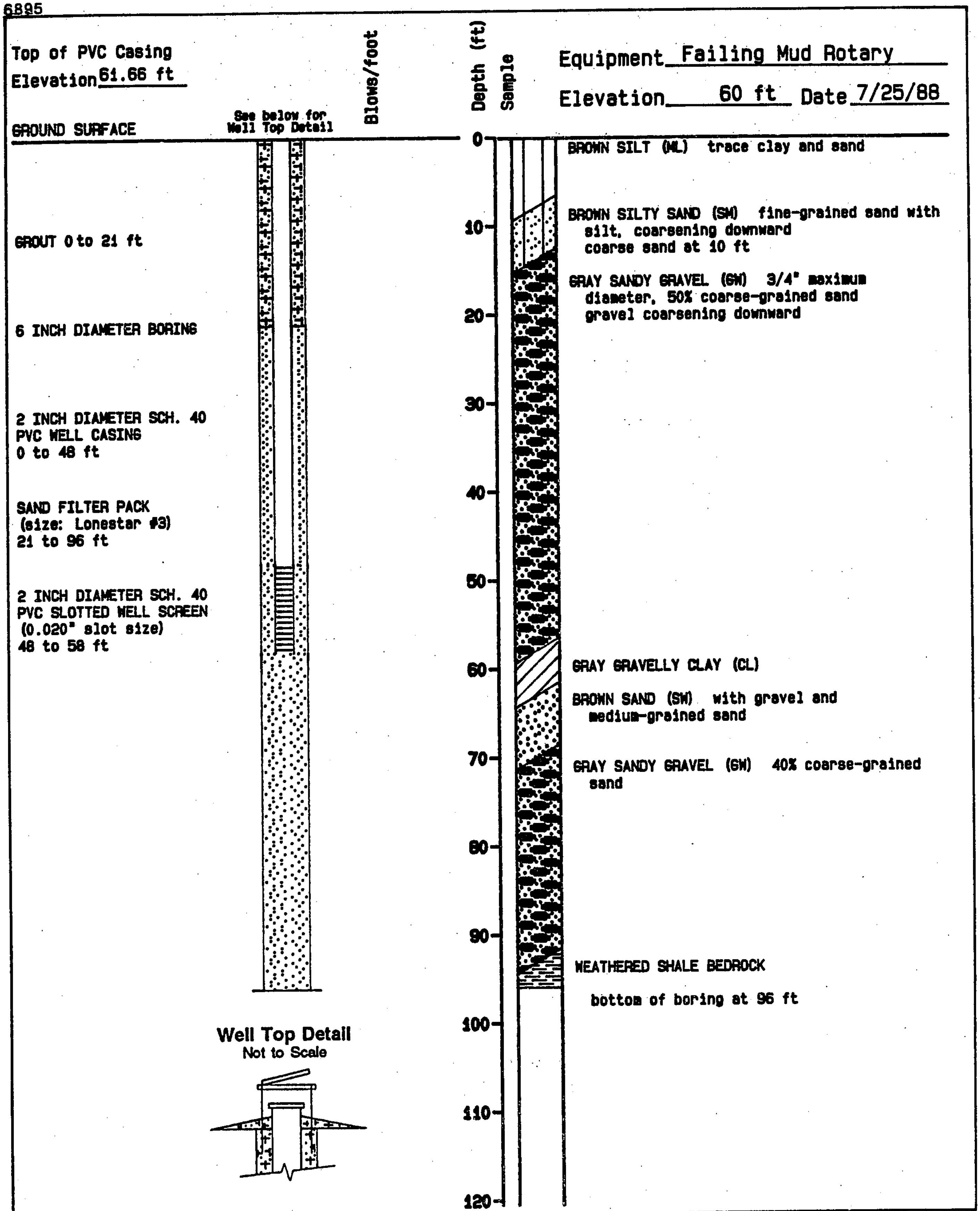
Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail TW-2
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-2**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TW	10/88		

6895



Harding Lawson Associates
Engineering and
Environmental Services

Log of Boring and Well Completion Detail TW-3
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-3**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TW	10/88		

6896

Top of PVC Casing Elevation 62.72 ft

Equipment Failing Mud Rotary

Elevation 61 ft Date 7/26/88

GROUND SURFACE — See below for Well Top Detail — Blows/foot — Depth (ft) — Sample

Well construction:

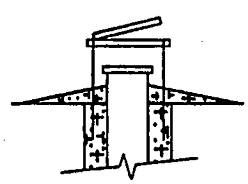
- GROUT 0 to 21 ft
- 6 INCH DIAMETER BORING
- 2 INCH DIAMETER SCH. 40 PVC WELL CASING 0 to 48 ft
- SAND FILTER PACK (size: Lonestar #3) 21 to 107 ft
- 2 INCH DIAMETER SCH. 40 PVC SLOTTED WELL SCREEN (0.020" slot size) 48 to 58 ft

Log:

- BROWN SANDY SILT (ML) 50% fine-grained sand
- GRAY SANDY GRAVEL (GW)
- BROWN SANDY SILT (ML) with trace clay, 20% fine-grained sand
- BROWN SILTY SAND (SM) coarse-grained, trace gravel
- GRAY SANDY GRAVEL (GW) 1" maximum diameter, 40% coarse-grained sand
- GRAY SILTY CLAY (CL) with trace sand and gravel
- GRAY SAND (SW) coarse-grained sand, 10% gravel
- GRAY GRAVEL (GW)
- WEATHERED GRAY SHALE BEDROCK bottom of boring at 107 ft

Depth (ft): 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail TW-4
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-4**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TW	10/88		

6897

Top of PVC Casing
Elevation 64.73 ft

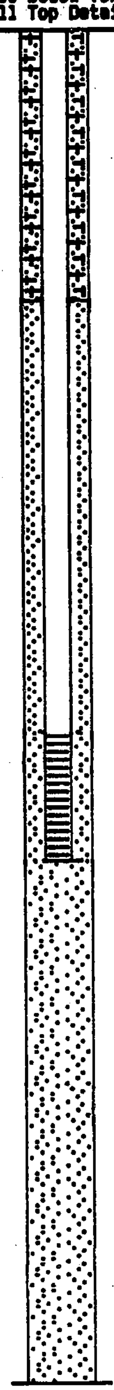
Blows/foot | Depth (ft) | Sample

Equipment Failing Mud Rotary

Elevation 63 ft Date 7/27/88

GROUND SURFACE

See below for Well Top Detail



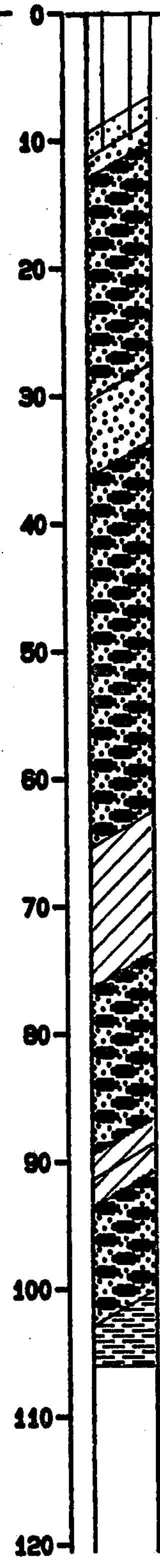
GROUT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 55 ft

SAND FILTER PACK
(size: Lonestar #3)
21 to 106 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
55 to 65 ft



BROWN SANDY SILT (ML) trace clay, 25% fine-grained sand

BROWN SILTY SAND (SM) fine- to coarse-grained sand, 40% silt

GRAY GRAVELLY SAND (SW) 50% sand, coarsening downward

GRAY SANDY GRAVEL (GW) 1" maximum diameter, 30% coarse-grained sand

REDDISH BROWN GRAVELLY SAND (SW) coarse-grained, 30% gravel

GRAY SANDY GRAVEL (GW) 1" maximum diameter, 40% coarse-grained sand

GRAYISH BROWN SANDY CLAY (CL) 20% fine- to coarse-grained sand

40% fine-grained sand, coarsening downward

GRAY SANDY GRAVEL (GW) 1-1/2" maximum diameter, 25% coarse-grained sand

GRAY SILTY CLAY (CL) trace fine-grained sand

BROWN SILTY CLAY (CL)

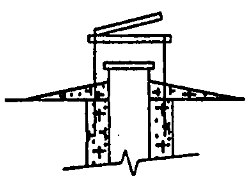
GRAY SANDY GRAVEL (GW) 40% sand, trace silt and clay

coarse gravel from 100-101 ft

WEATHERED BLACK SHALE BEDROCK

bottom of boring at 106 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail TW-5
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-5**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TW	10/88		

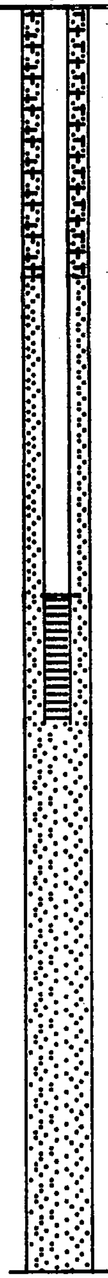
6898

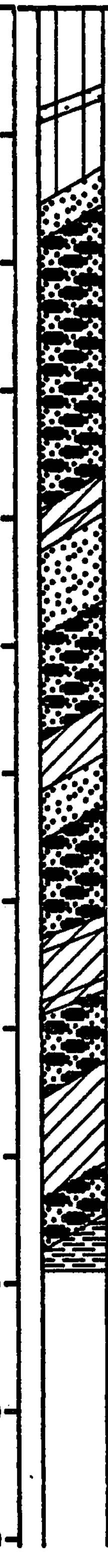
Top of PVC Casing
Elevation 63.28 ft

Equipment Failing Mud Rotary

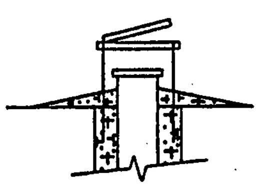
Elevation 61 ft Date 7/28/88

		Blows/foot	Depth (ft)	Sample	
GROUND SURFACE	See below for Well Top Detail		0		BROWN SILT (ML) trace fine-grained sand
					DARK BROWN SILTY SAND (SM) 60% coarse-grained sand, 40% fine-grained sand and silt
GROUT 0 to 21 ft			10		BROWN SILT (ML) 10% fine-grained sand
					GRAY GRAVELLY SAND (SW) 20% gravel
6 INCH DIAMETER BORING			20		GRAY SANDY GRAVEL (GW) 1" maximum diameter, 40% coarse-grained sand
2 INCH DIAMETER SCH. 40 PVC WELL CASING 0 to 46 ft			30		
SAND FILTER PACK (size: Lonestar #3) 21 to 99 ft					BROWN SILTY CLAY (CL) 30% silt, 10% sand
			40		GRAY SANDY CLAY (CL) 30% fine-grained sand
					BROWN GRAVELLY SAND (SW) 20% gravel
2 INCH DIAMETER SCH. 40 PVC SLOTTED WELL SCREEN (0.020" slot size) 46 to 56 ft			50		GRAY SANDY GRAVEL (GW) 1-1/2" maximum diameter, 40% coarse-grained sand
					DARK GRAY SILTY CLAY (CL)
			60		GRAY GRAVELLY SAND (SW) 20% gravel
					GRAY GRAVEL (GW)
			70		REDDISH BROWN SILTY CLAY (CL)
					GRAY SANDY CLAY (CL) with silt
					BROWN SILTY CLAY (CL)
			80		GRAY SANDY GRAVEL (GW) angular gravel to 1-1/2" diameter, 40% coarse-grained sand
					DARK GRAY SILTY CLAY (CL) trace fine-grained sand
			90		GRAY SANDY GRAVEL (GW) 1" maximum diameter, 40% coarse-grained sand
					WEATHERED GRAY SHALE BEDROCK
			100		bottom of boring at 99 ft
			110		
			120		





Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail TW-6
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-6**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TLW	10/88		

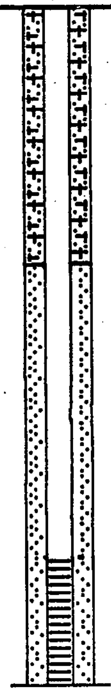
6899

Top of PVC Casing
Elevation 66.56 ft

Equipment Failing Mud Rotary

Elevation 65 ft Date 7/19/88

GROUND SURFACE	See below for Well Top Detail	Blows/foot	Depth (ft)	Sample	



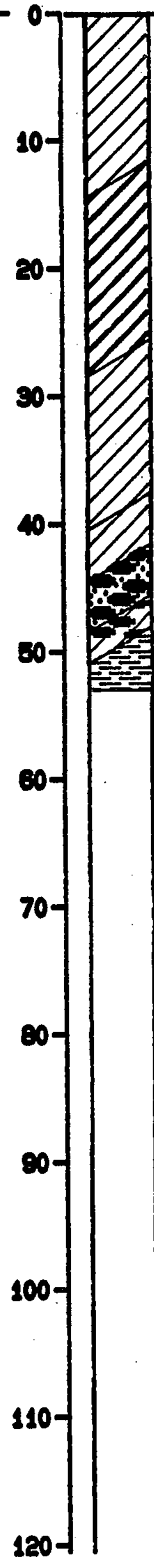
NEAT CEMENT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40 PVC WELL CASING 0 to 43 ft

SAND FILTER PACK (size: Lonestar #3) 20 to 53 ft

2 INCH DIAMETER SCH. 40 PVC SLOTTED WELL SCREEN (0.020" slot size) 43 to 53 ft



DARK BROWN SILTY CLAY (CL) trace fine-grained sand

increasing clay content at 8 ft

DARK BROWN CLAY (CH) stiff

BROWN SILTY CLAY (CL) trace fine-grained sand
mottled gray at 31 ft

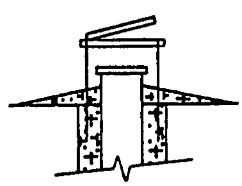
BROWN SANDY CLAY (CL-SC) 15% fine- to medium-grained sand, 15% coarse-grained sand
increasing sand at 41 ft

BROWN GRAVEL (GW-GP) 1" maximum diameter, <10% clay

GRAY CLAYEY GRAVEL (GC) 25% clay

BROWN FRACTURED SHALE BEDROCK
bottom of boring at 53 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail TW-7
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-7**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TW	10/88		

6900

Top of PVC Casing
Elevation 69.34 ft

GROUND SURFACE

See below for Well Top Detail

Blows/foot

Depth (ft)

Sample

Equipment Failing Mud Rotary

Elevation 67 ft Date 7/20/88

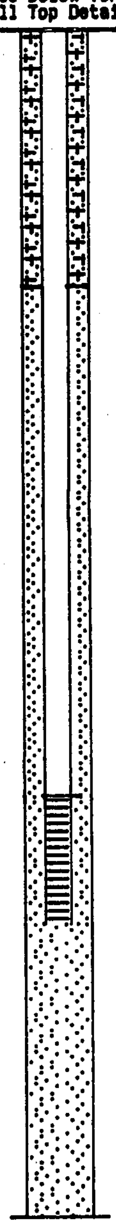
NEAT CEMENT 0 to 21 ft

6 INCH DIAMETER BORING

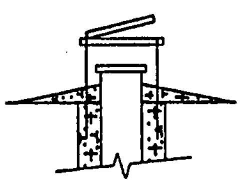
2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 60 ft

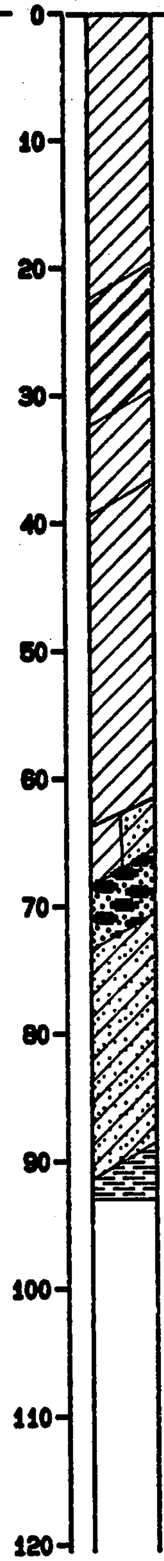
SAND FILTER PACK
(size: Lonestar #3)
20 to 93 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
60 to 70 ft



Well Top Detail
Not to Scale





DARK BROWN SANDY SILTY CLAY (CL) 30% silt, 20% fine-grained sand

color change to brown at 8 ft

BROWN SILTY CLAY (CH) 20% silt with fine-grained sand

GRAYISH BROWN SILTY CLAY (CL) 30% silt with fine-grained sand

BROWN SANDY CLAY (CL) 30% fine-grained sand

less sand at 48 ft

35% fine-grained sand at 59 ft

50% fine-grained sand at 64 ft

GRAY GRAVEL (GW) 1" maximum diameter, trace clay

GRAY GRAVELLY CLAYEY SAND (SC) 40% clay, medium-grained sand, 20% gravel possible weathered bedrock

GRAY SHALE BEDROCK
bottom of boring at 93 ft

Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail TW-8
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
A–8

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TLW	10/88		

Top of PVC Casing
Elevation 63.07 ft

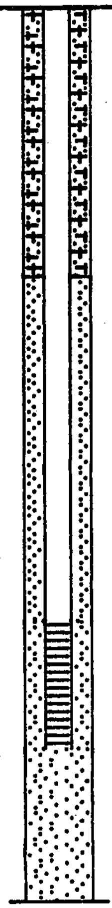
GROUND SURFACE

See below for Well Top Detail

Blows/foot | Depth (ft) | Sample

Equipment Failing Mud Rotary

Elevation 61 ft Date 8/24/88



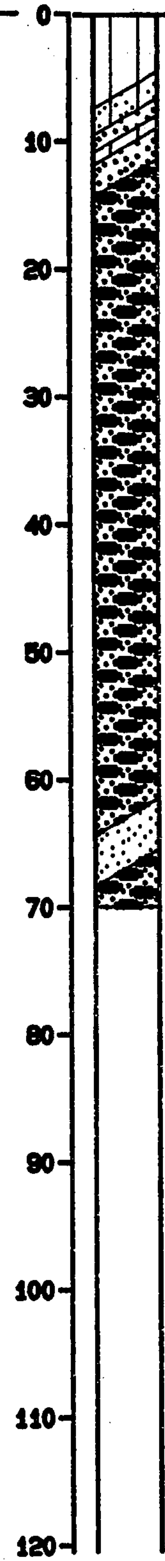
GROUT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 48 ft

SAND FILTER PACK
(size: Lonestar #3)
21 to 70 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
48 to 58 ft



BROWN SANDY SILT (ML) 40% very fine-grained sand
BROWN SILTY SAND (SM) very fine- to fine-grained sand, 50% silt
GRAY GRAVELLY SAND (SW) 40% gravel
BROWN SANDY SILT (ML) 40% fine-grained sand
GRAY GRAVELLY SAND (SW) 50% gravel

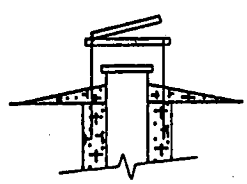
GRAY SANDY GRAVEL (GW) 1" maximum diameter, 40% medium- to coarse-grained sand

coarser gravel at 30 ft

GRAY SAND (SP) coarse-grained sand, trace gravel
GRAY SANDY GRAVEL (GW) 1-1/2" maximum diameter

bottom of boring at 70 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and
Environmental Services

Log of Boring and Well Completion Detail TW-9
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
A-9

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TLW	10/88		

6902

Top of PVC Casing
Elevation 62.35 ft

Equipment Failing Mud Rotary
Elevation 60 ft Date 8/19/88

GROUND SURFACE	See below for Well Top Detail	Blows/foot	Depth (ft)	Sample	

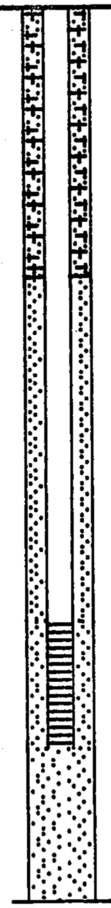
GROUT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 48 ft

SAND FILTER PACK
(size: Lonestar #3)
21 to 70 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
48 to 58 ft



Depth (ft): 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

BROWN SANDY SILT (ML) 40% fine-grained sand

BROWN SILTY SAND (SM) 40% silt, 10% clay

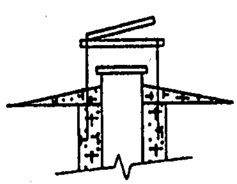
BROWN SILTY SAND (ML)

GRAY SANDY GRAVEL (GW) 1" maximum diameter,
40% medium- to coarse-grained sand

coarser gravel at 35 ft

bottom of boring at 70 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and
Environmental Services

Log of Boring and Well Completion Detail TW-10
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
A-10

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TLW	10/88		

6903

Top of PVC Casing
Elevation 63.38 ft

GROUND SURFACE

See below for Well Top Detail

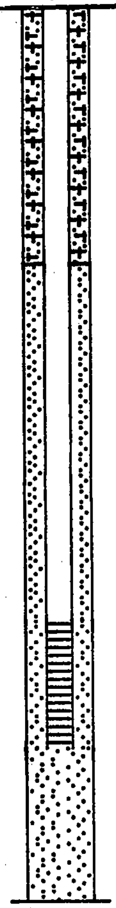
Blows/foot

Depth (ft)

Sample

Equipment Failing Mud Rotary

Elevation 61 ft Date 8/25/88



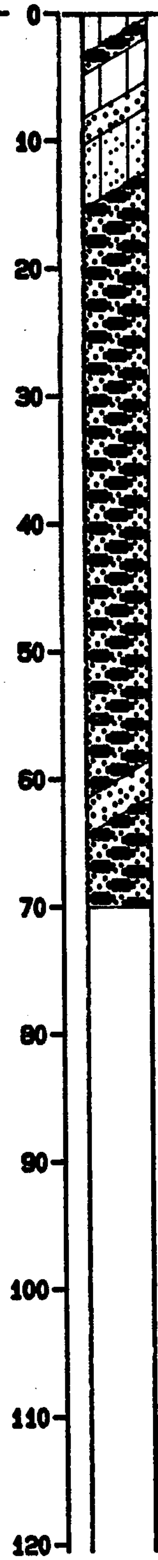
GROUT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 48 ft

SAND FILTER PACK
(size: Lonestar #3)
20 to 70 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
48 to 58 ft



BROWN SANDY SILT (ML) 45% fine-grained sand
BROWN GRAVEL (GW) 1" maximum diameter
BROWN SANDY SILT (ML) 20% fine-grained sand
BROWN SAND (SW) with fine-grained gravel

BROWN SILTY SAND (SM) medium-grained sand

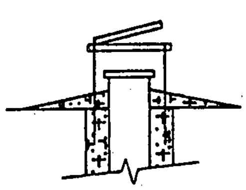
GRAYISH BROWN SANDY GRAVEL (GW) 1/2" maximum diameter, 25-30% medium- to coarse-grained sand

3/4" diameter gravel size

GRAY GRAVELLY SAND (SW)
GRAY SANDY GRAVEL (GW)

bottom of boring at 70 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and
Environmental Services

Log of Boring and Well Completion Detail TW-11
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
A-11

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916, 005.02	TWJ	10/88		

6904

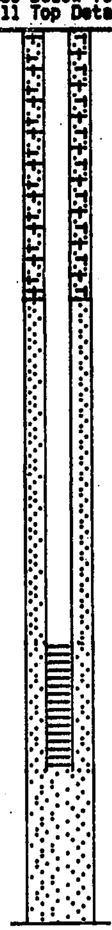
Top of PVC Casing
Elevation 65.13 ft

Equipment Failing Mud Rotary
Elevation 63 ft Date 8/22/88

Blows/foot | Depth (ft) | Sample

GROUND SURFACE

See below for Well Top Detail



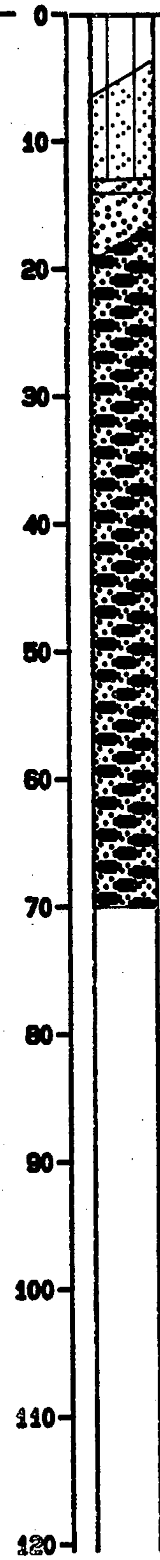
GROUT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 48 ft

SAND FILTER PACK
(size: Lonestar #3)
21 to 70 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
48 to 58 ft



BROWN SANDY SILT (ML) 40% very fine-grained sand

BROWN SILTY SAND (SM) 50% silt

GRAY SAND (SW) fine- to medium-grained, trace gravel and silt

GRAVELLY SAND (SW) 40% gravel to 1" diameter

GRAY GRAVEL (GW) 1-1/2" maximum diameter

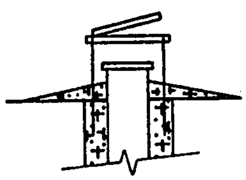
coarse-grained gravel at 30 ft

coarse-grained gravel at 36 ft

coarse-grained gravel at 56 ft

bottom of boring at 70 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and
Environmental Services

Log of Boring and Well Completion Detail TW-12
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
A-12

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TW	10/88		

6905

Top of PVC Casing
Elevation 62.95 ft

Equipment Failing Mud Rotary
Elevation 61 ft Date 8/23/88

GROUND SURFACE | See below for Well Top Detail | Blows/foot | Depth (ft) | Sample

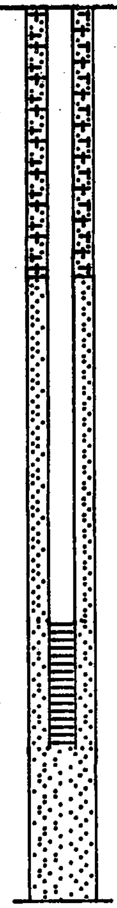
GROUT 0 to 21 ft

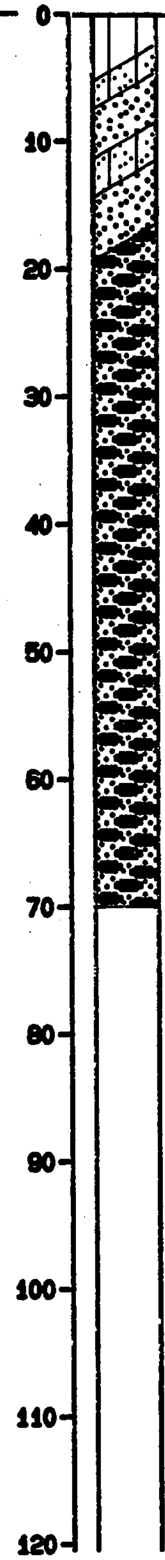
6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 48 ft

SAND FILTER PACK
(size: Lonestar #3)
21 to 70 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
48 to 58 ft





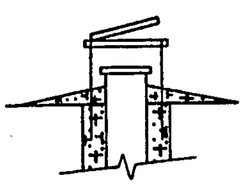
BROWN SANDY SILT (ML) 40% very fine- to fine-grained sand
BROWN SILTY SAND (SM) fine-grained sand, 50% silt
BROWN GRAVELLY SAND (SW) 40% silt and fine-grained sand, 20% gravel
BROWN SILTY SAND (SM)
GRAY GRAVELLY SAND (SW) 30% gravel

GRAY SANDY GRAVEL (GW) 1-1/2" maximum diameter, 40% coarse sand

coarse-grained gravel at 30 ft

bottom of boring at 70 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail TW-13
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
A-13

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916, 005.02	TLW	10/88		

6906

Top of PVC Casing
Elevation 65.01 ft

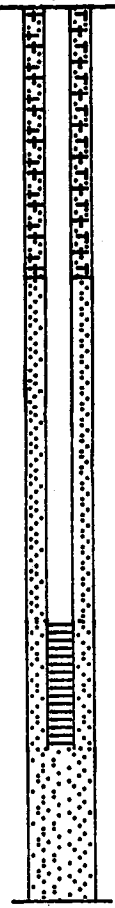
GROUND SURFACE

See below for Well Top Detail

Blows/foot | Depth (ft) | Sample

Equipment Failing Mud Rotary

Elevation 63 ft Date 8/26/88



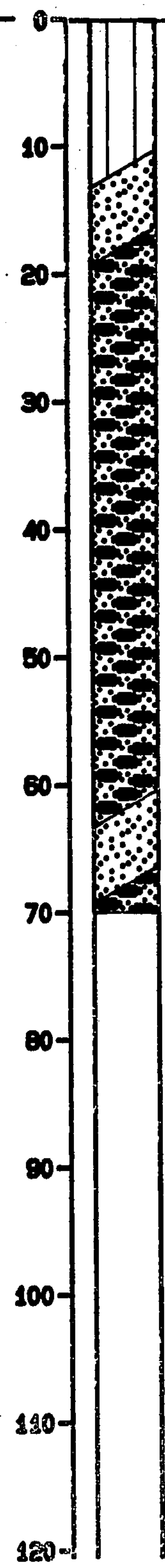
GROUT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 48 ft

SAND FILTER PACK
(size: Lonestar #3)
20 to 70 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
48 to 58 ft



BROWN SANDY SILT (ML) 40% fine-grained sand

GRAY GRAVELLY SAND (SW) 20% gravel

GRAY SANDY GRAVEL (GW) 10-20% coarse-grained sand

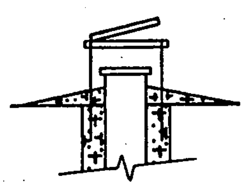
gravel to 1" diameter

GRAY GRAVELLY SAND (SW) coarse -grained sand, 40% gravel

GRAY SANDY GRAVEL (GW) 25% coarse-grained sand

bottom of boring at 70 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and
Environmental Services

Log of Boring and Well Completion Detail TW-14
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
A–14

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916, 005.02	TLW	10/88		

6907

Top of PVC Casing
Elevation 63.35 ft

GROUND SURFACE

See below for Well Top Detail

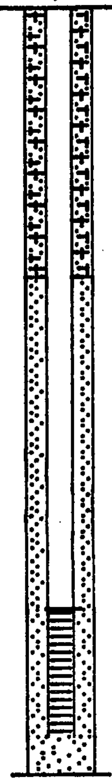
Blows/foot

Depth (ft)

Sample

Equipment Failing Mud Rotary

Elevation 61 ft Date 8/16/88



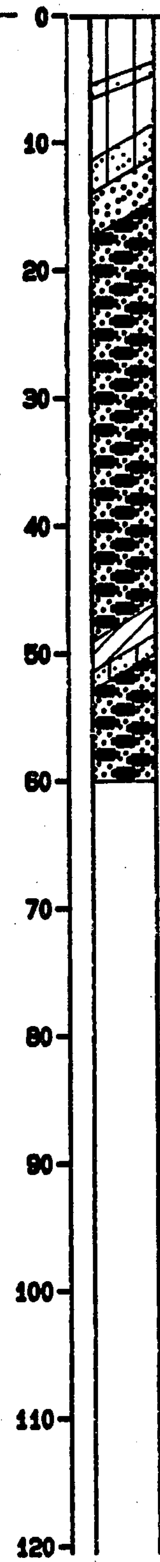
GROUT 0 to 21 ft

6 INCH DIAMETER BORING

2 INCH DIAMETER SCH. 40
PVC WELL CASING
0 to 47 ft

SAND FILTER PACK
(size: Lonestar #3)
20 to 60 ft

2 INCH DIAMETER SCH. 40
PVC SLOTTED WELL SCREEN
(0.020" slot size)
47 to 57 ft



BROWN SANDY SILT (ML) very fine-grained sand
BROWN SILTY SAND (SM) 20% silt
BROWN SANDY SILT (ML) 50% very fine-grained sand

BROWN SILTY SAND (SM) fine- to medium-grained sand, trace silt
GRAY SAND (SW) fine- to medium-grained

GRAY SANDY GRAVEL (GW) 50% medium- to coarse-grained sand
percentage of gravel increasing with depth

coarse gravel at 38 ft

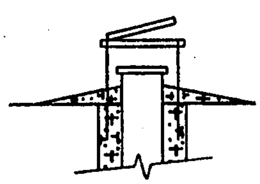
GRAY SANDY CLAY (CL) 30% fine-grained sand

BROWN SILTY SAND (SM)
GRAY SANDY GRAVEL (GW)

coarse-grained gravel at 56 ft

bottom of boring at 60 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail TW-15
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-15**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TLW	10/88		

Top of Steel Flange
Elevation 62.93 ft

Equipment Failing Mud Rotary
Elevation 62 ft Date 8/18/88

GROUND SURFACE — See below for Well Top Detail | Blows/foot | Depth (ft) | Sample

18 INCH DIAMETER BORING

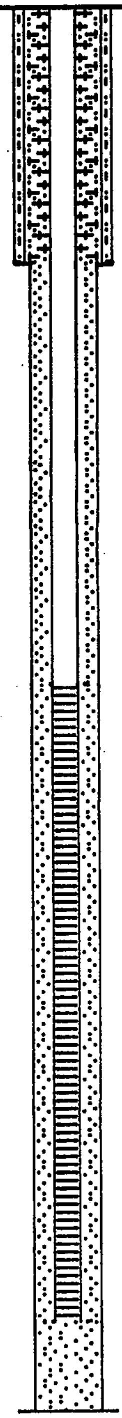
GROUT 0 to 5 ft

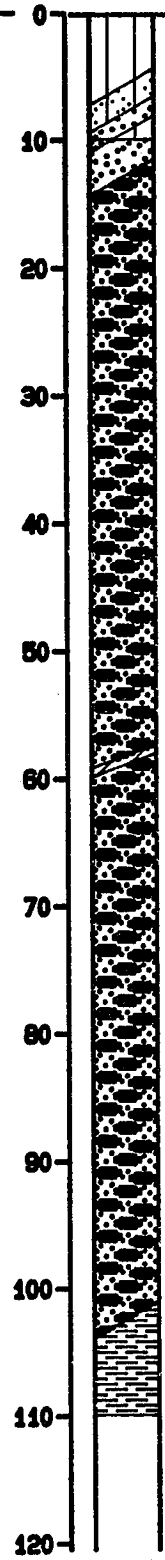
20 INCH DIAMETER CONDUCTOR CASING 0 to 20 ft

12 INCH DIAMETER STEEL WELL CASING 0 to 53 ft

SAND FILTER PACK (3/8" pea gravel) ft 5-110 ft

12 INCH DIAMETER STEEL WELL SCREEN (0.050" slot size) 53 to 103 ft





BROWN SANDY SILT (ML) 40% very fine-grained sand
BROWN SILTY SAND (SM) very fine- to fine-grained sand, 50% silt,
GRAY GRAVELLY SAND (SW) 40% gravel
BROWN SANDY SILT (ML) 40% fine-grained sand
GRAY GRAVELLY SAND (SW) 50% gravel

GRAY SANDY GRAVEL (GW) 40% medium- to coarse-grained sand

coarse gravels at 35 ft

GRAY SANDY CLAY (CL) trace fine-grained sand

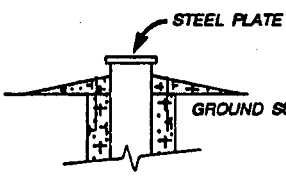
GRAY SANDY GRAVEL (GW) 50% medium- to coarse-grained sand

coarse gravel at 88 ft

WEATHERED GRAY SHALE BEDROCK

bottom of boring at 110 ft

Well Top Detail
Not to Scale



Harding Lawson Associates
Engineering and Environmental Services

Log of Boring and Well Completion Detail PW-1
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A-16**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	01916,005.02	TLW	10/88		

Major Divisions			Symbol	Typical Names
COARSE–GRAINED SOILS MORE THAN HALF IS COARSER THAN NO. 200 SIEVE	GRAVELS MORE THAN HALF COARSE FRACTION IS LARGER THAN No. 4 SIEVE SIZE	CLEAN GRAVELS WITH LITTLE OR NO FINES	GW	WELL GRADED GRAVELS WITH OR WITHOUT SAND, LITTLE OR NO FINES
			GP	POORLY GRADED GRAVELS WITH OR WITHOUT SAND, LITTLE OR NO FINES
		GRAVELS WITH OVER 12% FINES	GM	SILTY GRAVELS, SILTY GRAVELS WITH SAND
			GC	CLAYEY GRAVELS, CLAYEY GRAVELS WITH SAND
	SANDS MORE THAN HALF COARSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE	CLEAN SANDS WITH LITTLE OR NO FINES	SW	WELL GRADED SANDS WITH OR WITHOUT GRAVEL, LITTLE OR NO FINES
			SP	POORLY GRADED SANDS WITH OR WITHOUT GRAVEL, LITTLE OR NO FINES
		SANDS WITH OVER 12% FINES	SM	SILTY SANDS WITH OR WITHOUT GRAVEL
			SC	CLAYEY SANDS WITH OR WITHOUT GRAVEL
FINE–GRAINED SOILS MORE THAN HALF IS FINER THAN NO. 200 SIEVE	SILTS AND CLAYS LIQUID LIMIT 50% OR LESS		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTS WITH SANDS AND GRAVELS
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, CLAYS WITH SANDS AND GRAVELS, LEAN CLAYS
			OL	ORGANIC SILTS OR CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS LIQUID LIMIT GREATER THAN 50%		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACIOUS, FINE SANDY OR SILTY SOILS, ELASTIC SILTS
			CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
			OH	ORGANIC SILTS OR CLAYS OF MEDIUM TO HIGH PLASTICITY
HIGHLY ORGANIC SOILS			Pt	PEAT AND OTHER HIGHLY ORGANIC SOILS

UNIFIED SOIL CLASSIFICATION – ASTM D2487-85

Perm	—	Permeability
Consol	—	Consolidation
LL	—	Liquid Limit (%)
PI	—	Plastic Index (%)
G_s	—	Specific Gravity
MA	—	Particle Size Analysis
■	—	"Undisturbed" Sample
⊠	—	Bulk or Classification Sample

	Shear Strength (psf)	Confining Pressure		
TxUU	3200	(2600)	—	Unconsolidated Undrained Triaxial Shear
	(FM) or (S)			(field moisture or saturated)
TxCU	3200	(2600)	—	Consolidated Undrained Triaxial Shear
(P)				(with or without pore pressure measurement)
TxCD	3200	(2600)	—	Consolidated Drained Triaxial Shear
SSCU	3200	(2600)	—	Simple Shear Consolidated Undrained
(P)				(with or without pore pressure measurement)
SSCD	3200	(2600)	—	Simple Shear Consolidated Drained
DSCD	2700	(2000)	—	Consolidated Drained Direct Shear
UC	470		--	Unconfined Compression
LVS	700		—	Laboratory Vane Shear

KEY TO TEST DATA

Harding Lawson Associates
Engineers and Geoscientists

Unified Soil Classification Chart and Key to Test Data
Wolher Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE **A–17**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
EH	1916,005.02	TW	10/88		

Appendix B

WATER-LEVEL AND AQUIFER TEST DATA

Appendix B

WATER LEVEL AND AQUIFER TEST DATA

FIGURE B-1
Pumping Well Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

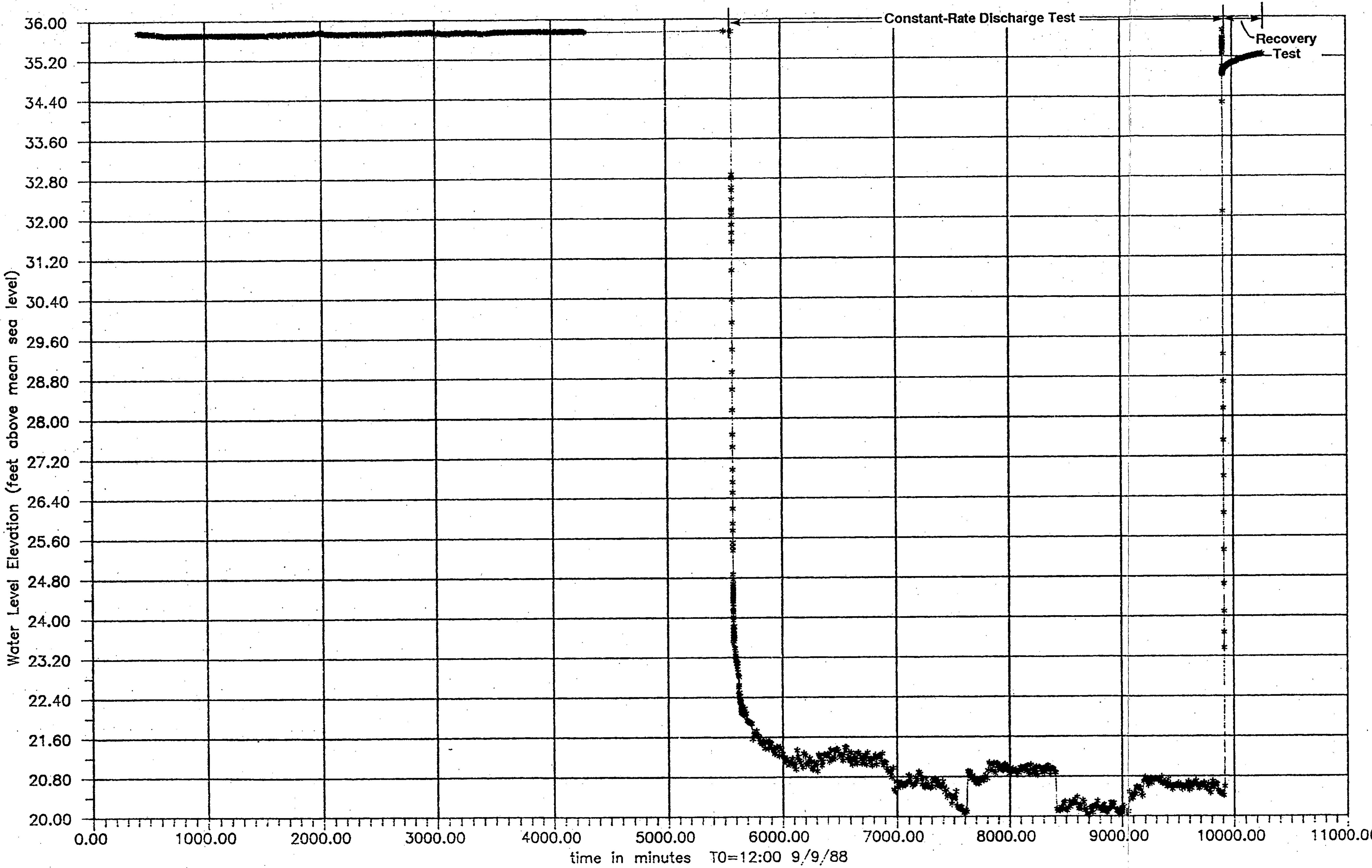


FIGURE B-2
Well TW-1 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

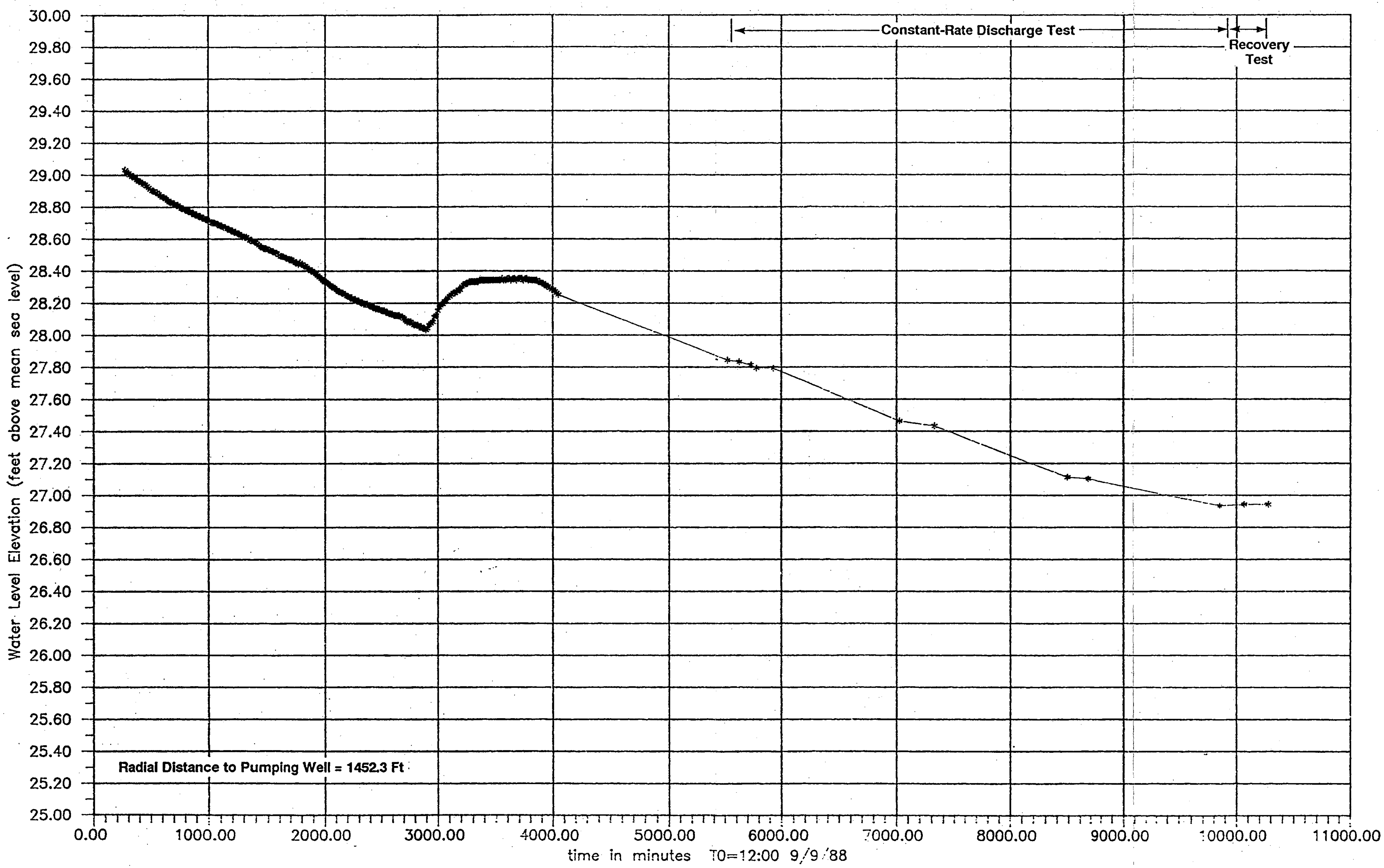


FIGURE B-3
Well TW–2 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

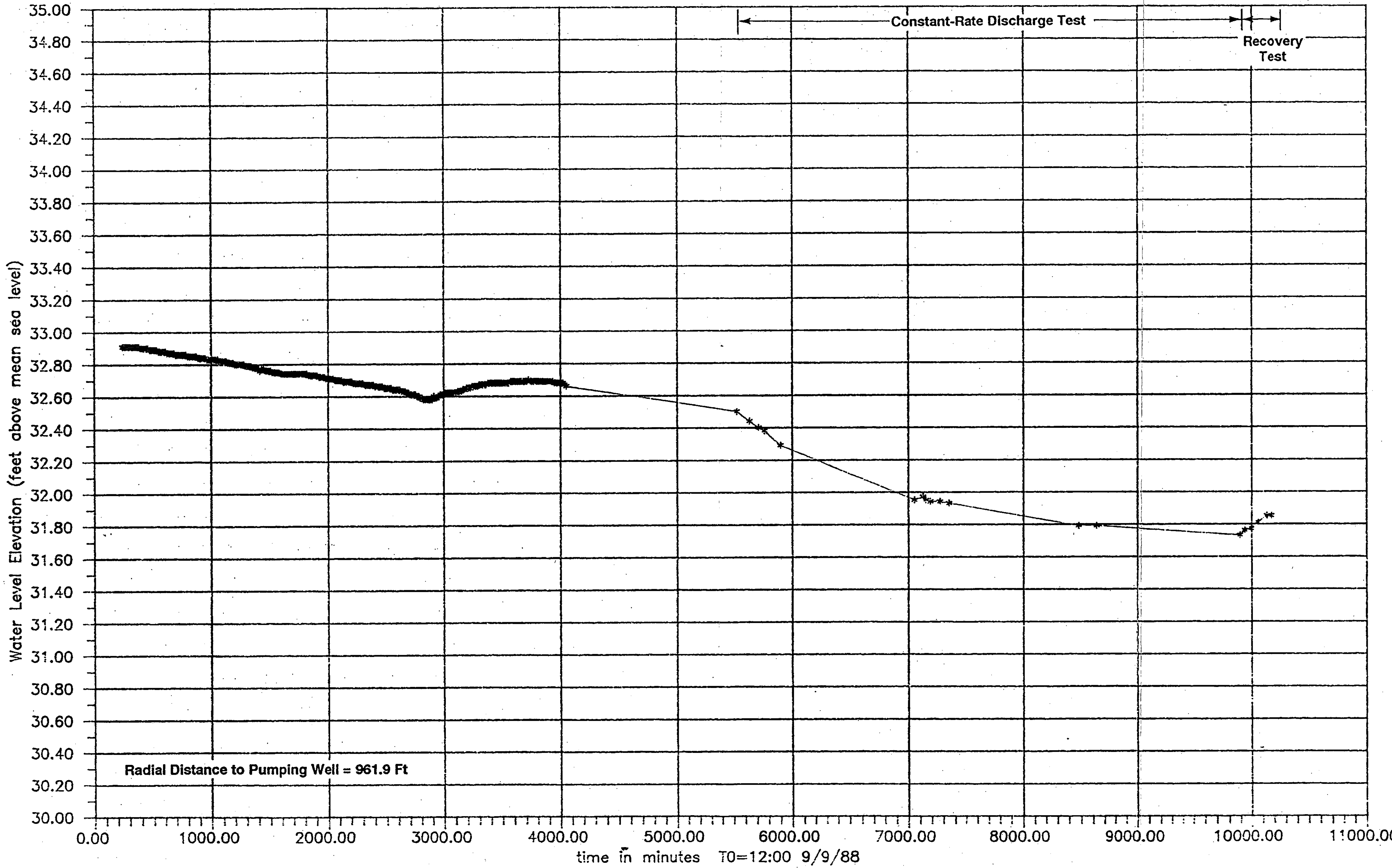


FIGURE B-4
Well TW-3 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

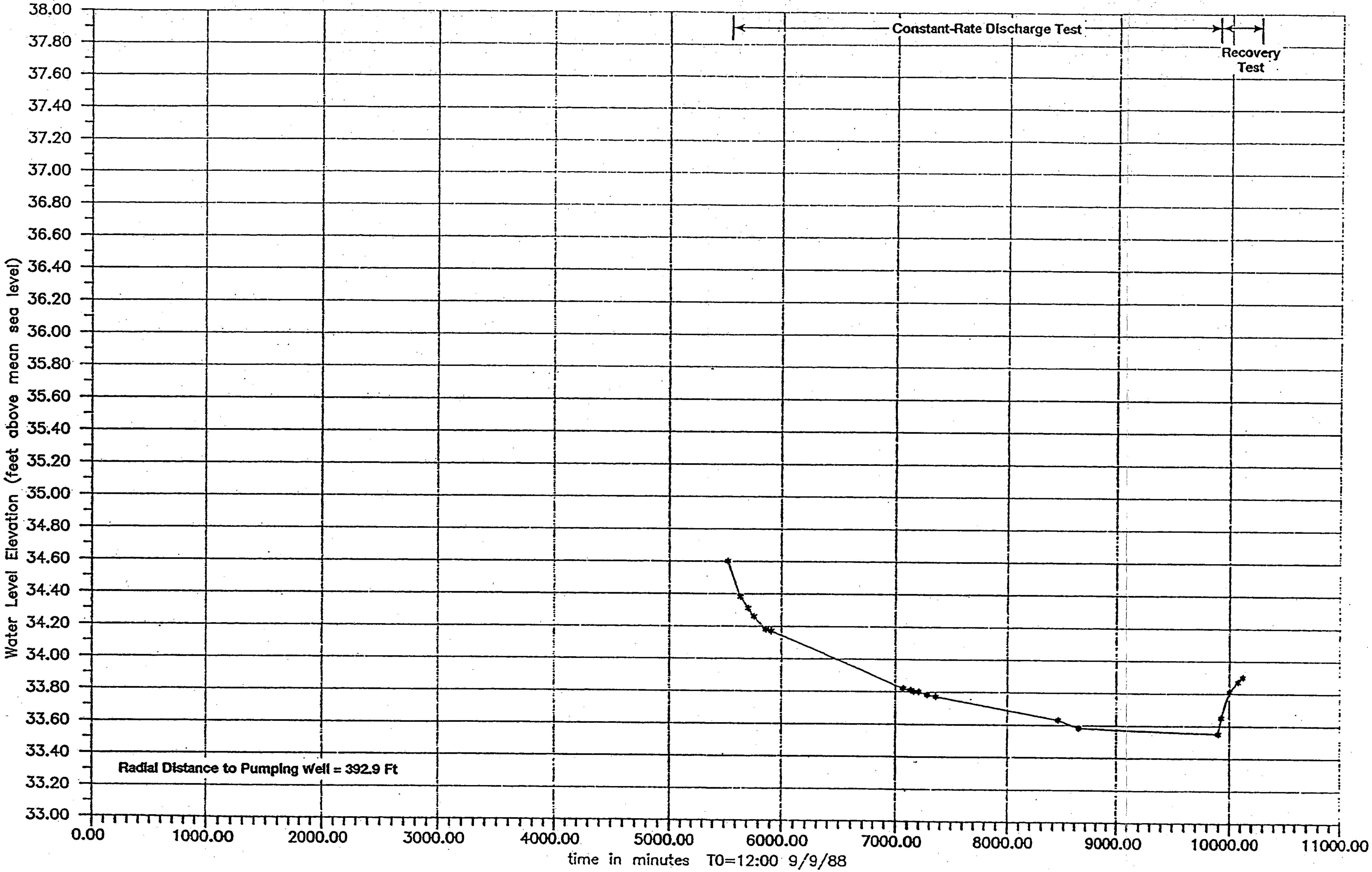


FIGURE B-5
Well TW—4 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

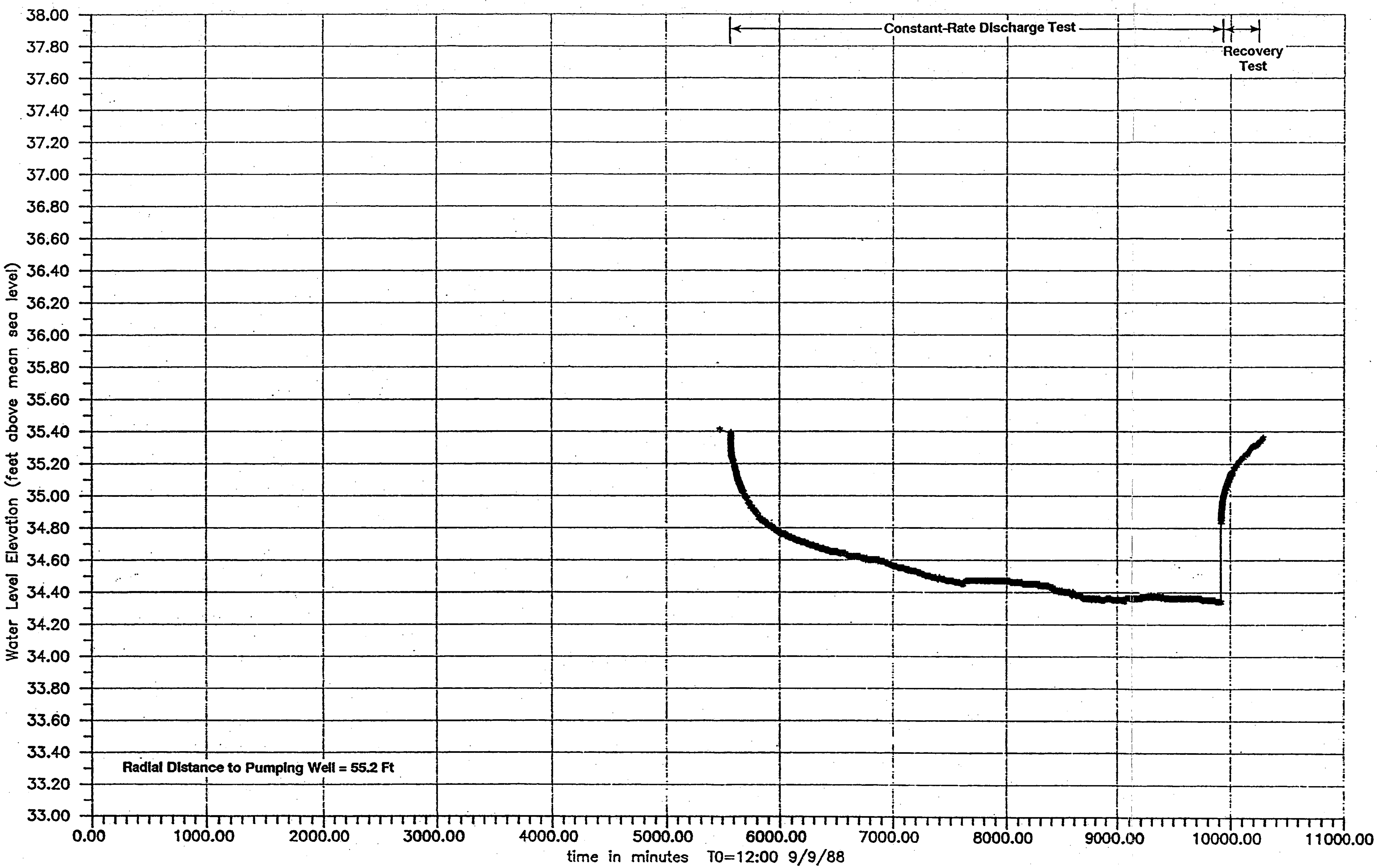


FIGURE B-6
Well TW–5 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

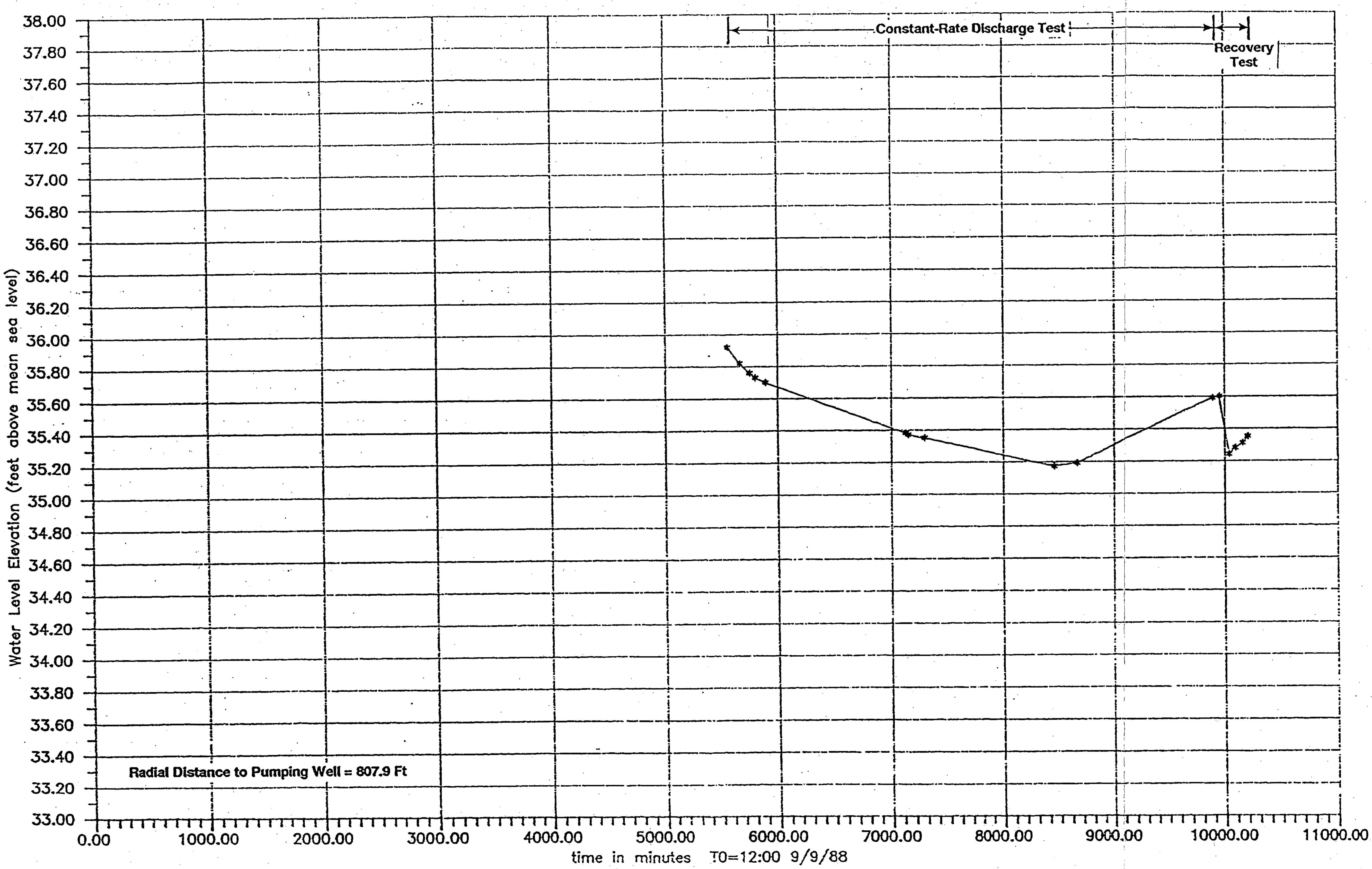


FIGURE B-7
Well TW–6 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

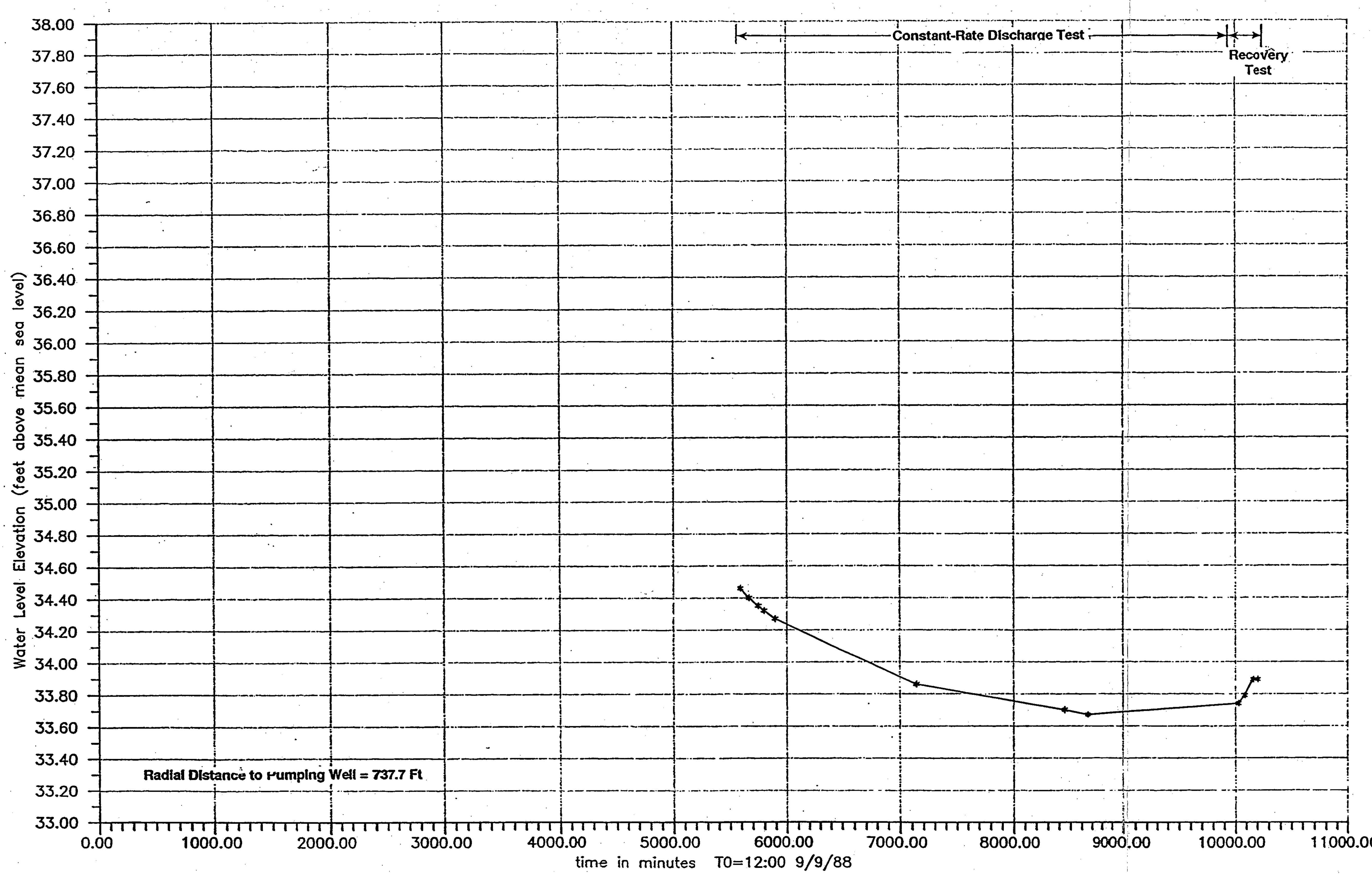


FIGURE B-8
Well TW—7 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

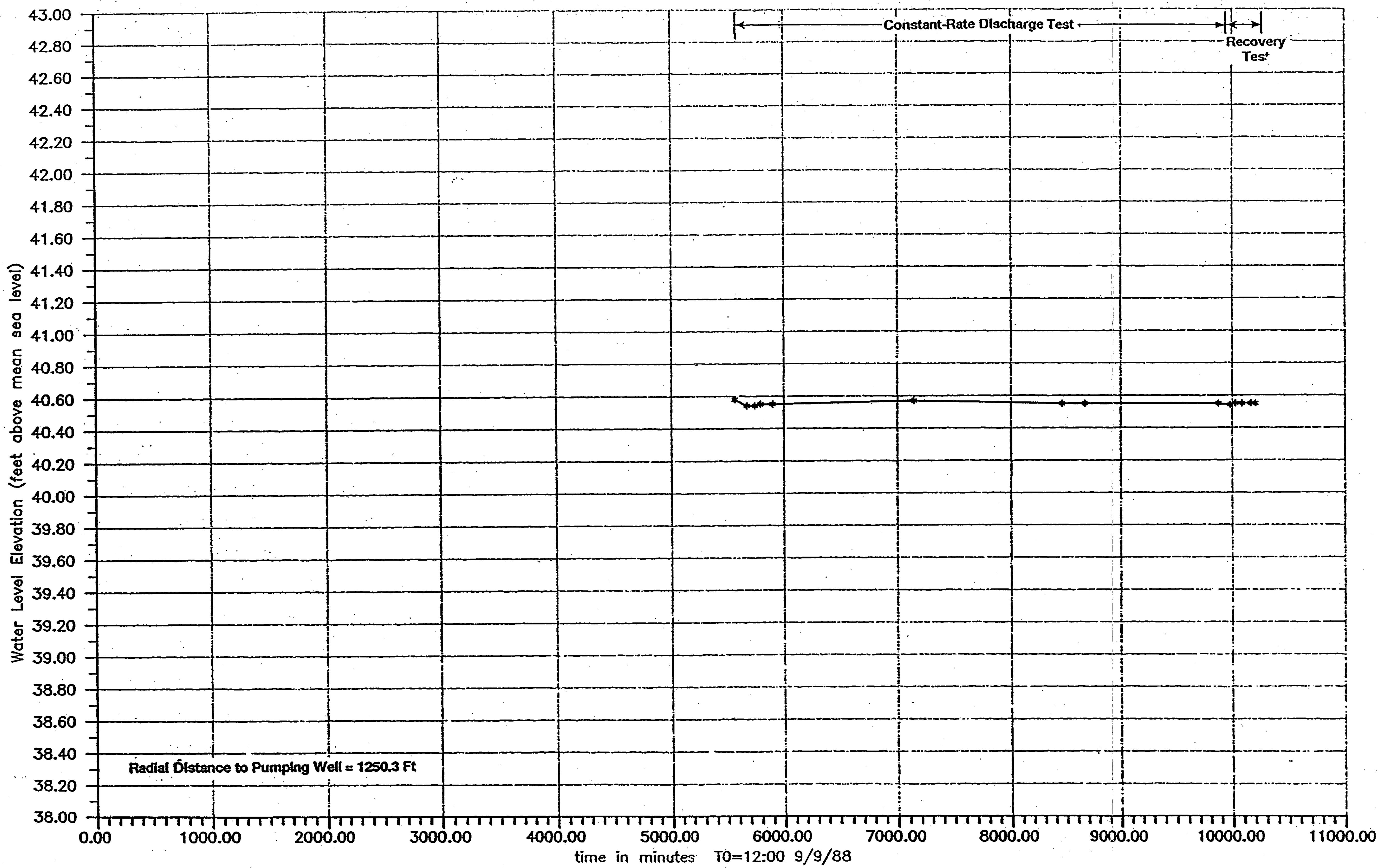


FIGURE B-9
Well TW–8 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

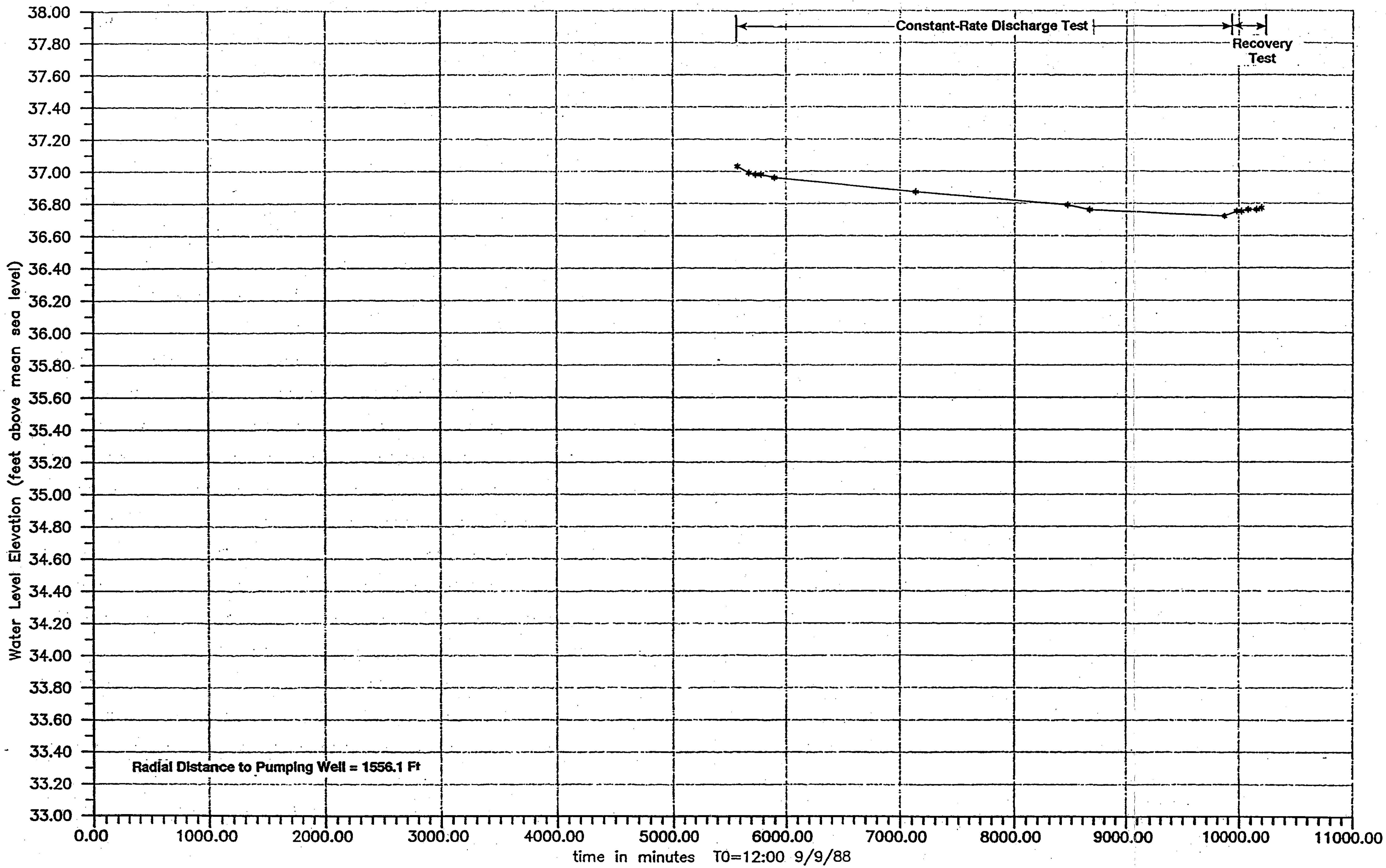


FIGURE B-10
Well TW–9 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

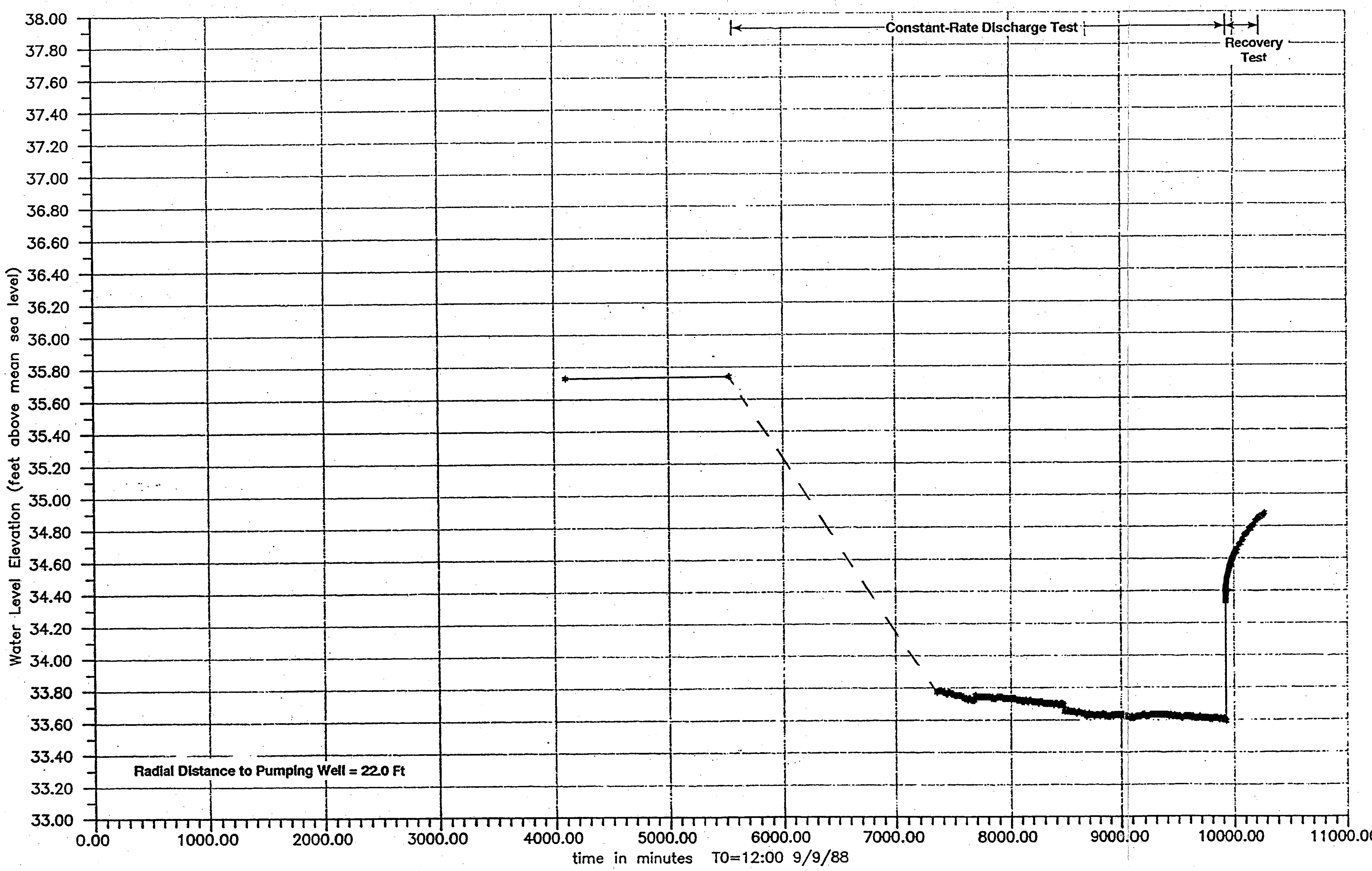


FIGURE B-11
Well TW–10 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

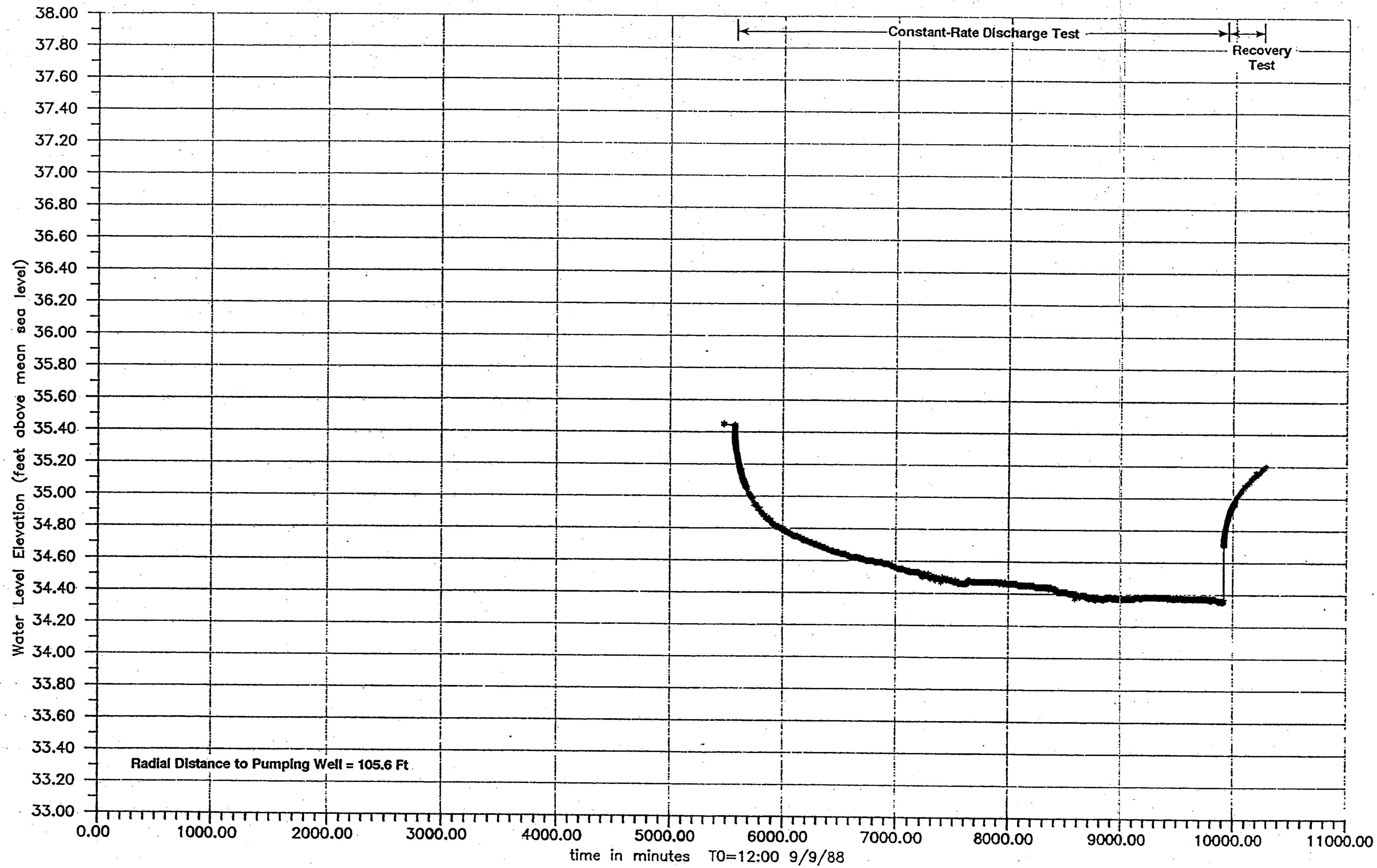


FIGURE B-12
Well TW–11 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

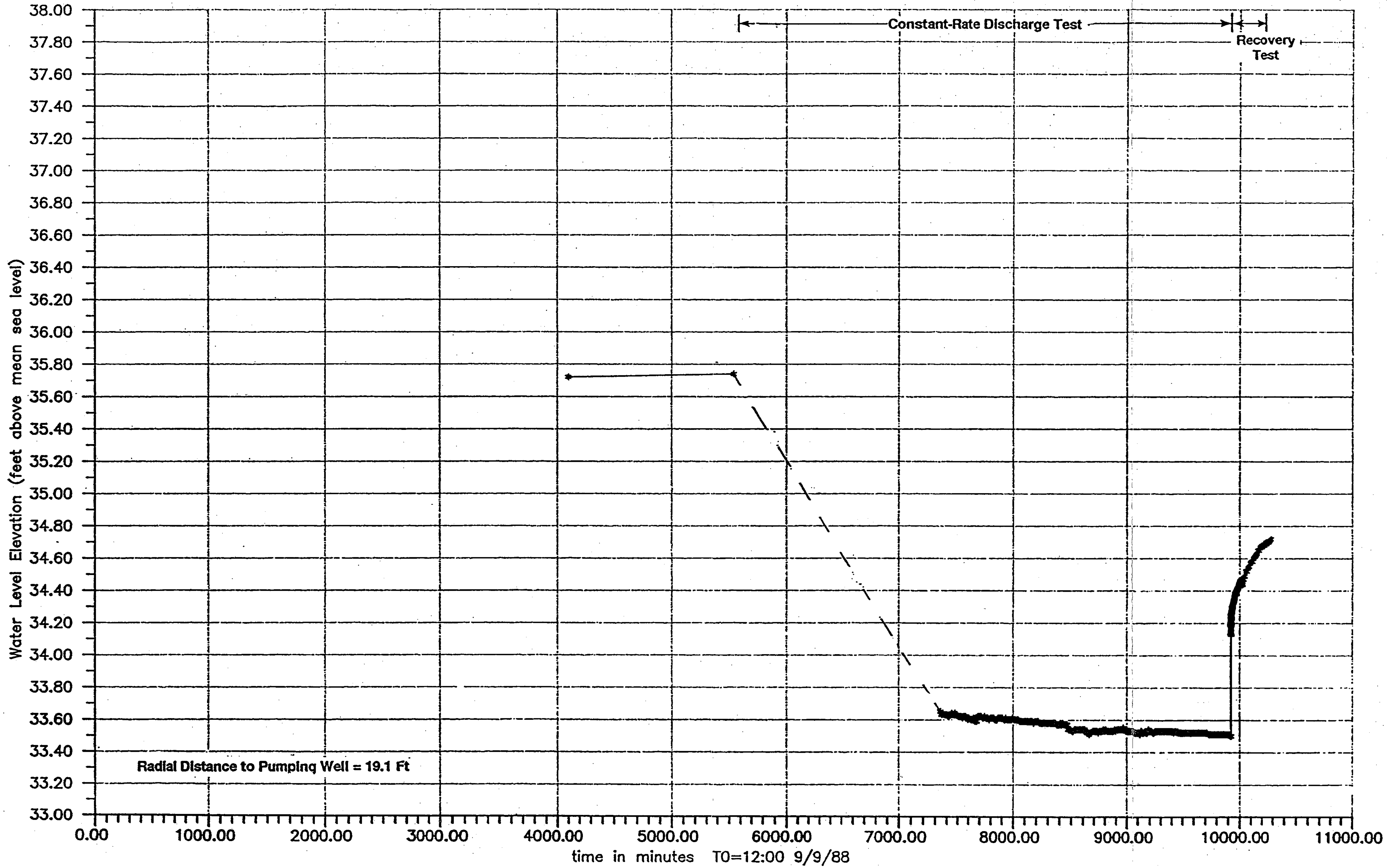


FIGURE B-13
Well TW-12 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

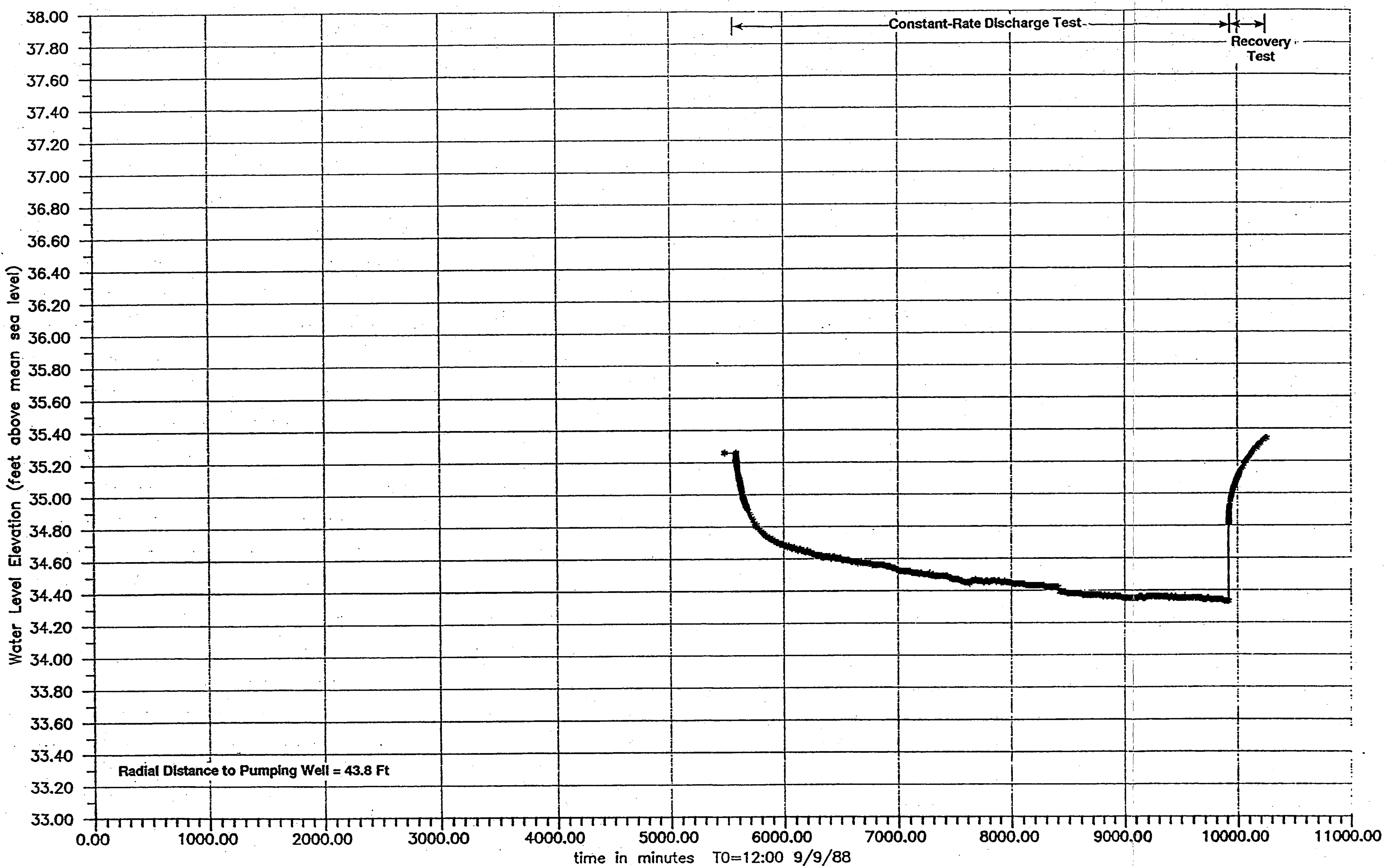


FIGURE B-14
Well TW-13 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

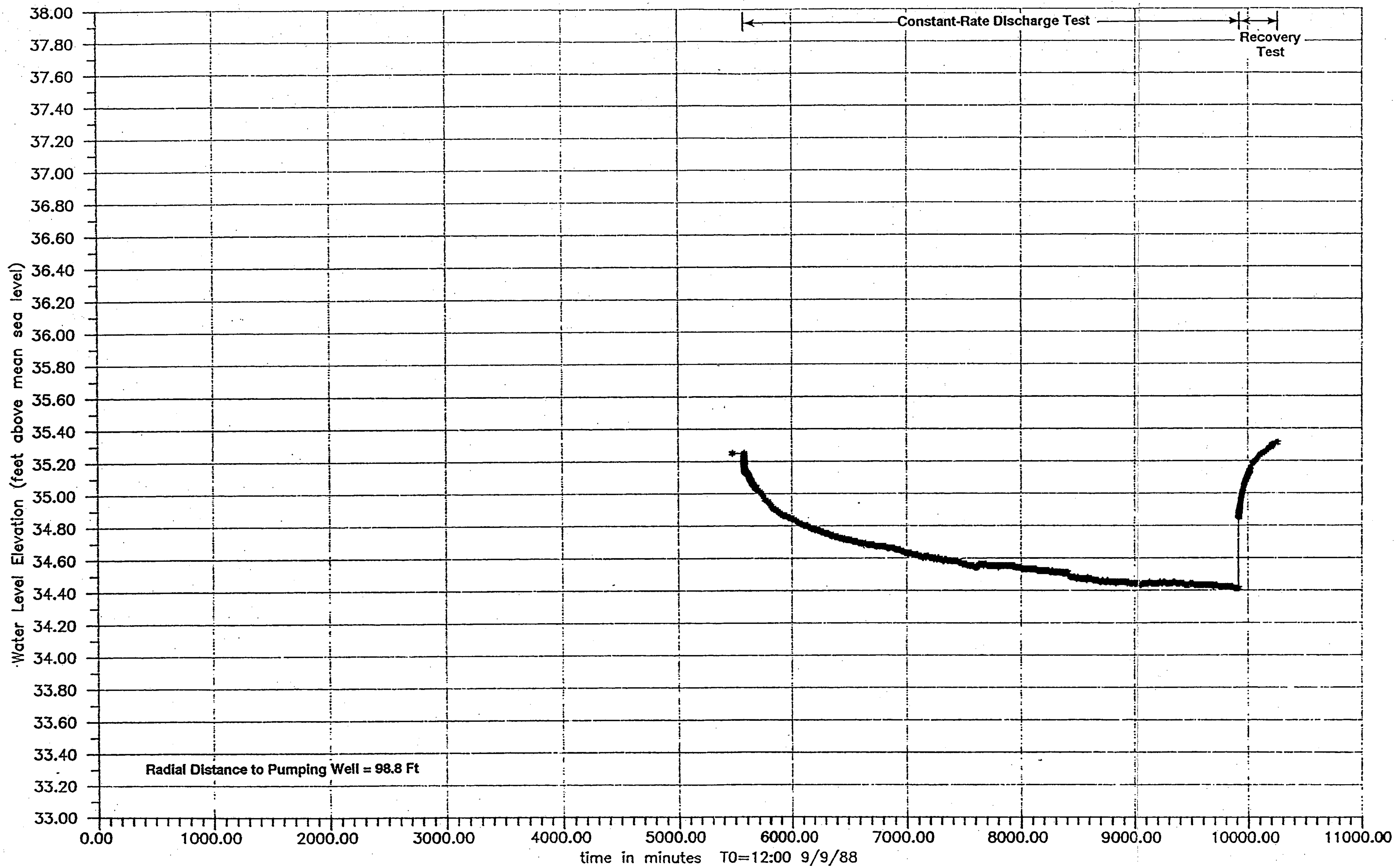


FIGURE B-16
Well TW–15 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

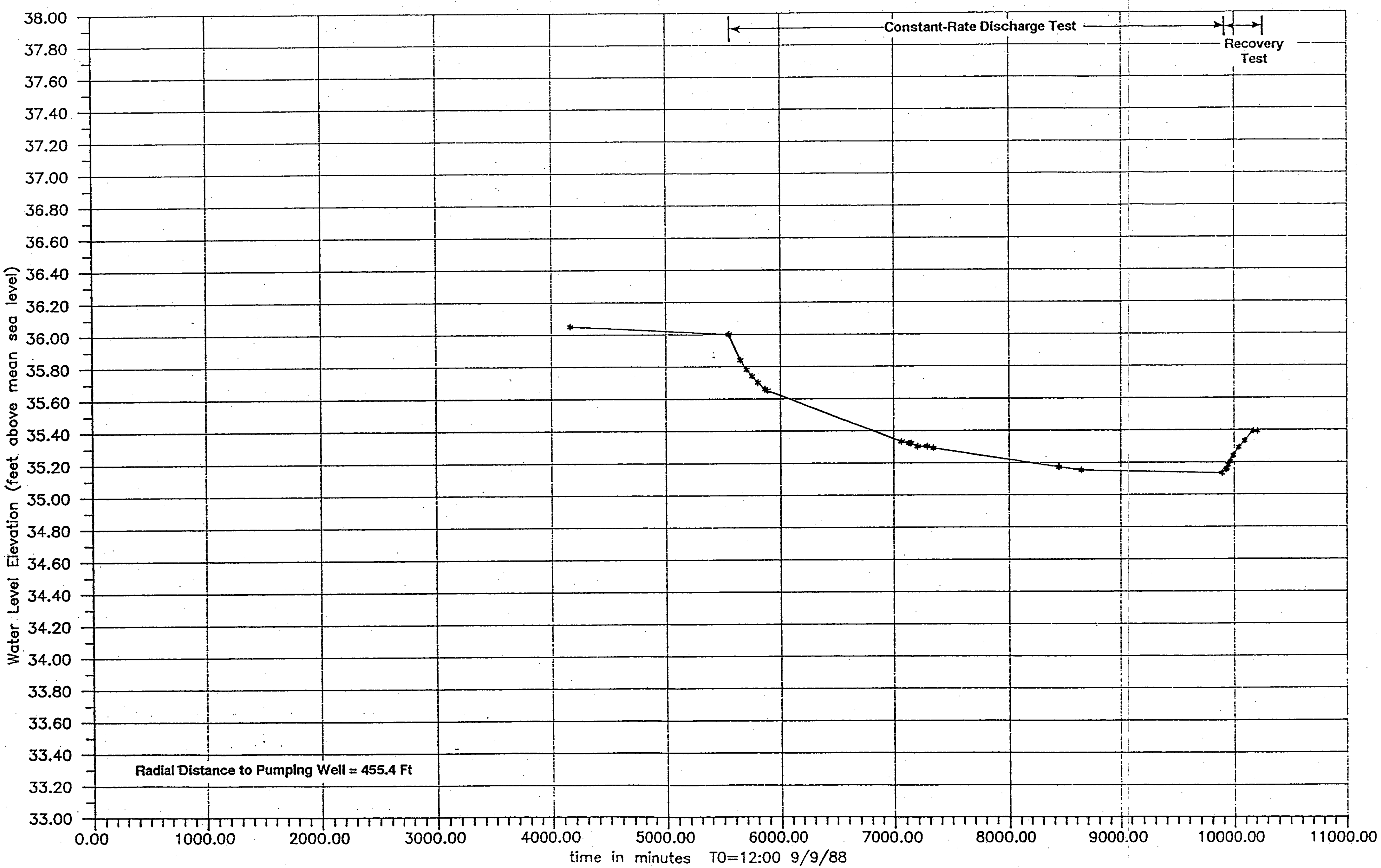
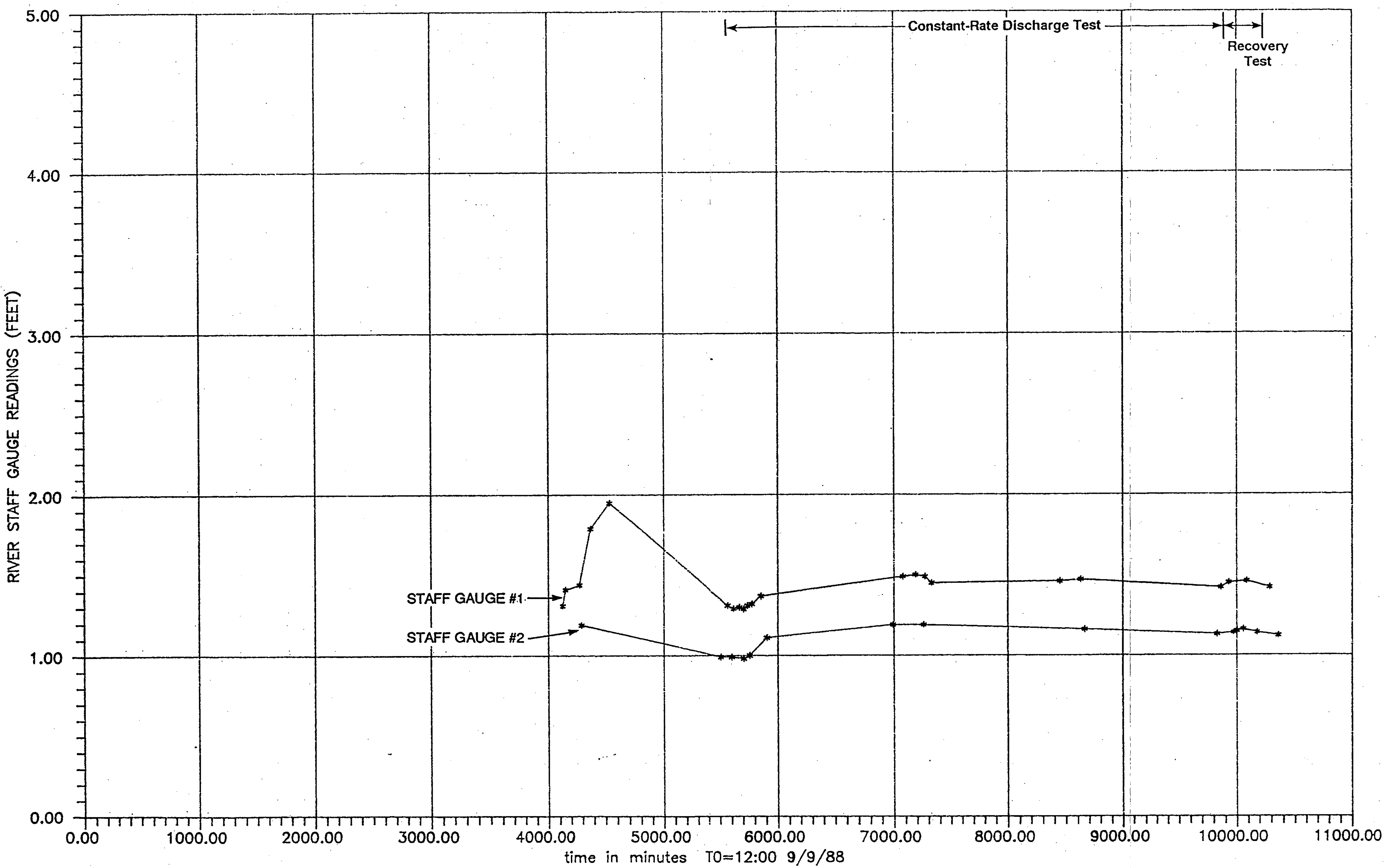


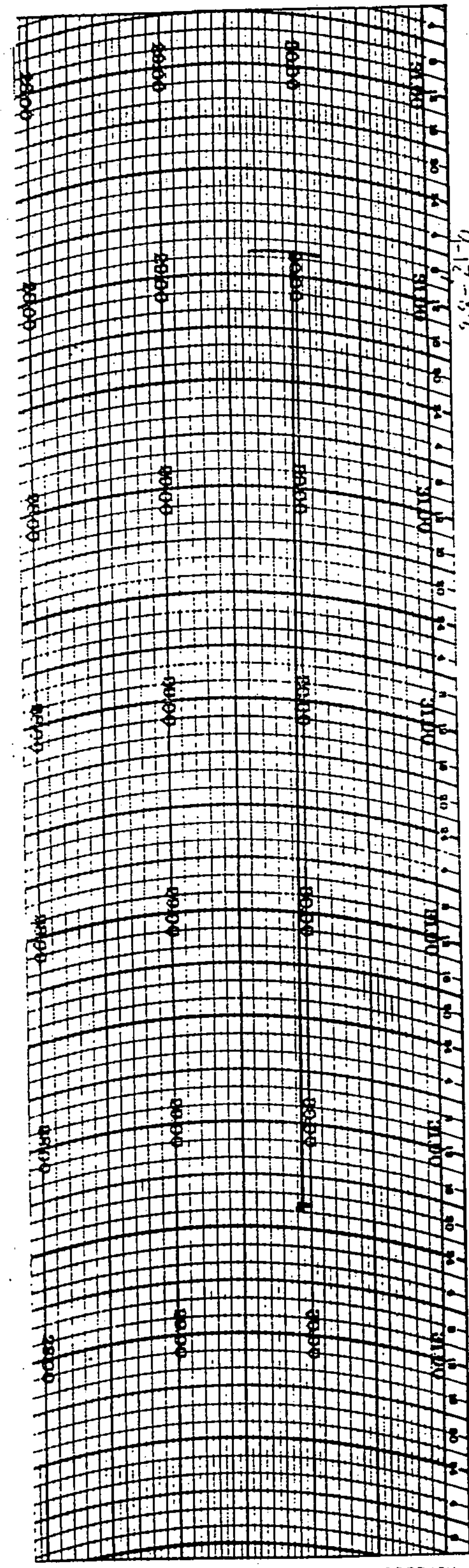
FIGURE B-17
River Stage Over Time
Wohler Aquifer Study
Sonoma County Water Agency



STAFF GAUGE #1 REFERENCE ELEVATION - Approximately 37 feet above Mean Sea Level

STAFF GAUGE #2 REFERENCE ELEVATION - Approximately 34 feet above Mean Sea Level

6927



WEATHERtronics
P.O. BOX 41039
SAC. CA. 95821

BAROGRAPH
CHART NO. 70202
70252

STATION SCWA DATE ON 9-12-88 DATE OFF 9-16-88

Harding Lawson Associates
Engineers and Geoscientists

Barograph Data
Wohler Aquifer Study
Sonoma County Water Agency
Santa Rosa, California

PLATE
B–18

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
MOI	1916,005.02		10/88		

Figure B–19
Cassions #1 & #2 Flow Rate Over Time
Wohler Aquifer Study
Sonoma County Water Agency

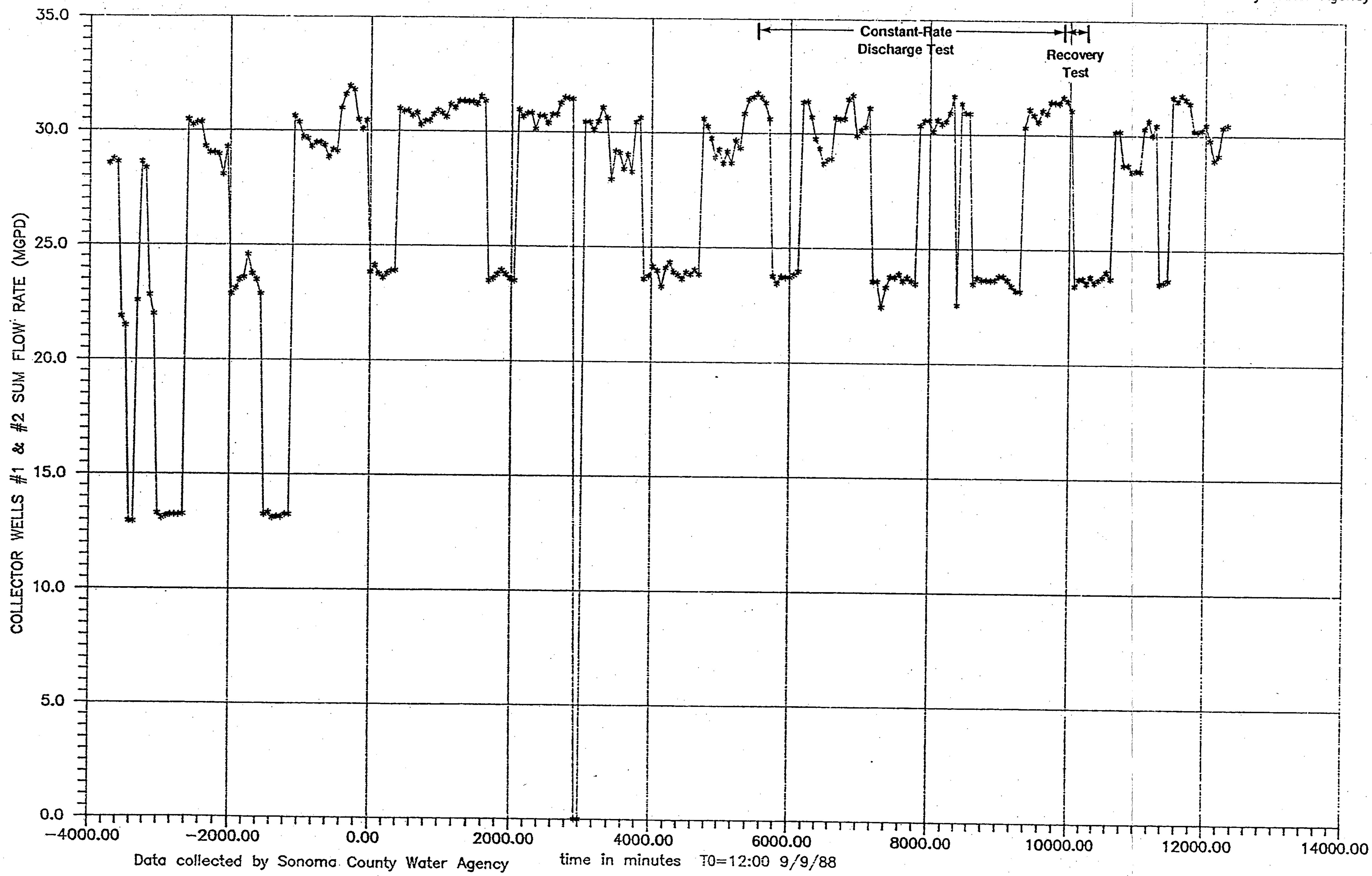


Figure B-20
Caisson #1 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency

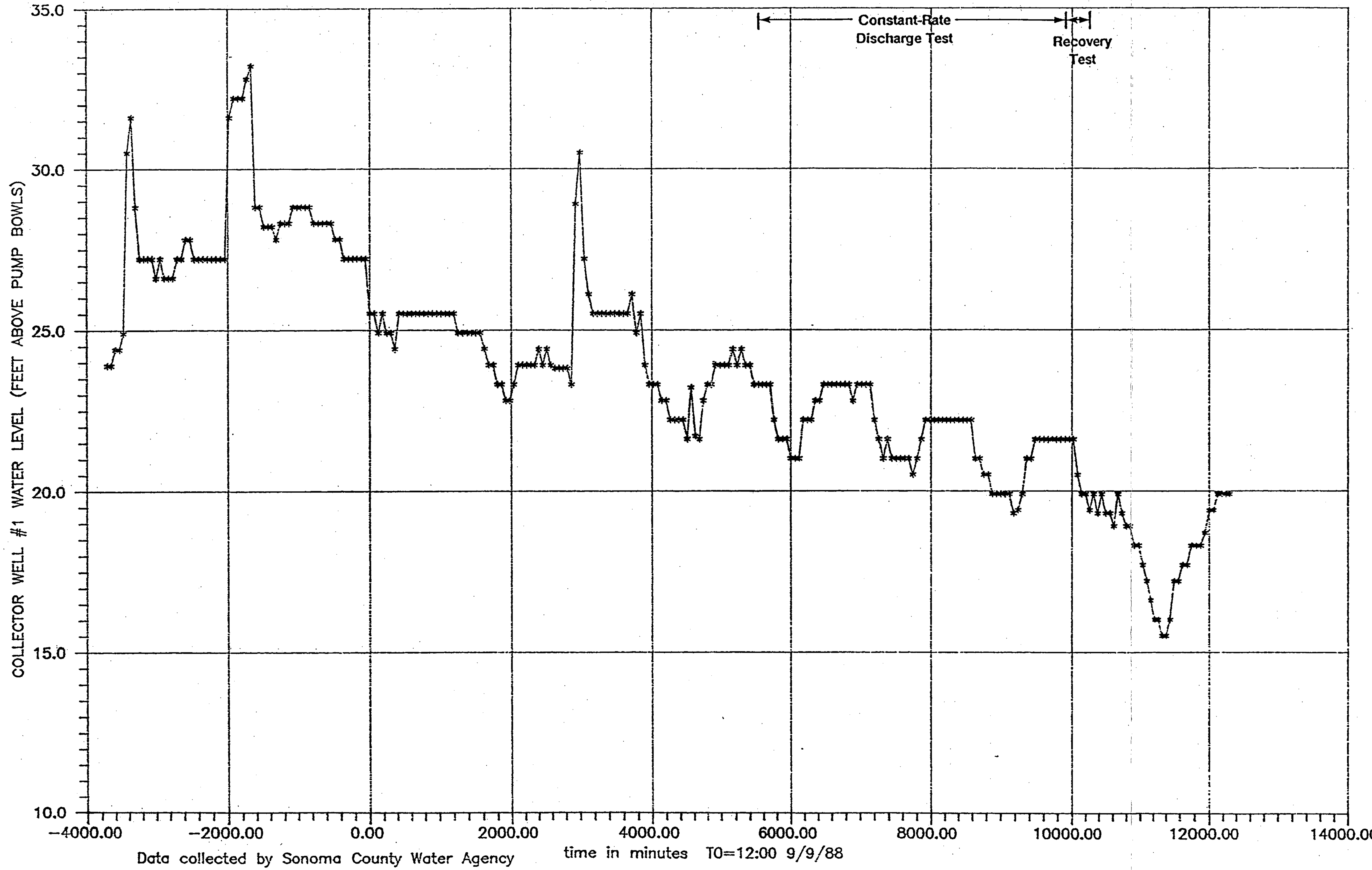
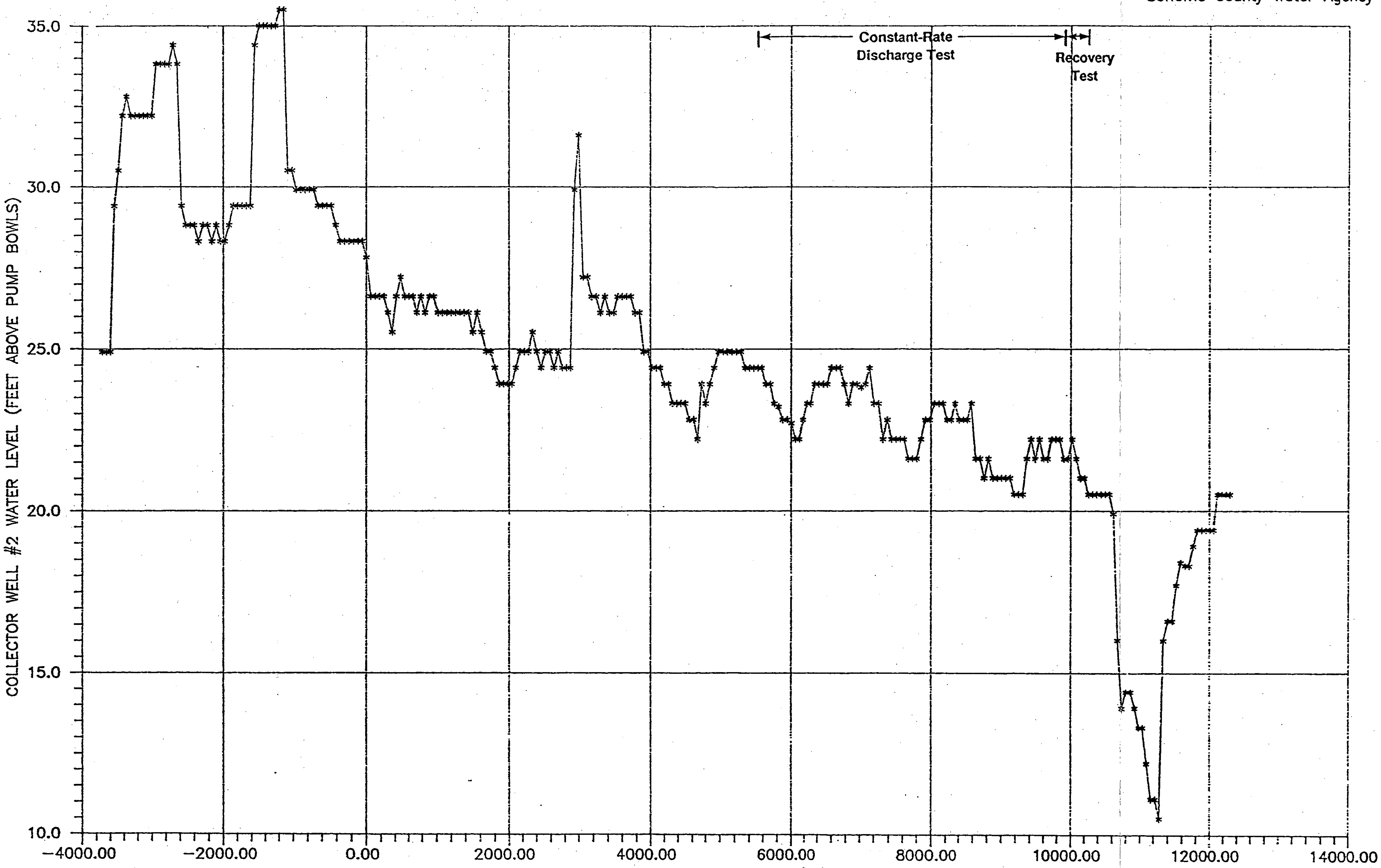


Figure B–21
Caisson #2 Water Level Over Time
Wohler Aquifer Study
Sonoma County Water Agency



Data collected by Sonoma County Water Agency

Table B-1. Water Level Data (Hand Measurements) SCWA Wohler Aquifer Study

Well TW-1 pvc ref. elevation = 69.14 ft AMSL

date	time	depth to water	water elev ft AMSL
jul 26	1235	42.84	26.30
aug 10	1608	42.70	26.44
aug 11	643	42.46	26.68
aug 16	758	42.50	26.64
aug 16	945	42.64	26.50
aug 16	1225	42.76	26.38
aug 16	1359	42.77	26.37
aug 18	811	42.70	26.44
aug 18	943	42.78	26.36
aug 19	801	42.53	26.61
aug 19	1000	42.66	26.48
aug 19	1127	42.76	26.38
aug 19	1334	42.83	26.31
sep 12	730	40.89	28.25
sep 13	800	41.30	27.84
sep 13	943	41.31	27.83
sep 13	1128	41.33	27.81
sep 13	1217	41.35	27.79
sep 13	1450	41.35	27.79
sep 14	905	41.68	27.46
sep 14	1304	41.71	27.43
sep 15	929	42.03	27.11
sep 15	1235	42.04	27.10
sep 16	1052	42.24	26.90
sep 16	1148	42.24	26.90
sep 16	1310	42.25	26.89
sep 16	1349	42.25	26.89

Well TW-2 pvc ref. elevation = 40.75 ft AMSL

date	time	depth to water	water elev ft AMSL
jul 26	1336	8.95	31.80
aug 10	1620	9.07	31.68
aug 11	656	8.97	31.78
aug 16	835	8.85	31.90
aug 16	1008	8.93	31.82
aug 16	1231	8.93	31.82
aug 16	1337	8.98	31.77
aug 18	815	8.97	31.78
aug 18	943	9.00	31.75
aug 19	807	8.90	31.85

aug 19	1008	8.97	31.78
aug 19	1131	9.00	31.75
aug 19	1330	9.02	31.73
sep 12	800	8.09	32.66
sep 13	807	8.25	32.50
sep 13	956	8.31	32.44
sep 13	1113	8.35	32.40
sep 13	1203	8.37	32.38
sep 13	1420	8.46	32.29
sep 14	934	8.80	31.95
sep 14	1048	8.78	31.97
sep 14	1114	8.80	31.95
sep 14	1152	8.81	31.94
sep 14	1313	8.81	31.94
sep 14	1430	8.82	31.93
sep 15	919	8.96	31.79
sep 15	1150	8.96	31.79
sep 16	859	9.02	31.73
sep 16	940	8.99	31.76
sep 16	957	8.98	31.77
sep 16	1045	8.96	31.79
sep 16	1142	8.92	31.83
sep 16	1300	8.88	31.87
sep 16	1343	8.88	31.87

Well TW-3 pvc ref. elevation = 61.66 ft AMSL

date	time	depth to water	water elev ft AMSL
jul 26	1329	27.00	34.66
aug 10	1625	27.25	34.41
aug 11	701	27.20	34.46
aug 16	839	27.38	34.28
aug 16	1012	27.41	34.25
aug 16	1235	27.41	34.25
aug 16	1334	27.43	34.23
aug 18	818	27.44	34.22
aug 18	956	27.45	34.21
aug 19	811	27.44	34.22
aug 19	1005	27.43	34.23
aug 19	1122	27.46	34.20
aug 19	1328	27.45	34.21
sep 13	810	27.06	34.60
sep 13	1002	27.28	34.38
sep 13	1110	27.35	34.31
sep 13	1200	27.40	34.26
sep 13	1341	27.48	34.18
sep 13	1429	27.49	34.17
sep 14	940	27.84	33.82

Table B-1. Water Level Data (Hand Measurements)
SCWA Wohler Aquifer Study

sep 14	1045	27.85	33.81
sep 14	1111	27.86	33.80
sep 14	1155	27.86	33.80
sep 14	1315	27.88	33.78
sep 14	1436	27.89	33.77
sep 15	908	28.03	33.63
sep 15	1153	28.08	33.58
sep 16	855	28.11	33.55
sep 16	922	28.01	33.65
sep 16	1039	27.85	33.81
sep 16	1137	27.79	33.87
sep 16	1255	27.73	33.93
sep 16	1338	27.70	33.96

Well TW-4 pvc ref. elevation = 62.72 ft AMSL

date	time	depth to water	water elev ft AMSL
jul 26	1322	27.01	35.71
aug 10	1630	27.24	35.48
aug 11	705	27.22	35.50
aug 16	844	27.16	35.56
aug 16	1017	27.18	35.54
aug 16	1241	27.19	35.53
aug 16	1329	27.20	35.52
aug 18	822	27.22	35.50
aug 18	1016	27.21	35.51
aug 19	814	27.20	35.52
aug 19	1024	27.20	35.52
aug 19	1147	27.20	35.52
aug 19	1325	27.21	35.51
sep 12	815	26.92	35.80
sep 13	822	26.90	35.82

Well TW-5 pvc ref. elevation = 64.73 ft AMSL

date	time	depth to water	water elev ft AMSL
jul 26	1315	26.18	38.55
aug 10	1637	28.86	35.87
aug 11	709	28.84	35.89
aug 16	1022	29.02	35.71
aug 16	1200	29.02	35.71
aug 16	1322	29.02	35.71
aug 18	832	29.04	35.69
aug 18	1012	29.04	35.69

Table B-1. Water Level Data (Hand Measurements)
SCWA Wohler Aquifer Study

aug 19	817	29.05	35.68
aug 19	1020	29.05	35.68
aug 19	1144	29.04	35.69
aug 19	1350	29.04	35.69
sep 13	827	28.81	35.92
sep 13	1021	28.91	35.82
sep 13	1150	28.97	35.76
sep 13	1240	29.00	35.73
sep 13	1409	29.03	35.70
sep 14	1039	29.35	35.38
sep 14	1100	29.36	35.37
sep 14	1320	29.38	35.35
sep 15	845	29.56	35.17
sep 15	1210	29.54	35.19
sep 16	846	29.14	35.59
sep 16	948	29.13	35.60
sep 16	1117	29.49	35.24
sep 16	1212	29.45	35.28
sep 16	1328	29.42	35.31
sep 16	1412	29.38	35.35

Well TW-6 pvc ref. elevation = 63.28 ft AMSL

date	time	depth to water	water elev ft AMSL
jul 26	1310	28.56	34.72
aug 10	1642	28.75	34.53
aug 11	713	28.70	34.58
aug 16	830	29.18	34.10
aug 16	958	29.16	34.12
aug 16	1211	29.18	34.10
aug 16	1350	29.18	34.10
aug 18	836	29.21	34.07
aug 18	1008	29.23	34.05
aug 19	820	29.20	34.08
aug 19	1014	29.21	34.07
aug 19	1137	29.20	34.08
aug 19	1347	29.24	34.04
sep 13	910	28.82	34.46
sep 13	1027	28.88	34.40
sep 13	1145	28.93	34.35
sep 13	1235	28.96	34.32
sep 13	1412	29.01	34.27
sep 14	1057	29.42	33.86
sep 15	850	29.58	33.70
sep 15	1216	29.61	33.67
sep 16	1108	29.54	33.74
sep 16	1206	29.49	33.79
sep 16	1324	29.39	33.89

sep 16	1406	29.39	33.89

Well TW-7 pvc ref. elevation = 66.56 ft AMSL

date	time	depth to water	water elev ft AMSL
jul 26	1301	25.48	41.08
aug 10	1647	25.66	40.90
aug 11	718	25.67	40.89
aug 16	954	28.19	38.37
aug 16	1215	27.48	39.08
aug 16	1341	27.26	39.30
aug 18	839	25.76	40.80
aug 18	1005	25.74	40.82
aug 19	823	25.72	40.84
aug 19	1011	25.77	40.79
aug 19	1135	25.72	40.84
aug 19	1344	25.71	40.85
sep 13	846	25.98	40.58
sep 13	1032	26.02	40.54
sep 13	1141	26.02	40.54
sep 13	1230	26.01	40.55
sep 13	1414	26.01	40.55
sep 14	1054	25.99	40.57
sep 15	855	26.01	40.55
sep 15	1224	26.01	40.55
sep 16	831	26.01	40.55
sep 16	1014	26.02	40.54
sep 16	1102	26.01	40.55
sep 16	1202	26.01	40.55
sep 16	1320	26.01	40.55
sep 16	1402	26.01	40.55

Well TW-8 pvc ref. elevation = 69.34 ft AMSL

date	time	depth to water	water elev ft AMSL
jul 26	1340	18.88	50.46
aug 10	1653	31.46	37.88
aug 11	722	31.45	37.89
aug 16	1003	32.36	36.98
aug 16	1218	32.35	36.99
aug 16	1345	32.35	36.99
aug 18	843	32.39	36.95
aug 18	1002	32.39	36.95
aug 19	826	32.40	36.94

aug 19	1017	32.39	36.95
aug 19	1140	32.40	36.94
aug 19	1339	32.40	36.94
sep 13	856	32.31	37.03
sep 13	1038	32.35	36.99
sep 13	1137	32.36	36.98
sep 13	1225	32.36	36.98
sep 13	1416	32.38	36.96
sep 14	1051	32.47	36.87
sep 15	858	32.55	36.79
sep 15	1220	32.58	36.76
sep 16	825	32.62	36.72
sep 16	1017	32.59	36.75
sep 16	1100	32.59	36.75
sep 16	1158	32.58	36.76
sep 16	1314	32.58	36.76
sep 16	1358	32.57	36.77

Well TW-9 pvc ref. elevation = 63.07 ft AMSL

date	time	depth to water	water elev ft AMSL
sep 12	819	27.34	35.73
sep 13	812	27.33	35.74
sep 16	825	29.48	33.59

Well TW-10 pvc ref. elevation = 62.35 ft AMS

date	time	depth to water	water elev ft AMSL
sep 12	835	26.58	35.77
sep 13	815	26.58	35.77

Well TW-11 pvc ref. elevation = 63.38 ft AMS

date	time	depth to water	water elev ft AMSL
sep 12	820	27.66	35.72
sep 13	818	27.64	35.74
sep 16	830	29.88	33.5

Table B-1. Water Level Data (Hand Measurements) SCWA Wohler Aquifer Study

Well TW-12 pvc ref. elevation = 65.13 ft AMS

date	time	depth to water	water elev ft AMSL
sep 12	820	29.35	35.78
sep 13	820	29.32	35.81

Well TW-13 pvc ref. elevation = 62.95 ft AMS

date	time	depth to water	water elev ft AMSL
sep 12	825	27.11	35.84
sep 13	823	27.11	35.84

Well TW-14 pvc ref elevation = 65.01 ft AMSL

date	time	depth to water	water elev ft AMSL
sep 12	830	29.48	35.53
sep 13	828	29.46	35.55

Well TW-15 pvc ref. elevation = 63.35 ft AMS

date	time	depth to water	water elev ft AMSL
sep 12	925	27.30	36.05
sep 13	827	27.35	36.00
sep 13	1009	27.51	35.84
sep 13	1103	27.57	35.78
sep 13	1153	27.61	35.74
sep 13	1245	27.65	35.70
sep 13	1345	27.69	35.66
sep 13	1407	27.70	35.65
sep 14	943	28.02	35.33
sep 14	1042	28.03	35.32
sep 14	1103	28.03	35.32
sep 14	1158	28.05	35.30
sep 14	1318	28.05	35.30
sep 14	1412	28.06	35.29
sep 15	840	28.18	35.17
sep 15	1205	28.20	35.15
sep 16	850	28.22	35.13

Table B-1. Water Level Data (Hand Measurements)
SCWA Wohler Aquifer Study

sep 16	925	28.20	35.15
sep 16	934	28.19	35.16
sep 16	945	28.17	35.18
sep 16	1002	28.15	35.20
sep 16	1032	28.11	35.24
sep 16	1122	28.06	35.29
sep 16	1216	28.02	35.33
sep 16	1333	27.96	35.39
sep 16	1416	27.96	35.39

Appendix C

AQUIFER TEST ANALYSES

Appendix C

AQUIFER TEST ANALYSES

FIGURE C-1
Well TW-4 Drawdown vs Time
Wohler Aquifer Study
Sonoma County Water Agency

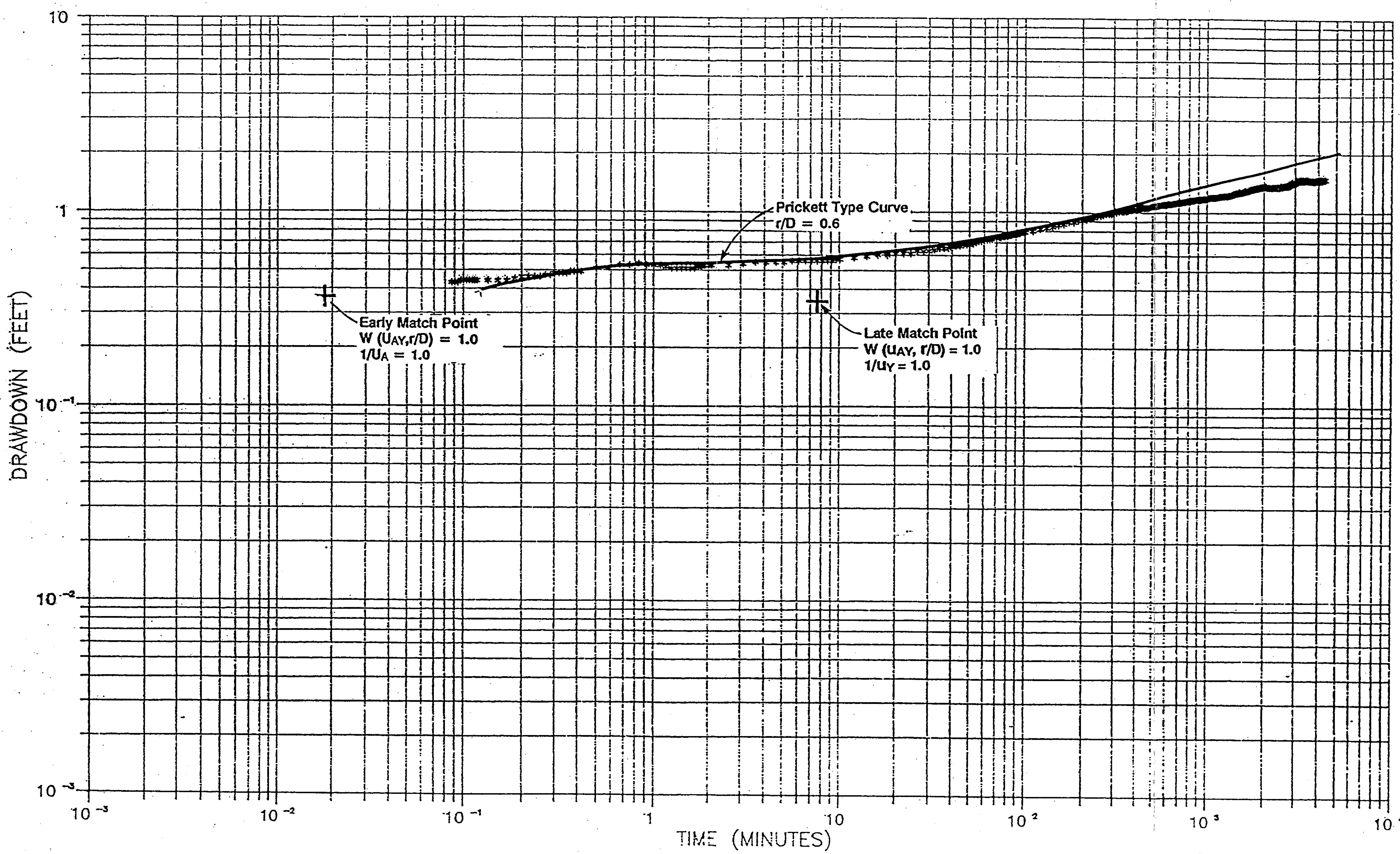


FIGURE C-2
Well TW-10 Drawdown vs Time
Wohler Aquifer Study
Sonoma County Water Agency

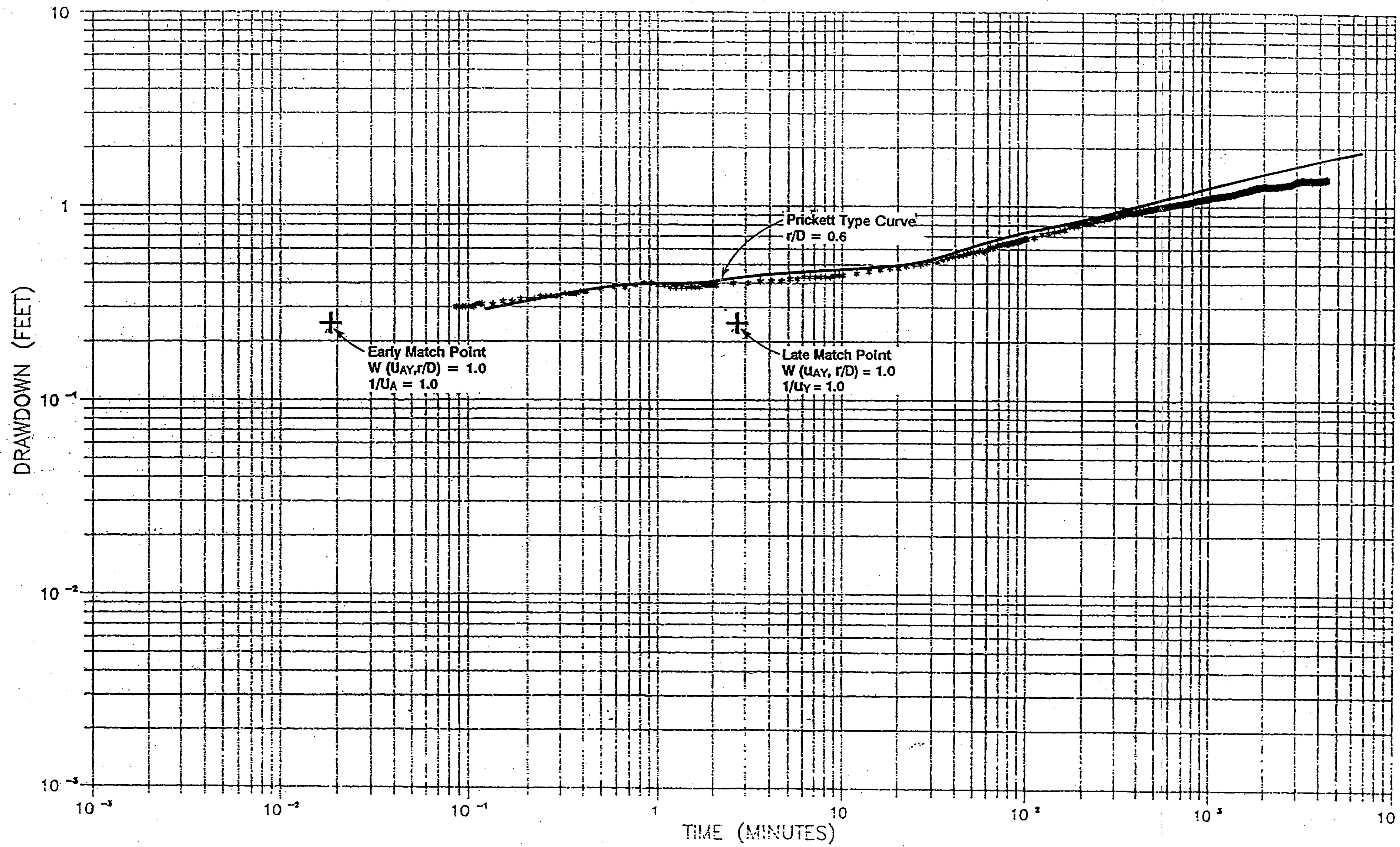


FIGURE C-3
Well TW-12 Drawdown vs Time
Wohler Aquifer Study
Sonoma County Water Agency

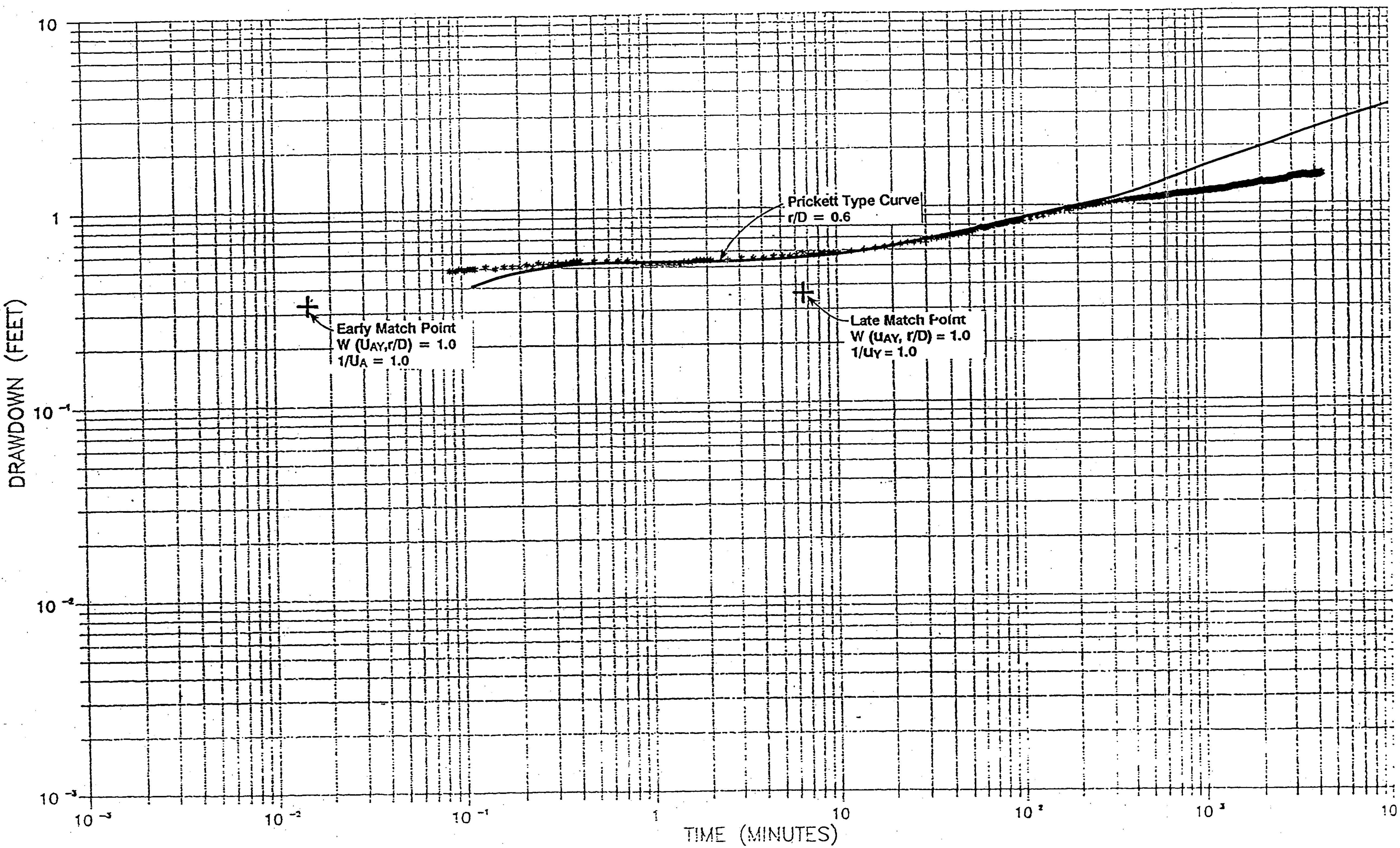


FIGURE C-4
Well TW–13 Drawdown vs Time
Wohler Aquifer Study
Sonoma County Water Agency

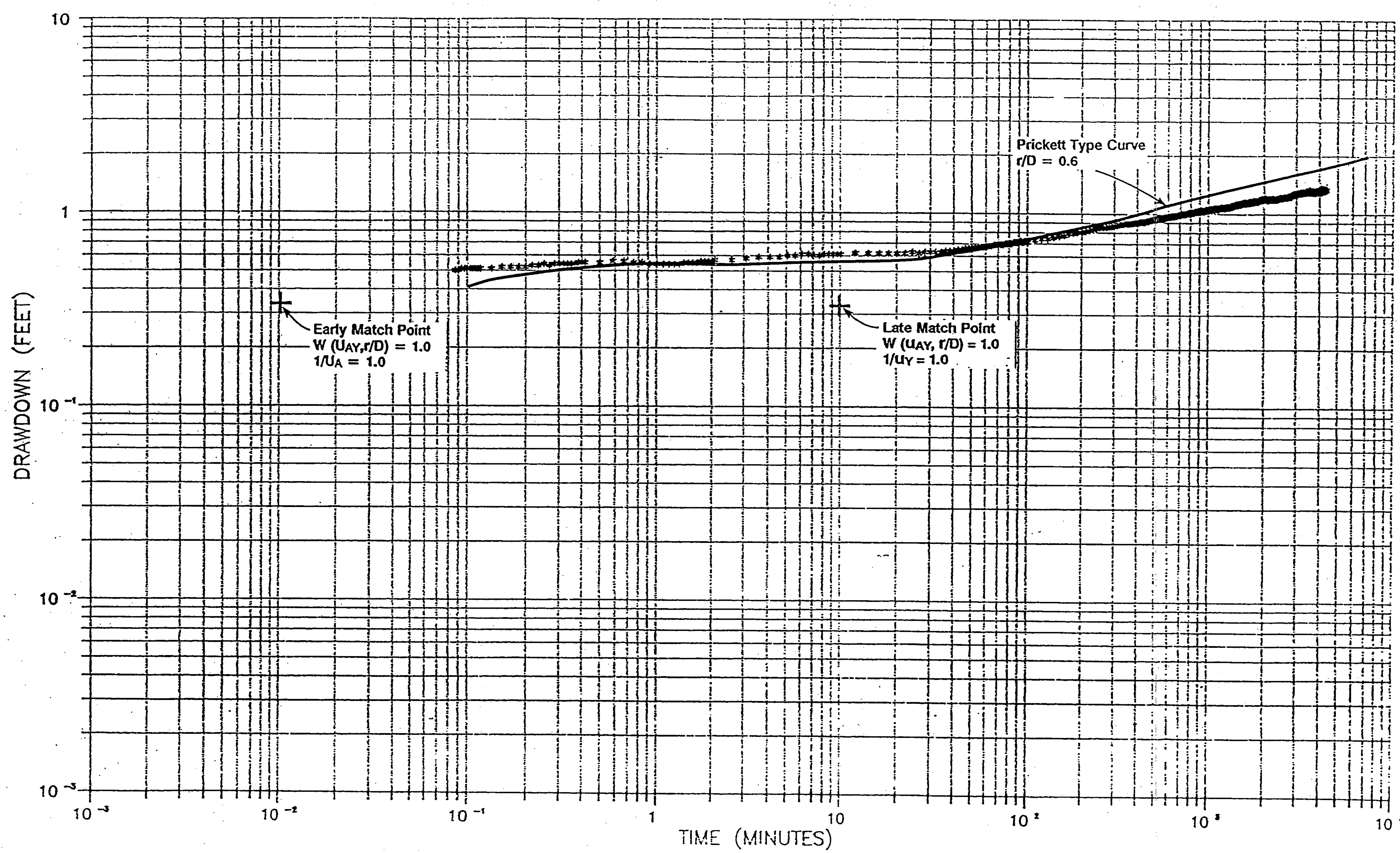


FIGURE C-5
Well TW-14 Drawdown vs Time
Wohler Aquifer Study
Sonoma County Water Agency

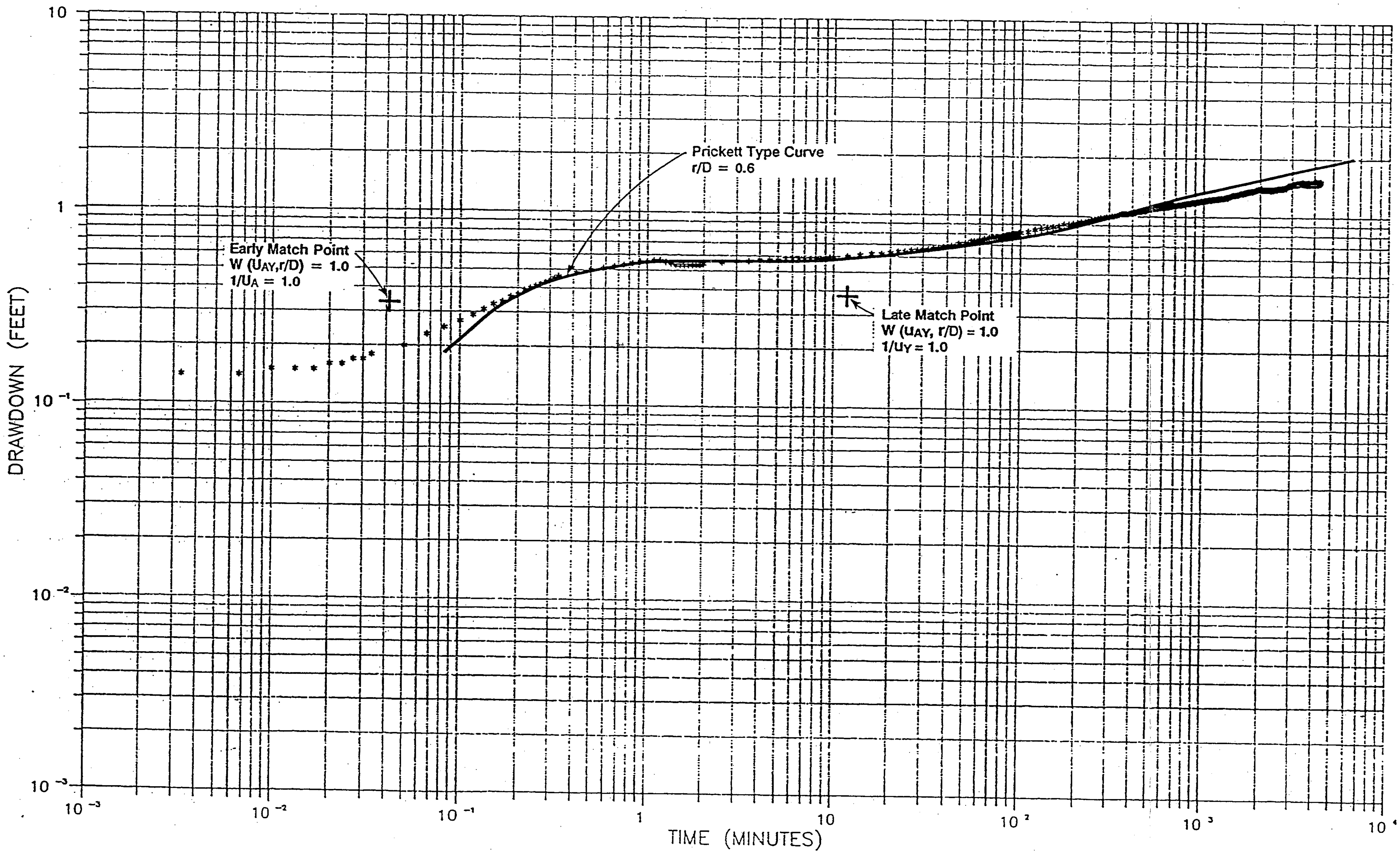


FIGURE C-6
Pumping Well – Residual Drawdown
Wohler Aquifer Study
Sonoma County Water Agency

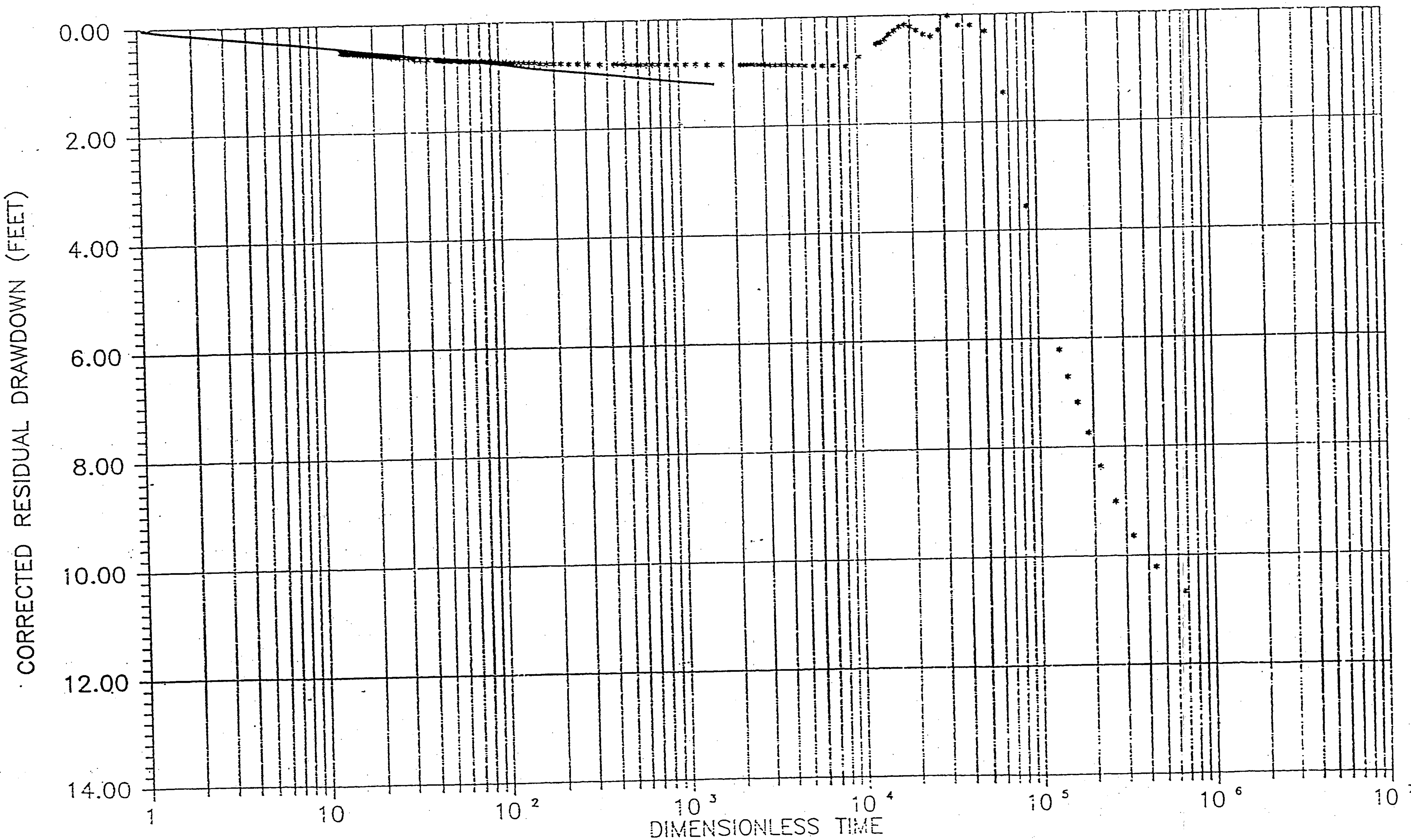


FIGURE C-7
Well TW—4 Residual Drawdown
Wohler Aquifer Study
Sonoma County Water Agency

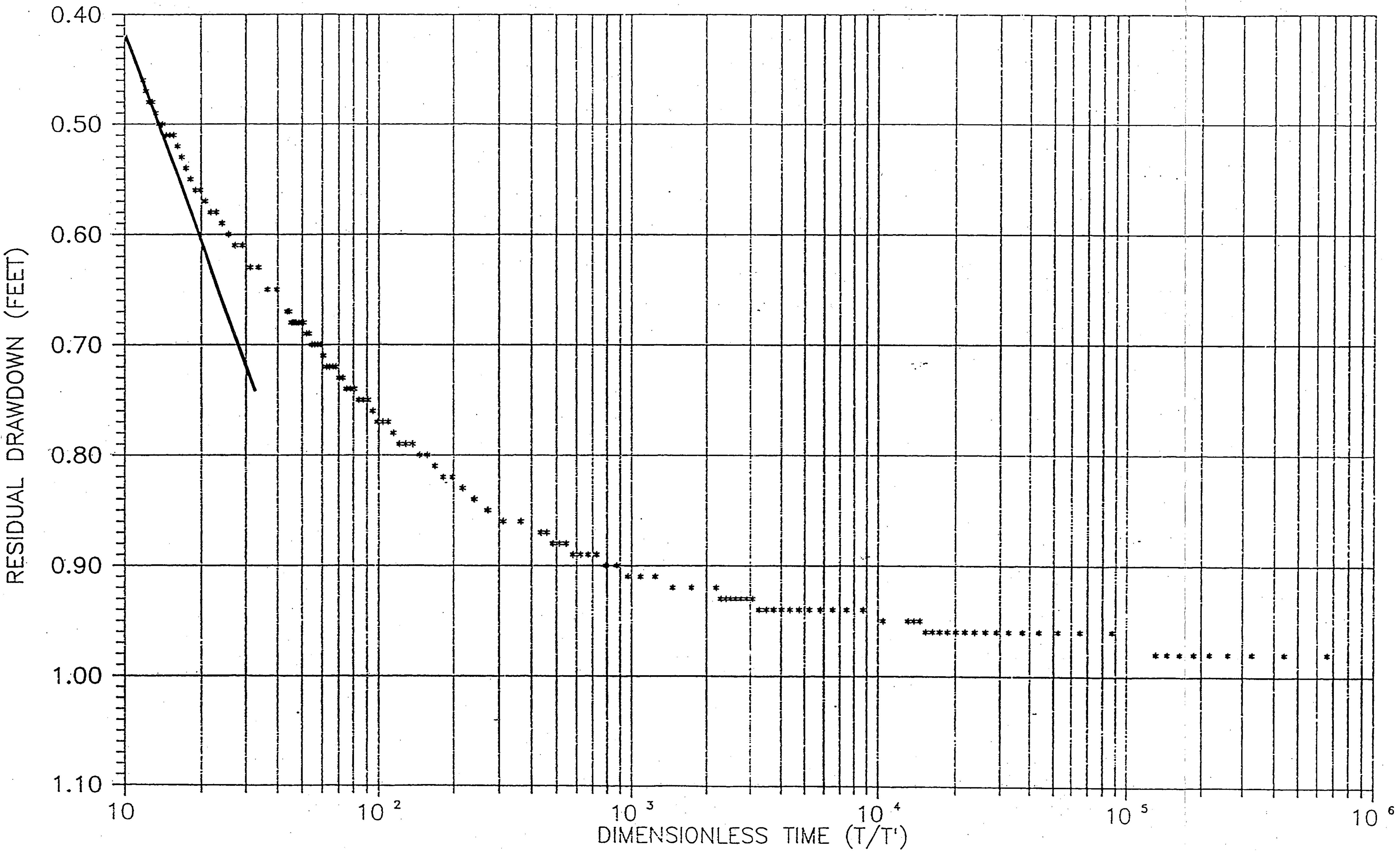


FIGURE C-9
Well TW—10 Residual Drawdown
Wohler Aquifer Study
Sonoma County Water Agency

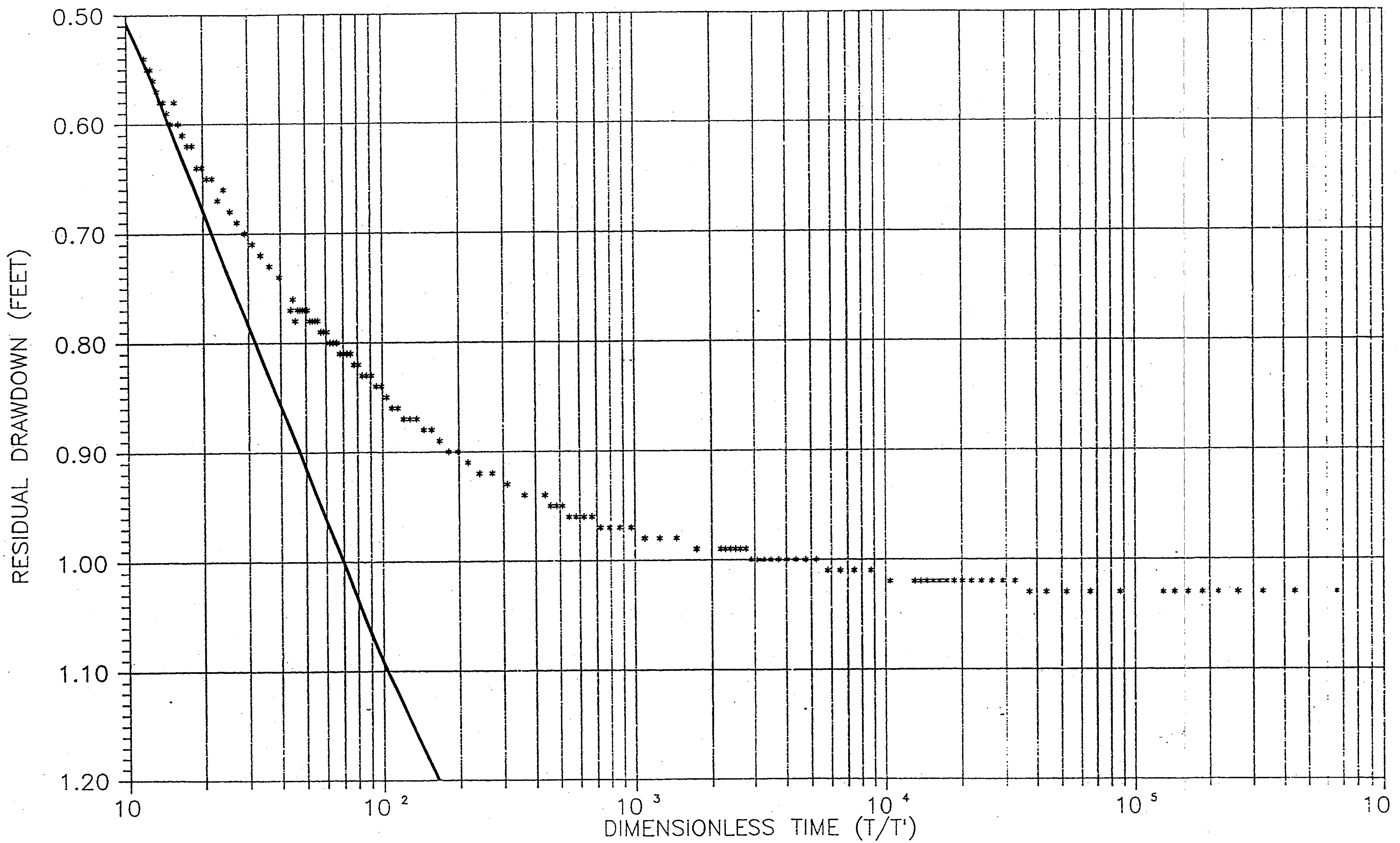


FIGURE C-10
Well TW-11 – Residual Drawdown
Wohler Aquifer Study
Sonoma County Water Agency

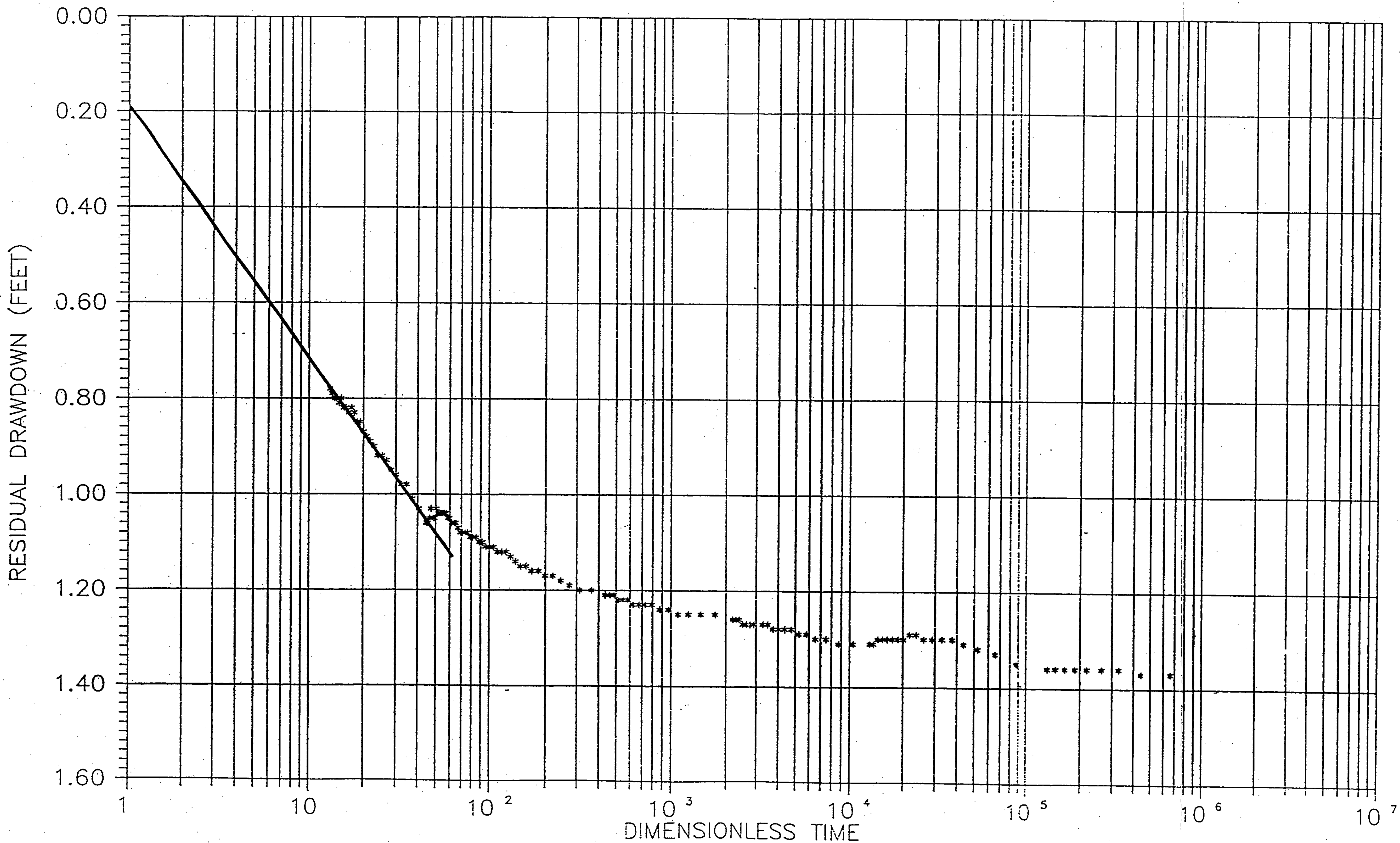


FIGURE C-11
Well TW-12 Residual Drawdown
Wohler Aquifer Study
Sonoma County Water Agency

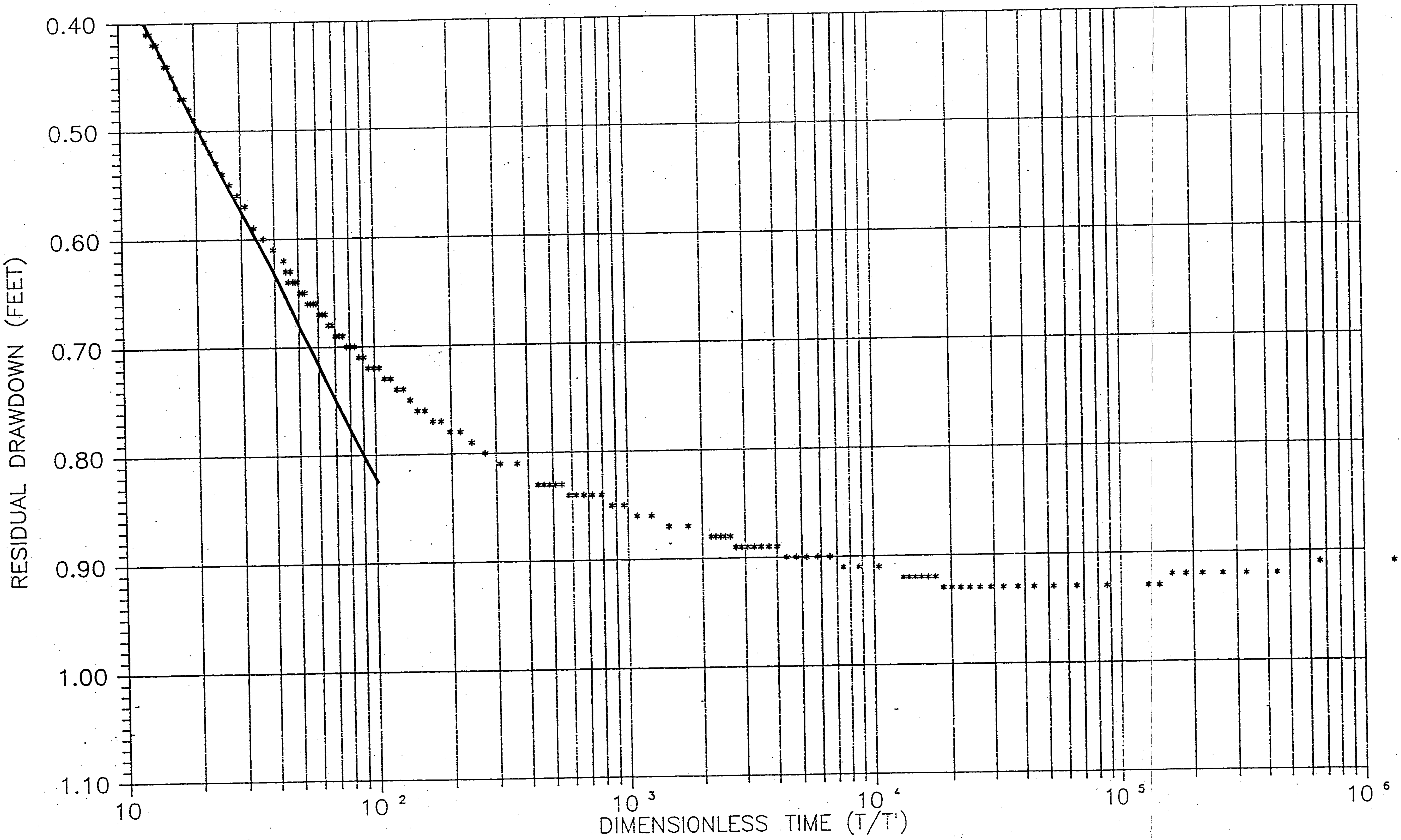


FIGURE C-12
Well TW-13 Residual Drawdown
Wohler Aquifer Study
Sonoma County Water Agency

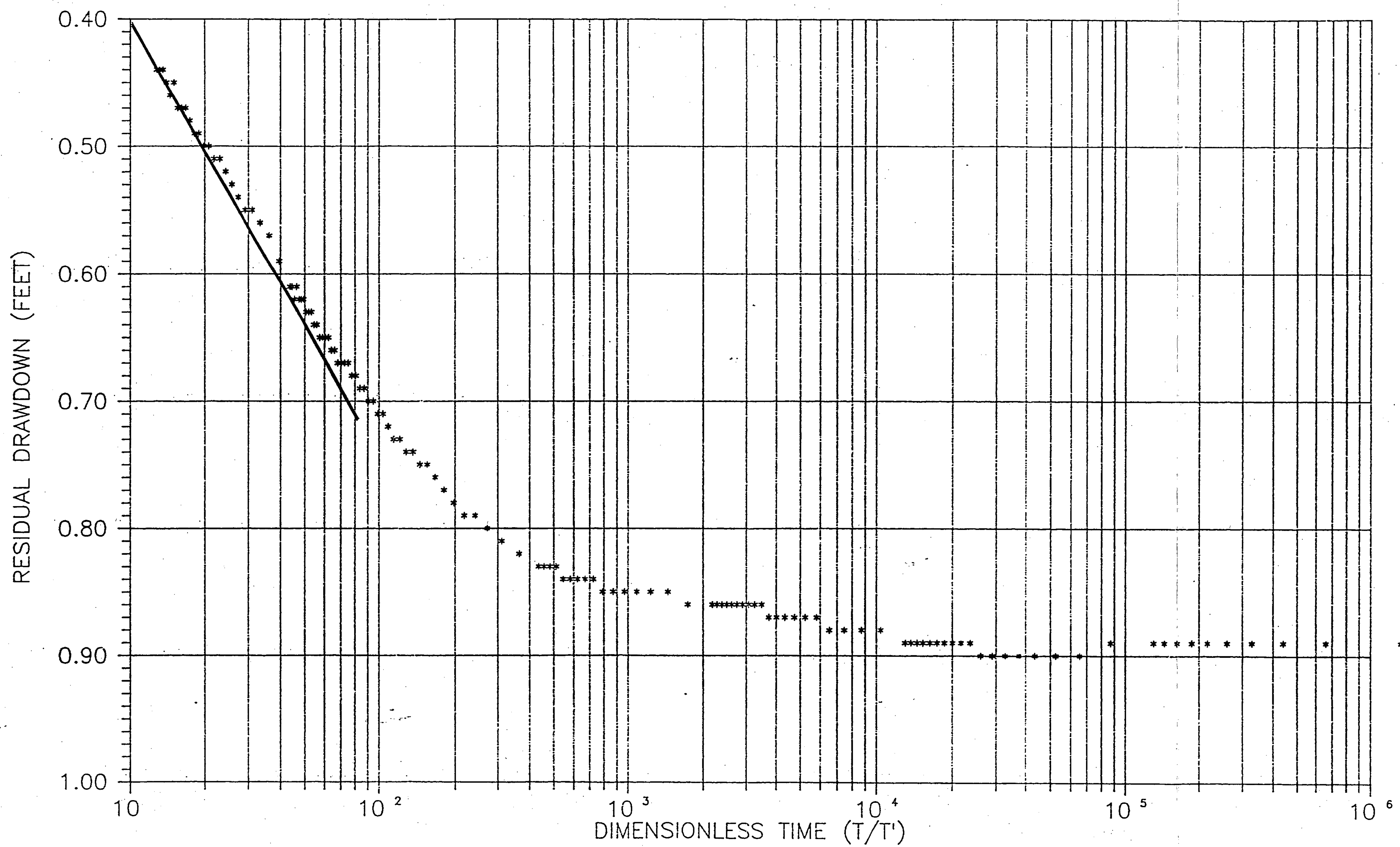
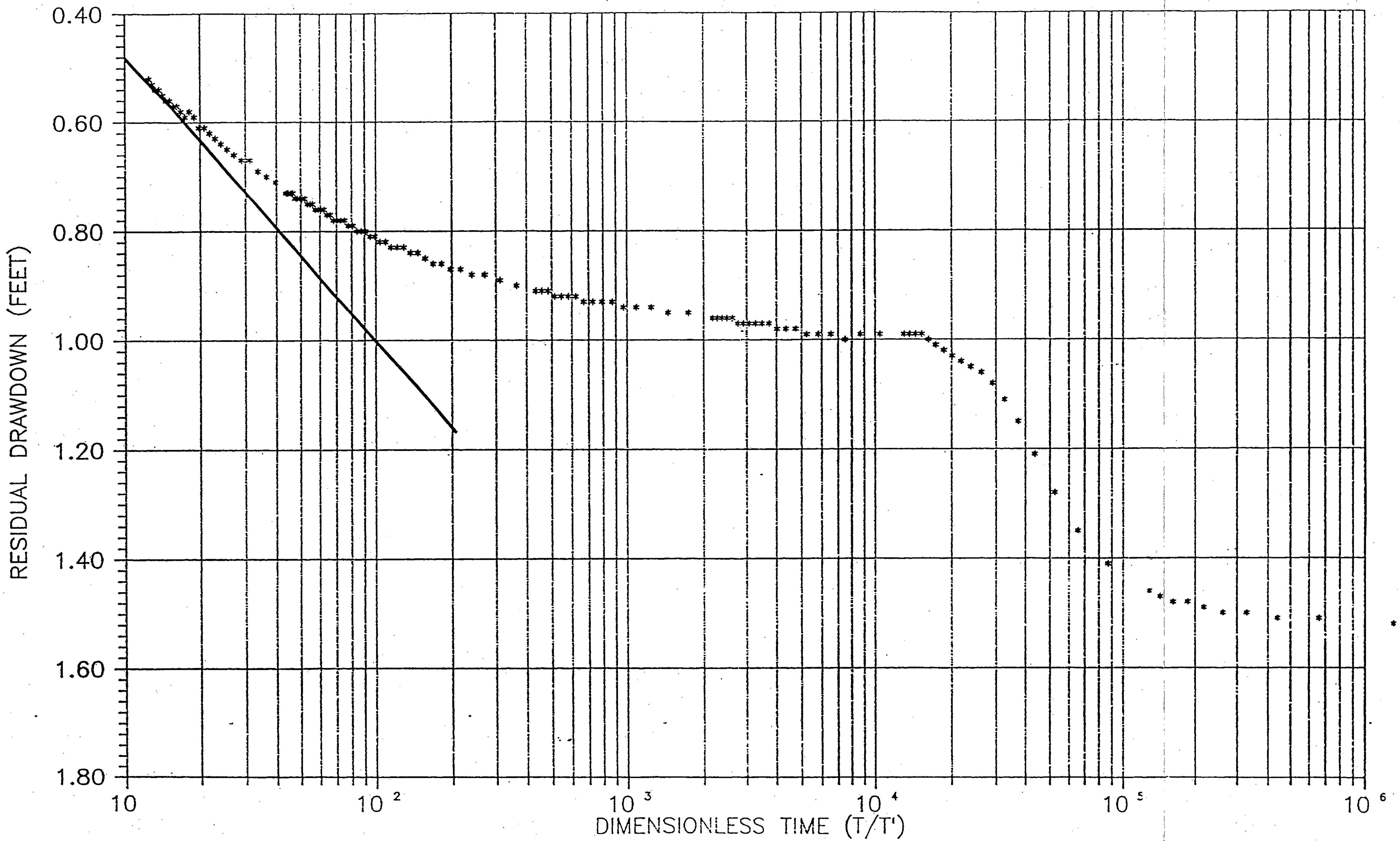


FIGURE C-13
Well TW-14 Residual Drawdown
Wohler Aquifer Study
Sonoma County Water Agency



Calculation Sheet 1. Unconfined Aquifer Type Curve Method for TW-4

PUMPED WELL PW-1

OBSERVATION WELL TW-4

Method of Analysis: Unconfined Aquifer Type Curve (Prickett, 1965)

Q	Constant discharge rate	2,494	gpm
r	Distance from observation well to pumped well	55.2	feet
b	Aquifer thickness	74	feet

Early-time type curve match point:

$1/u_A = 1.0$ $u_A = 1.0$ $W(u_{AY}, r/D) = 1.0$

Drawdown (s) = 0.34 ft time (t) = 1.32×10^{-5} days

$r/D = 0.6$

TRANSMISSIVITY

$T = 114.6\ Q\ W(u_{AY}, r/D)/s$

$T = 114.6\ (2{,}494)(1.0)/0.34$

T = 840,625 gpd/ft

T = 112,383 sq ft/d ≈ 110,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

K = 840,625/74 = 11,360 gpd/sq ft

K = 112,383/74 = 1,519 ft/day ≈ 1,500 ft/day

Calculation Sheet 1. Unconfined Aquifer Type Curve Method for TW-4 (continued)

STORATIVITY

$S_A = u_A Tt/1.87r^2$

$S_A = (1.0)(840{,}625)(1.32\times10^{-5})/1.87\ (55.2)^2$

$S_A = 1.99 \times 10^{-3}$

Late-time type curve match point:

$1/u_Y = 1.0$ $u_Y = 1.0$ $W(u_{AY}, r/D) = 1.0$

Drawdown (s) = 0.34 ft time (t) = 0.0053 days

r/D = 0.6

TRANSMISSIVITY (T)

$T = 114.6\ Q\ W(u_{AY}, r/D)/s$

$T = 114.6(2{,}494)(1.0)/0.34$

T = 840,625 gpd/ft

T = 112,383 sq ft/d ≈ 110,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

K = T/b

K = 840,625/74 = 11,360 gpd/sq ft

K = 112,383/74 = 1,519 ft/d ≈ 1,500 ft/d

SPECIFIC YIELD

$S_y = u_Y Tt/1.87\ r^2$

$S_y = (1.0)(840{,}625)(0.0053)/1.87(55.2)^2$

$S_y = 0.78$

RECHARGE BOUNDARY ANALYSIS

s_r Water-level deviation caused by pumping well 0.24 feet

Calculation Sheet 1. Unconfined Aquifer Type Curve Method for TW-4 (continued)

s_i	Water-level deviation caused by image well	0.24	feet
t_r	Time for water-level deviation to occur due to pumping well ($s_r = s_i$)	0.052	min
t_i	Time for water-level deviation to occur due to image well ($s_r = s_i$)	1,210	min
r_i	Distance from observation well to image well		

$$r_i = r\sqrt{\frac{t_i}{t_r}} = 55.2\sqrt{\frac{1,210}{0.052}}$$

$r_i =$ 8,420 ft

Calculation Sheet 2. Unconfined Aquifer Type Curve Method for TW-10

PUMPED WELL PW-1

OBSERVATION WELL TW-10

Method of Analysis: Unconfined Aquifer Type Curve (Prickett, 1965)

Q	Constant discharge rate	2,494	gpm
r	Distance from observation well to pumped well	105.6	feet
b	Aquifer thickness	75	feet

Early-time type curve match point:

$1/u_A = 1.0$ $u_A = 1.0$ $W(u_{AY}, r/D) = 1.0$

Drawdown (s) = 0.25 ft time (t) = 1.32×10^{-5} days

$r/D = 0.6$

TRANSMISSIVITY

$T = 114.6\ Q\ W(u_{AY}, r/D)/s$

$T = 114.6\ (2{,}494)(1.0)/0.25$

T = 1,143,250 gpd/ft

T = 152,841 sq $ft^2/d \approx 150{,}000\ ft^2/d$

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

K = 1,143,250/75 = 15,243 gpd/sq ft

K = 152,841/75 = 2,038 ft/day ≈ 2,000 ft/day

Calculation Sheet 2. Unconfined Aquifer Type Curve Method for TW-10 (continued)

STORATIVITY

$S_A = u_A Tt/1.87r^2$

$S_A = (1.0)(1{,}143{,}250)(1.32x10^{-5})/1.87\ (105.6)^2$

$S_A = 7.24 \times 10^{-4}$

Late-time type curve match point:

$1/u_Y = 1.0$ $u_Y = 1.0$ $W(u_{AY}, r/D) = 1.0$

Drawdown (s) = 0.25 ft time (t) = $2.64x10^{-3}$ days

r/D = 0.6

TRANSMISSIVITY (T)

$T = 114.6\ Q\ W(u_{AY}, r/D)/s$

$T = 114.6(2{,}494)(1.0)/0.25$

T = 1,143,250 gpd/ft

T = 152,841 sq $ft^2/d \approx$ 150,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

K = T/b

K = 1,143,250/75 = 15,243 gpd/sq ft

K = 152,841/75 = 2,038 ft/d ≈ 2,000 ft/d

SPECIFIC YIELD

$S_y = u_Y Tt/1.87\ r^2$

$S_y = (1.0)(1{,}143{,}250)(2.64x10^{-3})/1.87(105.6)^2$

$S_y = 0.14$

RECHARGE BOUNDARY ANALYSIS

s_r Water-level deviation caused by pumping well 0.11 feet

Calculation Sheet 2. Unconfined Aquifer Type Curve Method for TW-10 (continued)

s_i	Water-level deviation caused by image well	0.11	feet
t_r	Time for water-level deviation to occur due to pumping well ($s_r = s_i$)	0.033	min
t_i	Time for water-level deviation to occur due to image well ($s_r = s_i$)	1,220	min
r_i	Distance from observation well to image well		

$$r_i = r\sqrt{\frac{t_i}{t_r}} = 105.6\sqrt{\frac{1,220}{0.033}}$$

r_i = 20,304 ft

Calculation Sheet 3. Unconfined Aquifer Type Curve Method for TW-12

PUMPED WELL PW-1

OBSERVATION WELL TW-12

Method of Analysis: Unconfined Aquifer Type Curve (Prickett, 1965)

Q	Constant discharge rate	2,494	gpm
r	Distance from observation well to pumped well	43.8	feet
b	Aquifer thickness	75	feet

Early-time type curve match point:

$1/u_A = 1.0$ $u_A = 1.0$ $W(u_{AY}, r/D) = 1.0$

Drawdown (s) = 0.34 ft time (t) = 9.72×10^{-6} days

$r/D = 0.6$

TRANSMISSIVITY

$T = 114.6\ Q\ W(u_{AY}, r/D)/s$

$T = 114.6\ (2{,}494)(1.0)/0.34$

T = 840,625 gpd/ft

T = 112,383 sq ft/d ≈ 110,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

K = 840,625/75 = 11,208 gpd/sq ft

K = 112,383/75 = 1,498 ft/day ≈ 1,500 ft/day

Calculation Sheet 3. Unconfined Aquifer Type Curve Method for TW-12 (continued)

STORATIVITY

$S_A = u_A\ Tt/1.87r^2$

$S_A = (1.0)(840{,}625)(9.72x10^{-6})/1.87\ (43.8)^2$

$S_A = 2.28 \times 10^{-3}$

Late-time type curve match point:

$1/u_Y = 1.0$ $u_Y = 1.0$ $W(u_{AY},r/D) = 1.0$

Drawdown (s) = 0.34 ft time (t) = $4.58x10^{-3}$ days

r/D = 0.6

TRANSMISSIVITY (T)

$T = 114.6\ Q\ W(u_{AY},r/D)/s$

$T = 114.6(2{,}494)(1.0)/0.34$

T = 840,625 gpd/ft

T = 112,383 sq ft/d ≈ 110,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

K = 840,625/75 = 11,208 gpd/sq ft

K = 112,383/75 = 1,498 ft/d ≈ 1,500 ft/d

SPECIFIC YIELD

$S_y = u_Y Tt/1.87\ r^2$

$S_y = (1.0)(840{,}625)(4.58x10^{-3})/1.87(43.8)^2$

$S_y = 1.07$

RECHARGE BOUNDARY ANALYSIS

s_r Water-level deviation caused by pumping well 0.45 feet

Calculation Sheet 3. Unconfined Aquifer Type Curve Method for TW-12 (continued)

s_i	Water-level deviation caused by image well	0.45	feet
t_r	Time for water level deviation to occur due to pumping well ($s_r = s_i$)	0.16	min
t_i	Time for water level deviation to occur due to image well ($s_r = s_i$)	1,000	min
r_i	Distance from observation well to image well		

$$r_i = r\sqrt{\frac{t_i}{t_r}} = 43.8\sqrt{\frac{1{,}000}{0.16}}$$

r_i = 3,463 ft

Calculation Sheet 4. Unconfined Aquifer Type Curve Method for TW-13

PUMPED WELL PW-1

OBSERVATION WELL TW-13

Method of Analysis: Unconfined Aquifer Type Curve (Prickett, 1965)

Q	Constant discharge rate	2,494	gpm
r	Distance from observation well to pumped well	98.8	feet
b	Aquifer thickness	75	feet

Early-time type curve match point:

$1/u_A = 1.0$ $u_A = 1.0$ $W(u_{AY}, r/D) = 1.0$

Drawdown (s) = 0.34 ft time (t) = 6.94×10^{-6} days

$r/D = 0.6$

TRANSMISSIVITY

T = $114.6\ Q\ W(u_{AY}, r/D)/s$

T = 114.6 (2,494)(1.0)/0.34

T = 840,625 gpd/ft

T = 112,383 sq ft/d ≈ 110,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

K = T/b

K = 840,625/75 = 11,208 gpd/sq ft

K = 112,383/75 = 1,498 ft/day ≈ 1,500 ft/day

Calculation Sheet 4. Unconfined Aquifer Type Curve Method for TW-13 (continued)

STORATIVITY

$S_A = \quad u_A\, Tt/1.87r^2$

$S_A = \quad (1.0)(840{,}625)(6.94\text{x}10^{-6})/1.87\ (98.8)^2$

$S_A = \quad 3.20 \text{ x } 10^{-4}$

Late-time type curve match point:

$1/u_Y = 1.0$ $\quad u_Y = 1.0$ $\quad W(u_{AY}, r/D) = 1.0$

Drawdown (s) = 0.34 ft $\quad$ time (t) = $6.94\text{x}10^{-3}$ days

$r/D = \quad 0.6$

TRANSMISSIVITY (T)

$T = \quad 114.6\ Q\ W(u_{AY}, r/D)/s$

$T = \quad 114.6(2{,}494)(1.0)/0.34$

T = 840,625 gpd/ft

T = 112,383 sq ft/d ≈ 110,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

$K = \quad T/b$

K = 840,625/75 = 11,208 gpd/sq ft

K = 112,383/75 = 1,498 ft/d ≈ 1,500 ft/d

SPECIFIC YIELD

$S_y = \quad u_Y Tt/1.87\ r^2$

$S_y = \quad (1.0)(840{,}625)(6.94\text{x}10^{-3})/1.87(98.8)^2$

$S_y = \quad 0.32$

RECHARGE BOUNDARY ANALYSIS

s_r	Water-level deviation caused by pumping well	0.22	feet
s_i	Water-level deviation caused by image well	0.22	feet

Calculation Sheet 4. Unconfined Aquifer Type Curve Method for TW-13 (continued)

t_r	Time for water level deviation to occur due to pumping well ($s_r = s_i$)	0.029	min
t_i	Time for water level deviation to occur due to image well ($s_r = s_i$)	1,280	min

r_i = Distance from observation well to image well

$$r_i = r\sqrt{\frac{t_i}{t_r}} = 98.8\sqrt{\frac{1{,}280}{0.029}}$$

r_i = 20,757 ft

Calculation Sheet 5. Unconfined Aquifer Type Curve Method for TW-14

PUMPED WELL PW-1

OBSERVATION WELL TW-14

Method of Analysis: Unconfined Aquifer Type Curve (Prickett, 1965)

Q	Constant discharge rate	2,494	gpm
r	Distance from observation well to pumped well	75.0	feet
b	Aquifer thickness	75	feet

Early-time type curve match point:

$1/u_A = 1.0$ $u_A = 1.0$ $W(u_{AY},r/D) = 1.0$

Drawdown (s) = 0.35 ft time (t) = 2.78×10^{-5} days

$r/D = 0.6$

TRANSMISSIVITY

T = $114.6\ Q\ W(u_{AY},r/D)/s$

T = 114.6 (2494)(1.0)/0.35

T = 816,607 gpd/ft

T = 109,172 sq ft/d ≈ 110,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

K = T/b

K = 816,607/75 = 10,888 gpd/sq ft

K = 109,172/75 = 1,456 ft/day ≈ 1,500 ft/day

Calculation Sheet 5. Unconfined Aquifer Type Curve Method for TW-14 (continued)

STORATIVITY

$S_A = u_A Tt/1.87r^2$

$S_A = (1.0)(816{,}607)(2.78\text{x}10^{-5})/1.87\ (75)^2$

$S_A = 2.16 \text{ x } 10^{-3}$

Late-time type curve match point:

$1/u_Y = 1.0$ $u_Y = 1.0$ $W(u_{AY},r/D) = 1.0$

Drawdown (s) = 0.35 ft time (t) = $7.84\text{x}10^{-3}$ days

$r/D = 0.6$

TRANSMISSIVITY (T)

$T = 114.6\ Q\ W(u_{AY},r/D)/s$

$T = 114.6(2{,}494)(1.0)/0.35$

T = 816,607 gpd/ft

T = 109,172 sq ft/d ≈ 110,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

K = 816,607/75 = 10,888 gpd/sq ft

K = 109,172/75 = 1,456 ft/d ≈ 1,500 ft/d

SPECIFIC YIELD

$S_y = u_Y Tt/1.87\ r^2$

$S_y = (1.0)(816{,}607)(7.84\text{x}10^{-3})/1.87(75)^2$

$S_y = 0.61$

RECHARGE BOUNDARY ANALYSIS

s_r Water-level deviation caused by pumping well 0.16 feet

Calculation Sheet 5. Unconfined Aquifer Type Curve Method for TW-14 (continued)

s_i	Water-level deviation caused by image well	0.16	feet
t_r	Time for water-level deviation to occur due to pumping well ($s_r = s_i$)	0.074	min
t_i	Time for water-level deviation to occur due to image well ($s_r = s_i$)	1,360	min

r_i = Distance from observation well to image well

$$r_i = r\sqrt{\frac{t_i}{t_r}} = 75.0\sqrt{\frac{1,360}{0.074}}$$

r_i = 10,168 ft

Calculation Sheet 6. Residual Drawdown Method for Pumping Well

Method of Analysis: Residual Drawdown (Theis, 1935)

Q	Average discharge rate	2494	gpm
$\Delta s'$	Change in recovery per log cycle	0.53	feet
b	Aquifer thickness	75	feet

TRANSMISSIVITY (T)

$$T = \frac{264Q}{\Delta s'} = \frac{264(2494)}{0.53}$$

T = 1,242,294 gpd/ft

T = 166,082 ≈ 170,000 ft^2/d

HYDRAULIC CONDUCTIVITY (K)

K = T/b

K = 1,242,294/75 = 16,564 gpd/sq ft

K = 116,082/75 = 2,214 ≈ 2,200 ft/d

Calculation Sheet 7. Residual Drawdown Method for TW-4

Method of Analysis: Residual Drawdown (Theis, 1935)

Q	Average discharge rate	2,494	gpm
$\Delta s'$	Change in recovery per log cycle	0.64	feet
b	Aquifer thickness	74	feet

TRANSMISSIVITY (T)

$$T = \frac{264Q}{\Delta s'} = \frac{264(2494)}{0.64}$$

$= 1{,}028{,}775$ gpd/ft

$= 137{,}537\ ft^2/d \approx 14{,}000\ ft^2/d$

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

$= 1{,}028{,}775/74 = 13{,}902\ gpd/ft^2$

$= 137{,}537/74 = 1{,}859\ ft/d \approx 1{,}900\ ft/d$

Calculation Sheet 8. Residual Drawdown Method for TW-9

Method of Analysis: Residual Drawdown (Theis, 1935)

Q	Average discharge rate	2,494	gpm
$\Delta s'$	Change in recovery per log cycle	0.475	feet
b	Aquifer thickness	75	feet

TRANSMISSIVITY (T)

$$T = \frac{264Q}{\Delta s'} = \frac{264(2494)}{0.475}$$

$$= 1{,}386{,}139 \text{ gpd/ft}$$

$$= 185{,}313 \text{ ft}^2/\text{d} \approx 190{,}000 \text{ ft}^2/\text{d}$$

HYDRAULIC CONDUCTIVITY (K)

$$K = T/b$$

$$= 1{,}386{,}139/75 = 18{,}412 \text{ gpd/ft}^2$$

$$= 185{,}313/75 = 2{,}471 \text{ ft/d} \approx 2{,}500 \text{ ft/d}$$

Calculation Sheet 9. Residual Drawdown Method for TW-10

Method of Analysis: Residual Drawdown (Theis, 1935)

Q	Average discharge rate	2,494	gpm
$\Delta s'$	Change in recovery per log cycle	0.59	feet
b	Aquifer thickness	75	feet

TRANSMISSIVITY (T)

$$T = \frac{264Q}{\Delta s'} = \frac{264(2494)}{0.59}$$

$= 1{,}115{,}959$ gpd/ft

$= 149{,}192$ ft^2/d $\approx 150{,}000$ ft^2/d

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

$= 1{,}115{,}959/75 = 14{,}879$ gpd/ft^2

$= 149{,}192/75 = 1{,}989$ ft/d $\approx 2{,}000$ ft/d

Calculation Sheet 10. Residual Drawdown Method for TW-11

Method of Analysis: Residual Drawdown (Theis, 1935)

Q	Average discharge rate	2,494	gpm
$\Delta s'$	Change in recovery per log cycle	0.52	feet
b	Aquifer thickness	75	feet

TRANSMISSIVITY (T)

$$T = \frac{264Q}{\Delta s'} = \frac{264(2494)}{0.52}$$

$= 1{,}266{,}185$ gpd/ft

$= 169{,}276\ ft^2/d \approx 170{,}000\ ft^2/d$

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

$= 1{,}266{,}185/75 = 16{,}882\ gpd/ft^2$

$= 169{,}276/75 = 2{,}257\ ft/d \approx 2{,}300\ ft/d$

Calculation Sheet 11. Residual Drawdown Method for TW-12

Method of Analysis: Residual Drawdown (Theis, 1935)

Q	Average discharge rate	2,494	gpm
$\Delta s'$	Change in recovery per log cycle	0.46	feet
b	Aquifer thickness	75	feet

TRANSMISSIVITY (T)

$$T = \frac{264Q}{\Delta s'} = \frac{264(2494)}{0.46}$$

$$= 1{,}431{,}339 \text{ gpd/ft}$$

$$= 191{,}356 \text{ ft}^2\text{/d} \approx 190{,}000 \text{ ft}^2\text{/d}$$

HYDRAULIC CONDUCTIVITY (K)

$$K = T/b$$

$$= 1{,}431{,}339/75 = 19{,}085 \text{ gpd/ft}^2$$

$$= 191{,}356/75 = 2{,}551 \text{ ft/d} \approx 2{,}600 \text{ ft/d}$$

Calculation Sheet 12. Residual Drawdown Method for TW-13

Method of Analysis: Residual Drawdown (Theis, 1935)

Q	Average discharge rate	2,494	gpm
$\Delta s'$	Change in recovery per log cycle	0.35	feet
b	Aquifer thickness	75	feet

TRANSMISSIVITY (T)

$$T = \frac{264Q}{\Delta s'} = \frac{264(2494)}{0.35}$$

$$= 1{,}881{,}189 \text{ gpd/ft}$$

$$= 251{,}496 \text{ ft}^2\text{/d} \approx 250{,}000 \text{ ft}^2\text{/d}$$

HYDRAULIC CONDUCTIVITY (K)

$$K = T/b$$

$$= 1{,}881{,}189/75 = 25{,}083 \text{ gpd/ft}^2$$

$$= 251{,}496/75 = 3{,}353 \text{ ft/d} \approx 3{,}400 \text{ ft/d}$$

Calculation Sheet 13. Residual Drawdown Method for TW-14

Method of Analysis: Residual Drawdown (Theis, 1935)

Q	Average discharge rate	2,494	gpm
$\Delta s'$	Change in recovery per log cycle	0.47	feet
b	Aquifer thickness	75	feet

TRANSMISSIVITY (T)

$$T = \frac{264Q}{\Delta s'} = \frac{264(2494)}{0.47}$$

$= 1{,}400{,}885$ gpd/ft

$= 187{,}284\ ft^2/d \approx 190{,}000\ ft^2/d$

HYDRAULIC CONDUCTIVITY (K)

$K = T/b$

$= 1{,}400{,}885/75 = 18{,}678\ gpd/ft^2$

$= 187{,}284/75 = 2{,}497\ ft/d \approx 2{,}500\ ft/d$