RIPARIAN, STREAM AND FRESHWATER MARSH NATURAL COMMUNITIES

Natural Community Account

The Riparian, Stream and Freshwater Marsh Natural Community encompass all freshwater, aquatic, marsh and riparian habitat within Plan Area.

Associated Covered Species. Two of the 37 Covered Species (5%) and 3 of the 36 Special Management Species (8%) depend on riparian habitat for all or part of their life cycle. Another 3 Covered Species, and numerous not Covered Species, will benefit from the conservation strategies outlined below. Table 4-2 lists the animal species covered in this HCP that rely on riparian habitat and the general type of riparian vegetation they utilize most frequently.

Chris Lee

Background. This section defines the habitat types encompassed within the riparian, stream and freshwater marsh natural community. There are considerable amounts of overlap between each category and various classification schemes and definitions have been proposed; however, this section predominantly draws upon Cowardin et al. (1979).

Freshwater Aquatic Habitats. Aquatic habitats are characterized by the presence of standing or flowing water (Cowardin et al. 1979). This conservation strategy applies to two distinctly different aquatic systems, lotic and lentic: lotic systems include all moving water (i.e., streams or rivers) and lentic systems include stationary water (i.e., lakes, ponds, or pools).

Lotic systems within the Plan Areainclude ephemeral, intermittent and perennial streams and rivers.

Ephemeral streams or watercourses flow only in response to precipitation with flows ceasing a few days or weeks after the rains. Conversely, perennial streams have visible water flowing above the streambed year-round. Intermittent streams are those that fall in between; however, the nature of intermittency may be either spatial or temporal. Spatially intermittent streams have water that appears above the streambed in certain reaches whereas in other reaches, the water remains below the streambed. Temporally intermittent streams often flow for at least several months of the year. The source of much of this water is from the water table that rises above the surface of the streambed after being recharged by rainfall or snowmelt (Federal Register 2002).

Intermittent and ephemeral streams are often confused with one another. The critical difference is the connection that intermittent streams have with the groundwater table. Vegetation growing along intermittent streams often has access to the water table or at least a greater quantity of soil moisture due to the proximity of the water table. This creates distinct differences in the vegetation and hydrologic characteristics of intermittent versus ephemeral streams.

The aquatic component of lotic habitats is referred to, by Cowardin et al. 1979, as the riverine system. Riverine systems typically include all open water areas that occur within a defined channel of a stream as well as along perennial and intermittent stretches of streams and along some major dry washes. In some cases, riverine systems are bounded by palustrine wetlands that develop in the floodplain on either side of the defined channel.

The majority of the palustrine wetlands or floodplains that historically bordered the larger rivers in the County, such as the Sacramento River and adjacent sloughs and waterways, have been drained over the last century or more. This has resulted in the creation of many levees for water transport, flood protections, and agricultural development. The majority of aquatic habitat in the County is now in the form of these levees and manmade flood control channels. While in some respects, these manmade environments maintain certain characteristics of a riverine system (ex. they contain flowing water) the flow regimes and surrounding banks have been extensively modified. For example, these levees and channels contain the water flow required to support riparian vegetation, but generally lack this vegetation because they are frequently cleared for maintenance purposes. Vegetation along the banks generally consists of non-native grasses and forbs associated with upland situations with a few water tolerant species in the more saturated zones.

The delta marshlands is another example of an area that used to historically be wetlands that have been modified by levees and manmade flood control channels primarily for water transport, flood protections, and agricultural development. This area, which lies roughly to the north and northeast of Rio Vista, contains a part of the prominent Sacramento-San Joaquin River Delta (from here on referred to as the Delta). Prior to human development, this was a freshwater marshland dominated by river distributary channels and dense "tule" vegetation (Figure 3-3; Kuchler 1977). The dense vegetation, combined with slow baselevel (sea level) rise, led to the accumulation in parts of the area of thick peat deposits (only small parts of the Solano County Delta have peat soils), and in the predominantly mineral-rich lands that dominate the fringe of the Delta in Solano County.

The term lentic refers to a variety of habitats however, following classification used by Cowardin et al. 1979, these can be broadly divided into lacustrine and palustrine systems. Lacustrine systems refer to wetland and deepwater habitat, often greater than 20 acres in size and lacking trees, shrubs and persistent emergent vegetation (ex. lakes and reservoirs). Palustrine systems include all nontidal wetlands dominated by trees, shrubs, and persistent emergent vegetation (ex. Fresh water marshes) and/or are less than 20 acres in size and less than 2 meters deep at low water (ponds).

Freshwater marshes are the most common palustrine system within the Plan Area. Freshwater marsh habitat is unique in that it falls under the definitions of aquatic and riparian habitat (see definition below). Typical freshwater marsh habitat develops in shallow, standing or slow-moving water at the edge of ponds and streams, and at other sites that lack currents and are permanently flooded by fresh water. This plant community is typically dominated by up to 12-foot tall, perennial, emergent plants. Characteristic species include cattails (*Typha angustifolia, T. domingensis, T. latifolia*) and bulrushes (*Scirpus acutus, S. americanus, S. californicus*). Other smaller hydrophytic species are also present, including sedges (*Carex* spp.), flat-sedges (*Cyperus* spp.) bur-reed (*Sparganium eurycarpum*), and penny-wort (*Hydrocotyle verticillata*). This community corresponds to Holland's Coastal and Valley Freshwater Marsh, element code 52410 (Holland 1986).

Riparian. Riparian habitat is broadly defined as the transitional zone between aquatic and terrestrial (or upland) environments (ITFMWQ 1996). Therefore, riparian vegetation encompasses a wide variety of vegetation community types that may occur along water bodies such as intermittent and perennial streams, lakes, ponds, and floodplains and may also occur in areas, such as seeps and springs, where the water table is sufficiently high to provide water to the roots of plants nearly year round. Given this broad category, riparian vegetation varies widely in plant species composition and structure, depending on the hydrology, flooding regime, climate, soil, light and level of natural disturbance and human disturbance (Keddy 2000). As to be expected from the definition, riparian systems often exhibit characteristics of both aquatic and terrestrial environments; but they are not as dry as upland environments and they are not quite as wet as aquatic systems. This mixture of upland and aquatic characters make riparian systems highly diverse and productive environments. In Solano County, riparian habitat is generally comprised of riparian woodland and riparian scrub vegetation.

Riparian Woodland. The dominant trees in riparian woodland are most commonly winter-deciduous, broadleaved trees, up to 60 feet in height, with a canopy cover ranging from relatively open to very dense. "True" riparian species, *i.e*., species that are dependent on available water year round, are found along major rivers and streams and other freshwater features. Cottonwoods (*Populus* spp.) and willows (*Salix* spp.), mixed with bigleaf maple (*Acer macrophyllum*), Oregon ash (*Fraxinus latifolia*), box elder (*Acer negundo*), and California sycamore (*Platanus racemosa*) are the most commonly occurring "true" riparian trees in central California. Valley oak (*Quercus lobata*) is common in riparian areas in the Central Valley as are various species of walnut (*Juglans californica* ssp. *hindsii*; *J. nigra; J. regia*). Other trees, including coast live oak (*Quercus agrifolia*) and California bay (*Umbellularia californica*), are components of riparian vegetation in woodland/forest areas and also grow in less wet environments. Riparian woodland commonly has a shrubby understory (see *Scrub* below). Equivalent communities as described by Holland might include: Great Valley Cottonwood Riparian Forest (element code 61410), Great Valley Mixed Riparian Forest (element code 61420), Great Valley Valley Oak Riparian Forest (element code 61430), White Alder Riparian Forest (61510), and Central Coast Live Oak Riparian Forest (element code 61220; Holland 1986).

Riparian Scrub. An open to impenetrable scrub is almost always a component of riparian vegetation. Shrub species vary depending on the geographical location; broad-leaved, deciduous riparian thickets are usually dominated by any of several species of willow (*Salix* spp.), especially arroyo willow, forming dense thickets within the riparian corridor. Other shrubby species that may occur are blue elderberry (*Sambucus mexicana*), California blackberry (*Rubus ursinus*), Himalayan blackberry (*R. discolor*), California rose (*Rosa californica*), poison oak (*Toxicodendron diversilobum*), and California grape (*Vitis californica*). The herbaceous layer, if present, is a mix of grasses and forbs, commonly including Italian wildrye, and mugwort (*Artemisia douglasiana*). This community corresponds to Holland's Central Coast Riparian Scrub, element code 63200 (Holland 1986).

Riparian habitat functions as an important corridor between coastal (or bayshore) marsh habitats, floodplains, upland grasslands and oak woodlands. It provides a diversity of wildlife with food, cover, and breeding sites in close proximity to water. Overall, riparian or streamside vegetation provides important habitat for over 225 species of fish, amphibians, reptiles, birds, and mammals in California (RHJV 2000). Riparian habitats are considered to be particularly valuable for neo-tropical migratory songbirds, which have declined in recent decades. The ecological processes that shape the riparian zone and its ecological functions are discussed in more detail in the narrative conceptual model below.

Distribution within the Plan Area. To understand the distribution of the diversity of riparian and freshwater marsh habitat within the County an understanding of landscape level geological and hydrological processes are necessary. Referring back to the geology and hydrology overview detailed in the biological resources section (Section 3.0), Solano County lies at the intersection of numerous geographical and geological provinces that has resulted in the formation of unique biological and ecological conditions (Figure 3-2). The Coast Range, occupying the west and southwestern regions, possess segments of the sedimentary and volcanic rocks characteristic of the eastern edge of the central Coast Ranges. The northeastern portion of the County consists of alluvial fill derived from streams within the Inner Coast Range. Finally, the southeastern portion of the County is part of the Sacramento-San Joaquin Delta while the south central portion consists of marshland adjacent to the Suisun Bay and the Sacramento/San Francisco Bay interface. The latter portion, Suisun Bay marshlands, will be discussed in the coastal marsh section.

Solano County is unique in that it encompasses all three broad geomorphologic zones of large river basins: erosional, transfer, and depositional (Schumm 1977). In general, water in the County drains in a southeast direction. The flashier tributaries of the higher rainfall Inner Coast Range area carry high nutrient rich sediment into the seasonal wetlands (now largely agricultural lands) of the valley eventually draining into the Sacramento – San Joaquin Delta - San Francisco Estuary.

The transfer and, to a lesser degree, the depositional zones have been the most affected by human disturbance. The majority of urban development occurs on or downslope of the alluvial fans of the Vaca Mountains and on or upslope of the Delta and Suisun marshlands. This has necessitated the modification or development of drainage channels that are capable of transmitting the runoff from the higher rainfall regions of the Inner Coast Range through the urban and transportation corridors and across the valley floor communities (agricultural land, valley floor grassland and vernal pool natural communities) to the sloughs and estuary.

Riparian areas in Solano County have been severely degraded as a result of residential, commercial, and agricultural development. Although the structure (*i.e*., the vertical stratification of the riparian vegetation) has been maintained along some of the major streams in the County, the width of the “corridors” has been greatly reduced due to human activities. Riparian corridors are now commonly only as wide as the diameter of one tree’s canopy. In addition, sections of most major streams on the valley floor have been channelized and the natural riparian vegetation has been removed.

Well-developed riparian plant communities now primarily occur along the banks of small portions of the major creeks such as Putah Creek, Alamo Creek, Ulatis Creek, Dan Wilson Creek, Green Valley Creek, Ledgewood Creek, and Suisun Creek. In those remaining well developed riparian areas the tree canopy is dominated by Fremont’s cottonwood (*Populus fremontii*) and willows, including red willow (*Salix laevigata*), Pacific willow (*S. lucida* ssp. *lasiandra*), arroyo willow (*S. lasiolepis*), and sandbar willow (*S. exigua*), but other trees associated with riparian areas are also present. Scattered stands of willows and riparian shrubs are present along minor streams and drainages.

Narrative Conceptual Model. The narrative conceptual model for this natural community focuses primarily on stream and riparian habitat because they comprise the largest portion of freshwater aquatic habitat within the Plan Area. This section represents a general conceptual model, modified from Scott et al. (2004), describing the structural components and functional relationships that characterize riparian ecosystems within Solano County. The character and value of riparian zones arise as a result of an infinite number of complex interactions among abiotic (primarily geomorphology and hydrology) and biotic features (Kauffman et al. 1997). The following narrative conceptual model is divided into four main sections, the major abiotic drivers of ecosystem change and variability, major functional groups and ecological processes, key land use practices affecting the integrity of aquatic and riparian ecosystems within the Plan Areaand the consequences these land use practices have on the natural community.

Abiotic Drivers of Ecosystem Change and Variability. The major drivers of ecosystem change and variability in riparian ecosystems are climate, upland watershed conditions, fluvial geomorphic processes and streamflow regimes (Scott et al. 2004), each of which are briefly reviewed in the sections below.

Climate. Precipitation is the most important climatic factor shaping riparian ecosystems, particularly in Mediterranean climates characteristic of wet winters and dry summers. Inputs from precipitation predominantly drive fluvial geomorphic processes and support water-limited ecological processes such as primary production, nutrient cycling, and plant reproduction (Noy-Meir 1973, Comstock and Ehleringer 1992, Whitford 2002). For streams in Solano County, the timing and duration of precipitation drives the streamflow regime, particularly in the flashier headwater streams within the Inner Coast Range. The timing of precipitation is an important attribute because it strongly controls the timing of peak flow events. The timing of peak flows can significantly affect species composition (Barrat-Segretain and Amoros 1995) and the invasion of aquatic ecosystems by non native species (Fausch et al. 2001). Because flooding is the main disturbance in riparian communities, and the frequency, timing and duration of these events is predominantly driven by precipitation, the seasonality of precipitation is a major determinant of riparian ecosystem dominance by particular plants and animals (Comstock and Ehleringer 1992).

The climate of Solano County varies spatially depending mainly on the effects of topography on rainfall distribution. The eastern parts of the County (Sacramento Valley/Sacramento and Suisun Bay watersheds) are classified as having a Mediterranean/hot summer climate while the western portions (Napa River/San Pablo Bay watersheds) have a Mediterranean/cool summer climate (CDFG 2003). The average annual precipitation in the Central Valley lowland areas of the County is typically between 15 and 25 inches, with higher rainfall amounts reaching 25 to 40 inches in the western hills (CDFG 2003).

Upland Watershed Conditions. Upland watershed characteristics have a strong influence on riparian and aquatic ecosystems because the form of channels and floodplains, and many associated attributes of riparian ecosystems, are determined by the flux of water and sediment that passes through the valleys (Naiman et al. 2005, Scott et al. 2004). Water and sediment are ultimately derived from the upland watershed. The amount of water that reaches a stream via direct runoff is a function of the infiltration and interception capacities of the watershed (Mount 1995, Kauffman et al. 1997).

Infiltration capacities, the maximum rate at which soil or rock is capable of absorbing water, varies spatially on a large scale based on regional geology and can vary locally based on slope steepness and soil texture (Naiman et al. 2005). Similarly, the interception capacities, the maximum volume of precipitation the canopy and litter on a watershed can store, significantly affects the amount of runoff that reaches a stream. By definition, the interception capacity is a function of the vegetation in the upland watershed. For example, where grasses and crops are the dominant vegetation, interception typically removes 10 to 20 percent of precipitation, where as, a forest canopy may intercept up to 50 percent of direct precipitation (Mikkelsen and Vesho 2000).

By determining the amount of water that reaches a stream via direct runoff, the physical and biological characteristics of a watershed ultimately determine a streams hydrograph. The flood hydrograph represents the integrated effects of basin area, drainage density (average length of streams per unit area), channel geometry (basin morphometry), soils, and adjacent land use (i.e. upland watershed condition) (Ritter et al. 2002, Naiman et al. 2005). Catchment basins with high rates of interception and infiltration yield low density drainage networks with, high base flows (i.e. larger inputs from groundwater discharge) and lower magnitude peak floods. In contrast, catchment basins with low rates of interception and infiltration (i.e. large areas of impermeable surfaces or sparse vegetation) will yield high density drainage networks that will efficiently carry away the abundant runoff with low base flows and high peak discharges (i.e. several small, ephemeral, flashy streams) (Ritter et al. 2002).

Fluvial geomorphic processes. The most basic geomorphic processes within river basins are erosion, transport, and deposition (Naiman et al. 2005). These processes operate across all temporal and spatial scales, but vary in relative importance depending on the location within a drainage network. For larger river basins, Schumm (1977) defines, three broad geomorphologic zones: erosional zone, transfer zone, and depositional zone. The erosional zone includes headwater regions of the river basin where erosion dominates over deposition. The transfer zone extends across lowland regions linking uplands to the sea. In this area, processes of erosion and deposition maintain a dynamic equilibrium such that over long time scales, the net geomorphologic effect is simply to transfer sediments (Naiman et al. 2005). This is typically the most dynamic zone, corresponding to meandering river reaches that cut back and forth across broad floodplains. The depositional zone includes deltaic portions of rivers reaching the coastline and alluvial fan regions.

Solano County is unique in that it encompasses all three broad geomorphologic zones within two large drainage provinces, the Sacramento River/Delta and the San Francisco Bay Drainage Province. In general, water in the County drains in a southeast direction. The flashier tributaries of the higher rainfall Inner Coast Range area (corresponding to the erosional zone) carry high nutrient rich sediment into the seasonal wetlands (now largely agricultural lands) of the valley (transfer zone) eventually draining into the Sacramento – San Joaquin Delta - San Francisco Estuary (depositional zone).

At a smaller scale, site-specific rates of erosion, deposition, and lateral channel migration, shape the microtopography of channels; thus, substantially influencing the composition and demography of the vegetative communities (Naiman and Décamps 1997). Most rivers and streams alternate between shallow, high velocity, mixed cobble substrate areas (riffles) and deeper, slower velocity, finer substrate areas (pools). Riffles are generally formed by the deposition of gravel bars alternating from one side of a channel to the other. Pools are formed by erosion and scouring of the channel, usually during spring runoff (Naimen and Décamps 1997). The heterogeneity of riverine ecosystems can have strong affects on the aquatic community via direct and indirect pathways (Power 1992, 2001). Habitat specific substrate preferences are common among biota. For example, steelhead requires shallow riffles for spawning and deep pools with well-developed cover for rearing (Leidy 2000).

Soils. Riparian soils are typically derived from different parent material than adjacent upland soils. While the parent material of upland soils is generally the rock that underlies the site, the mineral component of riparian soils originates as stream-deposited sediment. Thus, riparian soils are potentially more heterogeneous in mineral character than their upland counterparts (Mikkelsen and Vesho 2000). During floods, riparian areas are flushed with pulses of nutrient rich sediment and organic litter from the uplands and upstream riparian areas. This periodic nutrient pulse and disturbance into the environment increases the soils heterogeneity and creates bare soil surface (Mikkelsen and Vesho 2000). The presence of bare soil surface increases plant diversity within riparian zones by creating hospitable microenvironments for seed germination (Bilby 1988).

Hydrology. Hydrology is the most important factor shaping rivers and riparian environments. Water carries important solutes and sediments through the system and is directly responsible for the creation, structure, maintenance and destruction of riparian environments (Naiman et al. 2005). This section briefly touches on the importance and complexity of how water flows through freshwater systems. The major hydrological features of riparian ecosystems are the streamflow regime, including the frequency, magnitude, and temporal distribution of the streamflow (including peak and low flows), subsurface hydrology (i.e. groundwater), and water quality (Kauffman et al. 1997).

Streamflow Regime. The streamflow regime, also referred to as the hydrograph characteristics (timing, frequency, duration and magnitude), of a stream is driven by complex interactions between precipitation, upland watershed conditions, ground water, fluvial geomorphic processes, soils and vegetation (Kauffman et al. 1997). Hydrographs reveal the seasonal and inter-annual variability in stream and river flows, and they take on characteristic forms depending on the size and shape of the catchment and the local climate (Naimen et al. 2005). Peaks on a hydrograph correspond to flood events that may scour riverbanks or transport sediments onto floodplains.

Small rivers or streams are typically sensitive to individual precipitation events and have dynamic hydrographs characterized by a large number of peaks (floods). Several streams within Solano County are either ephemeral or intermittent and can be without surface flow for considerable periods. The hydrograph of these streams are considerably variable, with peaks highly correlated with storm events. In perennial rivers, floods may be distributed throughout the year but are also usually concentrated in the rainy season. Large rivers, such as the Sacramento River, and their riparian environments are less sensitive to individual precipitation events because the scale of the basin surpasses the scale of the storm and because the flow of the river integrates the flow of a large number of upstream tributaries, some of which may be in flood while others are not.

Annual and inter-annual variation in streamflow is central in structuring the physical environment of riverine ecosystems and in determining community composition of riverine and riparian environments (Poff et al. 1997). This annual and inter-annual variation in streamflow exist on a continuum from high-power, low-frequency floods to low-power, high-frequency. The low-power floods that occur annually determine short-term ecological patterns such as seed germination and seedling survival (Baker 1990, Langlade and Decamps 1994). Medium-power, intermediate-frequency floods determine patterns of ecosystem structure with lifetimes between tens to hundreds of years (e.g. tree community zonation) (Baker 1990, Harris 1987, Hupp and Osterkamp 1985). Finally, infrequent, large magnitude floods have the potential to significantly redistribute sediment in channels and floodplains, creating disturbance patches and topographic diversity through large-scale erosion and deposition of sediments that persist for hundreds to thousands of years (e.g. oxbow lakes) (Naimen and Decamps 1997). Thus disturbances and environmental conditions created by flood events of various magnitudes and frequencies influence species abundance by determining the spatial and temporal occurrence of suitable habitat patches (Poff and Allan 1995). Furthermore, several native species have adapted to episodic floods and droughts and now require such conditions in order to persist (e.g. some species of fish and plants; Meffe 1984).

Alluvial Groundwater. Surface water and groundwater of river corridors are linked, forming a single hydrologic system that is connected to the regional groundwater system (Naiman et al. 2005). Water, including the nutrients and sediment it may be carrying, is continually exchanged among the river, riparian aquifer, and regional aquifer. The rate and magnitude of this exchange depends on local climate, valley form, discharge, riverbed, riparian substrate material, vegetation, channel configuration, microtopography and stream gradient (Naiman et al. 2005).

A characteristic trait of riparian vegetation is the nearly year-round access to water (Ward 1989, Amoros and Bornette 2002). In perennial streams, the base flow or the sustained flow during the dry season is supported by groundwater seepage into the channel. Intermittent streams also have a close connection with the groundwater table. Vegetation growing along intermittent streams often has access to the water table or at least a greater quantity of soil moisture due to the proximity of the water table. In fact studies have demonstrated that alluvial groundwater is the principle source of water for riparian trees (Dawson and Ehleringer 1991, Bush et al. 1992). Thus, subsurface flows associated with shallow alluvial aquifers is essential to the persistence of most riparian plant species. In addition, access and input from groundwater may ultimately influence the establishment and survival of existing riparian and wetland ecosystems (Woessner 2000) and even relatively modest fluctuations or declines (1.5-3 meters) may induce lethal moisture stress (Scott et al. 1999).

Biotic Functional Groups. Chapin et al. (1996) identified biotic functional groups as groups of species that have similar effects on ecosystem processes. Following the conceptual model format developed for riparian ecosystems of the Colorado Plateau (Scott et al. 2004), the biotic functional groups include soil biota, vegetation, invertebrates and vertebrates. In addition to live plants, the vegetation component also includes dead materials such as snags, fallen logs, and fine organic debris (litter).

Soil Biota. Soil biota represents a broadly defined functional group comprised of a diverse array of organisms that are important contributors to the structure and functioning of riparian ecosystems (Mikkelsen and Vesho 2000). Soil biota include microfloral components (bacteria, algae, and fungi), microfaunal components (nematodes, microarthropods, and protozoans), and macrofaunal components (earthworms, ants, termites, and larval stages of several insect families) (Mikkelsen and Vesho 2000). Most below ground ecosystem processes, nutrient cycling, water infiltration and storage, soil aggregate stability, and water and nutrient uptake by plants are mediated by soil organisms (Mikkelsen and Vesho 2000). However, the functioning of these belowground processes is also dependent on the amounts and types of organic-matter inputs from vegetation and on soil conditions such as moisture availability, soil structure, soil aeration, and soil temperature (Mikkelsen and Vesho 2000). For example, riparian zones are known for their ability to retain large amounts of Nitrogen (Groffman et al.1992), but denitrification can only occur under anoxic conditions in the presence of denitrifying bacteria. Denitrifiers are heterotrophic, facultative, anaerobic bacteria that use nitrate as an electron acceptor only when oxygen is absent (Hill 1996).

Litter decomposition rates are generally higher in riparian areas relative to drier upland regions (Mikkelsen and Vesho 2000). Litter decomposition is associated with invertebrate activity, which is second to moisture as the most important factor controlling decomposition in riparian soils (Mikkelsen and Vesho 2000). Soil animals, particularly macroinvertebrates, are generally more abundant and diverse in riparian soils versus upland soils (Xiong and Nilsson 1997). The combination of the right environmental conditions coupled with higher densities of microorganisms and soil invertebrates, yields faster decomposition rates and thus, faster rates of mineral cycling as well as higher proportions of bare soil. Both of which favor higher rates of primary productivity and mediate plant colonization (Xiong and Nilsson 1997). Overall, the significance of soil biota for ecosystem processes (particularly nutrient cycling) in riparian ecosystems has long been acknowledged, but recent research has reemphasized the importance and taxonomic diversity of this broad functional group (Mikkelsen and Vesho 2000).

Vegetation. The riparian zone is typically characterized by the vegetation which is generally recognized as the dominant functional type in riparian ecosystems (Scott et al. 2004). Riparian plant communities, and the individual plants within the community, provide a variety of ecologically beneficial functions and play important roles in structuring streamflow regimes, geomorphic processes, soils, food webs and habitat for fish and wildlife (Kauffman et al. 1997).

Riparian vegetation increases the stability of stream banks and floodplain areas by holding soils in place. Large woody debris and standing trees create barriers to the movement of sediment and litter material (Mikkelsen and Vesho 2000). Woody debris held 49% of the total amount of sediment stored in seven streams in Idaho, while the removal of woody debris from a stream in New Hampshire resulted in a seven-fold increase in particulate matter lost to the stream (Bilby 1988). The impediment of high streamflow by riparian vegetation results in nutrient and sediment deposition in upland areas adjacent to the stream channel. These depositional events are crucial components to riparian plant reproduction and help to reduce the magnitude of peak flows. In addition, when flows scour around roots or when trees fall into the channel, this creates pool and riffle areas, which, in turn, provide refugia for aquatic organisms during these scouring events. The increased height and stability of streambank terraces, increased nutrient deposition, and increased channel complexity provided by riparian vegetation improves the quality of aquatic and terrestrial habitat for all aquatic and riparian organisms.

Riparian vegetation provides for many of the fundamental components of upland habitats used by a variety of wildlife species. These components include a variety of tree, shrub, and grass/forb species that provide habitat complexity and vertical structural diversity, create a variety of nesting and foraging habitats, and provide excellent cover for a variety of species because of the vegetative complexity and density and the close proximity of water (Scott et al. 2004). For aquatic organisms, the vegetation surrounding the banks reduces water temperatures by shading. The regulation of water temperature by riparian vegetation provides optimal conditions for native fish such as steelhead (*Oncorhynchus mykiss*), who's optimal water temperatures range from 46-52 degrees Fahrenheit for adult migration, 39-52 degrees Fahrenheit for spawning, 48-52 degrees Fahrenheit for incubation and emergence, 45-60 degrees Fahrenheit for fry and juvenile rearing (Bovee 1978, Reiser and Bjornn 1979, Bell 1986). In addition to structural complexity, riparian vegetation is an important food resource for both aquatic and terrestrial food webs. Detrital input (i.e. leaf litter) provides food resources to a suite of microorganisms and invertebrates, which, in turn, become food resources to fish and wildlife.

Invertebrates. Streams and adjacent riparian zones are ecosystems that are closely linked and ecologists have long since recognized the exchange and flow of energy between these two habitats (Power et al. 2004). However, recent research has focused on the roles of invertebrates as prey subsidies stabilizing and increasing the diversity of both aquatic and riparian habitats (Baxter et al. 2005). These two sources include terrestrial invertebrates that fall into streams, feeding fish and the reciprocal flow of adult aquatic insects that emerge and feed riparian consumers like birds, bats and spiders (Baxter et al. 2005). Within both habitats, these subsidies have effects at individual, population, community, and ecosystem levels.

In temperate streams, terrestrial invertebrates subsidies to aquatic systems are dominated by larvae and adults of the orders Hymenoptera, Diptera, Coleoptera, Lepidoptera, Homoptera, Orthoptera, Hemiptera and Arachnida, as well as Collembola, Oligochaeta, and Gastropoda (Mason and MacDonald 1982, Cloe and Garman 1996, Wipfli 1997). The consumption of fallen terrestrial invertebrates by fish has been well documented, especially among salmonids (Cada et al. 1987, Wipfli, 1997), but has also been documented in other families (Baxter et al. 2005). Inputs of terrestrial invertebrates during summer months, has been calculated to be as high as 111 individuals m^{-2} day^{-1} and 223 mg m^{-2} day^{-1} (Cloe and Garman, 1996), and in small headwater streams, inputs of terrestrial invertebrates may be equal to the production of benthic invertebrates (Wipfli, 1997, Baxter et al. 2005). In streams where terrestrial invertebrate input is high, studies have found that this subsidy can make up more than 50% of a fishes annual diet and energy budget (Wipfli 1997, Nakano et al. 1999, Nakano and Murakami 2001). This flux of terrestrial invertebrates to streams is highly seasonal, and in temperate zones peaks occur during late spring, summer, or early autumn (Mason and MacDonald 1982, Cloe and Garman, 1996, Nakano and Murakami, 2001). Fluxes are also variable in time and space depending on the attributes of the riparian zone (Baxter et al. 2005).

Researchers studying riparian food webs are focusing on the role of aquatic insect emergence and finding that this aquatic prey subsidy to terrestrial systems is just as important to a wide range of riparian predators (e.g. birds, bats, lizards, spiders etc.) as terrestrial invertebrates are to stream fish (Baxter et al. 2005). In a headwater forest stream in Hokkaido, Japan, aquatic insect emergence provided 26% of the annual energy budget for the entire bird assemblage of 10 species (Nakano and Murakami 2001). Likewise, Sanzone et al. (2003) found that web-weaving spiders along Sycamore Creek, Arizona derived 100% of their carbon from in-stream sources. Power and Rainey (2000) also reported that individuals of a sheetweaving spider (Linyphiidae) derived at least half of their carbon from emergent insects, even when located hundreds of meters from a northern California river.

Fluxes in aquatic insect emergence can be large. Jackson and Fisher (1986) found that aquatic insect emergence in streams averaged about 10,000–20,000 insects m^{-2} $year^{-1}$ and about 2,000–7,000 mg per square meter per year, in dry mass, based on 20 independent studies. In total community emergence in temperate zones peaked in early summer and declined precipitously by late summer (Sabo and Power 2002). This flux of emergent insects also varies spatially, and is likely related to the insect species emerging and particular characteristics of river and riparian habitat (Baxter et al. 2005). In temperate zones, adult Diptera often make up 60–99% of emergent biomass, the rest being primarily adult Ephemeroptera, Plecoptera, Trichoptera, and Odonata (Jackson and Fisher 1986). Power and Rainey (2000) and Power et al. (2004) proposed that any habitat feature that retains or provides predation refuge for aquatic insects, such as floating algal mats, could enhance local emergence. Following emergence, the number of adult insects penetrating riparian zones typically declines exponentially with distance from the stream edge, and often reaches low levels within 10–25 m (Power and Rainey 2000, Power et al. 2004). However, differences in adult behavior among insect taxa (e.g. swarming near the water surface versus aggregation at upslope positions within or above the canopy) and their response to environmental conditions (e.g. forest or hill slope structure, weather) may mediate lateral flux of this subsidy into the catchment (Power and Rainey 2000, Power et al. 2004).

Wildlife. Riparian habitat provides a diversity of wildlife with valuable nesting, cover, foraging, and movement habitat all within close proximity to water (RHJV 2000). Overall, riparian vegetation provides important habitat for over 225 species of fish, amphibians, reptiles, birds, and mammals in California (RHJV 2000). The stream environment has many habitat types that appeal to a variety of fish species such as deep pools for resting, shallow riffles for foraging, and lagoon and estuary areas for nursery habitat. Steelhead, a federally threatened species and a covered species under the HCP, use shallow riffle habitat for spawning and deep pools with well-developed cover for rearing (Leidy 2000). Chinook salmon tend to spawn in the mainstems of rivers (or larger tributaries) in areas of gravel and cobble substrate. Other common native freshwater fish species in Solano County include hardheads (*Mylopharodon cenocephalus*), Sacramento blackfish (*Orthodon microlepidotus*) Sacramento pikeminow (*Ptychocheilus grandis*), Sacramento suckers (*Catostormus occidentalis*), California roach (*Lavinia symmetricus*), three spine stickleback (*Gasterosteus aculeatus*) and riffle sculpin (*Cottus gulosus*). In northern California, approximately 50 percent of both reptiles and amphibians prefer riparian or aquatic habitats (Raedeke et al. 1988). The foothill yellow-legged frog, a covered species under the Plan, is rarely encountered far from water and probably spends most of its time in or near streams at all seasons. Riparian zones have been identified as the most important habitats for landbird species in California (RHJV 2000). The structural complexity and species diversity of riparian corridors provides habitat required for nesting, sheltering, and foraging. Insect production is high within the riparian corridor, providing a rich food source for insectivores such as vireos, warblers, swallows, wrens, and flycatchers. Riparian forest trees such as box elder, big-leaf maple, and birch are highly productive, producing food resources for seed feeders such as grosbeak, finches, and sparrows. Migrating species such as the warbling vireo, a neo-tropic species that travels from Central America to nesting areas along California's Central Coast, use riparian corridors to rest and feed during their annual migration. Riparian habitats are considered to be particularly valuable for neo-tropical migratory songbirds, which have declined in recent decades. The combination of cover, water and food resources makes riparian habitat desirable for several species of mammal. In fact, approximately 25 percent of mammals in California are limited to or largely dependent upon riparian and other wetland communities (Williams and Kilburn 1984). These include species that use multiple habitat types such as ringtails, common muskrats, raccoons, mule deer, coyotes, and bobcats. Bats have been observed to hyper-aggregate over riparian areas following the resource flux produced from emerging aquatic insects.

Land Use Practices. The land use practices or primary pressures that directly affect Riparian, Stream and Freshwater Marsh communities in Solano County are listed below. Similar to the conceptual models for Valley Floor Grassland and Vernal Pools and the Inner Coast Range natural communities, the effects of the land use practices and the consequences of theses land use practices are summarized.

Urbanization. Urbanization alters the natural infiltration capability of the land and generates a host of pollutants that are associated with the activities of dense populations, thus causing an increase in storm water runoff volumes and pollutant loadings in storm water discharged to receiving water bodies. Urban development increases the amount of impervious surface in a watershed as farmland, forests, and meadowlands are converted into buildings with rooftops, driveways, sidewalks, roads, and parking lots with virtually no ability to absorb stormwater. Stormwater runoff washes over these impervious areas, picking up pollutants along the way while gaining speed and volume because of lack of dispersal and infiltration into the ground. The resulting storm water flows are higher in volume, pollutants, and temperature than the flows in less impervious areas, which have more natural vegetation and soil to filter the runoff (U.S. EPA 2000).

These changes in the infiltration capacity due to increases in impervious surfaces within a watershed can significantly affect the biotic composition of aquatic community. As little as 3% impervious cover in a contributing area has been shown to negatively impact the ecological integrity of aquatic ecosystems (May et al. 1997) and serious declines in biotic integrity have been observed when urban land exceeds 7% of total watershed area (Synder et al. 2003). In the watersheds of Puget Sound, Washington, amphibian species richness was significantly lower in watersheds where more than 40% of the land area was developed (Richter and Azous 1995, Richter and Azous 1997).

In Solano County, the location of development has necessitated the modification or development of drainage channels that are capable of transmission of runoff from the higher rainfall Vaca Mountains and uplands through the urban and transportation corridors and across the valley floor (through agricultural lands, grasslands and vernal pool habitat) to the sloughs and estuary (Noss et al. 2002). This has greatly altered the geomorphology of streams and surrounding riparian habitat.

Intensive Agriculture (Croplands). Water use and the draining of marshland for agricultural purposes in the County over the last century or more have resulted in the creation of many channelized and leveed water courses. While these channels contain the water flow that is required to support riparian vegetation, they are typically cleared of vegetation for maintenance purposes. The construction of levees and diversion of flow for crop production and the draining of regional aquifers are the largest impacts of agriculture on Riparian and freshwater systems. In addition to water diversion, chemical contaminants from agriculture significantly affect water quality.

Livestock Grazing. Researchers estimate that 80 percent of the damage incurred by streams and riparian systems in the western portion of the U.S is from grazing livestock (Agouridis et al. 2005). Because of the presence of water and shade, riparian areas are often subject to more intense grazing pressure than adjacent uplands (Fleischner 1994). Stream and riparian damage resulting from livestock grazing includes alterations in watershed hydrology, changes to stream channel morphology, soil compaction and erosion, riparian vegetation destruction, and water quality impairments (Belsky et al., 1999, Kauffman and Kruger 1984). For example, livestock access to Barker Slough in Solano County is considered a major source of channel erosion, increasing the amount of suspended sediments in the water column, and nitrogen both of which degrade the water quality of the slough (which is a major water source for the North Bay Aqueduct) (Singer and Eshel 2000). Damages from livestock have been linked to reduced abundance and diversity of riparian-dependent species, including birds, fish and amphibians (Scott et al. 2003, Suttle et al. 2004, Jansen and Healley 2003).

Recreation. The inappropriate use of designated open spaces, for example off-road vehicle use and vandalism, by recreation enthusiasts can threaten the ecological functions of riparian and fresh water ecosystems. Off-road vehicle use, bicycling and even hiking in inappropriate areas can lead to excess erosion, trampling, and soil compaction. This may, in turn affect, species composition in riparian zones via decreased sea germination and water quality.

Consequences of Land Use Practices. The consequences of the above land use practices (i.e. secondary pressures) on Riparian, Stream and Freshwater Marsh communities in Solano County are:

Habitat Loss, Alteration and Fragmentation. Riparian areas in Solano County have been severely degraded as a result of residential, commercial, and agricultural development. Although the structure (*i.e*., the vertical stratification of the riparian vegetation) has been maintained along some of the major streams in the County, the width of the "corridors" has been greatly reduced due to human activities. Riparian corridors are now commonly only as wide as the diameter of one tree's canopy. In addition, sections of most major streams have been channelized and the natural riparian vegetation has been completely removed. Many of the "riparian" habitats within and near cities and in agricultural portions of the County are very narrow and the vegetation is strongly influenced by non-native trees and shrubs (Noss et al. 2002).

Urban development and agriculture can severely impact stream hydrology. These include impacts to the flood discharge peaks and the lag time from peak rain mass to peak runoff, increases in the total discharge volume, changes in the seasonal distribution of runoff, and changes to the extent of the inundation of the floodplain during floods (Noss et al. 2002). Changes in seasonal hydrology as well as changes in stream cross-sectional geometry to accommodate a new discharge regime can influence the species composition and/ or stability of the banks and near-bank riparian vegetation.

Bank erosion can be a significant portion of the total sediment supply to Bay Area streams (Noss et al. 2002). If increased flows yields increased bed erosion, this may result in a net lowering of the channel bed and thus, intersection of groundwater at a lower level. This may cause the water table to lower. The direct withdrawal of groundwater and stream water for crop irrigation, reservoir management, and changes in infiltration associated with changes in vegetation cover and urban impervious surfaces may also lower the groundwater and alter the hydrology within a watershed (Noss et al. 2002).

Water Diversion and Channelization. Channelization and levees for water diversion and flood control both on-site and upstream destroy wetland and riparian habitat, restrict river flows, decrease water elevations at low flows and increase water levels at the same locations during floods (Scientific Assessment and Strategy Team 1994). Channelization funnels water into the stream, rather than allowing overbank flow to spread water across wetlands and decrease velocity. This change in stream behavior results in a decrease in the ability of wetlands to perform other functions, such as removing sediment and nutrients, and long-term surface water storage (Johnston et al. 1984, Rheinhardt et al. 1999) and altering stream morphometry which leads to scouring and incision.

Water Quality. Riparian zones play important roles in controlling excess sediment, nutrient and non-point sources of pollution from the surrounding watershed from entering streams and aquifers (Kauffman et al. 1997). A point source is a concentrated source of pollution, such as a pipe from a factory. Initial efforts to improve water quality under the National Pollutant Discharge Elimination System (NPDES) program primarily focused on reducing pollutants in industrial process wastewater and municipal sewage. As pollution control measures for industrial process wastewater and municipal sewage were implemented and refined, it became increasingly evident that more diffuse sources of water pollution ("non-point sources") were also significant causes of water quality impairment, and storm water runoff was specifically found to be a major cause of impairment.

Riparian and wetland habitats are effective mitigators of non-point source pollutants, especially nutrients and sediments, due to their ability to filter and transform contaminants. Because sediments and phosphorus are transported from uplands to streams and wetlands through surface flow (phosphorus largely attached to sediment particles) (Lowrance et al 1984), the primary removal mechanisms for phosphorus and metals are the settling of particles out of the water column and adsorption to organic matter and clay. Long-term removal can occur through roots, buried leaves, and sediment deposition (Richardson and Craft 1993). As long as there is sufficient time for transported material to come in contact with surface litter, riparian vegetation can be effective in retaining sediments and nutrients. For example, in a floodplain wetland in Sweden, 95% of phosphorus entering the wetland in surface runoff was removed within 16 m (Vought et al. 1994). In North Carolina, approximately 50% of the phosphorus leaving agricultural fields in runoff was removed in riparian areas (Cooper and Gilliam 1987).

Sedimentation. The main function of rivers is to catch, store and transport sediment for headwaters down to the ocean (Naiman et al. 2005). Thus, under normal conditions, fine sediments would enter and leave river channels naturally. However, when upland watershed conditions and stream flows are altered by anthropogenic activity, resulting in increased sediment loads and the elimination of gravel mobilizing flows, fine sediment becomes trapped and stored in river beds, transforming the topography and porosity of rivers (particularly gravelbed rivers) in ways that profoundly affect the ecosystem (Suttle et al. 2004).

Increased sediment loads can result from disturbances in the upland watershed, such as agriculture and urban development. Hupp et al. (1993) found that sedimentation rates tended to be higher in wetland and riparian areas where the upstream portions of the watershed were dominated by agriculture and urban development. These excess sediment loads, are often retained within adjacent wetland and riparian areas. For example, Phillips (1989) found that between 14% and 58% of eroded upland sediment is stored in alluvial wetlands and other aquatic environments.

This excess loading of fine sediment into rivers and wetlands can impact the aquatic system in several ways. Excess turbidity caused by high levels of suspended sediment decreases oxygen levels and photosynthesis rates, impairs the respiration and feeding of aquatic organisms, destroys fish habitat, and kills benthic organisms (Johnston 1993). In wetlands, high sedimentation rates decrease the germination of many wetland plant species by eliminating light penetration to seeds, lowering plant productivity by creating stressful conditions, and slowing decomposition rates by burying plant material (Jurik et al. 1994, Vargo et al. 1998). In rivers, excess sediment loads have been shown to decrease the growth and survival of juvenile steelhead trout (Suttle et al. 2004). These declines were associated with a shift in invertebrates toward burrowing taxa unavailable as prey and with increased steelhead activity and injury at higher levels of fine sediment (Suttle et al. 2004). Thus, excess sediment loads can substantially alter the structure of river food webs.

Chemical Contaminants. The degradation of riparian and wetland habitat and increased sources of pollutants infiltrating into rivers and streams has lead to the listing of several water bodies within the Plan Areaas impaired. Impaired waters do not meet water quality standards set forth under Section 303(d) of the 1972 Clean Water Act. The contaminants of concern and their potential source and affects within the Plan Areafor which impairments have been designated include the following:

- Diazinon, an organophosphate pesticide. Diazinon is one of the most widely used pesticides in the U.S. and is also one of the most commonly found pesticides in air, rain, surface water, and drinking water. Diazinon can affect the nervous system and poses a risk to birds. Under the supervision of the EPA, Diazinon is currently being phased out for indoor uses as well as for lawn, garden, and turf uses.

- Metals are introduced into aquatic systems as a result of weathering of soils and rocks, from volcanic eruptions, and from a variety of human activities involving the mining, processing, or use of metals and/or substances that contain metals. Although some metals such as copper are essential micronutrients (are needed in very small quantities by some organisms) others, such as mercury and lead, are not required even in small amounts by any organism. Virtually all metals, including the essential metal micronutrients, are toxic to aquatic organisms as well as to humans if exposure levels are sufficiently high.

- Salinity is related to the amount of dissolved ions present in water. Distinct plant and animal communities have evolved to exist within a range of salinities. When human influences cause fresh waters to become more saline or saline waters to become fresher, plant and animal communities can become displaced.

- DDT, Chlordane, and Dieldrin are all chlorinated organic pesticides that are now banned in the U.S. but which are still present in the environment. These pesticides, which are persistent and spread through the food chain, are thought to negatively affect reproduction in certain bird species.

- Dioxin is a substance formed primarily as a contaminant during the production of the chemicals from which certain herbicides are manufactured. Dioxin is highly toxic, and is known to affect the immune system in mammals and to cause birth defects and cancer.

- Furan is a carcinogenic compound released as a gas-phase component of wood smoke, cigarette smoke, and exhaust gas from diesel and gasoline engines.

- PCBs (polychlorinated biphenyls) are compounds (no longer produced in the U.S.) that were used in a wide variety of industrial applications including closed or semi-closed systems in electrical transformers, capacitors, heat transfer systems, and hydraulic fluids. In the environment, these long-lived chemicals have been found to display a degree of toxicity to certain organisms comparable to that of some pesticides.

- Selenium is a naturally-occurring non-metallic element. Human influences can increase the amount of selenium present in the environment through discharges from oil refineries and agricultural activities. Elevated selenium levels are known to affect hatchability in nesting diving birds. Exotic species may play a role in making the food chain more susceptible to selenium.

Eutrophication. Nutrients, including nitrogen and phosphorus are another contaminant for which several tributaries within the Plan Areahave been designated as impaired. When nutrients are released in unnaturally large quantities into aquatic systems (often from fertilizers) they can cause organic enrichment and eutrophication if the nutrients stimulate increased growth and productivity in the water body. Aquatic resources can be damaged by eutrophication because increased productivity can lower the concentration of dissolved oxygen in the water (suffocating fish), and can cause excessive and undesirable algal blooms, among other effects.

Eutrophication from excess nutrients (e.g., nitrogen and phosphorus) can be a significant stressor in aquatic systems. Over time, eutrophication may alter energy pathways by increasing primary production which often results in lower dissolved oxygen concentrations. These changes usually lead to highly productive, but taxonomically and trophically simple biological communities in both streams and wetlands (Sandin and Johnson 2000, Brinson and Malvarez 2002).

Riparian Buffers. Riparian zones play important roles in controlling excess sediment, nutrient and non-point sources of pollution from the surrounding watershed from entering streams and aquifers and providing habitat for wildlife (Kauffman et al. 1997). Riparian buffer zones are strips of natural vegetation along rivers and streams that filter polluted runoff and provide a transition zone between water and human land use. The most effective buffers for fish and wildlife have three zones: a streamside zone, a middle zone and an outer zone. The Streamside zone protects the stream bank from erosion and offers habitat. The best buffers have mature riparian vegetation for shade and erosion protection. The middle zone is designed to protect water quality, by slowing flow and catching sediments and offers wildlife habitat. The outer zone provides additional wildlife habitat.

The appropriate width of each zone, and thus the overall width of the riparian buffer zone, will depend on the needs of each species, the riparian habitat type (ex. the size of the stream or river), historic conditions, and attributes of the surrounding landscape (i.e. the surrounding topography and nearby land use). Despite site specific conditions, several studies have found that species richness (i.e., total number of species) and abundance (i.e., number of individuals within a species) of riparian-associated species were highest in wide and continuous riparian corridors versus narrow and fragmented corridors. Fragmentation of riparian woodlands could be especially detrimental to nonmigratory species such as song sparrows and spotted towhees that generally do not disperse over large distances (Jones and Stokes 2005). Maintaining narrow riparian areas in urban and highly disturbed areas are still important because even thin strips of connecting habitat, can benefit sedentary species that will not disperse through open habitats and act as dispersal corridors (Croonquist and Brooks 1993).

Habitat requirements vary considerably among various riparian-associated vertebrate taxa. However, the following general conclusions were made by Jones and Stokes (2005) regarding the relationship of habitat values to width and size of riparian areas in western Placer County.

- Large (more than 10 ha [25 ac]) and wide (more than 500 m [1,640 ft]) riparian corridors provide the highest habitat values for riparian-dependent wildlife with large home ranges and territories.
- Moderately large (5–10 ha [12–25 ac]) and wide (more than 100 m [328 ft]) corridors provide sufficient habitat values to support most native species that are strongly associated with these habitats.
- Small (less than 5 ha [12 ac]) and narrow (less than 30 m [98 ft]) riparian corridors provide habitat values for many species, but most area-sensitive species will probably not be present.
- Highly fragmented and narrow riparian corridors (< 5 m [16 ft]) provide habitat for only a few generalist species, but they may still provide some values for cover and as movement corridors in urbanized and agricultural areas.

Introduced species. Riparian corridors are generally more prone to invasion by exotic species than are upland environments (Malanson 1993) and typically host relatively high percentages of non-native species (Richter and Azous 1997). Exotic aquatic species are transported to California from other parts of the world, often within the ballast water of ships. This is regarded as a form of pollution by the NPDES programs, which may classify waterways as impaired based on the presence of exotic species. Waterways do become impaired if the exotics become established in their new home because they can disrupt the natural benthos (bottom-dwelling ecosystem) and disrupt food availability to native species. Overall, 51 species of fresh water fish have been introduced into California, most of them intentionally in the early part of the century to "improve" the fish resources of the State (Moyle 2002). These introductions have had disastrous affects on the native fish fauna as well as native amphibians (Moyle 1973, 2002). For example, several researchers have attributed the decline and extirpation of California red-legged frogs in many areas to the introduction of predatory fishes (Hayes and Jennings 1986).

Additional aquatic predators that have had significant negative affects on aquatic ecosystems, particularly on covered species within the Plan Area, are bullfrogs and crayfish. Moyle (1973) found a negative correlation between the presence of bullfrogs and native ranid frogs, specifically, California red-legged frogs and foothill yellow-legged frogs, in California streams, and argued that bullfrogs may be out competing and preying upon native anurans. In their introduced range, bullfrogs are important predators and competitors that influence the presence and abundance of other frog species (Hecnar and M'Closkey 1997) and there is now significant evidence that bullfrogs negatively affect California red-legged frogs within their introduced range (Cook 1997, Kiesecker and Blaustein 1998, Lawler et al. 1999).

Invasive Exotic Plants. In riparian environments, plant communities are frequently disturbed, and have high edge to area ratios making them especially vulnerable to invasion by exotic plants (Planty-Tabacchi et al. 1996). Once established, non-native herbs can persist on sites by maintaining non-native seed banks and creating soil and litter conditions that disfavor native species. Along many stream, native, woody riparian species are being replaced by the non-native species, such as tamarisk (*Tamarix ramosissima*) and Russian olive (*Elaeagnus angustifolia*). Important invasive species in Solano County riparian systems include eucalyptus, giant reed, pepper grass, Himalayan blackberry and palm trees. Anthropogenic changes in natural disturbance regimes are a major factor promoting the invasion of exotic species (Busch and Smith 1995).

Data Gaps, Uncertainties and Assumptions. While many threats to the Riparian, Stream and Freshwater Marsh Natural Community are well known, exactly how they affect the community and ways to ameliorate or eliminate these threats are not. For the model, most of the effects of land use practices on the Natural Community are speculation based the current understanding of the abiotic and biotic drivers of the system. Data gaps identified in the development of the conceptual model and conservation approach as well as important research needs identified by the Science Advisors, are discussed below (Noss et al. 2002).

Many of the riparian habitats within and near cities and in agricultural portions of the County are very narrow (i.e., only 1 or 2 tree canopies wide) and are often characterized by non-native trees and shrubs. The quality of remaining riparian habitat within the County will need to be assessed in more detail in order to refine priority areas for future acquisition, restoration and habitat enhancement.

The conservation strategy relies heavily on restoration and enhancement of riparian and stream habitat. For riparian restoration efforts to be successful, propagation and cultivation techniques for plant taxa used for restoration should be determined. This may require pilot restoration projects focusing on the re-establishment of riparian vegetation along drainages in the County where riparian vegetation formerly occurred. In addition, highly degraded riparian areas are commonly overrun by non-native treed and shrubs, pilot studies to determine cost-effective methods to eradicate and control invasive plants will also be necessary to ensure the success of the conservation strategy.

Steelhead and fall-run/late-fall-run chinook salmon in Solano County are near the boundaries of the coastal and Central Valley ESUs for both species. It would be useful to clarify the genetic relationships of anadromous salmonids in Solano County streams to those ESUs (i.e., to determine if the fish belong primarily to one or another of the currently defined ESUs). Studies are also needed to document the temporal changes in population composition of steelhead-rainbow trout vis-à-vis the steelhead and rainbow trout phenotypes. Potential causal relationships between changes in population phenotypic composition and environmental factors need to be clarified. Also, the extent to which juvenile steelhead-rainbow trout and juvenile chinook salmon utilize non-natal streams for rearing should be determined. Factors that affect the survival and growth rate of juvenile salmonids should be evaluated for known salmonid streams throughout the Plan Area.

In general, more baseline survey information is needed for the majority of riparian, stream and freshwater marsh Covered Species, such as, valley elderberry longhorn beetle, foothill yellow-legged frog, yellow-breasted chat, and tri-colored black birds to accurately assess their distribution within the Plan Area. This is also the first step in developing questions relating to means of enhancing populations. Despite pressures associated with urban, industrial, and agricultural development in the

County, the hydrological regime and status of sediment and water quality has not exceeded the tolerance of many key species to the point of extirpation. In that context, careful planning that includes a combination of one-time scientific evaluations and ongoing research and monitoring should be incorporated into the Monitoring and Adaptive Management Program.

Current Management and Monitoring Practices. Current management practices vary on existing public and private/land trust reserves. Traditional management of the reserves has primarily focused on wildfire fuel load reductions, generally through livestock grazing, with limited consideration for the effects of the grazing on streams, marshes, and associated riparian habitats. More recently, the Solano Land Trust and cities of Fairfield and Vacaville have begun to incorporate additional management measures in at least some of their open spaces to enhance, stream, riparian and marsh habitats. To date, these activities have primarily involved fencing to exclude livestock from channels and around ponds and planting/installation of riparian vegetation and other structure to reduce erosion and stabilize stream banks.

Outside of established open spaces, the primary management actions for stream and riparian communities has been to maintain channel capacity (through removal of downed woody material and accumulated in-channel sediments) and to repair bank/channel erosion where it threatens public facilities such as trails, pipelines, and outfall structures.

Key Monitoring and Adaptive Management Issues from Conceptual Model. From the conceptual model the main abiotic drivers affecting riparian stream and freshwater marsh ecosystems include climate (particularly precipitation), upland watershed conditions, geomorphic processes and hydrology. Monitoring variables that can provide information about these abiotic drivers should be incorporated into the monitoring program. For example, the major hydrological features of riparian ecosystems are the streamflow regime, including the frequency, magnitude, and temporal distribution of the streamflow (including peak and low flows).

The major biotic drivers of riparian stream and freshwater marsh ecosystems as outlined in the conceptual model include soil biota, vegetation, invertebrates and vertebrates. Riparian habitat provides a diversity of wildlife with valuable nesting, cover, foraging, and movement habitat all within close proximity to water (RHJV 2000). However, the quality of the riparian habitat and adjacent land use practices affect species diversity and composition. Certain species groups, particularly riparian birds, may prove to be a good surrogate variable for the health of the riparian community (RHJV 2000).

The main land use practices (primary pressures) affecting riparian stream and freshwater marsh habitat that will be directly addressed in the Monitoring and Adaptive Management Program are urbanization, livestock grazing and recreation. Urbanization alters the natural infiltration capability of the land and generates a host of pollutants, thus causing an increase in storm water runoff volumes and pollutant loadings in storm water discharged to receiving water bodies. These changes in the infiltration capacity due to increases in impervious surfaces within a watershed can significantly affect the biotic composition of aquatic community. Increases in the amount of developed area within key watersheds should be closely monitored along with water quality variables to identify where conservation measures are successfully ameliorating development pressures.

Livestock grazing is an important management tool that will be used on the majority of preserve/reserves throughout the county. However, riparian and stream habitat can be severely damaged by livestock if appropriate measures are not taken. For example, damage to riparian and stream habitat resulting from livestock grazing includes alterations in watershed hydrology, changes to stream channel morphology, soil compaction and erosion, riparian vegetation destruction, and water quality impairments (Belsky et al., 1999, Kauffman and Kruger 1984). The impacts of livestock on riparian and stream habitat need to be addressed when developing management plans for preserve/reserves throughout the County.

The consequences of the above land use practices (secondary pressures) on this community in Solano County that will be addressed in the Monitoring and Adaptive Management Program are: habitat loss and fragmentation, the quality of riparian buffers, water quality, introduced species and invasive exotic plants. The monitoring program for this Natural Community will collect baseline data on the effects of these pressures throughout the county and choose monitoring variables that appropriately represent the affects of these pressures.

Literature Cited

Agouridis, C. T., S. R. Workman, R. C. Warner, and G. D. Jennings. 2005. Livestock Grazing Management Impacts on Stream Water Quality: A Review. Journal of the American Water Resources Association (JAWRA) 41 (3):591–606.

Amoros, C. and G. Bornette. 2002. Connectivity and Biocomplexity in Waterbodies of Riverine Floodplains. Freshwater Biology 47:761–776.

Baker, W. L. 1990. Climatic and hydrologic effects on the regeneration of *Populus angustifolia james* along the Animas River, Colorado. Journal of Biogeography 17:59–73.

Barrat-Segretain M. H. and C. Amoros. 1995. Influence of flood timing on the recovery of macrophytes in a former river channel. Hydrobiologia 316:91–101.

Baxter, C. B., K. D. Fausch, and W. C. Saunders. 2005. Tangled webs: reciprocal flows of invertebrate prey link streams and riparian zones. Freshwater Biology 50(2):201–220.

Belsky, A. J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54(1):419-431.

Bilby, R. E. 1988. Interactions between Aquatic and Terrestrial Systems. Pp. 13–29 i*n* K. J. Raedeke, ed. Streamside Management: Riparian Wildlife and Forestry Interactions. University of Washington College of Forest Resources Contribution Number 59.

Bovee, K. D. 1978. Probability-of-use-criteria for the family Salmonidae. Instream Flow Information Paper 4, U.S. Fish and Wildlife Service, FWS/OBS-78/07. 79 pp.

Brinson, M. M. and A. I. Malvarez. 2002. Temperate freshwater wetlands: types, status, and threats. Environmental Conservation 29:15–133.

Busch, D.E., and S.D. Smith. 1995. Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U.S. Ecological Monographs 65(3):347-370.

Bush, D. E., N. L. Ingraham, and S. D. Smith. 1992. Water uptake in woody riparian phreatophytes of the southwestern United States: a stable isotope study. Ecological Applications 2:450–459.

Cada G.F., J. M. Loar and D. K. Cox. 1987. Food and feeding preferences of rainbow trout and brown trout in southern Appalachian streams. American Midland Naturalist, 117, 374–385.

California Department of Fish and Game (CDFG). 2003. Atlas of the Biodiversity of California.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. The American Naturalist 148: 1016-1037.

Cloe W.W.I. and G. C. Garman. 1996. The energetic importance of terrestrial arthropod inputs to three warmwater streams. Freshwater Biology, 36, 105–114.

Comstock, J. P., and J. R. Ehleringer. 1992. Plant adaptation in the Great Basin and Colorado Plateau. The Great Basin Naturalist 52: 195-215.

Cook D. 1997. Microhabitat Use and Reproductive Success of the California Red-Legged Frog (*Rana Aurora Draytonii*) and Bullfrog (*Rana Catesbiana*) *In* An Ephemeral Marsh. M.S. Thesis, Sonoma State University, Sonoma, California.

Cooper, J. R., and J. W. Gilliam. 1987. Phosphorus redistribution from cultivated fields into riparian areas. Soil Science Society of America Journal 51:1600-1604.

Cowardin, L. M. V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Dep. Interior, Fish and Wildlife Service. FWS/OBS - 79/31.

Croonquist, M. J. and R. P. Brooks. 1991. Effects of habitat disturbance on bird communities in riparian corridors. Journal of Soil and Water Conservation 48:65-70.

Dawson, T. E. and J. R. Ehleringer. 1991. Streamside trees that do not use stream water. Nature 350:335–337.

Fausch, K.D., Taniguchi Y, Nakano S, Grossman G.D., Townsend C.R. 2001. Flood disturbance regimes influence rainbow trout invasion success among five holarctic regions. Ecological Applications 11(5):1438-255.

Federal Register. 2002. Vol 07, no. 10.

Fleischner, Thomas L. 1994. Ecological costs of livestock grazing in Western North America. Conservation Biology. 8(3):629-644.

Groffman, Peter M., Arthur J. Gold, and Robert C. Simmons. 1992. Nitrate Dynamics in Riparian Forests: Microbial Studies. J. Environ. Qual. 21:666-671.

Harris R.R. 1987. Occurrence of vegetation on geographic surfaces in the active floodplain of a California alluvial stream. American Midland Naturalist. 118:393–405.

Hayes, M.P. and M.R. Jennings. 1988. Habitat correlates of distribution of the California red-legged frog (*Rana aurora draytonii*) and the foothill yellow-legged frog (*Rana boylii*): Implications for management. Pages 144-158 *In*: R. Sarzo, K. E. Severson, and D. R. Patton (technical coordinators). Proceedings of the Symposium on the Management of Amphibians, Reptiles, and Small Mammals in North America. U.S.D.A. Forest Service General Technical Report RM-166.

Hecnar, S.J and R. T. M'Closkey. 1997. Changes in the composition of a ranid frog community following bullfrog extinction. American Midland Naturalist 137(1):145-50.

Hill, Alan R. 1996. Nitrate Removal in Stream Riparian Zones. J. Environ. Qual. 25:743-755.

Holland, R.F. 1986. Preliminary descriptions of the terrestrial natural communities of California. California Department of Fish and Game, Sacramento.

Hupp, C. R., M. D. Woodside, and T. M. Yanosky. 1993. Sediment and trace element trapping in a forested wetland, Chickahominy River, Virginia. Wetlands 13:95-104.

Hupp, C.R. and W. R. Osterkamp. 1985. Bottomland vegetation distribution along Passage Creek, Virginia, in relation to landforms. Ecology 66:670–81.

Intergovernmental Task Force on Monitoring Water Quality (ITFMWQ). 1996. The Nationwide Strategy for Improving Water Quality Monitoring in the United States: Final Report of the Intergovernmental Task Force on Monitoring Water Quality. Open-File Report 95-742. http://water.usgs.gov/wicp/itfm.html

Jackson, J.K. & Fisher S.G. (1986) Secondary production, emergence, and export of aquatic insects of a Sonoran desert stream. Ecology 67:629–638.

Jansen, A. and M. Healey. 2003. Frog communities and wetland condition: relationships with grazing by domestic livestock along an Australian floodplain river. Biological Conservation 109(2):207-19.

Johnston, C. A. 1993. Mechanisms of wetland-water quality interaction. Pages 293-299 in G. A. Moshiri, editor. Constructed Wetlands for Water Quality Improvement. Lewis Publishers, MI.

Johnston, C. A., G. D. Bubenzer, G. B. Lee, F. W. Madison, and J. R. McHenry. 1984. Nutrient trapping by sediment deposition in a seasonally flooded lakeside wetland. Journal of Environmental Quality 13:283-290.

Jones and Stokes Associates. 2002. Program Environmental Impact Report for the Comprehensive Amendment to the City of Fairfield General Plan. SCH#2001032064. Prepared by Jones and Stokes Associates.

Jurik, T. W., S.-C. Wang, and A. G. v. d. Valk. 1994. Effects of sediment load on seedling emergence from wetland seed banks. Wetlands 14:159-165.

Kauffman, J. Boone, Robert L. Beschta, Nick Otting, and Danna Lytjen. 1997. An Ecological Perspective of Riparian and Stream Restoration in the Western United States. Fisheries. Vol. 22(5):12-24.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications...a review. J. Range Manage. 37:430-438.

Keddy, Paul A. 2000. Wetland Ecology: principles and conservation. Cambridge: Cambridge University Press.

Kiesecker J. M. and A. R. Blaustein. 1998. Effects of Introduced Bullfrogs and Smallmouth Bass on Microhabitat Use, Growth, and Survival of Native Red-Legged Frogs (*Rana Aurora*). Conservation Biology, 12:776-787.

Kuchler, A. W. 1977. Natural vegetation of California. Dept. of Geography, Univ. Kansas. U.S. Forest Service and California Native Plant Society.

Langlade, L.R. and O. Decamps. 1994. Plant colonization on river gravel bars: the effect of litter accumulation. CR Acad. Sci S´er. III 317:899–905.

Lawler, S.P., D. Dritz, T. Strange, And M. Holyoak. 1999. Effects of Introduced Mosquitofish and Bullfrogs on The Threatened California Red-Legged Frog. Conservation Biology, 13:613-622.

Leidy, R.A. 2000. Steelhead. Pp. 101-104 *In* P.R. Olofson (ed.). Goals Project. Baylands Ecosystem Species and Community Profiles: Life histories and environmental requirements of key plants, fish and wildlife. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. San Francisco Bay Regional Water Quality Control Board, Oakland, California.

Lowrance, R., Todd R.L, Asmussen L.E. 1983. Waterborne nutrient budgets for the riparian zone of an agricultural watershed. Agric. Ecosys. Environ. 10:371–84 148.

Malanson, G.P. 1993. Riparian Landscapes. Cambridge, UK: Cambridge University Press.

Mason, C.F. and S.M. MacDonald. 1982. The input of terrestrial invertebrates from tree canopies to a stream. Freshwater Biology, 12, 305–311.

May, C., R. Horner, J. Karr, B. Mar, and E. Welch. 1997. Effect of urbanization on small streams in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques 2(4):483- 494.

Meffe, G. K. 1984. Effects of abiotic disturbance on coexistence of predator and prey fish species. Ecology 65:1525-1534.

Mikkelsen, Kerri and Ilir Vesho. 2000. Riparian Soils: A literature Review. Center for Water and Watershed Studies, University of Washington. Available on line at: http://depts.washington.edu/cwws/Outreach/Publications/soillitreview.html

Mount, Jeffrey F. 1995. California Rivers and Streams: the conflict between fluvial process and land use. University of California Press. London, England.

Moyle, P. B. 1973. Effects of introduced bullfrogs, (*Rana catesbeiana*), on the native frogs of the San Joaquin Valley, California. Copeia 1:18-22.

Moyle, P. B. 2002. Inland Fishes of California. University of California Press. Berkeley, California.

Naiman and Décamps. 1997. The Ecology of Interfaces: Riparian Zones. Annual Review of Ecology and Systematics. Vol. 28: 621-658 (Volume publication date November 1997).

Naiman, Robert J., Henri Décamps, and Michael E. McClain. 2005. Riparia: ecology, conservation and management of Streamside Communities. Elsevier Academic Press. Oxford, UK.

Nakano, S. and M. Murakami. 2001. Reciprocal subsidies: dynamic interdependence between terrestrial and aquatic food webs. Proceedings of the National Academy of Science, U.S.A., 98, 166–170.

Nakano, S., Y. Kawaguchi, Y. Taniguchi, H. Miyasaka, Y. Shibata, H. Urabe and N. Kuhara. 1999 Selective foraging on terrestrial invertebrates by rainbow trout in a forested headwater stream in northern Japan. Ecological Research, 14, 351 360.

Noss, R. (Lead Reviewer and Editor), R. Amundson, D. Arnold, M. Bradbury, S. Collinge, B. Grewell, R. Grosberg, L. McKee, P. Northen, C. Swanson, and R. Yoshiyama. Facilitated by: B. DiGennaro and V. Russell. 2002. Report of Science Advisors. Solano County Natural Community Conservation Plan/Habitat Conservation. November 2002. Prepared for the California Department of Fish and Game and Solano County Water Agency. http://www.scwa2.com/hcp/Reports/ScienceAdvisorsReport_files/Solano%20Science%20Advisors%20Report%20-%20Final.pdf

Noy-Meir, I. 1973. Desert ecosystems: Environment and producers. Annual Review of Ecology and Systematics 4: 25-51.

Phillips, J. D. 1989. Fluvial sediment storage in wetlands. Water Resources Bulletin 25:867-873.

Planty-Tabachi, A., E. Tabacchi, R.J. Naiman, C. Deferrari and H. Décamps. 1996. Invasibility of species-rich communities in riparian zones. Conservation Biology 10:598-607.

Poff, N. L., and J. D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrologic variability. Ecology 76:606-627.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. Richter, R. Sparks, and J. Stromberg. 1997. The natural flow regime: a new paradigm for riverine conservation and restoration. BioScience 47:769-784.

Power, M. E. 2001. Prey exchange between a stream and its forested watershed elevates predator densities in both habitats. Proceedings of the National Academy of Sciences, USA. 98: 14-15.

Power, M.E. and W. E. Rainey. 2000. Food webs and resource sheds: towards spatially delimiting trophic interactions. *In* Ecological Consequences of Habitat Heterogeneity (Eds M.J. Hutchings, E.A. John & A.J.A. Stewart), pp. 291– 314. Blackwell Scientific, Oxford, U.K.

Power, M.E., W. E. Rainey, M.S. Parker, J. L. Sabo, A. Smyth, S. Khandwala, J.C. Finlay, F.C. McNeely, K. Marsee, and C. Anderson. 2004. River to watershed subsidies in an old-growth conifer forest. G.A. Polis M.E. Power and G. Huxel. (eds.) Food webs at the landscape level. University of Chicago Press, Chicago, IL.

Raedeke, K.J., R.D. Taber, and D.K. Paige. 1988. Ecology of Large Mammals in Riparian Systems of Pacific Northwest Forests. In Streamside Management: Riparian Wildlife and Forestry Interactions, edited by K. J. Raedeke. Seattle, WA: University of Washington, Institute of Forest Resources.

Reiser, D.W. and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. USDA, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, General Technical Report PNW-96. 54 pp.

Rheinhardt, R.D., M.C. Rheinhardt, M. M. Brinson, and K. E. F. Jr. 1999. Application of reference data for assessing and restoring headwater ecosystems. Restoration Ecology 7:241-251.

Richardson, C.J., and C.B. Craft. 1993. Effective phosphorus retention in wetlands: Fact or fiction? Pages 271-282 in G. A. Moshiri, editor. Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Ann Arbor, Michigan.

Richter, K. O. and A. L. Azous. 1995. Amphibian Occurrence and Wetland Characteristics *In* The Puget Sound Basin. Wetlands 15:306-312.

Richter, K.O. and A. L. Azous 1997. Amphibian Distribution, Abundance and Habitat Use. Pp. 95-110 *In* A.L. Azous And R.R. Horner (Eds.). Wetlands and Urbanization: Implications for the Future. Final Report of the Puget Sound Wetlands and Stormwater Management Research Program. Available on Noss, R. (Lead Reviewer and Editor), R. Amundson, D. Arnold, M. Bradbury, S. Collinge, B. Grewell, R. Grosberg, L. McKee, P. Northen, C. Swanson, and R. Yoshiyama. Facilitated by: B. DiGennaro and V. Russell. 2002. Report of Science Advisors. Solano County Natural Community Conservation Plan/Habitat Conservation. November 2002. Prepared for the California Department of Fish and Game and Solano County Water Agency. http://www.scwa2.com/hcp/Reports/ScienceAdvisorsReport_files/Solano%20Science%20Advisors%20Report%20-%20Final.pdf

Riparian Habitat Joint Venture (RHJV). 2000. The Riparian Bird Conservation Plan: A Strategy for reversing the decline of riparian associated birds in California. California Partners in Flight. Point Reyes Bird Observatory, Stinson Beach, CA.

Ritter, Dale F, R. Graig Kochel and Jerry R. Miller. 2002. Process Geomorphology, Fourth Edition. McGraw-Hill. New York, NY.

Sabo, J.L., M.E. Power. 2002. Numerical response of lizards to aquatic insects and short-term consequences for terrestrial prey. Ecology, 83(11), 2002, pp. 3023–3036.

Sandin, L. and R. K. Johnson. 2000. The statistical power of selected indicator metrics using macroinvertebrates for assessing acidification and eutrophication of running waters. Hydrobiologia 422:233-243.

Sanzone D.M., J. L. Meyer, E. Marti, E.P. Gardiner, J. L. Tank and N. B. Grimm. 2003. Carbon and nitrogen transfer from a desert stream to riparian predators. Oecologia, 134, 238–250.

Schumm, S.A., 1977. The Fluvial System. John Wiley and Sons, New York.

Scientific Assessment and Strategy Team. 1994. Science for floodplain management into the 21st century. Part V, Report of the Interagency Floodplain Management Review Committee to the Administration Floodplain Management Task Force, Washington D.C.

Scott, M. L., P. B. Shafroth, and G. T. Auble. 1999. Responses of riparian cottonwoods to alluvial water table declines. Environmental Management 23:347–358.

Scott, M.L., S.K. Skagen, and M.F. Merligiano. 2003. Relating breeding bird diversity to geomorphic change and grazing in riparian forests. Conservation Biology 17:284-296.

Scott, Michael L., Miller Mark E., and Schmidt John C. 2004. The Structure and Functioning of Riparian Ecosystems of the Colorado Plateau–Conceptual Models to Inform the Vital-Sign Selection Process. Southern Colorado Plateau Network Phase Two, Supplement IV Riparian Models (Draft). USGS Biological Resources Discipline. FORT Science Center. Fort Collins, CO.

Singer and Eshel. 2002. Baker Slough Water Quality Study. Prepared for Solano County Water Agency and DWR. UC Davis Department of Land, Agriculture and Water Resources.

Snyder, C. D., J. A. Young, and R. Villella. 2003. Influences of upland and riparian land use patterns on stream biotic integrity. Landscape Ecology 18:647-664.

Suttle, K.B., M.E. Power, J.M. Levine, and C. McNeely. 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. Ecological Applications 14: 969- 974.

U.S. Environmental Protection Agency (EPA). 2000. Storm Water Phase II Compliance Assistance Guide. Office of Water. EPA document number 8333-R-00-002, 97 p.

Vargo, S. M., R. K. Neely, and S. M. Kirkwood. 1998. Emergent plant decomposition and sedimentation: response to sediments varying in texture, phosphorus content and frequency of deposition. Environmental and Experimental Botany 40:43-58.

Vought, L. B.-M., J. Dahl, C. L. Pedersen, and J. O. Lacoursiere. 1994. Nutrient retention in riparian ecotones. Ambio 23:342-348.

Ward, J. V. 1989. The four dimensional nature of lotic ecosystems. Journal of the North American Benthological Society 8:2–8.

Whitford, W. G. 2002. Ecology of desert systems. Academic Press, San Diego. 343 pp.

Williams, D.F., and K.S. Kilburn. 1984. Sensitive, Threatened, and Endangered Mammals of Riparian and other Wetland Communities in California. *In* California Riparian Systems: Ecology, Conservation, and Productive Management, edited by R. E. Warner and K. M. Hendrix. Berkeley, CA: Berkeley: University of California Press.

Wipfli, M.S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests in southeastern Alaska. Canadian Journal of Fisheries and Aquatic Sciences, 54, 1259–1269.

Woessner, W.W. 2000. Stream and fluvial plain ground water interactions: Rescaling hydrogeologic thought. Ground Water 38:423–429.

Xiong, Shaojun and Christer Nilsson. 1997. Dynamics of leaf litter accumulation and its effects on riparian vegetation: a review. Botanical Review 63(3):240-265.