this precipitation falls as rain during the spring and summer, but most of the recharge from the surface to the surficial aquifer occurs in the winter and spring nongrowing seasons when evapotranspiration is low. Much of the agricultural land in the Delmarva Peninsula is used for soybeans and corn, which are used for poultry feed (Hamilton and others, 1993; Shedlock and others, 1999). In addition to grain crops, other crops such as fruits, vegetables, and nursery stock are grown for local and regional markets. Large poultry farms are found across the peninsula, which is one of the leading production areas of broiler chickens in the United States (Hamilton and others, 1993; Shedlock and others, 1999).

San Joaquin Valley

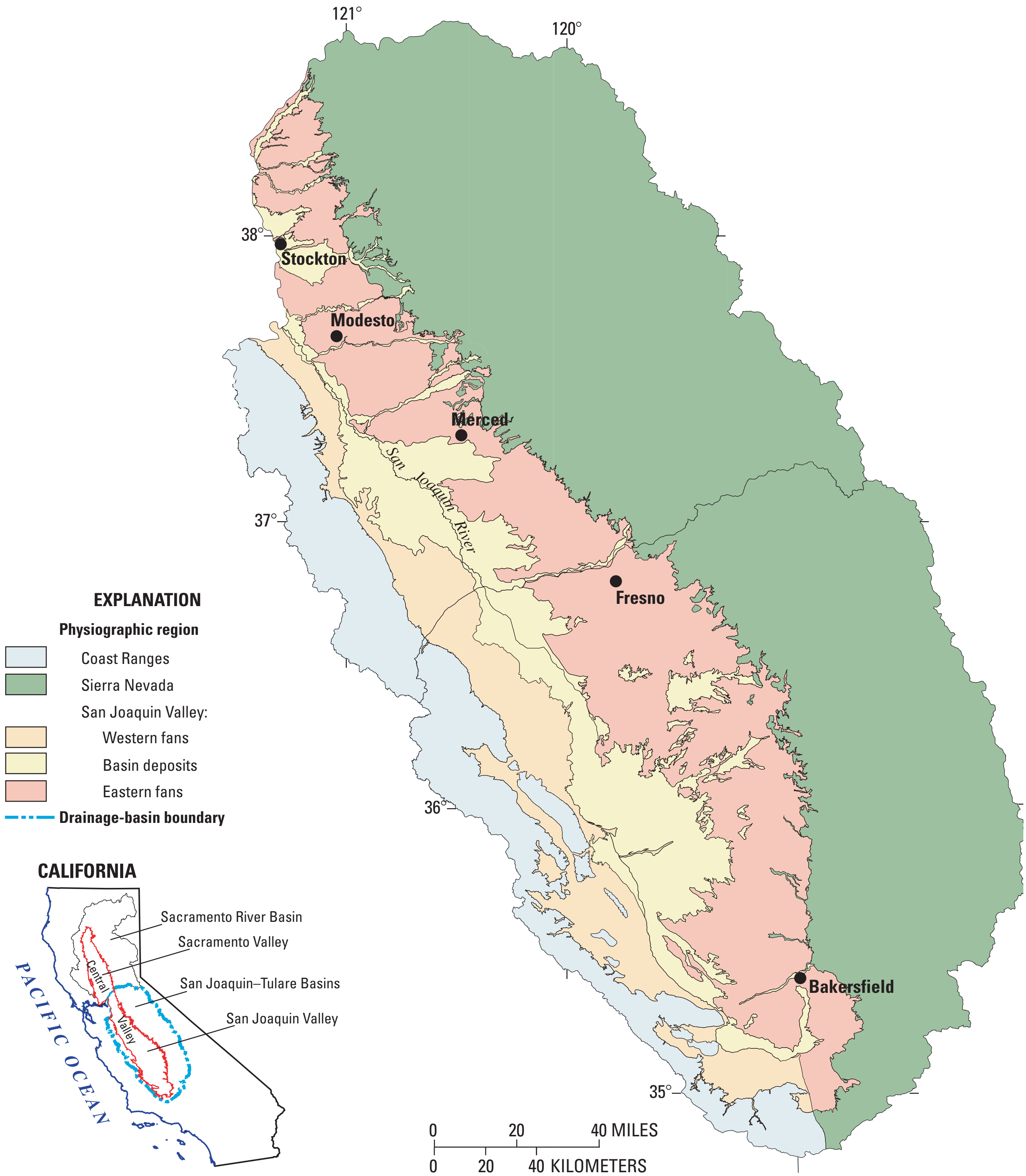
The San Joaquin Valley is the low-lying part of what is commonly referred to in the USGS as the San Joaquin–Tulare Basins (two separate basins that combine to form a larger basin). The San Joaquin–Tulare Basins are composed of three major physiographic regions—the Coast Ranges, the San Joaquin Valley, and the Sierra Nevada (fig. 8). The San Joaquin Valley, which is part of the Central Valley of California (fig. 8), is subdivided into three physiographic regions: the western fans, basin deposits, and eastern fans. Because most of the ground-water use, and potential impacts on ground water, occur within the valley's physiographic region, that part of the study unit was selected for detailed investigation. The valley, which consists of the San Joaquin and Sacramento Valleys, is a structural and topographic trough more than 805 km long. The San Joaquin Valley is the lower two-thirds of the Central Valley (fig. 8). A low east-west trending structural high in the valley floor just south of the Kings River area separates the southern part of the San Joaquin Valley into an area dominated by closed drainage. The climate in the San Joaquin Valley is Mediterranean with mild winters and hot summers. The average annual precipitation ranges from 127 to 406 mm (Page, 1986), most of which falls from November to April. As a result of the small amount of precipitation, ground-water recharge probably is almost exclusively acquired from infiltration of irrigation water. Most of the valley floor is irrigated.

A generalized geohydrologic section through the central part of the San Joaquin Valley is shown in figure 9. The regional freshwater aquifer system is in the Tulare Formation of the Pliocene and Pleistocene Epochs and in more recently deposited overlying alluvium. Because the Tulare Formation and overlying alluvium are lithologically similar, it is difficult to distinguish the boundary between them (Davis and others, 1959; Page, 1986), and so, it is not shown in figure 9. The Corcoran Clay Member of the Tulare Formation is an areally extensive fine-grained lacustrine deposit throughout the western part of the valley and the western part of the southern valley. It is used in this report to define the boundary of an upper and lower zone of the regional aquifers. The part of the Tulare Formation above the Corcoran Clay Member consists of Coast Ranges sediments on the west that interfinger eastward with sediments derived from the Sierra Nevada.

Alluvial, Pleistocene nonmarine, and other nonmarine deposits of the eastern part of the valley were derived primarily from the weathering of granitic intrusives of the Sierra Nevada, with fewer contributions from sedimentary and metasedimentary rocks of the foothills. The Sierran deposits are primarily highly permeable, medium to coarse-grained sands with low total organic carbon. The deposits generally are coarsest near the upper parts of the alluvial fans in the eastern part of the valley and finest near the valley trough. The depth to ground water below land surface varies greatly in these deposits (6 to 61 m). The combination of coarse-grained deposits and the relatively shallow water table results in a high potential for transport of nitrate or pesticides in irrigated areas of the eastern part of the valley (Domagalski and Dubrovsky, 1991, 1992).

The alluvial deposits of the western part of the valley tend to be of finer texture relative to those of the eastern part of the valley because of their origin in the Coast Ranges. The Coast Ranges to the west of the San Joaquin Valley are a complex mixture, consisting primarily of marine shales with smaller amounts of continental sediments and volcanic rocks. Ground water is less than 6 m below land surface over much of the western part of the valley, particularly in the lower parts of the alluvial fans. The unsaturated zone is primarily fine grained in these areas.

The southern part of the valley has closed drainage except in the wettest years, and lacustrine sediments have been deposited in the lowest topographic areas. These fine-grained sediments may tend to inhibit the transport of agricultural chemicals such as nitrate and pesticides. Stream-channel deposits of coarse sands are present along the San Joaquin River and its major east-side tributaries. In the valley trough, flood-basin deposits of varying extent flank the stream-channel deposits. The flood-basin deposits are interbedded lacustrine, marsh, overbank, and stream-channel sediment deposits generated by the numerous sloughs and meanders of the major rivers. The soils that have developed on these deposits generally are clays with low permeability (Davis and others, 1959). The stream-channel and flood-basin deposits are variable in nature with generally shallow water tables. The potential for contaminant transport may be high in places where the coarse-textured deposits are present.



map data: Fenneman and Johnson, 1946. California Division of Mines and Geology, 1958; 1959; 1964; 1965a,b; 1966; 1967; 1969. U.S. Geological Survey, 1978a. Page,1986

Figure 8. Physiographic regions of the San Joaquin–Tulare Basins, California, United States.

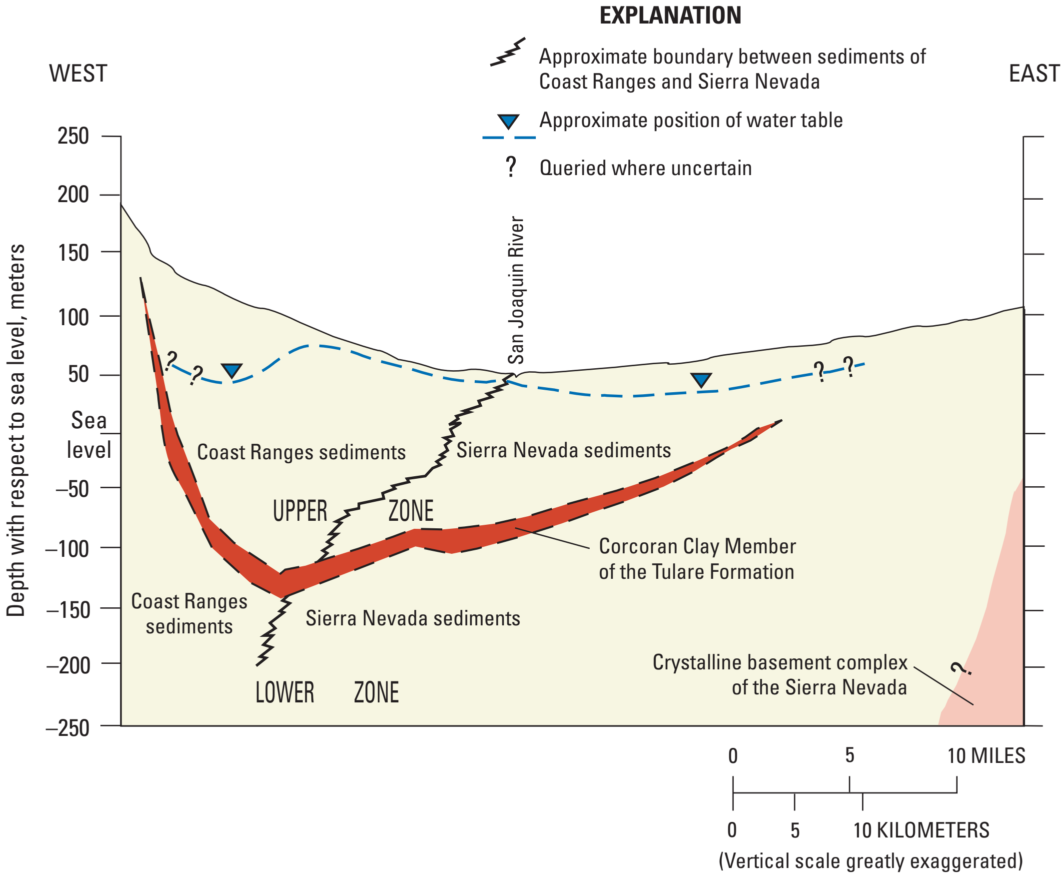
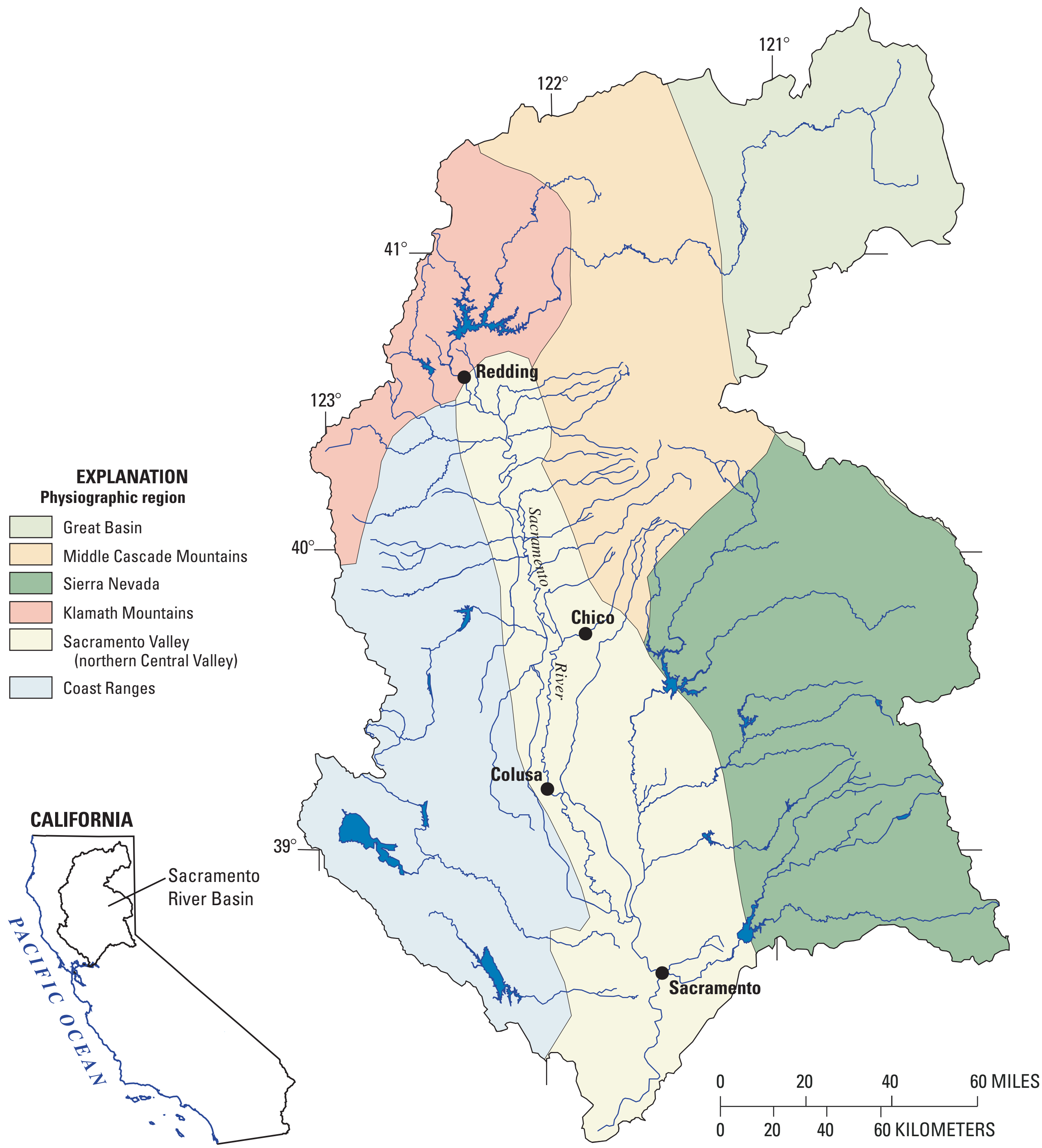


Figure 9. General geohydrologic cross section through the central part of the San Joaquin Valley, California, United States (modified slightly from Davis and others, 1959).

The San Joaquin Valley probably has the most diversified agricultural economy of the four regions included in this report. In 1987, about 10 percent of the total agricultural production in the United States came from California, of which 49 percent, or $6.82 billion (in United States dollars), was generated in the San Joaquin Valley (Gronberg and others, 1998). Major products are livestock and livestock products (35 percent), fruits and nuts (33 percent), cotton (13 percent), vegetables (6.5 percent), hay and grains (6 percent), and other crops (6.5 percent) (Gronberg and others, 1998).

Sacramento Valley

The Sacramento Valley is the low-lying part of the Sacramento River Basin (fig. 10). The Sacramento River Basin comprises six physiographic regions: the Great Basin, the Middle Cascade Mountains, the Klamath Mountains, the Coast Ranges, the Sierra Nevada, and the Sacramento Valley (fig. 10) (Domagalski and others, 1998). The Sacramento Valley is the primary region within the Sacramento River Basin where most of the ground-water use and potential effects on ground water occur. The Sacramento Valley is the northern one-third of the Central Valley. Page (1986) has described the geology of the Sacramento Valley as part of the northwestward-trending asymmetric-structural trough of the Central Valley that has been filled with sediment as much as 16 km in depth. The ages of the sedimentary rocks and deposits in the Sacramento Valley range from the Jurassic Period to the Quaternary Period (Holocene Epoch) and include marine and continental rocks and deposits. Much of the valley is classified as continental rocks and deposits that range from the Pliocene Epoch to Holocene Epoch, which are a heterogeneous mix of generally poorly sorted clay, silt, sand, and gravel. The valley also includes beds of claystone, siltstone, sandstone, and conglomerate. River and flood-basin deposits are also an important part of the valley's geology. The river deposits consist of gravel, sand, silt, and minor amounts of clays; the flood-basin deposits consist of clay, silt, and some sand deposited during flood stages of the rivers. The foothills of the Sierra Nevada and Cascade Mountains flank the eastern side of the valley. Those physiographic regions are composed of volcanic, marine, granitic, and continental rocks. The valley is flanked on the western side by rocks of the Coast Ranges, which are principally marine deposits. The Natural Resources Conservation Service (name changed from the "Soil Conservation Service" in



map data:
Fenneman and Johnson, 1946. U.S. Geological Survey, 1972; 1975a,b; 1976a,b,c,d; 1978b,c,d;
1979a,b,c; 1980; 1983a,b,d; 1984c,d,f,g,h. Steeves and Nebert, 1994

Figure 10. Physiographic regions of the Sacramento River Basin, California, United States (from Domagalski and others, 1998).

October 1994) has described the soils of the Sacramento Valley (Soil Conservation Service, 1993). Most of the soils are clay with very slow or moderately slow infiltration rates. Because of the regional extent of these clay soils, rice cultivation is a major agricultural practice in the Sacramento Valley. Fruits and nuts also are grown in the Sacramento Valley, but production is limited to regions with well-drained soils, primarily near river channels. Row crops, including corn and tomatoes, are also produced. Although clay soils are widespread throughout the Sacramento Valley, no major confining layers of clays, such as those that characterize parts of the San Joaquin Valley, occur in the Sacramento Valley. The aquifer of the Sacramento Valley resides under unconfined conditions in most of the valley (Page, 1986).

The average annual precipitation in the Sacramento River Basin is 914 mm/yr, with most of the precipitation in the form of rain or snow during November through March. The precipitation in the Sacramento Valley (fig. 10) is less than that of the overall basin, and the average annual precipitation measured in Sacramento is 472 mm/yr. Most of that precipitation falls also as rain during November through March. More rain falls in the mountainous regions, especially in the northern part of the basin.

Comparison of Study-Unit Characteristics

A comparison of geographic and hydrologic characteristics of the four study units is shown in table 1. The study units generally are in about the same range of latitude. The greatest differences are the variation in the amount of precipitation, the amount of irrigation water, and the density of population. The Delmarva Peninsula has the greatest amount of precipitation and, because a significant percentage of the annual precipitation falls during the growing season, there is less of a need for irrigation water. The Asian monsoon influences the weather of the Tangshan study unit, where most of the precipitation falls between June and September. Although Tangshan's precipitation coincides with its growing season, annual rainfall varies, and usually a significant amount of irrigation water is still needed. In contrast, little or no rain falls in the San Joaquin and Sacramento Valleys during the growing season, and as a result, successful agriculture in this region requires irrigation water.

DESIGN OF GROUND-WATER WELL NETWORKS FOR JOINT AGREEMENT

The overall design of the study was to characterize the regional ground-water quality in the Tangshan region of the People's Republic of China and to compare the water quality with that of similar areas in the United States. Unfortunately, it was not logistically possible or necessary to design the sampling strategy for the joint agreement such that all sampling would take place at the same general time. In fact, sampling for two of the study units of the United States—the Delmarva Peninsula and the San Joaquin Valley—took place prior to the actual design of the joint agreement for international study. Participants of the study determined that the basic concept of the NAWQA study-unit survey (Gilliom and others, 1995) would be the principal guidance for well selection and data analysis. The study unit survey relies primarily on the sampling of existing wells and, wherever possible, on the interpretation of existing data collected by other agencies or programs. Wells are selected using a grid-based random sampling approach (Scott, 1990; Alley, 1993). As mentioned, the ground-water well networks for study units in the United States were designed for specific studies, including but not limited to NAWQA, and had been sampled previously. The design for the joint agreement followed the criteria of these earlier studies as closely as possible. In all cases, the design of the ground-water networks was regional in scope. All well networks were designed to obtain water-quality data for a regional ground-water system in agricultural areas, and all study designs for these well networks included water-quality sampling for nitrate and other nutrient compounds. However, only the well networks of the San Joaquin Valley and the Tangshan aquifer system included samplings of a shallow well and a deep well in most chosen locations. Therefore, whereas comparisons can be made of the surficial aquifers in all four study units, comparisons of deeper aquifers can only be made for those in the San Joaquin Valley and the Tangshan study units.

The wells of the Delmarva Peninsula were sampled in 1989 and 1990, the wells of the San Joaquin Valley were sampled during 1985 through 1988, and those of the Sacramento Valley were sampled in 1996 and 1997. The wells of the Tangshan aquifer had two samplings for water quality. These were completed in May and September 1996 in order to obtain data prior to and following the rainy season, respectively. Much of the data analysis and interpretation for this study used the data from the May sampling, which included more comprehensive chemical analyses.

The design of the water-quality network for the Delmarva Peninsula is discussed in detail in Hamilton and others (1993). That study was part of the pilot program for the design of study-unit surveys for NAWQA. The Delmarva network consisted of two components: an aereal network and a transect network (fig. 7). The authors of this report decided that the two networks would be combined to provide better regional coverage of ground-water quality for this joint study.

Table 1. Comparison of geographic and hydrologic characteristics of the four study units in the People's Republic of China and the United States

[hm, hectometer; km, kilometer; m, meter; mm, millimeter; na, not available; yr, year; °C, degree Celsius]

Country:	People's Republic of China	United States		
Study unit:	Tangshan (Hai He River Basin)	San Joaquin Valley (California)	Sacramento Valley (California)	Delmarva Peninsula (DE, MD, VA)[1]
Geographic range:				
Latitude	39°03′–40°35′	35°–38°30′	38°–40°30′	37°–30°40′
Longitude	117°30′–119°18′	120°–120°30′	120°30′–122°20′	75°–76°20′
Area (km^2)	13,472	31,216	16,392	15,540
Precipitation[2] (mm/yr)	645	127–380	350–640	1,140
Evaporation (mm/yr)	1,585	1,245	1,245	na
Drought index (evaporation/precipitation)	2.456	9.8–3.3	3.6–1.9	na
Air temperature, °C (mean, highest, lowest)	10, 39.6, –22.07	16.5, 43.9, –8.9	16, 45, –7.8	13.4, 38.5, –20
Aquifer characteristics (single or multilayer)	Multilayer	Multilayer	Single	Single
Thickness of the main aquifer (m)	10–50	730–2,740	730	30.5 for surficial aquifer
Depth of ground water (m)	7.5	6 or greater	6 or greater	6.1
Average annual recharge amounts of ground water (m^3/yr)	169,000	1,850,222,700 (combined for San Joaquin and Sacramento Valleys)		6,315,456,000
Ground-water use ($10^4 m^3/km^2$/yr)	14.1	25.8	20.1	1.5
Utilization coefficient of ground water (exploitation amount/recharge amount)	Slightly greater than one	Greater than one	Less than one	Less than one
Area of farmland (km^2)	5,806	30,000	13,072	7,459
Proportion of farmland (farmland area/total land)	0.431	0.96	0.79	0.48
Irrigation water (m^3/hm^2)	44,275	4,540	5,080	na
Monitoring well amounts	111	178	59	103
Density of population (people/km^2)	512	87	134	45

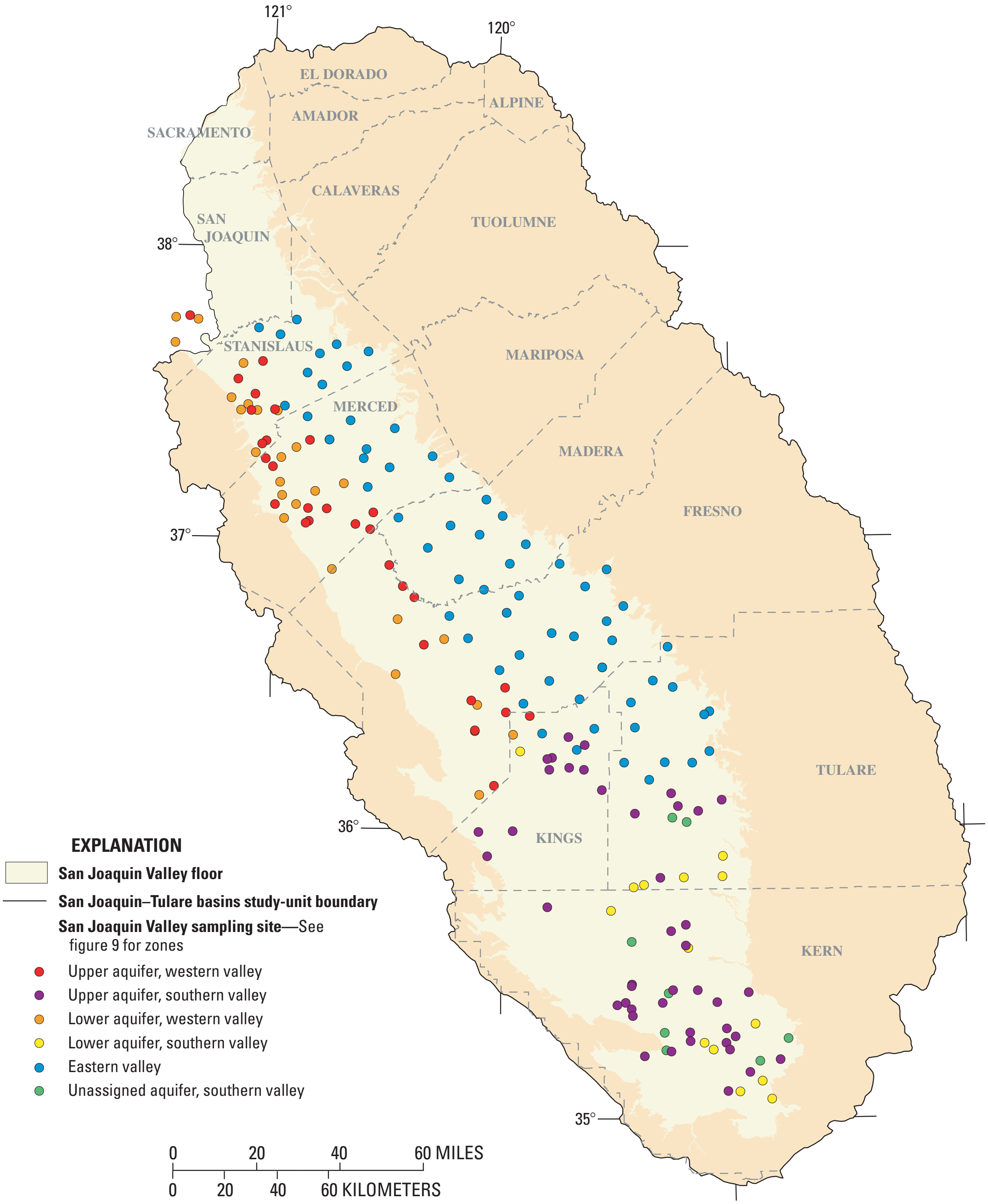
[1]DE, Delaware; MD, Maryland; VA, Virginia.

[2]Precipitation is shown as either the average or the range.

The design of the San Joaquin Valley network is described in Domagalski and Dubrovsky (1991). Those wells were sampled as part of the Regional Aquifer Systems Analysis (RASA) Program of the USGS. The basic design of the San Joaquin Valley RASA study was to sample a set of wells spaced randomly to evenly throughout the San Joaquin Valley, thereby approximating the general guidance for design of a NAWQA study-unit survey (fig. 11). The design of the San Joaquin Valley study most closely approximates that of the Tangshan study because shallow and deep wells were sampled through most of both study units.

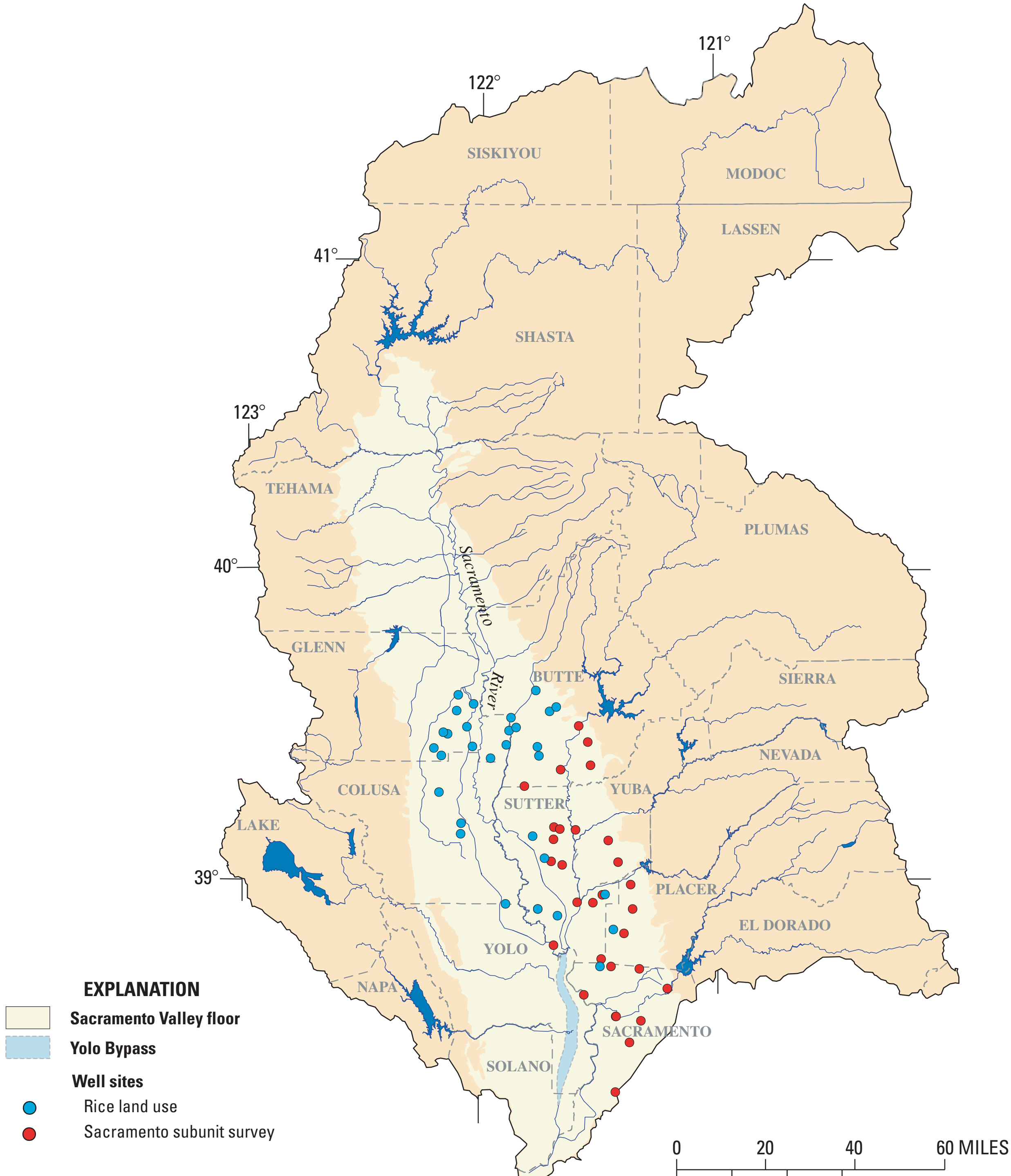
A general discussion of the design of the Sacramento Valley well network is given in Domagalski and others (1998). That well network included a study of a part of the Sacramento Valley (Sacramento subunit survey) and an agricultural (rice) land-use survey (fig. 12). The well network was based on the NAWQA guidance for well selection in a study unit. Because of the areally extensive nature of rice agriculture in the Sacramento Valley, the authors decided to combine two well networks for data interpretation to provide greater spatial coverage. However, the water-quality characteristics and interpretation of the water quality of the subunit survey and rice wells are discussed separately.

The well network for the Tangshan aquifer is shown in figure 4. A total of 111 wells, used for irrigation and domestic water, were sampled. Water-quality samples were also collected at three river sites—two on the Luan He River and one site on the Qinglong He



map data:
U.S. Geological Survey, 1978a. Charles Johnson, U.S. Bureau of Reclamation, unpub. data (county boundaries, scale 1:24,000), 1993

Figure 11. Locations of wells in the San Joaquin Valley, California, United States. Includes county boundaries.



map data:
U.S. Geological Survey, 1972; 1975a,b; 1976a,b,c,d; 1978b,c,d; 1979a,b,c; 1980; 1983a,b,d; 1984c,d,f,g,h.
Charles Johnson, U.S. Bureau of Reclamation, unpub. data (county boundaries, scale 1:24,000), 1993. Steeves and Nebert, 1994

Figure 12. Locations of wells in the Sacramento Valley, California, United States. Includes county boundaries.

River—to compare the chemistry of river water with that of ground water. The lower Luan He River was the only site sampled for major inorganic constituents, and all three sites were sampled for hydrogen and oxygen isotopes. At most locations, both a shallow and a deeper well were sampled. Four ground water transects were selected for detailed analysis by stable isotopes or dating analysis. Transects 1 and 2 (lines T1 and T2 shown in fig. 4) were sampled in June 1996, and the analyses included stable isotopes and dating. Water samples were also collected for the analysis of pesticides at select wells along those transects. Not all of the wells were sampled for all three types of dating methods because of logistics difficulties or because not all of the wells were suitable for this type of sampling. At the very least, samples for tritium (^{3}H) were collected. Transects 3 and 4 were sampled in September 1996 for stable isotopes to provide a better spatial resolution of the distribution of deuterium and oxygen isotopes in ground water. Water-quality technicians of the Hai He River Water Conservancy Commission or Tangshan Water Resources Bureau collected water-quality samples in May and September 1996. The May sampling occurred prior to the Asian monsoon season and the September sampling afterwards. In that way, the effects on water quality of very recently recharged water could be examined.

The well network for the Delmarva Peninsula (fig. 7) had a total of 103 wells sampled in 1989 and 1990. In the well network for the San Joaquin Valley (fig. 11), 178 wells were sampled. The wells of the western San Joaquin Valley were sampled in 1985, those of the southern part in 1986, and those of the eastern part in 1987. The 59 wells of the Sacramento Valley were sampled in 1996 and 1997. The well network of the Sacramento Valley is shown in figure 12.

METHODS AND SAMPLE ANALYSIS

The methodology chosen to collect water from ground-water wells for the study units of the United States conformed to established USGS procedures. Ground-water samples for the Delmarva study unit were collected according to the method in Hardy and others (1989), which called for the removal of standing water in the well by pumping at least three well-casing volumes of water and monitoring field-measured constituents such as temperature, pH, and specific conductance. After these field-measured constituents had stabilized, water samples were collected through non-contaminating equipment such as Teflon tubing. Water samples were filtered through 0.45 µm pore-size filters for dissolved constituents. Quality assurance and quality control practices for the Delmarva study were summarized in Jones (1987), Hardy and others (1989), and Koterba and others (1991). The purpose of the quality assurance and quality control practices was to ensure that accurate and representative water-quality data for each sampling network were acquired and to estimate the variability in selected water-quality constituents. These quality assurance and quality control practices included the cleaning of equipment used for sampling, collecting blank samples using the same procedures that are used for real water samples, and collecting replicate samples to determine variability caused by sampling or laboratory analysis.

A similar strategy was used for collecting water-quality samples from wells in the San Joaquin Valley, which is summarized in Dubrovsky and others (1991). Sampling for wells in the Sacramento Valley conformed to guidance provided by the NAWQA Program (Koterba and others, 1995). Most chemical analyses of water collected from all wells in the United States were conducted by the USGS's National Water Quality Laboratory in Arvada, Colorado, except for ^{3}H and $^{3}H/^{3}He$ analyses. Most of the analytical methods are described in Fishman and Friedman (1985). Some samples were analyzed for pesticides using the methods in Zaugg and others (1995).

Radiochemical analyses were completed on many samples, including some collected in the People's Republic of China. The dating methods were the ^{3}H, $^{3}H/^{3}He$, and CFC methods. Stable isotope analyses were limited to deuterium (^{2}H) to hydrogen (^{1}H) ratio and oxygen 18 (^{18}O) to oxygen 16 (^{16}O) ratios, both in water molecules; and to nitrogen (^{14}N to ^{15}N ratio) and oxygen (^{18}O to ^{16}O ratio) isotopes in nitrate.

Ground-water samples in the People's Republic of China were collected from existing domestic or irrigation wells. For wells that were not operational, standing water was removed prior to sampling. Water samples were collected for field-measured constituents (pH, dissolved oxygen, specific conductance, and alkalinity), major elements, nutrients, metals, and in some cases, coliform bacteria, according to standard methods for the collection of water samples established by the People's Republic of China. The samples were analyzed by the Hai He Basin Water Environmental Monitoring Center and the Tang-Qin Water Environmental Monitoring Center. A subset of samples collected in the People's Republic of China was analyzed by the National Water Quality Laboratory of the USGS for comparison. The results showed that the two laboratories obtained similar results for major constituents, nutrients, and metals.

NATURAL WATER CHEMISTRY

Ideally, natural water chemistry is defined on the basis of ground-water samples collected from aquifer zones that have been unaffected by agricultural or other anthropogenic activities. In practice, it is difficult to determine whether any ground water in a large agricultural region has been unimpacted by agricultural chemicals. Even water with no measurable nitrate may indeed have had a major flux of nitrate that subsequently degraded by bacterial action under anoxic conditions. In previous studies of the Delmarva Peninsula, such as Hamilton and others (1993), ground-water concentrations at or below 0.4 mg/L of nitrate as N were indicative of natural water unaffected by agricultural activities. Hamilton and others (1993) used the results from a sufficiently large population of wells in the Delmarva Peninsula to define this background. A study of ground water throughout the United States (Madison and Brunett, 1984) suggests that nitrate as N concentrations below 0.2 mg/L are indicative of natural ground water in the United States and that nitrate as N concentrations generally between 0.2 to 3.0 mg/L or in some cases, slightly higher, indicate water that is affected by agricultural activities. There are no corresponding studies from China that document levels of natural ground-water nitrate concentrations, but it is reasonable to assume that they are also low. A threshold value of 0.5 mg/L of nitrate as N has been chosen as the value below which ground water can be assumed to be relatively unaffected by agriculture, at least with respect to nitrate within the Tangshan region. The situation in the San Joaquin Valley, especially the western region of the valley, is more complicated because of localized areas of naturally occurring nitrate (Sullivan, 1978).

It is beyond the scope of the present study to determine the sources of nitrate measured in the wells of the western San Joaquin Valley. Therefore, it is possible that some of the nitrate concentrations that were measured were not the result of agricultural activities. However, the nitrate levels measured in the lower aquifer of the western San Joaquin Valley tend to have nitrate concentrations less than 0.5 mg/L (median = 0.4 mg/L). Given these caveats, natural ground-water chemistry is defined in this study as water with a low nitrate concentration. The composition of ground water with nitrate as N less than 0.5 mg/L and with nitrate as N less than 3 mg/L are used to compare ground water across these study units as likely having been unimpacted or minimally impacted by agricultural activities, respectively. This range of values is used for comparative purposes for all study units of this investigation, although some of the higher nitrate concentrations measured in the western San Joaquin Valley may have resulted from natural sources. Water with nitrate concentrations greater than 3 mg/L are therefore assumed as likely to have been affected by the use of nitrogen fertilizer.

The natural water chemistry of the Tangshan aquifer can be characterized as calcium–magnesium–carbonate water (fig. 13). The water of the Luan He River (fig. 14) is also a calcium–magnesium–carbonate type of water. The natural water chemistry of the ground water and the Luan He River is consistent with the mineralogy of the aquifer sediments, which include a mixture of igneous and carbonate rocks. Ground water of the Tangshan study unit tends to be close to saturation or supersaturated with respect to carbonate minerals. Natural sources of chloride and sulfate are not apparent in most of the aquifer system, except in the coastal zone where intrusion of salt water can lead to elevated concentrations of chloride and sulfate.

Hamilton and others (1993) have described the natural water chemistry of the surficial aquifer of the Delmarva Peninsula, noting that the water tends to be acidic and soft with low alkalinity, low sodium, and low specific conductance. The chemistry of the natural water tends to be primarily controlled by the chemical properties of rainfall and snowmelt, mineral dissolution, biological activity and its residence time in the soil zone and aquifer, and the nearby presence of saline water (Hamilton and others, 1993). Mineral dissolution may take place when the minerals of the soil and aquifer zones come in contact with water moving through the system, including meteoric water and irrigation water. The principle mineral of the aquifer is quartz with minor amounts of silicate minerals or clay minerals, as well as calcium carbonate from shells and shell fragments (Hamilton and others, 1993).

The major element chemistry of the natural ground water of the Delmarva Peninsula is displayed in a trilinear graph in figure 15. The chemistry of natural ground water, unaffected by agriculture, is displayed as white squares in figure 15. The cation and anion chemistry of natural ground water of the Delmarva Peninsula is variable (fig. 15). Much of the natural water is dominated by bicarbonate as the principal anion, but the water also includes a considerable amount of sulfate and chloride, which can be attributed to the proximity of the Atlantic Ocean. The cation chemistry shows that most of the natural ground water is dominated by sodium plus potassium, but several ground-water samples also have high amounts of calcium and magnesium. Most of the ground water of the Delmarva Peninsula is undersaturated with respect to carbonate minerals.

The chemistry of natural water in the San Joaquin and Sacramento Valleys of California is complicated because of the contrasting physiographic regions surrounding the valley and different types of sediment that make up the aquifer materials. The chemistry of the San Joaquin Valley ground water is not expected to be the same for each location because the chemical composition of the recharge water is different for each location.

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