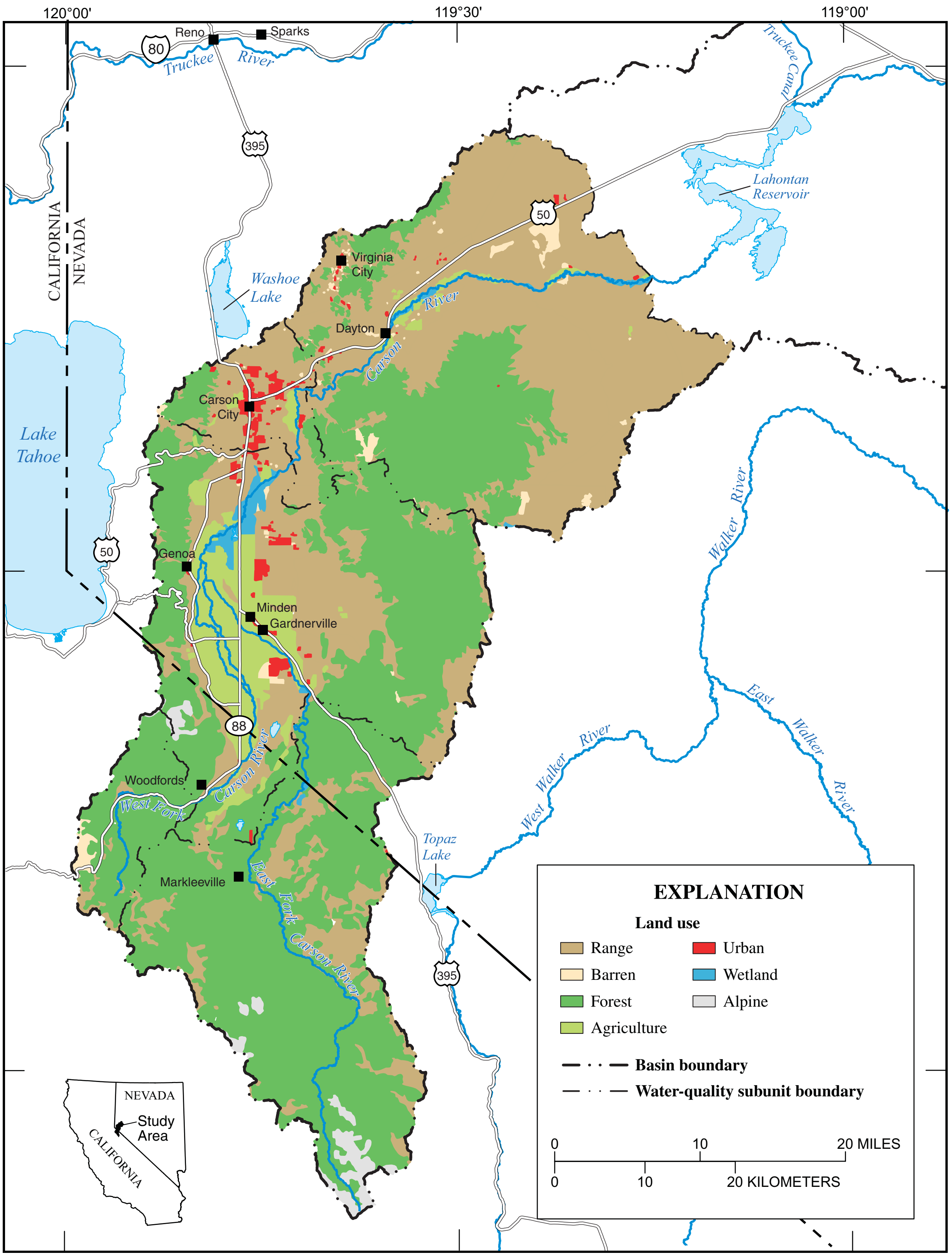

Base from U.S. Geological Survey digital data, 1:100,000- and 1:24,000-scale, 1979-82
Universal Transverse Mercator projection, zone 11
North American Datum 1927

Figure 9. Land use in the Carson River Basin upstream from Lahontan Reservoir, 1990.

Under acidic conditions, orthophosphate concentrations in water and soil solutions can be lowered by adsorption onto aluminum and iron oxyhydroxides and oxides and may precipitate as insoluble aluminum and iron phosphates (Vymazal, 1994). At pH values greater than 7, orthophosphate concentrations can be lowered by precipitation of phosphate as calcium phosphate.

Phosphorus bound to particulate matter is not immediately available to support plant growth, though it can provide a long-term source of phosphorus. Organic particulate phosphorus can be converted to orthophosphate as the organic matter is oxidized by physical-chemical processes (for example, photolysis) or as it is metabolized by bacteria and other living organisms. Sources of organic particulate phosphorus include decaying plant matter from leaves falling into streams, the death of aquatic organisms, or erosion from soils. Inorganic particulate phosphorus is converted to orthophosphate through chemical processes. Some forms of inorganic particulate phosphorus, such as the mineral apatite, can dissolve in streams and release orthophosphate to the streamwater. Other forms of inorganic particulate phosphorus, such as phosphorus bound to aluminum and iron oxyhydroxides and oxides, are unlikely to dissolve in streams. These forms dissolve in reducing environments (for example, sediments in lakes and reservoirs) where the orthophosphate then diffuses into the overlying water column. Sources of inorganic particulate phosphorus include eroding surface soil, streambanks, and resuspension of bed sediment.

Transport

Phosphorus can be transported in the riverine environment either as dissolved phosphate ions and complexes, or bound to organic and inorganic particles. Because phosphorus can bind to sediment particles, stream properties and sediment characteristics that result in large amounts of sediment transport affect the amount of phosphorus being transported. Stream properties that affect sediment transport include channel slope, size and character of the material in the bed and banks, flow velocity and volume, vegetation along the banks, and sinuosity of the stream.

Particle size, shape, and charge are important determinants in sediment and phosphorus transport because water discharge is required to move sediment particles and, once in solution, to keep the particles from settling out. Phosphorus binds preferentially to small sediment particles because small particles such as clays have surface charges and large surface area to volume ratios. Up to 50 percent of total phosphorus in soils may be associated with the clay fraction (Ryden and others, 1973). As a result, compared to sands and silts, less discharge is required to remove small, phosphorus-rich clay-sized particles from land surfaces. Once in small channels, fine particles are easily carried in suspension; whereas, coarser particles move in suspension for only short distances. Thus, clay-size phosphorus-rich particles likely are removed from fields, transported in small channels to the Carson River, and remain in suspension during low flow.

Phosphorus does not move easily or quickly through undisturbed soil profiles because, in general, phosphorus is strongly adsorbed by soil particles. This implies that movement of phosphorus to ground water from land-applied surface sources can be slow or unimportant. However, orthophosphate can rapidly move through sandy soils with low phosphorus sorption capabilities or through waterlogged soils where anoxic conditions are present (Sharpley and others, 1995). Mineral sources of phosphorus in the aquifer material can result in high phosphorus concentrations in ground water.

The amount of orthophosphate and organic particulate phosphorus being transported in streams may increase during winter. Leaves falling into streams and the death of algae and subsequent breakdown of the cells following a freeze will release phosphorus to the water, allowing for its movement downstream. Because metabolic activity of algae is lowest during winter, this bioavailable phosphorus may not be taken up by algae as rapidly as during the remainder of the year.

The amount of bioavailable phosphorus changes because of transformations between dissolved phosphorus and particulate phosphorus during transport. The amount of bioavailable phosphorus associated with deposited sediments generally is greater than that of suspended sediment (Sharpley and others, 1995). Once sediment settles to the bottom of a lake or stream, bioavailability will be increased by development of reducing conditions near the sediment-water interface.

POTENTIAL SOURCES OF PHOSPHORUS TO THE CARSON RIVER

Geological Sources and Forested Areas

The ultimate source of most of the naturally occurring phosphorus to the Carson River is the hundreds of thousands of acres of land in the headwaters of the Carson River where granitic and volcanic rocks form the bedrock. Igneous intrusive and volcanic rocks are the most common bedrock in the upper Carson River Basin (fig. 2) and pedogenic weathering of these rocks forms the soils which, in the end, contribute phosphorus to the river. Phosphorus is a common element in igneous rocks (Hem, 1985). The average phosphorus content of basalts and andesites (basic volcanic rocks; fig. 2) is 0.10–0.12 weight percent (as P) and for granodiorites (intrusive igneous rocks; fig. 2) is 0.09 percent (Hyndman, 1972). The average phosphorus content (expressed as P) of silicic igneous rocks is 0.07 percent (Huang, 1962). Although the average phosphorus contents of andesites and granodiorites are nearly the same, Susfalk (2000) observed that extractable phosphorus in granite derived soils from the eastern Sierra Nevada was up to three orders of magnitude greater than from andesite derived soils.

The most common mineral form of phosphorus is apatite (calcium phosphate with varying amounts of hydroxide, chloride, and fluoride ions). Apatite occurs as large crystals in pegmatites and as minute crystals in essentially all types of igneous rocks (Dietrich and Skinner, 1979).

In general, forested watersheds conserve phosphorus because of their low erodibility and, as a result, wooded areas are often used as buffer zones around streams to reduce input from agricultural land (Sharpley, 1995). Runoff from virgin forests carries little sediment and thus most of the transported phosphorus is in the dissolved form (Sharpley, 1995). However, phosphorus release from disturbed forests, such as in logged or burned areas, will be greater than in virgin forests because sediment runoff is greater. Much of the forest in the headwaters in the East and West Forks was logged heavily during the Comstock mining era (1862–80) to provide timber for railroads, mines, and mills (California Department of Water Resources, 1991). Numerous fires, burning hundreds to thousands of acres of forest, have occurred in the area during the last 50 years (Roland Shaw, U.S. Forest Service, oral commun., May 7, 2003).

Soils and Sediment

Sediment in runoff from nonpoint sources is estimated to be the source of 80 percent of total phosphorus in U.S. streams (Fennessey and Jarrett, 1994) and sediment potentially is a large source of phosphorus in the Carson River. In 1987, soil samples were collected at 372 sites within the Carson River Basin by the USGS as part of NAWQA. Field sampling, sample preparation, and analytical methods used for the soil samples are described in Tidball (1989) and Tidball and others (1991). Eighty-two of the 372 sampling sites are in the study area (fig. 10).

Total-phosphorus concentrations from the 82 sites in the study area ranged from 0.03 to 0.19 percent (from 300 to 1,900 mg/kg as P). The median phosphorus concentration was 0.08 percent and the 25th and 75th percentiles were 0.07 and 0.1 percent, respectively. These soil phosphorus concentrations are about the same as, or slightly less than, what is found in the soil-parent rock (see section Geological Sources and Forested Areas). The greatest number of samples with high phosphorus concentration are near the river, perhaps associated with cultivated or pasture land.

The banks and channels of long reaches of the Carson River are unstable and erosion is actively occurring (fig. 11). Low head dams in the river (fig. 7) are destroyed during spring runoff and need to be rebuilt annually using heavy equipment in the river. Bank and channel erosion and operation of heavy equipment in the river have the potential to contribute large amounts of phosphorus to the river. If the assumption is made that the median phosphorus concentration in soil from the basin (0.08 percent) is representative of the concentration in suspended sediment, the State water-quality standard of 0.1 mg/L would be exceeded when the suspended-sediment concentration exceeded 125 mg/L. The State water-quality standard probably will be exceeded at suspended-sediment concentrations even less than 125 mg/L because the phosphorus content of suspended sediment typically is greater than that of the soils from which it is derived (Sharpley and others, 1995). To put the value of 125 mg/L in perspective, the median suspended-sediment concentration in WY 1980 at Carson River near Carson City (site 34; fig. 5) was 234 mg/L and suspended-sediment concentrations in 10 of 16 samples collected that year exceeded 125 mg/L (Garcia and Carman, 1986).

Atmospheric Transfers

Wet and dry precipitation have the potential to contribute phosphorus directly to surface water. Wind erosion from cultivated land within and outside the basin can be a source of phosphorus to the atmosphere, where it can settle out in the dust or be rained out. In most cases, annual transport of phosphorus to lakes in precipitation is negligible compared with other nonpoint sources (Sharpley and others, 1995). In extremely oligotrophic lakes such as Lake Tahoe, atmospheric deposition may be an important source of phosphorus (Jassby and others, 1994). In the Carson River Basin, however, this is unlikely to be an important source of phosphorus.

Ground Water

Diffuse ground-water inflow to the river also may be a source of phosphorus to the river. Mauer (1986) found that during winter months the stream system in Carson Valley was gaining as a whole because of discharge from the ground water and excess precipitation. Orthophosphate concentrations in shallow ground water in Carson Valley typically are about 0.17 mg/L (see section Water Quality). Phosphorus concentrations were less than 0.1 mg/L for several hot springs near Genoa (Garside and Schilling, 1979). Analyses of phosphorus were not found for water from hot springs in the north part of Carson City and no information about ground-water quality was collected as part of this study.

Animal Grazing

Animal waste from fields near the Carson River and its tributaries may be an important source of phosphorus to surface waters. In Carson City and in Alpine and Douglas Counties in 1997 there were 10,552 beef cows and 807 milk cows (U.S. Department of Agriculture, 1997). Animal waste is rich in phosphorus; the average phosphorus content of manure from beef cattle is 5.6 g/kg and for dairy cattle is 11.7 g/kg (Sharpley, 1995, p. 8). Cattle with an average weight of 1,000 lbs excrete about 17 lbs of phosphorus per year, of which 60–80 percent may be in an inorganic form (Ryden and others, 1973). Given the average phosphorus excretion rate, the 11,359 beef and milk cattle in Carson City, and Douglas and Alpine Counties would

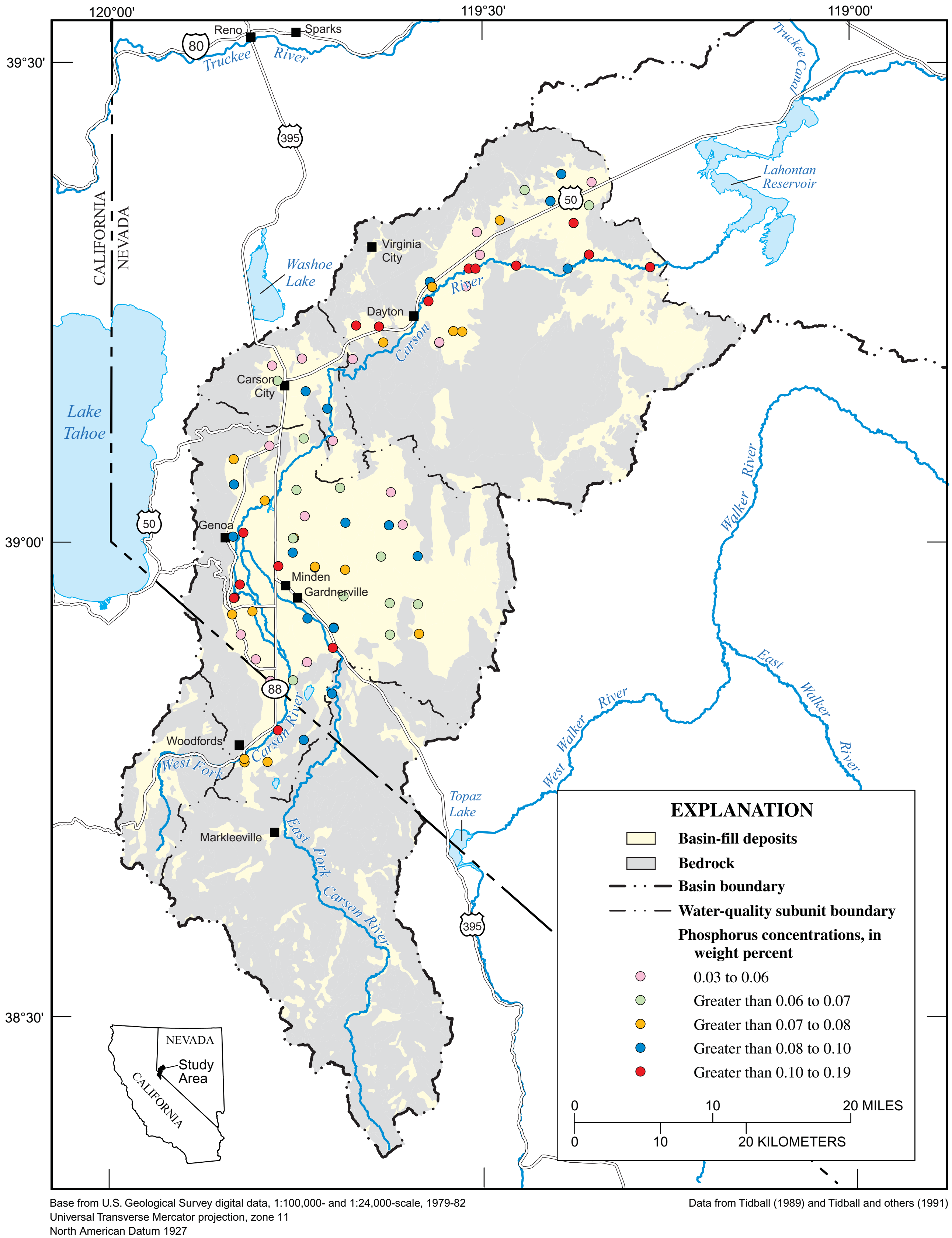

Figure 10. Phosphorus concentrations in soil samples collected in 1987 from the Carson River Basin upstream from Lahontan Reservoir.

Figure 11. Unstable reach along East Fork Carson River in Carson Valley. Such reaches can contribute large amounts of sediment to the river during high flow.

have excreted about 96.5 tons of phosphorus in 1997. This is a maximum value, however, because most of those cattle are not full time residents of the study area.

Phosphorus loading from large-animal waste to the Carson River depends on the season and the distance these animals are kept from lands where runoff can carry phosphorus into surface water. Movement of phosphorus is particularly great during winter months because of the combination of rainfall and snowmelt on frozen ground (Ryden and others, 1973). Management practices for controlling erosion and phosphorus loading to streams often involve fencing to limit cattle's access to the streams. Although allowing cattle access to streams may have positive effects such as controlling the invasive weed tall whitetop, it also has negative effects such as trampling of streambanks, which causes erosion and increased sediment and phosphorus loading to the streams. Grazing near streams (fig. 12) places waste in or very near the stream and slows development of plant-buffer zones that reduce runoff from fields where cattle graze.

Agriculture

The potential phosphorus loss from agricultural land is largely dependent on the relative importance of surface and subsurface runoff in the watershed (Sharpley and others, 1995). The amount of phosphorus carried in subsurface runoff to streams is lower than the amount carried in surface runoff because phosphorus from infiltrating water adsorbs to sediment particles as it percolates through the soil profile. Artificial drainage shortens soil-contact times and reduces removal of inorganic phosphorus from subsurface runoff.

Few studies exist on losses of phosphorus in runoff from arable land in the Carson River Basin. A study of agricultural-irrigation practices in Carson Valley found concentrations of total phosphorus and orthophosphate consistently greater in surface return flows than in applied irrigation waters (Miller and others, 1977, 1978, and 1984), and that the net loss of orthophosphate from fields through surface return flow ranged from 0.8 to 2.7 lb/acre/yr. One major factor affecting the

Figure 12. Cattle near tributary to Carson River in Carson Valley. Although cattle can control tall white top near streams, they also can contribute to nutrient loading in surface-water bodies.

amount of phosphorus in runoff from agricultural land is the time, amount, and intensity of rainfall (Ryden and others, 1973). Runoff from fields during high-intensity storms can mobilize soils and nutrients that would normally remain in place. Once the soils and nutrients have been moved from fields to ditches, they can be carried to the Carson River in less energetic flow regimes.

The amount of fertilizers used is very important in determining the amount of phosphorus in runoff from agricultural land. Compared with much of the United States, very little phosphate fertilizer is used in western Nevada (Alexander and Smith, 1990). In 1985, phosphate-application rates between 0.01 and 0.4 tons/acre were used, whereas rates in the central valley of California and much of the Midwest exceed 2.9 tons/acre (Battaglin and Goolsby, 1995).

Treated Sewage Effluent

Phosphorus concentrations are high in sewage because phosphorus is excreted from the body in waste and because phosphorus is used in household products, principally laundry and dishwashing detergents. The phosphorus content of treated effluent depends on the level of treatment, and unless sewage is specially treated to remove phosphorus, effluent can contain high phosphorus concentrations. Effluent from septic systems, for example, typically contains about 15 mg/L total phosphorus (Cantor and Knox, 1985).

Except for one site, since 1987 treated effluent has been able to reach the Carson River only indirectly. Virginia City discharges its treated effluent to Six-Mile Canyon; however, flow in the creek seldom reaches the Carson River. Carson City stores treated effluent in Brunswick Canyon Reservoir (fig. 13) during winter for use during the rest of the year for irrigation of parks, golf courses, and the Nevada State Prison Farm/Dairy. The reservoir leaks an average of 3,015 acre-ft/yr (Fellos, 2001) and springs have developed downgradient of the reservoir. The phosphorus load to the Carson River from this source is not known. The phosphorus content of springs near the Carson River below the reservoir is reported as <0.1 mg/L total phosphorus (Robert J. Saunders, Carson City Wastewater Reclamation Facility, NEV90008DMR Summary, written commun., Jan. 21, 2003).