CHLORIDE in the PIRU BASIN

Photo: Piru groundwater basin, looking downstream from Newhall Bridge

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Introduction

Chloride concentrations in groundwater have been increasing since 1999 in the eastern portion of the Piru groundwater basin. This investigation examines both groundwater data and surface water data to determine water quality trends and potential causes for those trends. This investigation provides a technical basis for policy on wastewater discharges in upstream Los Angeles County, the most significant documented source of chloride loading to the Piru basin. The cause of increasing chloride concentration in groundwater has been attributed by some to increases in chloride loading to the Santa Clara River, while others assert recent impacts fall within the normal fluctuations due to wet and dry climatic cycles. Of particular interest is the linkage between surface water quality and groundwater quality in various parts of the basin, and the historic variations in chloride concentrations throughout the basin.

Overview of Chloride Occurrence in the Piru Basin

Chloride in the majority of the Piru basin has historically ranged from approximately 30 to 65 mg/l (e.g., Map 4 and Map 5). However, the eastern portion of the basin, east of the confluence of Piru Creek, has historically recorded groundwater chloride concentrations exceeding 150 mg/l between the years 1957 and 1966 (Map 4 and Figure 1). The high chloride in the eastern portion of the basin in the 1950s and 1960s is attributed to the discharge of oilfield brines into tributaries to the Santa Clara River prior to the enactment of the federal Clean Water Act. West of Piru Creek, chloride concentrations remained well below 100 mg/l during that same time period, and reflect historic chloride concentrations in the basin. Following the prohibition of the improper disposal of oilfield brines in Ventura and Los Angeles counties, chloride concentrations remained below 100 mg/l for many years (Map 5 and Map 6).

The historical range of groundwater chloride concentrations in the Piru basin prompted the Los Angeles Regional Water Quality Control Board to set a water quality objective of 100 mg/l west of Piru Creek and 200 mg/l east of Piru Creek. This standard for the eastern portion of the basin remains at 200 mg/l even as water quality improved in the basin once oilfield brines were no longer discharged into the river, and is inconsistent with the surface water objective of 100 mg/l for the Santa Clara River in this vicinity. Recent and historic studies indicate the 100 mg/l chloride is the appropriate water quality objective for all waters of the Piru basin, being protective of chloride-sensitive agricultural uses common to the basin, and all other recognized beneficial uses (CH2M Hill, 2005, and LA RWQCB, 1994).

Since 1999, chloride in the eastern portion of the Piru basin has steadily increased from the post-Clean Water Act ambient level of approximately 80-100 mg/l to levels as high as 176 mg/l (Figure 1). This new occurrence of high chloride concentrations is clearly observable in the area east of Piru Creek (Maps 9-11). During and following the drought of the late 1980s, and for the past several years, chloride concentrations in wells located just west of Piru Creek have also exceeded 100 mg/l (Map 7). The occurrence, sources areas and fate of chloride in the Piru basin is examined in this report.

Hydrogeology of the Piru Basin, Groundwater Flow System

The Piru groundwater basin is an elongate alluvial basin located along the Santa Clara River Valley in eastern Ventura County. The basin is approximately ten miles long and less than two miles across at it widest point, covering an area of approximately 7,000 acres. Some investigators include the alluvium of lower Piru Canyon as part of the basin, resulting in a larger area of approximately 8,900 acres (CA DWR, 2003). The eastern boundary of the Piru basin is defined by the near-surface presence

of the non water-bearing rocks of the Pico Formation, where alluvial deposits are thin and subsurface flow is believed to be minor. The upstream basin boundary is commonly drawn near the former USGS gauging station at Blue Cut where the river channel is narrow and the river makes a distinct bend around exposed rocks of the Pico Formation. The downstream boundary of the Piru basin is located in the vicinity of the Fillmore Fish Hatchery, approximately two miles upstream of the A Street Bridge in the City of Fillmore. The downstream boundary is drawn at the bottom of the topographic narrows that extend more than two miles upstream from this location. These narrows restrict groundwater discharge from the basin, often resulting in rising groundwater that discharges to surface flow in the Santa Clara River (Map 1).

The basin fill (aquifers) of the Piru groundwater basin consists of recent and older alluvium, underlain by deposits of the San Pedro (Saugus) Formation (Mann, 1959). The recent and older alluvium is made up of highly-permeable coarse sand and gravel that exist basin-wide to a depth of approximately 60 - 80 feet. The San Pedro Formation consists of permeable sand and gravel and extends to a depth several thousand feet below land surface. The basin is generally bounded on the north by the San Cayetano fault and on the south by the Oak Ridge fault. Both faults are significant regional faults accommodating the north-south compressive regime of the Transverse Ranges, and the narrow plan shape and thick sediments of the Piru basin result from this compression. The Piru basin is considered an unconfined groundwater basin. Low-permeability units have been observed in specific locations, most commonly in the older alluvium, but nowhere are they so extensive or continuous that confined groundwater conditions are suggested (Mann, 1959).

Recharge to the Piru Basin

Major surface water inputs to the Piru basin include the Santa Clara River, Piru Creek, and Hopper Creek, all of which are gauged continuously for flow rates. Additional lesser inputs include inflow from minor side canyons, the direct percolation of rainfall, and direct recharge to outcrop on the basin margins beyond the extent of the basin fill. The near-surface sediments in the Piru basin have a tremendous percolation capacity, allowing the rapid infiltration of large volumes of surface water through the bottom of the river channel. The capacity of the basin to accept surface water as groundwater recharge is somewhat dependent on channel morphology and depth of the underlying groundwater, but recharge is rarely limited in the upstream portions of the basin where a broad, flat, braided sandy channel is normally located. Between the present location of the USGS gauging station at the Newhall bridge and the area upstream of the confluence of Piru Creek and the Santa Clara River, both the floodplain and the basin itself widens and surface water readily percolates into the ground, recharging the upstream end of the basin's groundwater flow system. The high percolation rates in this upstream end of the Piru basin cause the entire flow of the Santa Clara River to infiltrate during much of the year, creating a "dry gap" which typically extends some five miles downstream to the vicinity of Cavin Road east of the Fillmore Fish Hatchery (Map 1). The constriction of the Piru basin in this area coincides with a stable groundwater gradient that often intersects the bottom of the river channel, resulting in a gaining reach of the river where groundwater discharges to the river channel, re-establishing surface flow in the river system.

United Water has conducted various investigations of the percolation of surface water in the Piru basin over the past 75 years. While a principle study objective has been the optimization of the conveyance of water released from Lake Piru across the permeable midsection of the Piru basin, recharge estimates have also been calibrated for the reach of the Santa Clara River between the USGS flow gauge at Blue Cut and the confluence of Piru Creek. Recent studies by United Water confirm that this reach readily percolates large volumes of water: typical dry weather flows of approximately 25-30 cubic feet per second (cfs) percolate entirely in this reach, approximately 85 percent of flows as high as

100 cfs percolate here, and percolation as high as 1000 cfs has been estimated during flood flows. The width of the river channel exceeds 1000 feet throughout most of the basin, and high percolation rates are also commonly observed in the reach extending from Torrey Road to the area of rising water near the western downstream end of the basin. The Santa Clara River is the largest source of recharge to the Piru basin, and during typical base flow conditions (non-stormflow conditions), all of the river flow percolates to groundwater in the eastern third of the basin.

Piru Creek is the largest tributary to the basin, entering the basin from the north. The sediments of the Piru Creek fan are also highly-permeable, and significant recharge occurs at times along this channel. Additional recharge is possible in this vicinity via United Water's Piru spreading grounds, a 44-acre facility near the west bank of Piru Creek, which is supplied water by a diversion structure near the town of Piru. Artificial recharge totals at the Piru grounds are low in recent years, as the facility is used less than it was historically because of the importance of bypassing the maximum amount of water to the facilities in the Oxnard Plain to combat seawater intrusion. United Water commonly releases three to five cfs from Lake Piru during most of the year, which flows down Piru Creek before percolating to groundwater along Piru Creek where it meets the main groundwater basin.

Groundwater Flow in the Piru Basin

Groundwater flow paths in Piru basin appear to vary little from year to year, with the dominant flow moving westerly down the axis of the basin. Recharge sourcing from Piru Creek and Hopper Creek result in groundwater flow with a more southerly component in the north-central portion of the basin. This effect is most apparent during wet years when recharge from the tributaries is greater. In the eastern and western portions of the basin, where there is no significant recharge from sources along the edges of the basin, groundwater flow is consistently interpreted to be straight down the basin, parallel with the Santa Clara River channel. United Water's interpretation of available groundwater elevation data reveal that flow paths vary little between years, largely due to high permeability of the aquifers, the relatively even distribution of pumping for irrigated agriculture throughout the basin, and the lateral constraints on the flow system.

While the direction of groundwater flow varies little through time, groundwater gradients tend to vary with climatic conditions. United Water has contoured fifty years of spring and fall water level records, allowing the following observations. In the wettest years, the high percolation capacity of the basin allows it to rapidly fill to capacity, and the slope of the water table becomes fairly consistent across the entire basin (Map 2). This consistency in slope is also fairly persistent under all climatic conditions in the two-mile reach between Cavin Road and the downstream end of the basin, where the sides of the basin are nearly parallel and the aquifers of the basin discharge rising groundwater to the river. This groundwater discharge to the river maintains a fairly steady flux of groundwater exiting the basin.

Steep groundwater gradients are common in the eastern portion of the basin where the basin is narrow, basin fill is believed to be thinner, and the upstream portions of the alluvial and San Pedro aquifers remain saturated by the constant recharge of Santa Clara River water sourcing from Los Angeles County. As the basin becomes wider in the area just east of Piru Creek, flowpaths diverge, and the groundwater gradient becomes less steep. Where Piru Creek enters the basin from the north, the basin is at its widest, depths to groundwater are greater, and groundwater flow fields are more variable and dynamic due to the intermittent inputs from Piru Creek. The central third of the basin between Piru Creek and Hopper Creek is where much of the variable storage in the basin occurs. Water levels in this area are observed to decline during dry periods, and groundwater gradients become less steep (Map 3).

Chloride in the Santa Clara River

An extensive water quality record exists for the Santa Clara River near the Los Angeles-Ventura County line, allowing an evaluation of long-term trends. Sample collection points have historically included Blue Cut, the surface water diversion point for Rancho Camulos, and more recently the new gauging location at the Newhall bridge (and possibly the county line proper). These sampling locations are all located near the Blue Cut constriction where alluvium is thin, and it is reasonable to combine these records. Much of the older data were collected by the California Department of Water Resources, and much of the recent data by United Water Conservation District. Figure 1 displays recorded chloride concentrations from the past 55 years, and three distinct periods are apparent. Between 1951 and 1968, high and variable chloride concentrations were recorded in the river, with the source of the high chloride attributed to the surface discharge of oilfield brines. The Del Valle, Newhall-Potrero and Castaic Junction oil fields exist near the Santa Clara River between Interstate 5 and the county line. The Los Angeles Regional Water Pollution Control Board recognized this serious threat to water resources of the region, commissioned a study of local practices, and then took prompt action to stop surface water and groundwater pollution associated with this improper discharge of brines (e.g., CA DWR, 1959). Flow at Blue Cut during this period was considerably less than flow recorded in recent decades.

Between 1969 and 1975 chloride concentrations exceeding 100 mg/l were not recorded in the Santa Clara River at Blue Cut. Between 1975 and 1999 measured chloride concentration generally ranged from 70 to120 mg/l, with the average chloride concentration of this period of record being 93 mg/l. Data is unavailable for the dry years 1989 through 1991, except for one sample in 1990. The time period from the mid-1970s to the late-1990s was also a period of increasing flow in the Santa Clara River, corresponding to population growth in the Santa Clarita area and increased imports of water from the State Water Project.

The third distinct period apparent in Figure 1 is the period from 1999 to present, characterized by steadily increasing chloride concentrations in the Santa Clara River at Blue Cut. Beginning in the summer of 1999 chloride concentrations routinely exceed 120 mg/l, and chloride values of 150 mg/l were recorded in the winter, spring and fall of 2004. The year 2005 was the second-wettest on record for a number of gauges in the Santa Clara River Valley, and the increased runoff and groundwater discharge from the upper watershed has served to temporarily dilute chloride concentrations at Blue Cut. Additional flow was provided by sustained released from Castaic Lake, which continued into July 2005. However, the dilution benefits of this exceptionally wet year were short-lived, and chloride concentrations of 125 and 134 mg/l were recorded in August and November 2005, respectively.

Chloride in Piru Creek

Santa Felicia Dam was constructed by United Water Conservation District in 1955 in order to capture winter runoff from the Piru Creek watershed. Stored water is typically held through the summer and released in the fall for downstream beneficial uses. As the released water flows down Piru Creek and then the Santa Clara River, some of the water percolates to groundwater, providing recharge to the Piru, Fillmore and Santa Paula basins. However, releases are carefully managed to optimize the conveyance of water past these basins to the Freeman Diversion, where the water is diverted for groundwater recharge to the Oxnard Forebay basin and direct irrigation delivery on the Oxnard Plain. These activities directly support one of United Water's primary groundwater management objectives, the abatement and reversal of saline intrusion in coastal areas of the Oxnard Plain and Pleasant Valley

groundwater basins. Continuous releases of three to five cfs are maintained throughout the year to sustain fish and riparian habitat in Piru Creek below Santa Felicia Dam.

Pyramid Lake was completed in the upper Piru Creek watershed in 1973 by the California Department of Water Resources, as part of State Water Project (SWP). The reservoir receives larges volumes of SWP water sourcing from the Sacramento River in northern California, and provides regulated storage for hydroelectric power generation at Castaic Lake. United Water holds the rights to surface water yielded by the Piru Creek watershed, and DWR routinely releases water volumes down Piru Creek equaling that of measured inflow to Pyramid Lake. As a result, the water released downstream to Lake Piru often reflects the chemical character of SWP water. SWP water is prone to elevated chloride concentrations in certain years, most notably when northern California is experiencing dry climatic conditions. United Water also has an allocation to purchase as much as 3750 acre-feet of State Water to release down Piru Creek for storage in Lake Piru.

Historic water quality records from Piru Creek below Santa Felicia Dam are displayed in Figure 2. Water quality trends generally follow climatic cycles, with chloride increasing during drier conditions. The water quality record shows a pronounced peak in chloride concentration during and following the drought of the late 1980s-early 1990s, when local inflow to the lake was low and chloride concentrations in the SWP were high. A trend of increasing chloride was also observed in the years following the record wet year of 1998, reaching a maximum-recorded concentration of 77 mg/l in 2004. Chloride concentrations in Lake Piru dropped to 30 mg/l following the significant rains of 2005.

Chloride Concentrations in Groundwater

As detailed in the hydrogeology section above, the Piru basin readily accepts great volumes of recharge water from the channel of the Santa Clara River. One major source of recharge to the basin is the continuous percolation of surface water discharge from Los Angeles County, with daily average flows commonly ranging from 20 to 30 cfs since the early 1980s. A second major source of recharge is the downward percolation runoff during significant winter storms, which inundate broad areas of the Santa Clara River floodplain with floodwaters of low chloride concentration. These large storms tend to occur infrequently, and the timing of their occurrence is not predictable.

Figure 1 plots chloride concentrations from five Rancho Camulos wells along with chloride records collected at Blue Cut, located a short distance upstream (Map 1). All of these wells are located in the eastern third of the Piru basin where the only significant source of recharge is water flowing past Blue Cut. Chloride data from these wells are also shown on Maps 4 through 11. The strong correlation of chloride concentrations in these wells in the eastern third of the basin to chloride records from Blue Cut provides compelling evidence of the influence surface water quality has on groundwater in this portion of the basin, and confirms our understanding of the recharge and flow system of the basin.

Figure 3 plots all available surface water and groundwater chloride data for the discharge portion of the Piru basin west of Cavin Road. Prior to the mid-1970s, groundwater chloride concentrations were variable in this vicinity, but many records show chloride concentrations ranging from 20 to 45 mg/l. In later years chloride concentrations less than 40 mg/l become less common, and many records fall within a range of 45 to 70 mg/l. Surface water quality data are unavailable prior to 1992. Chloride in surface water samples collected near the Fillmore Fish Hatchery typically fall within the range of groundwater records in this area, reflecting the common condition of groundwater discharge to surface water near the downstream boundary of the Piru basin.

Annual maps showing the maximum-recorded chloride concentration were generated for the years 1955 through 2005, allowing a spatial display of historical chloride records for the Piru basin. The number of data points varies from year to year, but these water quality maps are valuable tools for

assessing changes in water quality in the basin. The following maps were selected to portray recent and historical water quality conditions in the basin, with consideration given to the quality of the annual data set and the hydrologic conditions of the year being displayed. In many cases, only a single chloride record exists for a given well in a single year, but when more than one record exists, the maximum-recorded value is plotted. Maximum and average chloride concentrations are also labeled at surface water monitoring locations. The following notes and comments are meant to accompany the annual maps selected for inclusion in this report.

Map 4, 1962 - A wet year following two dry years, but basin storage is still fairly low as this year falls within the long-term dryer period ranging from 1945 to 1977. Chloride impacts associated with oilfield brines are seen in surface water concentrations at Blue Cut and in groundwater east of Piru Creek. Good chloride records from this year show annual maximum chloride concentrations averaging 48 mg/l between Piru Creek and Cavin Road. West of Cavin Road, in the area where older waters are exiting the basin, chloride concentrations average 34 mg/l.

Map 5, 1972 - A dry year following several average and wet years, basin storage is similar to recent years (1999-2004). Chloride concentrations throughout the basin range from 26 to 90 mg/l. Limited records show the eastern portion of the basin has recovered from brine impacts. Data is lacking in the area immediately west of Piru Creek. Chloride records from all wells in the basin are recorded below 100 mg/l chloride for the next fifteen years (except for several records from a single well drilled adjacent the northern basin boundary).

Map 6, 1987 - A dry year following wet years in 1983 and 1986 and dry years in 1984 and 1985. A good annual data set shows groundwater chloride ranging from 35-98 mg/l.

Map 7, 1990 - Peak of the last drought. Groundwater chloride concentrations of 110 mg/l recorded near Piru Creek and United Water's Piru spreading grounds. Chloride concentrations as high as 100-110 mg/l are seen for the next three years in the area of the Piru Creek fan, sourcing from reservoir releases from Lake Piru. High-chloride water is imported to the Piru Creek watershed as an unintended consequence of the transfer of SWP water to southern California, but the actual purchase and import of SWP water to the lower Santa Clara River is minor. Chloride records are not available for Blue Cut or groundwater in the eastern Piru basin in this year (the one chloride record at Blue Cut appears to be erroneous).

Map 8, 1993 - Second consecutive wet year. The Piru basin is considered to be essentially full, with a fairly uniform groundwater gradient across the basin. These conditions saturate the uppermost aquifer in the basin, the highly-permeable deposits of younger alluvium. Following occurrences such as this, groundwater concentrations are often more variable throughout the basin, making it is more difficult to recognize chloride movement away from specific source areas. The downward flushing of salts accumulated in soils also occurs in the wettest years, and the relative importance of these two salt transfer mechanisms is not well understood. By this time chloride concentrations at Blue Cut and in groundwater in the eastern Piru basin regularly exceed 100 mg/l, conditions which continue to present times.

Map 9, 2001 - Wet year following a dry and average year, also a wet year at the end of the wettest decade on record (Santa Paula gauge #245). Lake Piru has low chloride concentrations and the

upper Piru Creek fan has apparently been flushed of high chloride by the multiple wet years following the last drought. Chloride at Blue Cut has increased steadily since 1999 (Figure 1), and impacts to groundwater in the eastern Piru basin match the surface water records. Chloride of 100 mg/l or more is recorded in wells west of Piru Creek for the second time in as many years, and this increase cannot be accounted for by sourcing from Piru Creek.

Map 10, 2004 - Dry year following average. Basin depletion greatest since the drought, steep groundwater gradients observed in the eastern portion of the basin. Surface water and groundwater chloride in eastern Piru basin recorded in excess of 150 mg/l. Record-high chloride of 138 mg/l recorded in Camulos well west of Piru Creek, with the only apparent source being water moving from the eastern Piru basin. Chloride concentrations in Piru Creek remain relatively low.

Map 11, 2005 - Very wet year, Piru basin fills to capacity again. High chloride is still very pronounced in groundwater in the eastern basin, and one well west of Piru Creek. The only apparent source of high chloride in the well west of Piru Creek is from the eastern Piru basin. As in 1993 when a good data set exists for similar hydrologic conditions, groundwater chloride concentrations are variable throughout the basin.

The chloride concentration maps presented here do not answer all questions related to the movement of chloride in the Piru groundwater basin, but they are very useful observational tools in a basin such as this where the sources of recharge and the groundwater flow system are well understood. Sufficient data are available to show the occurrence of chloride over time, and the periodic expansion of chloride pollution from well-defined inputs such as the Santa Clara River and Piru Creek. However, specific "packages" or "plumes" of historic high chloride inputs are often not traceable over long distances or many years. Most existing data are from production wells with large screened intervals, and various processes exist that promote the mixing or waters within the basin. Although the exact fate and migration pathways of chloride in the Piru basin are not completely understood, the chloride data presented here show the effect of long-term chloride loading in the basin, evidenced by the increasing chloride concentrations in groundwater and in surface flows at the discharge point of the basin (Figure 3). In the early 1960s chloride concentrations ranging from 20 to 40 mg/l were common in this locality. In recent years chloride concentrations ranging from 45 to 70 are the norm. This is the only significant avenue for chloride to exit the basin, and the tremendous ongoing mass of chloride being loaded at the upstream portions of the basin will continue to move downgradient, increasing chloride concentrations at this point, and points beyond.

Summary and Conclusions

The increase in chloride concentrations in the eastern Piru basin since 1999 directly correlates in time and concentration with the increase in chloride in the Santa Clara River at the county line. There is little doubt that the chloride in the river is causing the increase in chloride in the eastern basin – not only is there a direct correlation between the two, but the river is the sole significant recharge source to the eastern basin. In fact, the entire flow of the river infiltrates into the basin during most of the year, leaving a dry riverbed for a distance across the eastern portion of the Piru basin.

The connection between high chloride in the river and in the eastern Piru basin was previously demonstrated in the 1950s and 1960s when brine that was high in chloride was discharged into the Santa Clara River from oilfields along the river drainage. The Los Angeles Regional Water Pollution

Control Board took action to stop this discharge of high chloride into the river, which subsequently improved the water quality of both the river and the eastern Piru basin.

However, this oilfield discharge was actually less of a threat to the Piru basin than the current chloride pollution because flows in the river were much smaller in those days. Today, the importation, use, and discharge of State Water into the Santa Clara River has increased flows at the county line, and high chloride concentrations are consistently documented in wastewater discharges. This higher loading (a larger volume of high chloride water) allows chloride pollution to migrate farther downgradient within the Piru basin. In fact, higher chloride concentrations have occurred in wells just west of Piru Creek over the past several years, at the same time that recharge water percolating from Piru Creek had much lower chloride concentrations. An imminent threat to the basin is that these higher chlorides just west of Piru Creek are the beginning of degradation of the remainder of the Piru basin, caused by the high salt loading in the eastern Piru basin.

The salt loading in the Piru basin caused by higher salts in the Santa Clara River cannot be easily dismissed as an artifact of climatic conditions along the river. The period since 1999 has been wetter than normal, including the second wettest year on record (2005). Only in 2005 did chloride concentrations dip, and this was a temporary condition caused by the very high flows in the river that diluted salts being discharged into the river in Los Angeles County.

Water quality degradation of the Piru basin is clear during the past several years. The eastern basin continues to degrade as Santa Clara River water increases in chloride concentration. Degradation of the western portion of the basin may have commenced just west of Piru Creek, and the degraded water in the eastern Piru basin has no place to flow except into the western basin, creating the conditions for further degradation of the reminder of the Piru basin. It is clearly time for regulatory action to prevent further degradation of the Piru basin.

References

California Department of Water Resources Bulletin No. 75, 1959, Water Quality and Water Quality Problems, Ventura County.

California Department of Water Resources Bulletin No. 118 update 2003, California's Groundwater.

CH2M Hill, 2005, Literature Evaluation and Recommendations, Upper Santa Clara River Chloride TMDL Collaborative Process. Draft technical report evaluating existing scientific research on salt-sensitive crops such as avocado.

Los Angeles Regional Water Quality Control Board, 1994, Water Quality Control Plan, Los Angeles Region.

Mann, John, 1959, A Plan for Groundwater Management. Technical hydrogeologic investigation of the groundwater basins and water resources within the United Water Conservation District.

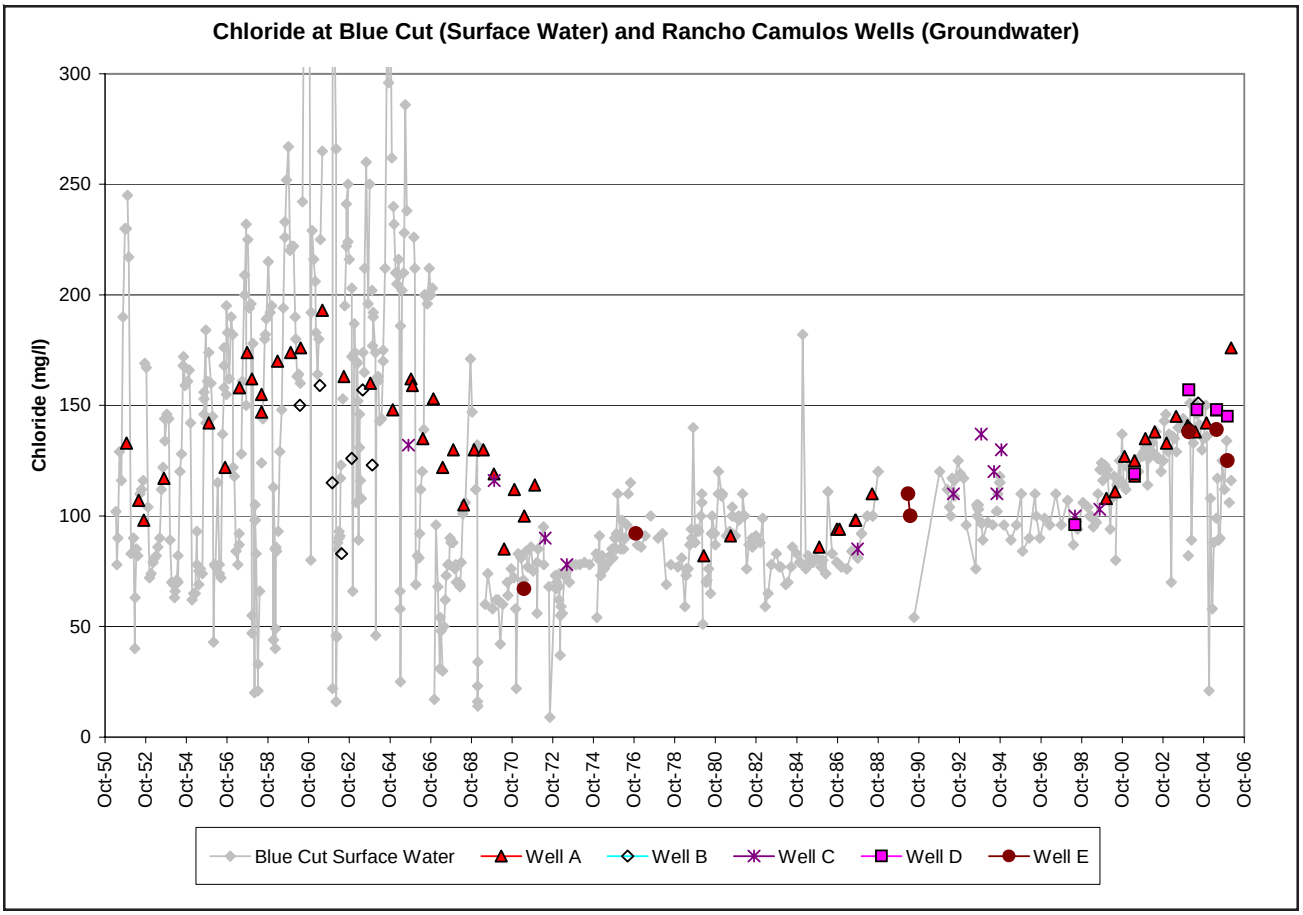


Figure 1.

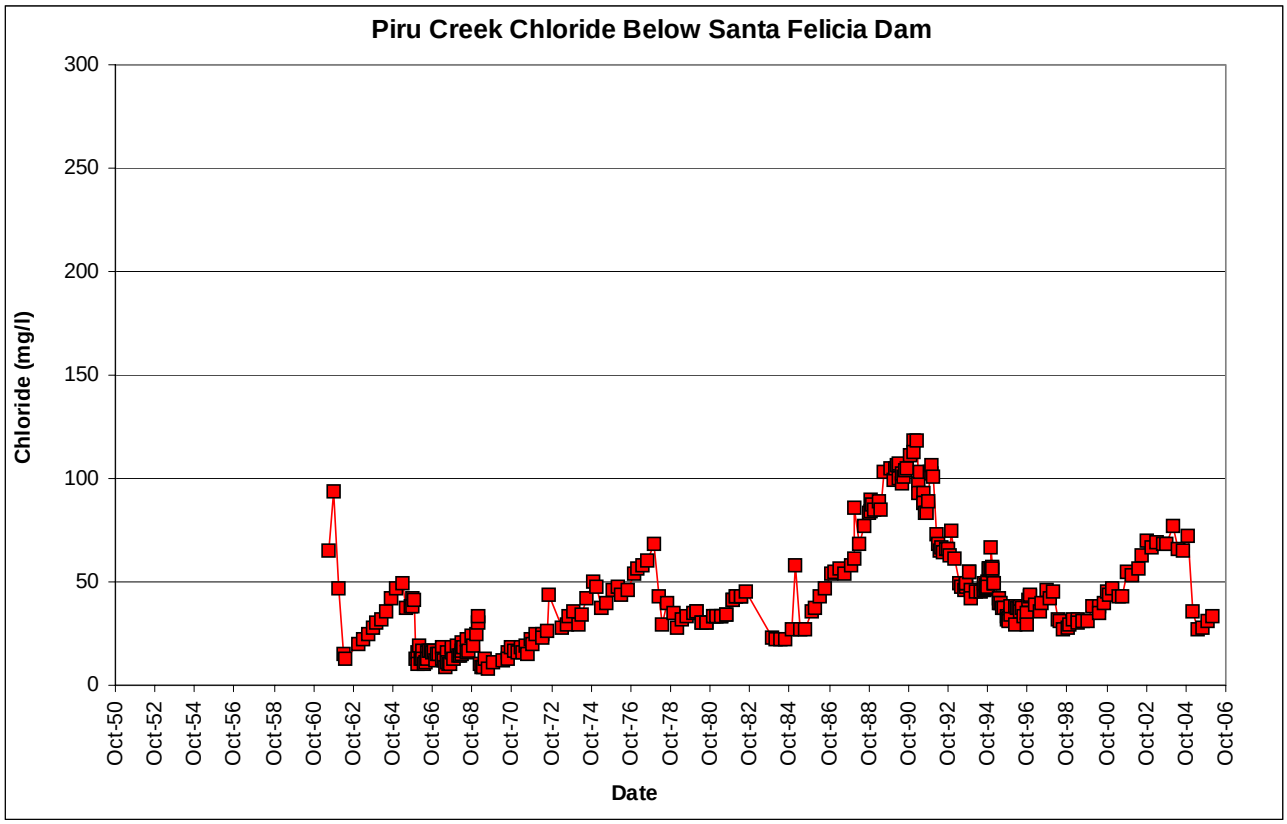


Figure 2.

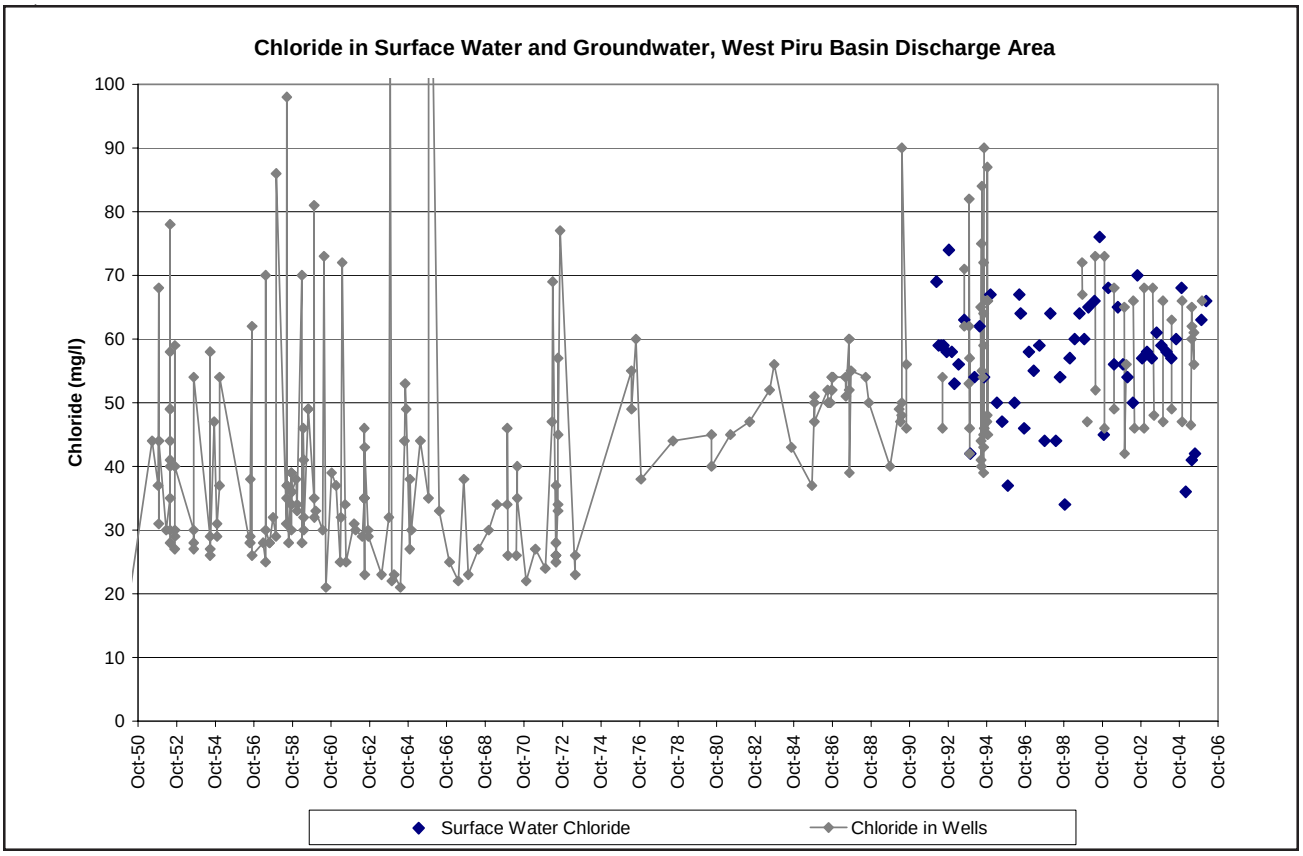
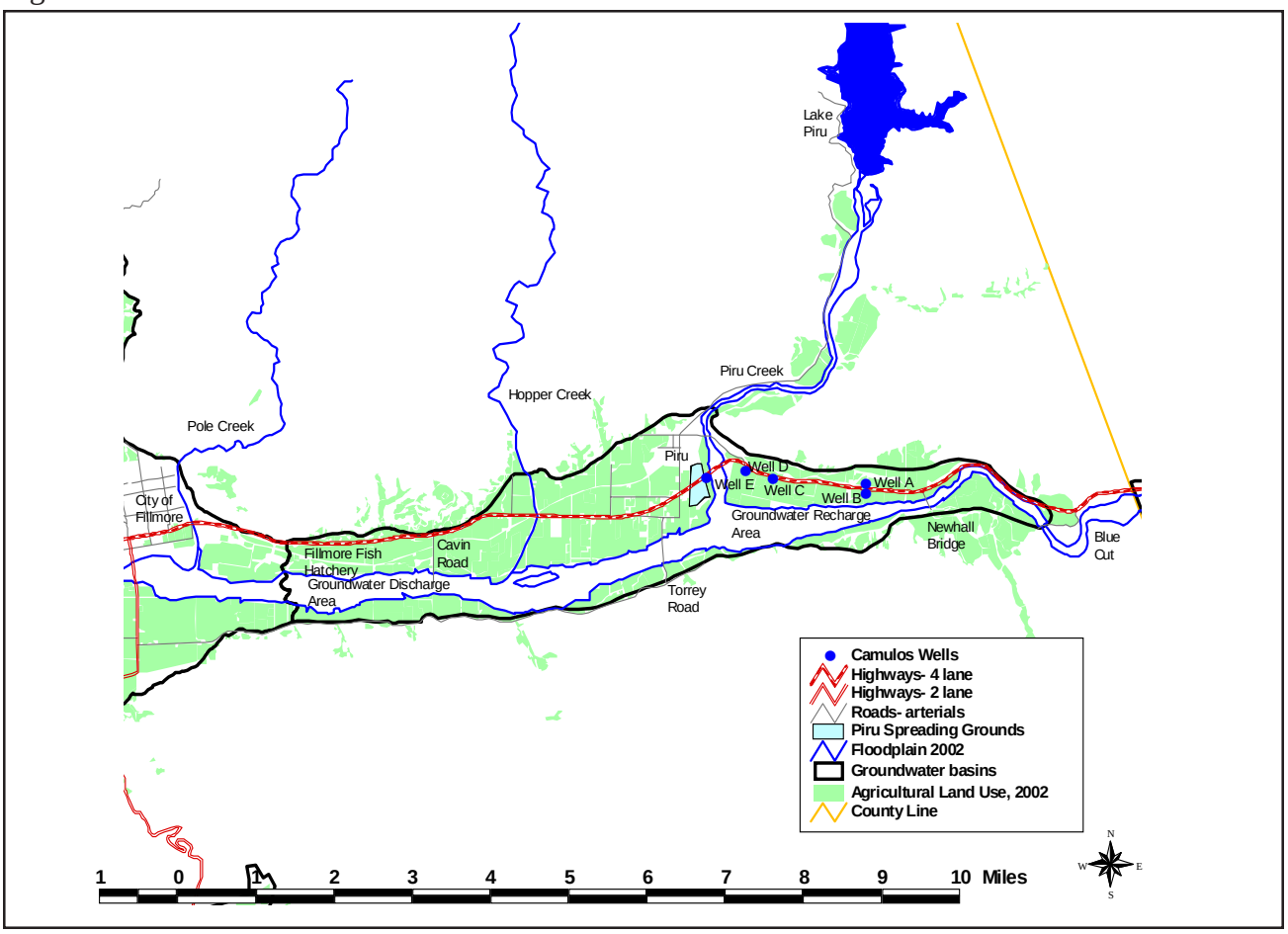
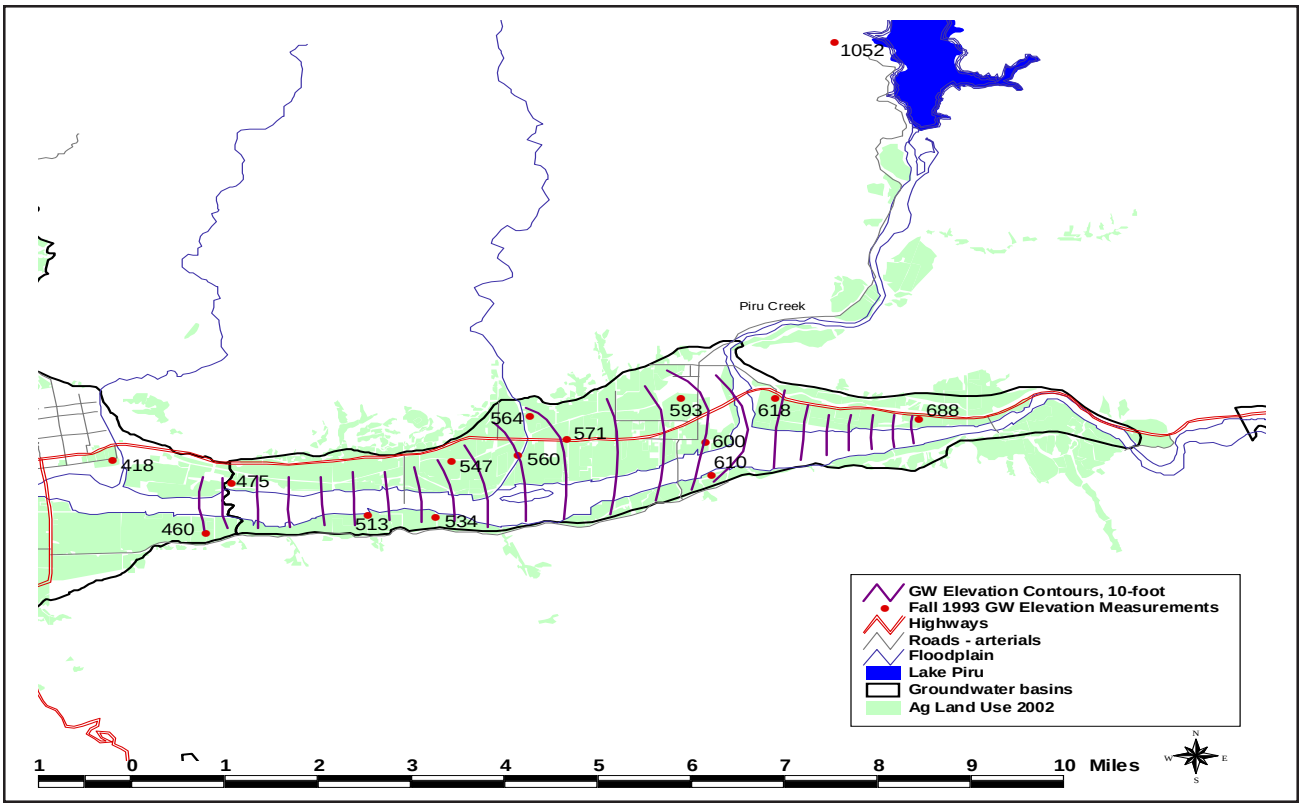


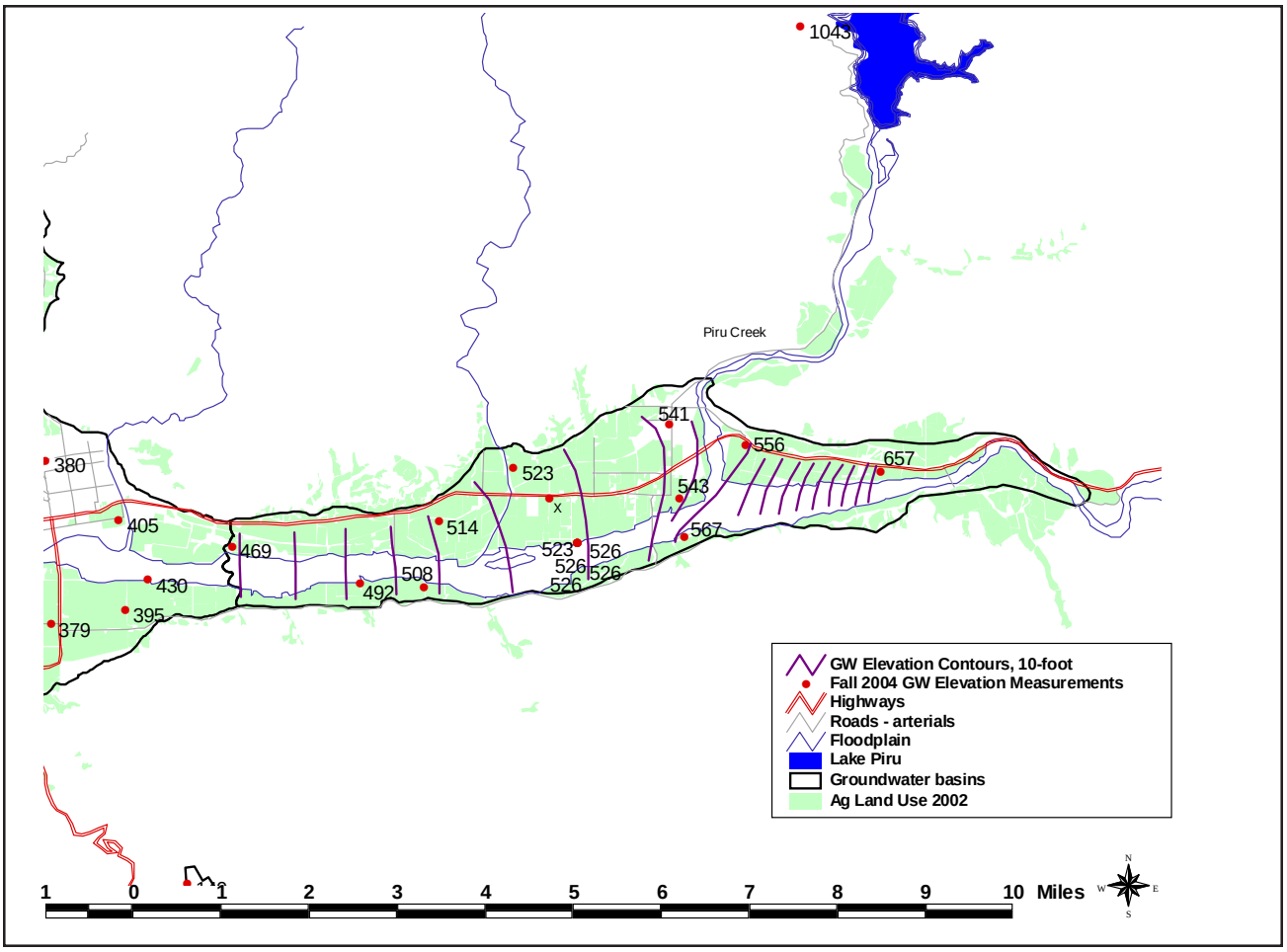
Figure 3.



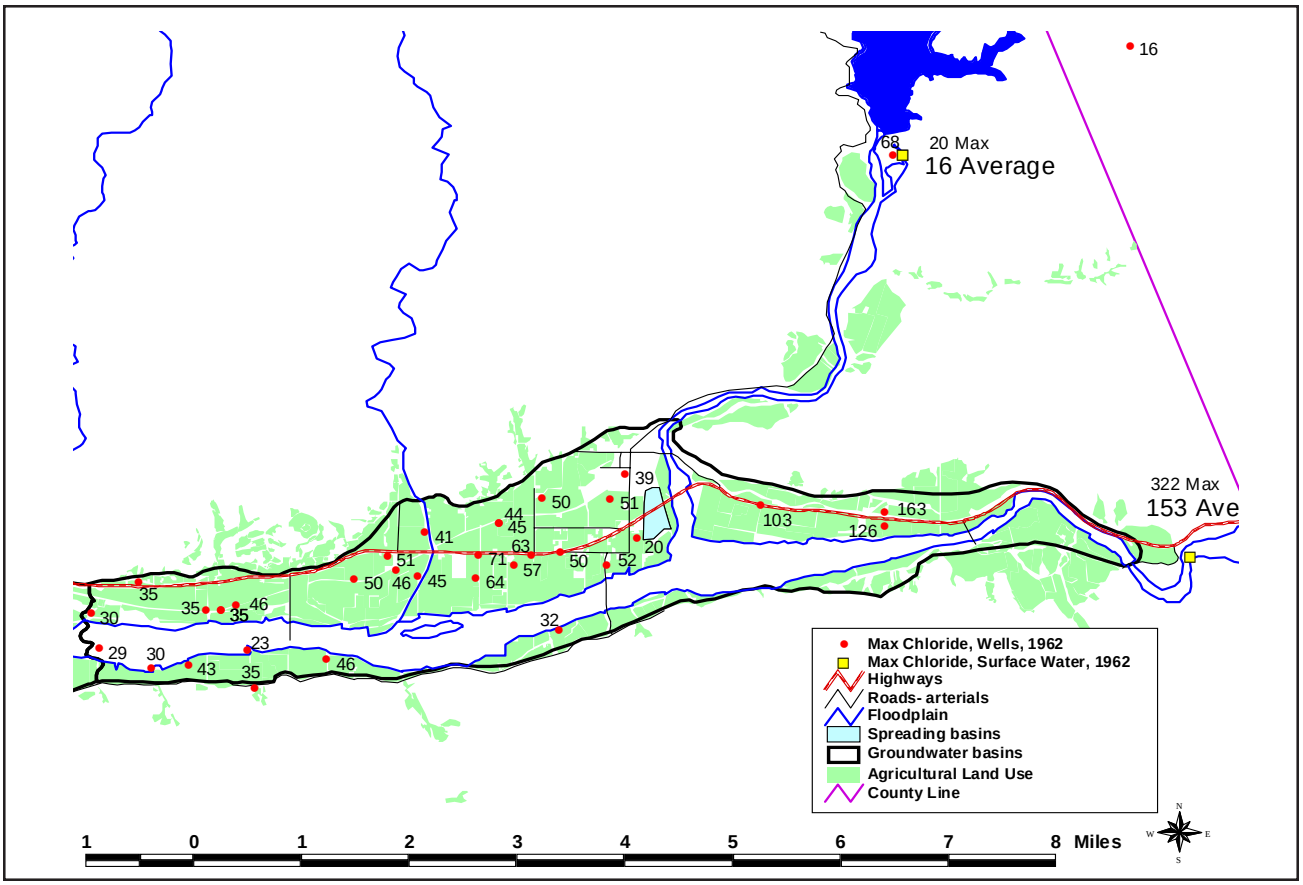
Map 1. Base mapof the Piru groundwater basin



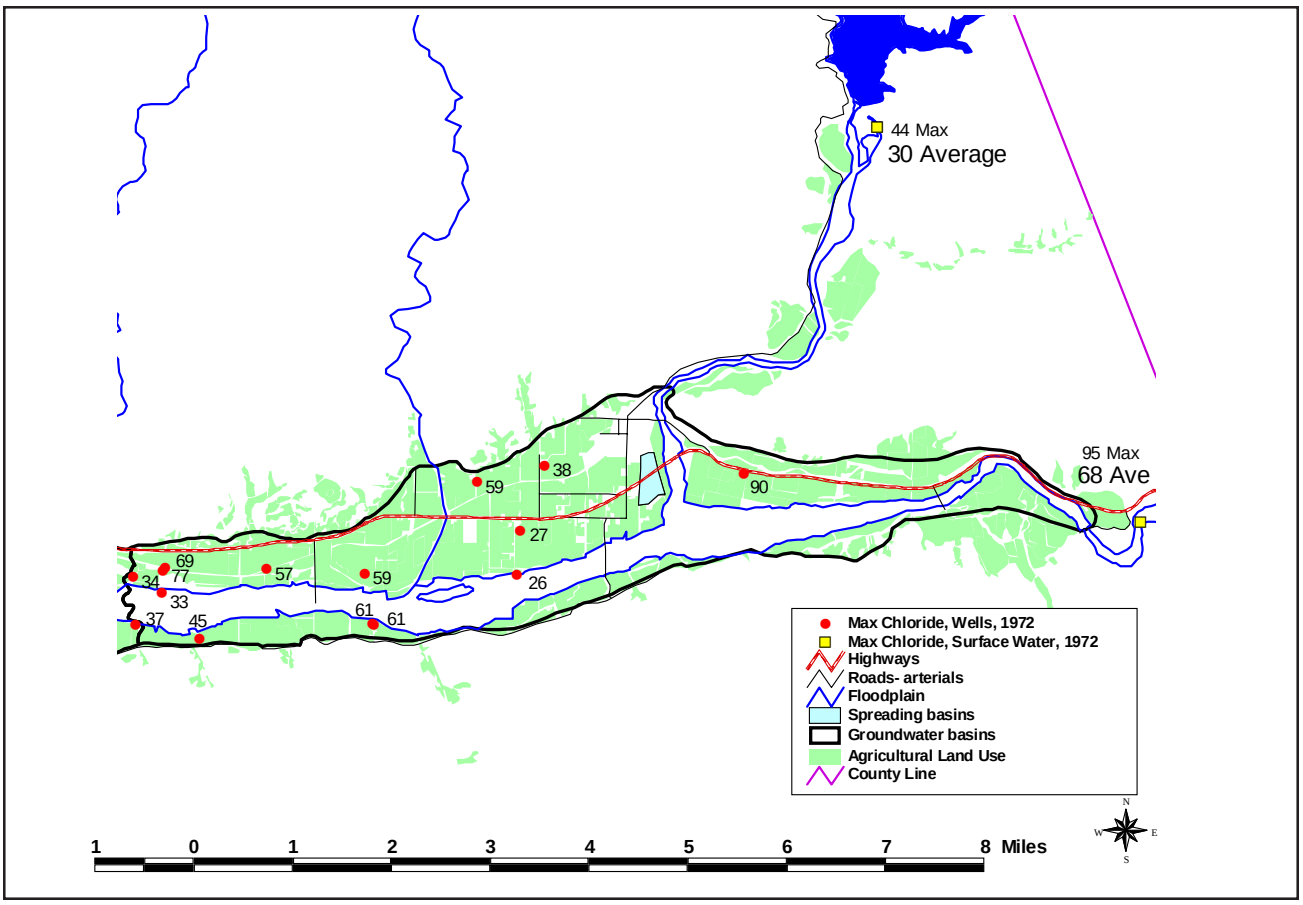
Map 2. Typical wet-year groundwater elevation contours, fall 1993.



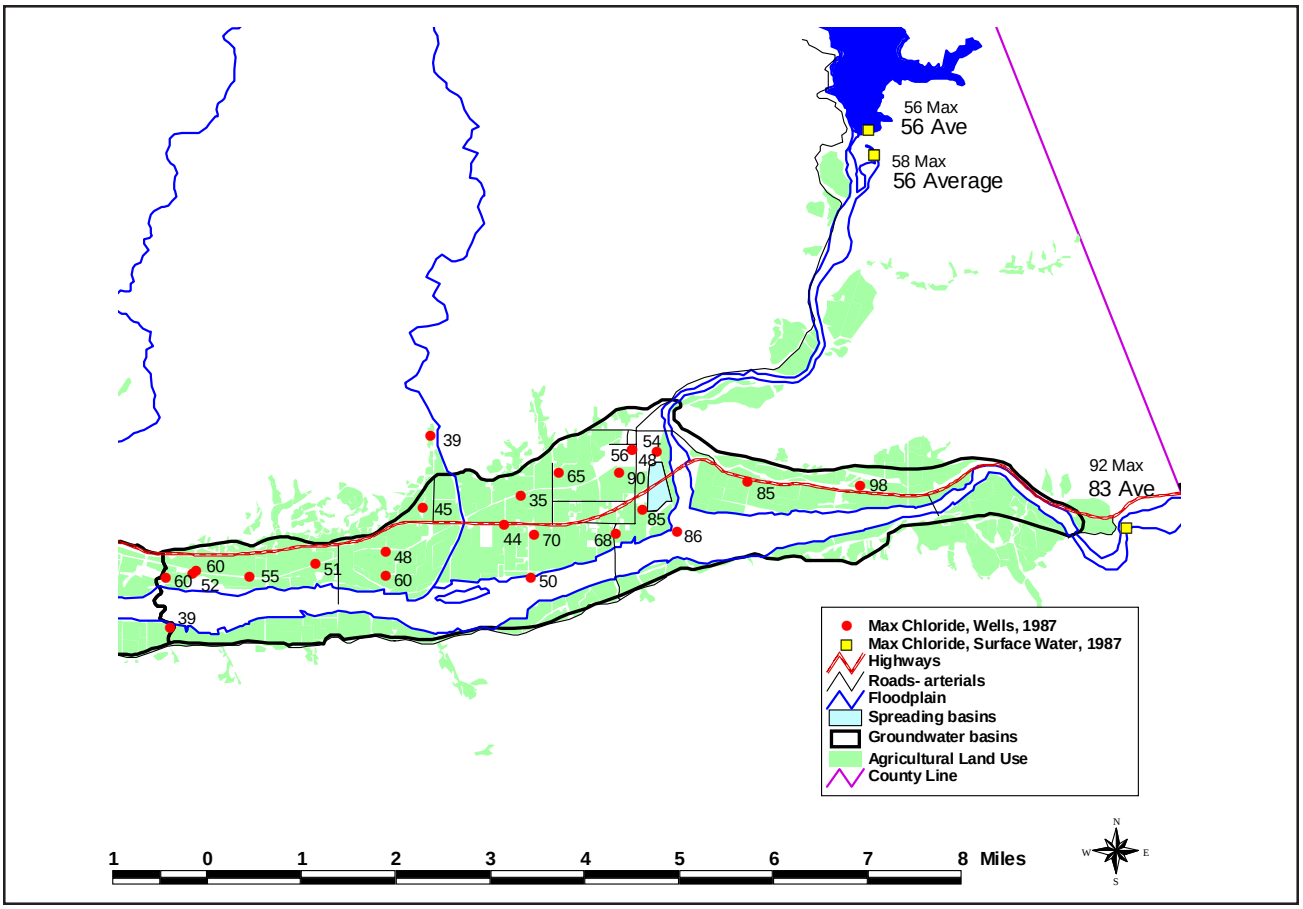
Map 3. Typical dry-year groundwater elevation contours, fall 2004



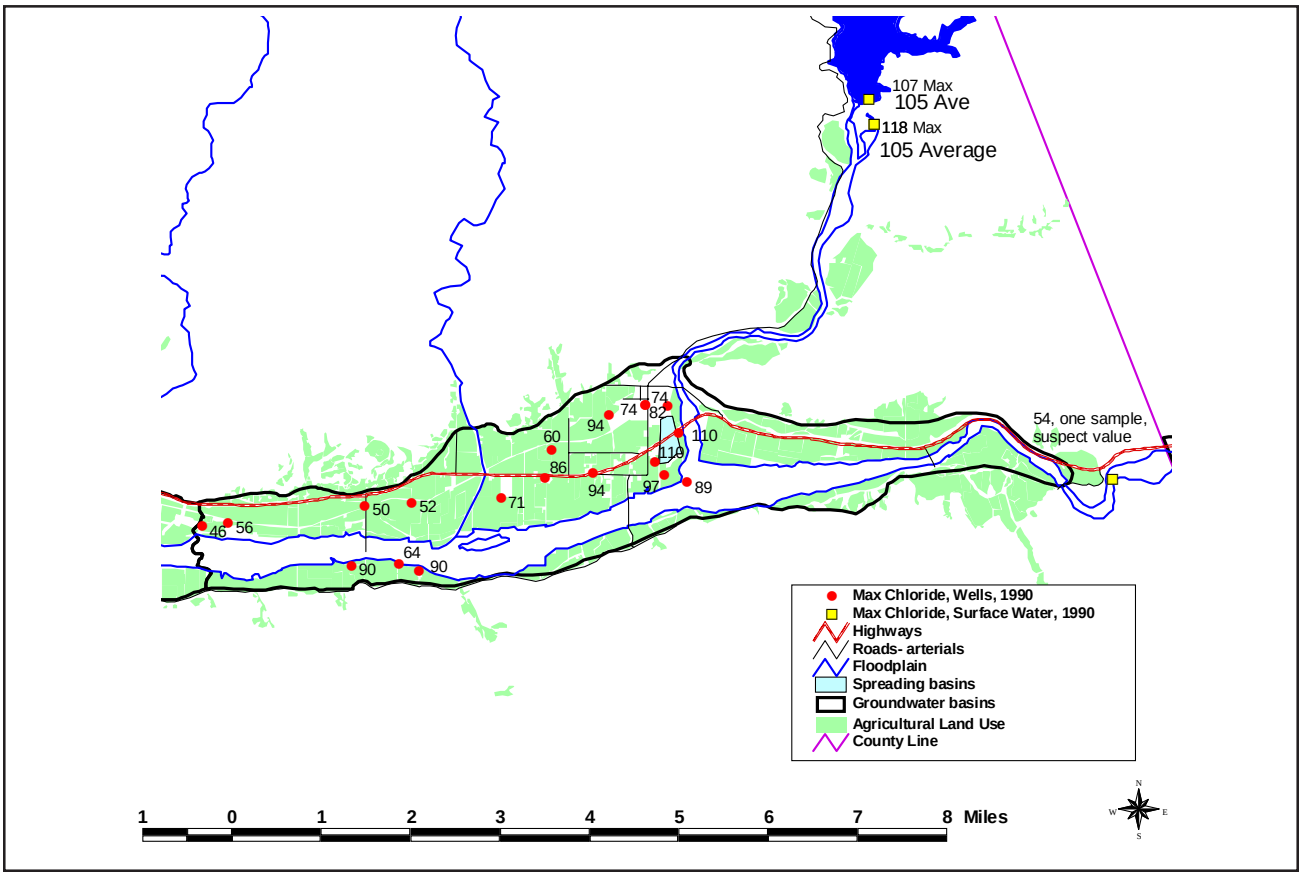
Map 4. Maximum-recorded chloride in wells and surface water, 1962.



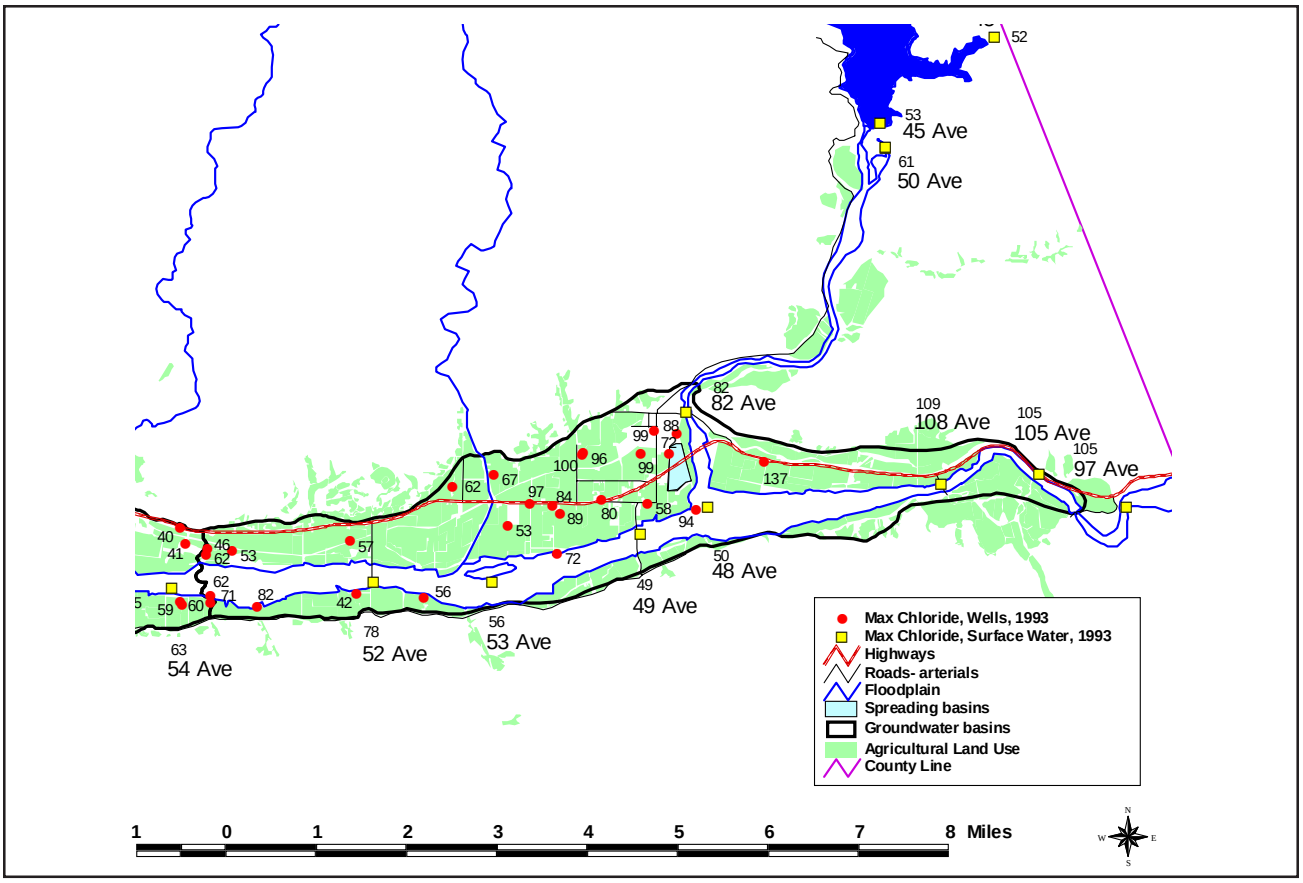
Map 5. Maximum-recorded chloride in wells and surface water, 1972



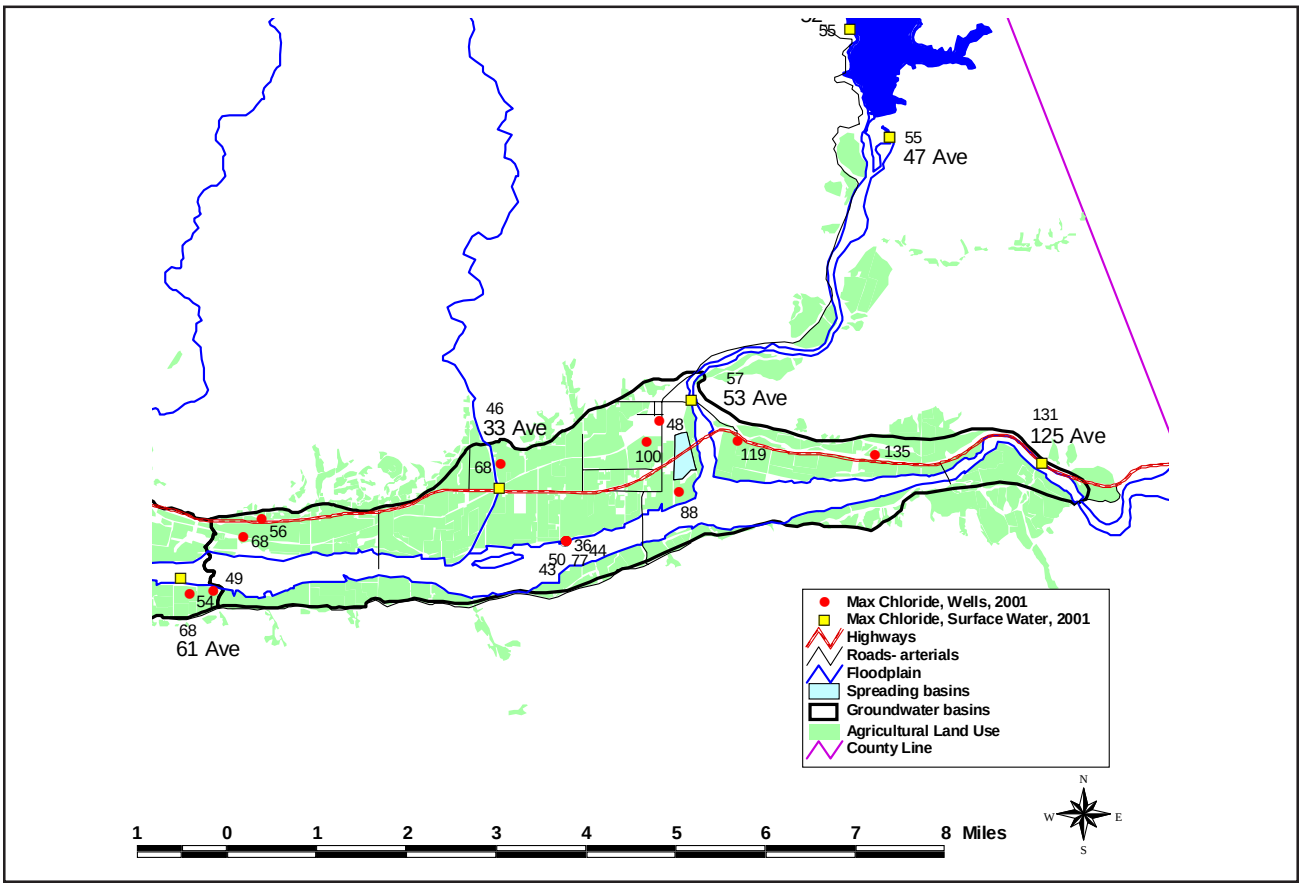
Map 6. Maximum-recorded chloride in wells and surface water, 1987



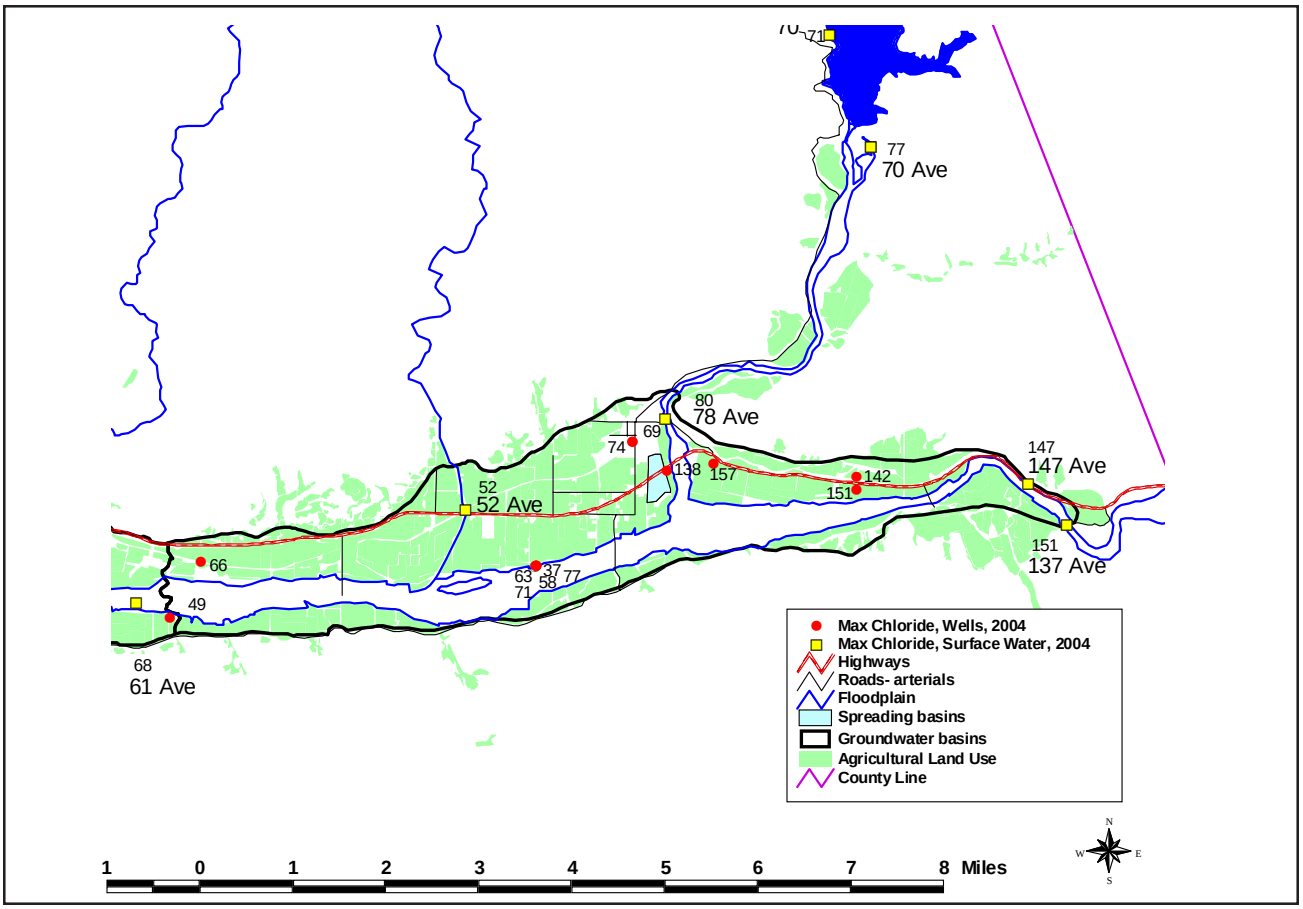
Map 7. Maximum-recorded chloride in wells and surface water, 1990



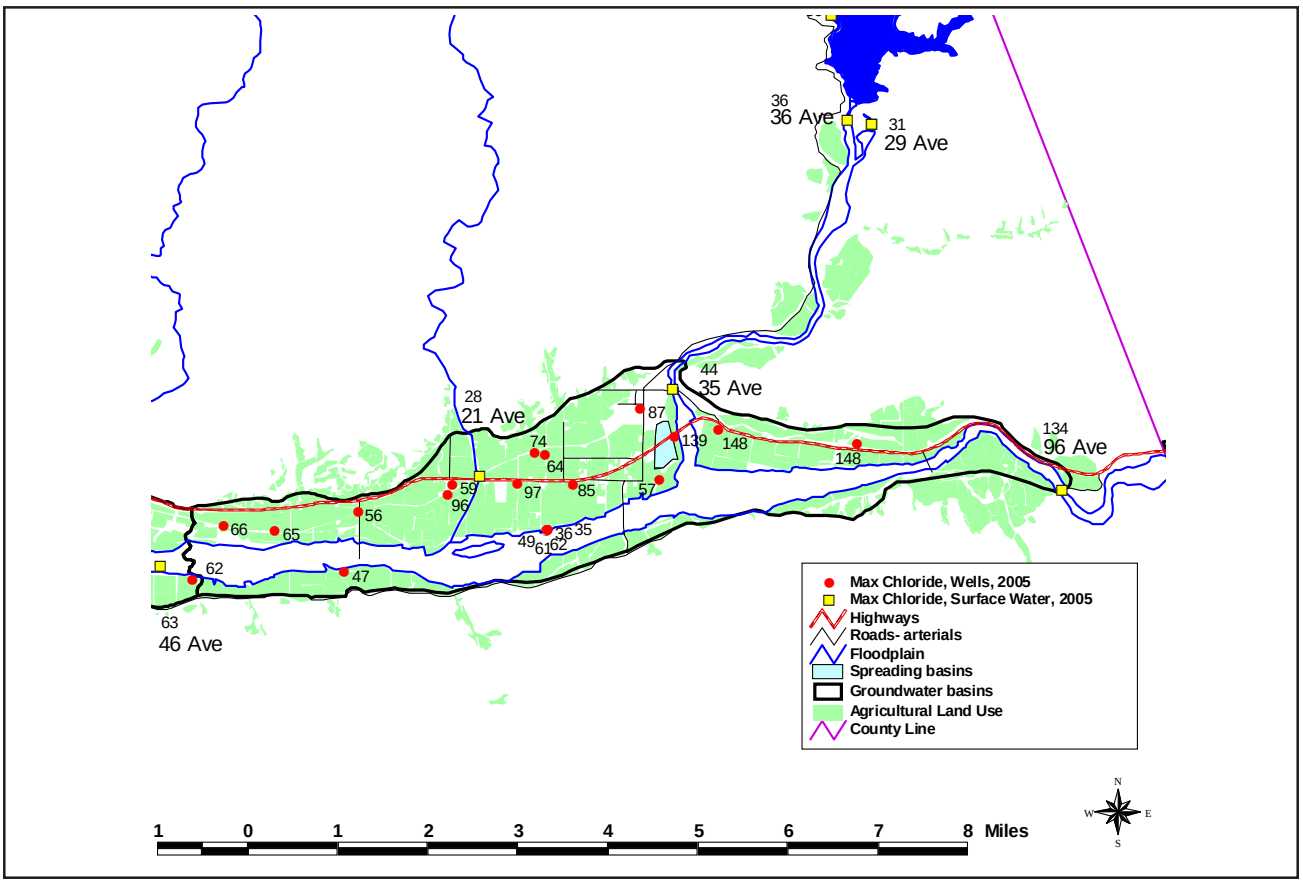
Map 8. Maximum-recorded chloride in wells and surface water, 1993



Map 9. Maximum-recorded chloride in wells and surface water, 2001



Map 10. Maximum-recorded chloride in wells and surface water, 2004



Map 11. Maximum-recorded chloride in wells and surface water, 2005