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State of California
The Resource Agency

Department of Water Resources
Northern District

WESTERN CANAL
GROUND WATER TEST PROGRAM

MEMORANDUM REPORT

NOVEMBER 6, 1991

Douglas P. Wheeler
Secretary for Resources
The Resources Agency

Pete Wilson
Governor
State of California

David N. Kennedy
Director
Department of Water Resources

State of California

The Resources Agency

Memorandum

Date : November 6, 1991

To : 1. Glen Pearson
2. Linton Brown
3. Dennis Letl

From : Patricia Huckabay
Northern District
Department of Water Resources

Subject: Subject: Western Canal Ground Water Test Program

The Western Canal Test Program was initiated in the Fall of 1990 to evaluate the use of limited quantities of pumping ground water for waterfowl needs in lieu of using surface water. This memorandum report discusses the regional geology, hydrogeology, and water quality of the ground water basin under the Western Canal Service area. Data in this report covers the period of October 9, 1990 through May 22, 1991.

Attachment

cc: John Fielden, Planning, Room 252-12
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DWR 155 (REV. 2/86)

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INTRODUCTION

The 1989-90 water year was the fourth year of dry or critical water supply in the Central Valley, and the State Water Project needed increased carryover storage in its reservoirs to assist in meeting delivery requests for 1990-91. Under existing agreements, the Department of Water Resources is obligated to deliver Feather River water through Thermalito Afterbay to Western Canal Water District. A test program was initiated in the Fall of 1990 to evaluate the feasibility of making greater use of the ground water resources underlying WCWD in lieu of using a like amount of Feather River water. This resulted in more carryover storage in Lake Oroville. In this test program, the ground water was used to supply water for waterfowl habitat. Findings for the ground water test program are summarized in this report.

Area of Investigation

The study area is part of the Sacramento Ground Water Basin that lies within the WCWD service area. It is in Butte County south of Durham and north of Richvale (Figure 1). The study area was divided into four major areas:

- Nelson in the northeast, consisting of 6 pumping wells and 15 observation wells on the McKnight Ranch, 4 pumping wells and 4 observation wells on the Wehah-Lundberg Ranches and 3 pumping wells and 6 observation wells in the Gorrill Ranch (Figure 2).

- Fenn in the northwest, consisting of 3 pumping wells and 1 observation well on the Fenn Ranch (Figure 3).

- Larrabee in the southwest, consisting of 1 pumping well and 1 observation well on the Larrabee Ranch.

- LaMalfa in the southeast, consisting of 1 pumping well on the LaMalfa Ranch.

Throughout this report, "pumping wells" refers to those wells under contract to provide water for the test program and "observation wells" are all other wells that were monitored during the test program. In a few cases, some of the pumping wells were not always pumping during the test period. Also, in a few cases, some of the observation wells may have been pumping for the well owner's private use during the test period.

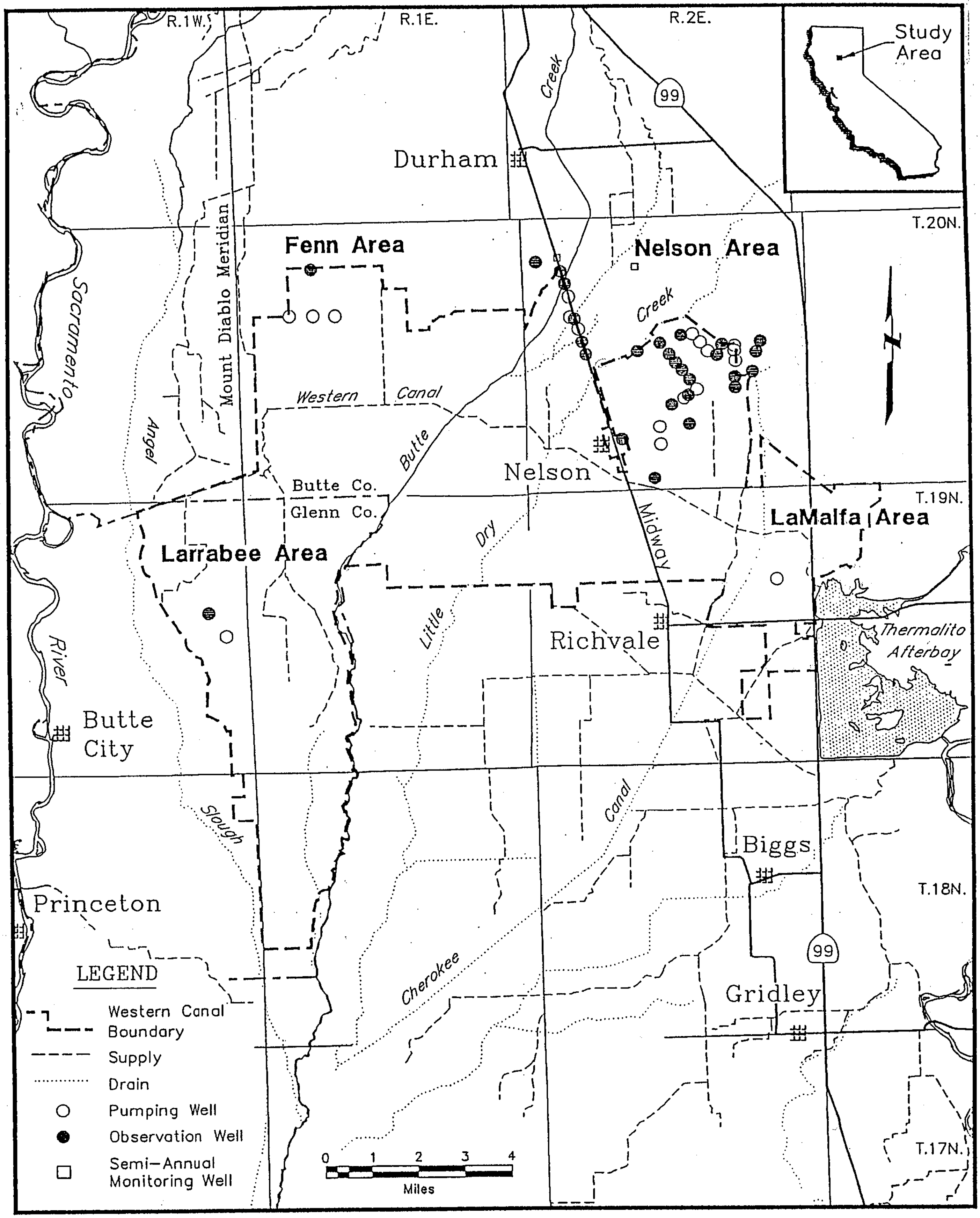

Figure 1. Location Map Showing Western Canal Boundary.

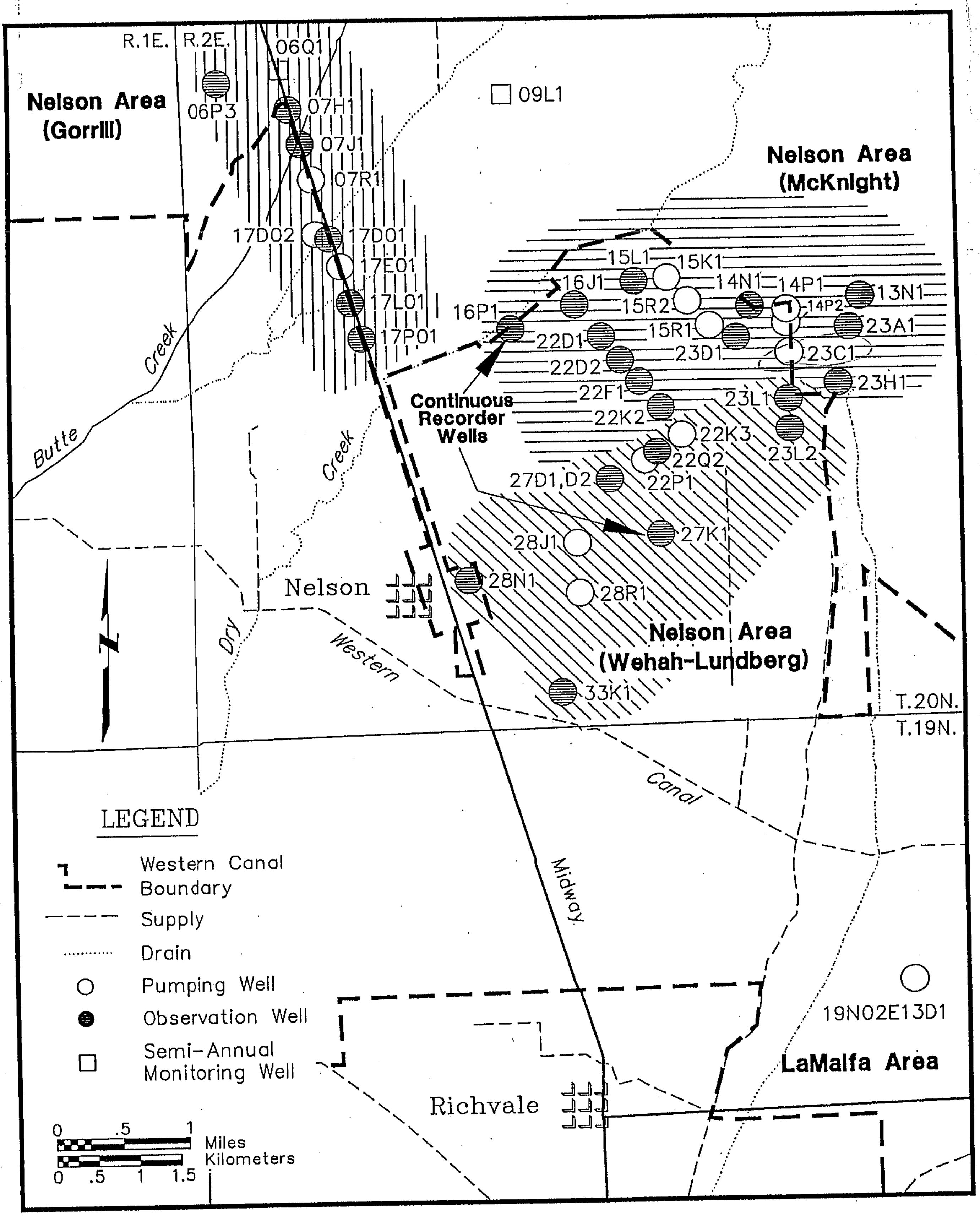

Figure 2. Well Locations Nelson and LaMalfa Areas

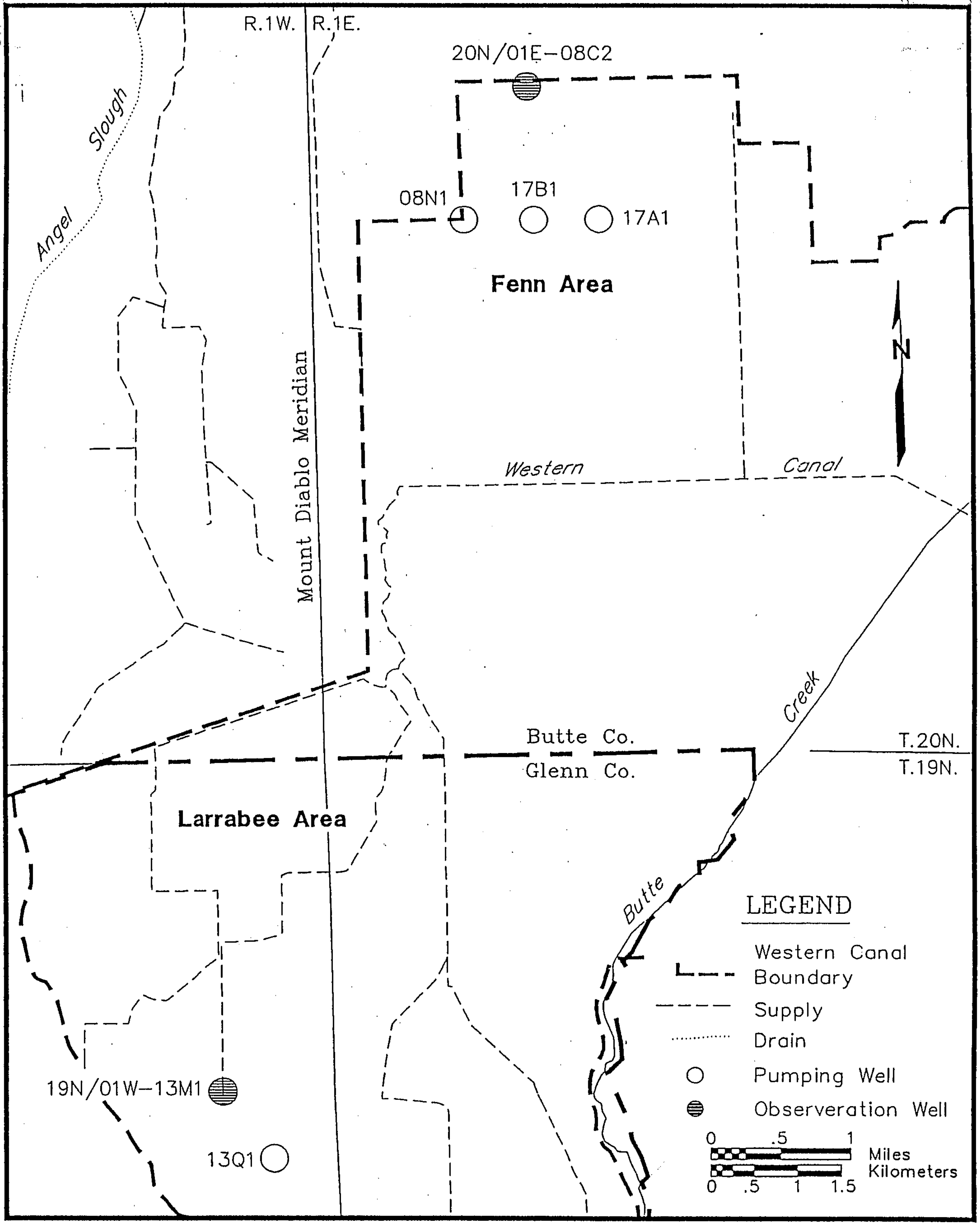

Figure 3. Well Locations Fenn and Larrabee Areas

Purpose and Scope

The purpose of the Ground Water Test Program was to:

- Evaluate the potential for and the impacts of increased ground water pumping of the ground water basin within WCWD's service area; and
- Increase Oroville Reservoir storage carried over into 1990-91.

Under existing agreements, DWR is obligated to convey water through Thermalito Afterbay to WCWD during:

- March 1 through October 31 period under WCWD's natural flow rights and PG&E's stored water rights, and
- November 1 to March 1 period for such additional quantity as the WCWD can beneficially use, including Western's historic obligations to supply water for waterfowl uses downstream from Western's boundaries.

The concepts of the Test Program were:

- Eighteen individually owned wells that would not otherwise be in use were pumped to meet part of WCWD's internal needs and obligations to downstream waterfowl habitat areas.
- The ground water pumped would be collected by WCWD and delivered to meet WCWD's water supply obligations.
- DWR would monitor ground water levels from existing wells within and surrounding the area in which the pumping took place. If there were any significant adverse impacts due to the increased pumping, all or a portion of the Test Program would terminate immediately.
- DWR would pay the well owners for pumping the ground water used in this Test Program, plus a portion of activation costs.
- DWR would pay the District for the administration of the Test Program.
- The Test Program was developed specifically for the current drought situation and is not a precedent for any future agreement.

The pumping period began on October 29, 1990 and ended on January 2, 1991.

Methods

A ground water monitoring grid of 45 wells was created (Figures 1 to 3). DWR began monitoring the water levels in wells of the McKnight and Wehah-Lundberg Sub-areas on October 15, 1990. The other wells were added within a month. Continuous recorders were placed at wells 20N/02E-16P1 and 20N/02E-27K1.

Ground surfaces elevations at each well were surveyed to make accurate determinations of direction of ground water flow. The ground water table was so flat that elevations from U.S.G.S. quad maps proved inadequate.

Flow meters were installed on each of the pumping wells except for the McKnight and Fenn wells. A single meter recorded discharge of the three Fenn wells through a channel located approximately 7,800 feet downstream. A single meter recorded flow for the six McKnight wells at a channel located approximately 14,000 feet downstream. A meter was also installed at one of the McKnight wells (20N/02E-14P2) for the pump test.

DWR conducted a 24-hour aquifer test for three pumping wells to define aquifer parameters. A specific capacity test was done for every pumping well to determine the magnitude and rate of drawdown and to develop transmissivity values in the area. The specific capacity test involved monitoring the drawdown for each pumping well for the first 60 to 90 minutes upon the onset of pumping.

The wells in the monitoring grid were then measured once every three to four days until the rate of ground water level change stabilized during pumping. The wells were then measured once every seven days. Three months after pumping ended, the frequency of measurement was reduced to once every 14 days. The Log of Activity in Appendix B summarizes most field activities.

Contour maps of ground water change were created for selected measurement periods to illustrate the drawdown and recovery in the area. This report includes contour maps for the ground water level change from static to maximum drawdown (before pumps were turned off) and from static to the 24 hour recovery of levels after pumping ceased.

Water quality samples were taken during the pumping period from the pumping wells.

Previous Studies

DWR's earliest detailed work in the Butte Basin area is in the Northern District's Memorandum Report, "Progress Report on Ground Water Development Studies, North Sacramento Valley", by P.J Lorens, June 1976. The report describes the geology and ground water availability in two regions, one of which is the Thermalito area in Butte County, which included the Butte Basin.

DWR Bulletin 118-6, "Evaluation of Ground Water Resources: Sacramento Valley", August 1978 presents a general inventory of Sacramento Valley's ground water resources in terms of geology, hydrology and water quality.

Summary and Conclusions

The Ground Water Test Program included 18 pumping wells. One of these wells, 19N/02W-13D01, was dropped out of the test program due to equipment problems. The rest were pumped for 47 to 65 days at a rate of 1,250 to 2,650 gallons per minute. A total of 7,750 acre-feet of water was produced. Thirty feet was the maximum drawdown when a single well was pumping within a two-mile radius. Seventy feet was the maximum drawdown where multiple wells were pumping within a two-mile radius. Well interference is evident in the latter situation. The three domestic observation wells, which draw from a shallower ground water zone, were not affected by the pumping wells.

Pump tests for single pumping wells reveal minimal impacts on neighboring wells. Less than five feet of drawdown occurred in observation wells located over 1,500 feet from the pumping well. The pump tests also suggest that the confining layer of the aquifer system below the Western Canal service area is leaky.

Ground water levels recovered quickly as soon as pumping ceased. The levels recovered, on the average, 81 percent within the first 24 hours after pumping in reference to the static level at the end of October 1990. After the March rain, the ground water level rose between .5 to 5.8 feet (averaging 3.0 feet) above the static level of Fall 1990. Ground water levels started to decline with the onset of pumping activities in early April 1991, which were not related to the test program.

The mineral, nutrient and minor elements aspects of water quality of the discharge from the pumping wells appear to be excellent for wildlife, domestic and agricultural uses.

On June 2, 1991, the surface area of Lake Oroville was 9,385 acres at 751.53 feet water level elevation. The wells produced 7,750 acre-feet of water during the test program. Thus the test program conserved about 0.8 feet of lake storage.

Overall, stress on the ground water basin due to the test program was minimal. The basin could have easily supported more pumping wells during the test program, assuming they were spaced to minimized well interference.

Recommendations

The Ground Water Test Program was the first opportunity for DWR to closely monitor the impacts of a well field in the Sacramento Valley. The following are our recommendations:

- DWR should continue to monitor the ground water levels in the wells in the test program to see how they "normally" fluctuate.
- There was some evidence of significant channel loss in transporting water through the local canals. Flow studies should be conducted to determine infiltration losses in what appears to be impermeable material.
- Flow meters should be installed as close to the destination point as possible for a more accurate accounting of the water delivered.
- Similar Test Programs should be conducted elsewhere in the basin to determine the variability of the hydrogeologic system.

REGIONAL GEOLOGY

The Western Canal Test Program study area is on the east edge of the Sacramento Valley, which is a structural trough oriented northwesterly, bounded on the east by the Sierra Nevada Mountains and the Cascade Ranges, and on the west by the Coast Ranges. The older granitic, metamorphic and marine sedimentary rocks of the surrounding mountains dip down into the valley and form the bedrock basement on which younger marine and alluvial sediments were deposited. In the axis of the valley, bedrock is at considerable depth but becomes shallow near the margins.

Immediately overlying the basement rocks are Eocene age marine and continental sedimentary rocks which contain saline or brackish water. Overlying the Eocene rocks is a sequence of continental deposits of post-Eocene age which contain fresh water; though, in deeper portions of the valley, brackish to saline water has intruded. The post-Eocene deposits were laid down by streams flowing into the valley trough from the surrounding mountains. Included in this assemblage of predominately sedimentary rocks are volcanic mudflows, lava flows, and volcanic ash deposits of middle to late Tertiary age. The post-Eocene assemblage extends to a depth of 1,400-1,600 feet below sea level and fresh water occurs to a depth of about 1,200 feet.

Several post-Eocene formations in the northeast portion of the Sacramento Valley are important sources of ground water. They include the Tuscan, Tehama, and Laguna Formations, and older and younger unnamed overlying alluvial fan, floodplain and recent stream deposits.

Figure 4 (geologic map) shows the areal distribution of the various geologic units in the Western Canal area. Figure 5 is a diagrammatic cross section which shows the general relationship of the various units in the subsurface.

<u>The Tuscan Formation</u> is an assemblage of Pliocene age volcanic rocks and interstratified volcanic sediments which blankets the western foothills of the southern Cascade Range. Tuscan rocks extend southwest into the valley where they are overlain by younger alluvial deposits. In the foothills, where the gently sloping surface of the Tuscan is deeply dissected by westerly flowing streams, exposures along canyon walls show the stratified character of the formation as well as the horizontal and vertical variation in sedimentary structures and grain sizes. Tuscan rocks include tuff-breccia, lapilli tuff, volcanic conglomerate and sandstone, with lesser quantities of tuff claystone and siltstone.

A typical tuff-breccia within the Tuscan is a hard, compact rock of low permeability, consisting of pebble-to boulder-sized clasts imbedded in a matrix of unsorted clay-to sand-sized volcanic

LEGEND AND DESCRIPTION OF GEOLOGIC UNITS

t

Tailings
Mine and dredge tailings consisting of boulder and cobble debris piled along the channels and flood plains of Dry and Butte Creeks and the Feather River.

Qsc

Stream Channel and Flood Plain Deposits
Unconsolidated deposits of sand and gravel adjacent to active stream channels. High to very high permeability.

Qb

Basin Deposits
Unconsolidated to moderately consolidated deposits of silt and clay, that form a thin surface mantel in the low basin area lying between the Sacramento River and the dissected uplands west of the Feather River. soil profiles are well developed with horizons of hardpan. Permeability is low.

Qaf

Alluvial Fan Deposits
A coalescing apron of clay, silt, sand and gravel, forming a wedge-like deposit at the base of the eastern foothill front from about Dry Creek north towards Chico. Permeability varies from low to high, locally.

Qoal

Older Alluvium
Includes older alluvial fan and stream terrace deposits that form the dissected rolling hills SW of Oroville, parallel to the Feather River and near Butte City east of the Sacramento River. Included are geologic units identified as the Victor, Modesto and Riverbank Formations by other studies. Permeability is moderate to low.

Ttu

Tuscan Formation
Interbedded lahars (tuff-breccias), volcanic conglomerate, volcanic sandstone, siltstone and pumaceous tuff. These rocks form the layered volcanic mantel of the eastern foothills north of Cottonwood and Little Cottonwood Creeks , and extend west under younger alluvial deposits in the valley. Sedimentary members form important aquifers in the subsurface, and lahars form confining layers. Permeability ranges from low in the tuff-breccias to high in the sedimentary. layers.

Tla

Laguna Formation
Interbedded alluvial sand, gravel and silt deposits at the northeast margin of the Thermalito Afterbay. Compacted and generally low in permeability, except in scattered gravels in the upper portion. Includes a veneer of erosional remnants of the Red Bluff Formation which consists of siliceous gravels and cobbles in a reddish brown silty, sandy matrix. Moderately consolidated, poorly to well cemented, with low permeability.

Tte

Tehama Formation
Primarily sandstone and siltstone with lenses of pebble and cobble conglomerate, found only in the subsurface in the study area. Interfingers with Tuscan and Laguna rocks beneath the younger alluvium and is contemporaneous with both. Permeability ranges from low to moderate.

Ti

Ione Formation
White to buff colored claystone, sandstone and conglomerate. Found overlying the Lovejoy Basalt of Table Mountain and forms the Campbell Hills. Permeability is generally. low.

MAP SYMBOLS

Geologic Contact

Subsurface extent of the Tuff-Breccias of the Tuscan Formation

Total subsurface extent of the Tuscan Formation

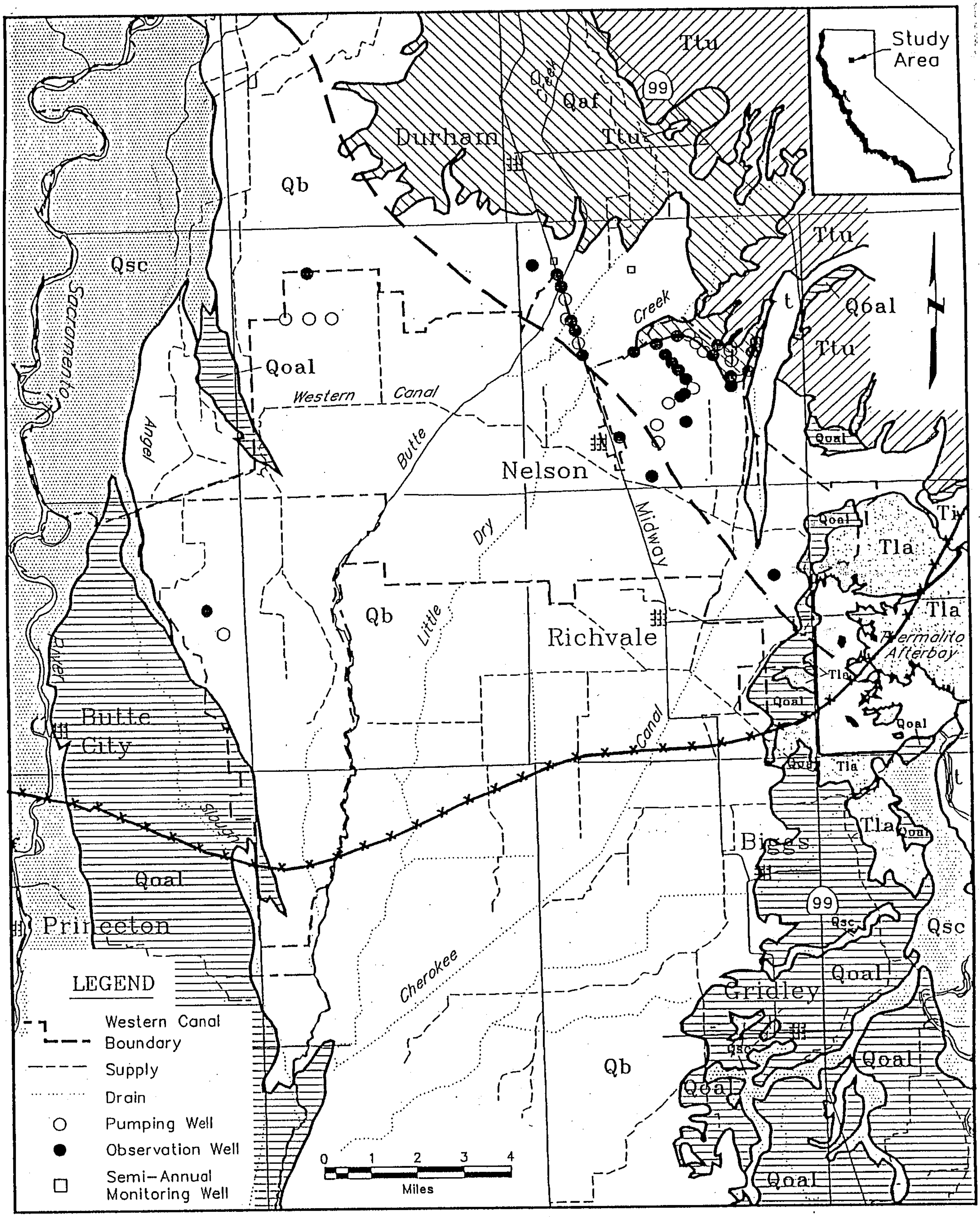

Figure 4. Geologic Map.

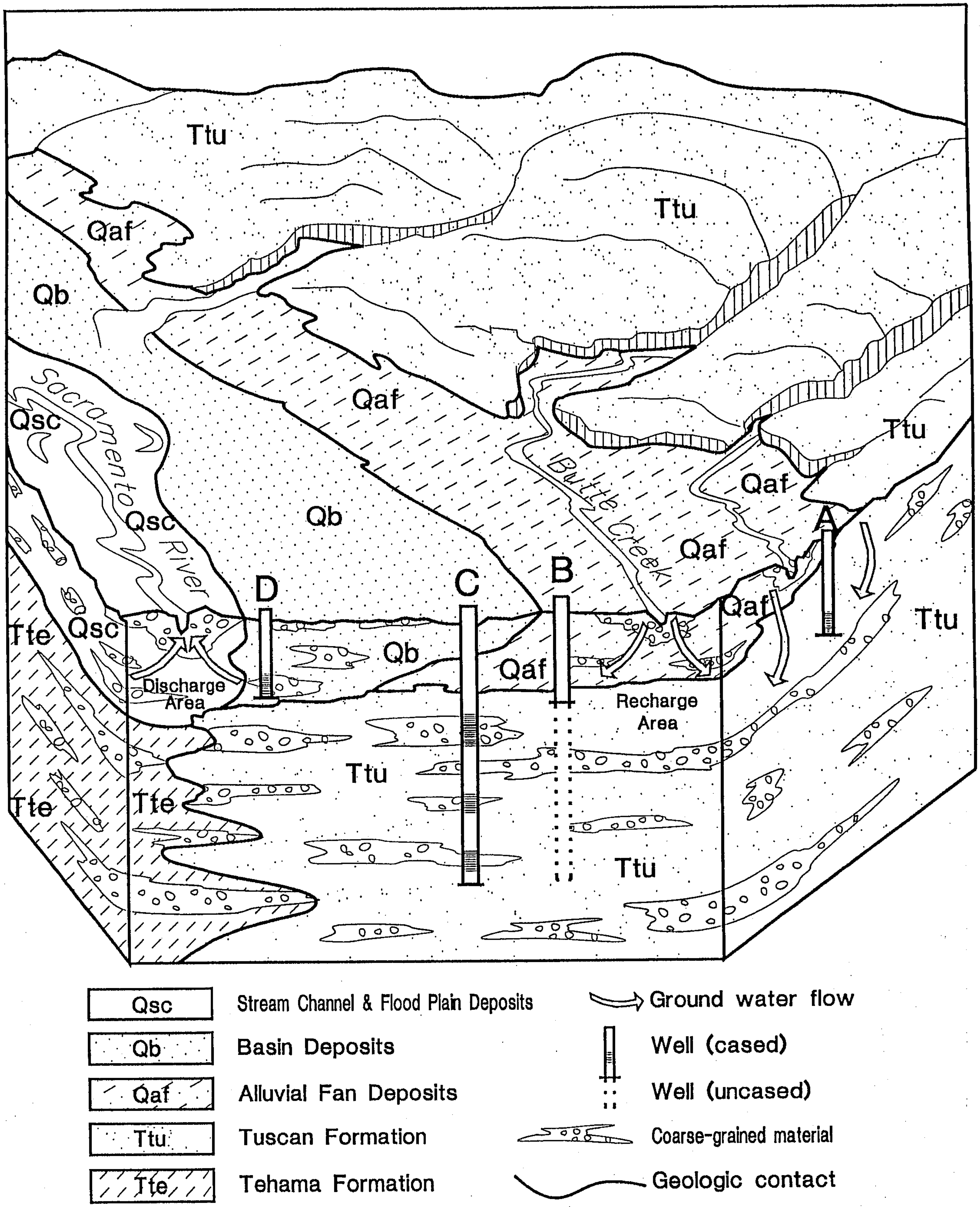

FIGURE 5 HYDROGEOLOGIC DIAGRAM
BUTTE BASIN - 1991

fragments. Individual beds range from 3 to 150 feet in thickness. At the surface, these rocks restrict percolation of water into the ground water basin and in the subsurface they can act as confining beds that restrict the upward or downward movement of water.

Tuff and lapilli beds within the Tuscan are very similar to the tuff-breccias, they differ essentially only in the size of fragments present.

Volcanic conglomerates of the Tuscan typically consist of poorly-sorted, sub-angular to sub-rounded, boulder- to pebble-sized clasts in a matrix of coarse grained sand. Minor amounts of silt and clay may also be present. Conglomerate beds commonly contain thin, lenticular interbeds of sandstone, and often grade into normal sandstone units. However, sharp erosional contacts are also common and conglomerates in cut-and-fill channels attest to the periodic changes between depositional and erosional environments. Tuscan conglomerates are generally friable and lack significant amounts of cementing material, and because of this characteristic weak consolidation, are moderately to highly permeable.

Tuscan sandstones vary from coarse to fine grained, and from poorly- to well-bedded. Bedding is often defined by grain-size changes or stringers of tuffaceous clay or siltstone. The coarser grained sandstones tend to be quite friable, but at some localities, weak cementing due to weathering and clay formation is found. The finer grained sandstones tend to be moderately- to well-indurated, making them less permeable than the coarser grained beds Siltstone and claystone are widely distributed in the Tuscan but do not constitute a large portion of the formation. They typically occur as thin interbeds associated with coarser-grained sediments, or as thin beds up to a few feet in thickness. Both silt and claystone beds are often thinly laminated. Most of these finer-grained sediments are typically compact and fairly hard, making them low in permeability as well as porosity.

The Laguna and Tehama Formations are upper Pliocene to lower Pleistocene age fluvial deposits of silt and clay with lenticular zones of sand and gravel which overlie and interfinger with the Tuscan. The Tehama Formation is generally on the west side of the valley and the Tuscan on the east side. In the study area, these formations are considered nearly contemporaneous in age and probably interfinger beneath the younger alluvium toward the central portion of the valley. The Laguna Formation is about 500 feet thick on the east side of the valley, and together, where the two interfinger mid-valley, probably total about 1000 feet in thickness. In the area around Thermalito Afterbay, a patchy veneer of weathered red gravel, identified as Red Bluff Formation in other studies, has been lumped with the Laguna. These thin Red Bluff remnants generally lie above the saturated zone and are therefore considered unimportant as aquifer materials.

slightly confusing

The Laguna and Tehama consists predominately of sandy, tuffaceous silt-stone and claystone with channelized and lenticular interbeds of sandstone and conglomerate. The finer-grained beds are generally well-consolidated,with low permeability, but the coarser beds can provide large quantities of ground water to wells.

In the subsurface, materials reported as "cemented" or "sandstone" are assumed to be Laguna or Tehama.

Older Alluvial Deposits include an assemblage of Pleistocene age stream terrace and alluvial fan deposits which form the low dissected hills on the east side of the valley from about Thermalito south. These deposits directly overly the Laguna Formation and underlie the younger basin deposits as far west as Butte Creek. The thickness of these deposits is uncertain, but judging from well logs they may vary from 0-250 feet.

These deposits include geologic units identified as the Victor, Modesto, and Riverbank Formations by other studies. These deposits vary from unconsolidated to cemented, with some hardpan layers. Permeabilities vary from low, especially with localized reduction of vertical permeability by hardpan, to high where coarser or unconsolidated materials predominate.

Younger Alluvial Deposits include alluvial fans, stream channel deposits, floodplain, and flood basin deposits. These are the most recently deposited materials and represent important ground water sources. Alluvial fans occur on the margins of the valley as wedges of coarse material that fine toward the valley and interfinger with or merge into the floodplain and basin areas. Stream channel and floodplain deposits are the materials deposited adjacent to major rivers or streams. In the study area, these include the Sacramento River and Butte Creek. Flood basin deposits are the finest materials, deposited as a thin mantel by receding floodwater in lowlying valley areas.

Alluvial fan deposits consist of heterogeneous mixtures of cobbles, gravel, sand, silt and clay. These deposits are unconsolidated and permeability is highly variable. Alluvial fan deposits are important in this area as recharge zones at the valley margins.

Basin deposits occupy the central portion of the study area as a mantle of clay, silt, and some sand up to a thickness of about 50 feet. Older basin deposits have a well developed hardpan layer that severely restricts the downward percolation of precipitation and applied irrigation water. A few younger basin deposits occur as discontinuous stringers of sand, silt and clay deposited by the Sacramento River in historic flooding.

The basin deposits are thin and of low permeability and therefore unimportant for ground water development, but the older alluvium underlying the basin deposits constitute some of the more important aquifers in the Sacramento Valley.

Stream channel deposits occupy the active channel of the Sacramento River, and portions of Butte Creek where it is not channelized by levees. Floodplain deposits flank the active channels and represent overbank deposits and the lateral shifting of bank and channel deposits as these streams meander across their floodplains. These highly permeable sand and gravel deposits constitute the youngest geologic unit. Despite their high permeability, these deposits are relatively thin and of limited areal extent, so are of limited importance except in development of water wells near the stream courses.

Tailings consist of boulder and cobble debris from mining and dredging operations. They are found along the channels and floodplains of Dry Creek, Butte Creek and the Feather River. These deposits are relatively thin and of limited areal extent, so they are of limited importance for ground water.

HYDROGEOLOGY

This section provides background material on the principles of hydrogeology and describes the types of aquifers, and the occurrence and movement of ground water in the Butte Basin.

The occurrence, movement, and fluctuations of ground water are determined through analysis of water-level data from wells throughout a ground water basin. The best data can be obtained only from qualified wells (wells with logs and information on the placement of perforations in the casing), which are perforated in a single stratum. These data can show both seasonal and long-term changes in water levels. Historical records of water levels are helpful in detecting trends in ground water storage in a basin.

Principles of Ground Water Hydrology

The movement of a drop of water from the time it enters the ground to the time it emerges, either naturally or by being pumped from a well, is controlled by underground conditions. Upon entering the ground, the water moves downward through the zone of aeration and into the zone of saturation, the upper surface of which is the water table. Figure 6 shows the occurrence of ground water within these zones. In the upper zone, or zone of aeration, most of the intergranular spaces in the geologic materials are filled partly with air and partly with water, and conditions may approach saturation due to infiltration of rainfall or irrigation water. Wells cannot produce ground water from the zone of aeration. "Perched" ground water can occur in an isolated saturated zone separated from the main body of ground water by a layer of rock or clay that water cannot pass through.

In the lower zone, or zone of saturation, the intergranular spaces in the underground materials are interconnected and filled with ground water. Ground water exists in this zone under unconfined and confined conditions. Widespread impervious layers overlay the confined subzone. Both can be recharged from direct precipitation and surface runoff. The water table is the upper surface of the water in the saturated zone and is approximately the level to which water will rise in a well.

Ground water resources are replenished when water from precipitation, streamflow, irrigation, and other sources sinks into the ground, and the area into which it sinks is called a "recharge area". Recharge areas normally include mountains, foothill slopes, and valley floors. Alluvial deposits on valley floors that are hydrologically connected to rivers and the streams are often important recharge areas. These deposits are usually very permeable and allow rapid infiltration.

Ground Water Occurrence

Most of the materials that make up the earth's outer crust have open spaces that may contain ground water. The openings range from minute pores in clays and small cracks in rocks to large passages found in some basalt flows and limestone areas. Porosity, or the percentage of empty space in a material, does not necessarily mean ground water can move through the material easily. If the openings are very small or are not connected, water movement is restricted and the material is said to have a low permeability and high porosity. For an example, materials such as clay, have a high porosity yet transmit little water to wells. In contrast, materials of high permeability but somewhat lower porosity, such as mixtures of coarse gravel and sand, can yield large amounts of ground water.

Impacts of Pumping

When a well is pumped, the water level around it is drawn down to form an inverted cone with its apex at the well. This cone of depression in the static water surface is shown in Figure 7. The size of the cone depends on how much water is being pumped and how fast water can flow through the aquifer to replenish the well. As pumping continues, the cone expands in depth and area until it reaches equilibrium between pumping demand and aquifer yield.

Where the amount of water pumped from an aquifer is greater than aquifer yield, water levels will continue to decline. In areas where intensive development has taken place in ground water reservoirs, the cones of depression of some wells will overlap with those of neighboring wells, producing a regional area of depression and lowering water levels. Figure 8 illustrates the effects of this interference among pumping wells. The extent of interference depends on the rate of pumping from each well, the spacing between wells, and the hydraulic characteristics of the aquifer into which the wells are drilled.

Ground Water Movement

General ground water movement in a ground water basin can be interpreted from maps that show lines of equal elevation of the static water table. The maps indicate the direction of ground water movement, at right angles to the contour lines, and water moves from the higher elevation contour to the lower, or from areas of recharge to areas of discharge. Under typical water table conditions, the slope of the water table and, therefore, the direction of ground water movement are closely related to the slope of the land surface. Under natural conditions, the rate of ground water movement in an aquifer is usually slow, from a few feet to a few hundred feet per year. However, pumping can create a temporary depression in the water table and change the direction and rate at which ground water moves--toward the well instead of the down the natural gradient.

Often, physical barriers that impede the movement of ground water are indicated by the patterns or spacings of the ground water contours. The effect of geologic faults on the movement of ground water can often be interpreted from contour maps. Where a fault offsets a water-bearing layer, ground water may be dammed, forming a higher water table on the recharge side, or may rise along the fault zone and appear at the ground surface as springs.

Ground Water Parameters

Ground water parameters describe the physical properties of an aquifer that determine movement and storage of ground water. They can be used to predict the effects of ground water levels due to pumping and recharge.

Transmissivity is the capacity of the aquifer to transmit water through its pore spaces. In terms of gpd/ft, transmissivity is the rate of flow (gallons per day) moving through the entire saturated thickness having a width of one foot under a unit hydraulic gradient of one foot per foot. It is also the product of hydraulic conductivity and the saturated aquifer thickness. Thus the transmissivity can vary within a given aquifer of uniform composition due to variation in aquifer thickness.

Storage coefficient is the capacity of the water bearing material to store and to transmit water. The storage coefficient is a dimensionless unit that represents the volume of water released or added to storage through a unit cross-section area of a vertical column of the aquifer due to a unit head change. For most confined aquifers, storage coefficients range from 0.00001 to 0.001. For most unconfined aquifers, the storage coefficient range from 0.1 to 0.3.[1]

Specific Capacity is the yield per unit drawdown of a production well. It is often used to estimate transmissivity where no pump test information is available. The specific capacity is a function of well construction (ie. location of perforated zones, well efficiency), pumping rate and duration, and aquifer characteristics (ie. aquifer thickness, storage coefficient, and transmissivity of the producing zone). Because specific capacity incorporates a drawdown value with the yield of a well, it is much more meaningful than just the yield. Also, theoretically, the specific capacity of a well with a given pump size should not change. Therefore, if the specific capacity changes with time then the well or the aquifer is experiencing changes - not the pumping equipment. For example, if the specific capacity of a well decreases with time, a likely cause is due to the clogging of well perforations.

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1 Heath, Ralph C., 1982, Basic Ground Water Hydrology, U.S. Geological Survey Water-Supply Paper; 2220.

Hydrogeology of the Western Canal Water District

Aquifer Characteristics

The discontinuous nature of the alluvial deposition in the study area makes correlation of aquifers from well to well difficult. As streams coursed north to south and east to west through time, new channels were created and abandoned, forming a complex system of now-buried channels. The extent of each geologic formation in the subsurface is also difficult to determine due to the lack of distinctive beds with which to correlate surface geology. The only easily identifiable, distinctive subsurface materials are volcanic sands and gravels, and lavas.

Table 1 (Well Qualification) is a summary of a determination of aquifers based on interpretation of well depths, construction and lithology shown on drillers reports, and correlated with measured ground water levels.

Occurrence of Ground Water

Water level measurements show that ground water occurs in two general zones in the study area. Levels measured in shallow wells, completed only in the unconfined, free water zone, and in deep wells, completed in lower confined to semiconfined zones, fluctuated independently of one another. Aquifer tests showed that leakance between the two zones does occur, but confining beds significantly limit hydrologic continuity between the two zones.

Nelson Area

Gorrill Sub Area: Six of the seven wells monitored on the Gorrill Ranch have known depths, and of these only three have documented construction data. Well drillers' reports show very thin basin deposits overlying Tuscan sediments, except adjacent to Butte Creek, where deposits of sand and sandy gravel were encountered to depths of about 35 to 40 feet. Of the wells with construction data, 1 well is perforated from the shallow unconfined alluvial zone through to the underlying semiconfined to confined layers. Perforations in the other two wells are in the deeper zone, where water-bearing volcanic sands and gravels are interbedded with lava and ash layers. The average depth of wells in this area is 470 feet. These wells are typically cased to consolidated beds of the Tuscan Formation (about 70-75 feet) and are open hole to the bottom.

McKnight Sub Area: Of the 21 wells monitored on the McKnight Ranch, only 11 have sufficient construction

Table 1

WELL QUALIFICATION

STATE WELL NUMBER	DEPTH (Feet)	PERFORATIONS (Feet)	WATER BEARING MATERIALS	MEASUREMENT QUALIFICATION GROUND WATER BODY	MEASUREMENT QUALIFICATION CONFIDENCE RATING	WELL LOG	REMARKS
NELSON AREA********							
Gorrill Sub-Area							
20N02E06P03M	327	120-327	Tuscan	Composite	Definite	131684	Open hole 120-327
20N02E07H01M	265	18-265	Qb+Qaf?+Tuscan	Composite	Definite	USBR	Open hole 70-265
20N02E07J01M			Tuscan	Composite	Possible		No data on record
20N02E07R01M	550		Tuscan	Composite	Possible	Gorrill log	*Owners notes
20N02E17D01M	508	374-500	Tuscan	Composite	Definite	USGS	Flowing well 1920
20N02E17D02M	551		Tuscan	Composite	Probable	USGS	Orig hole deepened
20N02E17E01M	612		Qsc?+Tuscan	Composite	Probable	USBR	
McKnight Sub-Area							
20N02E13N01M	162	64-162	Qaf+Tuscan	Composite	Probable	76263	Open hole 64-162
20N02E14N01M			Tuscan	Composite	Possible		
20N02E14P01M			Tuscan	Composite	Possible		
20N02E14P02M			Tuscan	Composite	Possible		
20N02E15K01M	762		Tuscan	Composite	Probable	5204	Log for 604-762
20N02E15L01M	645	534-570	Tuscan	Composite	Definite	USGS+5205	Orig hole deepened
20N02E15R01M	500		Tuscan	Composite	Probable	338	Orig hole deepened
20N02E15R02M	616	396-616	Tuscan	Composite	Definite	5203	Open hole 480-610
20N02E16J01M	502	14-300	Qaf+Tuscan	Composite	Definite	USGS	
20N02E16P01M			Tuscan	Composite	Possible		No data on record
20N02E22D01M	512	290-512	Tuscan	Composite	Probable	USGS	Open hole 290-512
20N02E22D02M	510	18-510	Qb+Tuscan	Composite	Definite	USGS	Open hole 312-510
20N02E22F01M	507	18-507	Qb+Tuscan	Composite	Definite	USGS	Open hole 266-507
20N02E22K02M			Tuscan	Composite	Possible		No data on record
20N02E23A01M			Qaf+Tuscan	Composite	Possible		No data on record
20N02E23C01M	625	420-625	Tuscan	Composite	Definite	42561	Open hole 440-625
20N02E23D01M			Tuscan	Unconfined	Possible		No data on record
20N02E23H01M			Qaf+Tuscan	Composite	Possible		No data on record
20N02E23L01M			Tuscan	Composite	Possible		No data on record
20N02E23L02M			Tuscan	Composite	Possible		No data on record
20N02E27D01M	68		Qb?+Tuscan?	Composite	Possible	None	
Wehah-Lundberg Sub-Area							
20N02E22K03M			Tuscan	Composite	Possible		No data on record
20N02E22P01M	510	218-510	Tuscan	Composite	Definite	USGS	Open hole 218-510
20N02E22Q02M	500		Tuscan	Composite	Probable	USGS	Deepened 185-500
20N02E27K01M			Tuscan	Composite	Possible		
20N02E28J01M	615	100-615	Tuscan	Composite	Probable	Old DWR	
20N02E28N01M		160-277	Qb+Tuscan?	Unconfined	Possible	Old DWR	Sounded to 38'
20N02E28R01M	500	120-500	Tuscan	Composite	Probable	Old DWR	Open hole 380-500
20N02E33K01M	300		Qb?+Tuscan	Composite	Possible		Owners est. depth
FENN AREA							
20N01E08C02M	700	118-700	Tuscan	Composite	Definite	132097	? Log match this well
20N01E08N01M	698	42-696	Qaf+Tuscan	Composite	Definite	16102	
20N01E17A01M			Qaf+Tuscan	Composite	Possible		No data on record
20N01E17B01M			Qaf+Tuscan	Composite	Possible		No data on record
LA MALFA AREA							
19N02E13D01M	119	56-119	Qb+Qoal?+Tuscan?	Composite	Probable	10978	Open hole 80 to 119
LARRABEE							
19N01W13M01M							No data on record
19N01W13Q01M	442	152-320	Qb+Qoal+Tuscan?	Composite	Probable	96293	

GROUND WATER BODY

UNCONFINED - Represents the free ground water level in the uppermost zone of saturation.
CONFINED - Represents the piezlometric surface of an aquifer under pressure.
COMPOSITE - Represents a water level that includes two or more confined levels and/or the free ground water level.

CONFIDENCE RATING

DEFINITE - Know well depth & perforated interval, have complete drillers report & good local geology.
PROBABLE - Know well depth, have partial drillers report & good local geology.
POSSIBLE - Know well depth, have poor local geology and/or uncertain well data.

data and lithologic information to allow interpretation of aquifer materials encountered. Well drillers reports show thin basin or alluvial fan deposits overlying Tuscan Formation rocks. Most of these wells were deepened and data are lacking for the upper 200-300 feet. Where data are available, they show the upper portion of the Tuscan consists of thick layers of sandy or gravelly clay with thin interbeds of sand or sandstone. These clay layers probably serve as the confining beds which separate the surficial zone from the underlying volcanic sands and gravels which contain large amounts of ground water under pressure. Of the nine known deep wells, the average depth is 575 feet. Four of these deep wells are developed exclusively in the deep zone and three are developed throughout their entire depth. Data on other wells are lacking.

<u>Wehah-Lundberg Sub Area</u>: Eight wells were monitored in the Wehah-Lundberg area. Depths are known for five of the eight, and construction data are available for three wells. Lithology on drillers reports shows considerable lateral variation in the shallow zone in this sub area. Some wells have up to 30 feet of gravel or sandy gravel in near surface deposits whereas other wells have clay, basin deposits, directly overlying Tuscan. The coarse layers may be older stream deposits filling channels eroded into the basin deposits. Available construction data show wells are perforated only in the deeper zone. One well (20N/02W-28N1) which was documented to be 277 feet deep was sounded and found to be only 38 feet deep. Levels in this well may only represent the shallow unconfined zone. Wells with known depths average 485 feet, and range from 300 to 615.

Fenn Area

The Fenn Ranch with four wells comprises this area. Two wells have depth and construction data. Drillers report lithology shows thin basin deposits overlying Tuscan sedimentary layers. These two wells are perforated in the semiconfined to confined zones in the Tuscan. One well is cased to an intermediate depth and open hole to the bottom, and the other is cased to the bottom. These wells are 698 and 700 feet deep, only one other well in the study area, on the McKnight Ranch, is deeper at 762 feet.

LaMalfa Area

One moderate depth well was monitored on the LaMalfa Ranch near Thermalito Afterbay. The drillers report shows thin basin deposits overlying what was interpreted as older alluvium, the sandy clay near the bottom may be Tuscan. This well is cased to 80 feet and is open hole below. Perforations start at 56 feet which is probably a transition zone between unconfined and semiconfined.

Larrabee Area

A producing well and an unused observation well on the Larrabee Ranch provided the data for this portion of the study area. While no data are available for the observation well, the report on the producing well shows it to be 442 feet deep and perforated from 152 feet to the bottom of the casing at 320 feet deep, and open hole below. Interpretation of the lithology provided by the driller is uncertain. It appears that in this area a thin layer of basin deposits overlies about 350-400 feet of older alluvium, represented by alternating beds of brown clay and sandy clay to about 250 feet and an increasing amount of interbedded sand and gravel beds toward the bottom. The production well encountered blue clays, sands and gravels at a depth of 385 feet, this may be the top of the underlying Tuscan or Tehama Formations.

Ground Water Movement

The direction of ground water movement may be determined by measuring water levels in wells and calculating variation in elevation from point to point. Since ground water movement is influenced by gravity, direction of movement is at right angles to elevation contours from higher to lower elevation. Where contour lines are closer together, the gradient is steeper and flow is faster, although the total quantity of flow for the same cross-sectional area may not be greater. The contour map based on Fall 1990 measurements (Figure 9) represents the ground water gradient at the end of the irrigation season in Butte County. Figure 10, based on 56 Spring 1991 measurements plus 45 wells from the test program shows ground water contours after the drought plagued winter recharge season. Both maps show the ground water flowing in a southwestern direction and draining into the Sacramento River. There are no indications of closed ground water depressions where pumpage was in great excess of recharge. There is an open depression around the Durham area where pumpage appears to be in excess of recharge. The contour pattern of both Spring and Fall measurements are the same, except Spring levels on the average rose 4.5 feet from Fall levels.

Ground Water Change

Ground water levels fluctuate annually in response to natural discharge and pumpage and to recharge from stream percolation, infiltration of rainfall, and applied irrigation water. Levels are usually highest in the spring and lowest in fall. Long-term fluctuations occur when recharge either exceeds discharge or is less than discharge. The hydrographs of well 20N/02E-09L1 and 20N/02E-06Q1 (Figure 11) illustrate the long term fluctuations in deep irrigation wells near the Western Canal service area. They show normal fluctuation from seasonal use and periods of drought

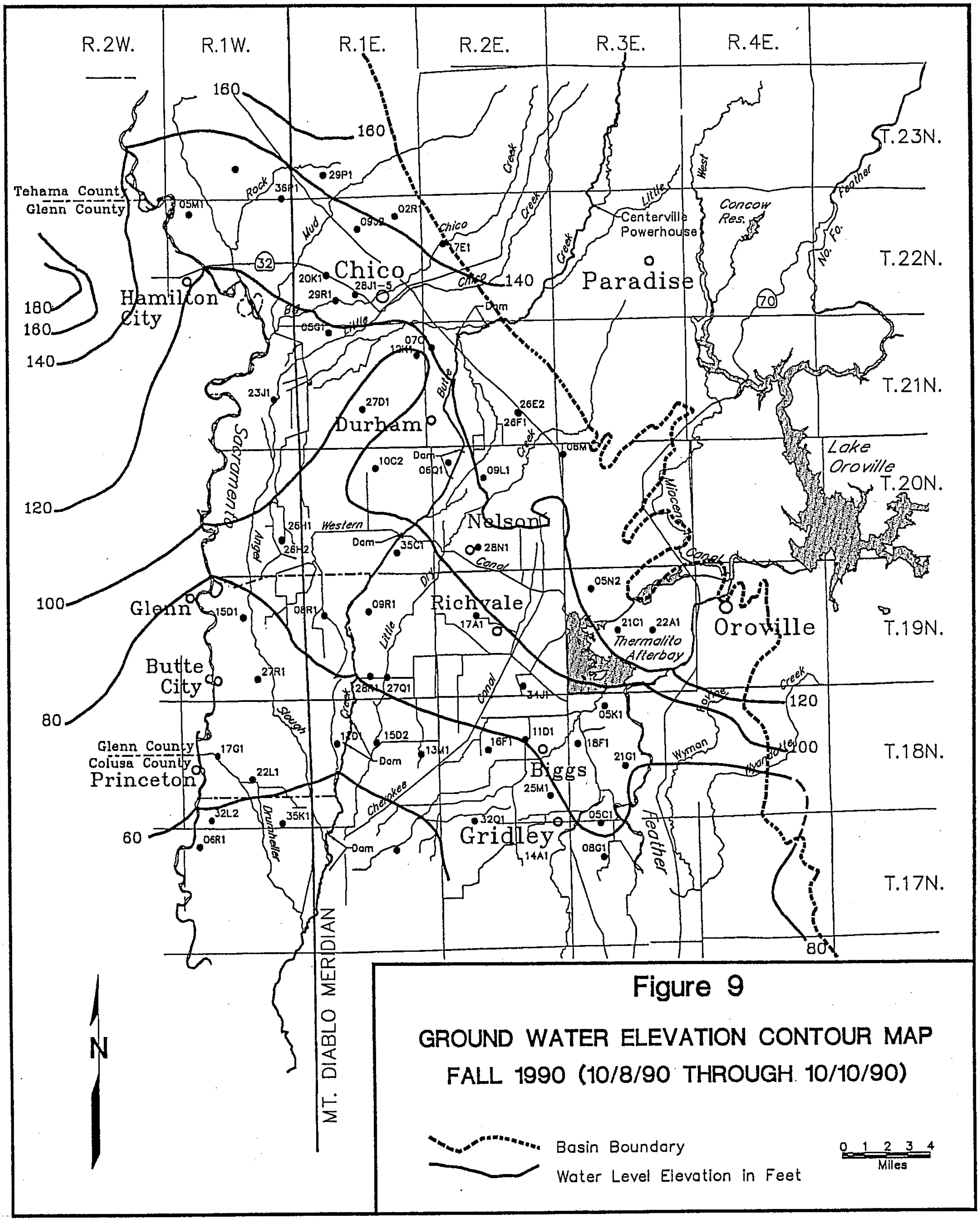


Figure 9

GROUND WATER ELEVATION CONTOUR MAP
FALL 1990 (10/8/90 THROUGH 10/10/90)

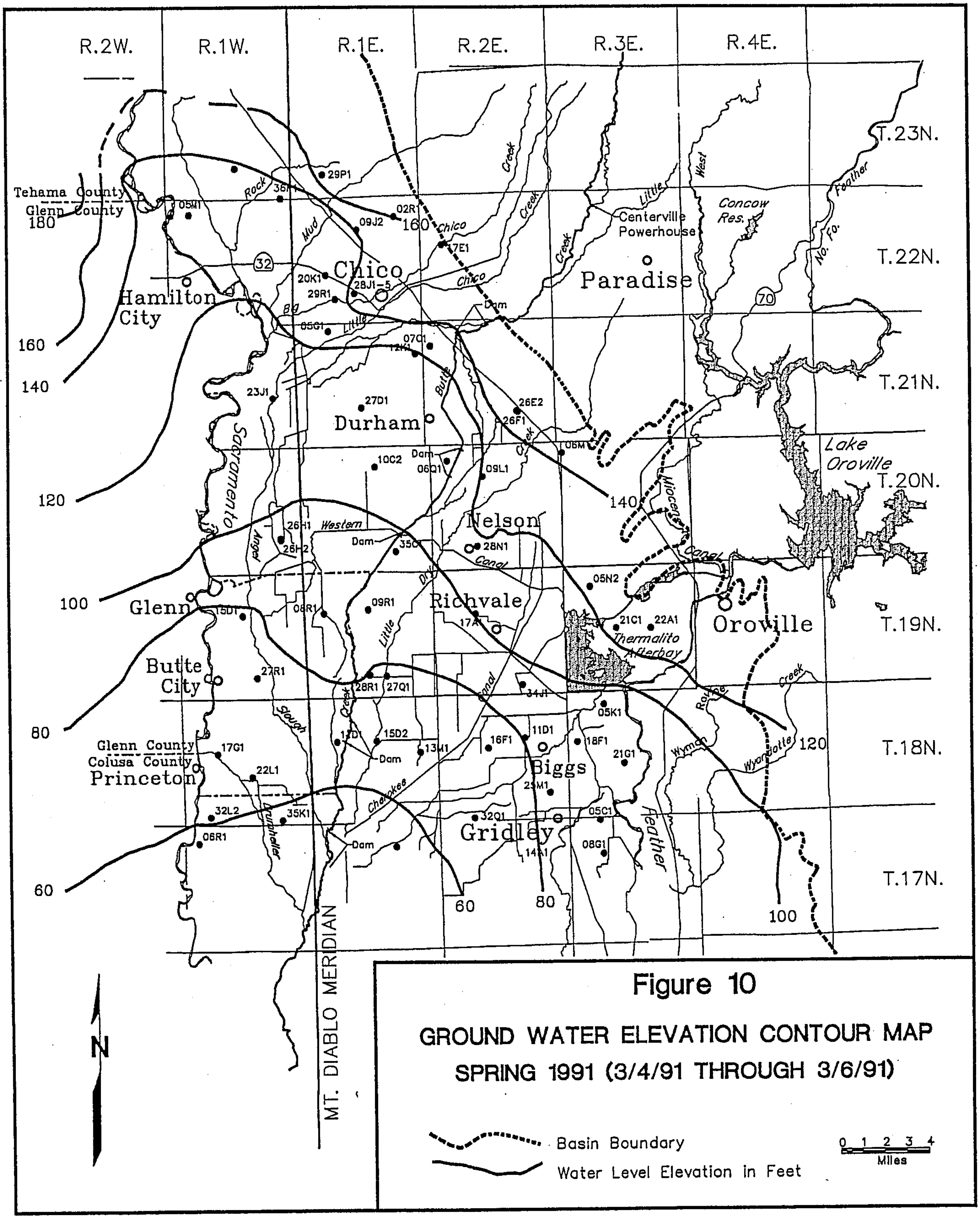


Figure 10

GROUND WATER ELEVATION CONTOUR MAP SPRING 1991 (3/4/91 THROUGH 3/6/91)

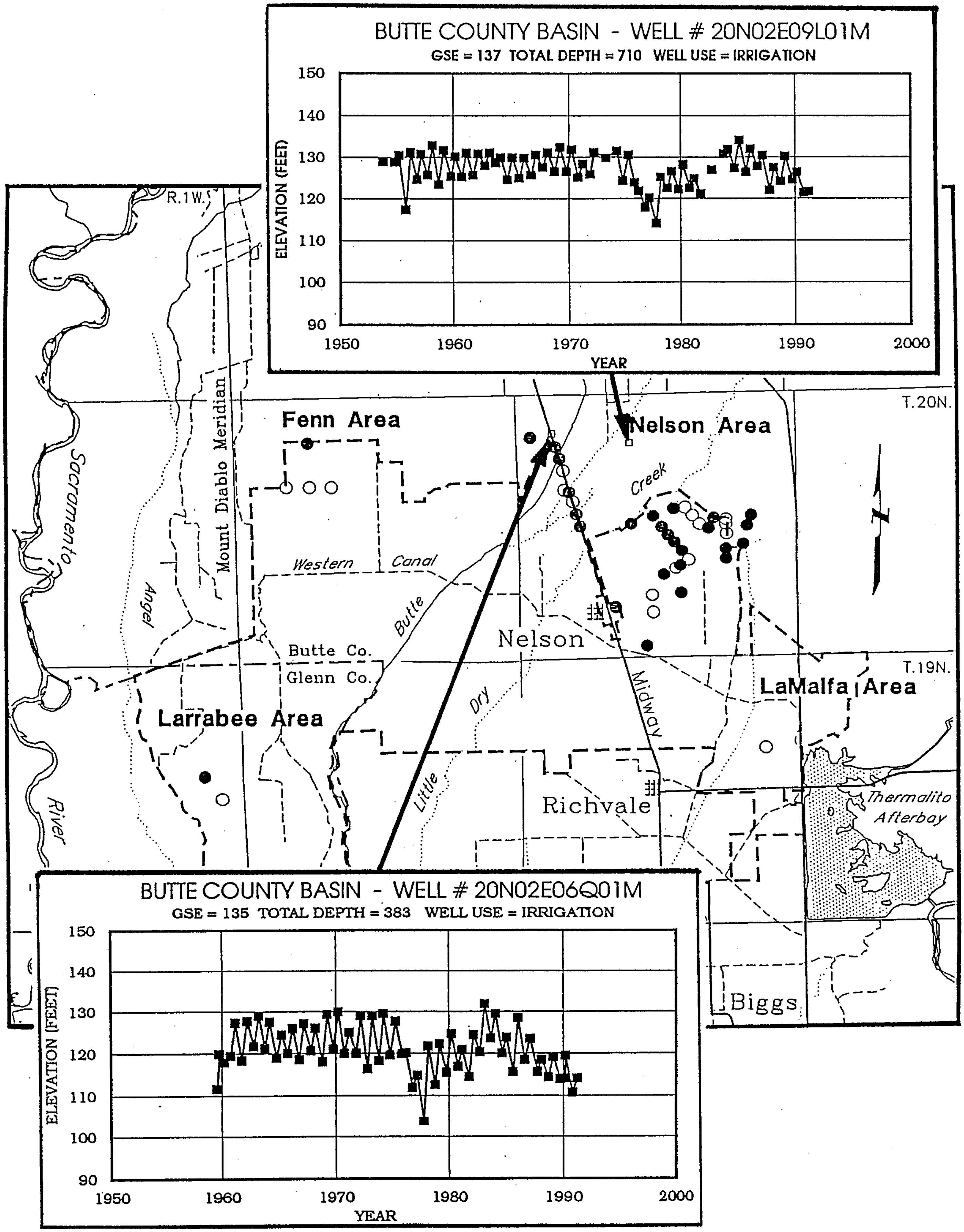


Figure 11 Long Term Records of Ground Water Levels in the Western Canal Area

and high precipitation. There is no evidence of long-term change in ground water levels at either of these wells.

Ground water levels were monitored in 45 wells during the test program. Ground water level change data from static (before the test program) to the maximum drawdown (before the pumping wells were turned off) and water level recovery data are shown in Table 2 and Figure 12. During the test program a few of the observation wells were pumped by landowners. Drawdown depressions of over 60 feet were concentrated in and around the wells near the Nelson area. The shape of the contours illustrate how "well interference" of multiple pumping wells affect ground water levels. Drawdowns of greater than 20 feet were limited to within the immediate vicinity of the pumping wells.

A ground water level change map from static to one day recovery after pumps were shut off is shown in Figure 13. Here, one of the observation wells (20N/02E-15L1) was still pumping. The drawdown contour of 20 feet retracted to less than 0.3 miles of the nearest pumping well. Basically, this map represents the change in storage from ground water pumping. The larger drawdowns are a function of well inefficiency, well interference, and the drawdown needed to get the ground water to flow into the well. Well inefficiency is affected by well construction. It is <u>not</u> related to <u>pump</u> inefficiency. Well inefficiency is the ratio of drawdown outside the casing as oppose to drawdown inside the casing. Inefficient wells have high turbuent flow losses. These losses are a function of filter material next to the well screen, well screen length, well screen condition, and pumping rate. Table 2 shows that all pumping wells, on the average, recovered 81 percent from the maximum drawdown within one day after pumping stopped.

Figure 14 shows water level changes for four pumping wells and one observation well (06P3) during the test and recovery period. Figure 15 shows the water level records of continuous water level recorders installed in two observation wells. Appendix C presents hydrographs for each well in the test program observation grid. Observation well 20N/02E-06P03 (Figure 14) is considered to be outside the influence of any pumping wells. All hydrographs of well levels show that most of the drawdown and recovery occur within the first few hours when pumping began and ended. The continuous records show fluctuations in ground water levels during the pumping period. These level changes are a result of nearby wells being turned off and then on again. The slight rise in water level in 27K1 in late December was caused by well 22P1 being shut down for repairs. Twenty-four hours after pumping ceased, the gradual recovery occurred until pumping was resumed in early April 1991. The March rains accelerated the recovery of ground water levels significantly in some of the wells.

Three shallow domestic wells (20N/02E-23D1, 20N/02E-27D1 and 20N/02E-28N1) in the Nelson Area were monitored to evaluate impacts of pumping from the deeper zone. Figure 16 illustrates

TABLE 2
WESTERN CANAL GROUND WATER TEST PROGRAM
SUMMARY FOR THE MAXIMUM DRAWDOWN AND 1 DAY RECOVERY OF PUMPING WELLS

WELL #	Pumping Started Date	Pumping Started Time	Pumping Ended Date	Pumping Ended Time	Pumping (days)	RPWS Static (feet)	Maximum Drawdown RPWS 1/2/91 (feet)	Maximum Drawdown Draw-down (feet)	One Day Recovery RPWS 1/3/91 (feet)	One Day Recovery 1 Day Recovery (feet)	One Day Recovery % from Max. Drawdown
NELSON AREA ***********											
Gorrill Sub-Area											
20N02E07R01M	11 1 90		1 2 91	13:00	62.0	11.7	59.7	48.0	18.4	41.3	86%
20N02E17D02M	11 5 90	10:30	1 2 91	12:35	58.1	11.9	55.6	43.7	19.5	36.1	83%
20N02E17E01M	11 5 90	10:30	1 2 91		57.6	10.8	48.6	37.8	19.5	29.1	77%
Mcknight Sub-Area											
20N02E14P01M	10 29 90	10:23	1 2 91	09:40	65.0	27.6	52.7	25.1	---	---	---
20N02E14P02M	10 29 90	11:15	1 2 91	09:40	64.9	30.1	76.9	46.8	42.1	34.8	74%
20N02E15K01M	10 29 90	13:05	1 2 91	12:00	65.0	21.2	---	---	41.7	---	---
20N02E15R01M	10 29 90	13:05	1 2 91	11:10	64.9	16.9	86.6	69.7	30.2	56.4	81%
20N02E15R02M	10 29 90	13:05	1 2 91	11:40	64.9	22.7	87.1	64.4	39.7	47.4	74%
20N02E23C01M	10 29 90	11:06	1 2 91	09:15	64.9	26.6	72.4	45.8	40.7	31.7	69%
Wehah-Lundberg Sub-Area											
20N02E22K03M	11 9 90	10:00	1 2 91	10:55	54.0	16.3	63.4	47.1	29.3	34.1	72%
20N02E22P01M	10 31 90	11:15	12 18 90	?	47.5	13.9	61.3	47.4	22.4	38.9	82%
20N02E28J01M	10 31 90	09:40	1 2 91	09:14	63.0	9.8	68.6	58.8	21.3	47.3	80%
20N02E28R01M	10 30 90	10:25	1 2 91	09:22	64.0	9.6	68.6	59.0	19.6	49.0	83%
FENN AREA *************											
20N01E08N01M	11 14 90	10:00	1 2 91	14:50	49.2	15.4	43.6	28.2	18.9	24.7	88%
20N01E17A01M	11 14 90	10:00	1 2 91	15:03	49.2	13.7	53.3	39.6	18.5	34.8	88%
20N01E17B01M	11 14 90	14:04	1 2 91	15:00	49.0	13.4	54.7	41.3	17.1	37.6	91%
LAMALFA AREA **********											
19N02E13D01M	11 30 90	11:30	12 1 90	?		6.2	---	---	---	---	---
LARRABEE AREA *********											
19N01W13Q01M	11 2 90	11:00	1 2 91	14:16	61.1	6.1	30.6	24.5	8.0	22.6	92%

1 Day Recovery Average % from Maximum Drawdown: 81%

NOTE: RPWS is the reference point to water surface (or depth to measuring point).
Static levels were measured just before pumping started.
Maximum drawdown levels were measured on 1/2/91 just before the pumps were turned off.
Drawdown = RPWS change between 1/2/91 and static.
1 Day Recovery = RPWS change between 1/2/91 and 1/3/91.
% Recovery from drawdown = 1 Day Recovery / Maximum Drawdown X 100 %.

06/12/91

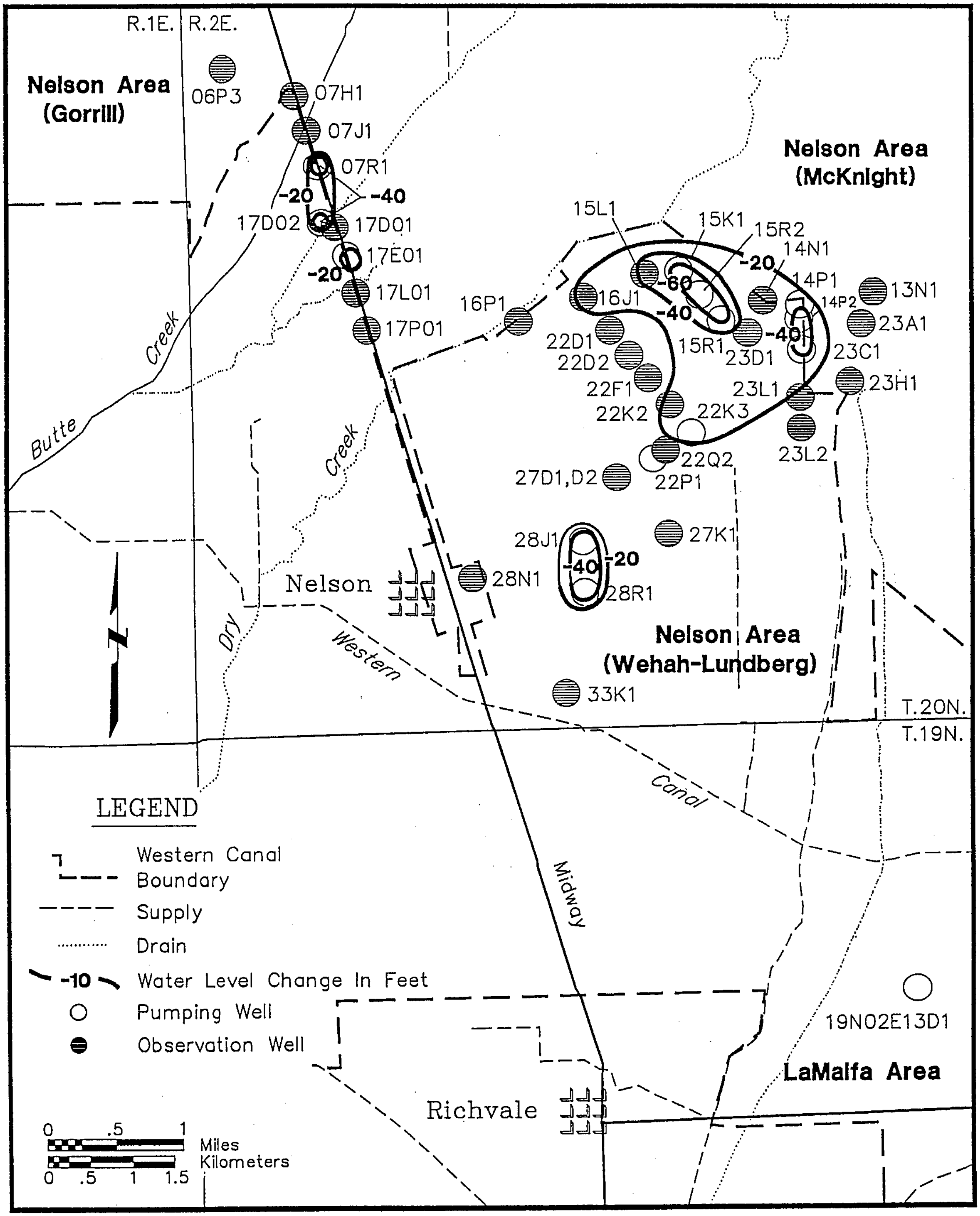


Figure 12. Western Canal–Nelson Area Ground Water Level Changes: Static to Maximum Drawdown 10/29/90 vs. 01/02/91.

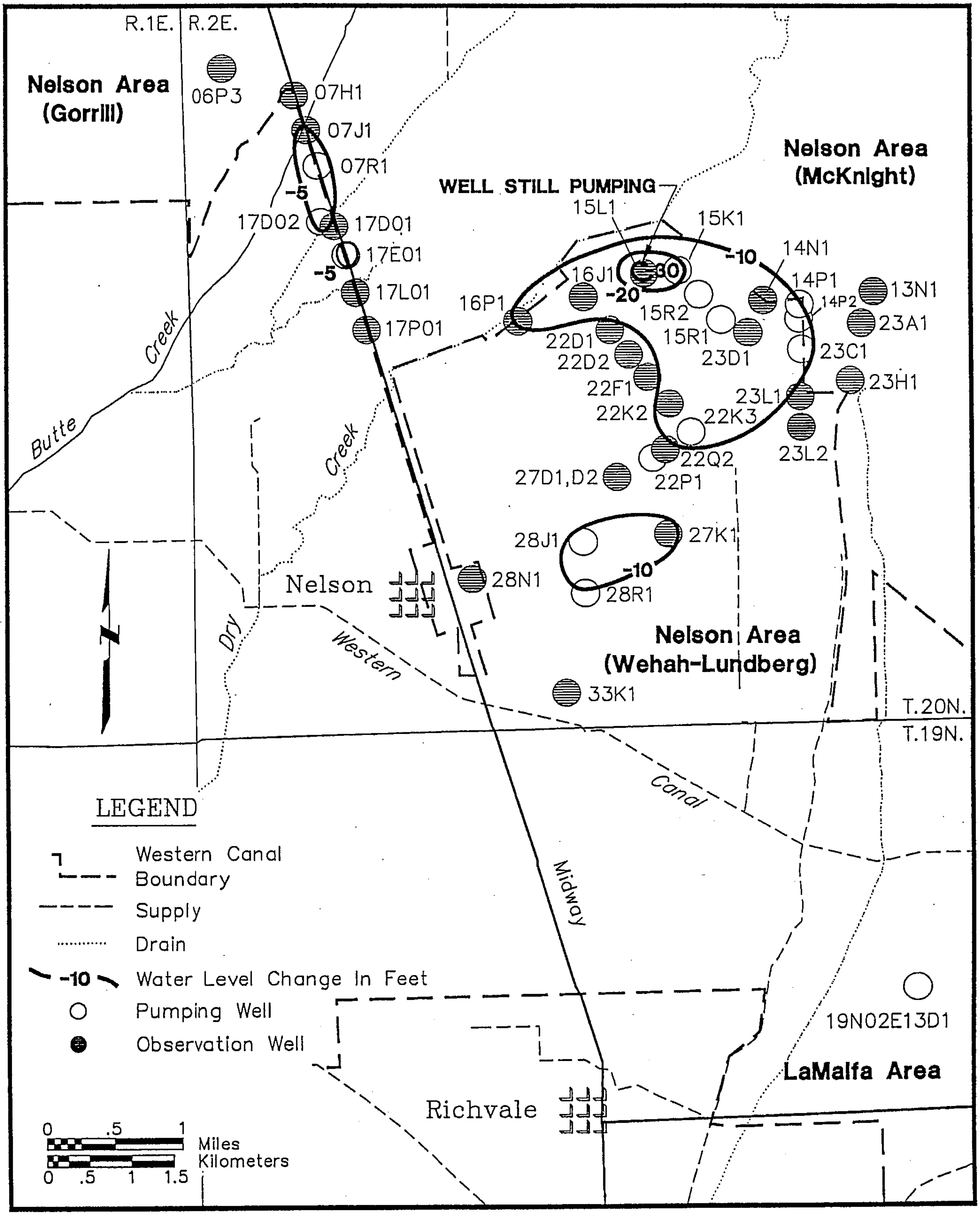


Figure 13. Western Canal–Nelson Area Ground Water Level Changes: Static to 24–Hour Recovery 10/29/90 vs. 01/03/91.

Figure 14

WESTERN CANAL GROUND WATER TEST PROGRAM
HYDROGRAPHS OF SELECTED DEEP WELLS

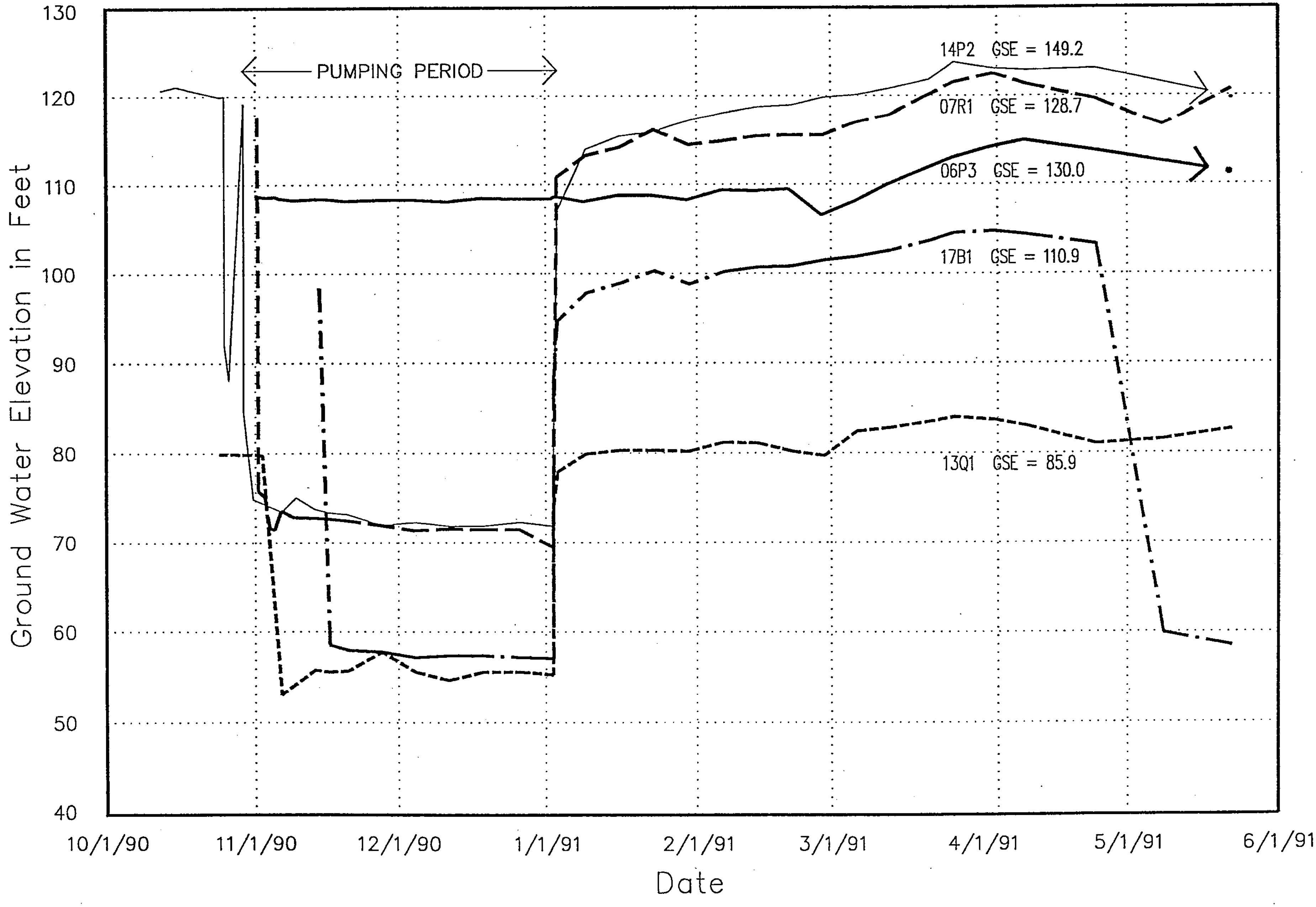
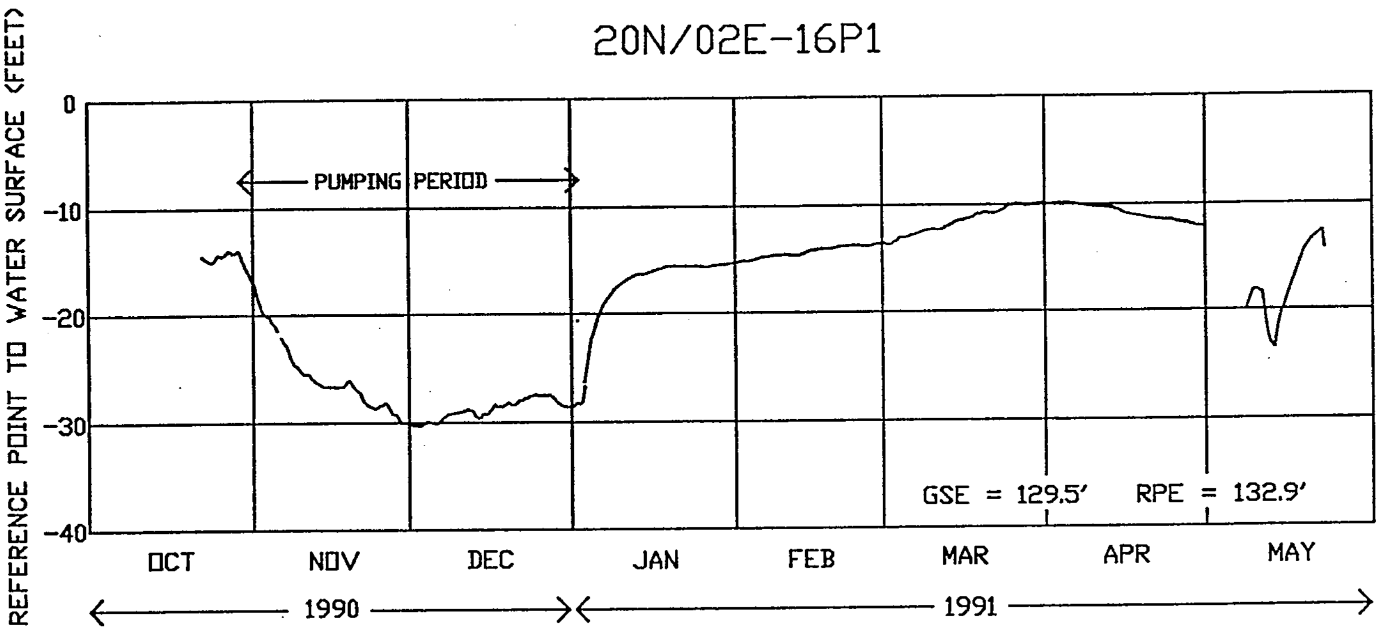


FIGURE 15

WESTERN CANAL TEST PROGRAM
WATER LEVELS FROM CONTINUOUS RECORDER RECORDS

20N/02E-16P1



20N/02E-27K1

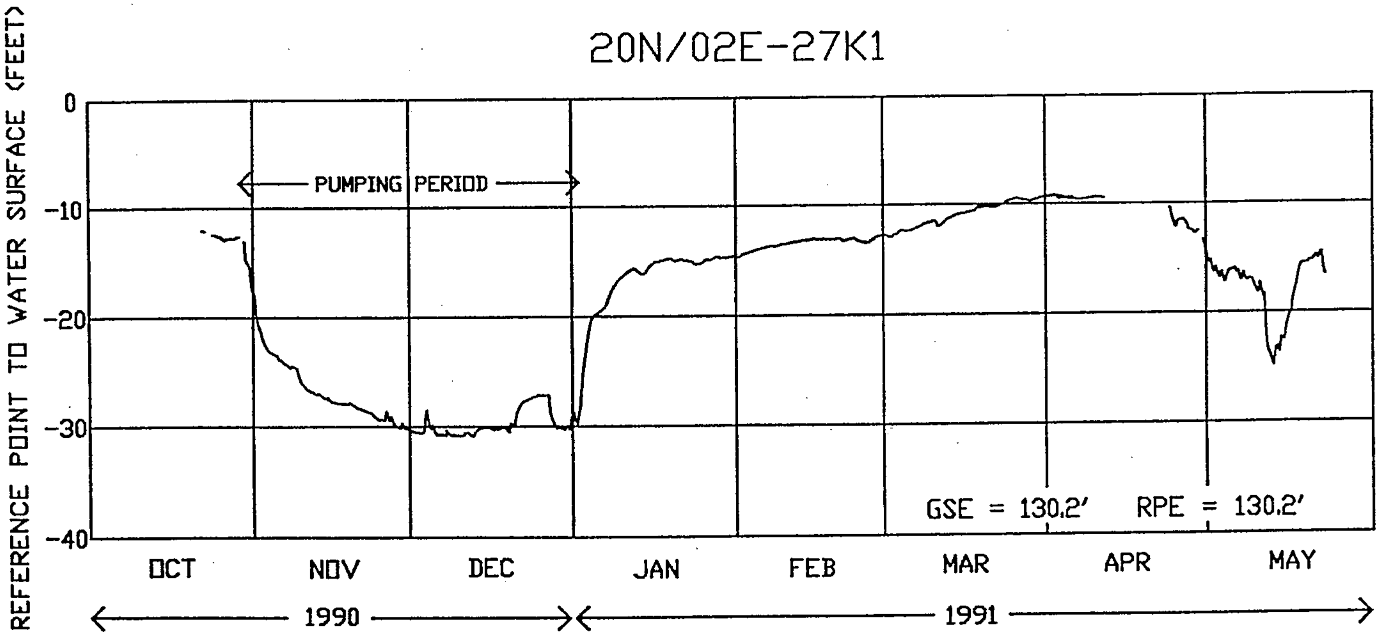
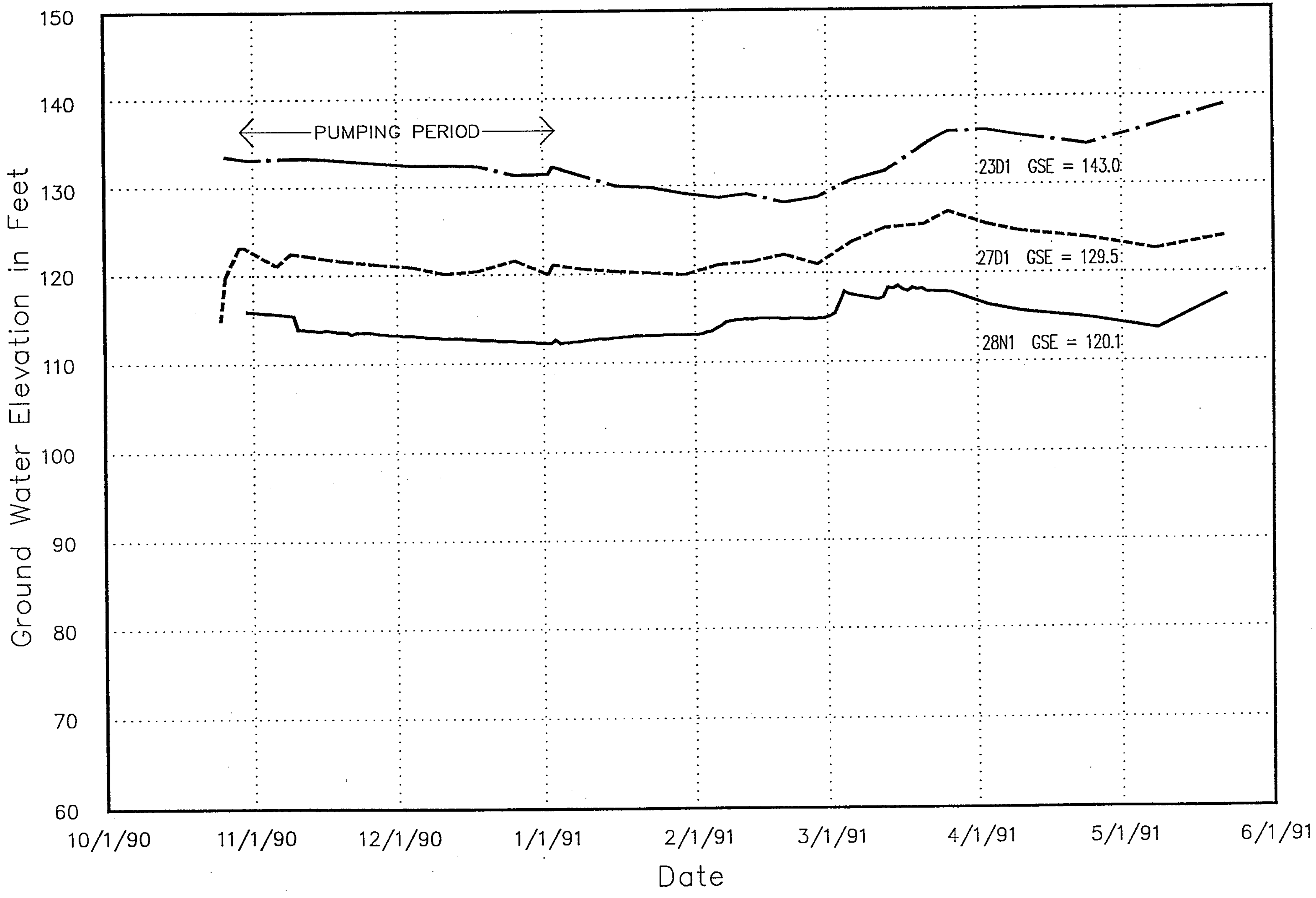


Figure 16

WESTERN CANAL GROUND WATER TEST PROGRAM
HYDROGRAPHS OF SELECTED SHALLOW WELLS



these domestic wells to be minimally impacted by the activities of the pumping wells. This suggests that the shallow zone and the deeper zone are separate and distinct ground water zones.

Channel Losses

Delivery losses through local canals appeared to be higher then expected. A single meter recorded a total flow of 2,180 acre-feet for the six McKnight wells at a channel located approximately 14,000 feet downstream. A meter installed at one of the McKnight's well (20N/02E-14P2) recorded a total flow of 545 acre-feet for the test period. All six wells were between 50 to 60 horsepower, and they were running about the same amount of time. The average maximum depth to ground water for the six wells was 75.1 feet. The maximum depth of the metered well was 76.9 feet. One can conclude that all six wells were pumping close to the same rate. The total flow at the downstream meter should be six times the single meter flow (3270 acre-feet). This suggests that a third of the water was lost through the channel or diverted between the two meters over the test period of 65 days.

Aquifer Tests

Constant discharge rate aquifer tests were performed on three wells. They are 20N/02E-14P2 (McKnight), 20N/02E-28R1 (Wehah-Lundberg), and 20N/02E-07R1 (Gorrill). The tests were performed to determine how much each pumping well would influence neighboring wells and to establish the transmissivity and storage coefficients of the aquifer they represent. Data were collected from the pumping wells and neighboring monitoring wells. The aquifer parameters were based on several formulas for both confined and leaky aquifer systems. All formulas for analyzing the pump test data assume the following conditions:[2]

- The aquifer is porous and flow through it is laminar obeying Darcy's law.
- The aquifer is homogenous, isotropic, with no restricting boundaries and its thickness is uniform throughout the area influenced by the pump test.
- Change of water level reflects the change in aquifer storage.

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2 Rosco Moss Company, 1990, Handbook of Ground Water Hydrology, "A Wiley-Interscience Publication", John Wiley & Sons.

- The pumping well fully penetrates the entire aquifer thickness and water flows horizontally to the well.

- The discharge rate of the pumping well is constant throughout the test.

- The observation wells represent the same aquifer conditions as the pumping well.

- Fluctuation in the water level by interference from nearby wells, tides, or means other than the pumping well is negligible.

In the real world, most pump test conditions do not adhere to all of the above assumptions. The lithologic composition of the aquifers in the study area is highly variable and wells often draw water from both the semi-confined and unconfined zones. In spite of non-ideal conditions, the formulas still provide approximate transmissivity and storage coefficient values for the aquifer system (Table 3). The U.S. Geological survey has used transmissivity values for the Tuscan Formation in this area from 30,000 gpd/ft (RASA model)[3] to 200,000 gpd/ft (Trescott Model)[4]. Table 3 establishes a reasonable range for parameters that are normally subject to wide variations. Exact answers are difficult to obtain, but the values are within the expected limits and establishes a reasonable basis for further analysis.

The drawdowns of the pumping and observation wells are illustrated on Figures 17 (McKnight), 18 (Wehah-Lundberg), and 19 (Gorrill).

McKnight 24-Hour Constant Discharge Aquifer Test

The six observation wells were between 589 feet to 3136 feet from the pumping well. They took between 3 to 200 minutes to respond to the effect of the pumping well.

The analysis of the test suggests that the well draws from a semi-confined or "leaky" aquifer system where the aquifer is recharged vertically from either a lower or, more likely, intermediate or upper aquifer zone. The analysis of the data produced the following parameters for the McKnight Ranch area: The transmissivity is between 158,000 to 182,000 gpd/ft, and the

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3 Willilamson, Alex K., 1989, Ground-water Flow in the Central Valley, California, Regional Aquifer-System Analysis, U.S. Geological Survey Professional Paper; 1401-D.

4 ____1978, Evaluation of Ground Water Resources: Sacramento Valley, California Department of Water Resources Bulletin 118-6.

Table 3

WESTERN CANAL TEST PROGRAM
AQUIFER TEST SUMMARY

MCKNIGHT RANCH

14P2 PUMPING WELL

Method	Transmissivity (FT²/MIN)	Transmissivity (GPD/FT)	Storage Coefficient	Remarks
DISTANCE-DRAWDOWN	13.27	143000		AVERAGE
CONFINED - THEIS	* 14.74	159000		
CONFINED - COOPER-JACOB	14.74	159000		
LEAKY - HANTUSH-JACOB	10.02	108000		r/B=.00306
LEAKY - HANTUSH, MODIFIED	9.98	107000		B=.001809

14P1 DIST=589'

Method	Transmissivity (FT²/MIN)	Transmissivity (GPD/FT)	Storage Coefficient	Remarks
DISTANCE-DRAWDOWN	12.62	136000	6.000E-03	
CONFINED - THEIS	16.97	183000	1.560E-03	
CONFINED - COOPER-JACOB	16.97	183000	1.512E-03	(POOR FIT)
LEAKY - HANTUSH-JACOB	* 16.93	182000	1.547E-03	r/B=.1136
LEAKY - HANTUSH, MODIFIED	17.19	185000	1.368E-03	B=.015

23C1 DIST=1261'

Method	Transmissivity (FT²/MIN)	Transmissivity (GPD/FT)	Storage Coefficient	Remarks
DISTANCE-DRAWDOWN	13.83	149000	9.000E-04	
CONFINED - THEIS	16.03	173000	2.737E-04	
CONFINED - COOPER-JACOB	16.50	178000	2.504E-04	
LEAKY - HANTUSH-JACOB	* 14.70	158000	2.924E-04	r/B=.1166
LEAKY - HANTUSH, MODIFIED	15.19	164000	2.768E-04	B=.01

WEHAH-LUNDBERG RANCH

28R1 PUMPING WELL

Method	Transmissivity (FT²/MIN)	Transmissivity (GPD/FT)	Storage Coefficient	Remarks
DISTANCE-DRAWDOWN	6.68	72000		AVERAGE
CONFINED - THEIS	* 11.99	129000		
CONFINED - COOPER-JACOB	11.98	129000		
LEAKY - HANTUSH-JACOB	10.47	113000		r/B=1.0E-05
LEAKY - HANTUSH, MODIFIED	8.82	95000		B=2.943E-05

28J1 DIST=2066'

Method	Transmissivity (FT²/MIN)	Transmissivity (GPD/FT)	Storage Coefficient	Remarks
DISTANCE-DRAWDOWN	6.50	70000	1.840E-03	
CONFINED - THEIS	12.65	136000	1.122E-03	
CONFINED - COOPER-JACOB	15.88	171000	8.539E-04	(POOR FIT)
LEAKY - HANTUSH-JACOB	* 12.65	136000	1.122E-03	r/B=0.2967
LEAKY - HANTUSH, MODIFIED	10.32	111000	8.761E-04	B=0.1219

27K1 DIST=4007'

Method	Transmissivity (FT²/MIN)	Transmissivity (GPD/FT)	Storage Coefficient	Remarks
DISTANCE-DRAWDOWN	6.78	73000	9.500E-04	
CONFINED - THEIS	9.00	97000	3.195E-04	
CONFINED - COOPER-JACOB	24.45	263000	2.466E-04	(POOR FIT)
LEAKY - HANTUSH-JACOB	* 8.99	97000	3.257E-04	r/B=1.22E-05
LEAKY - HANTUSH, MODIFIED	8.25	89000	3.118E-04	B=9.967E-06

Comments (Wehah-Lundberg Ranch): Last data point plots poorly. Distance-drawdown is based on last data point. Second to the last data point is at four hours which is not enough for the monitoring wells to respond to pumping at 28R1.

GORRILL RANCH

07R1 PUMPING WELL

Method	Transmissivity (FT²/MIN)	Transmissivity (GPD/FT)	Storage Coefficient	Remarks
DISTANCE-DRAWDOWN	7.70	83000		
CONFINED - THEIS	* 12.74	137000		
CONFINED - COOPER-JACOB	12.51	135000		(POOR FIT)
LEAKY - HANTUSH-JACOB	6.50	70000		r/B=.00106
LEAKY - HANTUSH, MODIFIED	9.86	106000		B=1.0E-05

Monitoring wells for 07R1 were too far from the pumping well to provide usable data.

Comments (Gorrill Ranch): Pumping well plots poorly for first 10 minutes and has an inflection point at 120 minutes. This may be due to surface water recharging the aquifer system. Pumping activity nearby may have also influenced the pump test.

* Best Transmissivity and Storage Coefficient values.
(The Theis method is the best solution for pumping wells and the Hantuse-Jacob method is the best solution for monitoring wells.)

Figure 17
McKNIGHT AQUIFER TEST
TIME VS DRAWDOWN CURVES

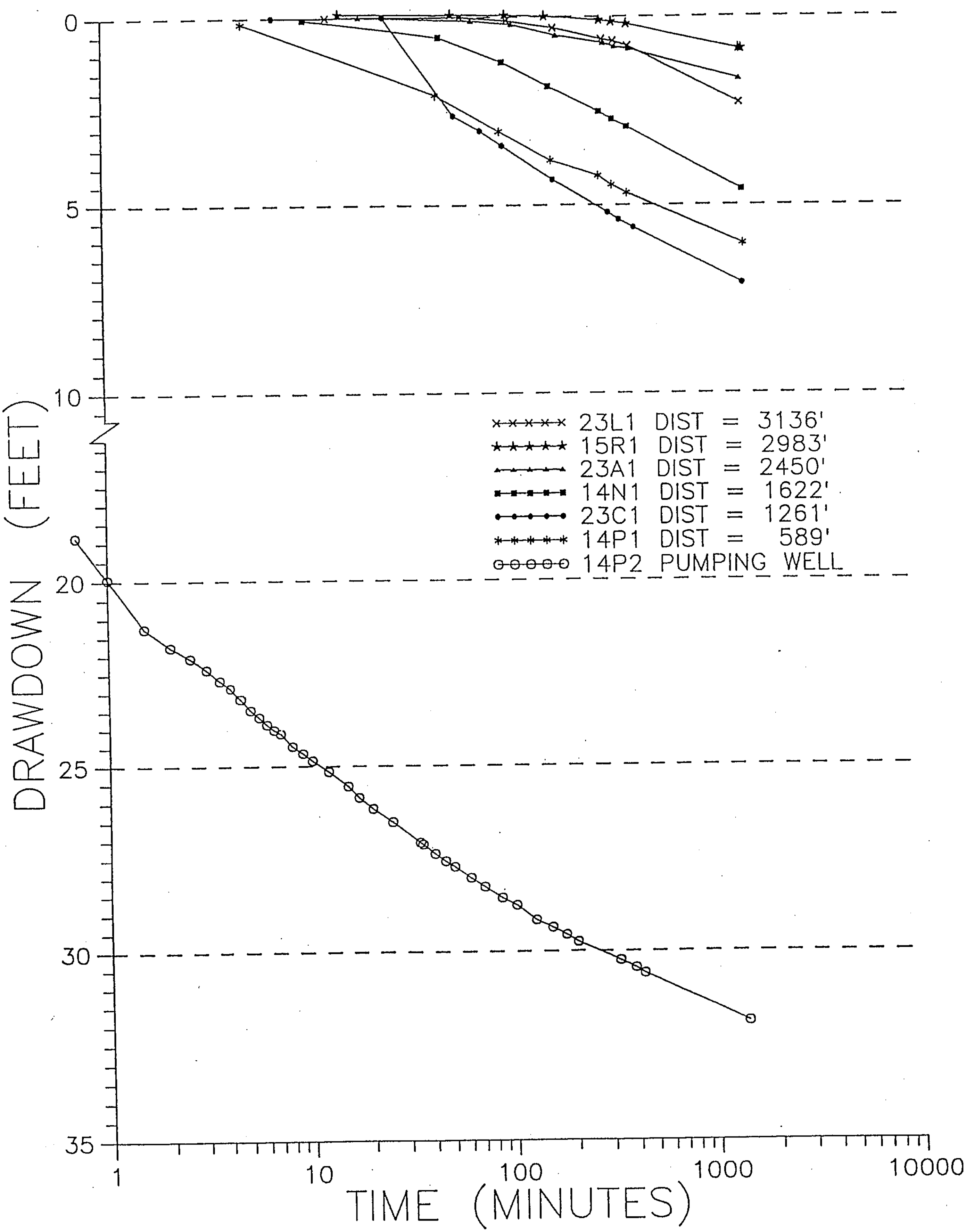


Figure 18
WEHAH-LUNDBERG AQUIFER TEST
TIME VS DRAWDOWN CURVES

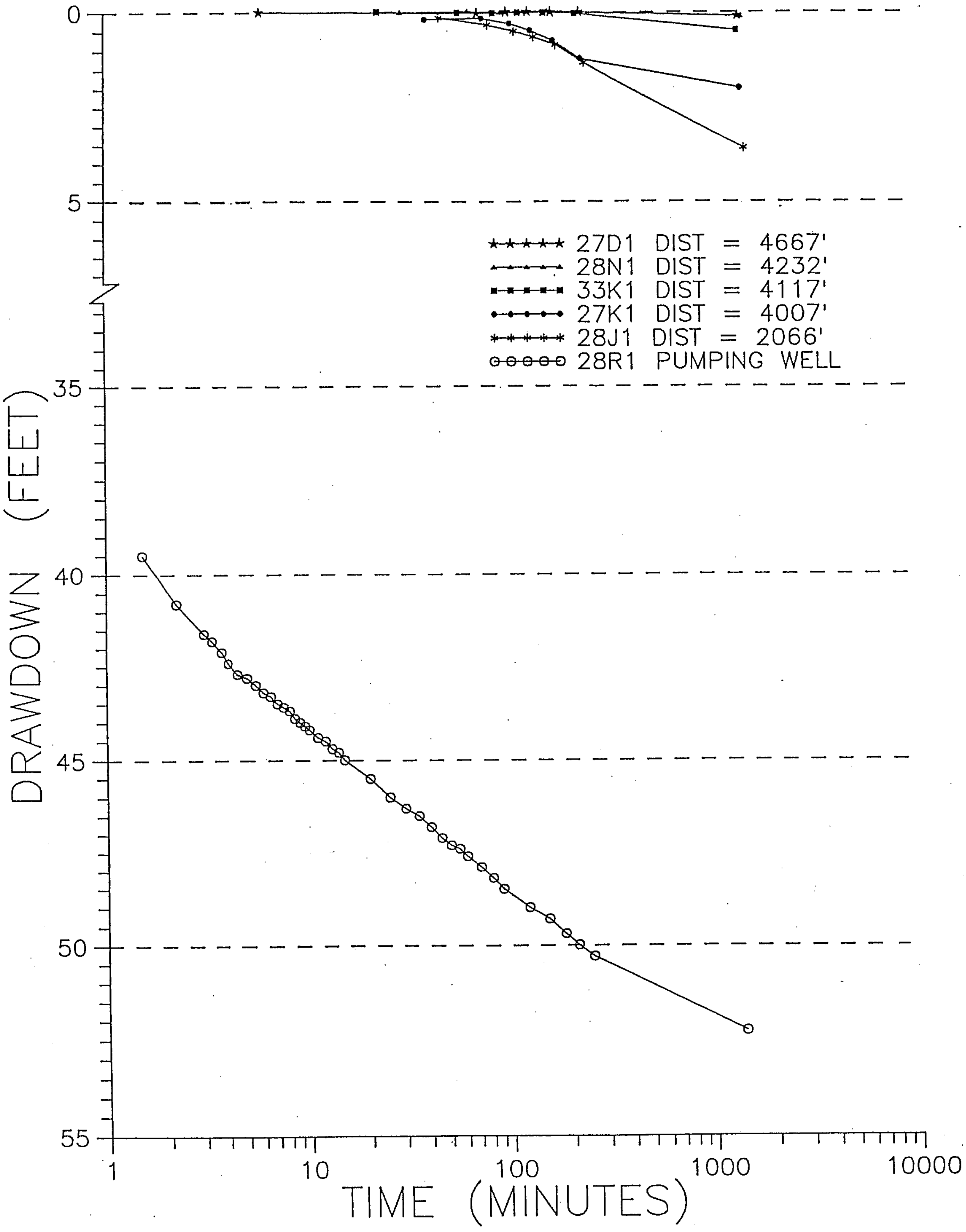
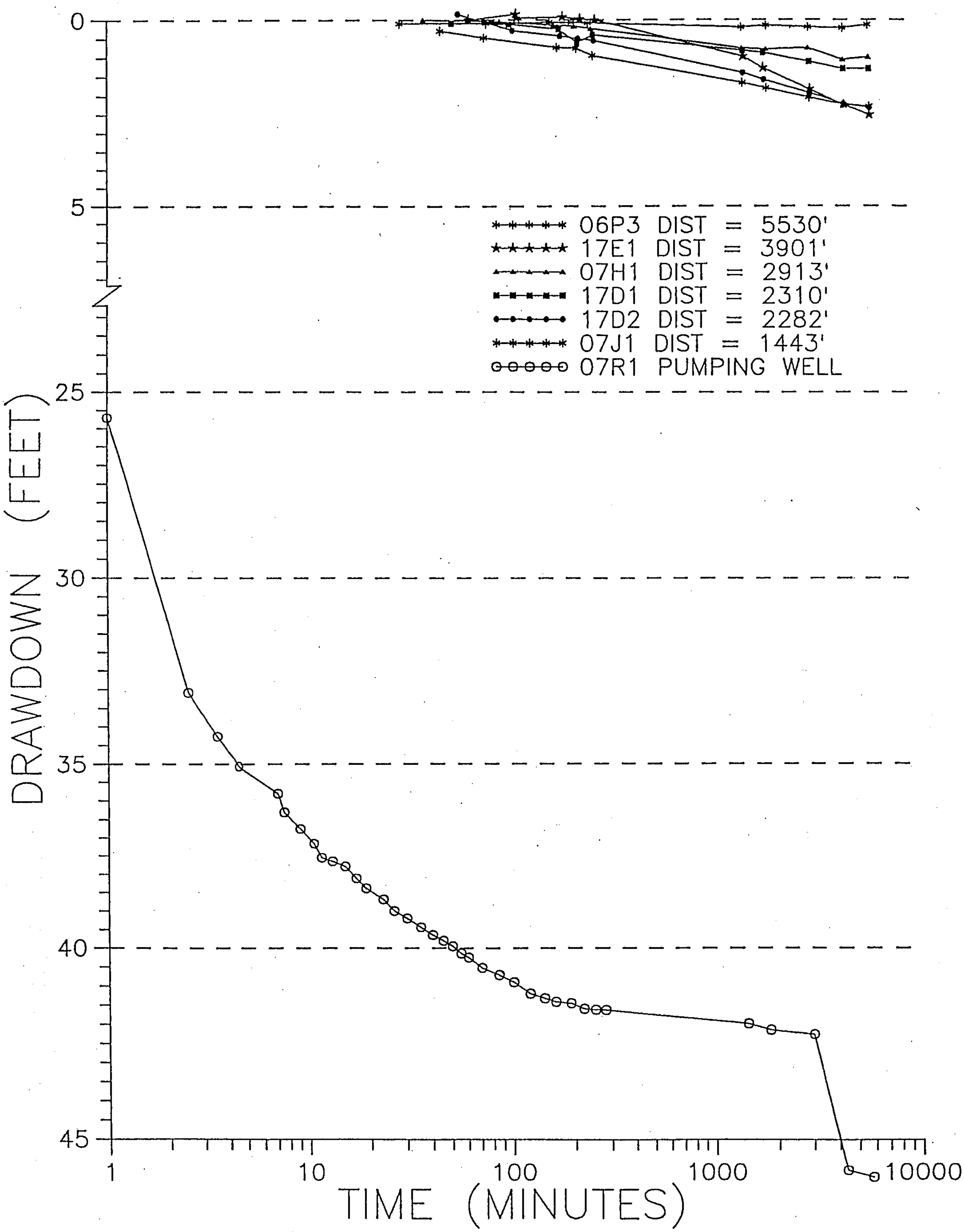


Figure 19
GORRILL AQUIFER TEST
TIME VS DRAWDOWN CURVES



storage coefficient is between 0.0003 to 0.0015. The area of influence of the pumping well after 24 hours extend 2700 feet to the north, 7200 feet to the south and 3800 feet to the east and west (Figure 20).

The drawdown of the pumping and observation wells is illustrated in the semi-log curves in Figure 17. After the first minute, the discharge rate of the pumping well decreased 13 percent from 2,700 to 2,350 gpm as the water level dropped. As discussed earlier, the discharge rate should be uniform through out the test. The time-drawdown curve of the recovery period mirrored that of the pumping period. Since the recovery is independent of the pumping rate, the variation in pumping rate proved to be insignificant.

Wehah-Lundberg 24-Hour Constant Discharge Aquifer Test

The observation wells were located between 2,066 to 4,667 feet from the pumping well. The drawdown for all the observation wells remained within four feet from the static level during the pumping period (Figure 18). The wells 28N1 and 27D1 located 4,232 and 4,667 feet away had negligible impact from the pumping well. These wells are reported to be relatively shallow wells. Therefore, their water level declines might be related more to leakage to the deeper zones than from drawdown in the producing zone.

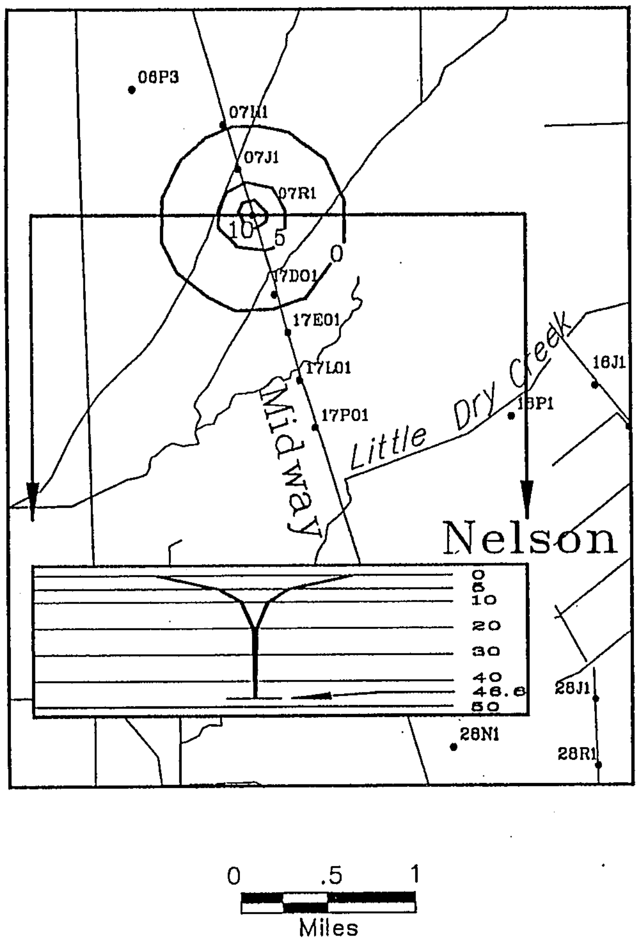
Analysis revealed that the well draws from a semi-confined aquifer. The transmissivity ranged between 97,000 to 136,000 gpd/ft, and the storage coefficient ranged between 0.0003 to 0.0011. The area of influence of the pumping well after 24 hours extend 3,300 feet to the north, 8400 feet to the south and 4,700 feet to the east and west (Figure 20).

The discharge rate of the pumping well decreased 11 percent from 2,300 to 2,050 gpm with the 24 hour period. Again, this variation can be ignored in the pump test analysis.

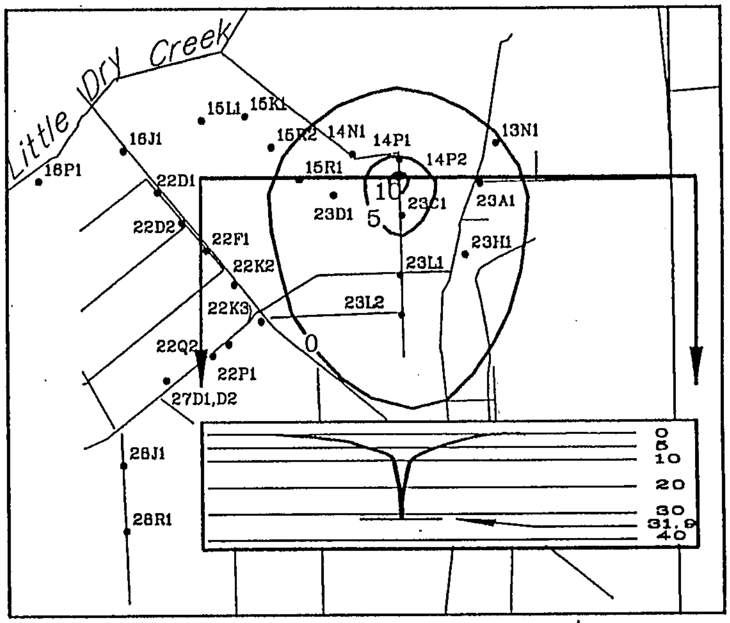
Gorrill 96-Hour Constant Discharge Aquifer Test

The discharge rate of the pumping well is estimated to be 1,850 gpm. A flow meter was not available during the test but was installed later during the test program. The observation wells were between 1,443 to 5,530 feet from the pumping well. For this well, all the observation wells appeared to be too far for any meaningful analysis. The drawdown for all observation wells remained within 2.3 feet from the static level during the pumping period (Figure 19). The drawdown curve sharply tapers off after 100 minutes of pumping, suggesting that the well may have reached a recharge boundary from Butte Creek. Since there were small changes with the levels in the monitoring wells, the aquifer test was extended to 96 hours (5,760 minutes). The curve took a sharp drop after 50 hours (3,000 minutes) suggesting that some other

Gorrill Pump Test (07R1)



McKnight Pump Test (14P2)



Wehah Pump Test (28R1)

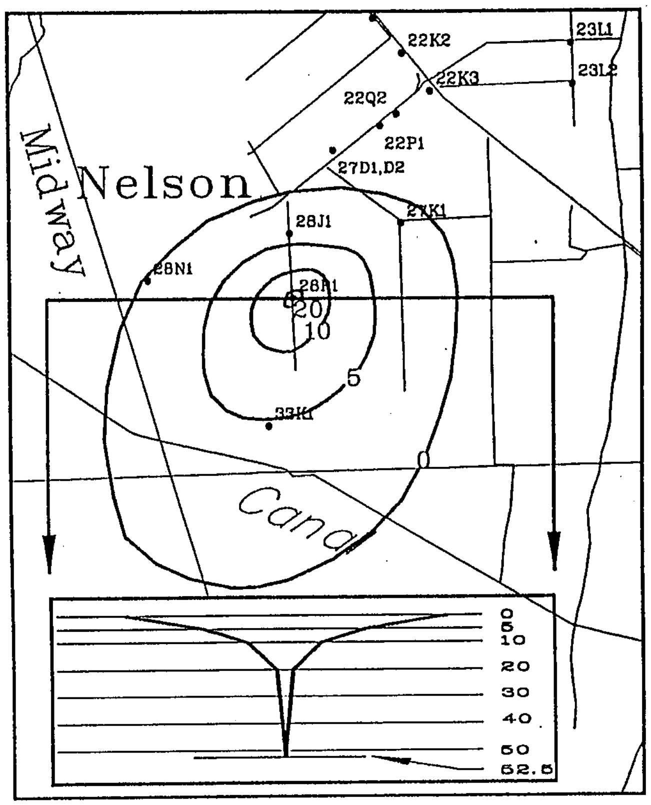


Figure 20

Contours with Cross-sections for Drawdown (in feet) from 24 hours of Pumping

pumping activity may have occurred in the area. Based on the pumping well, the transmissivity is calculated at 137,000 gpd/ft. The storage coefficient cannot be determined from the pumping well data. The area of influence of the pumping well after 24 hours extended approximately 2850 feet radially (Figure 20).

Specific Capacity Analysis

The specific capacity gives an idea of how much water could be produced from the well with an associated drawdown. For an example, well 19N/01W-13Q1 (Larrabee) has a specific capacity of 100 gpm/ft of drawdown. This well is currently yielding 2,000 gpm with 20 feet of drawdown. If the owner needed another 1,000 gpm, he could either drill a new well or just buy a larger pump and set it 10 feet lower than the existing pump. Specific capacity can also be used to estimate Transmissivity which is an important aquifer characteristic.

Ten pumping wells that had flow meters were monitored to determine their specific capacity after 60 minutes of pumping. The specific capacity ranged from 45.7 to 104.7 gallons per minute per foot of drawdown (Table 4). Generally, the transmissivity in gal/day/ft can be approximated by multiplying the specific capacity in terms of gal/min/feet by 2,000[5]. The following compares the range of transmissivity values generated by the specific capacity analysis to those by the aquifer tests:

Transmissivity Ranges (gpd/ft)

Location	24 HR Aquifer Test	Specific Capacity Test
McKnight	108,000 - 182,000	162,000
Wehah-Lundberg	97,000 - 136,000	90,000 - 162,000
Gorrill	137,000	91,000 - 208,000

5 Driscoll, Fletcher G., 1986, Groundwater and Wells, 2nd ed., Johnson Division, St Paul, Minnesota.

Table 4

WESTERN CANAL TEST PROGRAM
SPECIFIC CAPACITY SUMMARY FOR THE TEST WELLS

WELL #	DEPTH (FEET)	PERFORATION TOP	PERFORATION BOTTOM	LOG NUMBER	60 MIN SPECIFIC CAPACITY RATE (GPM)	DRAWDOWN (FEET)	SPECIFIC CAP. (GPM/FT)	ELEC USED (KWH/HR)	DISCHARGE EQUIPMENT
NELSON AREA ***********									
Gorrill Sub-Area									
20N02E07R01M	550	441 e	546 e	GORRILL	1850 e	40.5	45.7	39	50 HP U.S. MOTORS W/ BJ DWT PUMP
20N02E17D02M	551	350 e	549 e		2025	35.8	56.6	42	50 HP G.E. MOTOR W/BERKELEY TURBINE PUMP
20N02E17E01M	612	22 e	611 e		2650 e	25.3	104.7	45	50 HP U.S. MOTORS W/ BJ DWT PUMP
Mcknight Sub-Area								* Rate of delivery for 6 McKnight wells = 5420 gpm	
20N02E14P01M						18.5		37	50 HP U.S. MOTORS W/ BJ DWT PUMP
20N02E14P02M					2450	30.2	81.1	49	50 HP U.S. MOTORS W/ BJ DWT PUMP
20N02E15K01M	762	—	702 e	5204		15.8		44 e	50 HP U.S. MOTORS W/ ? DWT PUMP
20N02E15R01M	500	68 e	425 e	338		57.5		43	50 HP U.S. MOTORS W/ BJ DWT PUMP
20N02E15R02M	616	390	476	5203		54.5 e		51 e	60 HP BBJ ELECT W/ BJ DWT PUMP
20N02E23C01M	615	420	440	42561		21.3		45	50 HP U.S. MOTORS W/ BJ DWT PUMP
Wehah-Lundberg Sub-Area									
20N02E22K03M					1650	29.1	56.7	—	90 HP AMARILLO RT ANGLE DR W/ BJ DWT PUMP
20N02E22P01M	310	—	386 e	USGS	2600	32.1	81.0	—	40 HP US MOTORS ELEC W/ BJ DWT PUMP
20N02E28J01M	615	100	615	DWR		45.2		44	50 HP U.S. MOTORS ELEC W/ BJ DWT PUMP
20N02E28R01M	500	120	500	DWR	2150	47.6	45.2	46	50 HP BJ ELEC /W BJ DWT PUMP
FENN AREA **************									
20N01E08N01M	698	42	696	16102		21.6		62	75 HP NEWMAN ELEC W/ BJ TURBINE PUMP
20N01E17A01M						32.4		46	50 HP U.S. MOTORS ELEC W/ BJ DWT PUMP
20N01E17B01M						39.8 e		55 e	75 HP U.S. MOTORS ELEC W/ BJ TURBINE PUMP
LAMALFA AREA ***********									
19N02E13D01M	119	5	80	10978	1800	33.1	54.4	—	AMARILLO DIESEL W/ BJ DWT PUMP
LARRABEE AREA **********									
19N01W13Q01M	442	152	320	96293	2000	20.0	100.0	20	25 HP U.S. MOTORS ELEC W/ BJ TURBINE PUMP

* RATE OF DELIVERY FOR 6 MCKNIGHT WELLS IS BASED ON TOTAL DISCHARGE OF THE MAIN SPARING METER DIVIDED BY THE PUMPING PERIOD.

e ESTIMATED VALUES.

TRANSMISSIVITY IN TERMS OF (GPD/FT) = SPECIFIC CAPACITY X 2000

P. HUCKABAY 09/23/91

GROUND WATER QUALITY

Water acts as a solvent on minerals and soils as it passes over the earth's surface and underground. The amount and kinds of suspended or dissolved constituents reflect the many elements present in the environment of the hydrological cycle. The addition of these constituents may have a significant effect on the chemical behavior of the water and change its value for beneficial use.

Most of the dissolved mineral constituents in water are in the form of ions. The most common positively charged ions (cations) are calcium, magnesium, sodium, and potassium. The negatively charged ions (anions) include carbonate, bicarbonate, sulphate, chloride, and nitrate.

The mineral character or type of water is based on the predominant cation and anion, as indicated in chemical equivalent per million (epm). The name of the cation is used when its chemical equivalents constitute 50 percent or more of the total cations. Similarly, this applies to the anion group. For example, a magnesium bicarbonate character water is one in which the magnesium cation and bicarbonate anion each constitute half or more of the individual totals of cations and anions. Where no single constituent exceeds 50 percent, hyphenated combinations are used. An example is a magnesium-calcium bicarbonate water.

Mineral, nutrient, and minor element ground water quality in the Western Canal area appears to be excellent for wildlife, domestic, and agricultural uses.

The Water Quality and Biology Section sampled 22 wells in the Western Canal area between October 29 and December 17,1990, for temperature, pH, and electrical conductivity (Figures 21-23). Samples were collected at the start of well pumping and periodically until the well was shut down. Complete mineral, nutrient, and minor element samples were collected for five wells (13Q1, 08N1, 07R1, 14P1, and 28R1) near the beginning of their operation (Figures 22 and 23). Additional mineral samples were analyzed from these five wells near completion of the test program. Another well (15R2), whose discharge was whitish in appearance due to entrained gases, was sampled for minerals at the beginning of its operation.

Ground water temperatures were relatively warm ranging from 62.5 to 70°F (Table 5). Warm temperatures are a common occurrence in ground water originating from the Tuscan Formation along the east side of the northern Sacramento Valley. The pH ranged from near neutral (6.8) to slightly alkaline (7.9). Electrical conductivity ranged from 230 to 675 μmhos/cm, and decreased in most wells between the initial and final samples.

Ground water in the area was magnesium-calcium bicarbonate in nature. Nitrate levels ranged from 0.1 to 6.0 mg/L as NO_3 and

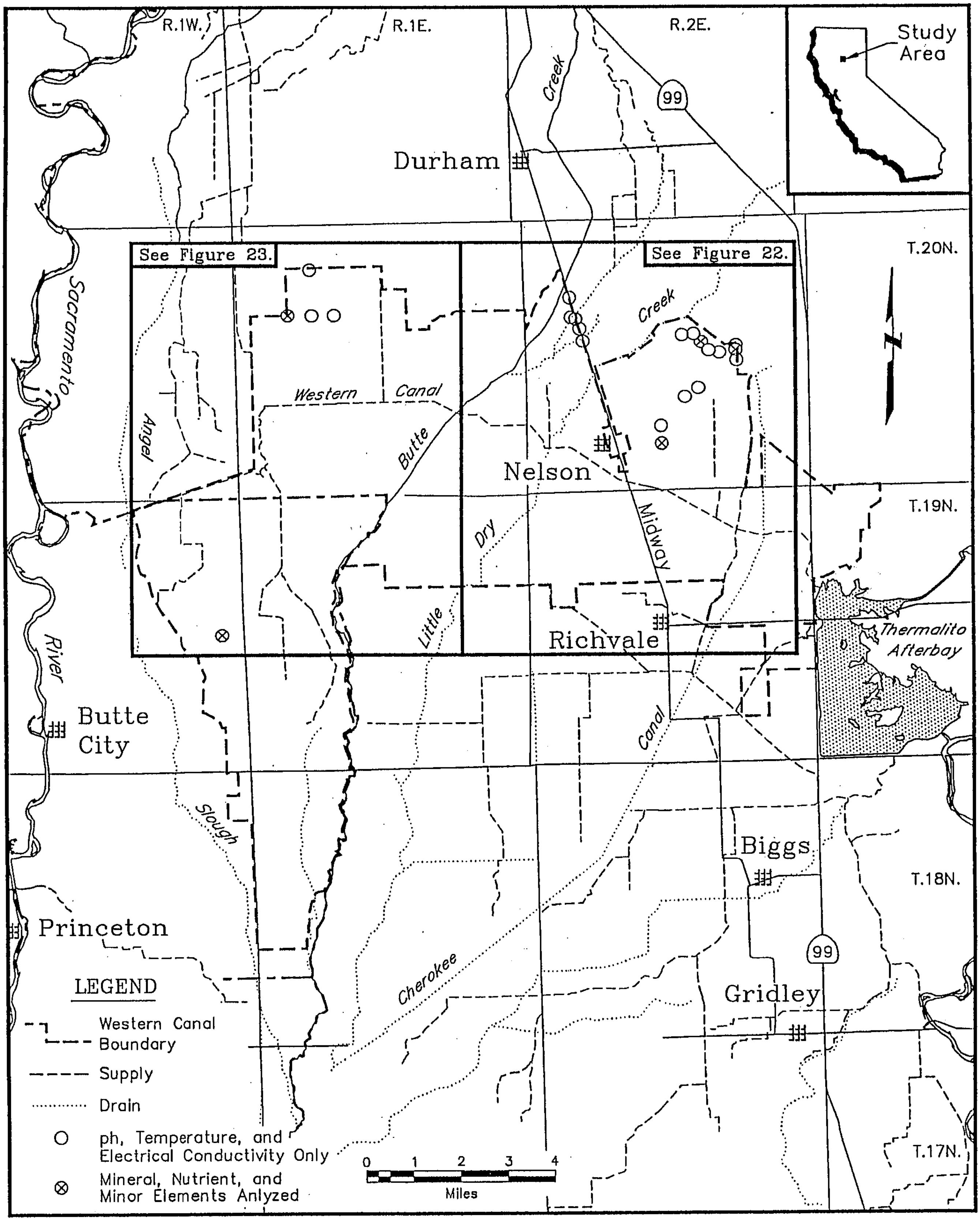


Figure 21. Location Map Showing Water Quality Sampling Wells.

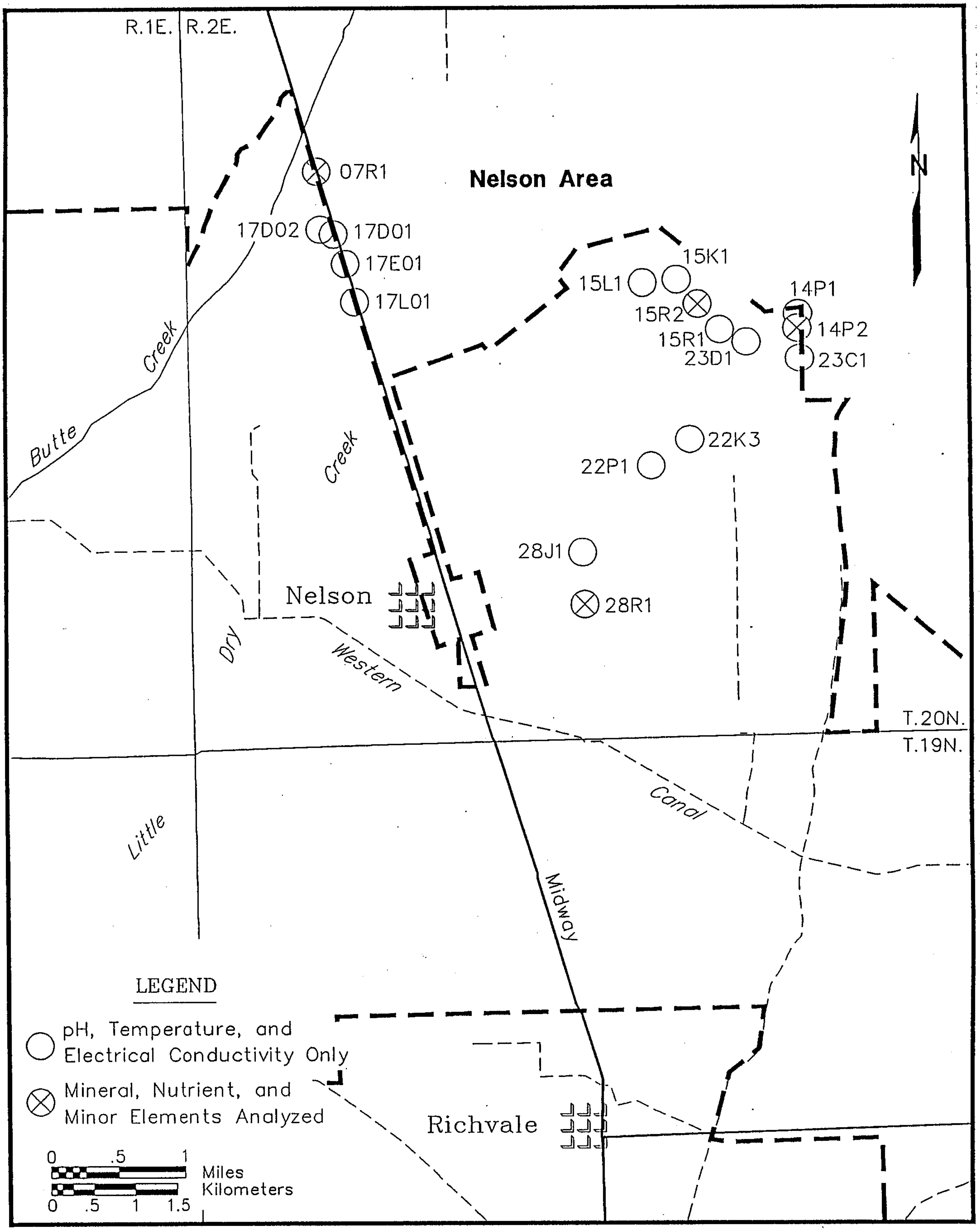


Figure 22. Well Locations for Water Quality Sampling.

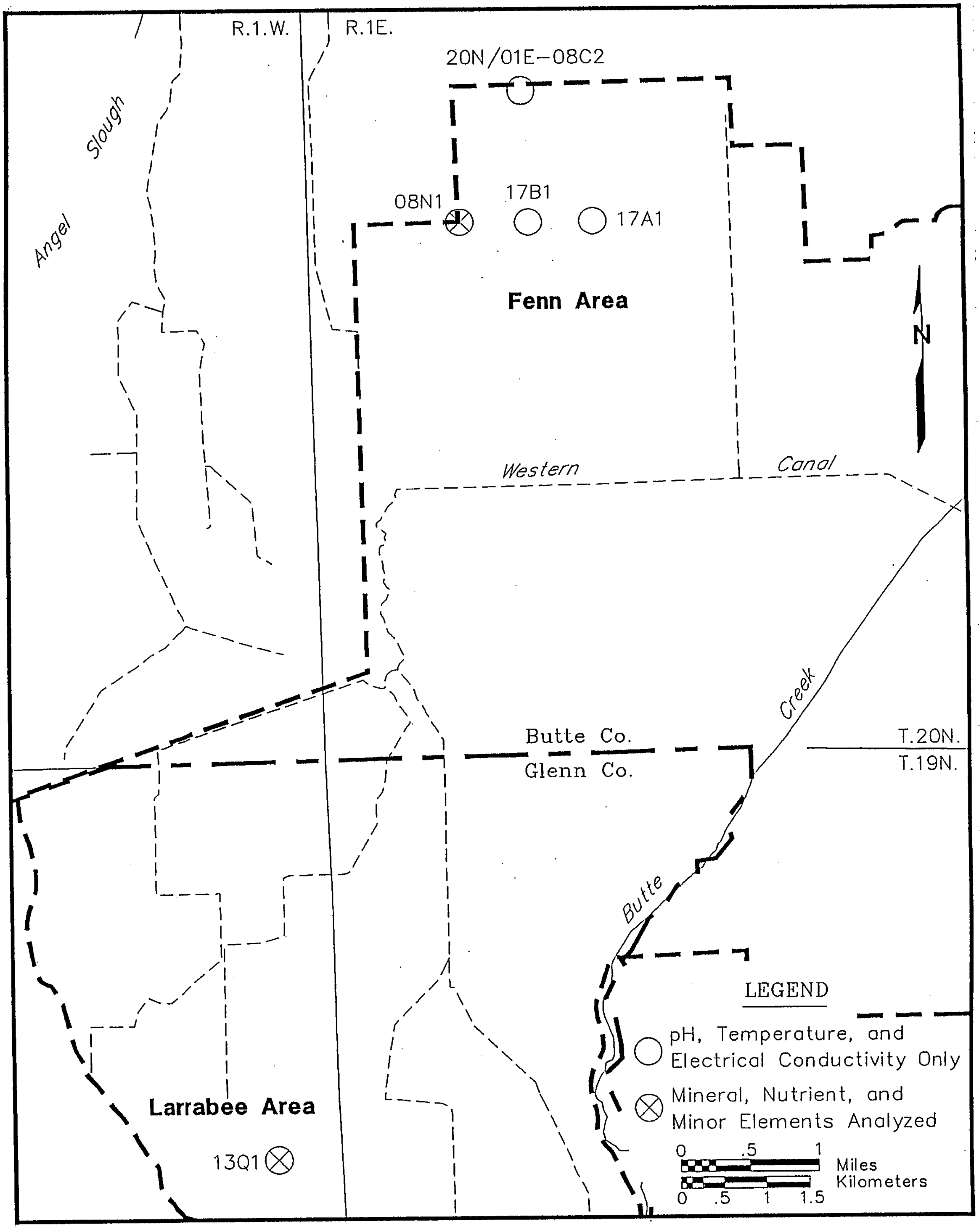


Figure 23. Well Locations for Water Quality Sampling.

Table 5. General ground water quality in the Western Canal area.

Source	Well Number	Date	Temperature (F)	pH (field)	E.C. field (umhos/cm)
Larrabee	13Q1	12/03/86	66	7.9	323
		12/16/86	66.5	7.6	322
Fenn	8N1	11/13/86	63	7.3	431
		11/15/86	63	7.3	475
		11/29/86	63	7.1	484
		12/16/86	63	7.1	479
	8C2	11/29/86	65	7.3	382
	17A1	11/13/86	62.5	7.5	326
		11/15/86	63.5	7.4	333
		11/29/86	64.5	7.5	309
	17B1	11/13/86	63.5	7.5	272
		11/15/86	63.5	7.4	280
		11/29/86	63.5	7.5	268
Gorrill	7R1	10/30/86	65	7.1	608
		11/15/86	65	7.3	578
		11/29/86	65	7.3	576
		12/16/86	65	7.3	555
	17D1	11/15/86	-	7.1	636
		11/29/86	-	7.3	649
	17D2	10/30/86	66	7.3	507
		11/15/86	65	7.3	466
		11/29/86	65	7.4	471
	17 E1	10/30/86	66	7.3	540
		11/15/86	65	7.3	482
		11/29/86	66	7.5	428
	17L1	11/29/86	65	7.3	530
Mc Knight	14P1	10/28/86	66	6.8	447
		11/15/86	68	7.0	346
		11/29/86	69	7.1	340
	14P2	10/25/86	67.5	6.9	337
		10/28/86	67.5	6.9	326
		11/15/86	69	7.1	299
		11/29/86	69	6.9	292
		12/16/86	70	7.1	288

Table 5. General ground water quality in the Western Canal area.

Source	Well Number	Date	Temperature (F)	pH (field)	E.C. field (umhos/cm)
	15K1	10/28/86	69	7.3	295
		10/30/86	70	7.3	244
Mc Knight (cont.)	15K1	11/15/86	70	7.3	243
		11/29/86	70	7.5	248
	15L1	11/29/86	67	7.5	345
	15R1	10/28/86	65	6.8	483
		10/30/86	66	6.9	469
		11/15/86	66.5	7.1	405
		11/29/86	67	7.1	387
	15R2	10/30/86	70	7.3	240
		11/15/86	70	7.3	233
		11/29/86	70	7.4	230
	23D1	11/15/86	65	7.3	496
		11/29/86	65	7.3	466
	23C1	10/28/86	66	6.9	452
		11/15/86	66.5	7.0	361
		11/29/86	67	7.0	351
Wehah-Lundberg	22K3	10/30/86	65	7.0	675
		11/13/86	65	7.0	569
		11/15/86	65	7.0	552
		11/29/86	65	7.1	518
	22P1	11/15/86	-	7.3	476
		11/29/86	-	7.3	472
	28J1	10/30/86	65	7.3	516
		11/15/86	66	7.5	402
		11/29/86	66.5	7.7	373
	28R1	10/29/86	65	7.3	485
		10/30/86	65	7.3	456
		11/15/86	66.5	7.5	340
		11/29/86	67	7.3	316
		12/16/86	67	7.7	309
Minimum			62.5	6.8	230
Maximum			70	7.9	649

were well below the EPA and DHS criteria of 45 mg/L for drinking water (Table 6). Total dissolved solids (176-340 mg/L) were well below the DHS drinking water standard of 500 mg/L.

Mineral quality of ground water in the Western Canal area appears to be excellent for agriculture. Sodium concentrations ranged from 9 to 16 mg/L and only accounted for 9 to 20 percent of the equivalent cations (Table 6). Chloride levels were also quite low ranging from 2 to 13 mg/L. Dissolved boron, which can be toxic to crops at concentrations above 0.75 mg/L, was below the detection limit of 0.1 mg/l for all eleven mineral samples. The adjusted sodium adsorption ratio is a value commonly used to evaluate the sodium permeability hazard to soils from irrigation water. Values less than three present no permeability hazard. Adjusted sodium adsorption ratios, ranging from 0.6 to 1.1 in the Western Canal wells, were far below problem levels.

Nutrient analyses indicated that nitrogen was in the form of nitrite plus nitrate with values ranging from 0.35 to 1.30 mg/L as N (Table 7). Total ammonia plus organic nitrogen and dissolved ammonia were below detection levels in ground water samples from the Western Canal Area. Dissolved orthophosphate and total phosphorus values ranged from 0.02 to 0.10 mg/L and 0.04 to 0.13 mg/L, respectively (Table 7). Nitrogen and phosphorus values were below levels that could present problems to any beneficial use.

Some farmers in the Butte Basin have expressed concern that use of ground water for irrigation of rice results in the formation of a "scum" in the fields. This "scum" was noted at the outfall of well 28R1 during the test program, and was largely composed of green algae. Nitrogen and phosphorus values are somewhat higher in the ground water samples than have been observed in surface water sources in the Western Canal area. Additionally, ground water temperatures are likely to be warmer than surface water temperatures early in the irrigation season prior to rice germination. The higher ground water nutrient levels and temperatures probably result in the "scum" formation when the immature rice plant is not tall enough to shade out the algae production.

Minor elements were below detection limits except for arsenic manganese and zinc (Table 8). Total arsenic was detected in two of five wells, but at very low concentrations (0.001 and 0.006 mg/L). These concentrations should not present a threat to aquatic or other wildlife and are well below the California primary drinking water standard of 0.05 mg/L. The EPA however states that for maximum protection of human health, arsenic concentrations should be zero. The EPA has not made a judgement on an "acceptable" risk level.

Total manganese was detected in one well at a concentration of 0.014 mg/L, and total zinc was detected in another well at 0.005 mg/L. These minute levels do not present a threat to any beneficial use of the water.

Table 6. Mineral ground water quality in the Western Canal area.

Source	Well Number	Date	Dissolved Calcium (mg/L)	Dissolved Magnesium (mg/L)	Dissolved Sodium (mg/L)	Dissolved Potassium (mg/L)	Dissolved Alkalinity (mg/L as CaCO3)	Dissolved Sulfate (mg/L)	Dissolved Chloride (mg/L)	Dissolved Nitrate (mg/L-NO3)	Dissolved Boron (mg/L)	Total Dissolved Solids (mg/L)	Dissolved Hardness (mg/L as CaCO3)	Electrical Conductivity (umhos/cm)	Adjusted Sodium Adsorption Ratio	Percent Sodium
Larrabee	13Q1	12/03/86	29	16	16	2.3	162	7	3	1.4	<0.1	207	139	316	1.1	20
		12/16/86	28	16	15	2.2	161	7	3	1.6	<0.1	210	136	315	1.0	19
Fenn	8N1	11/15/86	42	29	13	1.3	220	20	10	3.2	<0.1	297	225	463	0.8	11
		12/16/86	42	30	13	1.3	225	19	9	3.2	<0.1	296	229	469	0.8	11
Gorrill	7R1	10/30/86	56	41	14	2.5	288	18	2	5.6	<0.1	340	308	553	0.8	9
		12/16/86	50	37	13	2.4	228	14	3	5.4	<0.1	335	277	540	0.8	9
Mc Knight	14P2	10/25/86	28	20	10	1.7	161	12	3	6.9	<0.1	238	152	334	0.7	12
		12/16/86	24	17	9	2.0	136	7	3	5.0	<0.1	210	130	280	0.6	13
	15R2	10/30/86	19	14	10	2.3	122	2	2	<0.1	<0.1	176	105	235	0.7	17
Lundberg	28R1	10/30/86	38	26	14	2.1	210	12	13	5.2	<0.1	293	202	445	0.9	13
		12/16/86	24	19	10	2.2	148	4	6	3.4	<0.1	213	138	305	0.7	13
Minimum			19	14	9	1.3	122	2	2	<0.1	<0.1	176	105	235	0.6	9
Maximum			56	41	16	2.5	288	20	13	6.9	<0.1	340	308	553	1.1	20

Table 7. Nutrient ground water quality in the Western Canal area.

Source	Well Number	Date	Total NH4+org.N (mg/L as N)	Dissolved NO2 andNO3 (mg/L as N)	Dissolved NH4 (mg/L as N)	Dissolved o-PO4 (mg/L as P)	Total P (mg/L as P)
Larrabee	13Q1	12/03/86	<0.1	0.35	<0.01	0.05	0.07
Fenn	8N1	11/15/86	<0.1	0.79	<0.01	0.03	0.04
Gorrill	7R1	10/30/86	<0.1	1.30	<0.01	0.02	0.06
McKnight	14P2	10/25/86	<0.1	1.30	<0.01	0.10	Failed Quality Control
Lundberg	28R1	10/30/86	<0.1	1.20	<0.01	0.04	0.13
Minimum			<0.1	0.35	<0.01	0.02	0.04
Maximum			<0.1	1.30	<0.01	0.10	0.13

Table 8. Minor element ground water quality in the Western Canal area.

Source	Well Number	Date	Total Aluminum (mg/L)	Total Arsenic (mg/L)	Total Cadmium (mg/L)	Total Chromium (mg/L)	Total Copper (mg/L)	Total Iron (mg/L)	Total Mercury (mg/L)	Total Manganese (mg/L)	Total Nickel (mg/L)	Total Lead (mg/L)	Total Selenium (mg/L)	Total Zinc (mg/L)
Larrabee	13Q1	12/03/86	<0.1	0.006	<0.005	<0.005	<0.005	<0.1	<0.001	0.014	<0.005	<0.005	<0.001	<0.005
Fenn	8N1	11/15/86	<0.1	0.001	<0.005	<0.005	<0.005	<0.1	<0.001	<0.005	<0.005	<0.005	<0.001	<0.005
Gorrill	7R1	10/30/86	<0.1	<0.001	<0.005	<0.005	<0.005	<0.1	<0.001	<0.005	<0.005	<0.005	<0.001	0.005
McKnight	14P2	10/25/86	<0.1	<0.001	<0.005	<0.005	<0.005	<0.1	<0.001	<0.005	<0.005	<0.005	<0.001	<0.005
Lundberg	28R1	10/30/86	<0.1	<0.001	<0.005	<0.005	<0.005	<0.1	<0.001	<0.005	<0.005	<0.005	<0.001	<0.005
Minimum			<0.1	<0.001	<0.005	<0.005	<0.005	<0.1	<0.001	<0.005	<0.005	<0.005	<0.001	<0.005
Maximum			<0.1	0.006	<0.005	<0.005	<0.005	<0.1	<0.001	0.014	<0.005	<0.005	<0.001	0.005

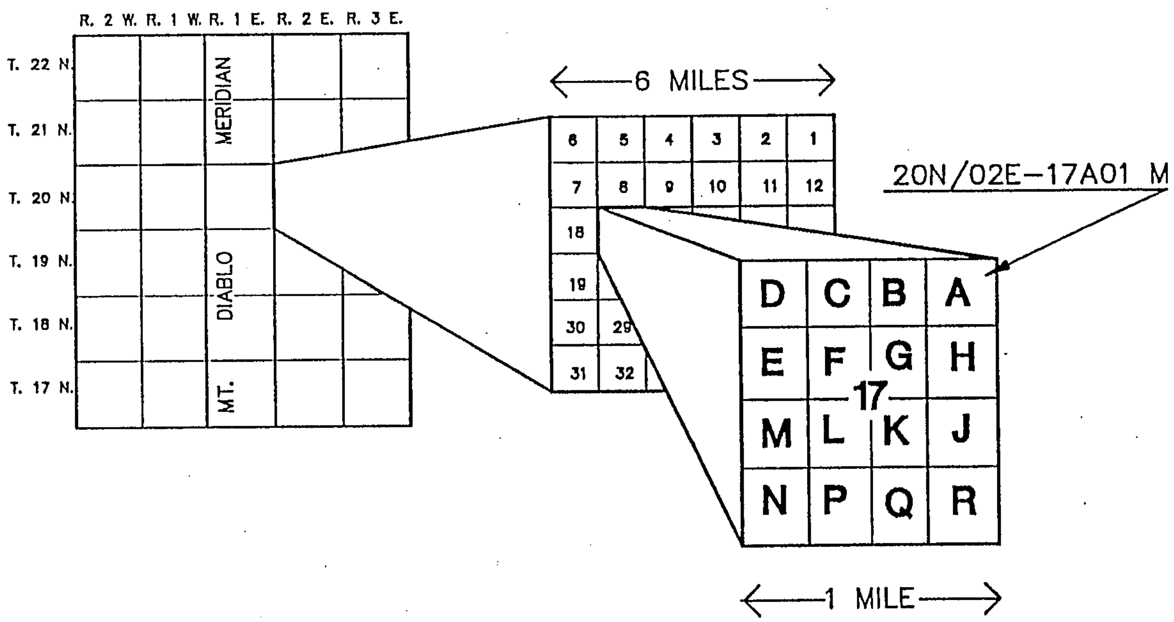
APPENDIX A
STATE WELL NUMBERING SYSTEM

State Well Numbering System

Each well in the monitoring program is assigned an official State Well Number. The Department of Water Resources has sole responsibility for assigning State Well Numbers to water wells in California, and each number uniquely identifies a well based on it location.

Each State Well Number includes township, range, and section number, and each section is further subdivided into sixteen 40-acre tracts, which are assigned a letter designation as shown below. Within each 40-acre tract, wells are numbered sequentially in the order they are inventoried. The final letter of the identification signifies the base line and meridian to which the well location refers. In Butte County, all wells are referenced to the Mount Diablo base line and meridian. The example below is for State Well Number 20N/02E-17A01 M.

State Well Numbering System



The lettering system does not contain the letters "I" and "O".

APPENDIX B
WESTERN CANAL TEST PROGRAM LOG OF ACTIVITY

APPENDIX B
WESTERN CANAL TEST PROGRAM
LOG OF ACTIVITY

DATE	WELL	*/#	ACTIVITY
10 9 90	---		DWR/WESTERN REACHED AGREEMENT
10 12 90	---		DWR STAFF INSPECTS WELLS ON McKNIGHT, LUNDBERG & GORRILL RANCHES
10 15 90	---		BEGIN WELL MEASUREMENTS (GSP/WME) ON McKNIGHT, LUNDBERG AND LAMALFA RANCHES
10 19 90	---		WESTERN/DWR AGREEMENT DESCRIBED TO THE BUTTE BASIN ADVISORY COMMITTEE
10 22 90	20N/02E-16P01		SET UP RECORDER
	20N/02E-27K01		SET UP RECORDER
10 24 90	---		DWR STAFF INSPECTS WELLS ON FENN & LARRABEE RANCHES
	20N/02E-14P02		INSTALLED METER
10 25 90	20N/02E-14P02		24 HOUR AQUIFER TEST - PUMPING WELL ON McKNIGHT RANCH
	20N/02E-23C01		AQUIFER TEST MONITORING WELL
	20N/02E-23L01		AQUIFER TEST MONITORING WELL
	20N/02E-23A01		AQUIFER TEST MONITORING WELL
	20N/02E-14P01		AQUIFER TEST MONITORING WELL
	20N/02E-14N01		AQUIFER TEST MONITORING WELL
	20N/02E-15R01		AQUIFER TEST MONITORING WELL
10 26 90	SEE ABOVE		RECOVERY TEST OF ABOVE WELLS
	20N/02E-14P02		WATER QUALITY SAMPLING FOR MINERAL, NUTRIENT & MINOR ELEMENT ANALYSIS
10 29 90	---		MEASURED WELL-GRID TO ESTABLISH STATIC WATER LEVELS
	20N/02E-14P01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (McKNIGHT)
	20N/02E-14P02	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (McKNIGHT)
	20N/02E-23C01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (McKNIGHT)
	20N/02E-15R01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (McKNIGHT)
	20N/02E-15R02	*	STARTED PUMPING, (PUMP FAILED DURING THE SPECIFIC CAPACITY TEST) REPAIRED PUMP AND STARTED PUMPING (McKNIGHT)
	20N/02E-15K01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (McKNIGHT)
	20N/02E-28R01		INSTALL METER FOR LUNDBERG WELL
	20N/02E-22Q01		INSTALL METER FOR LUNDBERG WELL
	20N/02E-13D01		DELIVERED METER TO WESTERN CANAL WATER DISTRICT FOR LAMALFA WELL.
10 30 90	---		WORKED OUT DETAILS FOR GORRILL RANCH PUMP TEST
	20N/02E-28R01	*	STARTED PUMPING, 24 HR AQUIFER TEST - PUMPING WELL ON LUNDBURG RANCH (NO RECOVERY TEST). SAMPLED FOR GENERAL WATER QUALITY ANALYSIS.
	20N/02E-27D01		AQUIFER TEST (MONITORING WELL)
	20N/02E-28N01		AQUIFER TEST (MONITORING WELL) MONTHLY WELL
	20N/02E-27K01		AQUIFER TEST (MONITORING WELL)
	20N/02E-33K01		AQUIFER TEST (MONITORING WELL)
	20N/02E-28J01		AQUIFER TEST (MONITORING WELL)
10 31 90	---		MEASURE WELL GRID
	20N/02E-28J01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (LUNDBERG)
	20N/02E-22P01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (LUNDBERG)
	20N/02E-22K03		PUMPED FOR FEW HOURS (TO CHECK OPERATION OF PUMP) AFFECTING NEARBY WELLS
	20N/02E-07R01		WATER QUALITY SAMPLING FOR MINERAL, NUTRIENT & MINOR ELEMENT ANALYSIS (GORRILL).
	20N/02E-17D02		GENERAL WATER QUALITY SAMPLING (GORRILL)
	20N/02E-17E01		GENERAL WATER QUALITY SAMPLING (GORRILL)
	20N/02E-15K01		GENERAL WATER QUALITY SAMPLING (McKNIGHT)
	20N/02E-15R01		GENERAL WATER QUALITY SAMPLING (McKNIGHT)
	20N/02E-15R02		WATER QUALITY SAMPLING FOR MINERAL ANALYSIS (McKNIGHT).
	20N/02E-28R01		WATER QUALITY SAMPLING FOR MINERAL, NUTRIENT & MINOR ELEMENT ANALYSIS (LUNDBERG)

* BEGIN PUMPING FOR WATER DELIVERY
# END PUMPING FOR WATER DELIVERY

APPENDIX B
WESTERN CANAL TEST PROGRAM
LOG OF ACTIVITY

DATE			WELL	*/#	ACTIVITY
11	1	90	19N/01W-13Q01		DELIVERED METER TO WESTERN CANAL WATER DISTRICT FOR THE LARRABEE WELL.
			20N/02E-07R01	*	STARTED PUMPING, 30 HR AQUIFER TEST - PUMPING WELL GORRILL #4 (NO RECOVERY TEST)
			20N/02E-06P03		AQUIFER TEST (MONITORING WELL)
			20N/02E-07H01		AQUIFER TEST (MONITORING WELL)
			20N/02E-07J01		AQUIFER TEST (MONITORING WELL)
			20N/02E-17D01		AQUIFER TEST (MONITORING WELL) DOMESTIC WELL
			20N/02E-17D02		AQUIFER TEST (MONITORING WELL)
			20N/02E-17E01		AQUIFER TEST (MONITORING WELL)
11	2	90	19N/01W-13Q01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST - LARRABEE
11	5	90	20N/02E-17D02	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST - GORRILL #5
			20N/02E-17E01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST - GORRILL #6
11	6	90	---		MEASURE WELL-GRID
11	9	90	---		MEASURE WELL-GRID
			20N/02E-22K03	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST - LUNDBERG WELL
11	13	90	---		MEASURE WELL-GRID
11	14	90	20N/01E-08N01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (FENN)
			20N/01E-17A01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST, SAMPLED FOR GENERAL W.Q. (FENN)
			20N/01E-17B01	*	STARTED PUMPING (NO PUMP TEST INFORMATION), SAMPLED FOR GENERAL W.Q. (FENN)
			20N/01E-22K03		GENERAL WATER QUALITY SAMPLING FOR PUMPING WELL (LUNDBERG)
11	16	90	---		MEASURE WELL-GRID
			---		GENERAL WATER QUALITY SAMPLING FOR ALL PUMPING WELLS IN THE NELSON & FENN AREA
			20N/02E-08N01		WATER QUALITY SAMPLING FOR MINERAL, NUTRIENT & MINOR ELEMENT ANALYSIS (FENN).
			20N/02E-17D01		GENERAL WATER QUALITY SAMPLING FOR MONITORING WELL (GORRILL)
			20N/02E-23D01		GENERAL WATER QUALITY SAMPLING FOR MONITORING WELL (McKNIGHT)
11	20	90	---		MEASURE WELL-GRID
11	26	90	20N/02W-22P01		PUMP WAS OFF FOR 30 MINUTES FOR MAINTENANCE, THEN RESUMED PUMPING
			20N/01W-08C02		OBSERVATION OF MONITORING WELL PUMPING TO IRRIGATE FIELDS (FENN AREA)
			20N/02W-15L01		MONITORING WELL PUMPING SINCE WED 11/21/90 AT 4PM.
11	27	90	---		MEASURE WELL-GRID
11	30	90	19N/02E-13D01	*	STARTED PUMPING, 1 HR SPECIFIC CAPACITY TEST - LAMALFA
			---		END OF 1ST PAY PERIOD FOR PUMPING WELLS
			---		GENERAL WATER QUALITY SAMPLING FOR ALL PUMPING WELLS IN THE NELSON & FENN AREA
			20N/01E-08C02		GENERAL WATER QUALITY SAMPLING FOR MONITORING WELL (FENN)
			20N/02E-17D01		GENERAL WATER QUALITY SAMPLING FOR MONITORING WELL (GORRILL)
			20N/02E-17L01		GENERAL WATER QUALITY SAMPLING FOR MONITORING WELL (GORRILL)
			20N/02E-15L01		GENERAL WATER QUALITY SAMPLING FOR MONITORING WELL (McKNIGHT)
			20N/02E-23D01		GENERAL WATER QUALITY SAMPLING FOR MONITORING WELL (McKNIGHT)
12	1	90	19N/02E-13D01	#	STOPPED PUMPING - LAMALFA
12	4	90	---		MEASURE WELL-GRID
			19N/01W-13Q01		WATER QUALITY SAMPLING FOR MINERAL, NUTRIENT & MINOR ELEMENT ANALYSIS (LARRABEE).
12	11	90	---		MEASURE WELL-GRID
12	17	90	19N/01W-13Q01		WATER QUALITY SAMPLING FOR MINERAL ANALYSIS (LARABEE).
			20N/01E-08N01		WATER QUALITY SAMPLING FOR MINERAL ANALYSIS (FENN).
			20N/02E-07R01		WATER QUALITY SAMPLING FOR MINERAL ANALYSIS (GORRILL).
			20N/02E-14P02		WATER QUALITY SAMPLING FOR MINERAL ANALYSIS (McKNIGHT).
			20N/02E-28R01		WATER QUALITY SAMPLING FOR MINERAL ANALYSIS (LUNDBERG).

* BEGIN PUMPING FOR WATER DELIVERY
# END PUMPING FOR WATER DELIVERY

APPENDIX B
WESTERN CANAL TEST PROGRAM
LOG OF ACTIVITY

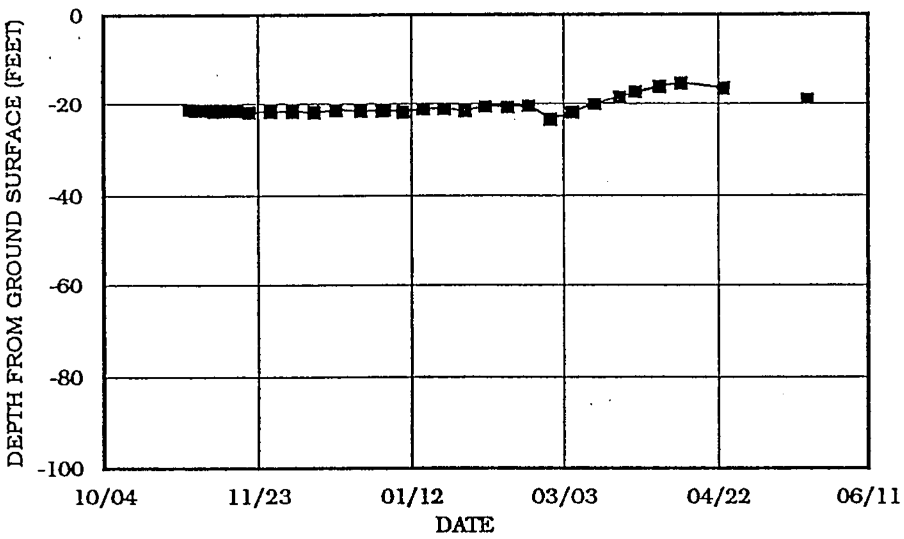
DATE			WELL	*/#	ACTIVITY
12	18	90	---		MEASURE WELL-GRID
12	26	90	---		MEASURE WELL-GRID
1	2	91	---		MEASURE WELL-GRID
			---	#	LAST PAY PERIOD ENDS, SHUT DOWN ALL PUMPING WELLS
			20N/02E-07R01		RECOVERY TEST - GORRILL
			20N/02E-14P02		RECOVERY TEST - McKNIGHT
			20N/02E-28R01		RECOVERY TEST - LUNDBERG
			20N/01E-08N01		RECOVERY TEST - FENN (3 MEASUREMENT POINTS)
			20N/01E-17A01		RECOVERY TEST - FENN (3 MEASUREMENT POINTS)
			20N/01E-17B01		RECOVERY TEST - FENN (3 MEASUREMENT POINTS)
			19N/01W-13QO1		RECOVERY TEST - LARRABEE (3 MEASURMENT POINTS)
1	3	91	---		MEASURE WELL-GRID
1	9	91	---		MEASURE WELL-GRID
1	16	91	---		MEASURE WELL-GRID
1	23	91	---		MEASURE WELL-GRID
1	30	91	---		MEASURE WELL-GRID
2	6	91	---		MEASURE WELL-GRID
2	13	91	---		MEASURE WELL-GRID
2	20	91	---		MEASURE WELL-GRID
2	27	91	---		MEASURE WELL-GRID
3	6	91	---		MEASURE WELL-GRID
3	13	91	---		MEASURE WELL-GRID
3	21	91	---		MEASURE WELL-GRID
3	26	91	---		MEASURE WELL-GRID
4	3	91	---		MEASURE WELL-GRID
4	10	91	---		MEASURE WELL-GRID
4	24	91	---		MEASURE WELL-GRID
5	8	91	---		MEASURE WELL-GRID
5	22	91	---		MEASURE WELL-GRID

* BEGIN PUMPING FOR WATER DELIVERY
# END PUMPING FOR WATER DELIVERY

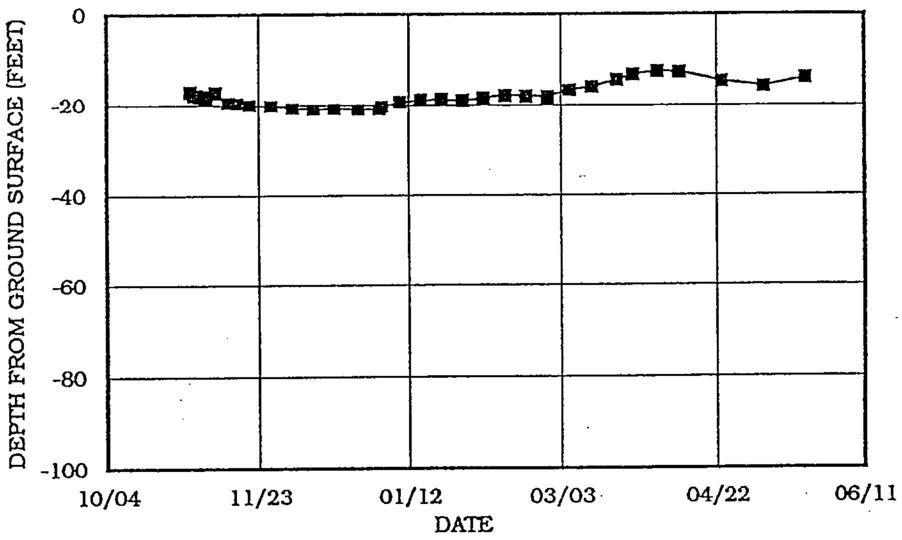
APPENDIX C
HYDROGRAPHS OF PUMPING AND OBSERVATION WELLS

NELSON AREA - Gorrill Sub-Area

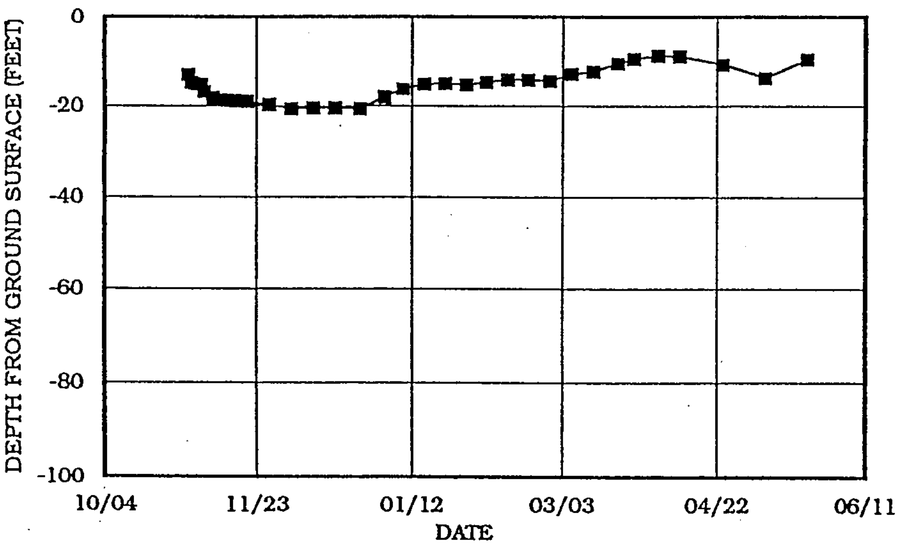
BUTTE COUNTY - WELL # 20N02E06P03M
GSE = 130 TOTAL DEPTH = ? WELL USE = IRR



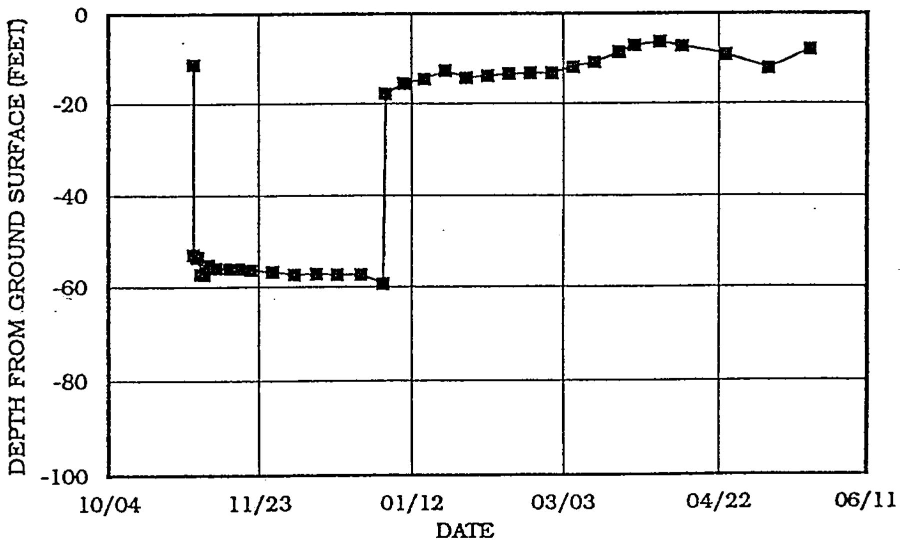
BUTTE COUNTY - WELL # 20N02E07H01M
GSE = 134 TOTAL DEPTH = ? WELL USE = Irr



BUTTE COUNTY - WELL # 20N02E07J01M
GSE = 130 TOTAL DEPTH = ? WELL USE = Irr

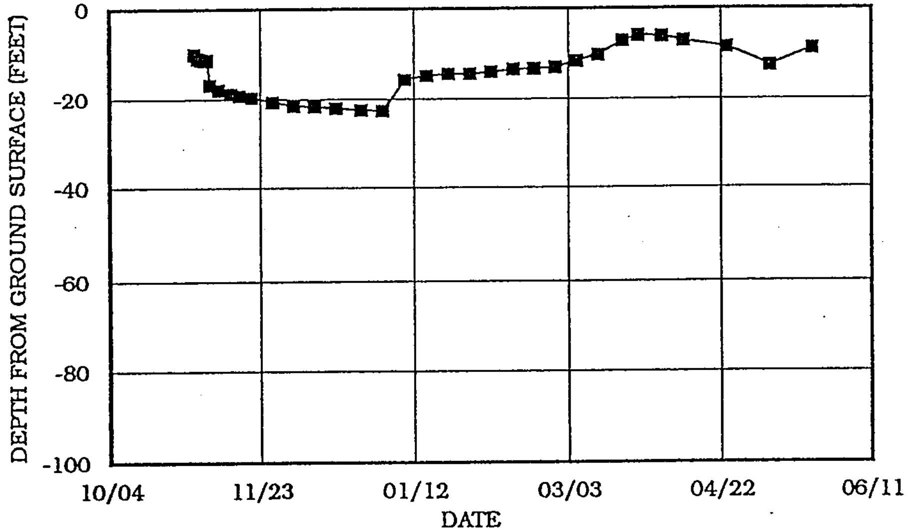


BUTTE COUNTY - WELL # 20N02E07R01M
GSE = 129 TOTAL DEPTH = ? WELL USE = IRR

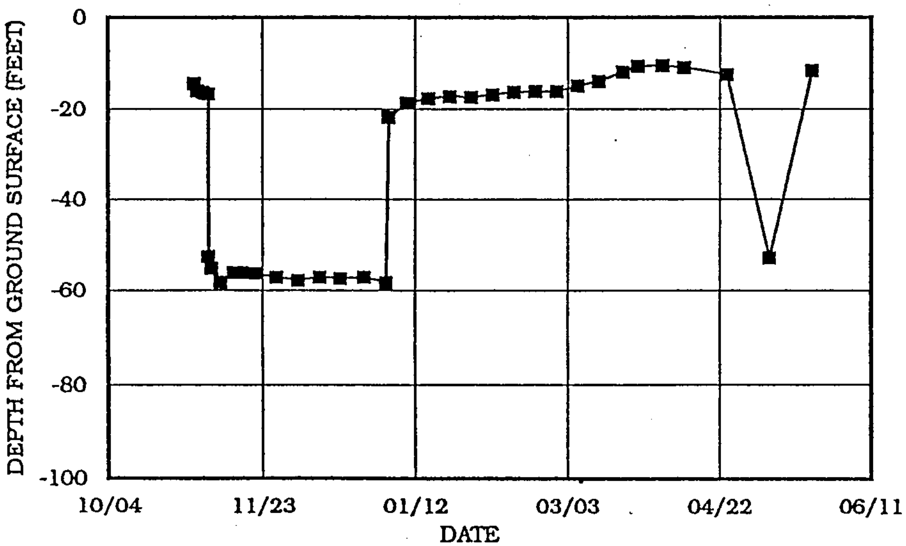


NELSON AREA - Gorrill Sub-Area

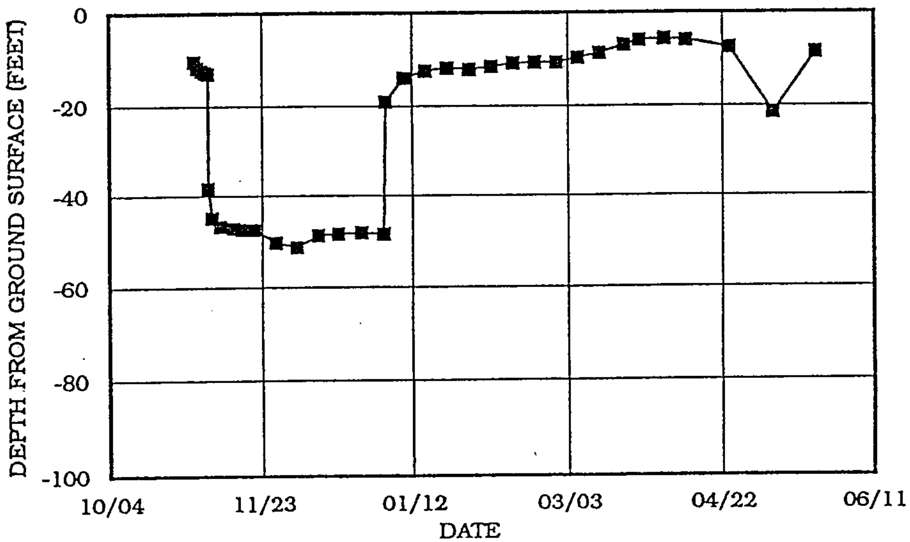
BUTTE COUNTY - WELL # 20N02E17D01M
GSE = 129 TOTAL DEPTH = ? WELL USE = Irr



BUTTE COUNTY - WELL # 20N02E17D02M
GSE = 130 TOTAL DEPTH = ? WELL USE = IRR



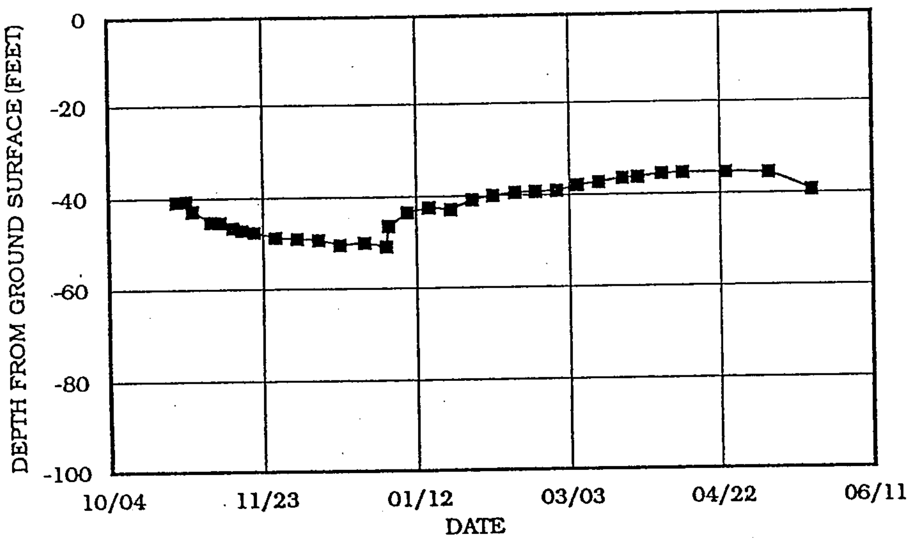
BUTTE COUNTY - WELL # 20N02E17E01M
GSE = 126 TOTAL DEPTH = ? WELL USE = IRR



NELSON AREA - McKnight Sub-Area

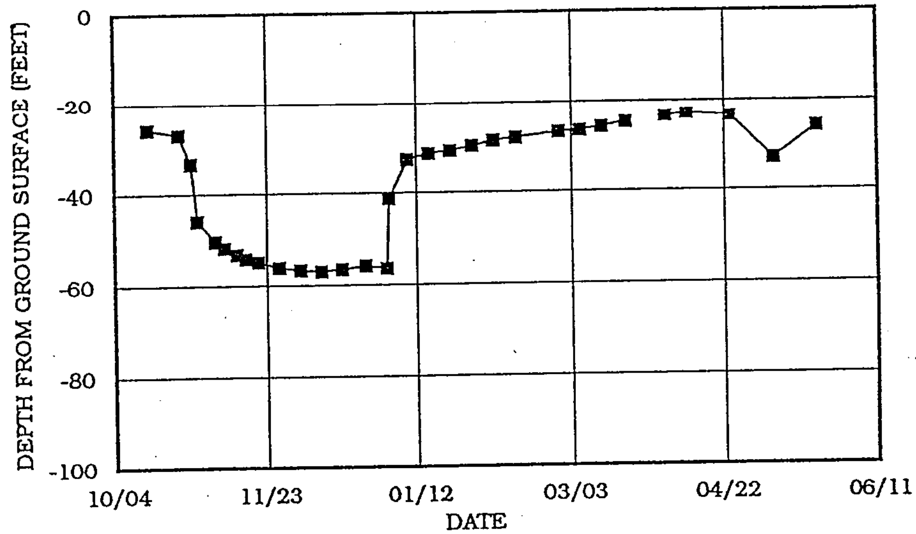
BUTTE COUNTY - WELL # 20N02E13N01M

GSE = 151 TOTAL DEPTH = 162.0 WELL USE = Irr



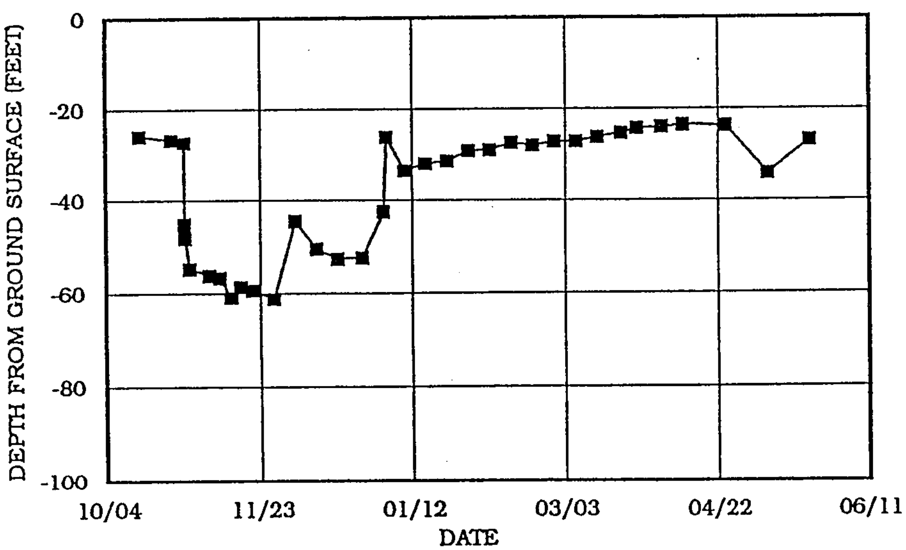
BUTTE COUNTY - WELL # 20N02E14N01M

GSE = 148 TOTAL DEPTH = ? WELL USE = Unused



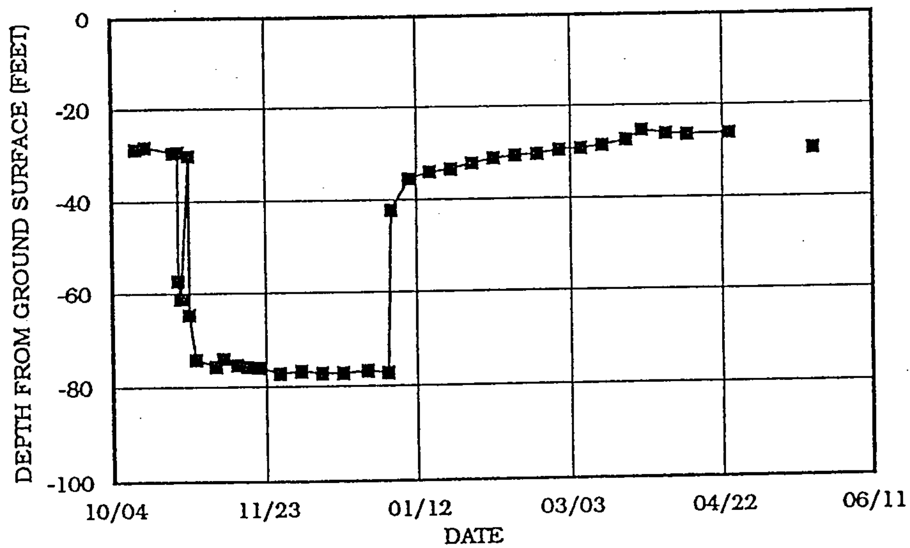
BUTTE BASIN - WELL # 20N02E14P01M

GSE = 148 TOTAL DEPTH = UNK WELL USE = IRR



BUTTE COUNTY - WELL # 20N/02E-14P02

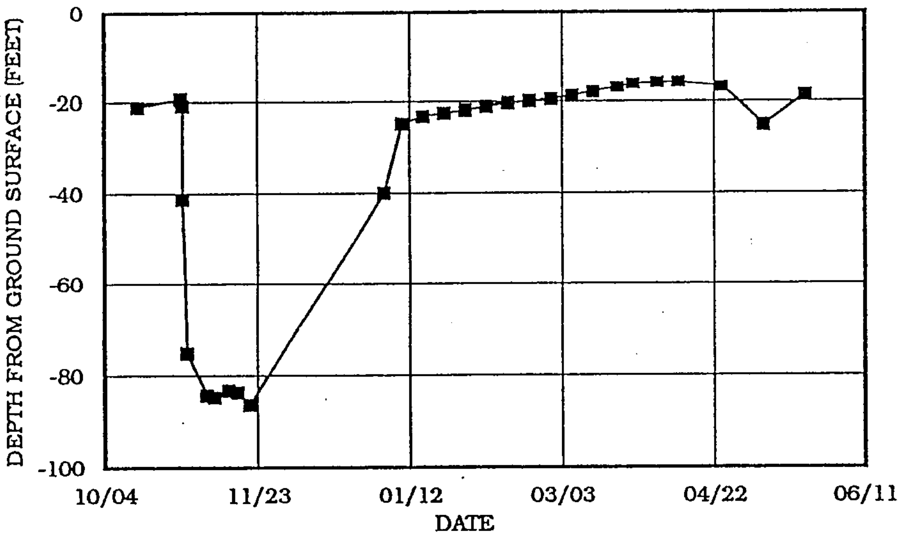
GSE = 149 TOTAL DEPTH = ? WELL USE = IRR



NELSON AREA - McKnight Sub-Area

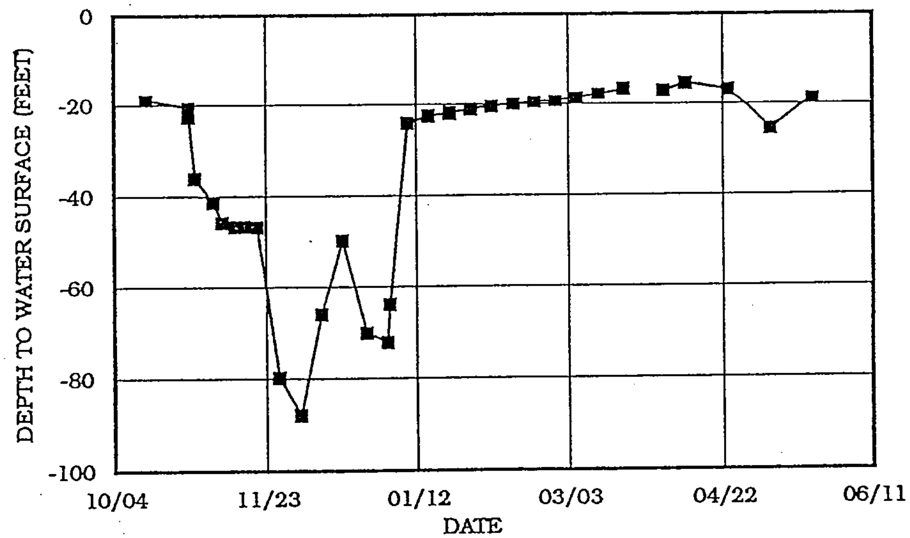
BUTTE COUNTY - WELL # 20N02E15K01M

GSE = 141 TOTAL DEPTH = 750 WELL USE = IRR



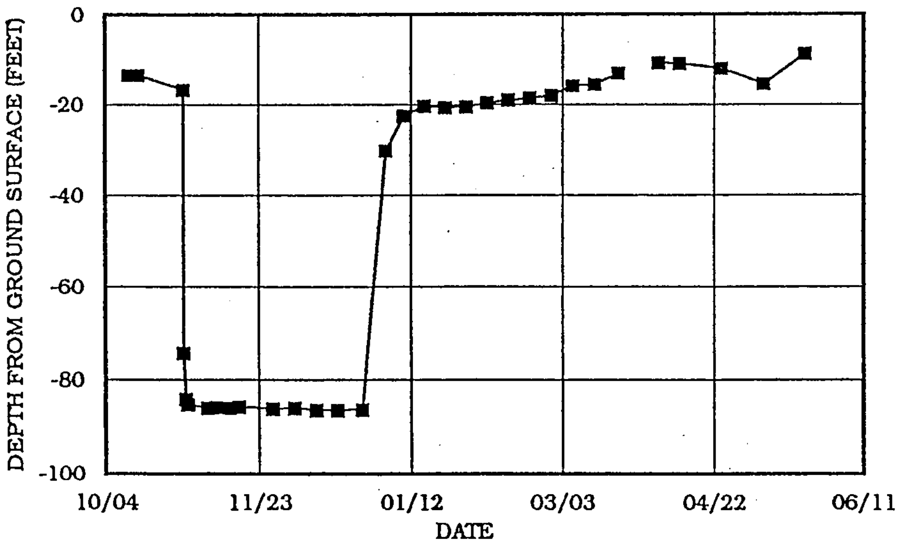
BUTTE COUNTY - WELL # 20N02E15L01

GSE = 141 TOTAL DEPTH = 645 WELL USE = IRR



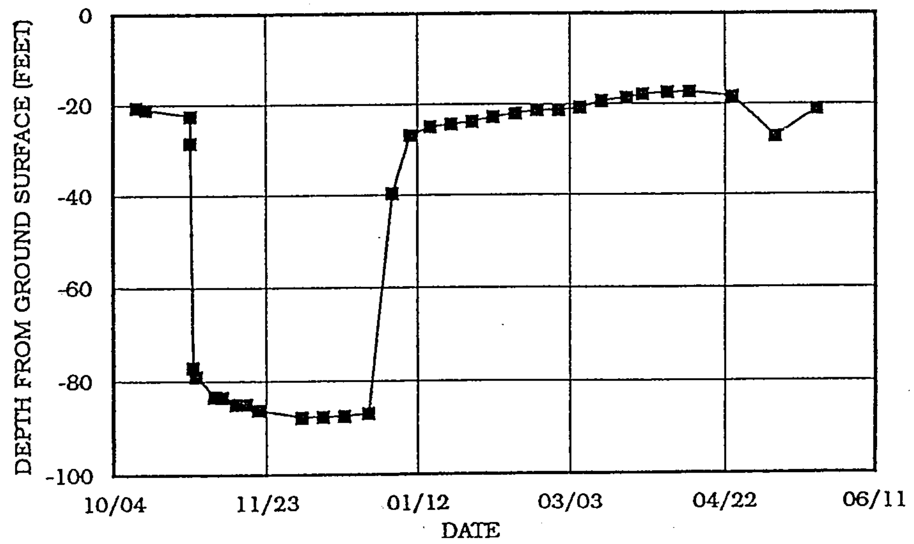
BUTTE COUNTY - WELL # 20N02E15R01M

GSE = 143 TOTAL DEPTH = 500 WELL USE = IRR



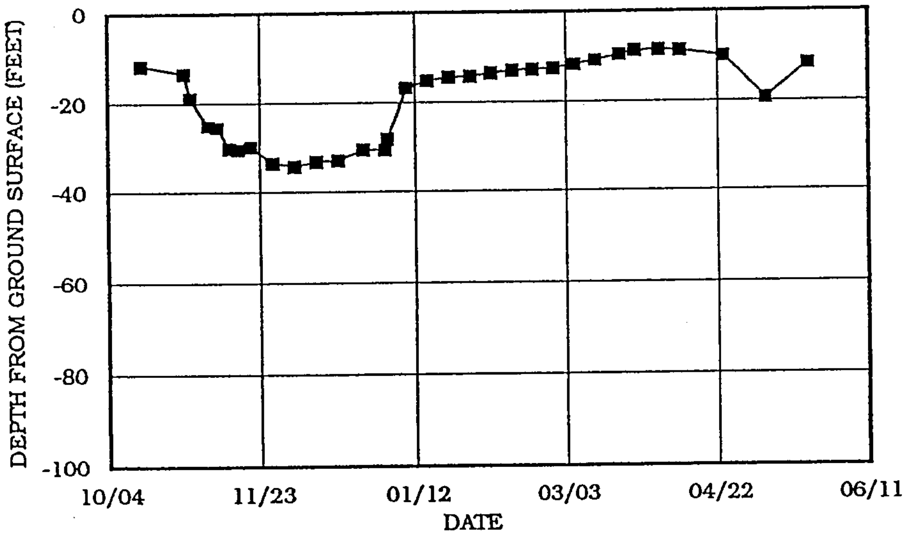
BUTTE COUNTY - WELL # 20N02E15R02M

GSE = 143 TOTAL DEPTH = 610 WELL USE = IRR

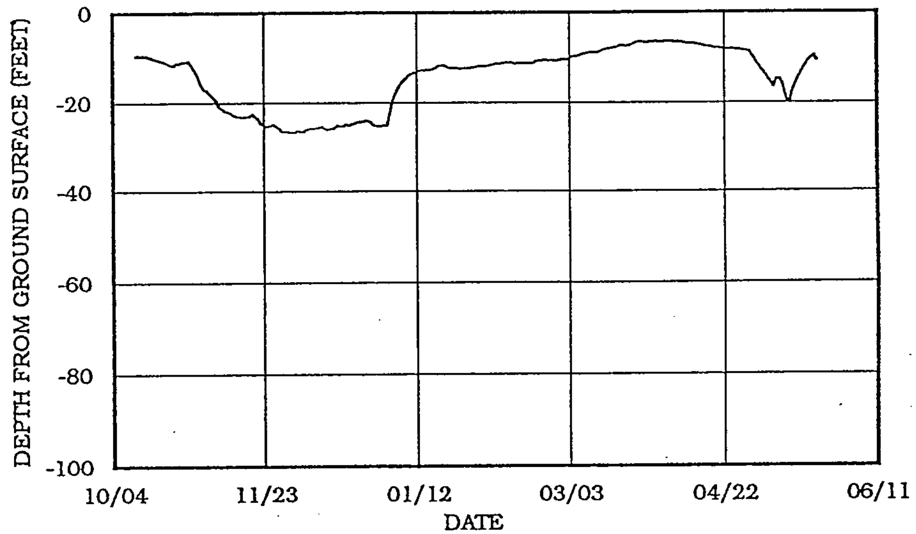


NELSON AREA - McKnight Sub-Area

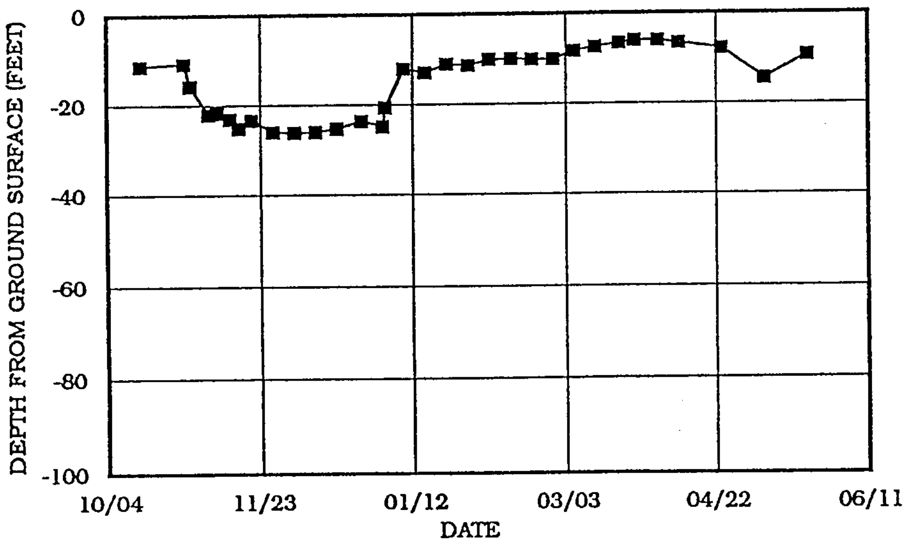
BUTTE COUNTY - WELL # 20N02E16J01M
GSE = 132 TOTAL DEPTH = 502 WELL USE = Irr



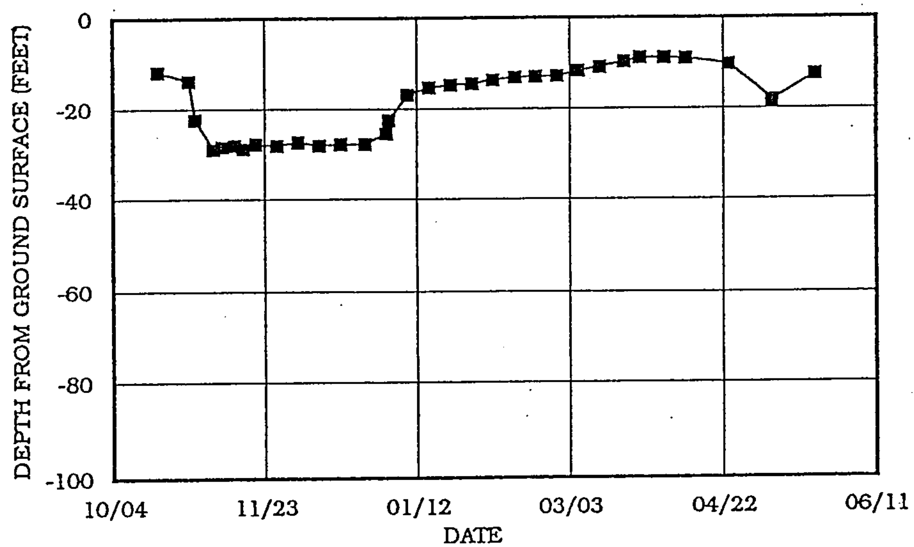
BUTTE COUNTY - WELL # 20N02E16P01M
GSE = 130 TOTAL DEPTH = ? WELL USE = Irr



BUTTE COUNTY - WELL # 20N02E22D01M
GSE = 133 TOTAL DEPTH = ? WELL USE = Irr



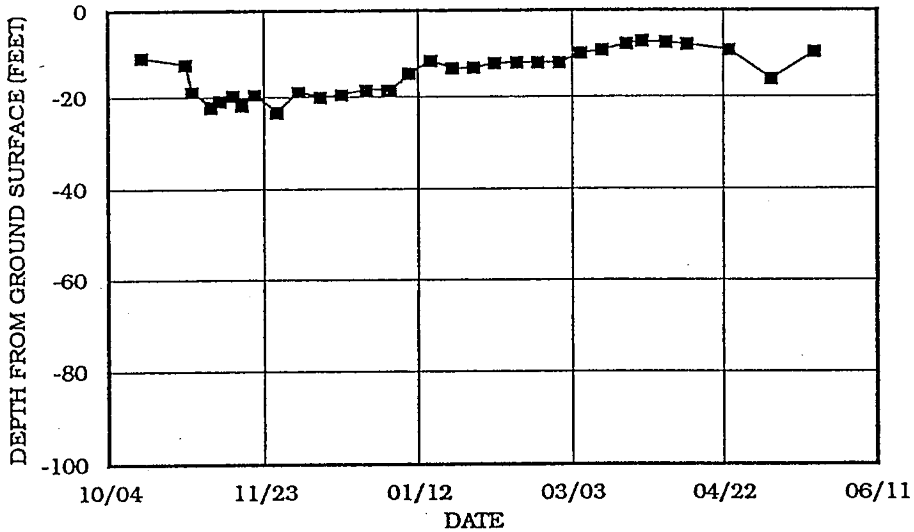
BUTTE COUNTY - WELL # 20N02E22D02
GSE = 133 TOTAL DEPTH = 510 WELL USE = Irr



NELSON AREA - McKnight Sub-Area

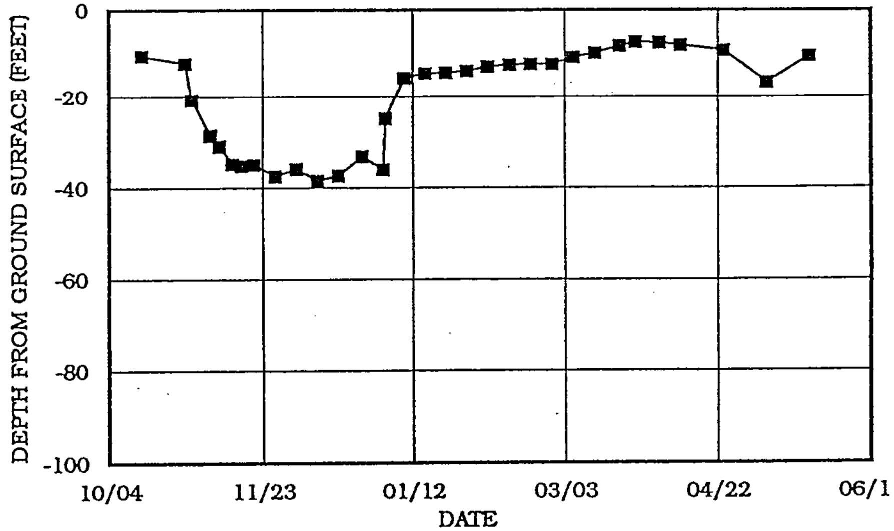
BUTTE COUNTY - WELL # 20N02E22F01M

GSE = 134 TOTAL DEPTH = 507 WELL USE = Irr



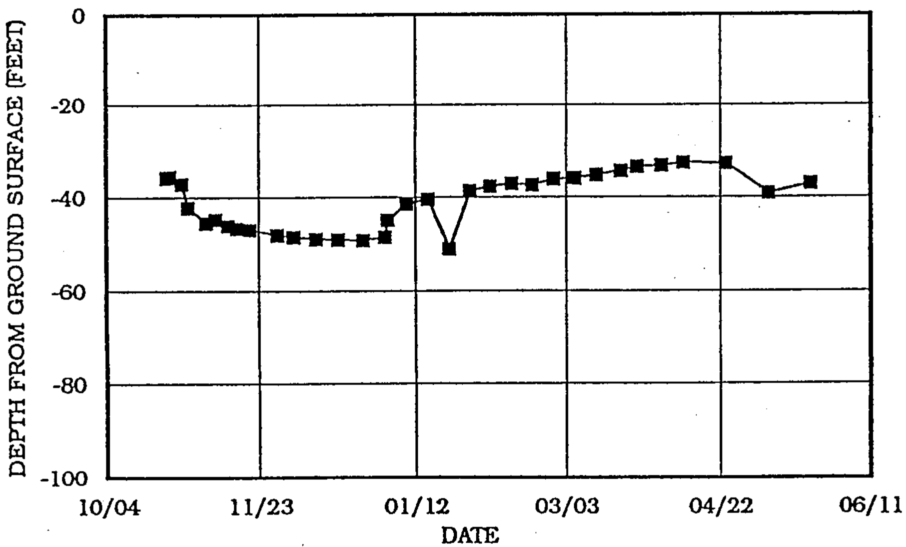
BUTTE COUNTY - WELL # 20N02E22K02M

GSE = 134 TOTAL DEPTH = ? WELL USE = Irr



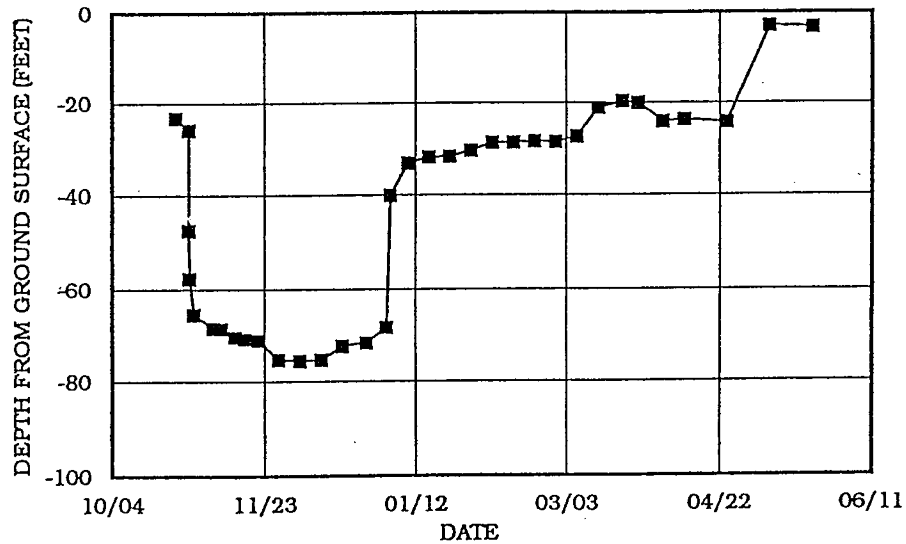
BUTTE COUNTY - WELL # 20N02E23A01M

GSE = 157 TOTAL DEPTH = ? WELL USE = Irr



BUTTE COUNTY - WELL # 20N02E23C01M

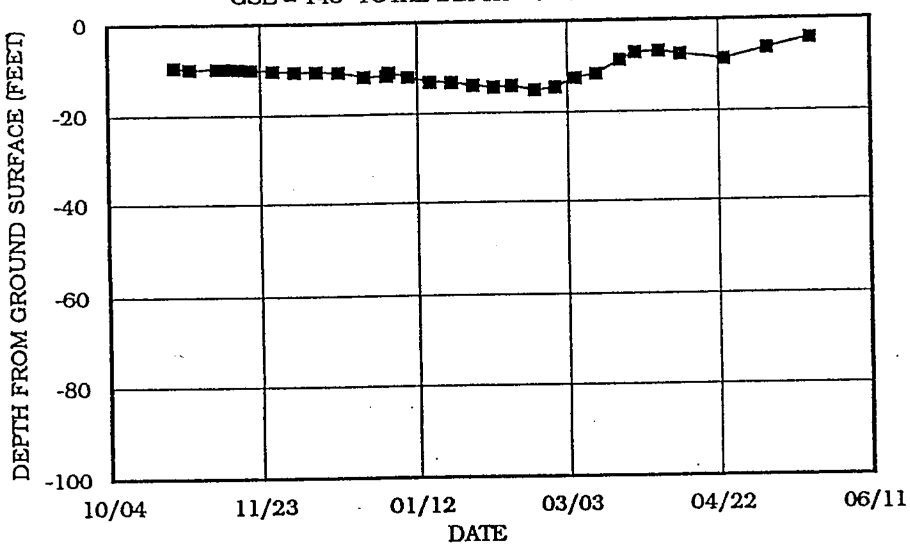
GSE = 148 TOTAL DEPTH = 615 WELL USE = IRR



NELSON AREA - McKnight Sub-Area

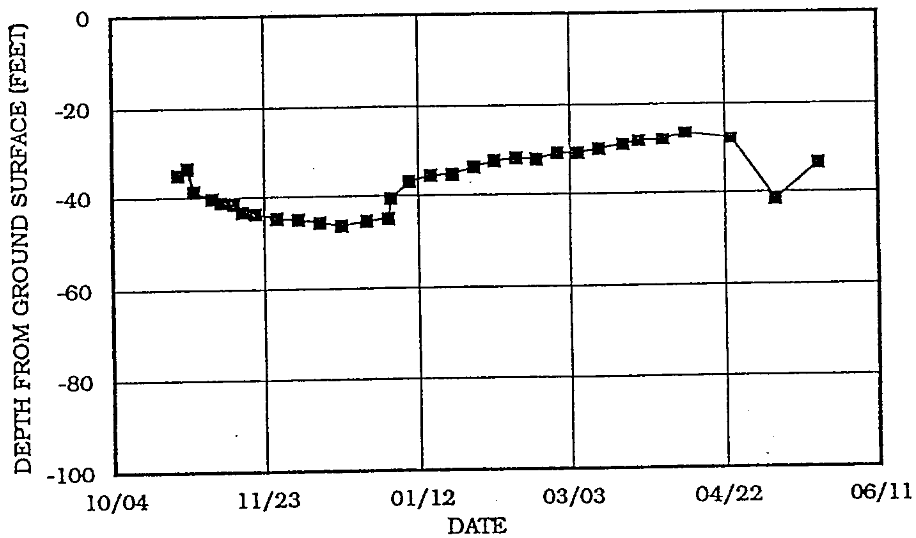
BUTTE COUNTY - WELL # 20N02E23D01M

GSE = 143 TOTAL DEPTH = ? WELL USE = Dom



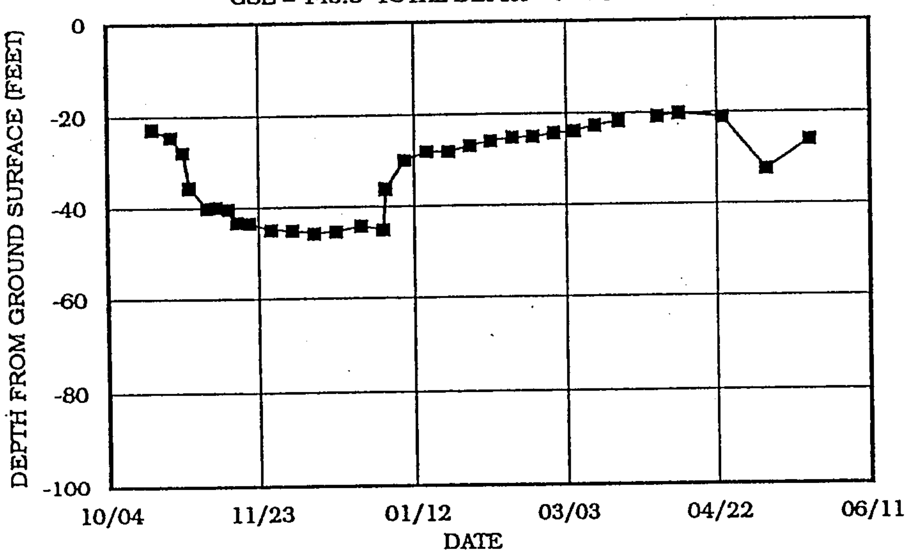
BUTTE COUNTY - WELL # 20N02E23H01M

GSE = 151 TOTAL DEPTH = ? WELL USE = Irr



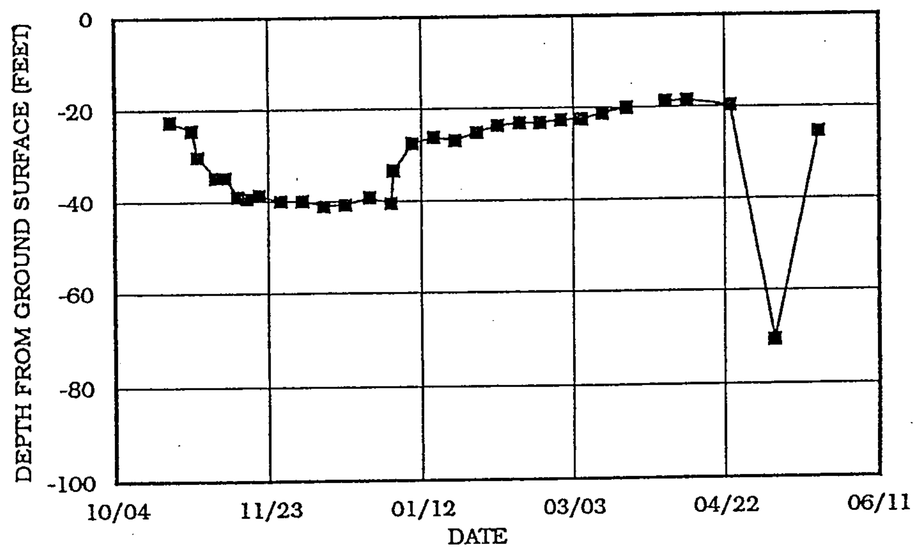
BUTTE COUNTY - WELL # 20N02E23L01M

GSE = 143.5 TOTAL DEPTH = ? WELL USE = Irr

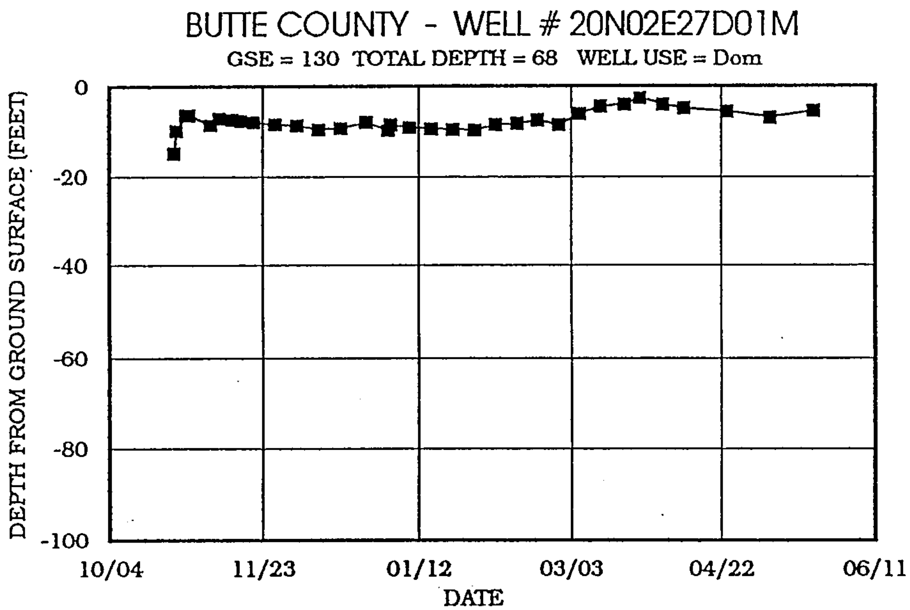


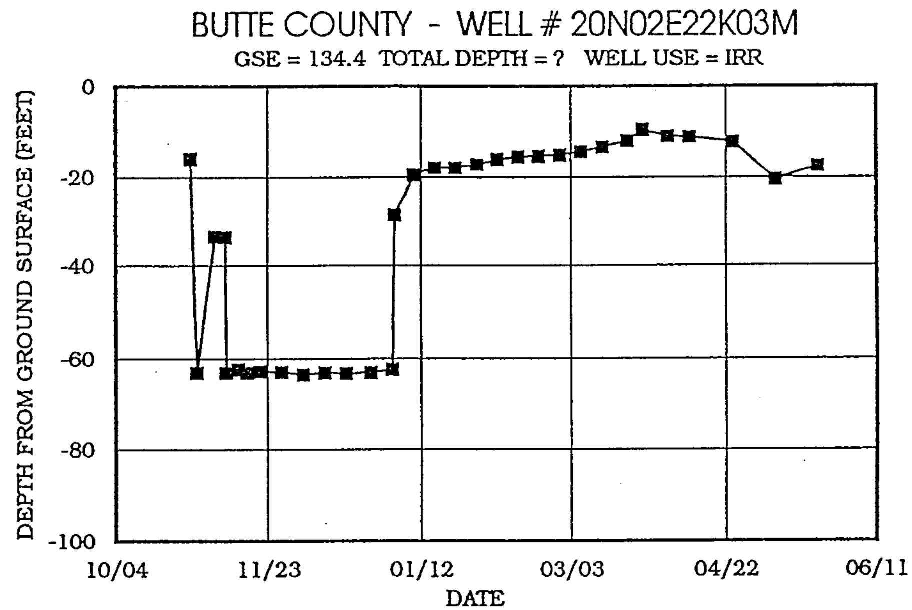
BUTTE COUNTY - WELL # 20N02E23L02M

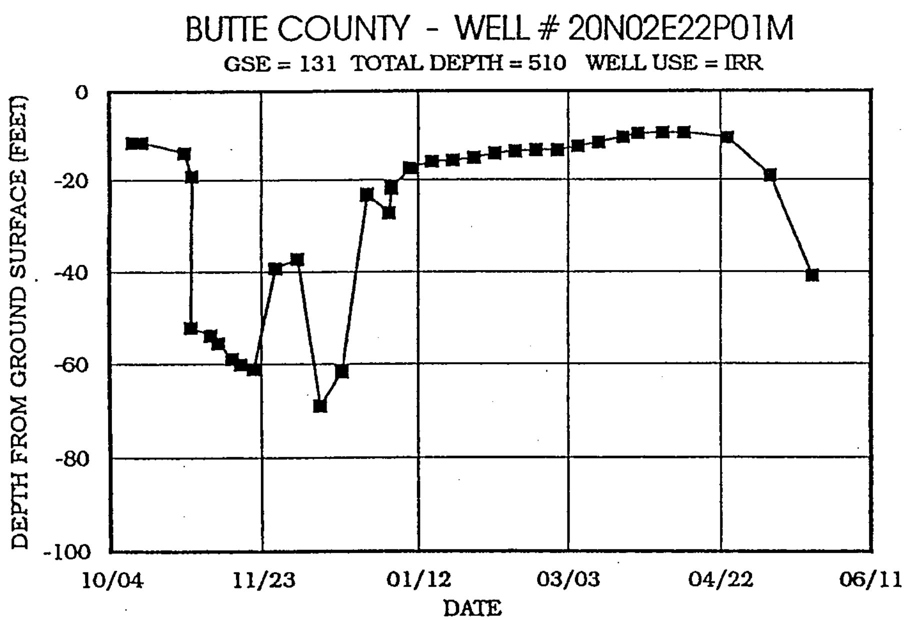
GSE = 142 TOTAL DEPTH = ? WELL USE = Irr

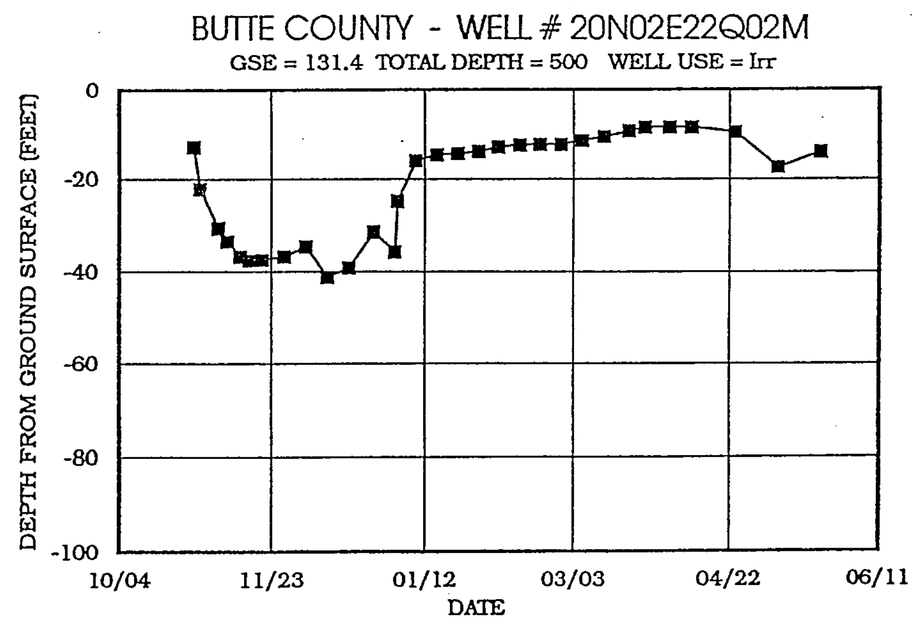


NELSON AREA - Wehah-Lundberg Sub-Area





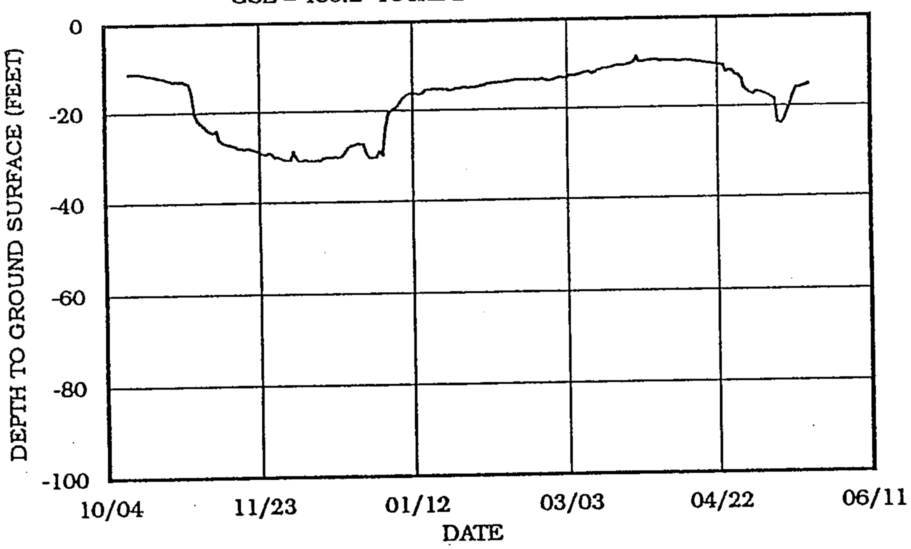




NELSON AREA - Wehah-Lundberg Sub-Area

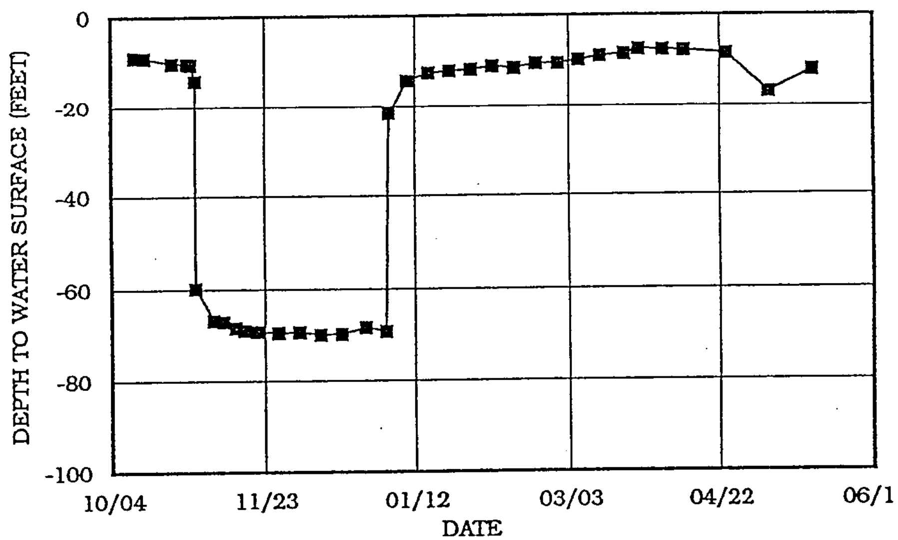
BUTTE COUNTY - WELL # 20N02E27K01M

GSE = 130.2 TOTAL DEPTH = ? WELL USE = Irr



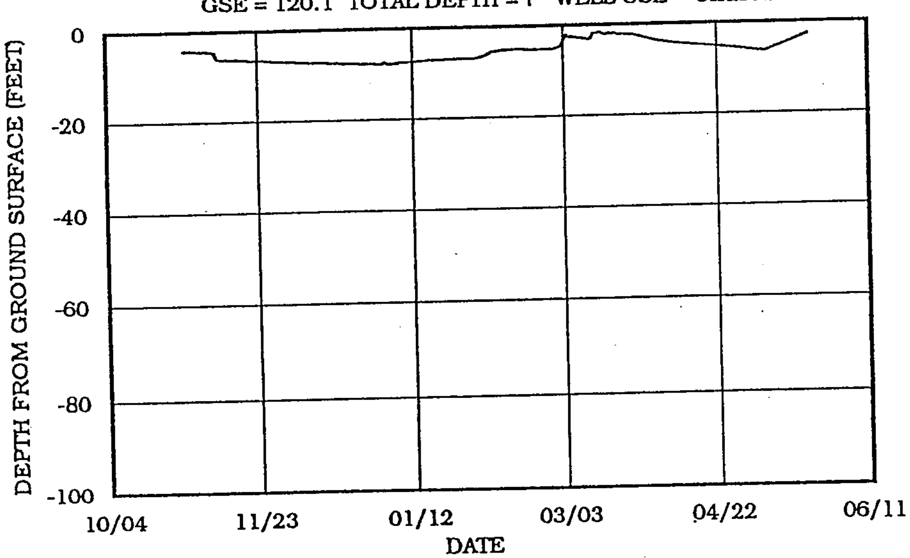
BUTTE COUNTY - WELL # 20N02E28J01M

GSE = 126 TOTAL DEPTH = ? WELL USE = IRR



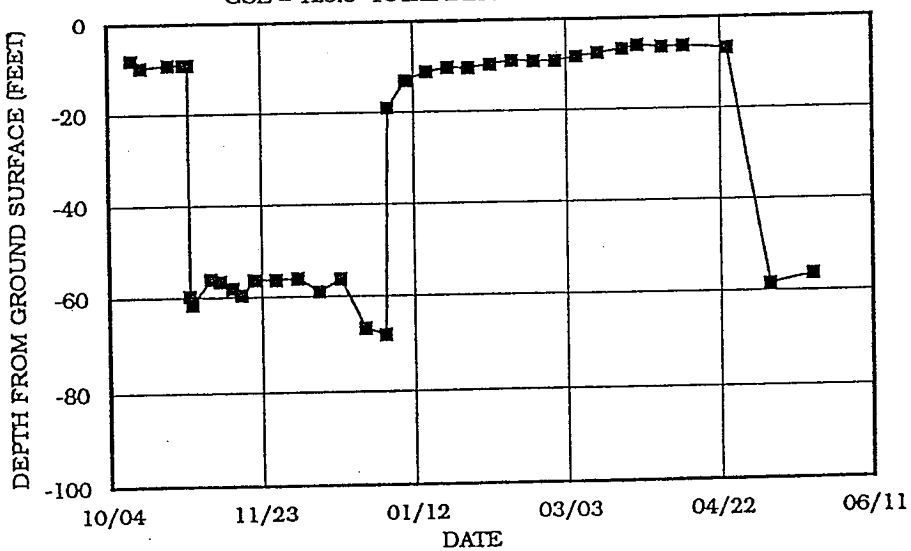
BUTTE COUNTY - WELL # 20N02E28N01M

GSE = 120.1 TOTAL DEPTH = ? WELL USE = Unused



BUTTE COUNTY - WELL # 20N02E28R01M

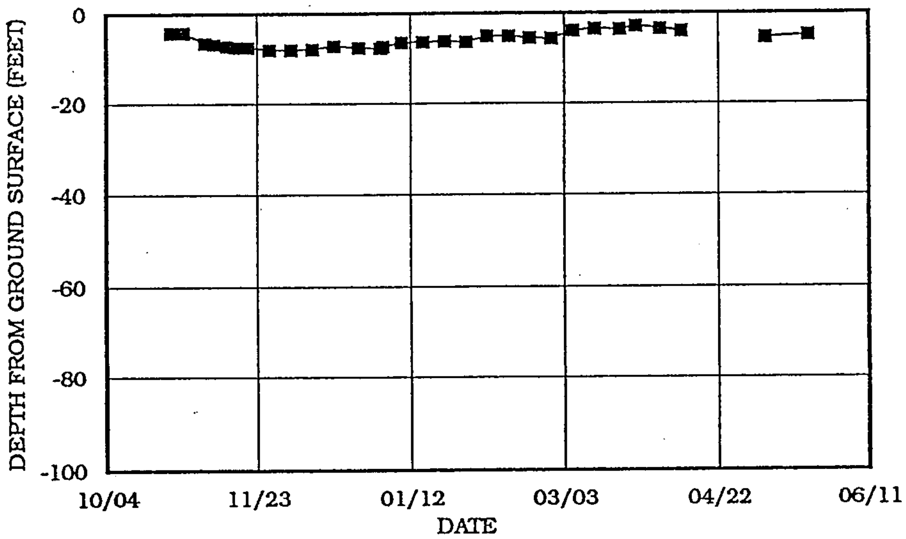
GSE = 123.9 TOTAL DEPTH = ? WELL USE = IRR



NELSON AREA - Wehah-Lundberg Sub-Area

BUTTE COUNTY - WELL # 20N02E33K01M

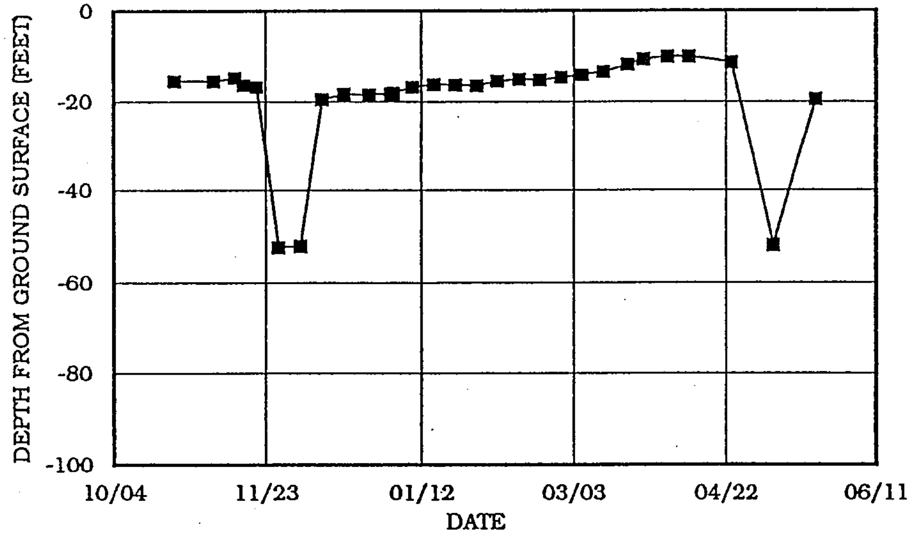
GSE = 118.8 TOTAL DEPTH = 300 WELL USE = Irr



FENN AREA

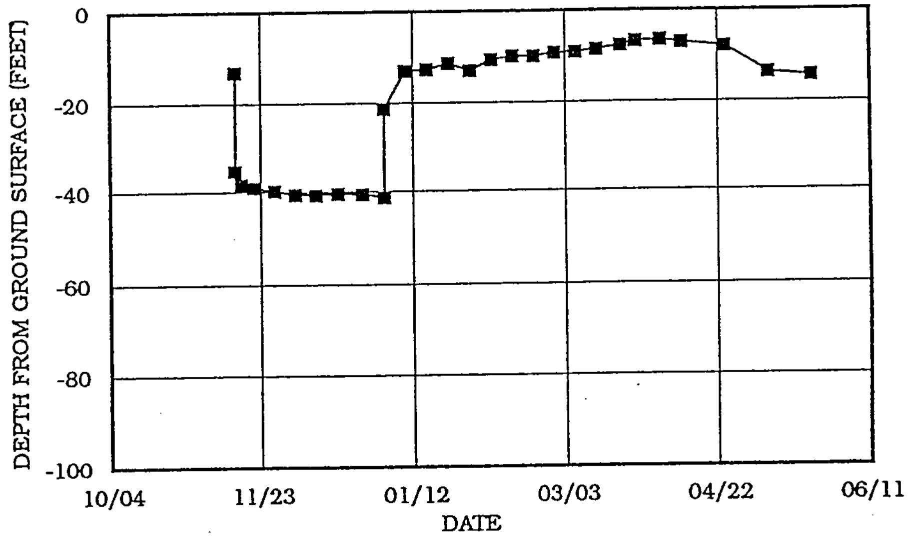
BUTTE COUNTY - WELL # 20N01E08C02M

GSE = 115 TOTAL DEPTH = ? WELL USE = Irr



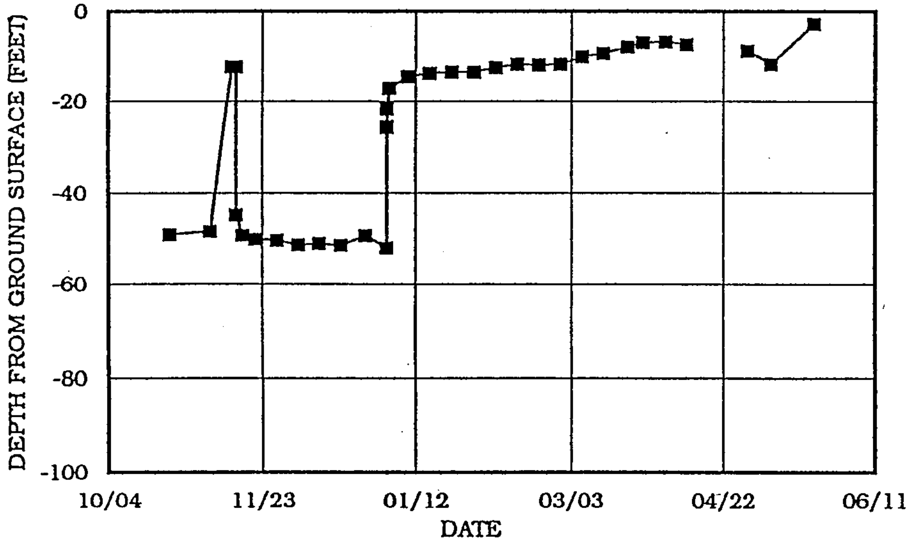
BUTTE COUNTY - WELL # 20N01E08N01M

GSE = 111 TOTAL DEPTH = ? WELL USE = IRR



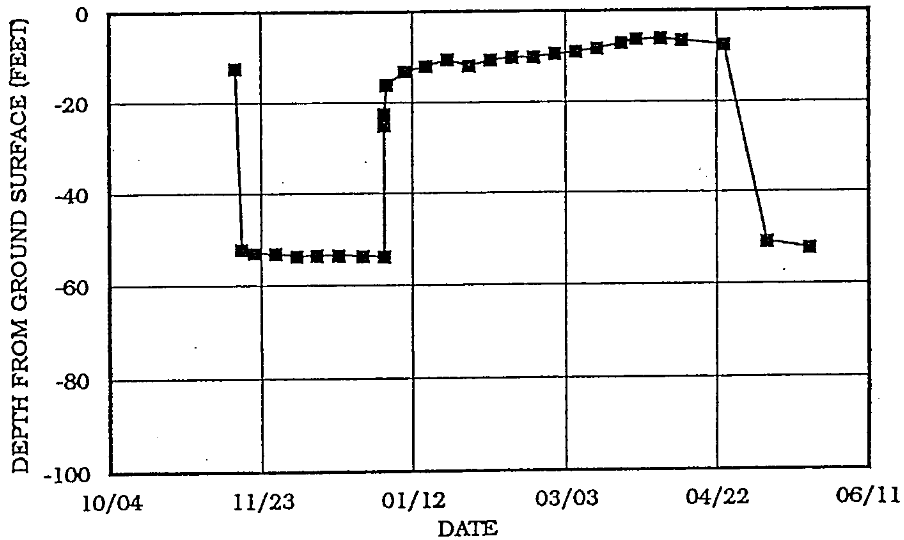
BUTTE COUNTY - WELL # 20N01E17A01M

GSE = 114 TOTAL DEPTH = ? WELL USE = IRR



BUTTE COUNTY - WELL # 20N01E17B01

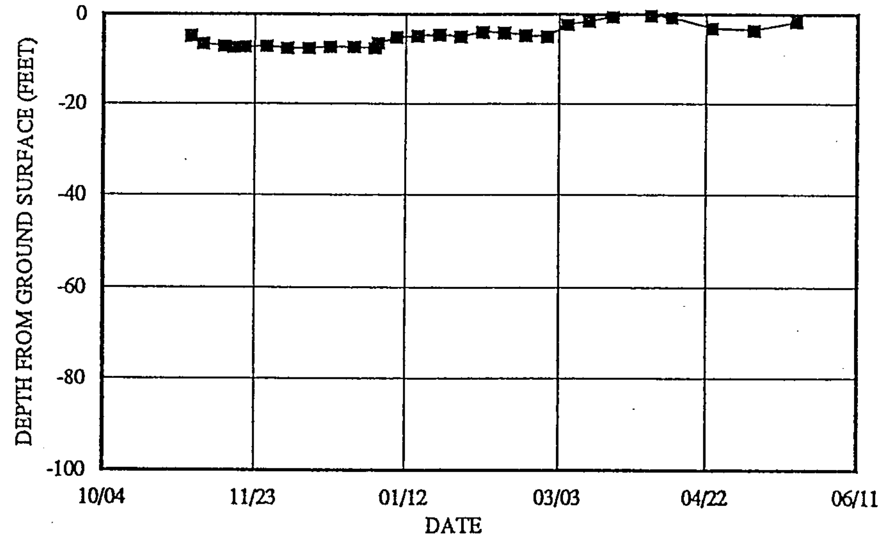
GSE = 111 TOTAL DEPTH = ? WELL USE = IRR



LARRABEE AREA

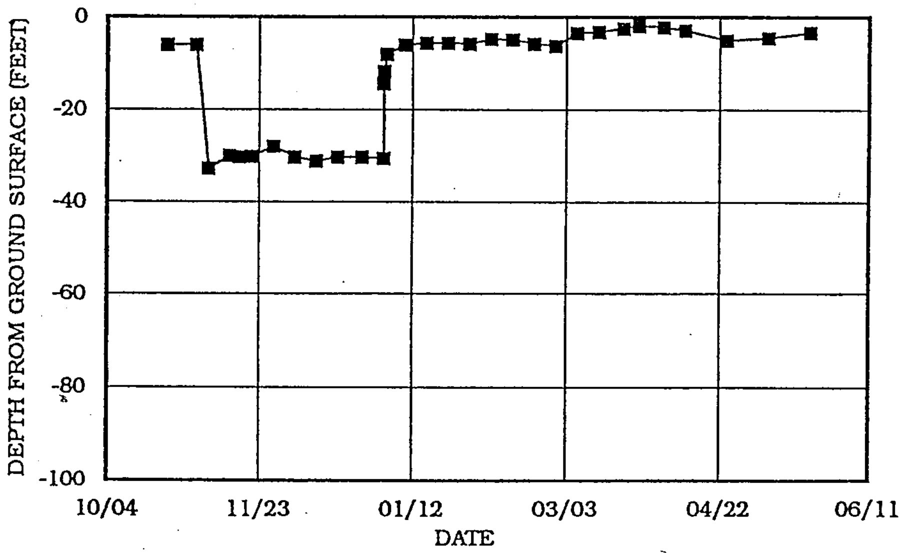
GLENN COUNTY - WELL # 19N01W13M01M

GSE = 86 TOTAL DEPTH = ? WELL USE = Irr

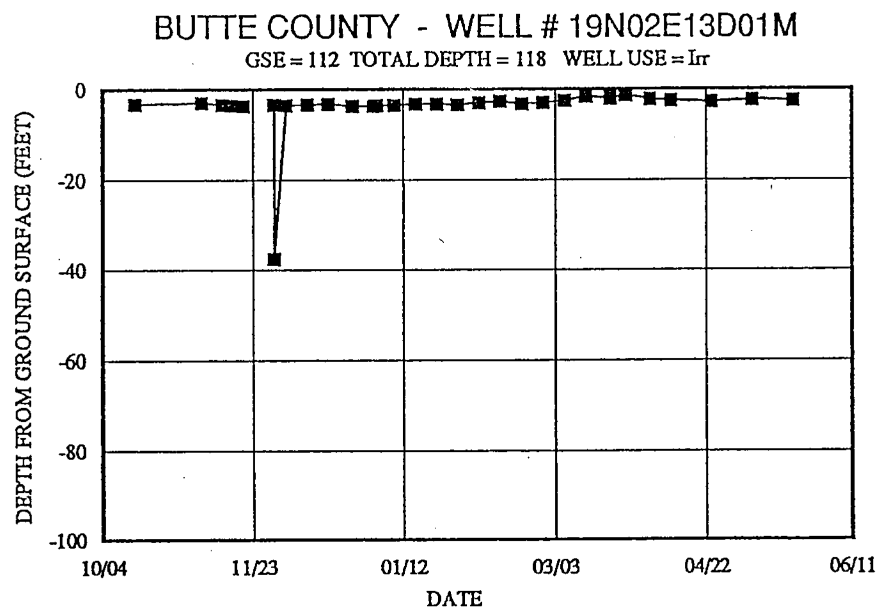


GLENN COUNTY - WELL # 19N01W13Q01

GSE = 86 TOTAL DEPTH = ? WELL USE = IRR



LAMALFA AREA



APPENDIX D
DEFINITION OF ABBREVIATED TERMS

Appendix D Definition of Abbreviated terms

DOM	Domestic
DWR	Department of Water Resources
FT	Feet
GPM	Gallons per minute
GSE	Ground surface elevation
IRR	Irrigation
RPE	Reference point elevation
RPWS	Reference point to water surface (distance to water from measuring point)
WCWD	Western Canal Water District