



Consulting Engineers

TECHNICAL MEMORANDUM NO. 4 GROUNDWATER FEASIBILITY STUDY

DATE: February 26, 2004 Project No.: 702-03-01.04

TO: Dean Eckerson CC: Michael Ban
City of Petaluma Steve Simmons
Pamela Tuft

FROM: Kenneth Loy *KLL*

SUBJECT: Groundwater Resource Evaluation

INTRODUCTION

The City of Petaluma (City) is in the process of developing a new General Plan, which will guide the growth of the City through the year 2025. Current and projected limitations in the availability of regional and local water resources require that the Water Resources Element of the new General Plan provide the planning basis for growth such that the City's demand for water will not exceed the projected availability or sustainable yield of the resource. To provide this basis, the Water Resources Element must accurately project the future demands for water and its availability. In support of this objective, West Yost & Associates (WYA) was retained to evaluate the role that local groundwater may play in the overall water supply for the City. An initial step in this evaluation was the assessment of the local groundwater resources in the vicinity of Petaluma. This draft technical memorandum presents the results of the groundwater resource assessment.

GROUNDWATER PRODUCTION AND WELL YIELDS

The City is primarily reliant upon imported water delivered under contract from the Sonoma County Water Agency (SCWA). Figure 1 shows the annual water production for the City between 1959 and 2002. The volume of water delivered by the SCWA increased from 600 acre-feet annually (afa) in 1959 to 10,700 afa in 2002. Over the same period, City groundwater pumping increased from approximately 700 afa in 1959 to a maximum of approximately 1,400 afa in 1986. Between 1987 and 1991 groundwater pumping decreased to zero, largely as a result of customer complaints over the aesthetic qualities of the groundwater. Groundwater pumping was resumed in 1998 to meet peak demands in the summer months. Between 1998 and 2002, groundwater pumping ranged from 406 to 1,052 afa, satisfying about 10 percent, at most, of the total water demand.

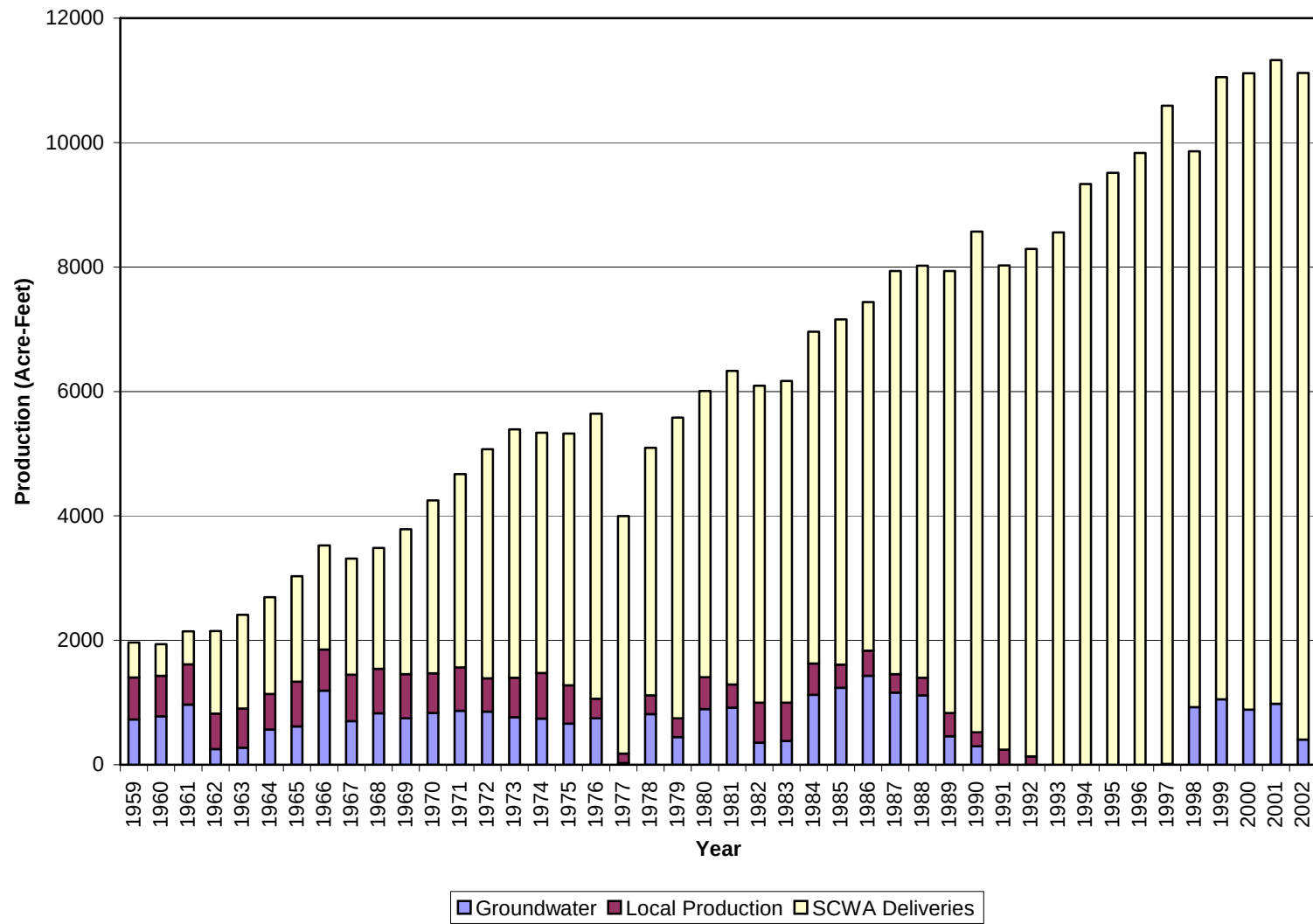


Figure 1
City of Petaluma
Groundwater Resource Assessment
 Historical Water Production

The City has 21 groundwater wells. Table 1 provides a summary of the basic construction and equipping of the wells, and Figure 2 shows their locations. Six of the wells are currently permitted by the California Department of Health Services (DHS) for drinking water supply. One of the active wells (Stony Point) cannot be operated at its full capacity because it produces unacceptable drawdown in neighboring wells. Two of the inactive wells (Scott and Willow Brook) are former agricultural wells that are not constructed in compliance with California drinking water well standards and are not equipped. Two abandoned wells (Stub and Station 5) are also shown on Figure 2, because they factor into the historical groundwater production and their logs help constrain the geology.

The specific capacity of the wells ranges from 1 to 6 gallons per minute per foot of drawdown (gpm/ft). The short-term capacity of the wells, defined as the capacity that could be maintained through a 2-week emergency, ranges from approximately 100 to 1,000 gallons per minute (gpm). However, as indicated by the low specific capacities of the wells, production at these short-term rates can not be maintained due to the large drawdowns and resulting reductions in yield. Summer peaking capacities, defined as the capacity that could be maintained for a four-month period extending from May through August, range from approximately 60 to 180 gpm.

LOCATION AND SUB-BASIN DEFINITION

Figure 2 shows the location of the City in relation to the Petaluma Valley and other regional geographic features. The Petaluma Valley is located in the California Coast Ranges geomorphic province, which consists of a series of northwest to southeast trending mountain ranges and valleys. These mountain ranges and valleys developed as a result of the extensive folding and faulting, which are common throughout the region. Several of the faults remain active. The Petaluma Valley is bounded on the west, north, and east by individual segments of the Coast Ranges and on the south by San Francisco Bay.

California Department of Water Resources (DWR) in *Bulletin 118-4, Evaluation of Ground Water Resources: Sonoma County, Volume 3: Petaluma Valley* (DWR, June 1982) defines a 60,000-acre study area extending from Penngrrove, south to the Marin County line and San Pablo Bay, and from the Two Rock area east to the crest of Sonoma Mountain (Figure 2). The DWR study area encompasses most of the Petaluma River watershed. Figure 3 shows the delineation of the upper Petaluma Valley watershed, which includes the City. For the purposes of this evaluation, the City groundwater sub-basin was taken to be the portion of the Petaluma River watershed that could potentially provide groundwater recharge in the vicinity of the City. This definition of the City groundwater sub-basin differs from the DWR study area (Figure 2) in that the lower Petaluma River watershed, including the entire drainage of San Antonio Creek, was excluded from the City groundwater sub-basin (Figure 3). San Antonio Creek drains the area southwest of the City and enters the Petaluma River downstream of the City. The San Antonio Creek drainage probably does not have a significant influence on groundwater near the City.

The total area of the groundwater sub-basin is approximately 45,000 acres, with approximately two-thirds of this area located northeast of the Petaluma River (Figure 3).

Table 1. City Well Information

Well	Status	Install Date	Well Depth, feet	Screened Intervals, feet	Well Casing Diameter, inches	Specific Capacity ^(a) , gpm/ft	Capacity							
							Short-Term (14 Days)				Summer Peaking (4 Months)			
							Inactive		Permitted		Inactive		Permitted	
							MGD	gpm	MGD	gpm	MGD	gpm	MGD	gpm
Airport	Active	1996	450	220-NA 260-300 380-400 420-400	10	1.75			0.25	173.61			0.21	145.83
Casa de Arroyo	Inactive	1977	229	89-149 209-229	12.75	1.48	0.25	175.00			0.18	125.00		
Condiotti (Garfield)	Inactive	1977	360	220-320 340-360	8	2.18	0.22	150.00			0.12	79.86		
Cross Creek	Standby	1998	480	330-260 320-460	10	1.26			0.13	90.28			0.10	69.44
Frates	Active	1995	500	60-400 480-500	10	1.67			0.25	173.61			0.21	145.83
Kings Mill	Standby	1994	500	200-240 300-400	10	1.04			0.16	111.11			0.13	90.28
Luchessi	Standby	1996	500	180-200 260-280 600-380 400-440	10	2.37			0.22	152.78			0.19	131.94
Miwok (Tahola)	Inactive	1977	425	305-385	8	1.03	0.14	100.00			0.07	48.61		
Park Place	Active	1984	314	80-120 180-185 205-265 285-310	8.675	3.50			0.27	187.50			0.26	180.56
Prince Park North	Active	1993	500	180-240 380-480	8	4.00			0.25	173.61			0.24	166.67
Prince Park South	Active	1993	500	140-180 260-320 440-500	8	5.60			0.24	166.67			0.23	159.72

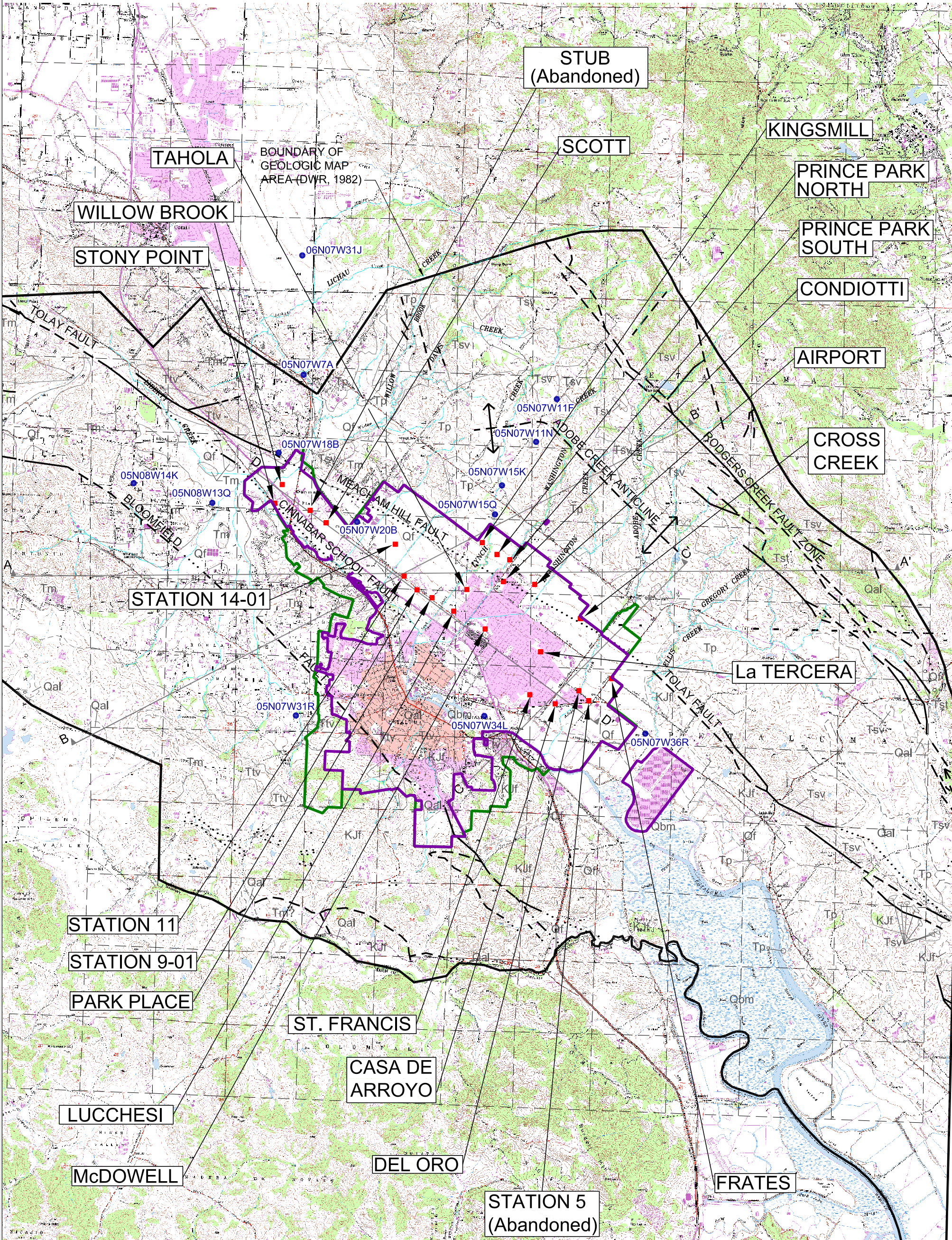
Table 1. City Well Information cont.

Well	Status	Install Date	Well Depth, feet	Screened Intervals, feet	Well Casing Diameter, inches	Specific Capacity ^(a) , gpm/ft	Capacity							
							Short-Term (14 Days)				Summer Peak (4 Months)			
							Inactive		Permitted		Inactive		Permitted	
							MGD	gpm	MGD	gpm	MGD	gpm	MGD	gpm
Scott	Inactive	1949	680	NA	12	4.64	0.25	173.61			0.22	152.78		
Station 9	Standby	1998 ^(b)	523	180-280 320-420	10	1.16			0.17	118.06			0.15	104.17
Station 11	Standby	1998 ^(b)	520	280-500	10	1.11			0.11	76.39			0.09	59.72
Station 14	Inactive	1957	560	52-253 280-538	14	1.70	0.19	129.86			0.10	69.44		
Stony Point	Active	1977	597	318-448 490-580	12.75	4.41			0.86	597.22			TBD ^(c)	TBD
Willow Brook	Inactive	1957 Inactive	409	30-50 125-175 230-255 355-407	12.75	NA	0.25	173.61			0.18	125.00		
La Tercera	Under Construction					1.75			0.22	152.78			TBD	TBD
McDowell	Under Construction					1.48			0.45	312.50			TBD	TBD
St Francis	Under Construction					2.18			0.13	90.28			TBD	TBD
Del Oro	Under Construction					1.26			0.22	152.78			TBD	TBD
Total							1.30	902.08	3.93	2729.17	0.87	600.69	1.81	1256.16

(a) Specific capacities from driller's well test or other City tests after installation.

(b) Redrilled

(c) TBD – To be determined



- CITY WELL CITY OF PETALUMA WELL
- 05N07W15Q APPROXIMATE LOCATION OF WELL WITH DWR HYDROGRAPH
- GEOLOGIC CONTACT, DASHED WHERE APPROXIMATE
- - - - - FAULT, DASHED WHERE APPROX. LOCATED, DOTTED WHERE CONCEALED
- ↕ ANTICLINE, SHOWING APPROXIMATE TRACE OF AXIAL SURFACE AND DIP DIRECTION.
- A — A' LINE OF CROSS SECTION
- CITY LIMIT
- URBAN GROWTH BOUNDARY

REFERENCE:
EVALUATION OF GROUND WATER RESOURCES: SONOMA COUNTY,
VOLUME 3: PETALUMA VALLEY, CALIFORNIA DEPARTMENT OF
WATER RESOURCES BULLETIN 118-4, JUNE 1982
NOTE: SEE TABLE 2 FOR EXPLANATION OF GEOLOGIC UNITS.

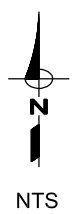
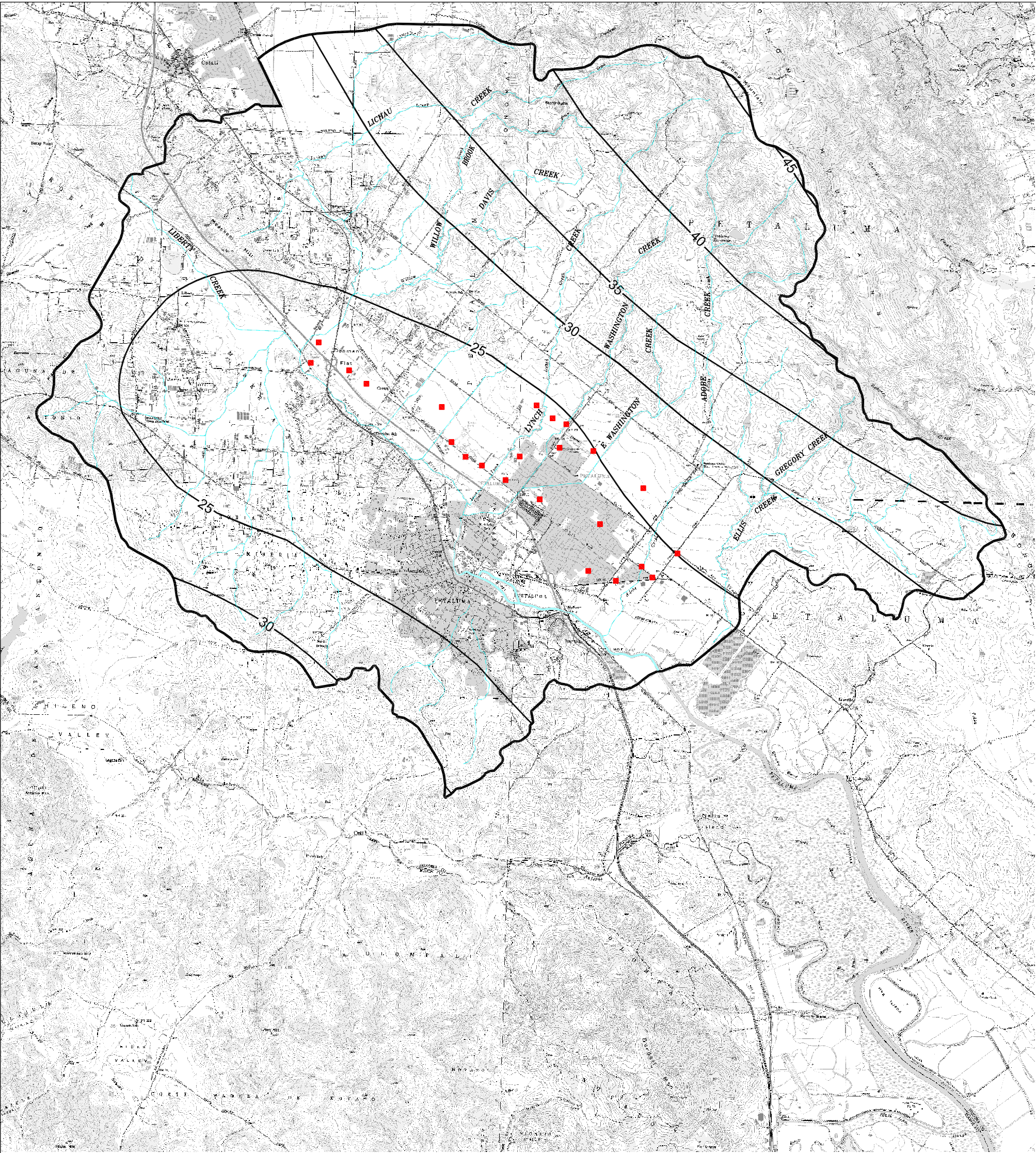


Figure 2
City of Petaluma
Groundwater Resource Assessment
GEOLOGIC MAP &
CROSS SECTION LOCATIONS





LEGEND

GROUNDWATER SUB-BASIN BOUNDARY

30 LINE OF EQUAL MEAN SEASONAL PRECIPITATION IN INCHES

CITY OF PETALUMA WELL

REFERENCE:
SONOMA COUNTY MEAN SEASONAL PRECIPITATION,
SONOMA COUNTY WATER AGENCY, REVISED JUNE 1983

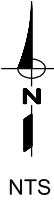


Figure 3

City of Petaluma
Groundwater Resource Assessment
GROUNDWATER SUB-BASIN BOUNDARIES



The elevation of the land surface overlying the groundwater sub-basin ranges from approximately 10 feet above mean sea level (msl) near where the Petaluma River flows out of the sub-basin, to approximately 2,300 feet at the peak of Sonoma Mountain. Typical elevations within the City, and much of the valley floor northeast of the Petaluma River, range from approximately 30 to 60 feet msl. The land surface elevations in most of the area to the northwest of the Petaluma River, exclusive of the City, are higher, ranging from approximately 60 to 200 feet msl. The maximum elevation on the southwest margin of the basin is approximately 560 feet msl.

PRECIPITATION

Figure 3 shows the mean annual precipitation in the City groundwater sub-basin. The mean rainfall varies with the land surface elevation, with the lowest mean rainfall (approximately 25 inches per year) occurring on the valley floor and western portion of the area. Higher mean annual rainfall (approximately 25 to 30 inches per year) occurs over a limited area on the southwestern edge of the basin. The highest rainfall (approximately 30 to 45 inches per year) occurs on the northeastern part of the area on the slopes of Sonoma Mountain. Figure 3 shows that the bulk of the drainage network tributary to the Petaluma River originates on the flanks of Sonoma Mountain. This is a reflection of the larger land surface area northeast of the Petaluma River and the higher elevations in this area, which result in significantly greater average rainfall and runoff.

GEOLOGY

Figure 2 shows the distribution of geologic units compiled by the California Department of Water Resources (DWR) in *Bulletin 118-4, Evaluation of the Ground Water Resources: Sonoma County, Volume 3: Petaluma Valley* (DWR, June 1982). In the following discussion, the geologic units are presented in order from oldest to youngest. Table 2 provides a general summary of the geologic units and their typical hydrogeologic properties.

Table 2. Summary of Geologic Units^(a)

Geologic Unit	Map ^(b) Symbol	Lithology	Specific Yield	Comments
Bay Mud Deposits	Qbm	Mud, rich in organic matter, silty mud, silt and fine sand	Very low (<3%)	Low yields. Generally contain brackish water, either connate or as the result of intrusion.
Alluvium	Qal	Unconsolidated sand, silt, clay and gravel.	Variable (3-15%)	Moderate to high yields. Water quality is excellent. Minor amounts of methane gas. Lenses of very fine sand.
Alluvial Fan Deposits	Qf	Unconsolidated fine sand, silt, and silty clay, coarse sand and gravel, with gravel more abundant near fan heads	Moderate to high (8-17%)	Moderate to high yields. Water quality is excellent. Minor amounts of methane gas. Lenses of very fine sand.

Geologic Unit	Map ^(b) Symbol	Lithology	Specific Yield	Comments
Sonoma Volcanics	Tsv (Tst)	Volcanic flows (labeled Tsv on Figure 2) and tuff, agglomerate and volcanic sediments (Tst).	Highly Variable (0-15%)	Variable yields, yields from Tst generally higher. Boron in some water may affect plants. Some waters thermal.
Merced Formation	Tm (Tmo, Tmr)	Mostly marine coarse-to-fine grained sandstone with minor amounts of clay. Sandstone is typically yellow, gray, or buff-white in surface exposures (Tmo) and distinctively blue in subsurface cuttings (Tmr).	High (10-20%)	Generally high yields. Lenses of very fine sand. Consists of an upper oxidized unit (Tmo) and a lower reduced unit (Tmr). Drillers' well logs generally describe the lower unit as blue sand, blue sandstone, cemented sand, or blue rock with some intervals of blue clay. Zones of high concentration of methane gas and hydrogen sulfide (H ₂ S). May occasionally exceed secondary drinking water standards for iron and manganese. Water not as hard as other formations.
Petaluma Formation	Tp	Mostly non-marine clay and shale with minor amounts of sandstone.	Low (3-7%)	Generally low yields. Yields may be higher for wells penetrating lenses of coarse material. Merced and Petaluma formations deposited at about the same time – drillers' logs indicate alternating layers of blue sandstone and blue clay. Zones of hydrogen sulfide (H ₂ S). May contain objectionable levels of iron and manganese
Tolay Volcanics	Ttv	Volcanic flows, tuffs, breccias and agglomerates.	Highly Variable (0-10%)	Variable yields. Fair to good water producer west of the City.
Franciscan Complex	KJf	Mélange, including chert, sandstone, shale, greenstone and serpentinite.	Very low (<3%)	Low yields. Poor quality water in thermal and serpentinite areas. Good quality south of the City.

(a) Based on Table I in DWR Bulletin 118-3, Evaluation of Ground Water Resources Sonoma County, Volume 3: Petaluma Valley (June 1982).

(b) Map symbols used on Figure 2.

Franciscan Complex

Jurassic and Cretaceous rocks of the Franciscan Complex are the oldest rocks in the vicinity of Petaluma. These rocks underlie the adjacent ranges and are probably present at depth beneath the valley floor. The Jurassic and Cretaceous age rocks are composed mostly of metasedimentary and other metamorphic rocks that locally yield small quantities of water from fractures and permeable lenses (Kunkel and Upson, 1960).

The Franciscan Complex is exposed at the surface south of the City (Figure 2). Limited surface exposures are also present southeast of the City along the trace of the Tolay Fault.

Tolay Volcanics

The Miocene to early Pliocene Tolay Volcanics were originally mapped as Sonoma Volcanics, but radiometric age dating has shown that extrusion of the Tolay Volcanics occurred before deposition of the Petaluma and Merced Formations and extrusion of the Sonoma Volcanics (DWR, 1982). The Tolay Volcanics consists of lava flows, breccias, tuffs and agglomerates with interbedded stream channel deposits (Morse and Bailey, 1935; DWR, 1982).

According to DWR (1982), the Tolay Volcanics have a highly variable specific yield, and are considered to be a fair to good water producer west of Petaluma. The lava flows are essentially nonwater bearing except where highly fractured by faulting.

The Tolay Volcanics are exposed at the surface south of the City and on Meacham Hill (Figure 2).

Petaluma Formation

The mid-to-late Pliocene Petaluma Formation consists of continental and shallow marine to brackish water deposits of clay, shale, and sandstone with lesser amounts of conglomerate and nodular limestone and occasional thick beds of diatomite (DWR, 1982). The formation is characterized by abundant clay. A 1,059-foot stratigraphic section of the Petaluma Formation near Lakeville contained 70 percent clay, shale and clayey or shaley beds (Weaver, 1949, DWR; 1982). Hydrogen sulfide has been found in wells penetrating the Petaluma Formation in the Santa Rosa Plain (DWR, 1982).

The Petaluma Formation is capable of yielding moderate amounts of water to wells provided that appreciable thicknesses of sand and gravel are penetrated by the screened section of the well. The unit has a low overall specific yield because of the large percentage of fine-grained material (Table 2).

The Petaluma Formation is exposed over much of the northeastern portion of the sub-basin but is not present west of the Petaluma River (Figure 2).

DWR (1975) states that “the area from the vicinity of Lakeville southeast is stratigraphically indefinite” because of disagreement in the geologic literature over whether the rocks in the area should be assigned to the Petaluma or Merced Formations. The upper part of the Petaluma Formation may be contemporaneous with the Merced Formation. Therefore, following the interpretation of DWR (1975), fossiliferous sandstones, indicative of the Merced Formation, found within the Petaluma Formation are interpreted to be individual beds of the Merced Formation.

Merced Formation

The Miocene to Pliocene Merced Formation consists of an upper oxidized continental unit of brown sandstone, clay and gravel, and a lower reduced, shallow marine unit of blue sandstone with shells. The two units are separated by an erosional surface and sometimes by lava flows of the Sonoma Volcanics (DWR, 1982). Marine fossils are abundant within the lower unit, and are generally noted as clamshells on drillers’ logs. Also common are zones of poorly consolidated very fine sand, frequently reported by drillers as quick sand (DWR, 1982). High concentrations of methane have been found in well penetrating the Merced Formation in the Santa Rosa Plain.

Hydrogen sulfide has been encountered in a City municipal well (Condiotti) installed in the Merced Formation (DWR, 1982).

Both units of the Merced Formation are excellent aquifers. When not separated by lava flows the units are hydraulically connected. When lava flows are present the water in the lower unit can be confined (DWR, 1982).

The Merced Formation is present northwest of the City and is also mapped at the land surface north of the City in the vicinity of Meacham Hill (Figure 2). According to DWR (1982), the lower unit of the Merced Formation is present at a depth of approximately 250 feet beneath Petaluma Valley. Cardwell (1956) noted that the permeability of the Merced Formation is lower in the southeastern part of the sub-basin than in the northwestern part.

Sonoma Volcanics

In the vicinity of the City, the Pliocene Sonoma Volcanics consists of a thick and heterogeneous sequence of basalt, andesite and rhyolite flows interbedded with locally welded, pumiceous ash flow tuff and volcanic sedimentary deposits, including tuffaceous sands and volcanic gravels (Fox, et. al., 1973; Ford, 1982; DWR, 1982). Because of their heterogeneous nature, the Sonoma Volcanics have a highly variable specific yield. In the Petaluma Valley, the volcanic flow rocks are essentially nonwater bearing except where fractured by fault activity (DWR, 1982).

The Sonoma Volcanics are present at the surface near the crest of Sonoma Mountain, southeast of the City along the trace of the Tolay Fault and near the north edge of the City (Figure 2).

Alluvial Fan Deposits

Pleistocene to Holocene (Recent) alluvial fan deposits form a nearly continuous layer over the northeastern Petaluma Valley (Figure 2). These deposits consist of poorly sorted coarse sand and gravel and moderately sorted fine sand, silt, and silty clay. The gravel content increases near the heads of the alluvial fan deposits.

The alluvial fan deposits contain lenses of very fine sand, which may be derived from the fine sands of the Merced Formation. These sands are frequently the cause of sanding problems in wells. The alluvial fan deposits may contain minor amounts of methane gas, which is thought to have migrated from the underlying formations (DWR, 1982).

The alluvial fan deposits typically have moderate to high yields, and excellent water quality (Table 2).

Alluvium

Pleistocene to Holocene alluvium forms thin surficial deposits along the creeks in the Petaluma Valley. The alluvium is composed of interbedded sand, silt, clay and gravel. The deposits have a variable specific yield depending on the proportions of these constituents and the thickness of the alluvium. Most deposits are less than 100 feet thick (DWR, 1982). Within the study area, alluvium is only mapped beneath central Petaluma (Figure 2).

Bay Mud Deposits

Holocene bay mud deposits cover the southern part of the Petaluma Valley but are only present in a relatively small part of the study area, in the vicinity of the Petaluma River (Figure 2). They are typically composed of mud, silty mud, and silt with small amounts of sand and are rich in organic material (DWR, 1982). The bay mud deposits typically contain brackish to saline water trapped at the time of deposition. The bay mud deposits have very low permeability and specific yield (Table 2).

GEOLOGIC STRUCTURE

Deposition of the Sonoma Volcanics, Merced Formation and Petaluma Formation began in the mid Miocene, but the formations are mostly Pliocene age (1.8 to 5 million years). Deposition of the Petaluma Formation began somewhat earlier than Merced Formation and the Sonoma Volcanics, but otherwise the formations were formed over similar time frames in adjacent geographic areas. Most of the Merced Formation was formed in a shallow marine environment, while most of the Petaluma Formation and all of the Sonoma Volcanics were formed on land. Interbedding probably exists at the original depositional contact between Merced Formation and Petaluma Formation, and units of the Sonoma Volcanics are known to exist within the Merced and Petaluma Formations. Subsequent faulting has probably significantly affected the lateral and, to a somewhat lesser extent, vertical contact relationships between the formations. Folding, predominately in the Petaluma Formation, has probably affected the hydraulic properties of this formation.

Faults

Faults may affect groundwater flow by bringing geologic materials with different hydraulic properties into contact across the fault plane or by fracturing the materials, which could either increase or decrease permeability depending on the degree of fracturing and other geologic processes, such as mineralization, active within the fault zone. Faults can, therefore, act as boundaries or barriers affecting the lateral flow of groundwater between adjacent areas and can act as conduits allowing vertical or lateral flow within the fault zone.

Four faults or fault systems are documented within the City groundwater sub-basin. Offset along the faults is probably dominated by right lateral strike slip, with southeast-northwest displacement consistent with the San Andreas fault system; however, vertical displacement has probably also occurred. Both senses of motion have probably affected the rock types encountered in the vicinity of the City.

The Rodgers Creek fault zone is a major, seismically active, fault zone located in the northeastern part of the groundwater sub-basin. The trace of the fault zone coincides with Rodgers Creek to its headwaters (Figure 2). Thereafter, the fault zone continues its northwesterly trend across the southwestern flank of Sonoma Mountain. Because the fault zone is located near the margin of the groundwater basin it is unlikely to have a significant influence on groundwater flow.

The Tolay Fault is mapped at the surface in rocks to the east and southeast of the City, where it brings rocks of the Franciscan Complex in contact with the Petaluma Formation. Relatively small slivers of rock mapped as Sonoma Volcanics are also present along this section of the fault trace (DWR, 1982). The Tolay Fault is also mapped to the northwest of the City along the southwestern flank of Meacham Hill, where it offsets rocks of the Merced Formation (Fox, et. al., 1973). The fault is inferred to be continuous between the mapped areas but buried beneath alluvial fan deposits. The trace of the inferred buried section of the fault passes beneath the City in the vicinity of the airport and is shown as the Meacham Hill fault on Figure 3. The fault probably impedes groundwater flow where it brings the Merced or Petaluma Formation on the northeast side of the fault in contact with low permeability rocks of the Franciscan Complex on the west side of the fault. The effect of the inferred buried section of the fault on groundwater flow is unknown. There is no significant identified change in groundwater elevations across the inferred trace of the fault, and displacement of geologic units has not been recognized in well drillers' logs.

The Cinnabar School Fault offsets the Merced Formation at the base of the hills north and northwest of the City (DWR, 1982). The fault merges with the Tolay Fault mapped by Fox, et. al. (1973) at Meacham Hill and extends southeast to approximately Lynch Creek in the subsurface, based on well drillers logs (Ford, 1982). The fault brings the upper oxidized unit of the Merced Formation in contact with the lower reduced unit. According to DWR (1982), the upper oxidized unit is not present on the northeast side of the fault.

The Bloomfield Fault is located northwest of the City and primarily offsets rocks of the Merced Formation (Figure 2). The fault's effects on groundwater flow are presently unknown.

Folds

The permeability and other material properties of sedimentary rocks, such as the Merced and Petaluma Formations, are typically anisotropic due to the alignment of mineral grains along bedding planes during deposition of the sediments. This alignment of the mineral grains results in higher permeability along than across bedding plans. Subsequent folding of the bedding planes causes a reorientation of the direction of maximum and minimum permeability.

The Petaluma Formation has numerous folds, the largest of which is the Adobe Creek Anticline, located on the flank of Sonoma Mountain northeast of the City (Figure 2). This structure is aligned in such a way that the bedding planes are sloping downwards from Sonoma Mountain toward the City in more or less the same orientation as the topographic surface and the direction of groundwater flow.

Major folds have not been identified in the Merced Formation, but the entire formation dips slightly to the east (DWR, 1982).

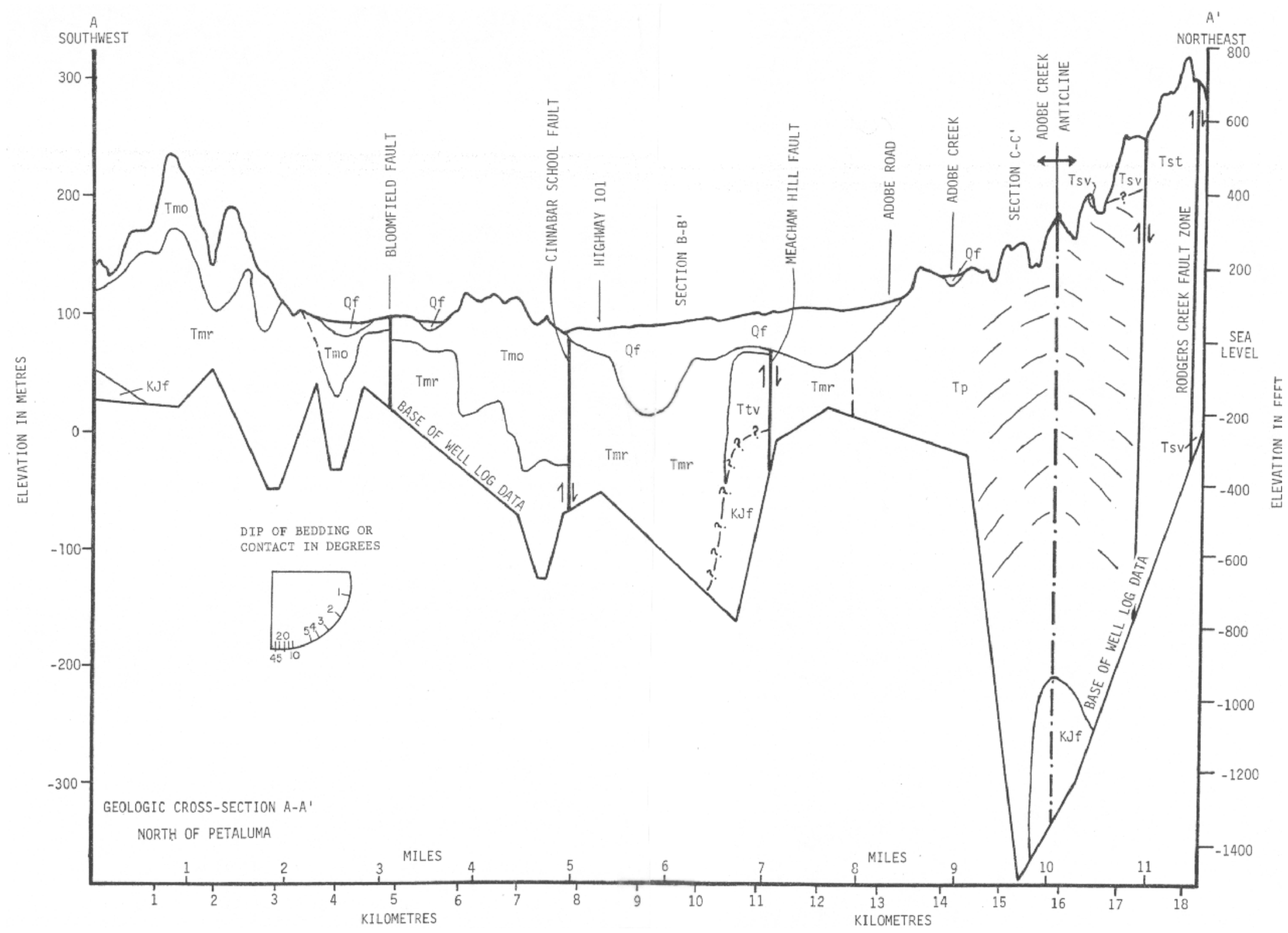
WELL FIELD GEOLOGIC CONDITIONS

Figure 2 shows the locations of the City wells in relation to the mapped geologic units and structure. Figures 4 through 7 are geologic cross sections through the groundwater sub-basin in the vicinity of the City wells. The cross sections shown on Figures 4 through 6 are oriented approximately perpendicular to the geologic structure. Therefore, these cross sections show the subsurface relationships between the geologic units and the mapped faults, as interpreted from confidential well drillers logs by DWR (DWR, 1982). The cross section shown on Figure 7 is oriented approximately parallel to the geologic structure and shows the relationship between the geology and the construction of many of the city's production wells.

Based on the geologic mapping shown on Figure 2, all of the wells are located east of the Cinnabar School Fault, with the possible exception of the Stony Point well. According to DWR (1982) the upper oxidized unit of the Merced Formation is not present east of the Cinnabar School Fault (Figures 4 and 5). The log of the Stony Point well indicates the presence of yellow, shell-bearing sandstone, which is probably the upper oxidized unit of the Merced Formation (Figure 7). This may mean that the Stony Point well is located on the west side of the Cinnabar School Fault. Alternatively, the upper oxidized unit of the Merced Formation is present east of the fault in the vicinity of the Stony Point, former Stub and Scott wells, possibly extending as far south as the Station 11 well (Figure 7). With the exception of the Stony Point well, the logs for these wells are not sufficiently detailed to confirm the presence of the upper oxidized unit, but, for example, in the Station 14 well, blue sands and clays indicative of the lower reduced unit of the Merced Formation were not noted above a depth of 270 feet (Figure 7). The upper oxidized unit was not noted in the Willow Brook well log, constraining the unit's northeasterly extent.

Bluish sediments containing cemented sands and gravels with occasional shells were encountered between the Willow Brook well and the Lucchesi well to depths of at least 690 feet (Figure 7). Based on the relatively high percentage of sand and gravel and on the presence of shells, the sediments are probably part of the lower reduced unit of the Merced Formation. The Merced Formation is exposed to the north of the wells at Meacham Hill (Figure 2).

The Lucchesi well appears to mark the approximate southerly extent of the Merced Formation beneath the McDowell Boulevard corridor (Figure 7). The gray, sandy rock encountered near the bottom of the Lucchesi well may be a part of the Franciscan Complex, and farther to the south at the McDowell well, competent rock was encountered at a depth of approximately 190 feet. Although a lithologic log was not prepared for the McDowell well, City staff reported that the drilling and pump testing conditions were consistent with fractured volcanic rock. DWR (1982) inferred the presence of the Franciscan Complex and Tolay Volcanics along a portion of the Meacham Hill Fault northeast of the McDowell well (Figure 4). Figure 7 is drawn consistent with this interpretation. Further evidence of a subsurface fault block containing rocks of the Franciscan Complex was found in the St. Francis well, where metasedimentary rocks were encountered beginning at a depth of approximately 280 feet. Rocks of the Franciscan Complex are exposed to the southeast of the wells, along the west side of the Tolay Fault (Figure 2).

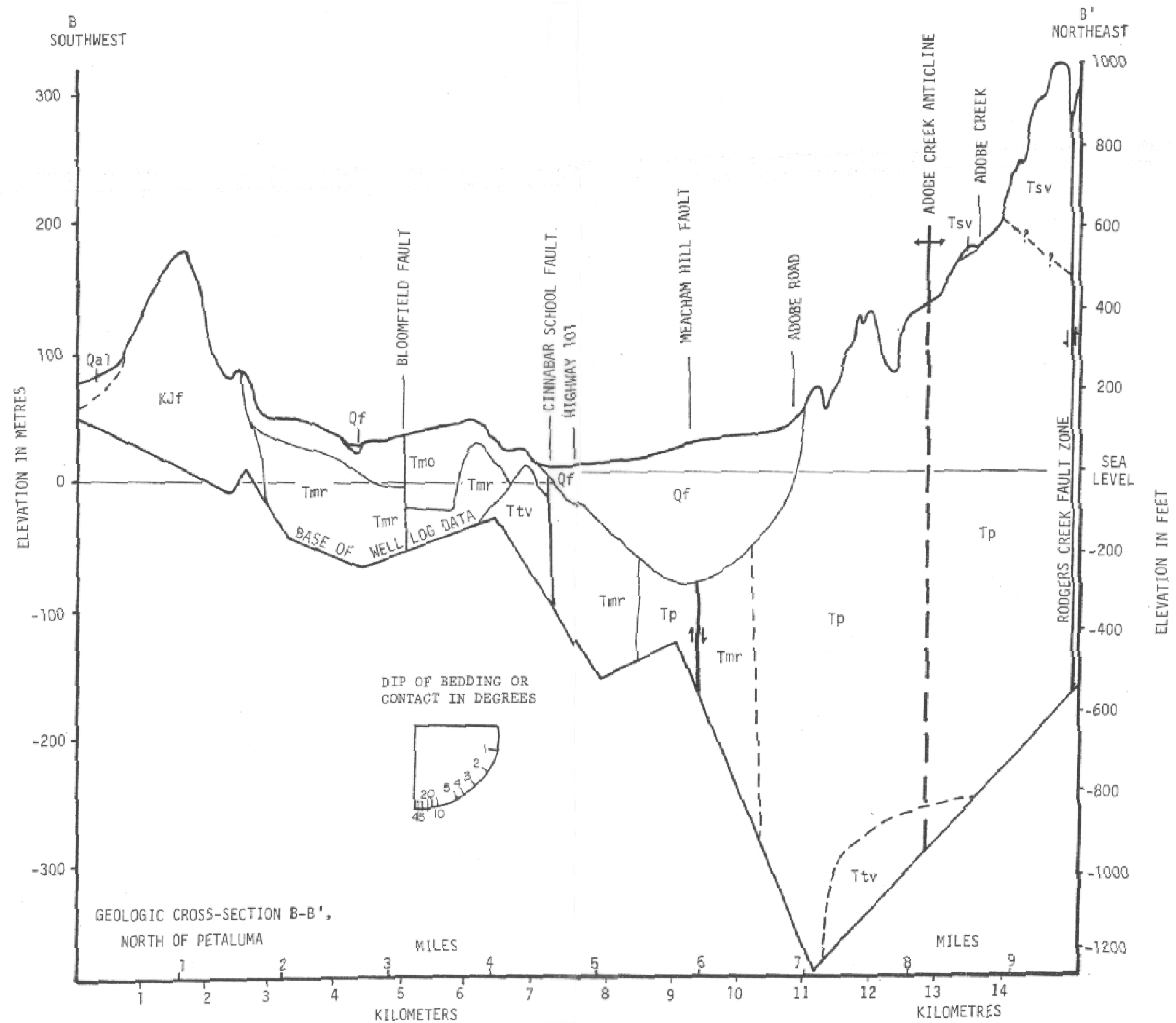


NOTE:
SEE TABLE 2 FOR EXPLANATION OF GEOLOGIC UNITS.

REFERENCE: EVALUATION OF GROUND WATER RESOURCES: SONOMA COUNTY, VOLUME 3: PETALUMA VALLEY, CALIFORNIA DEPARTMENT OF WATER RESOURCES BULLETIN 118-4, JUNE 1982.

Figure 4

City of Petaluma
Groundwater Resource Assessment
CROSS SECTION A-A'



NOTE:
SEE TABLE 2 FOR EXPLANATION OF GEOLOGIC UNITS.

REFERENCE: EVALUATION OF GROUND WATER RESOURCES: SONOMA COUNTY, VOLUME 3: PETALUMA VALLEY, CALIFORNIA DEPARTMENT OF WATER RESOURCES BULLETIN 118-4, JUNE 1982.

Figure 5

City of Petaluma
Groundwater Resource Assessment
CROSS SECTION B-B'

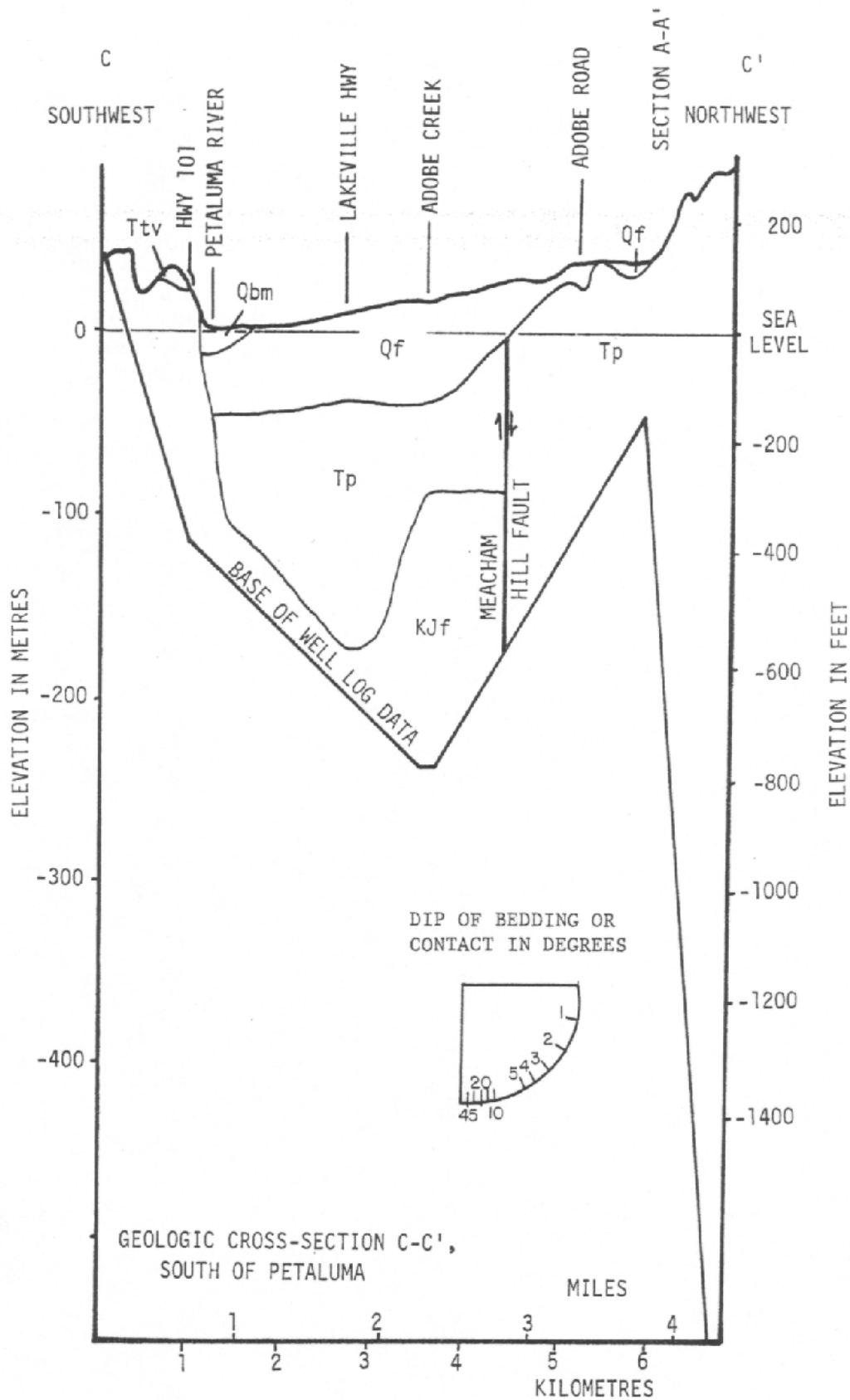


Figure 6

NOTE:
SEE TABLE 2 FOR EXPLANATION OF GEOLOGIC UNITS.

REFERENCE: EVALUATION OF GROUND WATER RESOURCES:
SONOMA COUNTY, VOLUME 3: PETALUMA VALLEY,
CALIFORNIA DEPARTMENT OF WATER RESOURCES BULLETIN
118-4, JUNE 1982.

City of Petaluma
Groundwater Resource Assessment
CROSS SECTION C-C'

WEST
YOST
& ASSOCIATES

A relatively thick sequence of alluvial fan sediments appears to be present south of the McDowell well, in the vicinity of the St. Francis and Casa de Arroyo wells. The Casa de Arroyo well is currently inactive, in part due to sand production. Most of the screened interval of the well appears to be in the alluvial fan sequence. The sand may be due to the presence of fine-grained sands in the alluvial fan sequence. These sands are thought to be derived from the Merced Formation (DWR, 1982). A large proportion of the screened interval of the St. Francis well also appears to be in the alluvial fan sequence, possibly indicating that the well could be susceptible to sand production.

The Kingsmill, Prince Park North, Prince Park South and Airport wells are probably located on the east side of the Meacham Hill Fault and probably produce water from the Merced Formation (Figure 2). The location of the Meacham Hill Fault is only approximately known beneath the Petaluma Valley. Surface geologic mapping compiled by DWR (1982) shows surface exposures of the Merced Formation in the hills to the northwest of the wells (Figure 2). DWR (1982) also inferred the presence of the Merced Formation in the subsurface on the east side of the Meacham Hill Fault at least as far south as the Airport well (Figures 4 and 5). Farther south, possibly beginning in the vicinity of the Cross Creek well, the Merced Formation does not appear to be present east of the Meacham Hill/Tolay Fault, either at the surface or in the subsurface (Figures 3 and 6).

Aquifer Hydraulic Properties

The hydraulic properties of the aquifer system in the vicinity of the City wells are not well known. Judging from the low specific capacities of the wells (Table 1) and the relatively fine-grained nature of the aquifer materials, the average hydraulic conductivity is probably low. The transmissivity and hydraulic conductivity in the vicinity of the Stony Point well were roughly estimated based on the rate of water level recovery in the well after it was used to supply supplemental water during the summer of 2003. The calculated transmissivity was 300 ft²/day. The calculated hydraulic conductivity was 1.4 ft/day, assuming that the aquifer thickness was equal to the 220-foot screened interval of the well. These values probably represent the upper limits of transmissivity and hydraulic conductivity in the most permeable zones encountered by the City wells, because the Stony Point well has a relatively high specific capacity (for a City well) and appears to be one of the few wells screened in the upper oxidized unit of the Merced Formation.

WATER QUALITY

The City performs chemical analyses for California Title 22 constituents to ensure compliance with the Department of Health Services requirements for permitted production wells. Comprehensive information on groundwater quality for the Petaluma groundwater sub-basin is not available. For the purpose of this TM the available water quality information was reviewed to obtain a general assessment of groundwater quality in the sub-basin and how water quality may constrain the use of groundwater.

Water quality information that was reviewed for this analysis included:

- Selected Title 22 water quality analysis performed by the City for permit compliance,
- *Bulletin 118-4, Evaluation of the Ground Water Resources: Sonoma County, Volume 3: Petaluma Valley* (DWR, June 1982), and
- *Geohydrology as Applied to Land Use Problems in the West Petaluma Area, Sonoma County, California*, Master's Thesis, California State University, Sacramento (Ford, R.S., 1982).

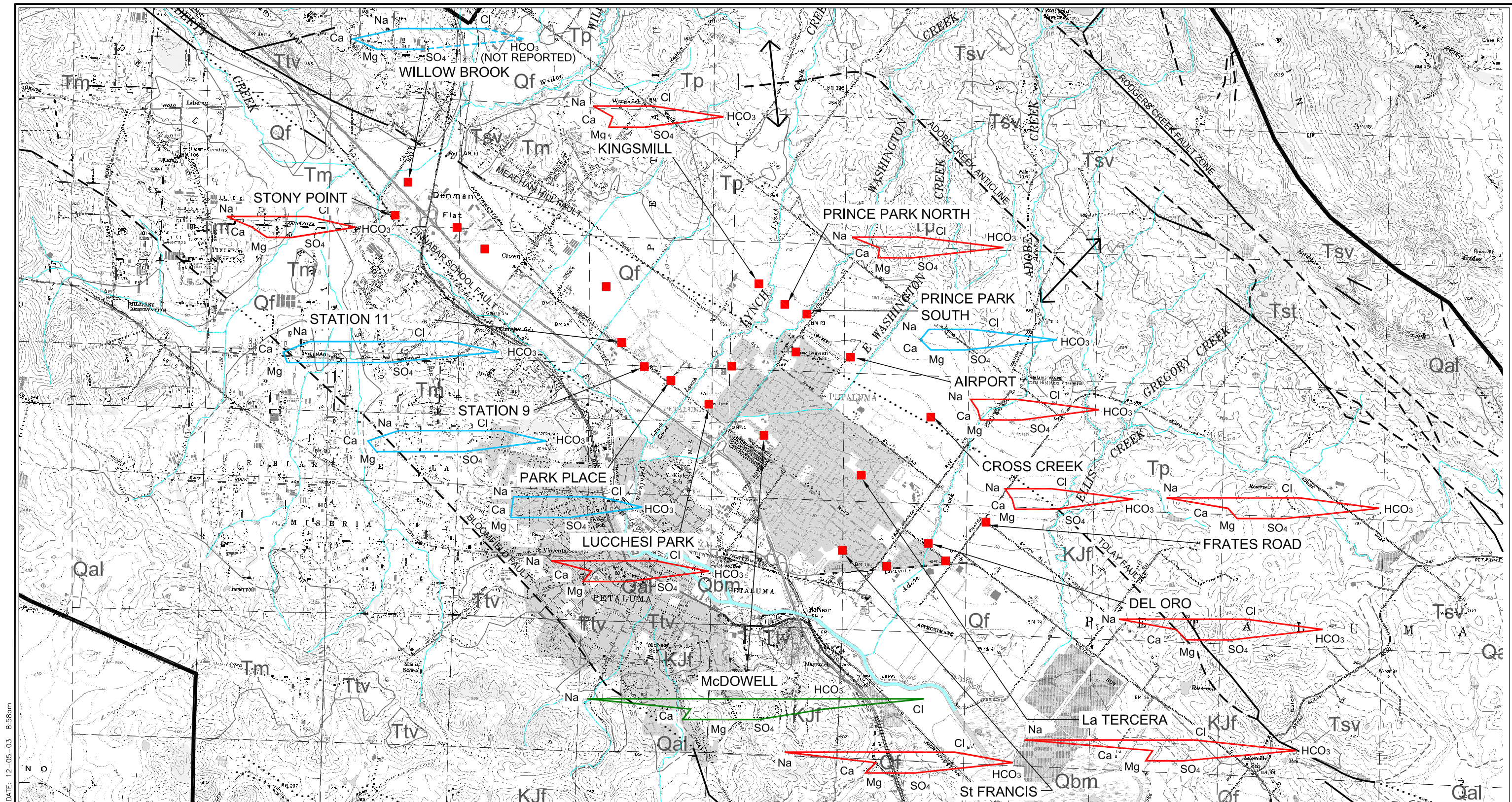
The following sections present an overview of the general water quality in the Petaluma sub-basin; the occurrence of naturally occurring chemical constituents that could require treatment; non-point sources of groundwater pollution; and aesthetic considerations.

Major Naturally-Occurring Constituents in Groundwater

All groundwater contains dissolved constituents that are products of natural processes of the hydrologic cycle. Rainfall contains only small concentrations of dissolved constituents. On reaching the land surface, dissolution of minerals contributes dissolved ions, including calcium, magnesium and sodium, the major cations (positively charged ions) found in groundwater, and sulfate and chloride, which, along with bicarbonate, are the major anions (negatively charged ions) typically found in groundwater. The bicarbonate ion is formed by dissolution of carbon dioxide from the atmosphere and released by organic processes in the soil. Dissolved carbon dioxide contributes to the dissolution of minerals as water is recharged. The quantity of dissolved salts depends on the specific surface area of the aquifer material, the solubility of the minerals present, the pH and Eh of the system and the residence time of the water in the aquifer.

Total dissolved solids (TDS) concentrations in the City production wells (active and inactive) range from 282 milligram per liter (mg/l) in the Prince Park South well to 750 mg/l in the McDowell Park well (Figure 8 and Attachment A). Wells nearest the margins of the sub-basin, for example Prince Park North, Prince Park South, Kingsmill and Stony Point, had the lowest TDS concentrations. These wells are located relatively near the margin of the groundwater sub-basin in the vicinity of ephemeral streams (Lynch Creek and Washington Creek). The relatively low TDS concentrations measured in the wells may be an indication that the wells are located near areas where groundwater recharge is occurring.

Figure 8 shows the major constituents that contribute to the TDS concentrations. The major constituent concentrations are expressed in milliequivalents per liter (meq/l), which are equal to concentration in mg/l times the combining weight of the ionic species. The combining weight of an ion is its formula weight divided by its charge. Ideally, the concentration of anions and cations expressed in meq/l will be equal.



LEGEND:

Milliequivalents per milliliter
-8.5 -7.5 -6.5 -5.5 -4.5 -3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5

Cations: Na, Ca, Mg
Anions: Cl, HCO₃, SO₄
MAJOR ION CONCENTRATION IN MILLIEQUIVALENTS PER LITER

■ MUNICIPAL WELL LOCATION

COLOR INDICATES WATER TYPE

Red arrow: Na-HCO₃
Blue arrow: Ca, Mg-HCO₃
Green arrow: Na-Cl



Figure 8

City of Petaluma
Groundwater Resource Assessment
WATER QUALITY IN CITY WELLS



In most of the City wells the major cations present are calcium, magnesium and sodium in roughly equal concentrations. However, sodium is the dominant cation in the McDowell, La Tercera, Lucchesi, St. Francis, Del Oro and Frates wells. This suggests a pattern similar to the distribution of TDS concentrations, in that wells located closest to the margins of the sub-basin have the lowest ratio of sodium to calcium (Figure 8 and Attachment A). The Piper diagram in Figure 9 also illustrates this trend. The Piper diagram is a plot of percentage concentrations of major cations and anions found in the City wells. Since the Piper diagram shows all of the results on a single plot, it is well suited for depicting water quality trends.

As a general rule, the ratio of sodium to calcium and magnesium concentrations in groundwater increases with residence time. This is due to cation exchange, which can be thought of as a natural water softening process that occurs when groundwater containing calcium and magnesium comes in contact with clay containing exchangeable sodium. The longer the water is in contact with the aquifer, the higher the ratio of sodium to calcium and magnesium, and the softer the water. This relationship may be obscured by other factors, including geologic heterogeneities that may cause variation in the sodium concentrations, independent of the residence time of the groundwater, and saltwater intrusion. These factors notwithstanding, the relative concentrations of sodium, calcium and magnesium in the wells may also indicate recharge zones.

The anions were typically dominated by bicarbonate with lesser concentrations of sulfate and chloride. The distributions of chloride and sulfate were similar to TDS and sodium, with the lowest concentrations detected in peripheral wells (e.g., Prince Park South) and the highest concentrations nearest the center of the sub-basin (e.g., Station 11 and McDowell). The McDowell well had atypically high sodium and chloride concentrations (Figure 9).

The Willow Brook well appeared to be an exception to the general trends in major ion concentrations. The well had a higher than expected TDS concentration, given the well's location near the periphery of the sub-basin. A possible explanation is that the sample results for the well are significantly older than for the other wells (1991). The year 1991 was near the end of a relatively significant drought period, implying that TDS concentrations may vary with hydrologic conditions and the amount of groundwater recharge.

Hardness results from divalent cations, primarily calcium and magnesium, dissolved in groundwater. These ions interact with soap to form precipitates and with other anions to form scale. Water from the City wells is moderately hard (75 to 150 mg/l as calcium carbonate) to very hard (over 300 mg/l as calcium carbonate) (Attachment A).

Minor Naturally-Occurring Constituents in Groundwater

Minor naturally occurring constituents that could constrain the City's use of groundwater for potable supply and which have been detected in the City's wells include arsenic, iron, and manganese. Figure 8 shows the locations of the wells referred to in the following discussion. Selected results for arsenic, iron and manganese are provided in Attachment A.

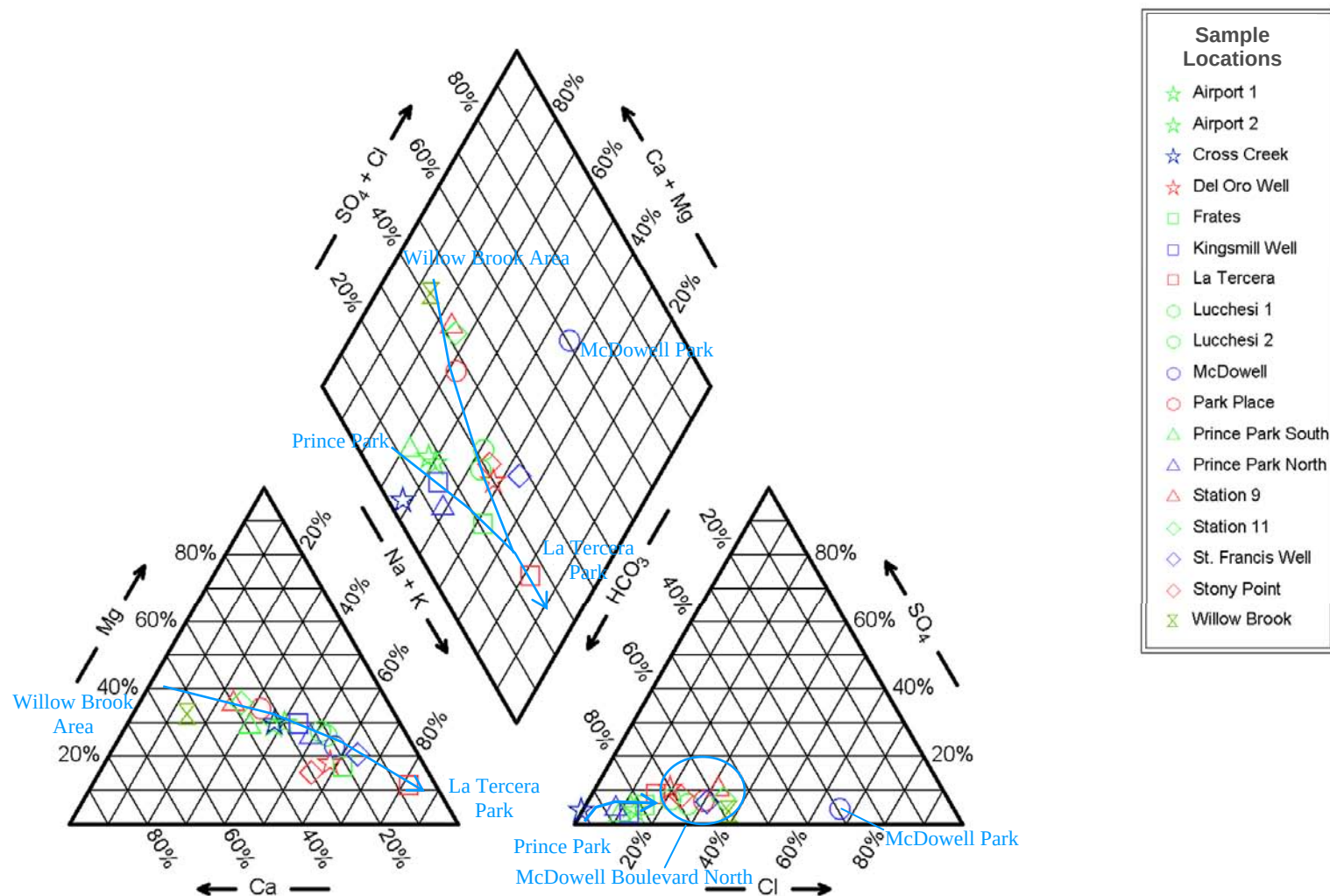


Diagram shows variation in groundwater quality along possible flow paths from recharge areas to the interior of the Petaluma groundwater sub-basin.

Figure 9
City of Petaluma
Groundwater Resource Assessment

Piper Diagram

Arsenic

Arsenic is a naturally occurring constituent in groundwater and commonly occurs at concentrations ranging from 10 to 50 micrograms per liter ($\mu\text{g/l}$) in the western United States, where it is typically associated with volcanic deposits and geothermal systems (Welch, et. al., 1988).

Arsenic has been detected in the City wells at concentrations ranging from less than 2 to 11 $\mu\text{g/l}$ (Attachment A). The Frates well was the only well in which the arsenic concentration exceeded the pending 10- $\mu\text{g/l}$ federal MCL (Figure 8 and Attachment A). The well is located in the northeastern portion of the groundwater sub-basin near the trace of the Meacham Hill Fault. Possible factors contributing to the occurrence of arsenic in this area may be the presence of volcanic rocks containing arsenic in the vicinity of the fault (Figures 2 and 4 through 7); the presence of arsenic-bearing mineralization in the fault zone; movement of arsenic-bearing groundwater within the fault zone; and relatively low oxidation reduction potential in the area.

Iron

Iron concentrations in the City wells ranged from less than 100 to 630 $\mu\text{g/l}$. The iron concentrations exceeded the 300- $\mu\text{g/l}$ MCL in four wells: McDowell, Willow Brook, St. Francis and Del Oro (Figure 8 and Attachment A).

Manganese

Manganese concentrations in the City wells ranged from less than 0.02 to 140 $\mu\text{g/l}$. The manganese concentrations exceeded the 50- $\mu\text{g/l}$ MCL in seven wells: Airport, McDowell, Willow Brook, Station 9, Prince Park South, St. Francis and Del Oro (Figure 8 and Attachment A).

Non-point Sources of Groundwater Pollution

Non-point sources of groundwater pollution are diffuse discharges that occur over a wide area. Non-point sources of groundwater pollution reported in the Petaluma groundwater sub-basin include nitrate, coliform organisms and saltwater intrusion. These are assessed below.

Nitrate and Coliform

Nitrate is a naturally occurring compound that forms when nitrogen and oxygen combine in the soil. Nitrate occurs naturally in groundwater or can be introduced through a variety of land uses, including row crop agriculture, irrigated agriculture and various waste disposal practices. Typical waste materials resulting in nitrate pollution include animal manures from commercial poultry, dairy, hog and beef operations; wastewater treatment plant effluent applied to land; household wastes disposed of in septic systems; and landfill leachate.

Small amounts of nitrate in groundwater are normal, but larger concentrations can result in serious health problems. The 45-mg/l MCL for nitrate (quantified as nitrate as opposed to nitrogen) is considered by the State and Federal governments to be the maximum concentration that can be safely consumed from a public water system. Excessive nitrate consumption can lead to health problems, including irritation of gastrointestinal tract and bladder; and methemoglobinemia, or blue baby syndrome, so named because affected infants take on a bluish

tinge. Blue baby syndrome is caused when nitrate is converted to nitrite by bacterial activity in the stomach. Typically, in adults, this bacteria is destroyed by stomach acid. The stomachs of infants (especially less than 3 months of age in humans) are not fully developed and do not produce strong acids. This allows the bacteria to survive, leading to the build up of nitrite in the blood. The nitrite oxidizes the ferrous iron in the blood to ferric iron, thereby limiting its ability to carry oxygen to the cells. The syndrome is readily treated if diagnosed.

Serious nitrate contamination has been documented in the western portion of the Petaluma groundwater sub-basin (Ford, 1982; DWR, 1982). A case of blue baby syndrome was diagnosed in the winter of 1978-1979. This led to an extensive sampling program conducted jointly by DWR, the California Department of Health Services and the Sonoma County Health Department in 1979. Of 200 wells sampled, 33 percent had nitrate concentrations greater than the 45-mg/l MCL (DWR, 1982). Figure 10 shows the degree and extent of nitrate and coliform contamination as documented in Ford (1982).

The extent of microbial contamination shown on Figure 10 was based on sampling 79 wells by the Sonoma County Public Health Service. Samples from 15 of the wells contained coliform organism in concentrations ranging from one to 2,400 most probable number per 100 milliliters (MPN/100 ml). Four of these samples also contained *Escherichia coli* (*E. coli*), indicating that the contamination resulted from fecal wastes produced by warm-blooded animals (Ford, 1982).

The nitrate and coliform contamination in the western portion of the Petaluma groundwater sub-basin are attributable to an unfavorable combination of land use, geologic and well construction factors. Historically, and especially prior to World War II, the land use was dominated by poultry farming, but dairying and veal production have also been practiced (Ford, 1982). In more recent years, much of the land use has transitioned to rural residential housing. As the land has been subdivided, the number of domestic wells and septic tanks has increased.

The area is underlain by the Merced Formation (Figure 2), which is vulnerable to contamination due to its relatively high permeability and ability to accept recharge. The only significant barriers to vertical movement of contaminants are the discontinuous lava flows found at some locations between the upper oxidized and lower reduced units of the Merced Formation. In the western portion of the sub-basin, these lava flows are typically below the depth of most domestic wells.

Typical domestic wells are shallow in comparison to municipal wells and are not required to be constructed with the same safeguards that are required for DHS approval of a well used for public supply. One of the key safeguards that is intended to prevent the introduction of shallow contamination into a groundwater well is the sanitary seal (encasement of the well casing in concrete down to an impermeable layer). Wells used for public supply are required to have a minimum 50-foot sanitary seal. Inadequately sealed domestic wells are vulnerable to shallow groundwater contamination and can serve as conduits that can transport contaminants to greater depths in the aquifer system.

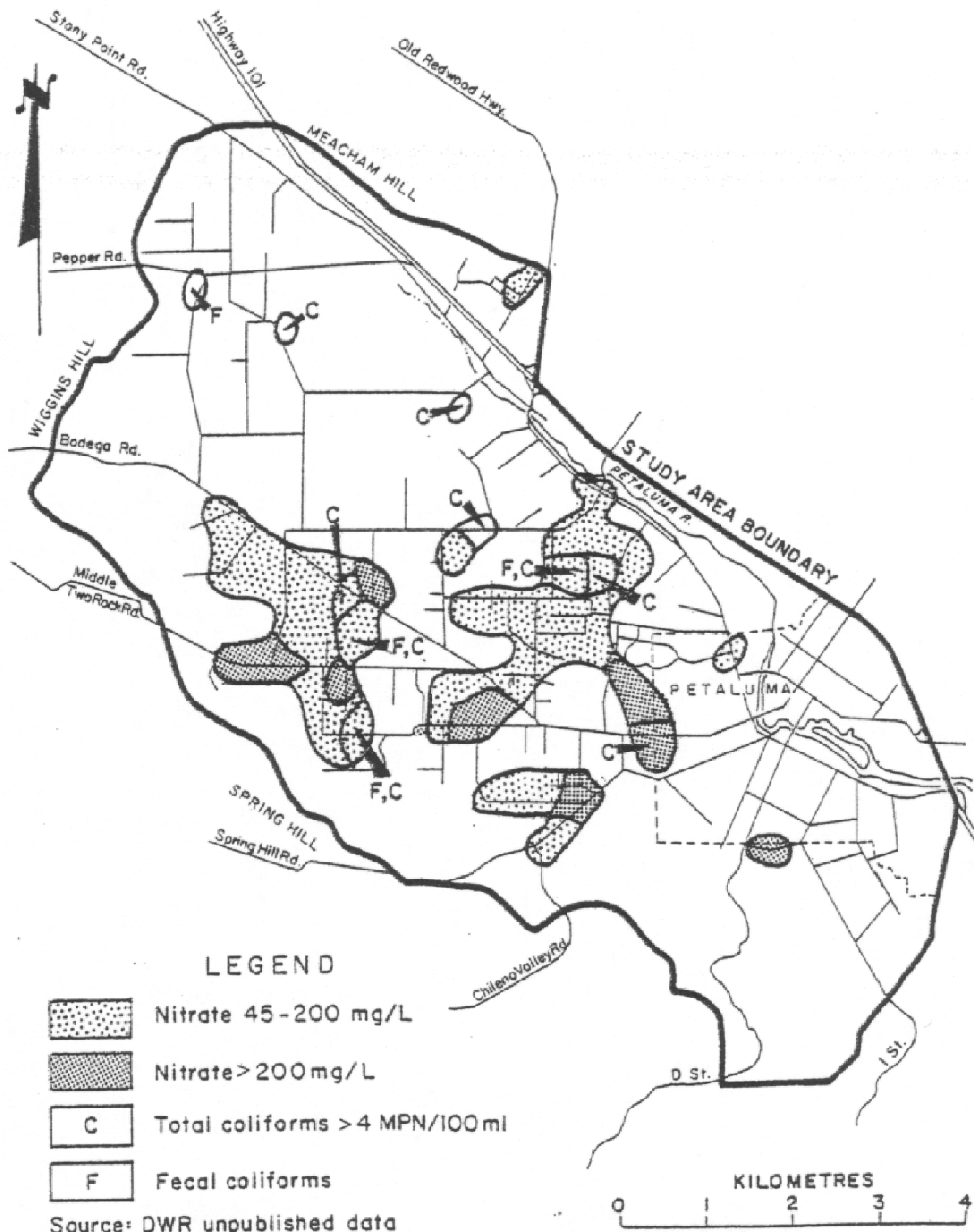


Figure 10

City of Petaluma
Groundwater Resource Assessment
HISTORICAL EXTENT OF NITRATE AND
COLIFORM IN THE WEST PETALUMA AREA



REFERENCE: GEOHYDROLOGY AS APPLIED TO LAND USE PROBLEMS IN THE WEST PETALUMA AREA, SONOMA COUNTY, CALIFORNIA, MASTERS THESIS BY ROBERT S. FORD, CALIFORNIA STATE UNIVERSITY, SACRAMENTO, MAY, 1982.

The vertical extent of nitrate and coliform is not well defined in the western portion of the sub-basin, nor are recent concentration trends. However, the highest nitrate and coliform concentrations found in the 1979 sampling were in shallow wells, some of which may have been poorly sealed (Ford, 1982; DWR 1982). Nitrate is relatively mobile in groundwater and could affect wells over a range of depths, depending on the groundwater flow regime. Wells screened at or near the water table and improperly sealed wells are the most susceptible to coliform contamination.

The City has no supply wells in the western portion of the groundwater sub-basin (Figure 2).

The City is required to sample its public supply wells for many possible contaminants, including nitrate and coliform. The coliform concentrations have been within DHS guidelines and are typical of municipal well systems. The City water is chlorinated as an added precaution.

Typical nitrate concentrations in the City wells (reported as nitrate) ranged from less than 2 to 12 mg/l and were significantly less than the 45-mg/l MCL (Attachment A). The 12-mg/l result from the Park Place well could be an indication that the well is affected by nitrate originating in the western portion of the sub-basin, given the well's location (Figure 2).

Saltwater Intrusion

The use of groundwater was proportionally higher in the vicinity of the City prior to importation of surface water in 1962 (Figure 1). DWR (1982) states that saltwater intrusion from the tidally influenced portion of the Petaluma River affected aquifers in the bay mud and alluvial fan deposits prior to 1962 (Figure 2), and that the available water quality results had indicated that there had been no further incursions after the importation of surface water. They attributed the lack of further saltwater intrusion to substitution of groundwater with surface water.

DWR's observation regarding the substitution of surface water for groundwater is probably accurate for domestic wells, which tend to be relatively shallow and which are more likely to be screened in the bay mud or alluvial aquifers. The reduction in demand from domestic wells, which occurred when imported surface water became available, therefore lessened the risk of further saltwater intrusion in the shallow aquifers. However, the risk of saltwater intrusion due to municipal pumping in deeper aquifer zones is more uncertain. Although the City's long-term percentage use of groundwater decreased sharply beginning in 1962, the long-term average annual use did not change appreciably between 1959 and 1988 (Figure 1).

Selected sample results for the City wells are provided in Attachment A. Sodium concentrations ranged from 18 to 170 mg/l, and the highest concentrations were found in the McDowell, La Tercera, St. Francis and Del Oro wells (Figure 8). These four wells are relatively close to the tidally influenced section of the Petaluma River and the affected bay mud and alluvial aquifers. The relatively high sodium concentrations could indicate a contribution to the water quality from saltwater. However, with the exception of the McDowell well, the water quality is dominated by sodium and bicarbonate, and the chloride concentrations are less obviously elevated. The McDowell well is the only well with water quality dominated by sodium and chloride (Figure 9).

The trends in the sodium and chloride concentrations are shown graphically on Figure 9. Sodium concentrations tend to increase from the Willow Brook area to the vicinity of the St. Francis, La Tercera and Frates wells (Figure 8). Possible factors that could explain the increase include saltwater intrusion, cation exchange along the groundwater flow paths from recharge areas to discharge areas, and variations in the composition of the geologic materials. Chloride concentrations exhibited an increasing trend from the northeastern edge of the sub-basin (Prince Park area) to the interior of the basin along McDowell Boulevard North (Figure 9).

While no clear evidence of saltwater intrusion exists in the municipal wells, the proximity of some of the wells to the tidally influenced section of the Petaluma River and the affected bay mud and alluvial aquifers suggests that there is potential for saltwater intrusion in the municipal production zone even under the current levels of groundwater production.

Aesthetic Considerations

Customer complaints over taste and odor have been received by the City during periods in which the production wells have been used to supplement peak demands in the summer months. Hydrogen sulfide has been noted in the Condiotti well (DWR, 1982). City staff have reported that the Lucchesi well produces water with objectionable taste and odor.

POTENTIAL RECHARGE AREAS

Very limited information is available to assess recharge areas in the Petaluma sub-basin. Reliable estimates would require measurements of stream discharge, rainfall, soil permeability and rates of evapotranspiration. Except for precipitation records, this information is currently not available. DWR (1982) identified potential recharge areas within the Petaluma sub-basin based on soil type and slope. Infiltration rates were inferred from U.S. Soil Conservation Service maps. Only those areas with infiltration rates greater than 0.6 inches per hour and slopes less than 15 percent were considered to be capable of producing groundwater recharge. Using this approach DWR (1982) tentatively identified approximately 20 percent of their study area as contributing to groundwater recharge (Figure 11). Comparison of Figures 2 and 11, shows that most of these areas are located northwest of the City in areas underlain by the Merced Formation. Other areas with favorable soil types are located near the crest of Sonoma Mountain and in the City. The latter area probably produces minimal recharge because of urbanization.

The amount of groundwater recharge would probably be underestimated if the areas shown on Figure 11 were the only areas in which recharge was assumed to occur. Recharge probably also occurs through the channels of streams that are tributary to the upper Petaluma River, and through permeable soils that have not been identified in past mapping efforts.

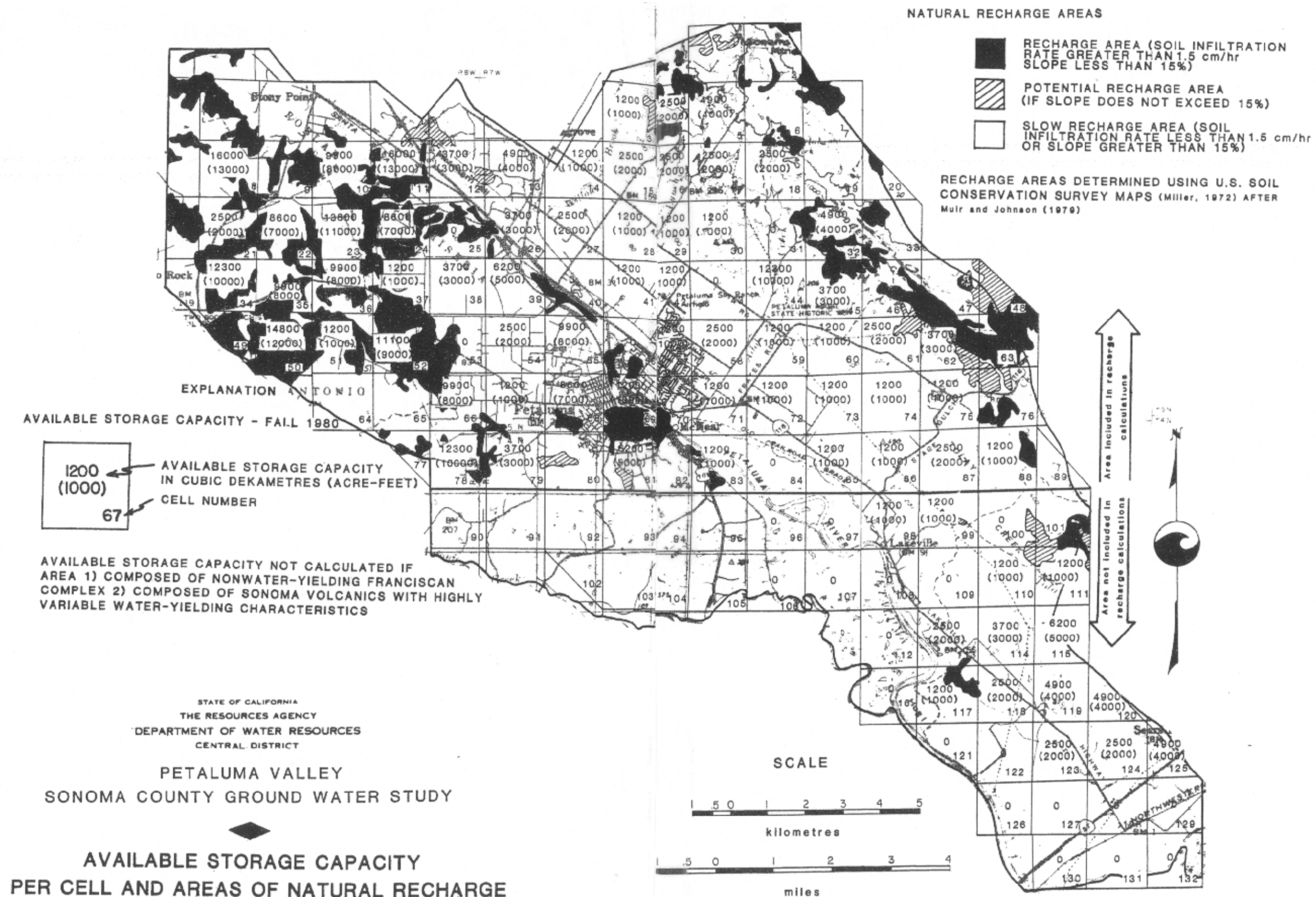


Figure 11

City of Petaluma
Groundwater Resource Assessment
NATURAL RECHARGE AREAS
DELINEATED BY DWR

REFERENCE: EVALUATION OF GROUND WATER RESOURCES:
SONOMA COUNTY, VOLUME 3: PETALUMA VALLEY, CALIFORNIA
DEPARTMENT OF WATER RESOURCES BULLETIN 118-4, JUNE
1982.

Of the potential recharge mechanisms, streams may have the most significant contribution. Figure 3 shows the locations of the major streams of the sub-basin. The southwest flank of Sonoma Mountain has the largest catchment area, highest number of streams and receives the highest average annual rainfall of lands in the sub-basin. The streams draining the southwest flank of Sonoma Mountain are also typically longer than in other areas of the sub-basin. The streams cross over areas underlain by the Merced and Petaluma Formations and alluvial fan deposits (Figure 2). Erosion of the stream channels may have exposed permeable beds within the Merced and Petaluma Formations. The heads of the alluvial fan deposits may be relatively permeable, and significant recharge could occur where the streams cross from the Merced and Petaluma Formations onto the alluvial fans. Although most of the streams are ephemeral, the duration of flow may far exceed the cumulative duration of precipitation recorded in any given year.

SUSTAINABLE YIELD

The sustainable yield of a groundwater basin is the maximum rate at which water can be removed without causing adverse impacts under a given set of operational constraints. The yield varies with hydrologic conditions, the way in which adverse impacts are defined, and the operational parameters according to which the water is withdrawn. Sustainable yield therefore varies with time as hydrologic and operational conditions, and stakeholder needs and preferences change.

The City shares the Petaluma groundwater sub-basin with other Sonoma County groundwater users. Groundwater production by the City has the potential to affect these other groundwater users and vice versa. Adverse impacts have not been formally defined for the sub-basin by the groundwater users. Possible adverse impacts that could be used to assess sustainable yield include:

- Progressive decline in groundwater elevation and reduction in groundwater storage
- Increased pumping costs, or development of non-economic pumping conditions
- Degradation of groundwater quality due to saltwater intrusion, spread of nitrate contamination or other reasons
- Reductions in surface water flow and associated ecological affects

Adoption of these or other definitions of adverse impacts could be used to assess the sustainable yield and develop specific objectives and criteria for management of the groundwater sub-basin. Quantification of the sustainable yield will also require development of a hydrologic budget for the groundwater sub-basin. Prior to development, the groundwater sub-basin was in quasi-equilibrium, with recharge balanced by discharge. Relative to the pre-development conditions, sustainable levels of pumping would need to be offset by increases in recharge, decreases in discharge, decreases in the volume of groundwater in storage, or a combination of these factors. Information needed to develop the groundwater budget and sustainable yield estimates includes surface water inflows and outflows; precipitation; consumptive use; changes in groundwater storage; and the volume of groundwater inflow and outflow. Most of this information is not available.

DWR (1982) estimated that the average annual recharge was 40,000 afa under the operating conditions of the time. This quantity is not equivalent to the sustainable yield, largely because the annual recharge is offset by an unknown quantity of discharge. A valid estimate of sustainable yield must be determined using changes in recharge, discharge and storage, as opposed to the total quasi-equilibrium values of these parameters.

A limited analysis of the yield of the City's wells was performed using information from DWR (1982); groundwater elevation information from the DWR Water Data Library at <http://wdl.water.ca.gov>; and historical groundwater production and elevation information for City wells.

DWR (1982) documents that groundwater elevations near the City declined from the mid-1950s through early 1960s, when surface water deliveries began to offset groundwater demand. After the importation of surface water, groundwater elevations recovered and remained stable except during the 1976-1977 drought. During the drought they declined by about 10 feet relative to the lowest water level in a normal year. Water levels returned to normal in most areas by spring 1978. DWR concluded that the volume of groundwater in storage had not changed appreciably since the recovery of water levels after importation of surface water. Figure 12 shows the groundwater elevation contours for fall 1980 from DWR (1982).

Figure 1 shows the City's annual groundwater production between 1959 and 2002. Groundwater production ranged from 0 to approximately 1,400 afa during the period. Production in 1976 was about 750 afa, declined to near zero in 1977, and returned to about 800 afa in 1978. Over the same period, groundwater elevations declined by about ten feet and then recovered. This provides a rough indication of the decrease in groundwater storage that could be expected to occur in the future given the hydrologic conditions and level of development of the time. The 1976-1977 drought did not affect the long-term storage of the groundwater sub-basin. Determination of whether the sustainable yield of the basin was exceeded, however, would depend on a broader range of potential impacts. For example, local declines in groundwater elevation may have had significant affects on the cost of groundwater production, diminished flow in sensitive streams or contributed the spread of nitrate or saltwater.

Attachment B contains hydrographs for 13 wells in the Petaluma groundwater sub-basin. Figure 2 shows the locations of the wells. Records for five of the wells begin in 1980; the records for the remaining eight wells begin in 1989. The hydrographs do not show a significant, sustained decline in groundwater elevations associated with the 1987-1992 drought. Except at well 05N07W15Q, the groundwater elevations have remained relatively stable over the measurement period. Well 05N07W15Q is located north of the City near Lynch Creek (Figure 2). Groundwater elevations declined by roughly 40 feet beginning in June 1998. The Prince Park North and Prince Park South wells went into production in mid-1998 and the Airport well went into production the following year. The wells are located less than a mile from well 05N07W15Q. The drawdown measured at well 05N07W15Q may be an indication that the permeability and recharge characteristics of the groundwater sub-basin are such that localized affects, such as the drawdown measured in well 05N07W15Q, may constrain the sustainable yield at least as much as more global factors such as the change in total sub-basin storage.

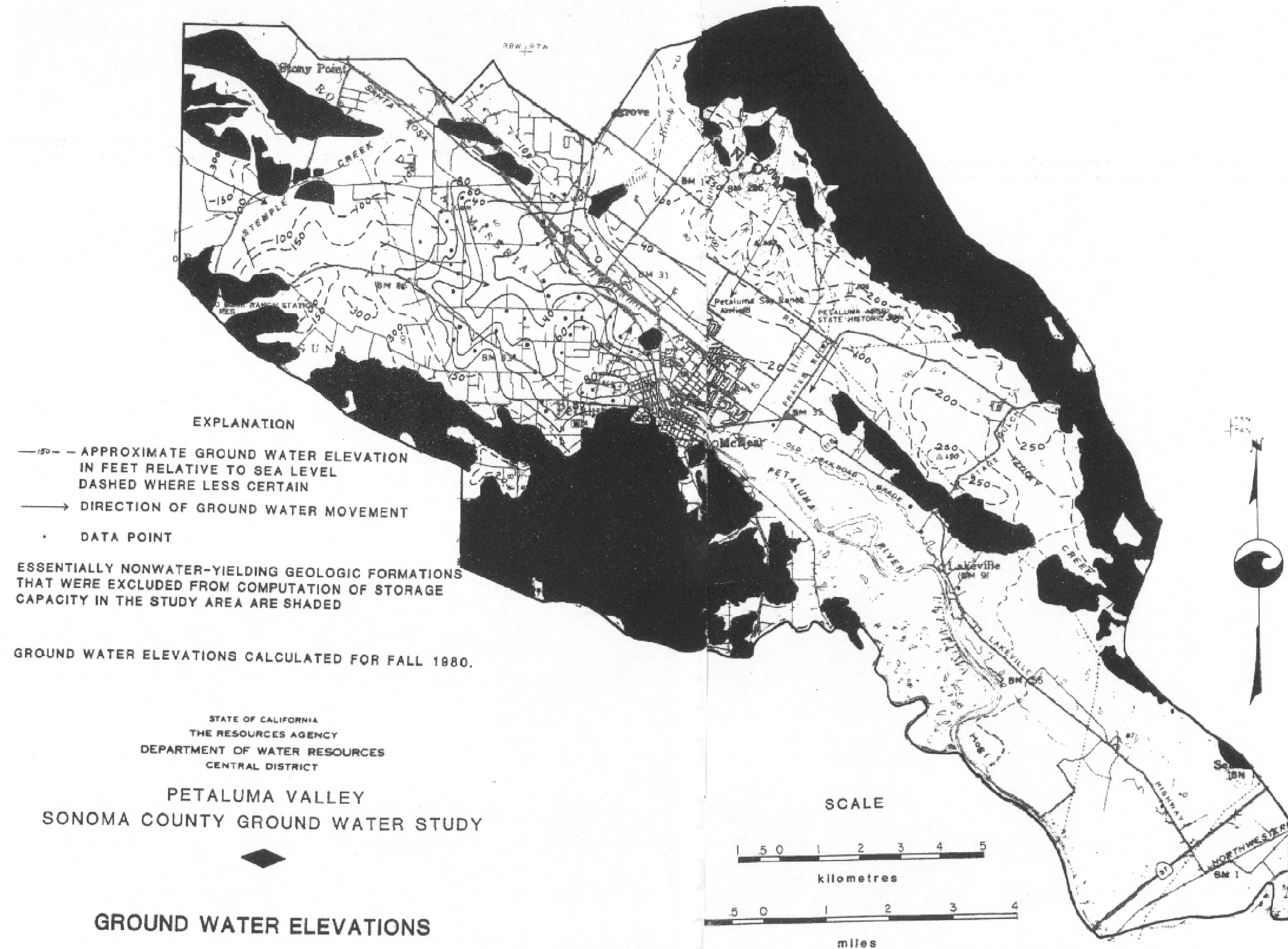


Figure 12

City of Petaluma
Groundwater Resource Assessment
FALL 1980 GROUNDWATER ELEVATIONS



REFERENCE: EVALUATION OF GROUND WATER RESOURCES:
SONOMA COUNTY, VOLUME 3: PETALUMA VALLEY, CALIFORNIA
DEPARTMENT OF WATER RESOURCES BULLETIN 118-4, JUNE
1982.

Attachment C contains graphs of the production and groundwater elevations measured in selected City wells. The groundwater elevations were measured using airlines during pumping and non-pumping conditions. Although the data are not definitive, they do provide an indication of the changes in water levels caused by operation of the City's wells. The groundwater elevations in most of the wells showed evidence of drawdown on a seasonal basis and six wells (Airport, Frates, Lucchesi, Park Place, Prince Park North and Prince Park South) showed evidence of longer-term declines in groundwater elevation over the past five years. These five wells produced most of the groundwater used by the City over the past five years, with total production in the 400 to 1,000 afa range.

SUMMARY AND CONCLUSIONS

The City currently relies on local groundwater to supplement imported water supplies only during short-term emergency situations. Groundwater is produced from six permitted wells out of a total of 21 wells. Specific capacities in the active wells are low, ranging from approximately 1 to 6 gpm/ft. Short-term production rates range from approximately 100 to 1,000 gpm per well. Production rates decline rapidly due to the relatively low permeability of the aquifer system, with long-term rates ranging from 60 to 180 gpm per well. The reduction in flow rate with time is a physical limitation imposed by the drawdown, which decreases the aquifer transmissivity and hence yield.

Water from the City's wells is typically hard, has high TDS and EC and is affected by arsenic, iron and manganese. Arsenic has been detected at concentrations exceeding the pending 10-µg/l federal MCL in at least one of the active wells. Manganese has been detected above the 50-µg/l MCL in at least seven wells and appears to be a problem in at least three of the City's newest wells. Several of the wells are reported to produce water with unpleasant taste and odor. The City currently has no production wells in the northwestern part of the groundwater sub-basin. The permeability of the aquifer beneath the northwestern area is probably high relative to the rest of the Petaluma groundwater sub-basin, but the area is impaired by nitrate contamination. Geologic conditions in the northwestern area may be favorable to the production of groundwater from deeper zones that are not affected by nitrate contamination.

Saltwater intrusion has affected the shallow portions of the aquifer system in the vicinity of the tidally influenced reach of the Petaluma River. Saltwater intrusion in the shallow aquifer zones appears to have peaked in the late 1950s prior to the importation of surface water. This probably reduced the demand on the shallow aquifer system. Importation of surface water reduced the proportion of groundwater produced from the deeper municipal production zones but not the total production from these zones. Although not definitive, the water quality data suggest that chloride and, possibly, sodium concentrations increase with decreasing distance from the tidally influenced section of the Petaluma River. The risk of saltwater intrusion in the municipal production zones may be an important consideration in developing the impact criteria needed for evaluation of the sustainable yield of the sub-basin.

The available groundwater elevation and production data suggest that groundwater elevations are relatively stable in most areas of the Petaluma groundwater sub-basin, but in some areas, including the vicinity of the City's active production wells, water levels are in the midst of a long-term decline. This may be of particular concern because a number of the active wells are located

in the Prince Park area or downgradient. Lynch Creek and Washington Creek enter the groundwater sub-basin to the northeast of the wells and may contribute significant recharge. Key issues are whether drawdown in the area is inducing additional recharge from the creeks that would otherwise be lost, and if so whether the induced stream losses are harming the ecology of the creeks. Similar issues may be relevant in the vicinity of other ephemeral streams entering the sub-basin, but currently insufficient data exist to verify this.

The available groundwater elevation and production data also suggest that the criteria established for evaluating negative consequences of groundwater production may be dominated by relatively localized considerations, such as consequences of excessive drawdown in specific areas. If so, future estimates of the sustainable yield of the sub-basin may be lower than expected based on the size of the groundwater sub-basin alone. This is because the objective of minimizing excessive, localized drawdown will create the need for widely spaced wells, some of which will not be feasible due to groundwater impairment, incompatible land use or other issues. The relatively localized drawdown appears to result primarily from the low permeability of the aquifer system.

The sustainable yield of the groundwater sub-basin is the maximum rate at which water can be removed without causing adverse impacts under a given set of operational constraints. The yield varies with hydrologic conditions, the way in which adverse impacts are defined, and the operational parameters according to which the water is withdrawn. The past estimate of 40,000 afa for the average annual recharge is not equivalent to the sustainable yield of the sub-basin. A valid estimate of sustainable yield should be based on changes in recharge, discharge and storage.

The sustainable yield of the sub-basin could not be determined due to limitations in the available data and the lack of criteria for assessing the potential impacts of groundwater production. However, the City's production over the past five years has ranged from approximately 400 to 1,000 afa. Production was roughly in this range during the 1976-1977 and 1986-1992 droughts, and although groundwater levels declined over the short term, they rebounded early in the first year after the drought periods in most areas of the groundwater sub-basin.

The apparent need for significant spacing between wells may be the controlling factor that places an upper limit on the City's groundwater production, even though this limit may be less than the overall yield of the groundwater sub-basin. A production rate of 2,000 to 3,000 afa appears to be a reasonable assumption for the city's maximum developable groundwater capacity, given the known constraints on water quality and the potential risks associated with excessive drawdown and saltwater intrusion.

The city's groundwater production has been exclusively from the northeastern portion of the sub-basin. It may be possible to increase production if new wells can be located in other areas of the sub-basin. This would minimize the potentially negative impacts, if localized drawdown is determined to be excessive.

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ATTACHMENT A

Selected Groundwater Chemical Analysis Results

Table A-1. Summary of Selected Groundwater Quality Results
City of Petaluma
Groundwater Resource Evaluation

Constituent	Units	MCL	Wells								
			Airport	Airport	Cross	Del Oro	Frates	Kingsmill	La Tercera	Lucchesi	Lucchesi
			05/21/96	05/20/98	Creek 11/30/01	Well 11/05/03	03/17/95	Well 09/19/02	09/19/02	05/08/96	03/17/98
pH	N/A	6.5-8.5	7.7	7.9	7.4	8.0	7.8	8.0	8.2	8.1	8.2
EC	(umhos/cm)	900	590	650	590	740	560	500	820	600	643
Hardness	mg/L	N/A	210	205	180	170	110	140	73	150	154
Alkalinity	mg/L	N/A	270	276	190	270	220	200	300	210	235
TDS	mg/L	500	380	392	320	430	360	270	490	310	370
HCO ₃	mg/L	N/A	330	336	230	320	270	240	370	250	286
F	mg/L	4	0.25	0.2	0.11	0.38	0.14	0.29	0.26	0.16	0.14
Cl	mg/L	250	28	33	NR	52	31	21	48	57	50
SO ₄	mg/L	250	16	13	7.6	38	15	7.2	35	17	23
NO ₃ -NO ₃	mg/L	10	<4.5	<0.4	5.6	7.0	4	3.1	<2	<4.5	<0.4
As	mg/L	0.010	0.0035	0.0049	0.0039	0.0073	0.011	0	<0.002	NR	0.0042
Ba	mg/L	1	0.14	0.132	0.15	<0.1	0.11	0	<0.10	NR	<0.10
Ca	mg/L	N/A	44	41	37	39	24	26	11	27	27
Cu	mg/L	1	<0.05	<0.01	<0.05	<0.05	<0.05	NR	<0.05	NR	<0.01
Fe	mg/L	0.3	0.23	<0.05	0.16	0.46	0.25	0.14	<0.10	NR	<0.05
K	mg/L	N/A	NR	2.90	NR		NR		NR	NR	1.90
Mg	mg/L	N/A	24	25	21	18	12	18	11	21	21
Mn	mg/L	0.05	0.053	0.07	<0.03	0.067	<0.03	0.036	<0.02	NR	0.04
Na	mg/L	N/A	59	63	50	110	82	51	150	74	80
Pb	mg/L	0.015	<0.005	<0.005	NR	<0.005	<0.005	0	<0.005	NR	<0.005
Zn	mg/L	5	<0.05	0.072	0.29	<0.05	<0.05	0.088	<0.05	NR	0.062

NA: Not Applicable

NR: Not Reported

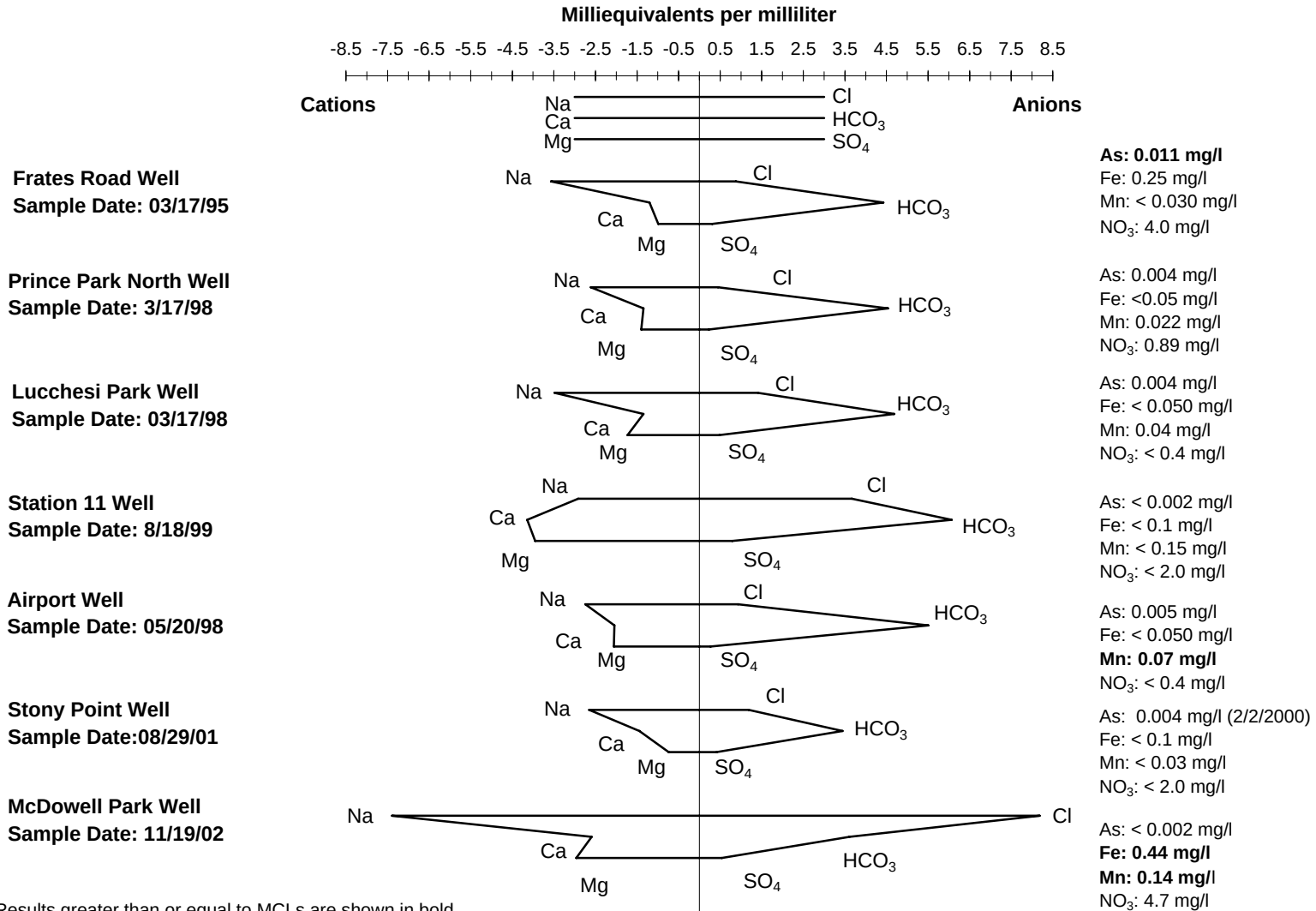
Table A-1. Summary of Selected Groundwater Quality Results cont.
City of Petaluma
Groundwater Resource Evaluation

Well	Units	MCL	Wells								
			McDowell	Park Place	Prince Park North	Prince Park South	St. Francis Well	Station 11	Station 9	Stony Point	Willow Brook
			11/19/02	05/17/01	03/17/98	01/06/98	10/14/03	08/18/99	08/25/99	08/29/01	04/01/91
pH	N/A	6.5-8.5	8.0	7.2	7.9	7.8	7.9	8.0	7.6	8.0	8.0
EC	(umhos/cm)	900	1300	660	496	466	870	1100	870	560	755
Hardness	mg/L	N/A	280	230	137	160	160	410	350	110	238
Alkalinity	mg/L	N/A	180	200	227	220	260	300	240	170	155
TDS	mg/L	500	750	410	306	282	520	600	470	300	413
HCO ₃	mg/L	N/A	220	240	277	270	320	370	290	210	
F	mg/L	4	0.14	0.21	0.16	0.26	0.1	NR	<0.10	0.24	NR
Cl	mg/L	250	290	67	16	19	93	130	94	42	125
SO ₄	mg/L	250	26	20	11	6.8	26	38	41	20	16.6
NO ₃ -NO ₃	mg/L	10	4.7	12	0.89	<0.4	6.1	<2.0	4.2	<2.0	4.95
As	mg/L	0.010	<0.002	<0.002	0.0042	NR	<0.002	<0.002	0.0035	NR	NR
Ba	mg/L	1	0.2	<0.10	<0.10	NR	0.1	<0.10	0	NR	0.23
Ca	mg/L	N/A	52	45	27	38	27	83	74	29	59.5
Cu	mg/L	1	<0.05	<0.05	<0.01	NR	<0.05	<0.05	<0.05	<0.05	NR
Fe	mg/L	0.3	0.44	<0.10	<0.05	NR	2.5	<0.10	0.12	<0.10	0.63
K	mg/L	N/A	NR	NR	2.30	1.50		NR	NR	NR	NR
Mg	mg/L	N/A	36	28	17	17	22	48	40	9	21.9
Mn	mg/L	0.05	0.14	<0.03	0.022	NR	0.12	<0.15	0.053	<0.03	0.091
Na	mg/L	N/A	170	50	60	35	130	67	52	61	18
Pb	mg/L	0.015	<0.005	<0.005	<0.005	NR	<0.005	<0.10	0	NR	0.51
Zn	mg/L	5	<0.05	<0.05	<0.05	NR	<0.05	<0.05	<0.05	<0.05	NR

NA: Not Applicable

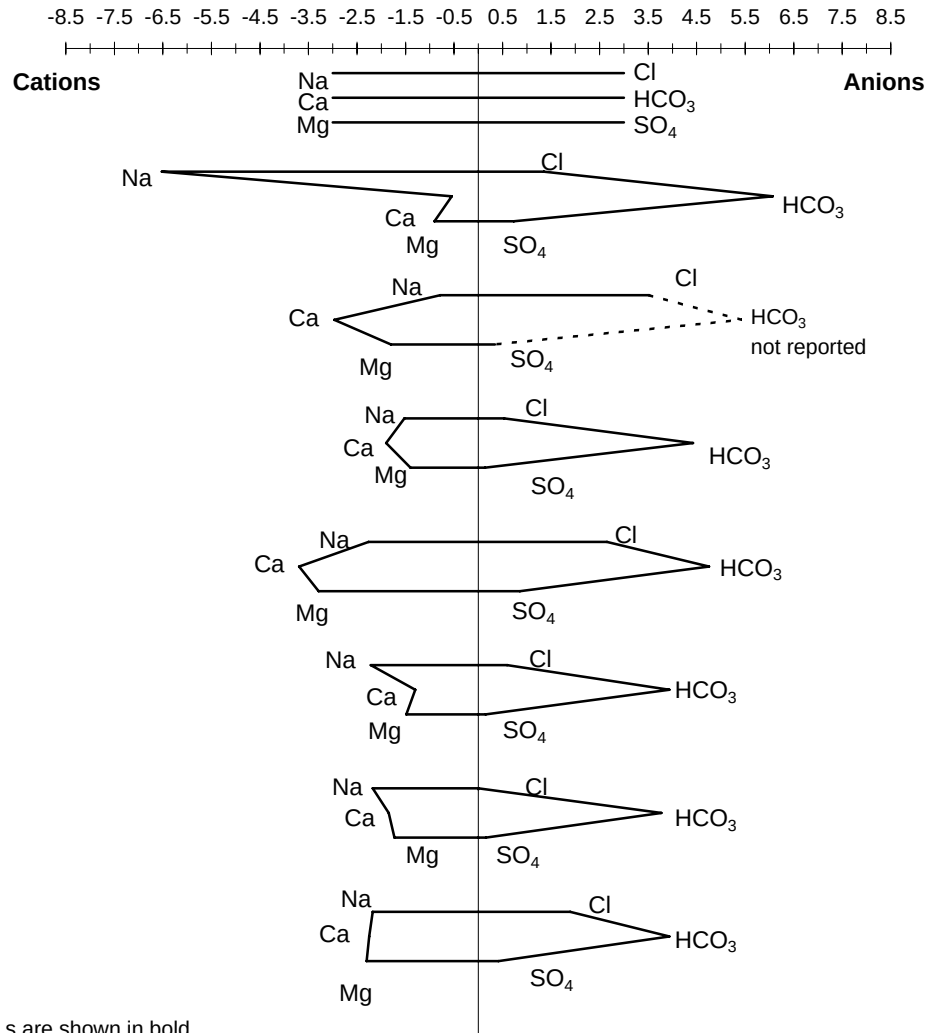
NR: Not Reported

City of Petaluma Groundwater Quality



City of Petaluma Groundwater Quality

Milliequivalents per milliliter



As: <0.002 mg/l
Fe: <0.1 mg/l
Mn: < 0.02 mg/l
NO₃: <2.0 mg/l

As: <0.002 mg/l
Fe: 0.63 mg/l
Mn: 0.091 mg/l
NO₃: 4.95 mg/l

As: <0.01 mg/l (12/3/1992)
Fe: <0.10 mg/l (12/3/1992)
Mn: 0.06 mg/l (12/3/1992)
NO₃: 1.70 mg/l (12/3/1992)

As: 0.004 mg/l
Fe: 0.12 mg/l
Mn: 0.053 mg/l
NO₃: 4.2 mg/l

As: <0.002 mg/l
Fe: 0.14 mg/l
Mn: 0.036 mg/l
NO₃: 3.1 mg/l

As: 0.0039 mg/l
Fe: 0.16 mg/l
Mn: <0.03 mg/l
NO₃: 5.6 mg/l

As: <0.002 mg/l
Fe: <0.1 mg/l
Mn: <0.03 mg/l
NO₃: 12 mg/l

Note: Results greater than or equal to MCLs are shown in bold

City of Petaluma Groundwater Quality

Milliequivalents per milliliter

-8.5 -7.5 -6.5 -5.5 -4.5 -3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5

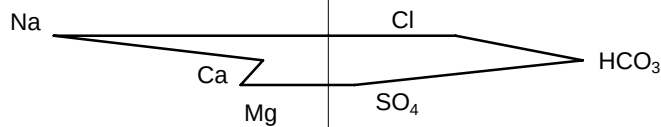
Cations

Na
Ca
Mg

Anions

Cl
HCO₃
SO₄

St. Francis Well
Sample Date: 10/14/03



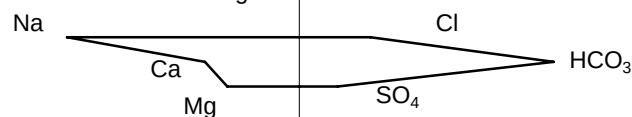
As: <0.002 mg/l

Fe: 2.5 mg/l

Mn: 0.12 mg/l

NO₃: 6.10 mg/l

Del Oro Well
Sample Date: 11/05/03



As: 0.0073 mg/l

Fe: 0.46 mg/l

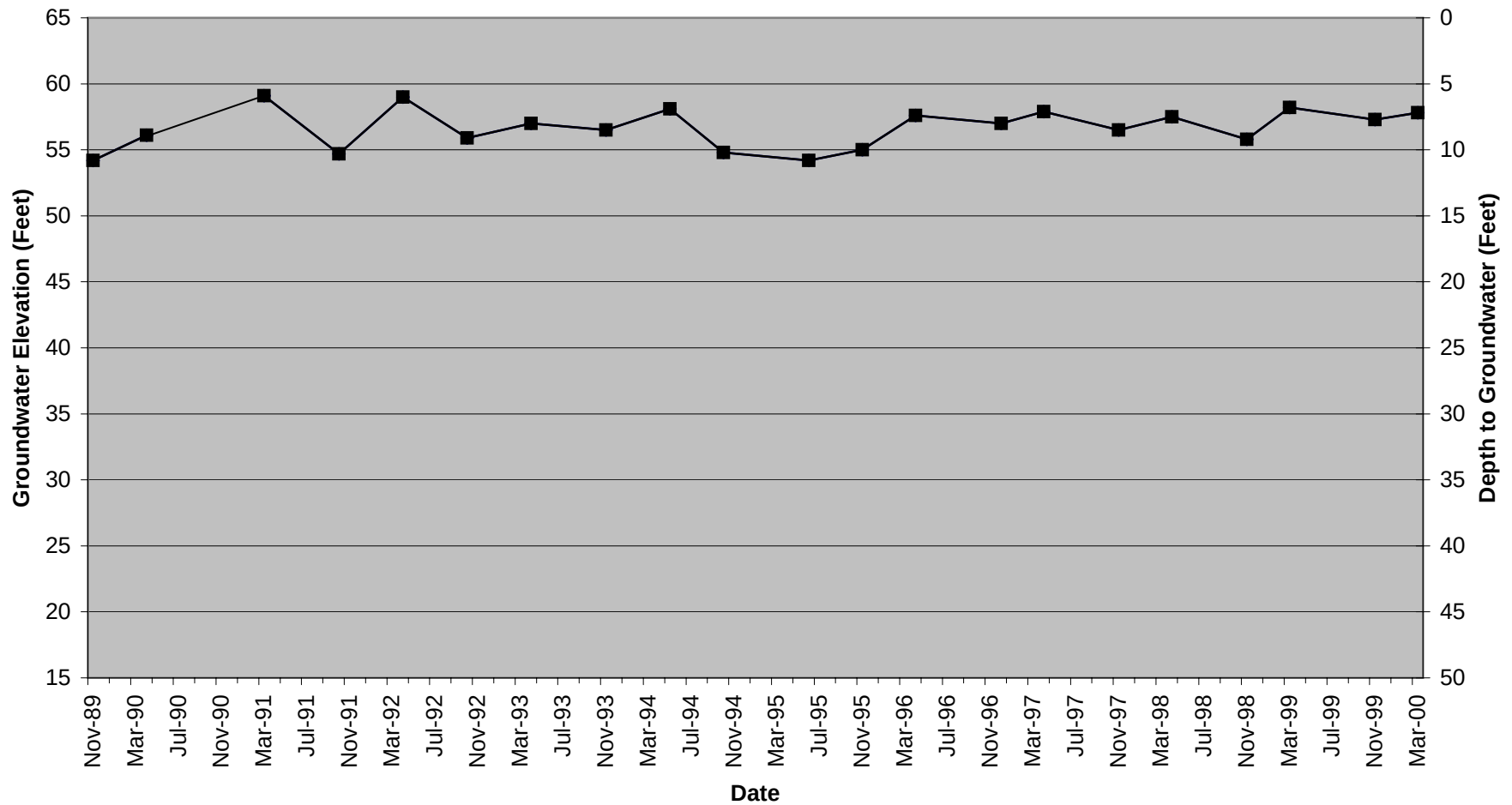
Mn: 0.067 mg/l

NO₃: 7.0 mg/l

ATTACHMENT B

DWR Hydrographs

Hydrograph of 05N07W07A001M
Pengrove Area
Land Surface Elevation: 65 feet



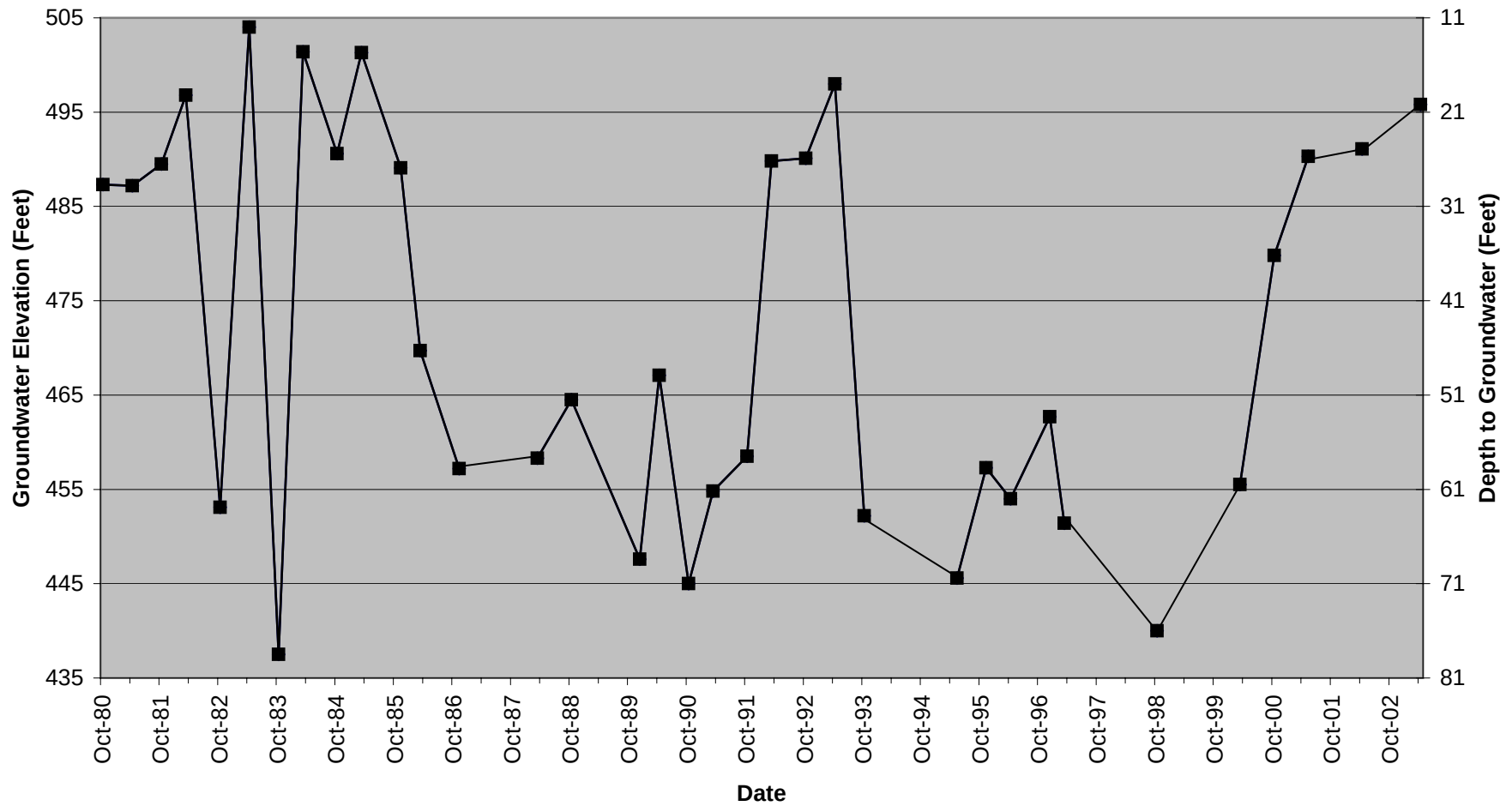
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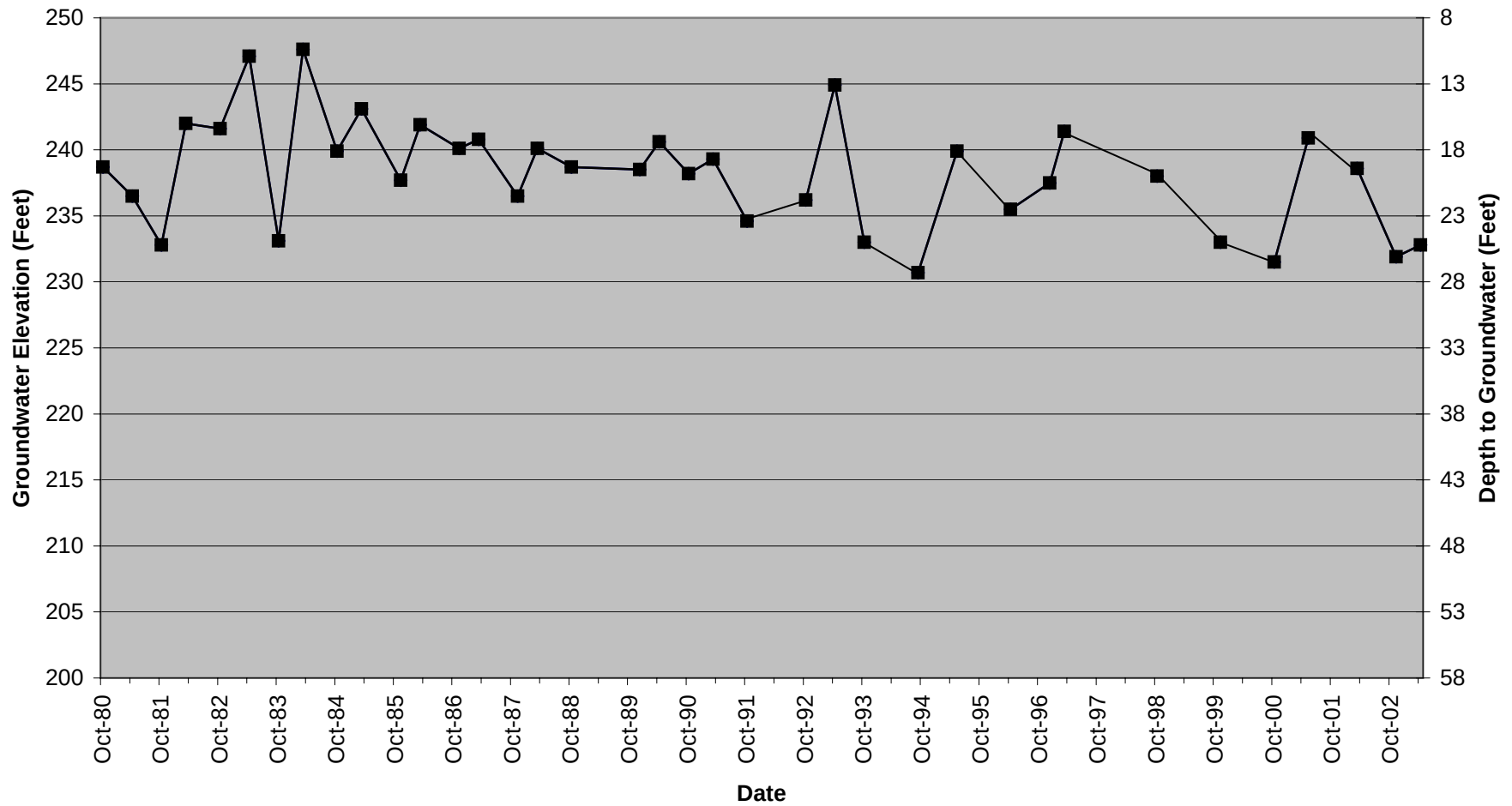
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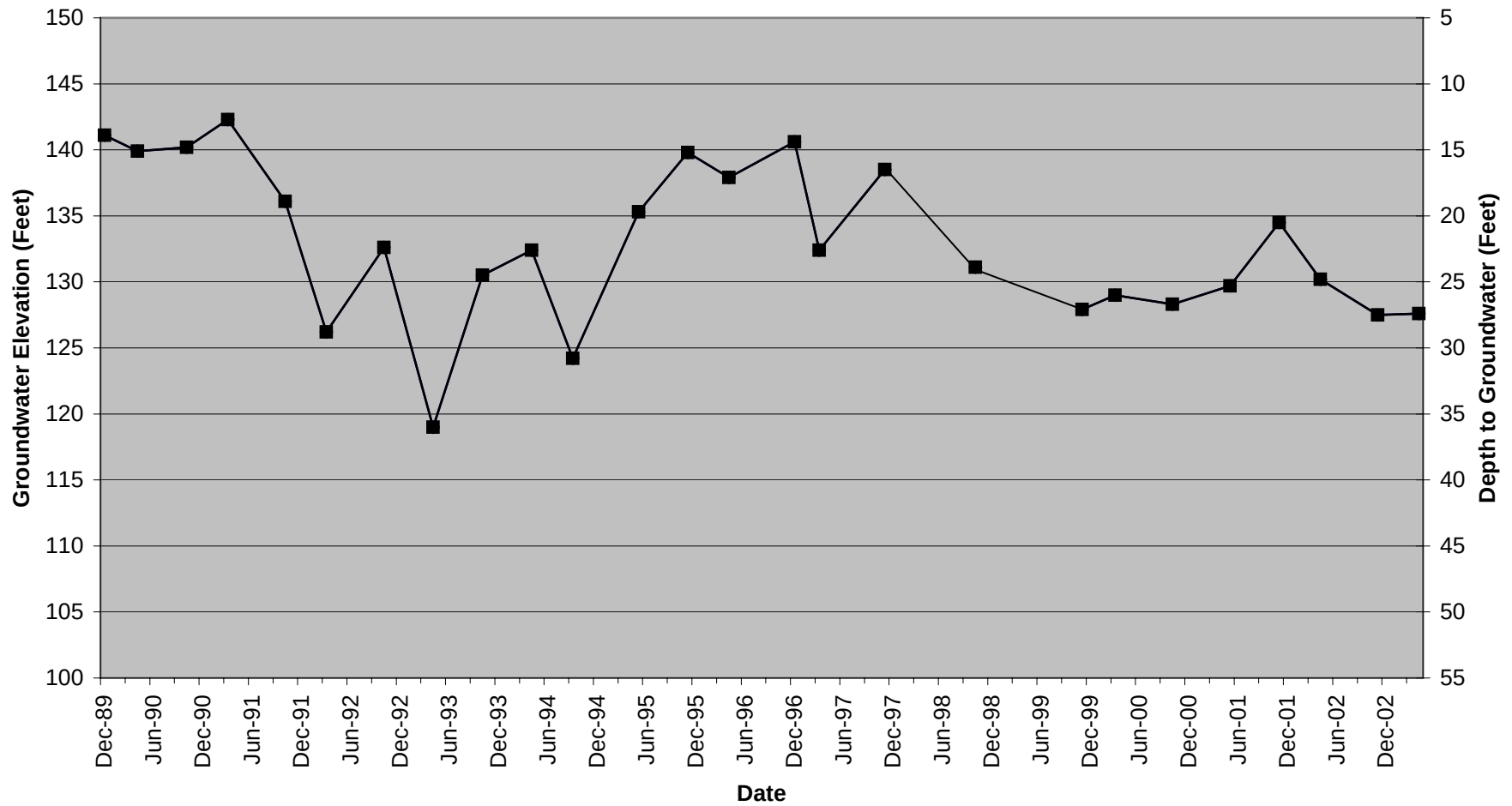
Hydrograph of 05N07W11F001M
Petaluma Valley
Land Surface Elevation: 516 feet



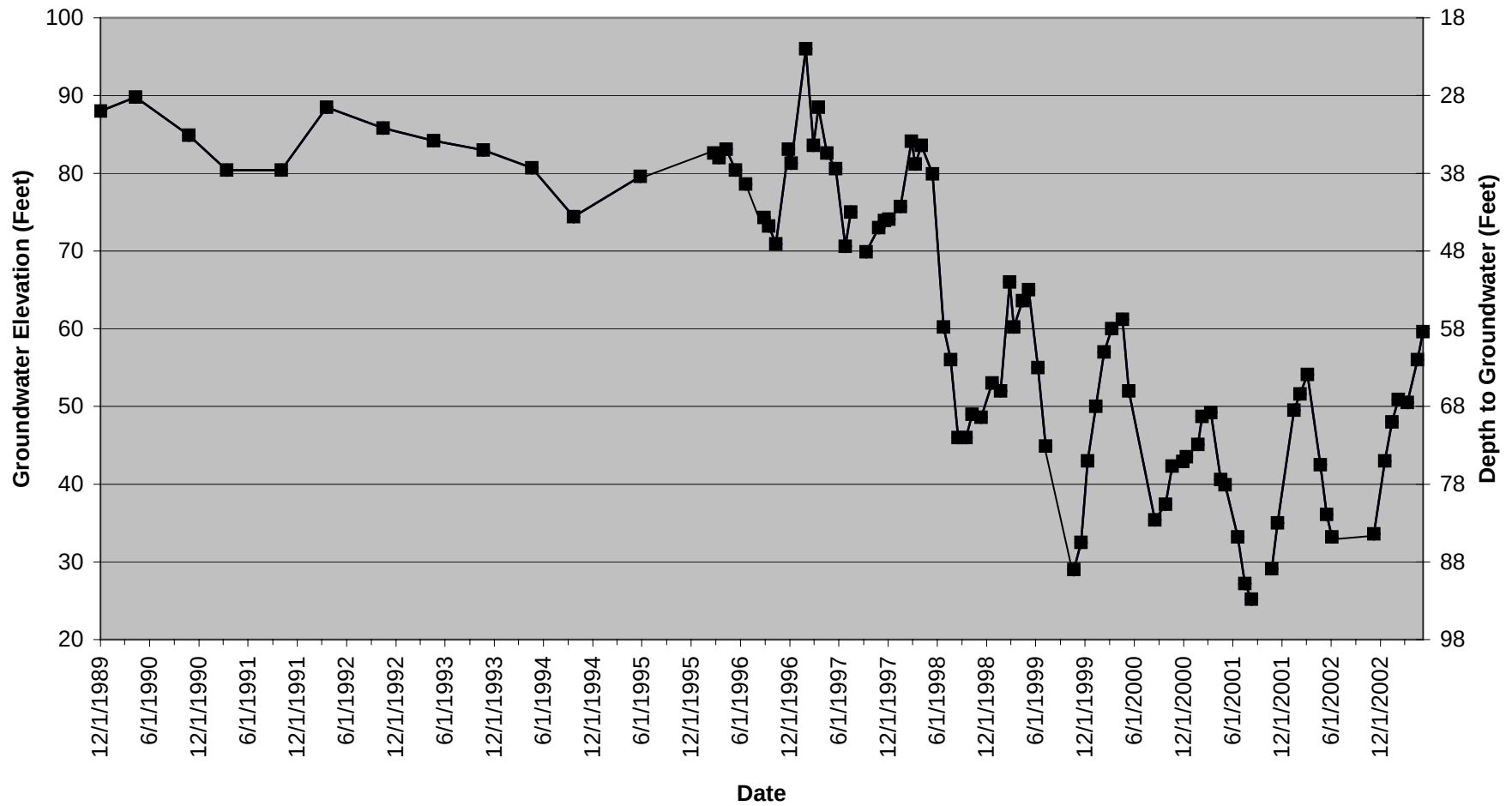
Hydrograph of 05N07W11N001M
Petaluma Valley
Land Surface Elevation: 258 feet



Hydrograph of 05N07W15K002M
Petaluma Valley
Land Surface Elevation: 155 feet



Hydrograph of 05N07W15Q001M
Petaluma Valley
Land Surface Elevation: 118 feet



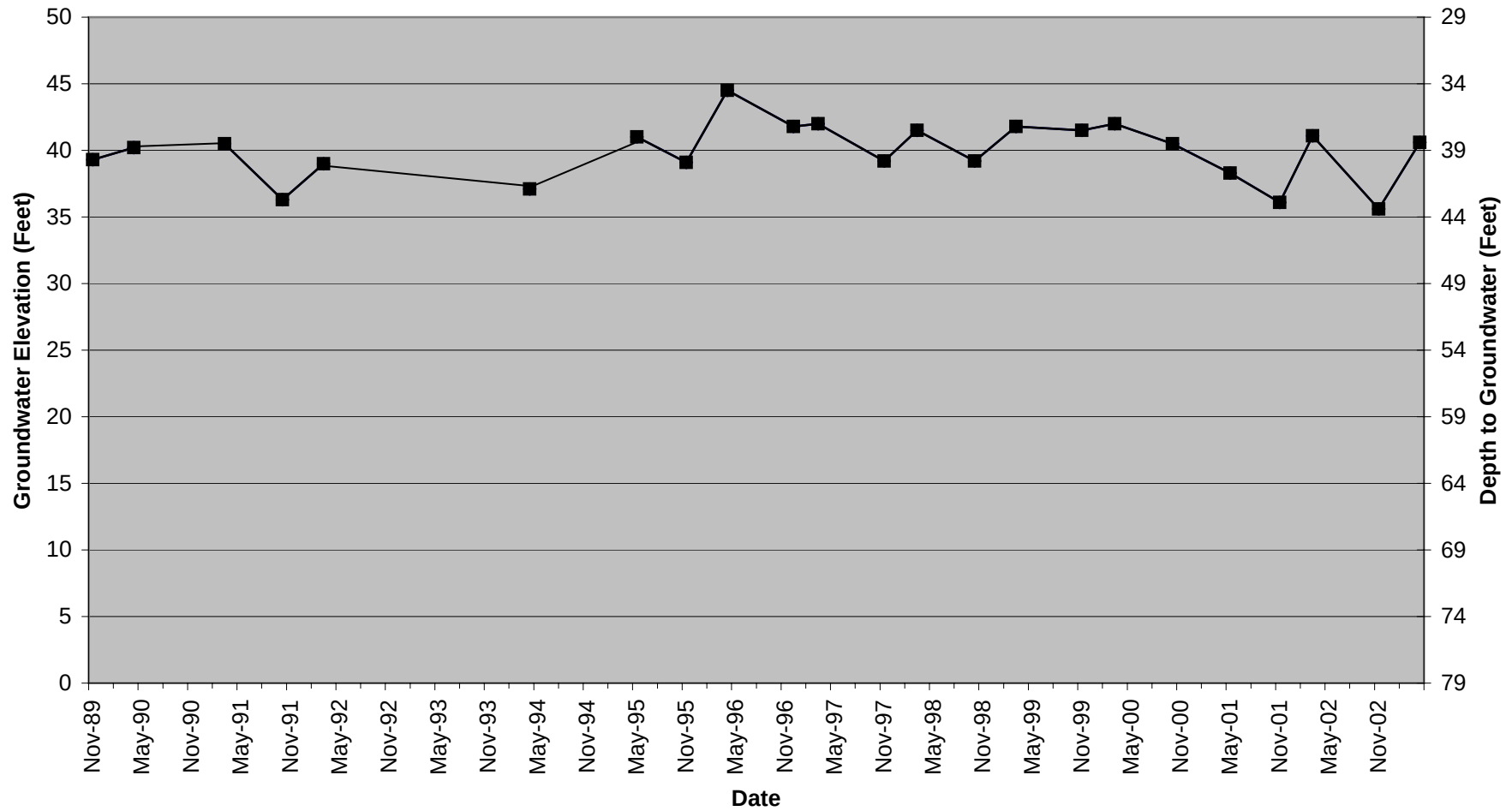
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Hydrograph of 05N07W18B001M
Petaluma Valley
Land Surface Elevation: 79 feet



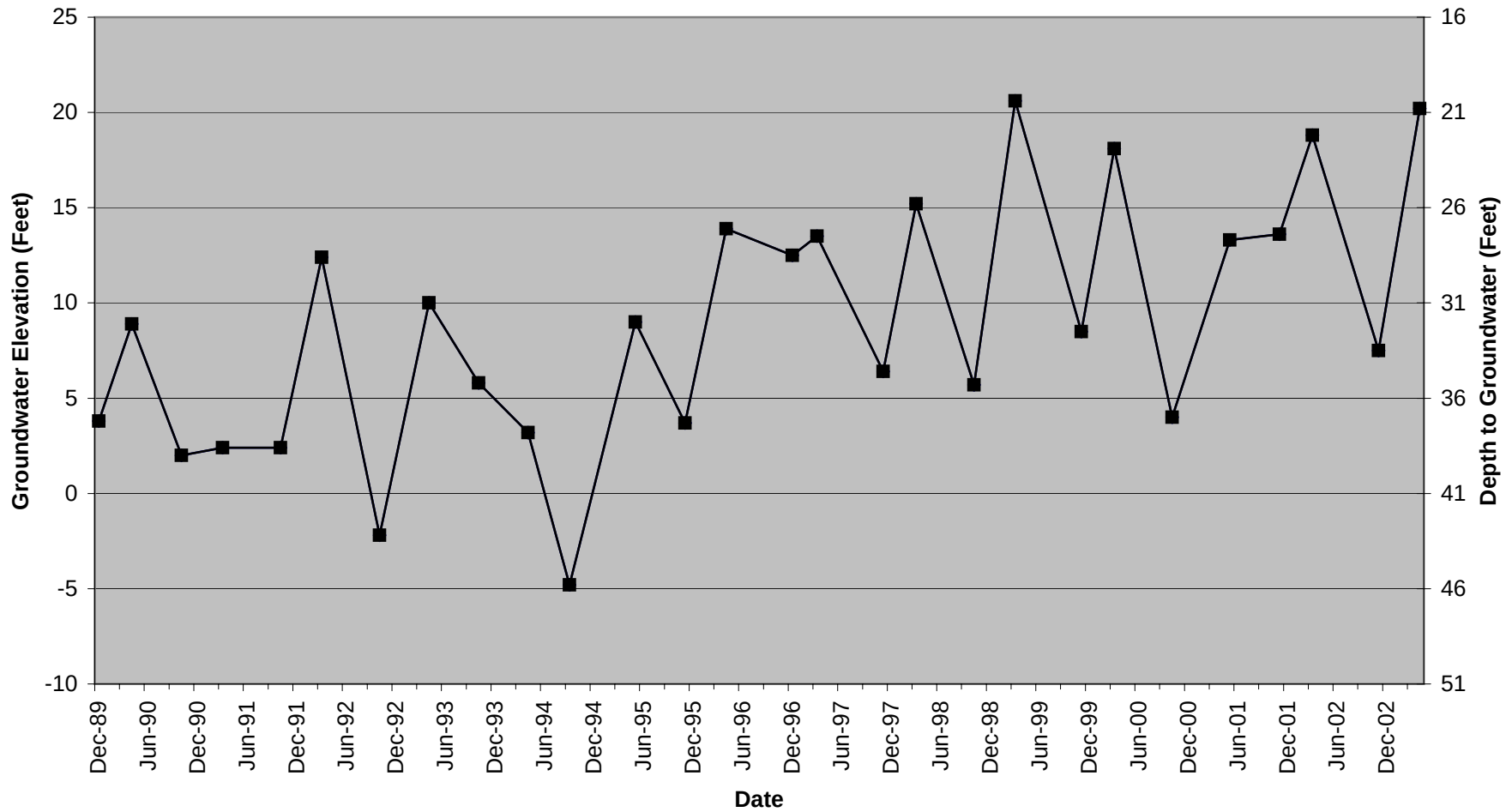
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Hydrograph of 05N07W20B002M
Petaluma Valley
Land Surface Elevation: 41 feet



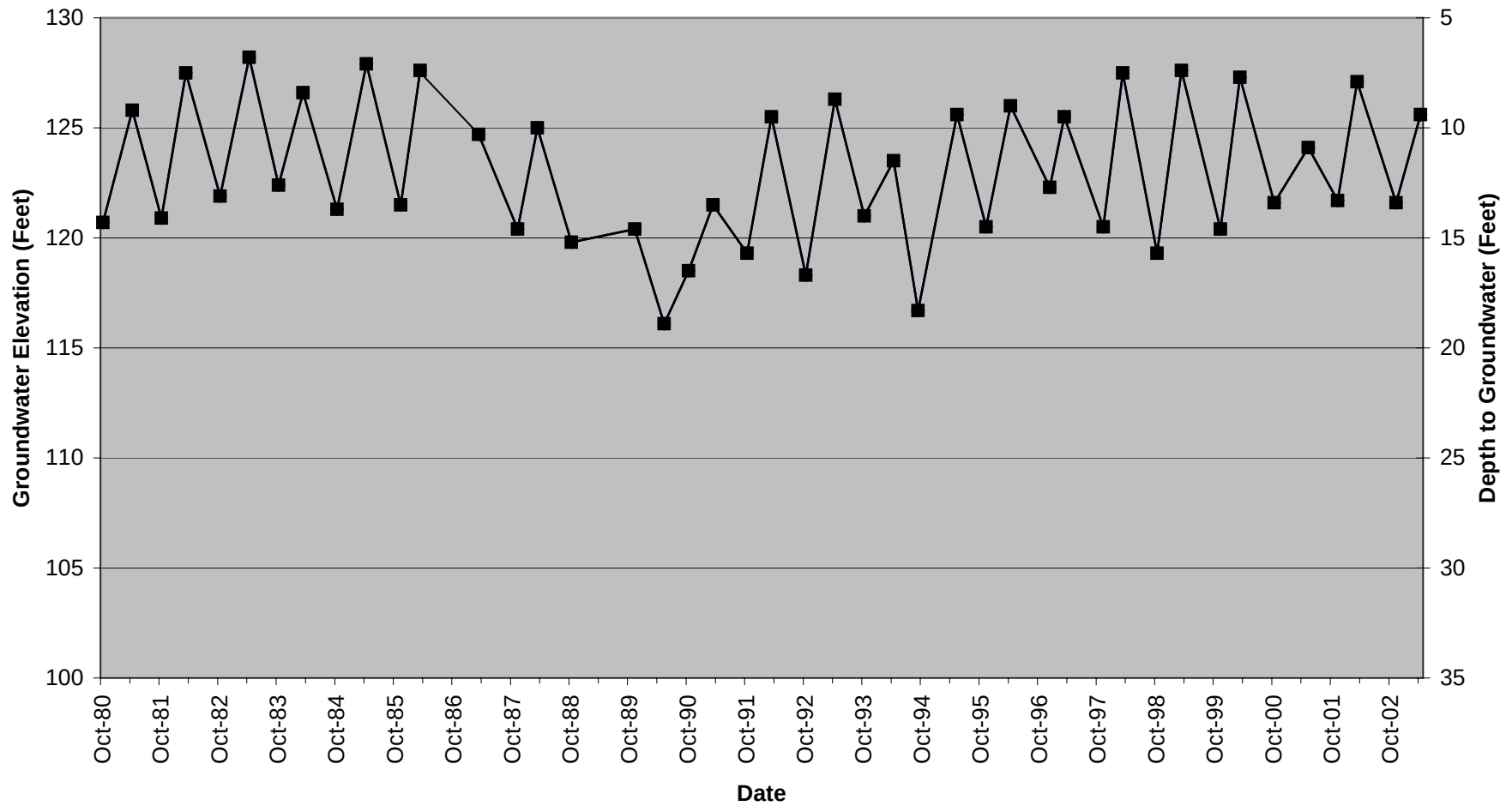
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Hydrograph of 05N07W31R002M
Petaluma Valley
Land Surface Elevation: 135 feet



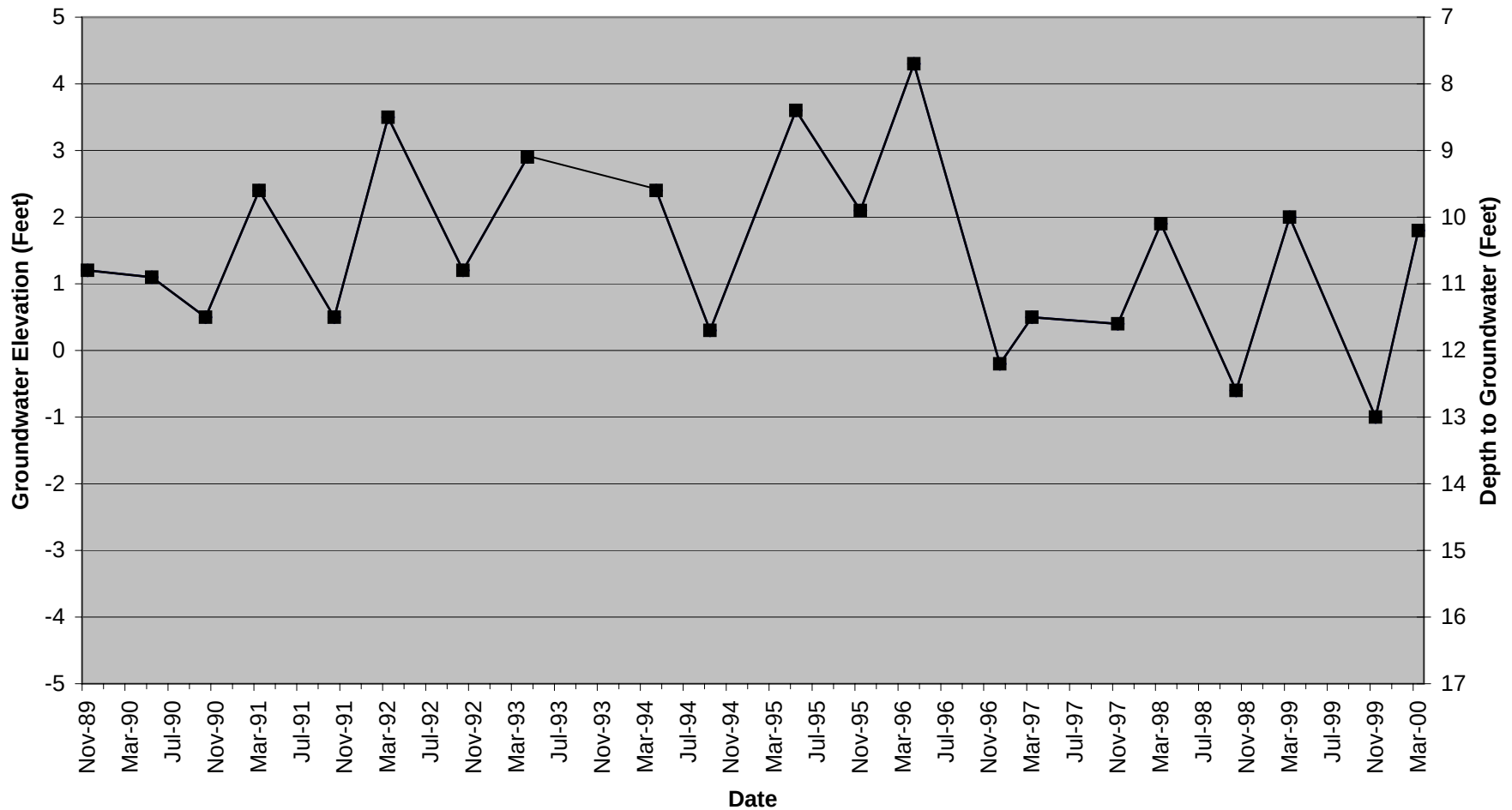
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Hydrograph of 05N07W34L001M
Petaluma Valley
Land Surface Elevation: 12 feet



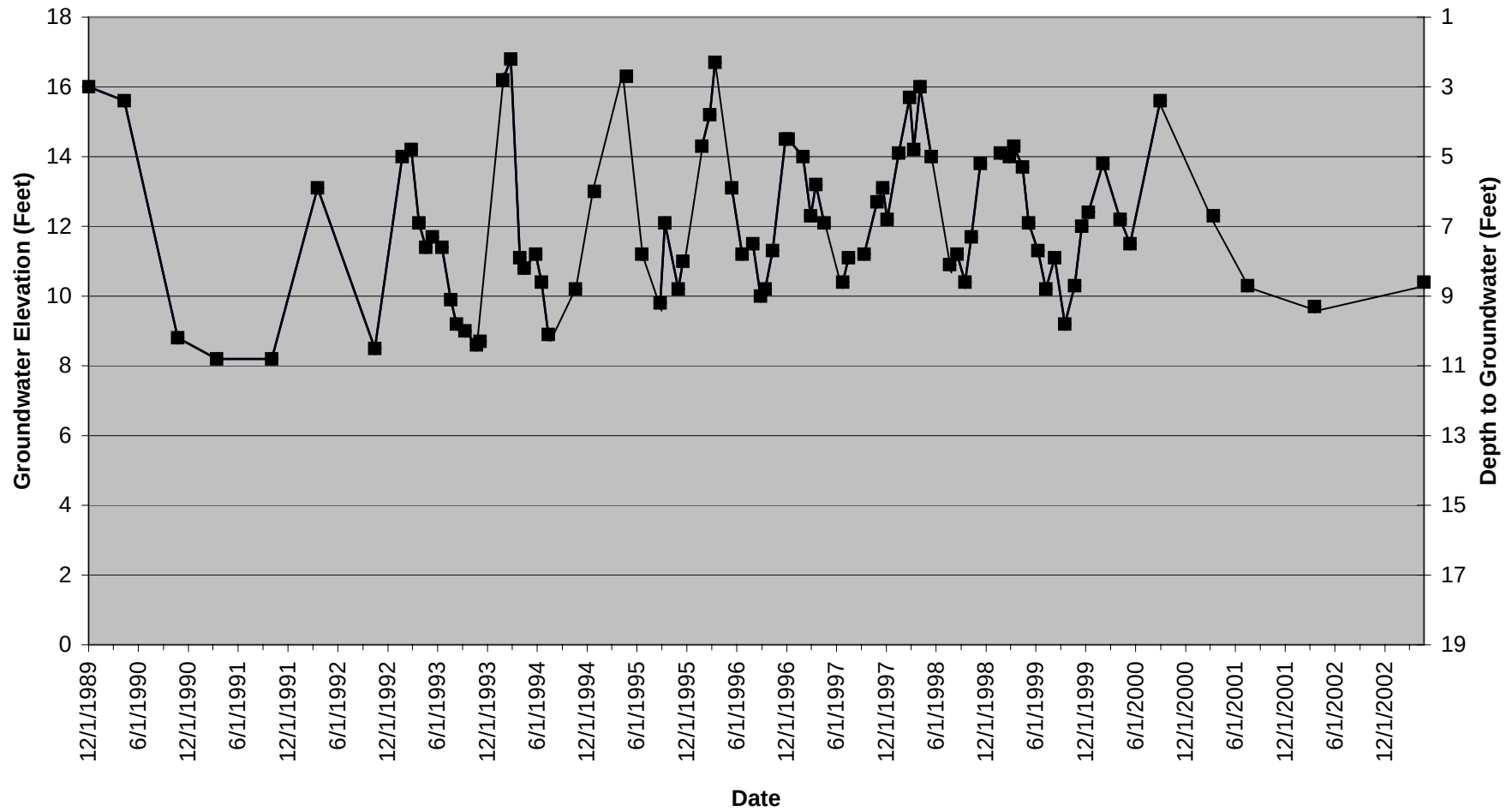
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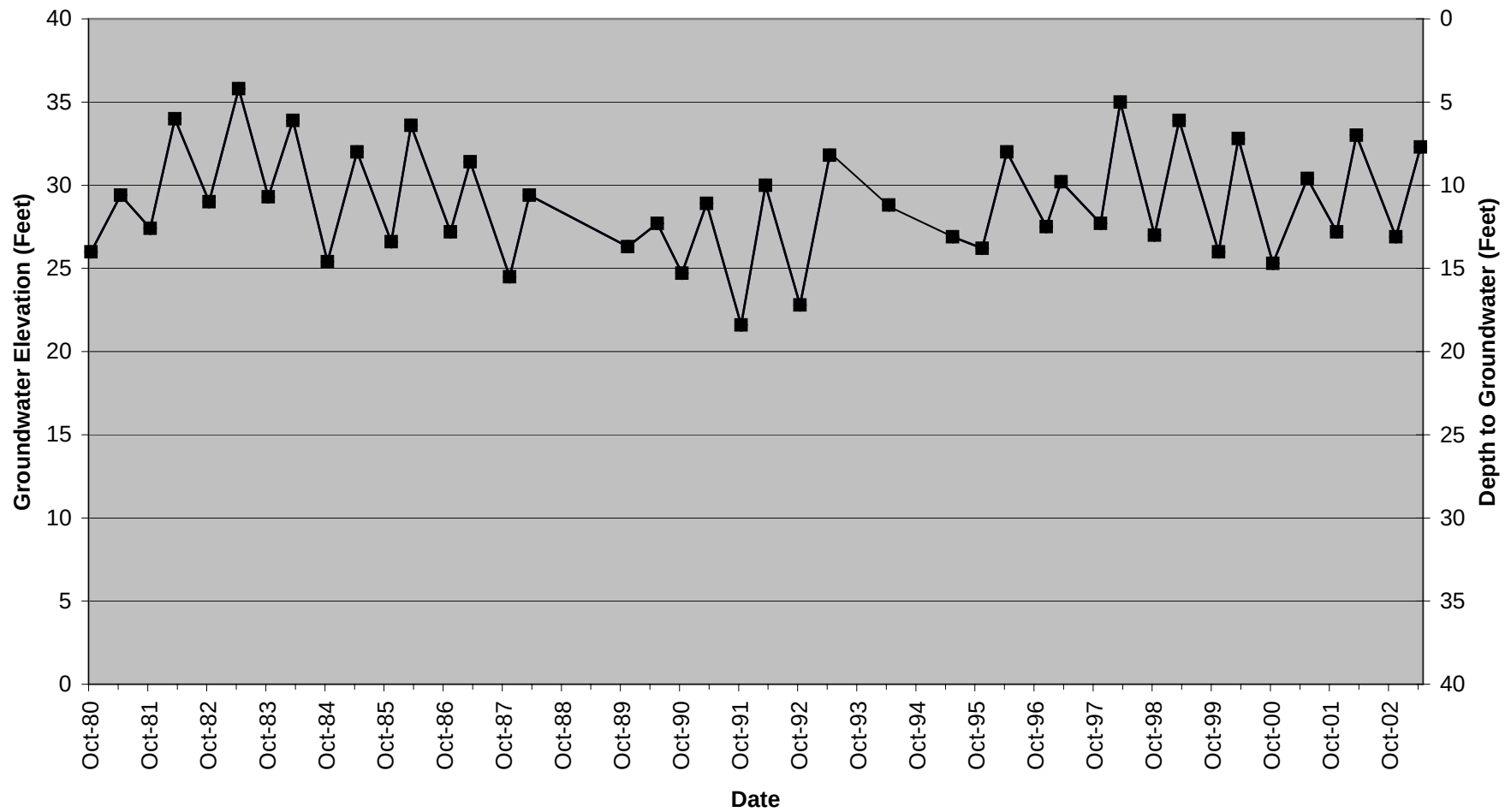
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Hydrograph of 05N07W36R001M
Petaluma Valley
Land Surface Elevation: 19 feet



Hydrograph of 05N08W13Q001M
Petaluma Valley
Land Surface Elevation: 40 feet



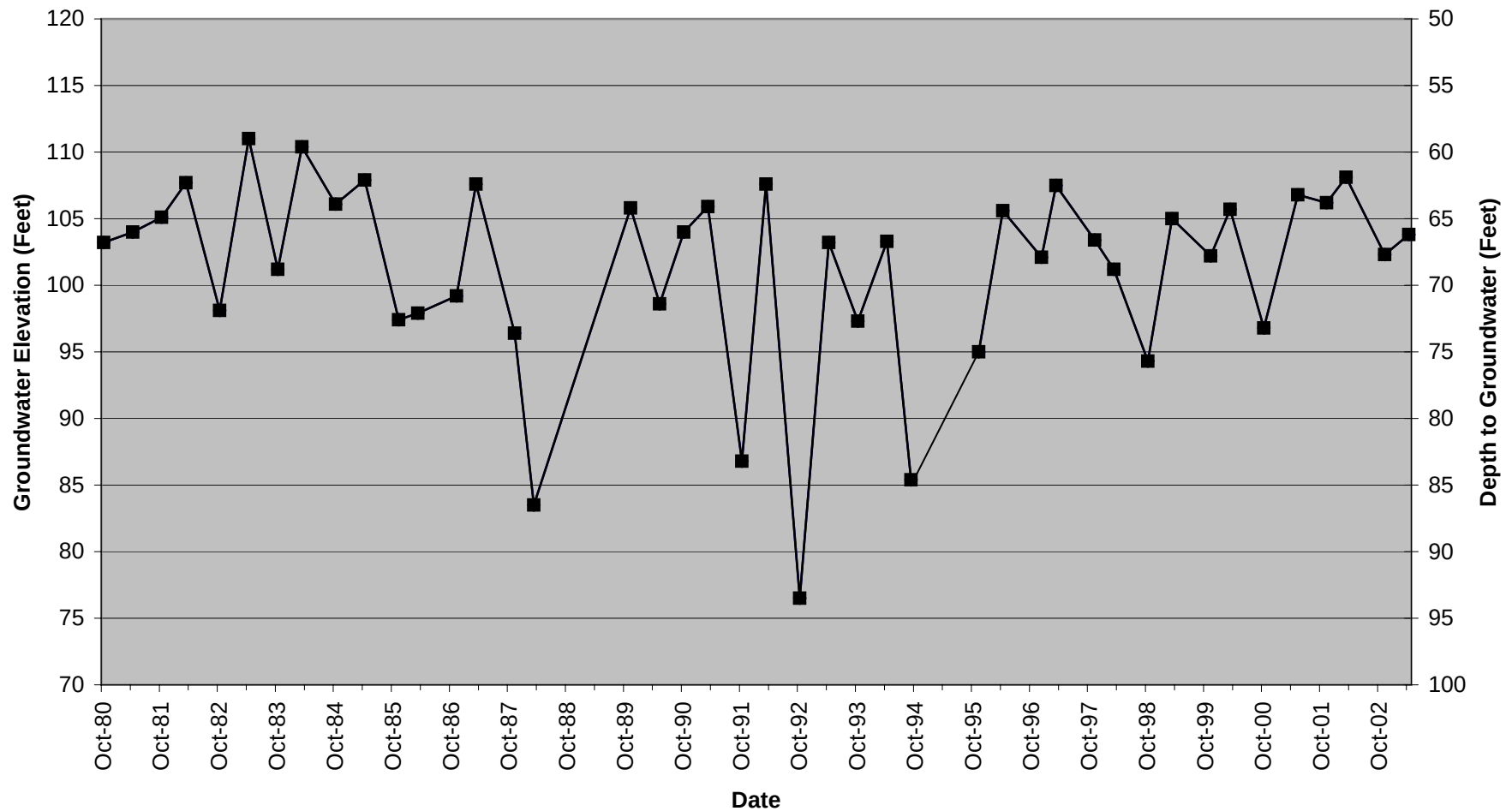
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Hydrograph of 05N08W14K002M
Petaluma Valley
Land Surface Elevation: 170 feet



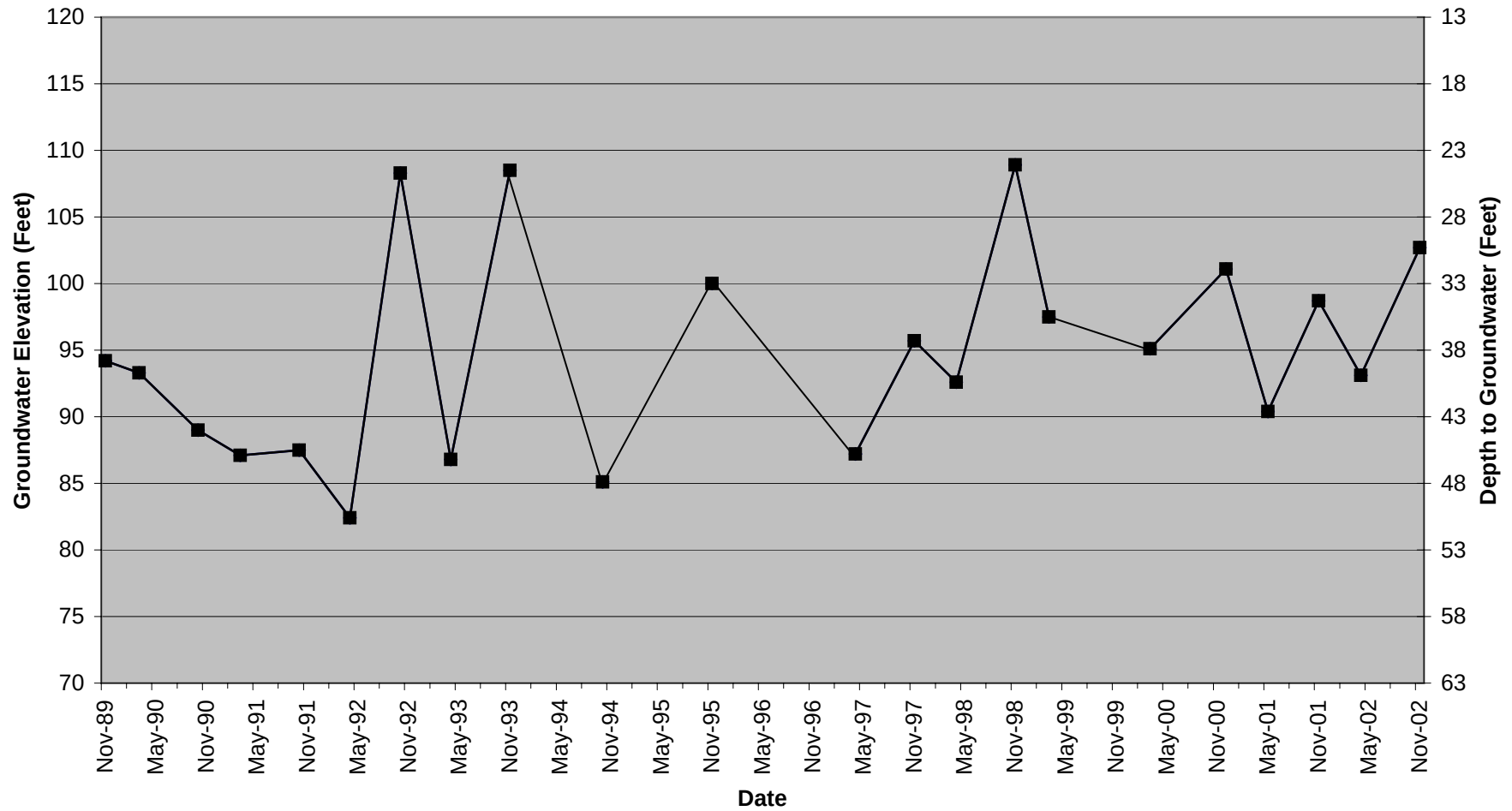
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Hydrograph of 06N07W31J001M
Santa Rosa Plain
Land Surface Elevation: 133 feet



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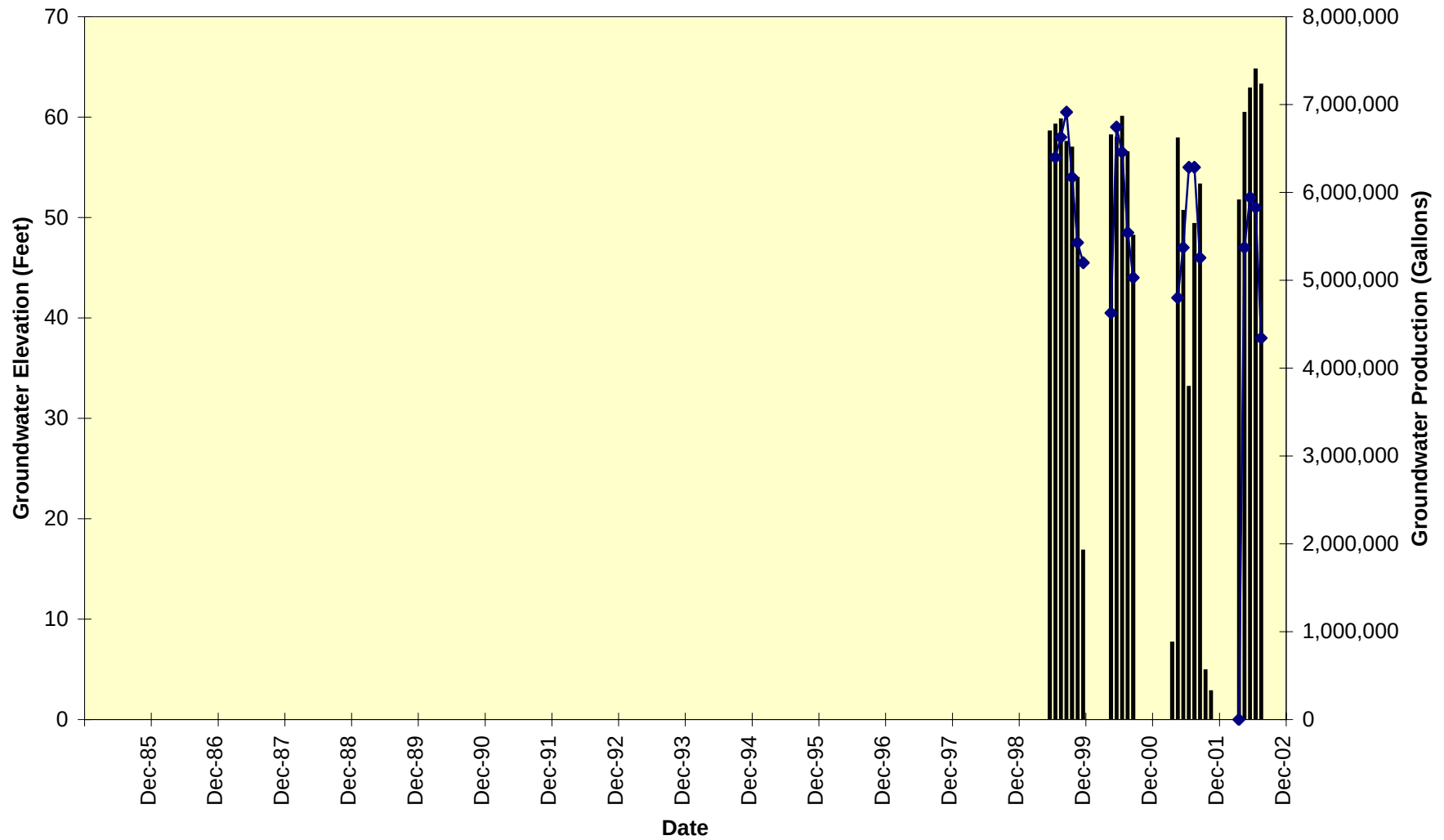
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ATTACHMENT C

Production and Groundwater Elevations in City Wells

Airport Well Monthly Production and Groundwater Elevation



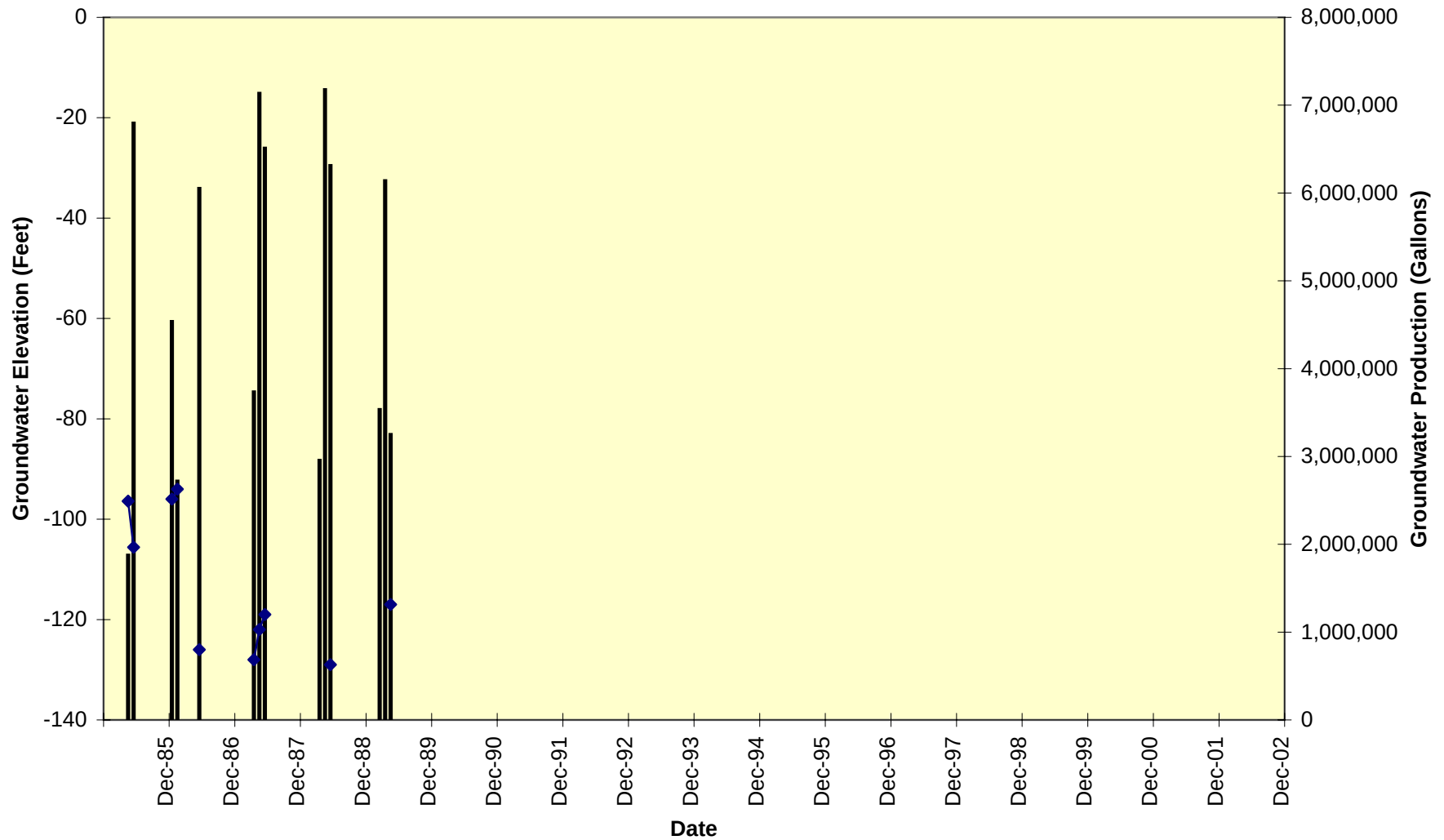
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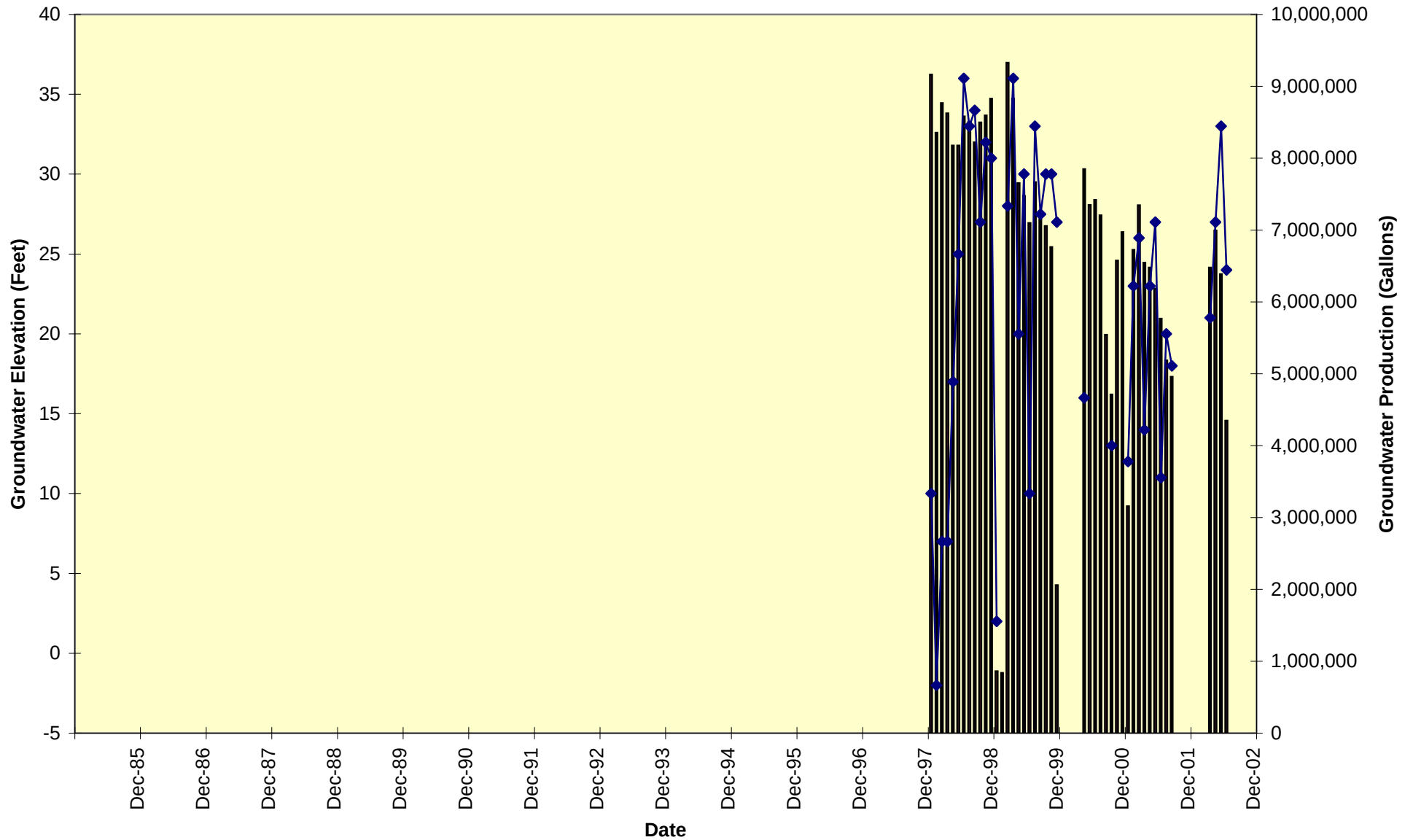
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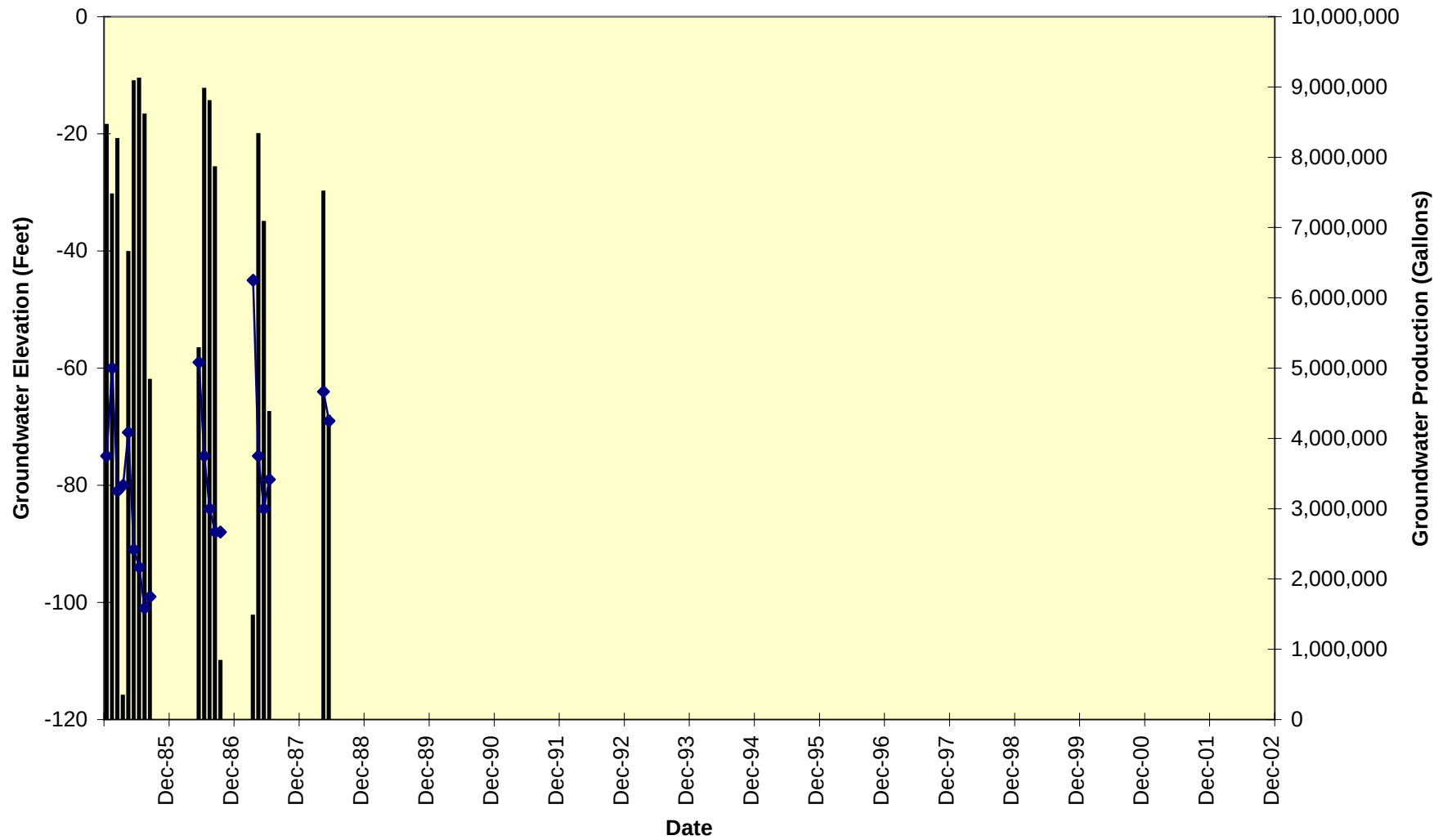
Casa De Arroyo Well **Monthly Production and Groundwater Elevation**



Frates Well Monthly Production and Groundwater Elevation



Garfield Well Monthly Production and Groundwater Elevation



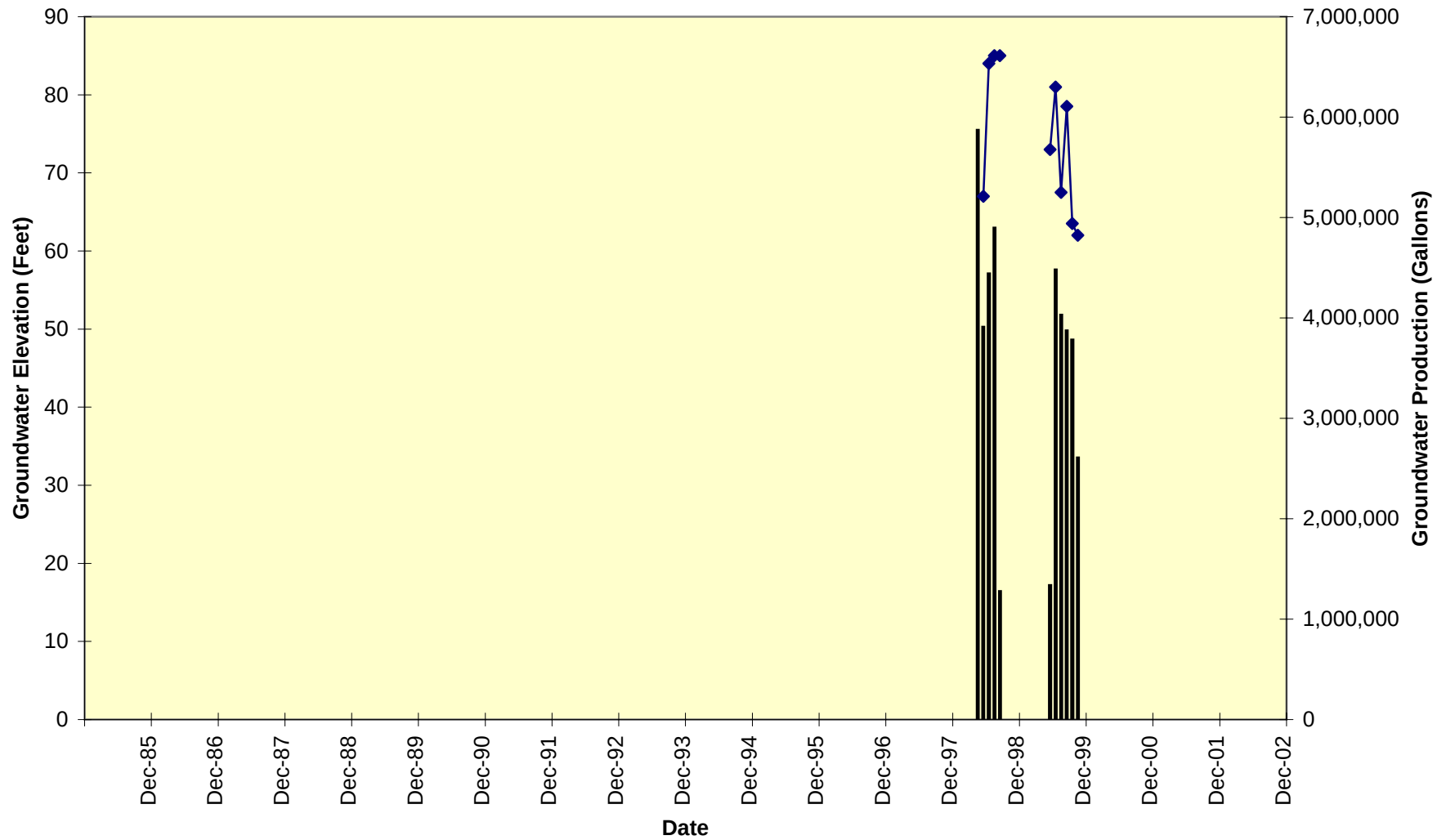
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Kings Mill Well Monthly Production and Groundwater Elevation



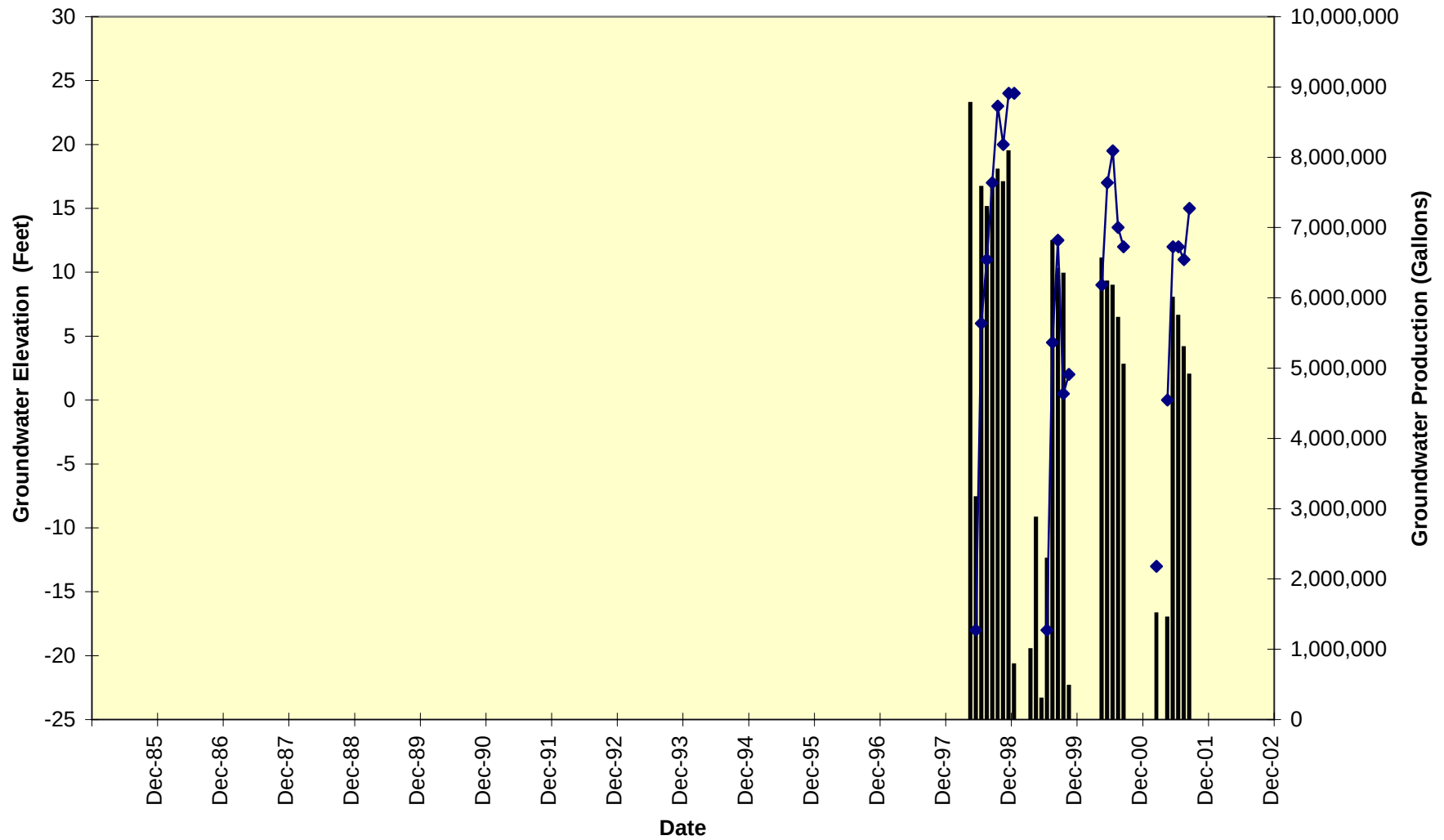
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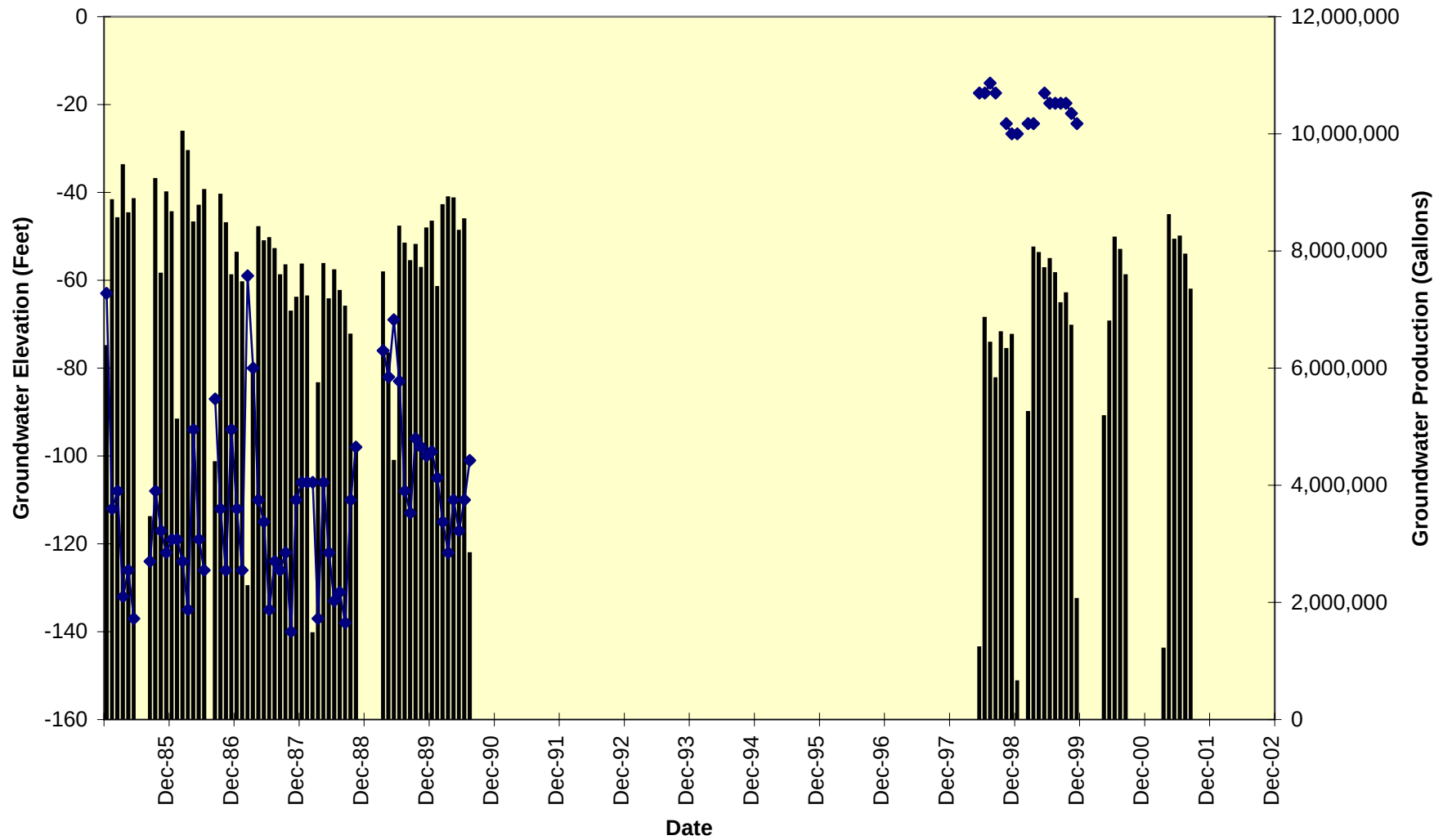
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Luchessi Well **Monthly Production and Groundwater Elevation**



Park Place Well **Monthly Production and Groundwater Elevation**



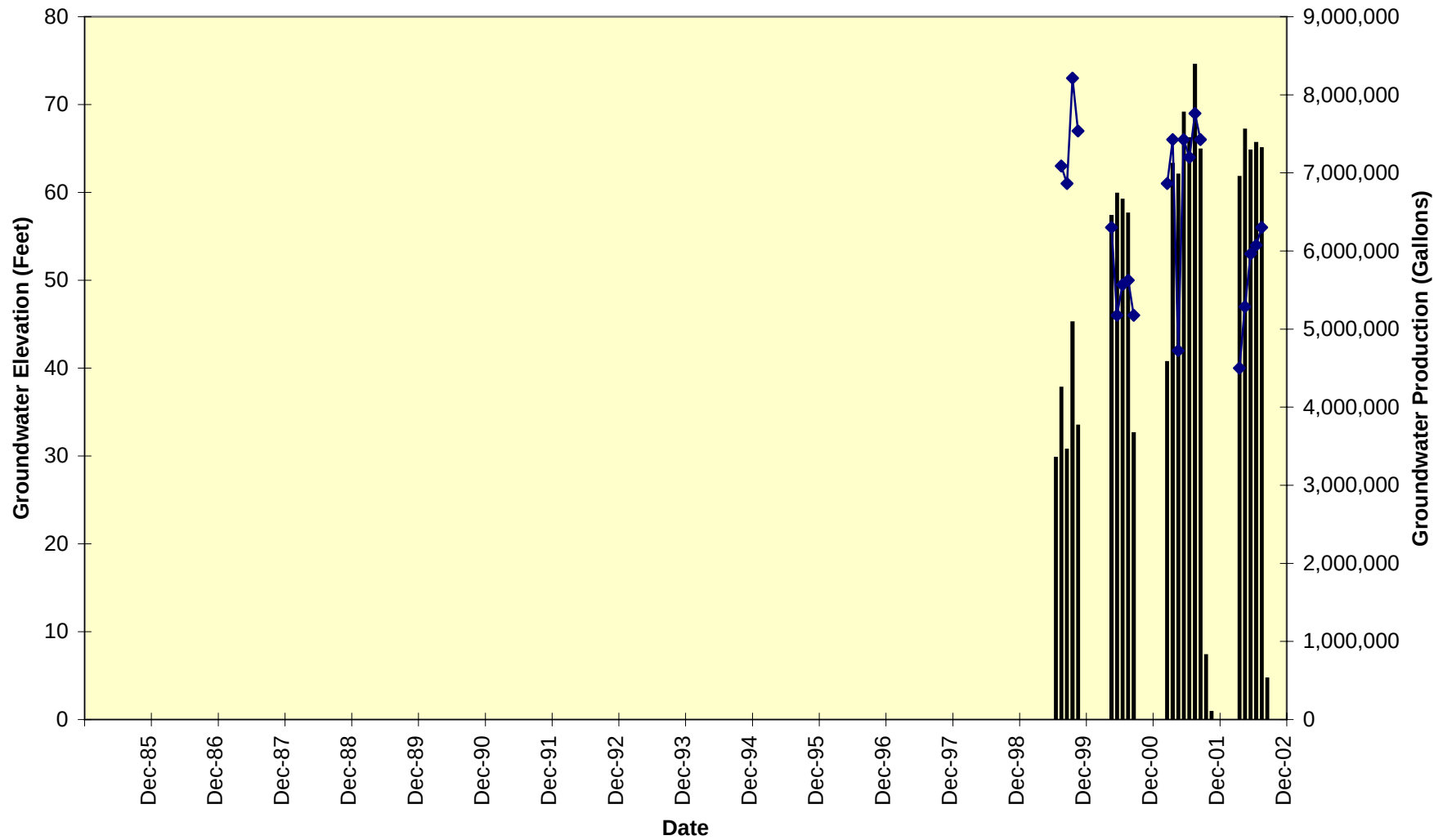
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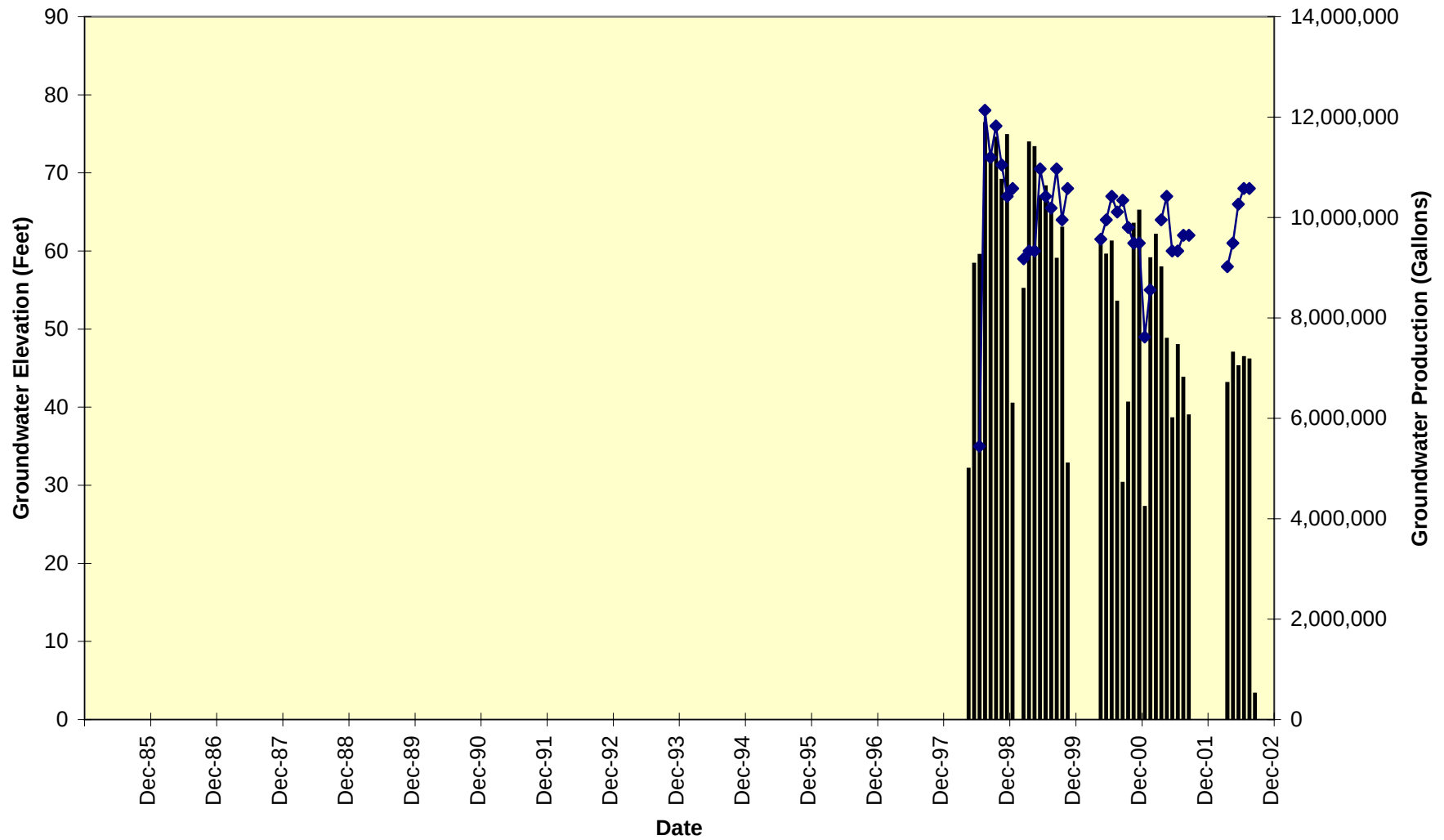
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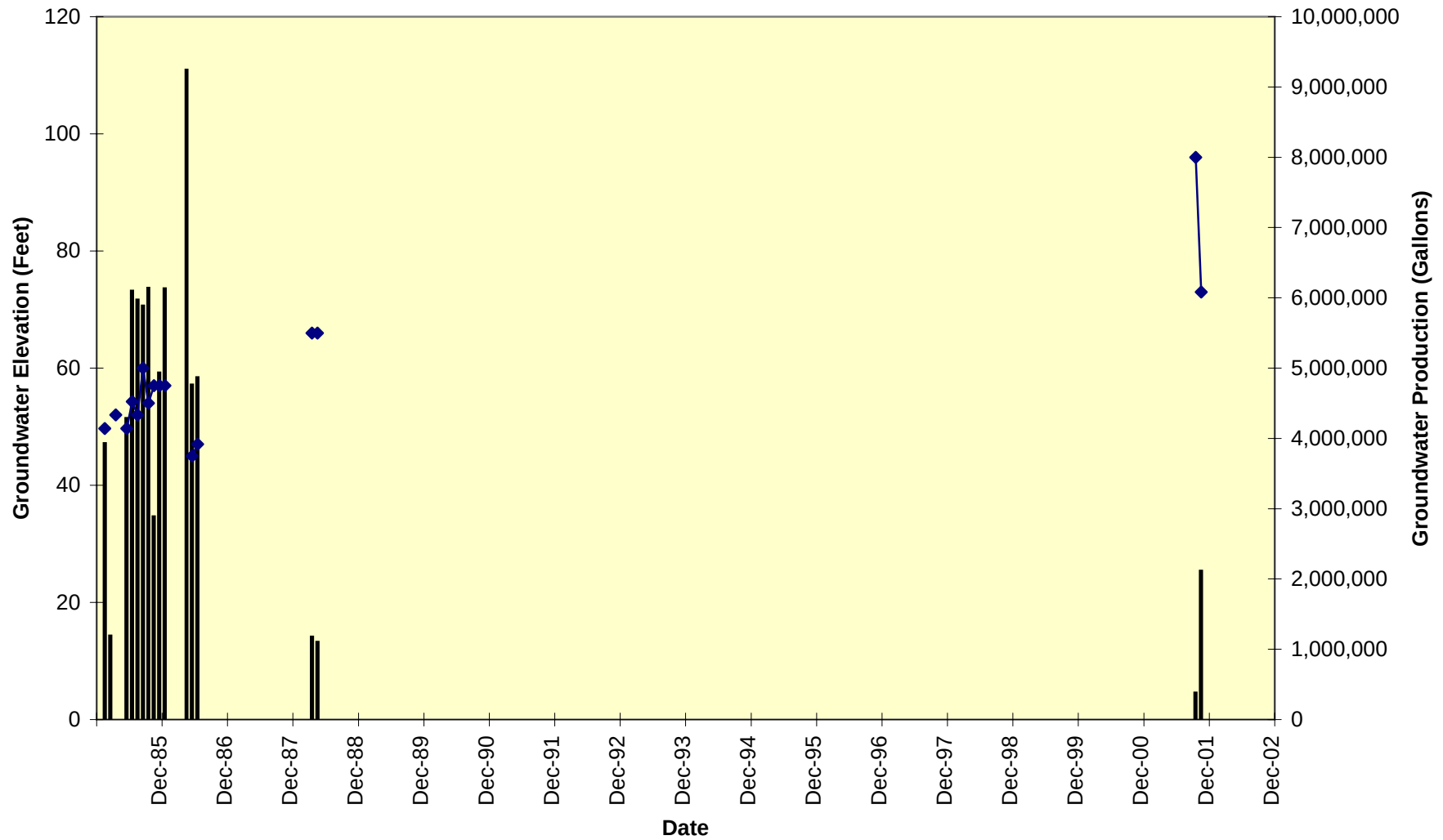
Prince Park North Well Monthly Production and Groundwater Elevation



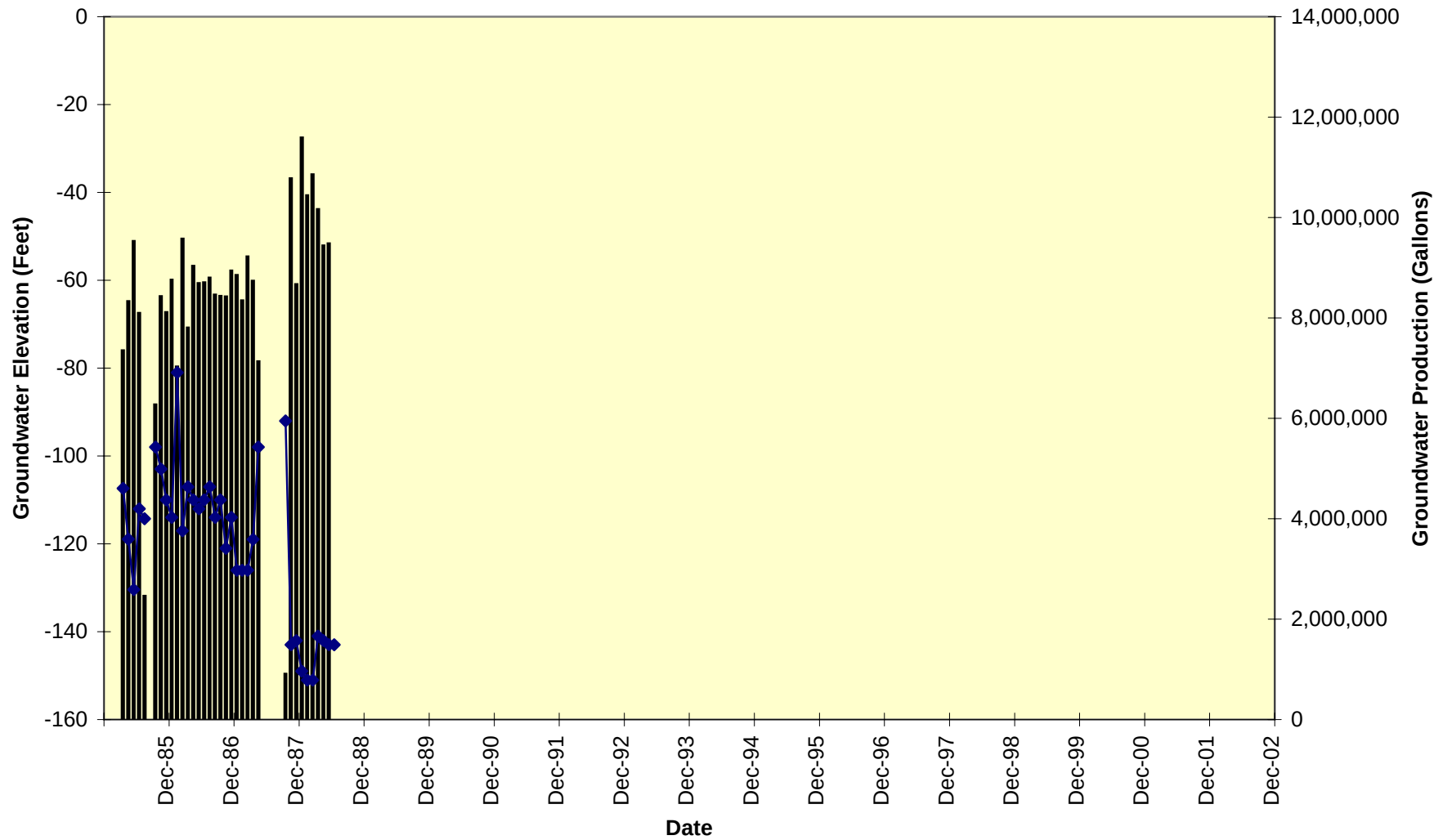
Prince Park South Well Monthly Production and Groundwater Elevation



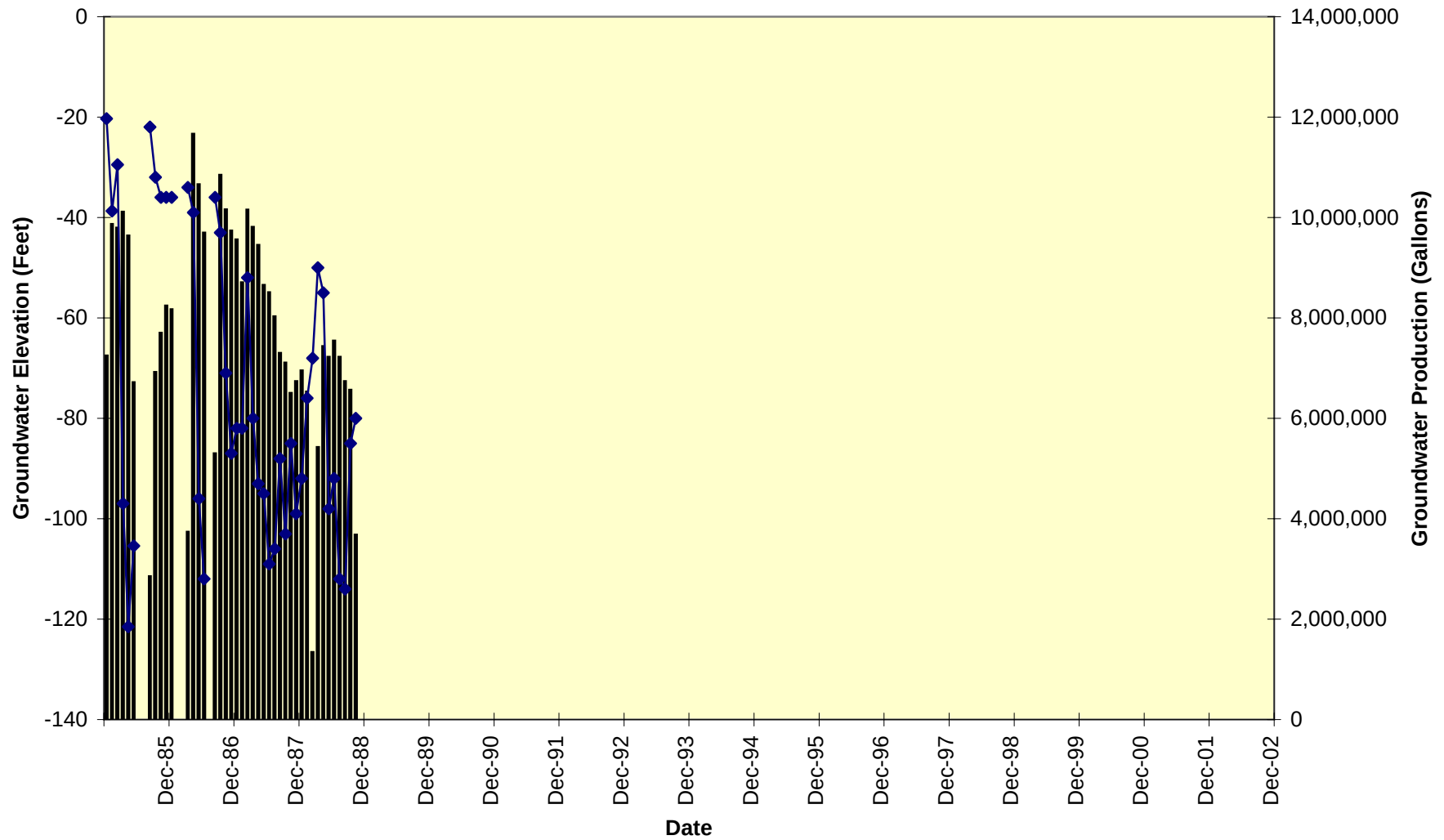
Scott Well **Monthly Production and Groundwater Elevation**



Station 5 Well **Monthly Production and Groundwater Elevation**



Station 9 **Monthly Production and Groundwater Elevation**



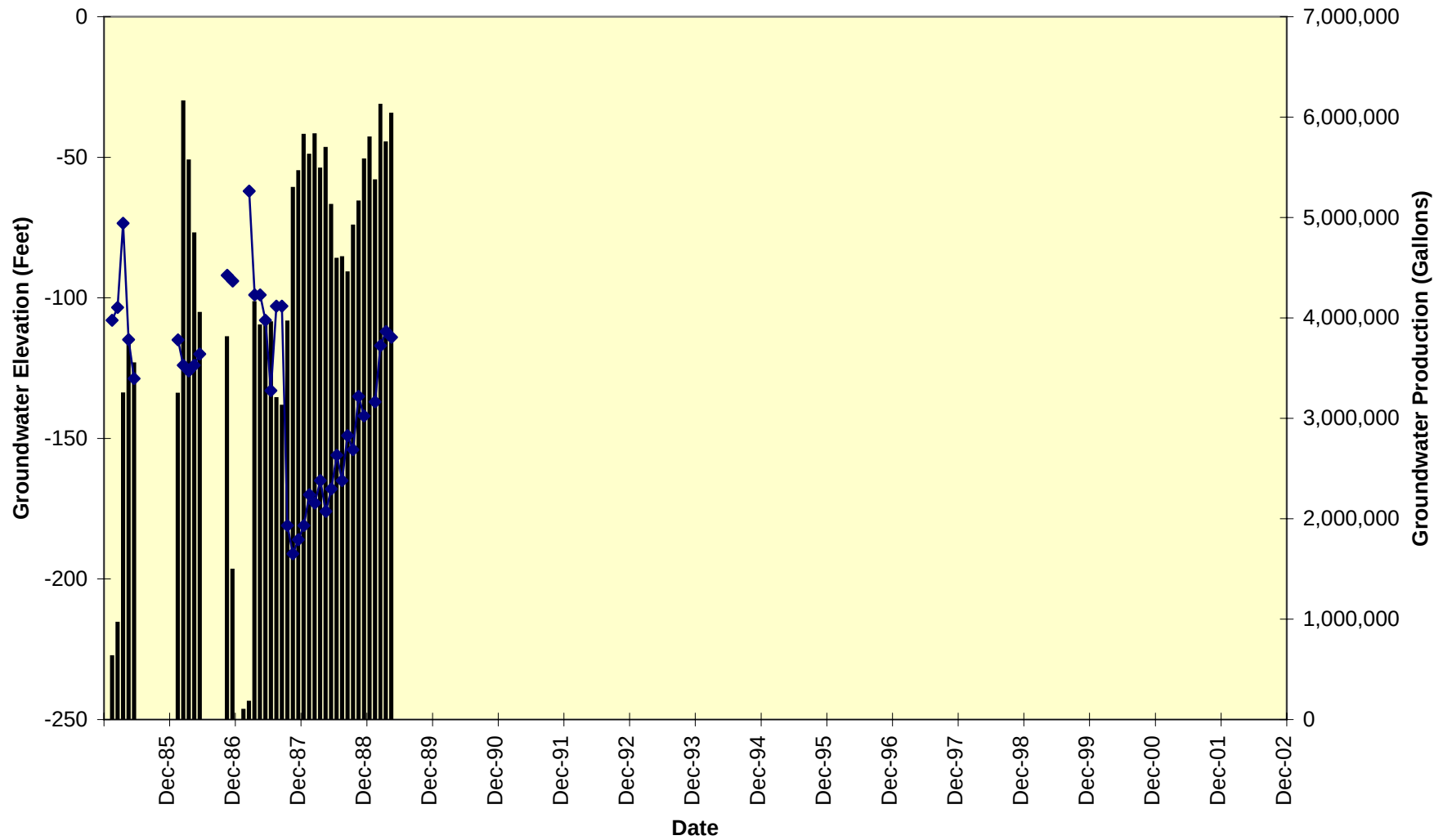
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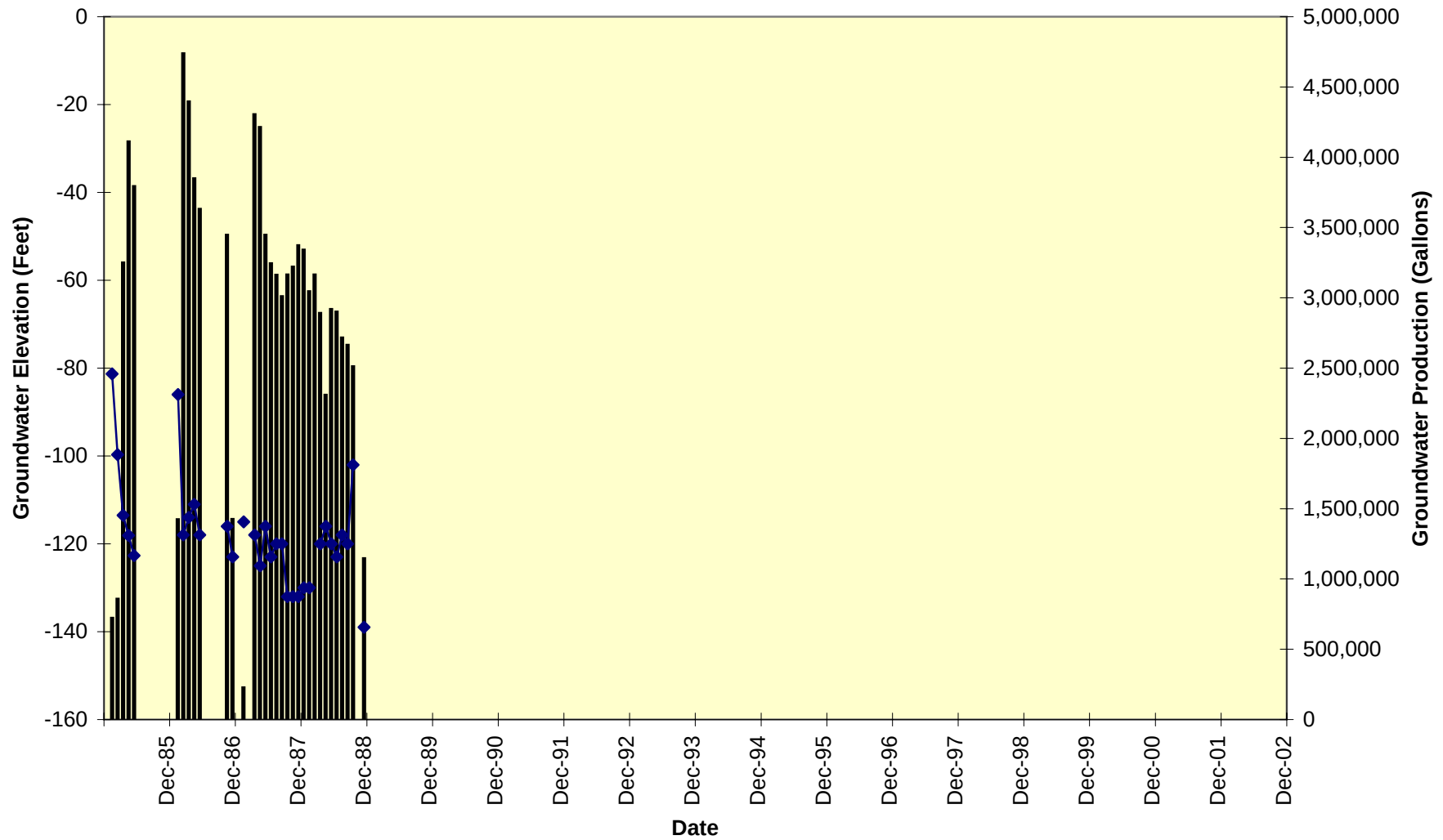
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Station 11 Well **Monthly Production and Groundwater Elevation**



Station 14 Well **Monthly Production and Groundwater Elevation**



Attachment C

02/26/04

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Stony Point Well **Monthly Production and Groundwater Elevation**

