Investigation of an *Escherichia coli* O157:H7 Outbreak Associated with Dole Pre-Packaged Spinach

Attachment 11

CDC Addendum Report, "Irrigation Water Issues Potentially Related to 2006 E. coli O157:H7 in Spinach Outbreak"

Irrigation Water Issues Potentially Related to 2006 *E. coli* O157:H7 in Spinach Outbreak

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Abstract

In September, 2006, *E. coli* O157:H7 infections associated with fresh spinach affected over 200 people in 26 states. The Centers for Disease Control and Prevention (CDC) assisted the Food and Drug Administration (FDA) and the State of California Department of Health Services Food and Drug Branch (FDB) in a field environmental investigation to attempt to determine how and why the spinach became contaminated. CDC's involvement in the environmental investigation focused on potential water issues that may have been related to the outbreak, including surface runoff from grazing areas onto cultivated fields, construction of irrigation wells, depths to groundwater and groundwater-surface water interaction, and direct use of surface water for irrigation. Of these factors, depths to groundwater and groundwater-surface water interactions were the most likely water-related factors contributing to this outbreak.

Introduction

This report summarizes the field environmental investigation by the Centers for Disease Control and Prevention (CDC) related to the 2006 *E. coli* O157:H7 outbreak associated with spinach in 26 states. The information provided is an addendum to the comprehensive report on the environmental investigation for this outbreak prepared by the Food and Drug Administration (FDA) and the State of California Department of Health Services Food and Drug Branch (FDB). The epidemiologic investigation of this outbreak, which was coordinated and led by CDC, is reported separately, and was initially reported in the Mortality and Morbidity Weekly Report (MMWR, 2006).

During September, 2006, several states reported cases of *E. coli* O157:H7 infection to CDC. It was quickly established that cases in multiple states contained matching strains of the bacteria and the epidemiologic evidence implicated fresh spinach as the vehicle. Eventually, over 200 cases in 26 states were identified, and traceback investigations led to a processing plant and produce farms in the central California coast area. From September 19–October 3 and November 6–17, 2006, CDC deployed CDR Rick Gelting, PhD, PE of the National Center for Environmental Health to Salinas, California, to assist FDA and FDB with environmental investigations related to the outbreak. Dr. Gelting's primary task was to investigate potential water issues that may have been related to the outbreak. To accomplish this, large amounts of data about wells and groundwater were obtained from numerous sources, including

- San Benito County Water District (SBCWD),
- Monterey County Water Resources Agency,
- Central Coast Regional Water Quality Control Board,
- United States Geological Survey (USGS),
- California Department of Water Resources,
- U.S. Department of Agriculture's Agricultural Research Service (USDA/ARS),
- various growers in San Benito and Monterey Counties,
- FDA, and
- FDB.

Information that was gathered included:

- Drillers' logs for wells on and near ranches identified by traceback investigations,
- Locations of irrigation wells relative to contamination sources and surface waters,
- Records of depth to groundwater in monitoring wells over time,
- Water quality analyses for both groundwater wells and surface waters,
- Data on location and timing of percolation from surface waters into groundwater,
- Streamflow in rivers and streams, and
- Records of direct use of surface water for irrigation on farms.

Analysis of the data collected related to water issues is ongoing; this report is a compilation of the results to date.

The investigation of water issues potentially related to the outbreak focused on several topics, including

- surface runoff from grazing areas onto cultivated fields,
- construction of irrigation wells,
- depths to groundwater and groundwater-surface water interaction, and
- use of surface water for irrigation.

These issues have broad implications for potentially contaminating agricultural produce; therefore, they are discussed in this report in a general way. This general discussion references the four ranches that traceback investigations by FDA and FDB initially focused on in the 2006 outbreak: Paicines, Taix, and Wickstrom Ranches in San Benito County and Eade Ranch in Monterey County (see main FDA/FDB report for ranch locations).

Later in the outbreak investigation, further laboratory analysis led to pulsed-field gel electrophoresis (PFGE) matches of *E. coli* O157:H7 strains from patients and bagged spinach to environmental samples at Paicines Ranch. Therefore, this report discusses the water-related issues at Paicines Ranch in more detail.

Surface runoff from grazing areas onto cultivated fields

Many agricultural fields in the central California coast area are close to cattle grazing pastures. Agricultural fields are typically located in flatter valley floor areas and pastures are on surrounding hillsides. Because cattle are considered one of the primary reservoirs for *E. coli* O157:H7, surface runoff from grazing areas onto crop fields is a potential concern, especially during heavy rainfall events.

Precipitation in this area of California is highly seasonal, with a rainy season in winter and spring and a dry season in summer and fall (Figure 1). In 2006, virtually no precipitation fell from June through September. Because this outbreak occurred in August and September, no significant direct runoff occurred during the time when the crops associated with this outbreak were growing. In addition, more than one crop per year is grown on the fields implicated in the outbreak, and leafy produce had been harvested from the same fields earlier in the growing season without known health impacts. For these reasons, it does not appear that surface runoff from grazing areas was a factor in this outbreak.

Construction of irrigation wells

Construction techniques can ensure that a drilled irrigation well does not become a conduit for surface contamination to reach groundwater. These techniques include the installation of grouting (such as cement or bentonite clay) in the annular space between the well bore and the well casing (Figure 2). Grouting ensures that surface runoff does not flow downward in this space. Many well ordinances specify the minimum depth to which grouting should be installed (e.g., 50 feet). A concrete pad or apron may also be installed on the surface to help direct surface runoff from the well and prevent it from reaching this annular space. Once a well is installed, it is not usually possible to determine whether grouting was installed without locating the original well driller's log. (It should be noted, however, that even when well logs are available, they are not always completely accurate.)

Many of the agricultural wells in use in San Benito and Monterey Counties were constructed many years before modern well ordinances that require grouting were in place. Grouting was not installed in many of these older agricultural wells. In 1987, Monterey County enacted a county well ordinance that requires grouting in new wells. A review of well logs in Monterey County showed that grouting was first used for some wells starting around 1970, but this practice did not become universal until the 1987 well ordinance. San Benito County also has a well ordinance that requires grouting.

As shown in Table 1, the majority of the agricultural wells in use at the initial fields of interest in both counties were constructed before these ordinances were in place, and most of these wells are not grouted. These ungrouted wells are potential conduits for contamination from the surface or shallow groundwater to reach deeper groundwater.

Table 1: Agricultural Wells at Fields from Traceback Investigations

Ranch	County	Well status
Paicines	San Benito	3 irrigation wells (only 2 active in 2006): well logs for all 3 located (drilled 1965, 1973, 1977); none grouted
Taix	San Benito	1 irrigation well: well log located (drilled 1992); grouted
Wickstrom	San Benito	1 irrigation well: no well log located
Eade	Monterey	4 irrigation wells: well logs located for 3 (drilled 1955, 1960, 1977); none of these 3 grouted

Although specific figures were not located, there are a significant number of abandoned wells in Monterey and San Benito Counties that have not been properly destroyed. To prevent an abandoned well from becoming a conduit for contamination to enter groundwater, the entire well should be filled with cement. This procedure does not appear to be common in this area when wells are no longer in use.

Depths to groundwater and groundwater/surface water interactions

Historically, pumping of groundwater provided the majority of irrigation water for both Monterey and San Benito Counties. Both counties also augment groundwater supplies by storing winter runoff in reservoirs, then releasing it during the summer to percolate into streambeds and recharge groundwater.

In Monterey County, over 90% of irrigation is still supplied by groundwater.

In San Benito County, decades of overpumping of groundwater led to dropping groundwater levels, especially in the larger valleys such as the San Juan and Gilroy-Hollister Valleys. In some cases, groundwater levels dropped by more than 100 feet below preagricultural pumping levels. In the late 1980s, SBCWD began importing water into the county from the U.S. Bureau of Reclamation's Central Valley Project (CVP). CVP manages water in the Sacramento and San Joaquin Valleys of central California. The water imported into San Benito County is surface water from the Bureau of Reclamation's San Luis Reservoir. Water is pumped from the San Luis Reservoir to the San Justo Reservoir near Hollister; where it is distributed in pressurized pipelines for agricultural use through what is known locally as the "Blue Valve" system (Figure 3). Some of this imported water is also utilized for municipal use after treatment. In 2006, this imported surface water made up more than half of the irrigation water supply in San Benito County. The imported water is also used to recharge groundwater during the dry season by releasing it into streams and rivers and allowing it to percolate into streambeds.

Because of the prolonged drought in California in the late 1980s and early 1990s, SBCWD did not receive a full allotment of water from CVP until 1995. When this full allotment became available, groundwater levels in San Benito County rebounded dramatically.

Groundwater levels at present are approaching the levels in 1913 before widespread pumping of groundwater for agriculture began in this area (Figure 4). Studies by SBCWD attribute this rapid rise in groundwater levels largely to recharge from sustained low flows in streams (principally the San Benito River) rather than to other factors such as decreased pumping of groundwater (Yates, et al., 2000). These sustained low flows during 1995–1998 continued because of both wet winters and the availability of imported water for percolation into streambeds to recharge groundwater. Since 1998, percolation of imported water from the CVP has been much lower because the groundwater reservoir has remained relatively full (Figure 5).

The large-scale change in the groundwater regime in San Benito County has several potential consequences. First, groundwater levels in many areas of the county are fairly shallow—within 20 or 30 feet or less of the surface. In addition, investigations by SBCWD show that this rebound of groundwater levels probably also means that shallow groundwater is hydraulically connected to deeper groundwater, which may not have been the case when deeper groundwater levels were depressed by pumping (Yates, et al., 2000). These studies also show that vertical groundwater gradients in San Benito County are consistently downward in most areas.

All of these factors indicate that groundwater in general in San Benito County is probably more susceptible to contamination than it was before groundwater levels rebounded in 1995–1998. In the past, an unsaturated layer between any shallow, perched groundwater and deeper groundwater would have helped to prevent pathogens from the surface or shallow groundwater from reaching deeper groundwater because unsaturated zones tend to be hostile environments for pathogens. Although many of the wells in the county are drilled deep, they do not necessarily draw water only from deeper groundwater because of the hydraulic connection between shallow and deep zones. Pumping tends to create downward gradients in groundwater, which can draw contaminants downward, especially if wells are poorly constructed, as discussed above. In addition, many agricultural wells are perforated over large intervals and therefore can draw groundwater from a large zone of the subsurface rather than just from deeper groundwater. For example, the well in use at Taix Ranch is perforated for 400 feet; from 160 feet to 560 feet below the ground surface.

Groundwater in general is not considered a favorable environment for most pathogens, and it is often assumed that they do not move far in the subsurface. However, some studies have demonstrated that pathogenic bacteria can move considerable distances in sand and gravel aquifers (Freeze and Cherry, 1979). Studies have also shown that although they experience die-off, indicator bacteria (such as total and fecal coliforms) are relatively stable in groundwater in both laboratory and field settings (Bitton, et al., 1983). In one laboratory experiment, generic *E. coli* persisted for over 3 months in a synthetic groundwater; the addition of organic matter did not affect persistence (Ma, et al., 1999). Recent research work being funded by CDC on public health impacts of onsite wastewater systems also indicates that larger pathogens such as *cryptosporidium* may be more mobile in the subsurface than is commonly assumed (Tollestrup, et al., 2006).

The scale of agricultural pumping for irrigation can be quite large; many wells in the central California coast area draw 3,000 gallons per minute (gpm) over long periods of time. Such pumping can lead to more rapid transport of contaminants in the subsurface. In addition, because sediments in the county are highly variable and wells usually penetrate many soil layers, most wells draw water from coarse-grained formations where both transport and survival of pathogens would be enhanced.

The time frame over which groundwater levels in San Benito County rebounded and remained close to preagricultural pumping levels (1995–2006) corresponds with the period during which known *E. coli* O157:H7 outbreaks related to leafy produce from the central California coast area occurred (1996–2006). However, the available traceback investigations for outbreaks that occurred before 2006 largely led to ranches not in San Benito County. Nonetheless, the potential public health impact of large scale inter-basin water transfers appears to be worthy of further investigation.

In the Upper Valley region of Monterey County (where the Eade Ranch is located), groundwater levels fluctuated seasonally over the time frame of the outbreaks but the same type of large-scale change in groundwater regime does not appear to have occurred.

Direct use of untreated surface water for irrigation

Of the four ranches that were the focus of the initial traceback investigations, only one (Taix Ranch in San Benito County) made direct use of surface water for irrigation. The source for this irrigation was imported water from the San Luis and San Justo Reservoirs delivered through the Blue Valve water system. Records of water use from the Taix Ranch do not appear to show that any large changes in the proportions of surface water versus groundwater use occurred in 2006 versus the previous 2 years. Water quality records from limited sampling of the San Justo Reservoir and the Blue Valve system also do not indicate water quality problems from this source in 2006. Large volume ultrafiltration samples obtained by CDC, FDA, and FDB from San Luis and San Justo Reservoirs in November 2006 were negative for *E. coli* O157:H7. Because later investigations based on PFGE sample matches did not focus on Taix Ranch, further intensive investigations of potential water related issues did not take place at this location.

Paicines Ranch: intensive sampling and investigation of potential water issues

As mentioned above, laboratory analysis during the environmental investigation of this outbreak led to PFGE matches of *E. coli* O157:H7 strains from patients and bagged spinach to environmental samples at Paicines Ranch. Specifically, PFGE patterns from patients and bagged spinach matched those from fecal samples from cattle and wild pigs at the ranch, and from one water sample and one sediment sample from the San Benito River on the ranch. In addition, other water samples from the San Benito River either upstream of the ranch or on the ranch were positive for *E. coli* O157:H7, but did not match the outbreak strain (complete results of environmental sampling are discussed in more depth in the main FDA/FDB report and the USDA/ARS addendum). Both conventional grab samples and large volume ultrafiltration samples obtained by CDC, FDA, and FDB from the irrigation wells on Paicines Ranch were negative for *E. coli* O157:H7.

San Benito River System: Background

A discussion of potential water-related issues at Paicines Ranch must be prefaced by some background information on the San Benito River system. Flow in the San Benito River in the area of Paicines Ranch is regulated by Hernandez Reservoir, which is approximately 40 miles south of the Ranch (see main FDA/FDB report for ranch locations). Winter runoff is captured in the reservoir, then released in the dry season for percolation into streambeds to recharge groundwater. If the reservoir fills during the winter, water runs over a spillway and into the river channel. Other than such spills, SBCWD manages the rate of release for both groundwater recharge and flood control capacity in the reservoir.

From Hernandez Reservoir, the San Benito River flows north toward Hollister, passing through the Paicines Ranch property near the small town of Paicines. Near the ranch, water from the river is also diverted into Paicines Reservoir, which is approximately 2 miles north of the Ranch (Figure 6). Water from Paicines Reservoir is released into Tres Pinos Creek east of the reservoir for percolation recharge of groundwater. In addition, imported surface water from CVP, which is stored in San Justo Reservoir, can be released into Tres Pinos Creek for groundwater recharge, although virtually none has occurred since 2004. Both of these points of release of water into Tres Pinos Creek are downstream of Paicines Ranch and do not affect any water-related issues for the ranch.

From the Paicines area, the San Benito River continues to flow north toward Hollister. During the dry season, flow in the river is managed by SBCWD so that all flow percolates into the ground by a point just south of Hollister. This is accomplished by managing releases from both Hernandez Reservoir and San Justo Reservoir, where imported CVP water is stored. Dry season flows for percolation are managed in this manner because the groundwater basins in San Benito County are essentially full, as discussed above in the section titled Depths to Groundwater and Groundwater/Surface Water Interactions. Beyond Hollister, parts of the riverbed are typically dry during the summer until further downstream, where irrigation return flows and groundwater flow back into the river further west near San Juan Batista contribute to streamflow. During the winter rainy season, continuous flow in the river is sometimes maintained to the confluence of the San Benito River with the Pajaro River near Highway 101.

Paicines Ranch

The cultivated fields on Paicines Ranch are near where the San Benito River flows through the ranch. Cattle from surrounding pastures and wild pigs in the area have ready access to the river. Some of the positive *E. coli* O157:H7 samples that matched the outbreak strain were from river water and from cattle feces in the river. Additional samples indicated *E. coli* O157:H7 contamination of the river water further upstream, although it was not the outbreak strain. Investigations in the Salinas Valley have shown fairly widespread *E. coli* O157:H7 contamination of surface waters there, indicating that this pathogen may be commonly found in rivers and streams (Central Coast Water Board, 2006). Water from the San Benito River is not directly used for irrigation on Paicines Ranch because all irrigation water is supplied by wells.

However, the river is used to recharge groundwater through percolation, so some connection exists between the river and groundwater in the area of Paicines Ranch.

The Paicines Ranch area is in a relatively narrow valley with a much smaller groundwater basin than the larger valleys further downstream such as the San Juan Valley. The San Benito River flowing directly through this narrow valley is a comparatively large source of water for percolation recharge into the smaller groundwater basin. Because of this, the Paicines groundwater basin tends to fill every winter with percolation from the river (G Yates, consulting hydrologist, Berkeley, California, personal communication, 2007). Because the Paicines groundwater basin is relatively full during the early part of the growing season, any additional potential recharge from the San Benito River is rejected and flow from the river continues downstream instead of percolating into the ground in this area. Wells in the area are therefore drawing from stored groundwater early in the growing season. In addition, heavy rains fell during spring 2006, which probably reduced the amount of groundwater pumping, especially early in the growing season. During 1998, which also had a wet spring, irrigation water use in San Benito County was 34% lower than average (Yates, et al., 2000).

However, as more groundwater is pumped over the course of the growing season, groundwater levels tend to go down, as shown in Figure 7. When this occurs, another opportunity exists for recharge from the San Benito River into the Paicines groundwater basin. One of the irrigation wells on Paicines Ranch is also an SBCWD groundwater level monitoring well; such fluctuations are also evident in this well (Figure 8). In March 2006, the groundwater level in this well was above the river bed elevation, so recharge was rejected. As more groundwater was pumped during the growing season, groundwater levels were depressed to approximately the level of the riverbed in July 2006, and then below that level, once again allowing recharge to take place late in the growing season.

SBCWD records of releases from Hernandez Reservoir and USGS streamflow data for the San Benito River provide further evidence that groundwater recharge later in the growing season is occurring. Figure 9 shows releases from the reservoir for 2006 and the average releases for 2000–2006. (Only the most recent data were used for this comparison because in 2000, SBCWD changed the amount of water released because of the dramatic rise of groundwater levels in the county discussed earlier.) Both the 2006 and the 2000–2006 average graphs show high spring releases in March or April because the reservoir fills up from winter rains. In addition, releases in August and September 2006 were much higher than average. These higher than average releases from Hernandez Reservoir resulted in higher than average flow in the San Benito River below the reservoir during the same months. This is reflected in the graph in Figure 10, which shows the flow in the San Benito River at the USGS stream gaging station near Willow Creek School upstream of Paicines Ranch. Flows in August and September 2006 were again much higher than average at this gaging station.

However, these higher than average flows in the San Benito River during August and September 2006 were not maintained further downstream below Paicines Ranch. At the closest USGS stream gaging station downstream of the ranch (at Highway 156 near Hollister; Figure 6), flow in these same months was reduced to zero or just above, and was actually lower than average (Figure 11). In other words, flow in the San Benito River in August and September 2006 went from higher than average upstream of Paicines Ranch to practically zero downstream of the ranch. Two main factors account for this reduction in flow in the river. First, a small proportion of the flow was diverted to Paicines Reservoir (Table 2). Other than small losses to evaporation, the remainder of the flow percolated into the riverbed between the two gaging stations to recharge groundwater. Not all of this recharge took place into the Paicines groundwater basin. Nonetheless, because groundwater levels in the SBCWD water level monitoring well on Paicines Ranch fell below the level of the riverbed during August and September 2006 (discussed above), some of that recharge would have taken place into the Paicines groundwater basin.

Table 2: Comparison of Flows

	August 2006	**September 2006**
Hernandez Releases	3,597 acre-feet	2,267 acre-feet
Diversion to Paicines Reservoir	675 acre-feet	263 acre-feet
Difference = approximate percolation losses in San Benito River	2,922 acre-feet	2,004 acre-feet

The timing of recharge from the San Benito River into the Paicines groundwater basin is important because of its possible relation to the 2006 outbreak. Illnesses during this outbreak took place during August and September—the same period of time when recharge in this area would have started to occur again in 2006, according to groundwater level monitoring data. One water sample from the San Benito River on Paicines Ranch was contaminated with *E. coli* O157:H7 that matched the outbreak strain. If pathogens in the water that was recharging from the river into the groundwater were able to reach the wells used for irrigation on Paicines Ranch, they could have contributed to this outbreak. As shown in Figure 8, the horizontal distance between Paicines Well #2 and the San Benito River is approximately one-quarter of a mile. Although the specific field on the ranch that was implicated by the traceback investigation is actually located closer to Well #1, irrigation piping is connected to both wells, and either can be used to water any of the Paicines Ranch fields east of the San Benito River. As discussed in the section titled Depths to Groundwater and Groundwater/Surface Water Interactions, pathogen survival in the subsurface is dependent on various factors, including time. Drillers' logs for wells on Paicines Ranch indicate coarse-grained soils consisting of gravel and sand or loose gravel at shallow depths less than 30 feet, with additional loose or coarse gravel layers at depths ranging from 40 to 150 feet. In addition, the high rate of pumping in agricultural wells (up to 3,000 gpm) for extended periods of time can create large gradients toward the wells because pumping creates drawdown of groundwater. This is illustrated in Figure 7, where the Shields #4 well was measured during pumping in July 2006, and the water level is approximately 30 feet lower than for the July measurements of other years. These factors lead to more rapid groundwater flow, which would enhance survival of pathogens in the subsurface because of reduced travel time. Under these conditions, pathogens from surface water in the San Benito River could potentially reach the wells in the Paicines area and contaminate irrigation water, although definitive evidence of this was not demonstrated in this environmental investigation.

Conclusions

The environmental investigation of potential water issues related to the 2006 *E. coli* O157:H7 outbreak associated with fresh spinach focused on four areas:

- surface runoff from grazing areas onto cultivated fields,
- construction of irrigation wells,
- depths to groundwater and groundwater-surface water interaction, and
- direct use of surface water for irrigation.

Of these factors, depths to groundwater and groundwater-surface water interactions were the most likely water-related factors contributing to this outbreak. Fecal samples from cattle and wild pigs and San Benito River water samples taken on Paicines Ranch matched the strain found in patients and bagged spinach. Hydrogeologic conditions at the ranch indicate that *E. coli* O157:H7 in surface water could potentially have reached wells on the ranch and contaminated irrigation water. Those conditions included a groundwater table that dropped below the level of the San Benito River late in the growing season, allowing surface water to recharge groundwater on the ranch. High rates of pumping of irrigation wells and layers of coarse-grained soils would also have contributed to creating the conditions under which contamination from the river could have reached the irrigation wells. In addition, both cattle and wild pigs having ready access to the San Benito River would have facilitated the contamination of the river with *E. coli* O157:H7.

Although the other factors mentioned above did not appear to have contributed to this outbreak, they still represent potential concerns for preventing contamination of irrigation water, and should be kept in mind when developing recommendations for agricultural practices related to irrigation water.

Public health recommendations

- Because groundwater levels in most of San Benito County have largely recovered from past overdrafts and depths to groundwater are now generally shallow, the SBCWD Annual Groundwater Report for Water Year 2006 (San Benito County Water District, 2006) recommends that percolation of both local (i.e., San Benito River) and imported CVP water be reduced to help control groundwater levels. From a public health perspective, this would also help to reduce potential contamination of deeper groundwater from the surface or shallow groundwater.

- To better ascertain the water quality impacts on groundwater of stream percolation, further analysis and study of groundwater-surface water interactions is needed. This could include computer modeling, field tracer tests, water sampling, and laboratory analysis.

- Additional research should be undertaken on potential public health impacts of large-scale inter-basin water transfers and large changes in groundwater regimes.

- Further investigation should be conducted at the Paicines Ranch to determine whether the irrigation wells are a groundwater source under the direct influence of surface water. Techniques used for such studies in drinking water systems could be employed. A comparative chemical analysis of groundwater from these irrigation wells and the nearby San Benito River should also be included. Longitudinal water sampling of the irrigation wells should also be done to see whether changes in water quality occur over time: single grab samples do not always detect contamination. In addition, groundwater properties do not typically vary quickly, whereas surface water quality responds rapidly to storm events. Longitudinal sampling over time could help to identify whether these wells are directly influenced by surface water. Microscopic particulate analysis could also be used to aid in determining if a direct hydraulic connection exists between these wells and the river.

- Further analysis of potential water-related issues from past *E. coli* O157:H7 outbreaks related to leafy produce from the central California coast should be conducted to identify any commonalities or trends that may be indicators of potential problems.

- Other potential sources of groundwater contamination that may influence agricultural water quality should also be investigated. For example, monitoring wells have shown groundwater contamination west of the Hollister domestic wastewater treatment plant. Because none of the fields identified in traceback investigations for this outbreak were near this area, further analysis was not undertaken within this investigation.

- Establishing buffer zones for streams and rivers or other means of limiting livestock access to surface waters should be explored.

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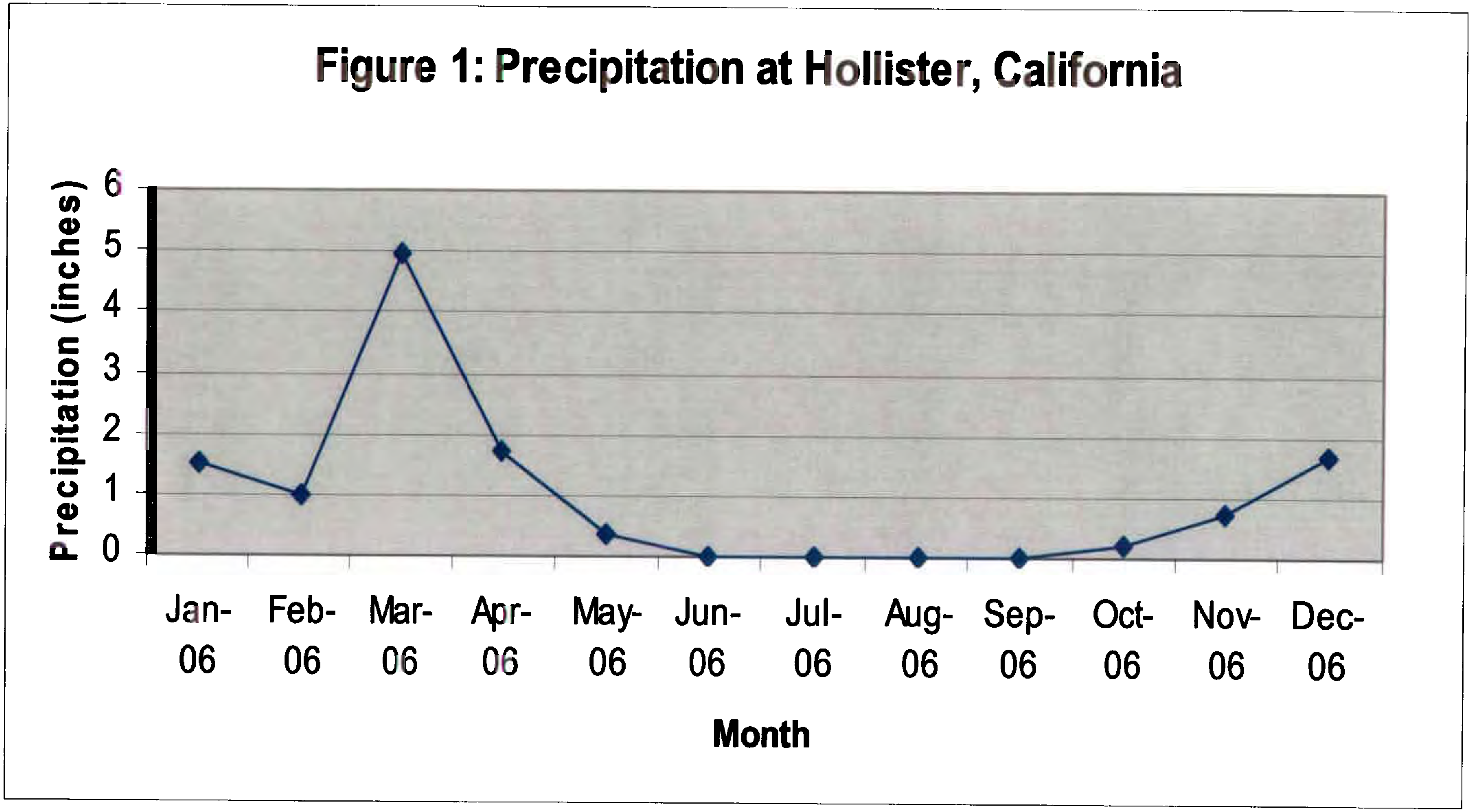


Figure 1: Precipitation at Hollister, California
Precipitation (inches)
6
5
4
3
2
1
0
Jan-06
Feb-06
Mar-06
Apr-06
May-06
Jun-06
Jul-06
Aug-06
Sep-06
Oct-06
Nov-06
Dec-06
Month

Figure 2: Well Cross-Section

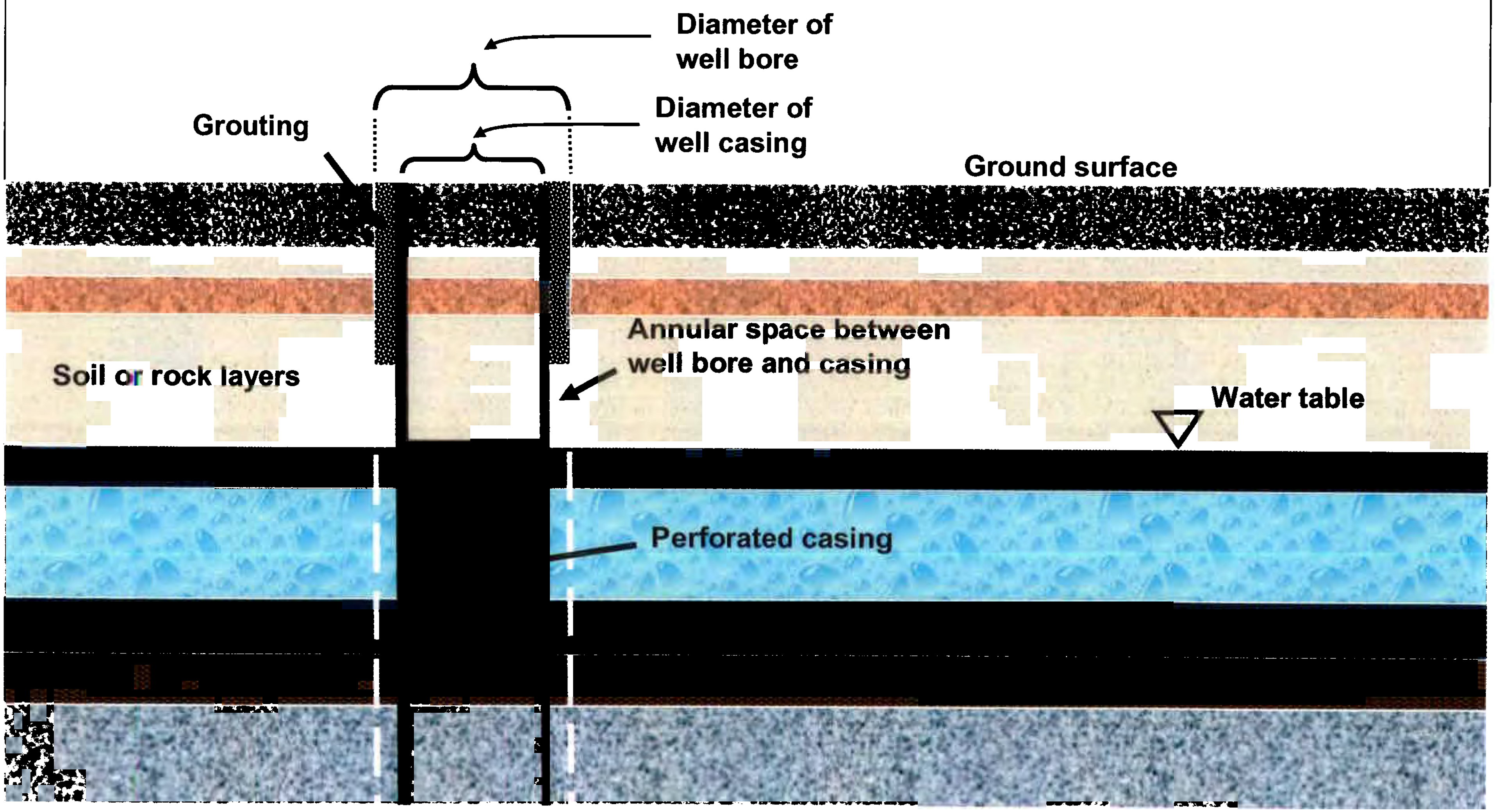


Figure 3: Map of Reservoir Locations

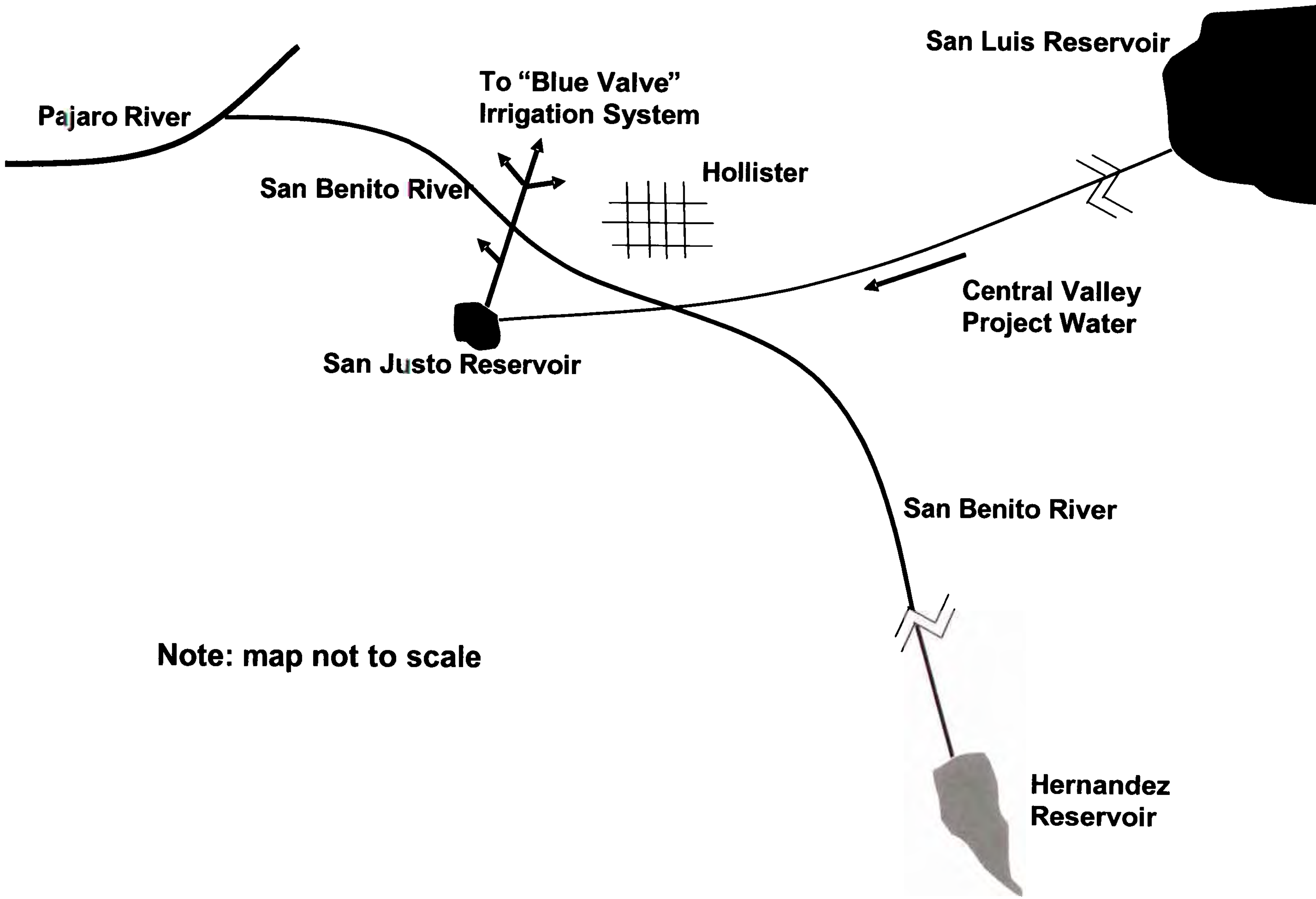


Figure 4: Cross-section of San Juan Valley Showing Changes in Groundwater Levels

(From SBCWD Annual Groundwater Report for Water Year 2005)

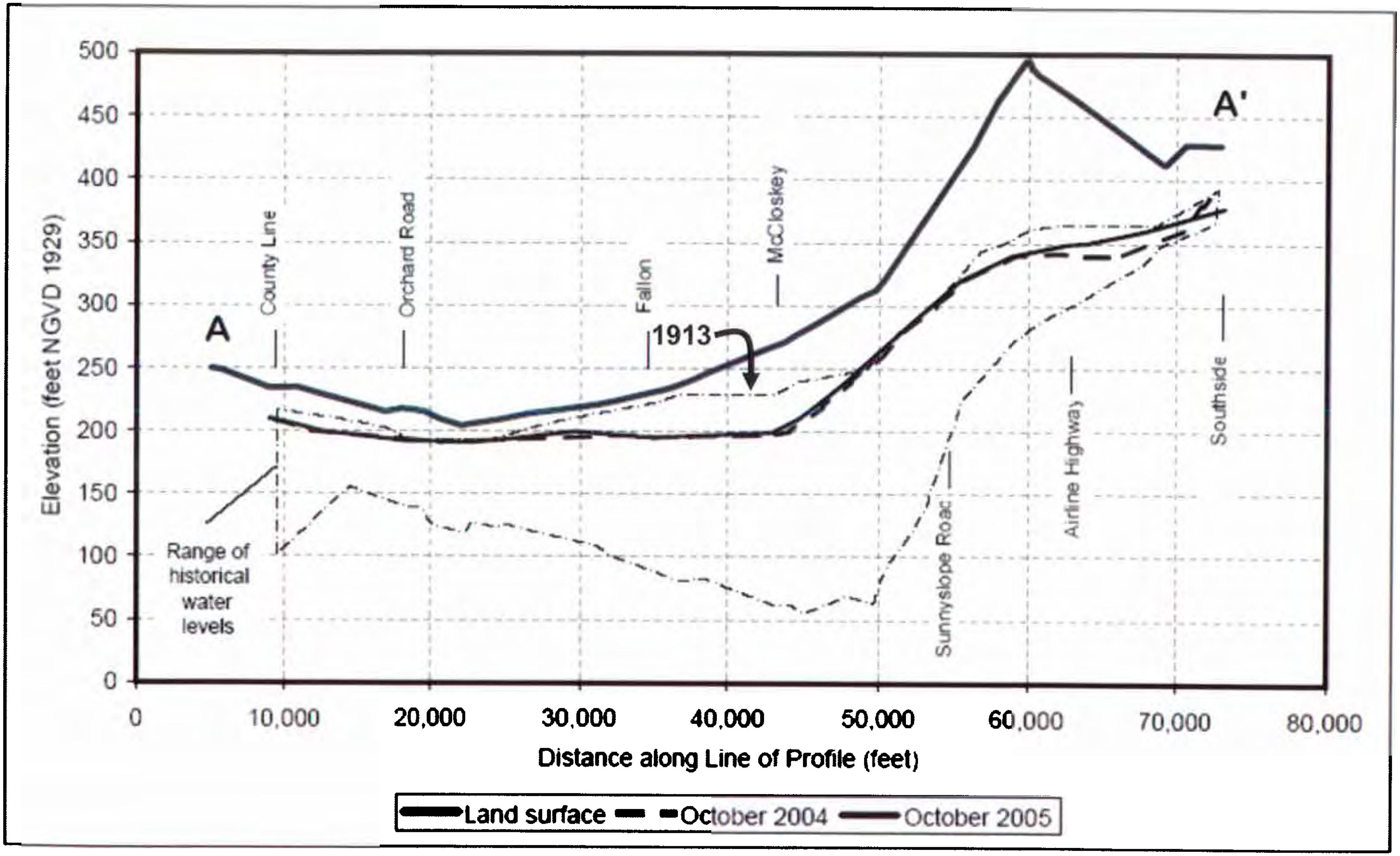


Figure G-5. Profile of Historical Groundwater Levels along Profile Line A-A'

Figure 5: Total Percolation of Imported Central Valley Project Water in San Benito County

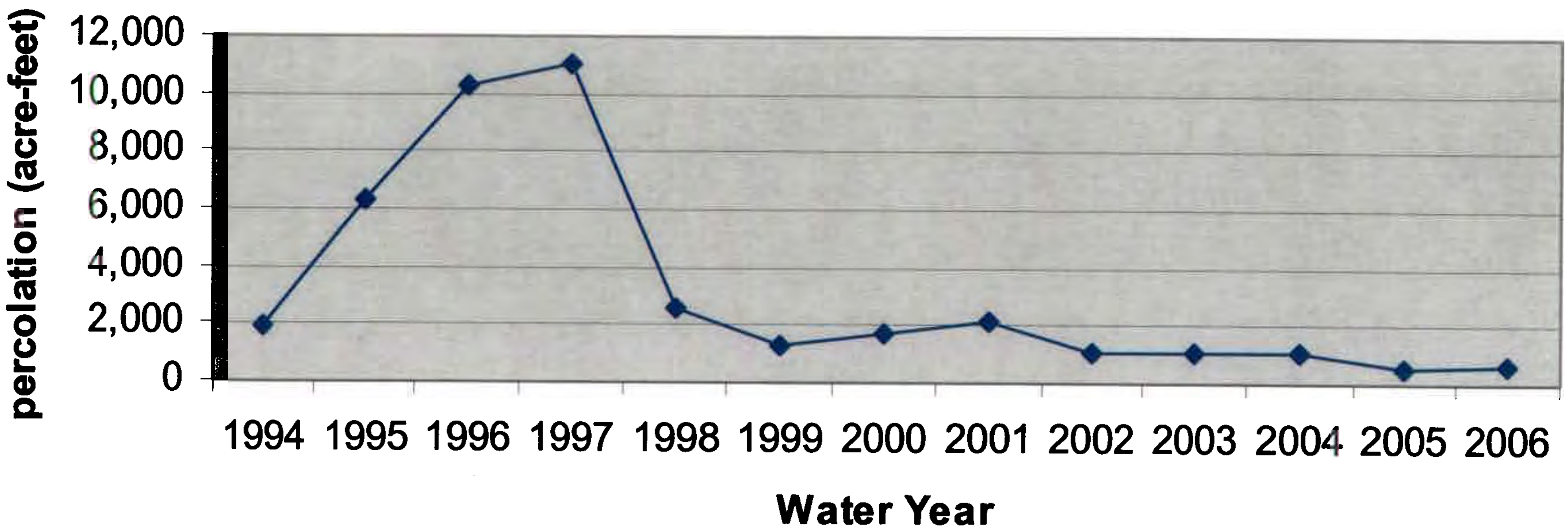
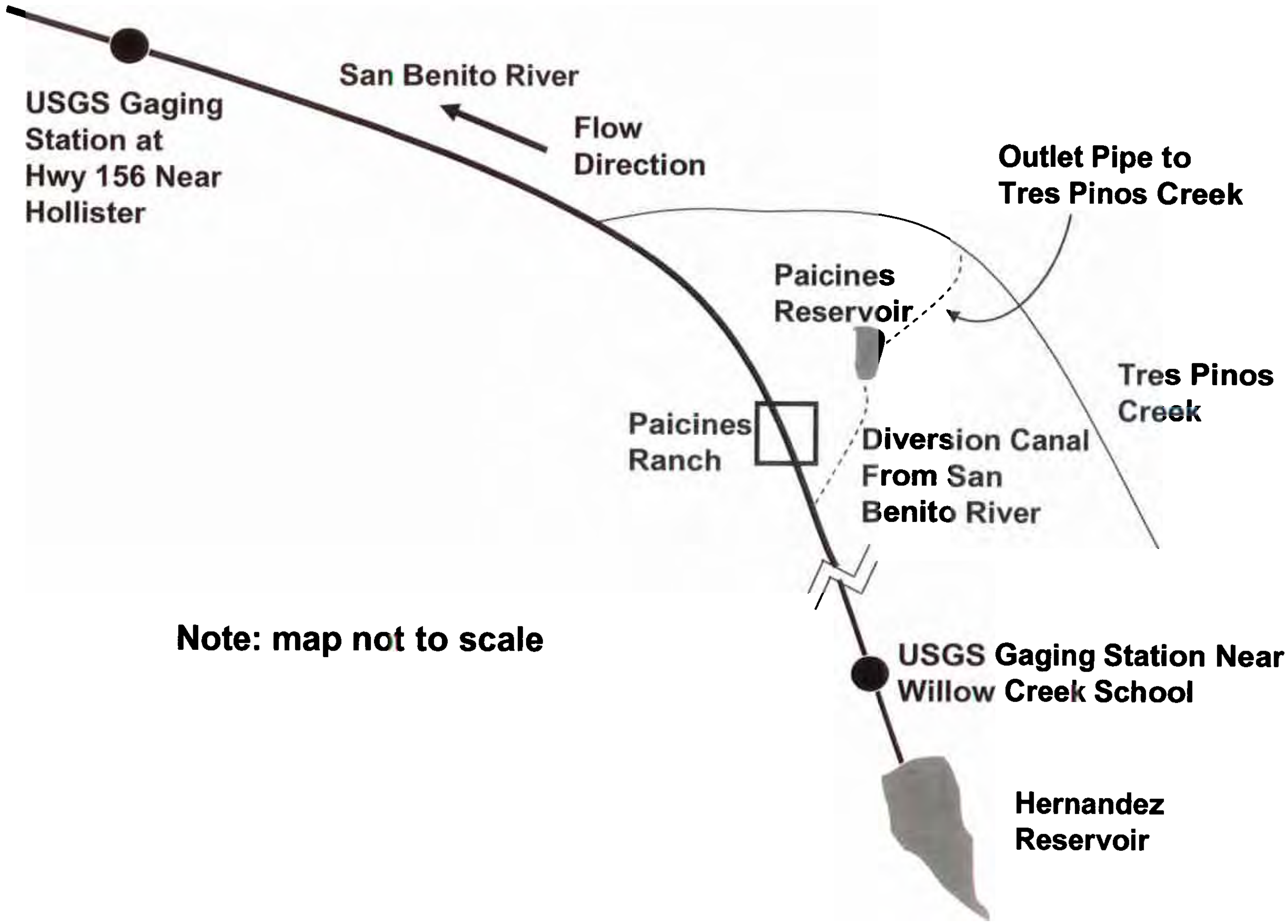


Figure 6: Map of San Benito River System



Note: map not to scale

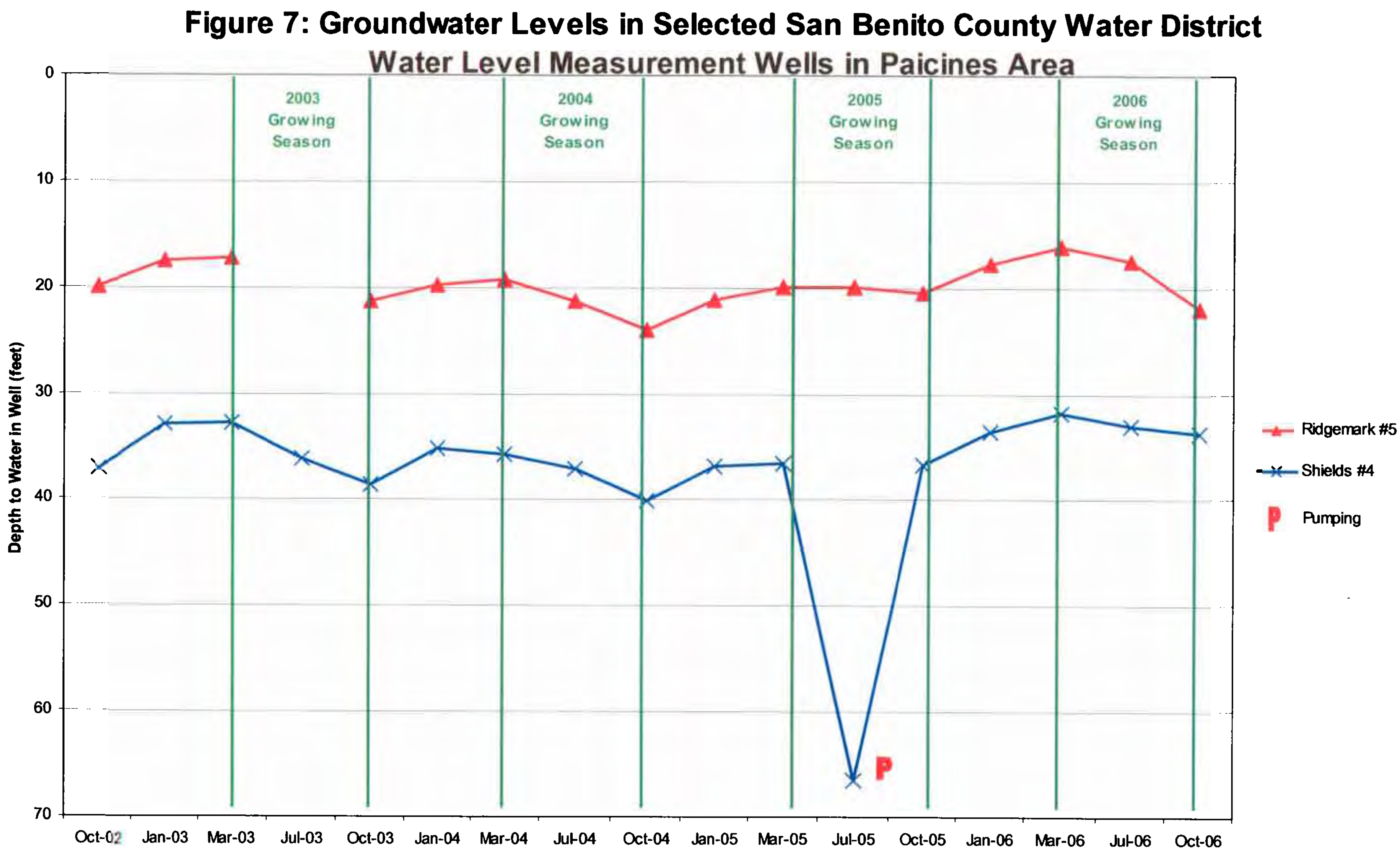
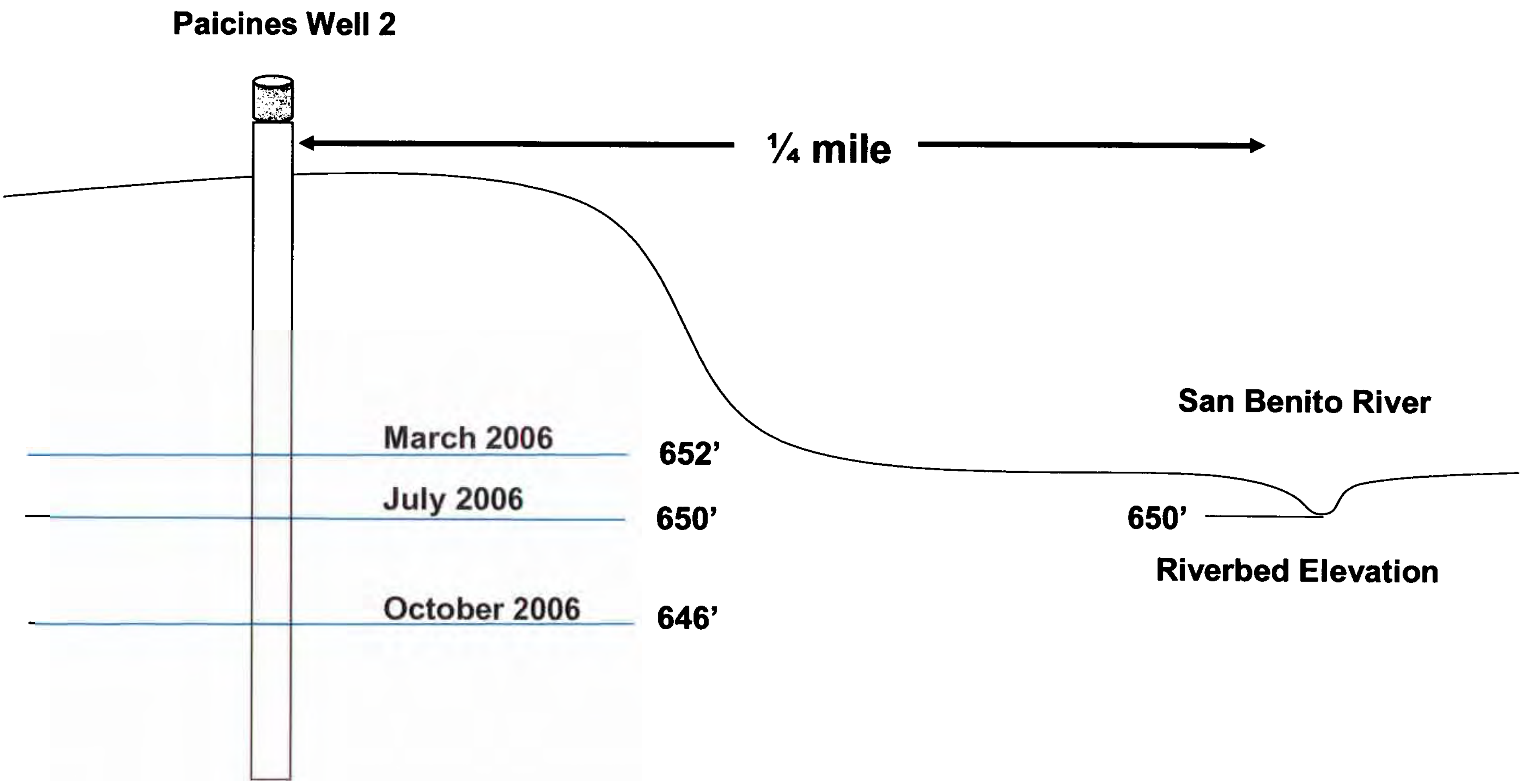


Figure 7: Groundwater Levels in Selected San Benito County Water District
Water Level Measurement Wells in Paicines Area
Depth to Water in Well (feet)
0
10
20
30
40
50
60
70
2003 Growing Season
2004 Growing Season
2005 Growing Season
2006 Growing Season
Oct-02
Jan-03
Mar-03
Jul-03
Oct-03
Jan-04
Mar-04
Jul-04
Oct-04
Jan-05
Mar-05
Jul-05
Oct-05
Jan-06
Mar-06
Jul-06
Oct-06
Ridgemark #5
Shields #4
P Pumping
P

Figure 8: Ground water elevation in Paicines Well #2
(San Benito County Water District Water Level Measurement Well Ridgemark 5)



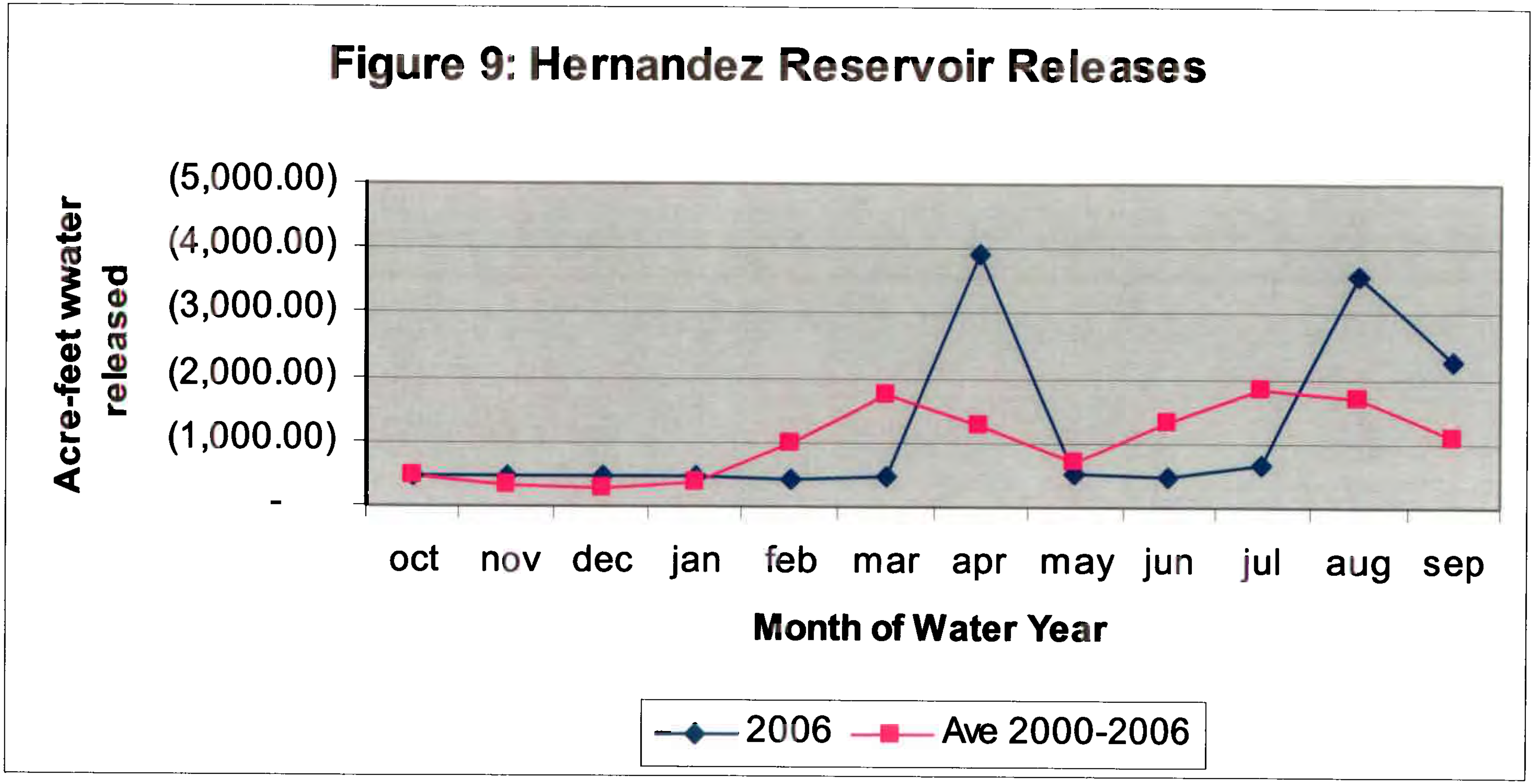


Figure 9: Hernandez Reservoir Releases
Acre-feet wwater released
(5,000.00)
(4,000.00)
(3,000.00)
(2,000.00)
(1,000.00)
-
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
aug
sep
Month of Water Year
2006
Ave 2000-2006

Figure 10: Streamflow at USGS Gaging Station Above Paicines Ranch

From: http://waterdata.usgs.gov/ca/nwis/

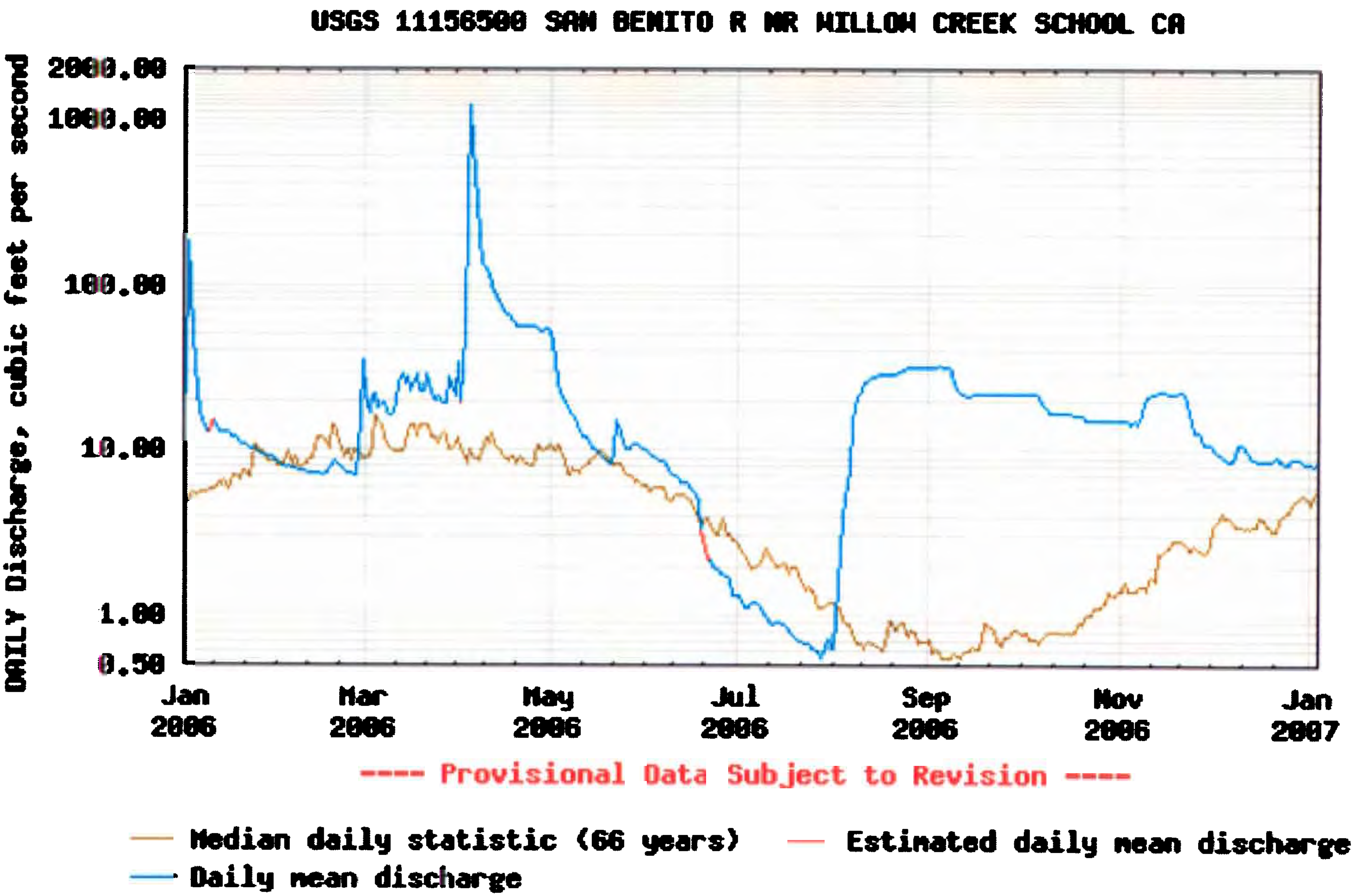


Figure 11: Streamflow at USGS Gaging Station Below Paicines Ranch

From: http://waterdata.usgs.gov/ca/nwis/