THE PAST AND PRESENT CONDITION OF THE

MARSH CREEK WATERSHED

Prepared by the Natural Heritage Institute
and the Delta Science Center at Big Break

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Funded by the State of California Coastal Conservancy,
the San Francisco Bay Fund, the CALFED Bay-Delta Program,
the Witter Foundation, and the David and Lucile Packard Foundation

FOURTH EDITION • APRIL 2007

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"The watershed is beyond the dichotomies of orderly/disorderly, for its forms are free, but somehow inevitable. The life that comes to flourish within it constitutes the first kind of community. A watershed is a marvelous thing to consider: this process of rain falling, streams flowing, and oceans evaporating causes every molecule of water on earth to make the complete trip every two million years."

GARY SNYDER

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Acknowledgements

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Funded by
The State of California Coastal Conservancy
The San Francisco Bay Fund
The CALFED Bay-Delta Program
The Witter Foundation
David and Lucile Packard Foundation

Reprint funded by
California Department of Conservation

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Introduction

Contra Costa, the "opposite coast," describes a meandering shoreline embracing the confluence of two great rivers, the Sacramento and the San Joaquin. High overhead, Mt. Diablo the "devil mountain," connects the Great Central Valley to the Delta coastline along rock-carved creeks like Marsh, Briones, Sand, Dry, Deer, and Nunn. Scientists speak of the important connectivity of ecological processes that exists between Diablo and the Delta, while most of us speak of it as home. Our home is no longer a wild place of grizzlies, elk, antelope, and native peoples, and it can never be again. We have sacrificed the primeval to build agriculture, homes, businesses, and protective flood controls. Without the sacrifice, we would not be here today. As we have grown, we have also learned that we can better manage ourselves to protect and restore our Marsh Creek watershed for continued prosperity, health, and happiness. It is even possible to regain some of the wilderness we have lost. We have new awareness, new tools, and a pressing responsibility, particularly as residents living on the edge of the Delta - California's most important natural resource. If we do not step up, who will?

This edition of the Marsh Creek report includes a primer on basic creek science and local land use issues, past and present. The intention of the primer is to draw attention to Marsh Creek, lay groundwork, and help residents gain appreciation and personal involvement in what is at stake in the watershed. Careful work and community acceptance have allowed us to now focus more on watershed issues, goals, and immediate accomplishments, including an outline for the future.

We are most gratified that over the course of preparing these reports, more and more people have joined the Delta Science Center and the Natural Heritage Institute (NHI) in charting a positive course for the future of the Marsh Creek watershed. Our earliest collaborators included Contra Costa County, particularly Flood Control, the East Bay Regional Park District, Los Medanos College, Ironhouse Sanitary District, the Contra Costa Resource Conservation District, California State University at Hayward, and Oakley's Freedom High. The City of Brentwood embraced the initial effort and helped attract UC Berkeley graduate students from the College of Environmental Design. In the process, the people of Oakley rallied in support of CALFED, Department of Water Resources, and the Coastal Conservancy's significant purchase of the Cypress Corridor at Dutch Slough. The National Oceanographic and Atmospheric Administration and the American Rivers Council have also come on board in support of salmon stocks in Marsh Creek. California State Parks and the Urban Stream Program of the Department of Water Resources have committed funds for land acquisition and restoration along the Creek. New supporters keep joining the collaboration, bringing new resources to the watershed. Pacific Gas and

Electric Company and Dupont have signed on and the US Army Corps of Engineers has authorized up to $5 million for wetland restorations in east Contra Costa County. More than $30 million is now coming to the watershed in support of people, wildlife, habitat and quality of life. To date, there have been no major disagreements about this infusion of resources to protect and restore the watershed.

By building partnerships and collaborating on win-win situations, we can change how we treat our watershed, while letting the wild things return. Change is often slow, but if we can help shape tomorrow, rather than letting it shape us, we believe east Contra Costa will prosper as a healthy home and a productive economy. Let's keep the momentum. We are on a roll.

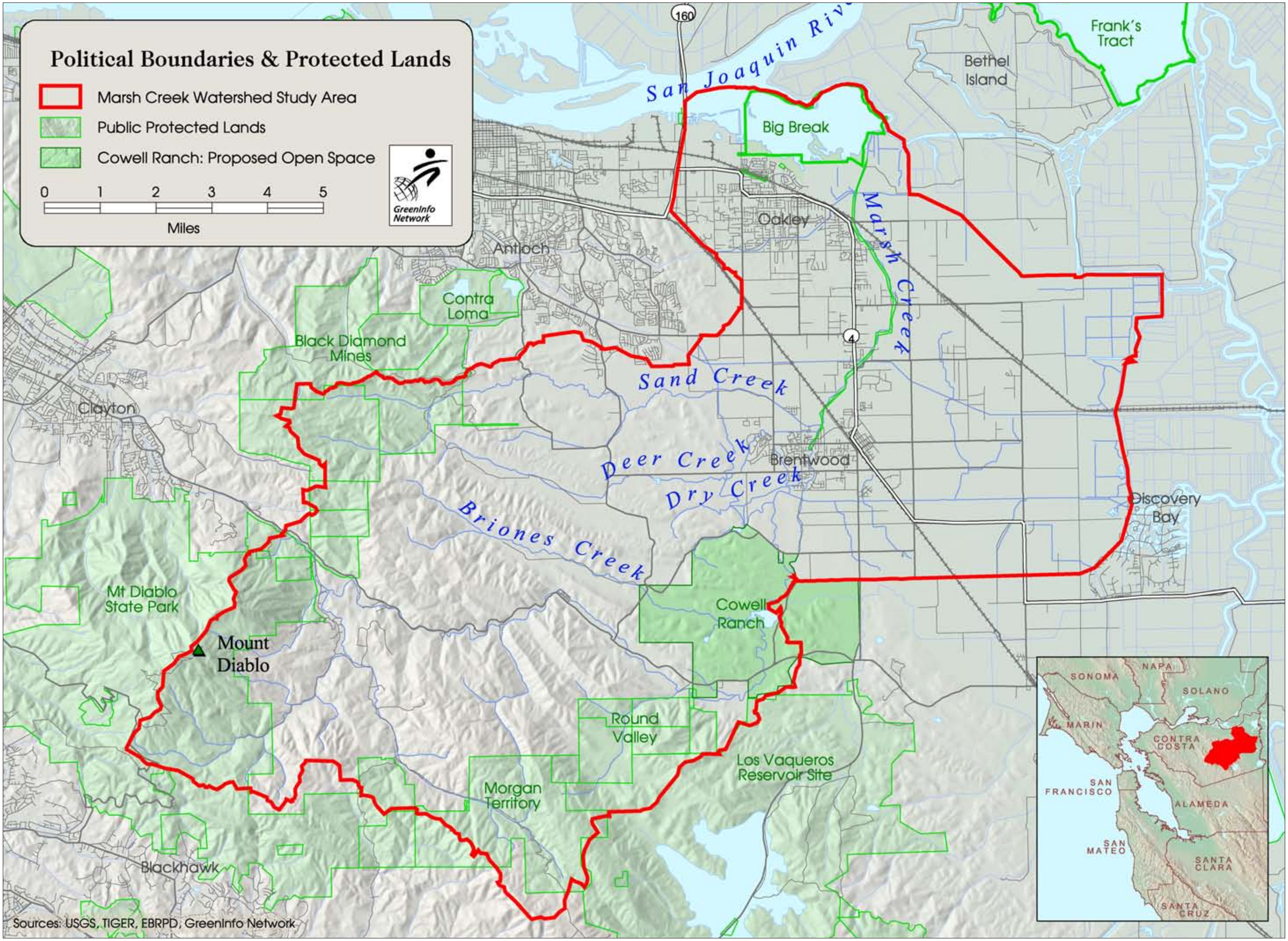

Political Boundaries & Protected Lands
Marsh Creek Watershed Study Area
Public Protected Lands
Cowell Ranch: Proposed Open Space
0 1 2 3 4 5
Miles
GreenInfo Network
San Joaquin River
Frank's Tract
Bethel Island
Big Break
Oakley
Antioch
Marsh Creek
Contra Loma
Black Diamond Mines
Sand Creek
Clayton
Deer Creek
Brentwood
Dry Creek
Briones Creek
Discovery Bay
Mt Diablo State Park
Cowell Ranch
Mount Diablo
Round Valley
Los Vaqueros Reservoir Site
Morgan Territory
Blackhawk
SONOMA
NAPA
SOLANO
MARIN
CONTRA COSTA
SAN FRANCISCO
ALAMEDA
SAN MATEO
SANTA CLARA
SANTA CRUZ
Sources: USGS, TIGER, EBRPD, GreenInfo Network

Figure 1

Chapter 1
Where It Is Located

The Marsh Creek watershed drains the north side of Mt. Diablo and includes the cities of Oakley, Brentwood, and part of Antioch in eastern Contra Costa County approximately 40 miles northeast of San Francisco. This watershed drains 128 square miles of rangeland, farmland, and urban land and is the second largest watershed in the County. Marsh Creek flows for approximately 30 river miles from its headwaters in the Morgan Territory, on the eastern flank of Mt. Diablo, to its mouth at Big Break in the western Delta and is an important ecological link between the Delta and the Diablo Range.

Technically, the boundaries of a watershed are defined as a region or area that drains to a particular creek or river. For the purposes of this report, however, we have more broadly defined the watershed to include areas that historically or politically affect or are affected by Marsh Creek. Figure 1 depicts the watershed study area and the location of various cities and parks. Although much of the area east of Brentwood and Oakley does not actually drain into Marsh Creek, we have included it in the study area because it has been historically flooded by Marsh Creek and it is part of a broad alluvial plain over which the Marsh Creek channel has migrated during the last several thousand years.

Marsh Creek's major tributaries – Briones, Dry, Deer, and Sand creeks – all flow southeasterly draining the eastern highlands of Mt. Diablo State Park or Black Diamond Mines Regional Preserve. Briones Creek, which drains the undeveloped Briones Valley, flows into Marsh Creek at the Marsh Creek Reservoir, while Dry, Deer, and Sand creeks all flow into Marsh Creek within the city limits of Brentwood. Much of the land in the northern lowland section of the watershed is privately owned and lies within the cities of Antioch, Oakley, and Brentwood as well as unincorporated County land. All of the privately owned land in the watershed's southern uplands is unincorporated and falls within the planning jurisdiction of the County. Although most of the land within the watershed is under private ownership, the watershed is bounded by large areas of publicly owned open space including Morgan Territory Regional Preserve, Los Vaqueros watershed lands, Round Valley Regional Preserve, Mt. Diablo State Park, Black Diamond Mines Regional Preserve, Contra Loma Regional Park, and the Big Break Regional Shoreline.

Between its headwaters in the Morgan Territory and its mouth at Big Break, Marsh Creek and its tributaries flow through three distinct geographic zones – the upper, intermediate, and lower zones based on elevation, channel gradient, valley width, and vegetation (Figure 2). Although each of Marsh Creek's tributaries has its own

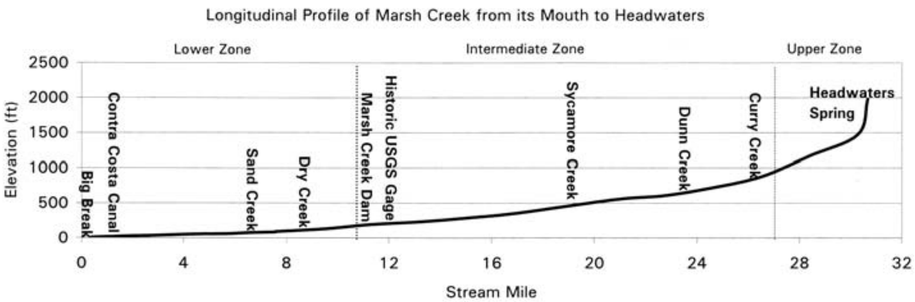


Figure 2 – Long Profile

upper, intermediate, and lower zone, discussion of each tributary will be included in the section where its confluence with Marsh Creek is located. The upper zone of Marsh Creek begins at a series of unnamed springs in the Morgan Territory and extends approximately 4 stream miles downstream to just above its confluence with Curry Creek. The intermediate zone flows from the confluence with Curry Creek to the Marsh Creek Reservoir. The lower zone begins at the spillway of the Reservoir and extends downstream to Marsh Creek's mouth at Big Break.

The Upper Zone

In the upper zone, Marsh Creek flows first through a steep, narrow, and densely vegetated canyon and then into a broader grassland valley. The landscape is dominated by chaparral on the hot south facing slopes and pine and oak woodlands on the cooler north facing slopes. Typical vegetation along the steep drainages of Marsh Creek and its tributaries is a mixed riparian woodland containing oak, bay, buckeye, ash, alder, sycamore, big leaf maple, and willow. The slope of the stream, the aspect of the hillside, and the availability of surface water and groundwater determine the density and type of vegetation. In this zone of the watershed, Marsh Creek flows in a northwesterly direction and drops abruptly at steep slopes ranging from approximately 800 feet per mile (15%) near the headwaters to 350 feet per mile (5%) near the downstream boundary. The topography is heavily influenced by tectonic uplift and faulting as witnessed by the fractured and twisted mélange of bedrock covering the flanks of Mt. Diablo. The local geology controls the course of Marsh Creek in this upper zone as the channel follows the northwesterly strike of the upturned sedimentary bedrock ridges. The ridges and valleys of this zone are composed of ancient marine sedimentary rocks, some of which are highly erodible and easily fractured (United States Geological Survey, 1994). The predominant soil overlaying the bedrock is a Dibble silty clay loam, which has developed in situ and is characterized by limited soil development and thus is very shallow with a maximum depth to bedrock of less than 34 inches.

In the upper zone of the watershed, the Marsh Creek channel is confined within narrow bedrock canyons. These erosion resistant bedrock canyons control both the planform and profile of the channel. As Marsh Creek flows through these confined reaches it is unable to meander and as a result is generally straight, following existing cracks, fissures, and faults in the bedrock. Because of the steep topography, resistant bedrock, and the lack of lateral channel movement, the slow erosion of the channel bed is the main geomorphic process in this zone, leading to a gradual deepening of the channel. Variability in the composition, erosivity, and alignment of the local bedrock helps create a diverse streambed profile illustrated by a mosaic of deep pools and shallow riffles.

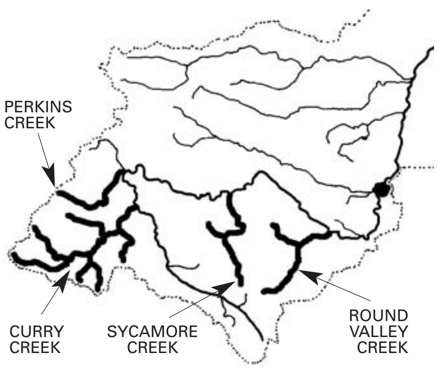
When the winter rains come, most of the water runs off the steep slopes, percolates into the porous sandstone bedrock, or is absorbed by the shallow Dibble soils where it is later used by thirsty plants. Where vegetation is sparse, the surface of the shallow Dibble soils quickly become saturated. Further precipitation runs off the steep slopes into hillside gullies and the channels of Marsh Creek and its tributaries. Where vegetation is dense, it slows the falling raindrops, allowing more time for water to be absorbed by the soil or to percolate into the bedrock. Water that percolates into the bedrock gradually travels through porous sandstone layers and joints in the bedrock until it re-emerges in pools, seeps, and springs along Marsh Creek. It can take months or even years for percolated water to travel through the bedrock and re-emerge in the Creek. Thus, late into the summer months after the rainy season has ended and most of the Creek is dry, pools of water fed by percolating groundwater persist in bedrock depressions along Marsh Creek, providing a critical dry season water source for a host of aquatic and terrestrial species.

Perhaps the most intriguing geological attribute of the upper zone of the Marsh Creek watershed is the sequence of rocks known as the Mt. Diablo Ophilite that forms the top of Mt. Diablo. Ophilite is composed of ancient oceanic material that is believed to have formed offshore of North America 165–180 million years ago (Mt. Diablo Interpretive Association, 2000). Unlike the more common types of oceanic crustal material that were scraped off the ocean floor as the Pacific Plate dived below the North American Plate and deposited on top of existing bedrock, the Mt. Diablo Ophilite is unique because it was not scraped off and deposited, but instead was a huge chunk of oceanic crust sandwiched between the Pacific and North American plates before tectonic forces pushed it upward. These forces caused it to puncture the overlying sedimentary formations of the North American Plate in a geologic process known as piercement approximately 4 million years ago. Today, this plug of metamorphosed oceanic rock now forms the core of the northern highlands of Mt. Diablo and is skirted by the sandstone formations that it once punctured as it emerged from below (United States Geological Survey, 1994; Mt. Diablo Interpretive Association, 2000).

Vast tracts of Marsh Creek's upper zone are relatively undeveloped with the primary land uses restricted to livestock grazing and recreation. Historically, the upper zone was home to mercury mining operations and ranches. Today, the majority of the land in this zone of the watershed is either in Mt. Diablo State Park or in the East Bay Regional Park District's Morgan Territory Regional Preserve and Round Valley Regional Preserve.

The Intermediate Zone

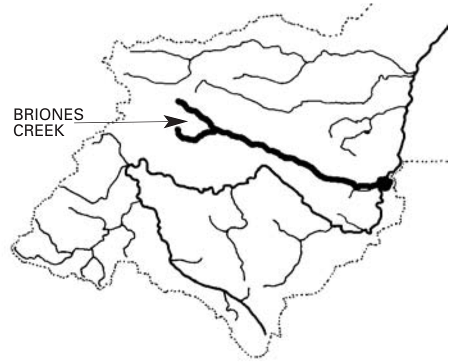
Downstream of the steep bedrock upper zone, Marsh Creek enters a more open and gently sloping intermediate zone that extends from Curry Creek to the Marsh Creek Reservoir. Marsh Creek flows through this zone for approximately 16 stream miles with an average slope of approximately 1% or 50 vertical feet per stream mile. The creek continues to flow in a northwesterly direction for a few miles until its confluence with Perkins Creek, where it abruptly turns right and begins to flow due east. Geologic maps indicate the severe faulting along the eastern flank of Mt. Diablo may contribute to the abrupt turn of the Creek (United States Geological Survey, 1994; Mt. Diablo Interpretive Association, 2000). The landscape in this zone consists of rolling foothills and valleys vegetated with a mosaic of annual grasslands, oak woodlands, and chaparral. The geology in this zone is similar to that of the upper zone in that the bedrock is still dominated by ancient marine sandstones and shales sitting



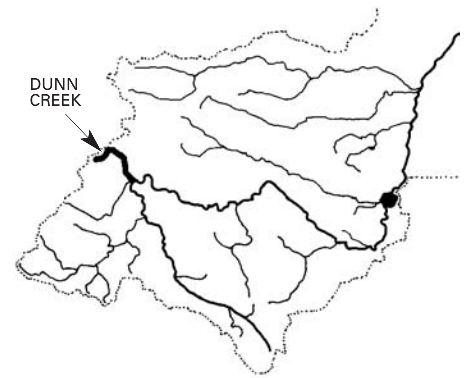
on top of the Mt. Diablo Ophilite. The major difference from the upper zone is that the stream flows through relatively broad alluvial valleys rather than narrow bedrock canyons.

The major tributaries in this zone include Curry Creek, Perkins Creek, Sycamore Creek, Round Valley Creek, and Briones Creek. Curry, Perkins, Sycamore, and Round Valley creeks are important tributaries because they contain isolated coldwater pools throughout the summer and therefore provide important habitat for aquatic species. In addition to the many perennial pools in Marsh Creek's tributaries, there are isolated springs supporting intermittent perennial flow in Marsh Creek in this zone of the watershed.

Briones Creek is the largest sub-watershed in the intermediate zone and drains approximately 10 square miles of grassland and oak-savannah before its confluence with Marsh Creek directly upstream of the Marsh Creek Reservoir. Briones Creek is a seasonal creek that runs through shallow (10–20 inches to bedrock), alluvial soils.

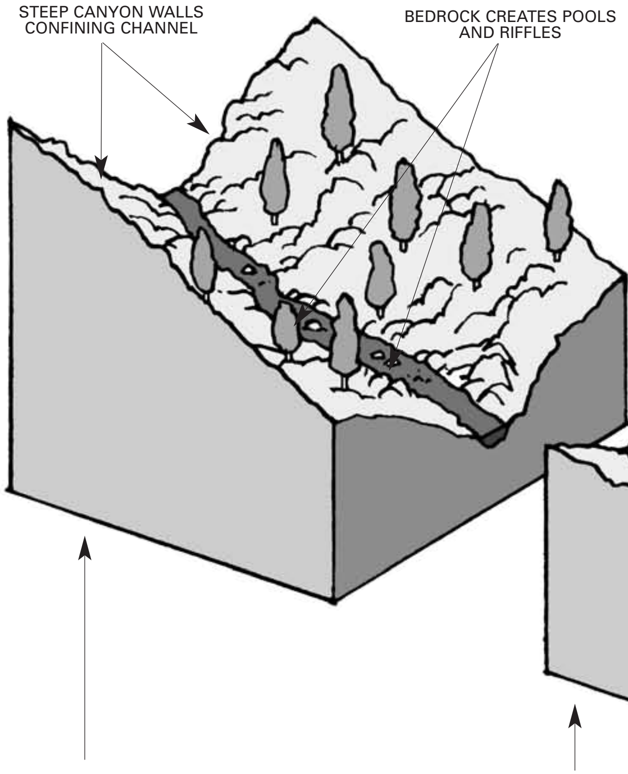


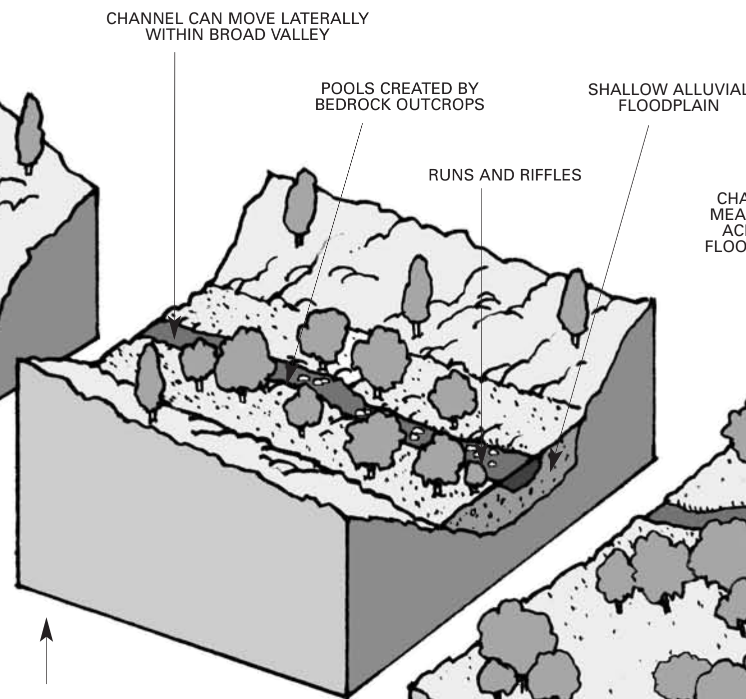
These soils confer tremendous instability to the channel and hence, the channel is very mobile and development of woody riparian vegetation is sparse (Wagstaff and Associates, 1996). This sub-watershed supports some of the best native rangeland currently existing in the watershed and contains rare terrestrial communities including Valley Sink Scrub and Northern Claypan Vernal Pools as well as rare plant species such as San Joaquin spearscale *(Atriplex joaquiniana)* and big tarplant *(Blepharizonia plumosa ssp. plumose)* (Wagstaff and Associates, 1996). A smaller tributary, Dunn Creek, is important because it drains the historic Mt. Diablo Quicksilver Mine – the primary source of mercury in the watershed. Marsh Creek watershed mercury issues are discussed in greater detail in Chapter 3.

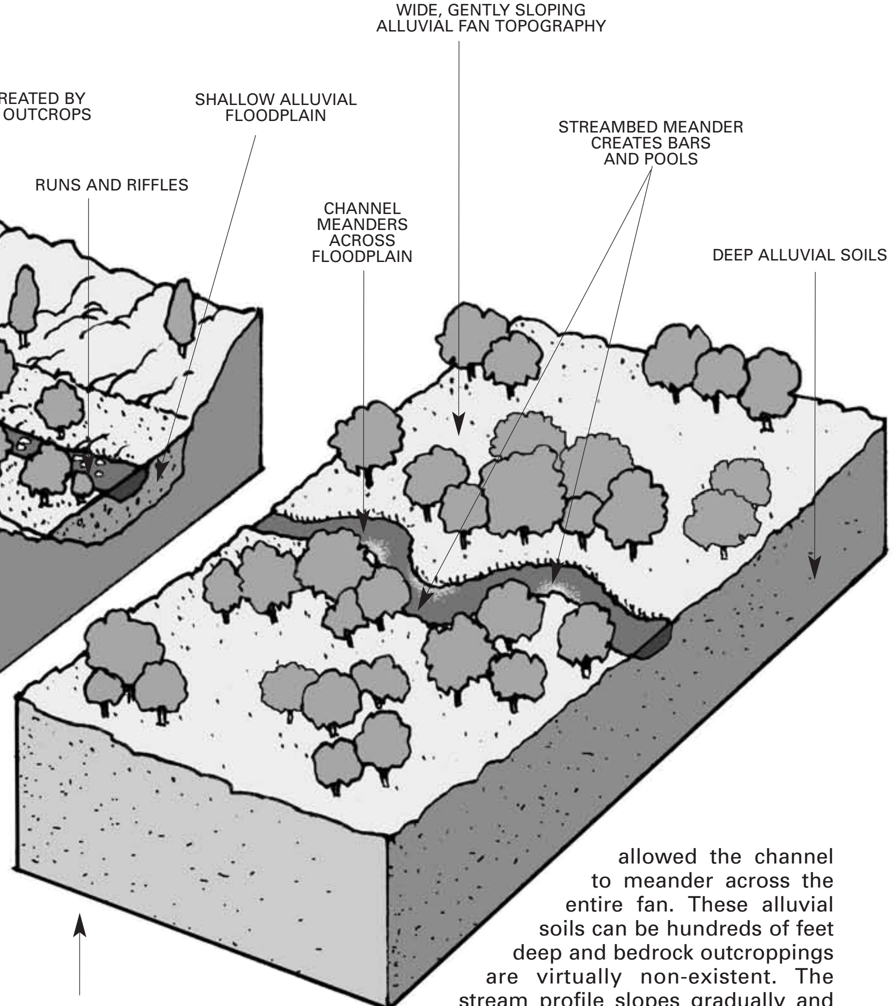


Throughout the intermediate zone, Marsh Creek and its tributaries generally flow across alluvial soils that have been deposited in the valley bottoms over thousands of years. Over time the channel has migrated back and forth across the valley bottom, limited only by the valley walls and sandstone outcrops that occasionally punctuate the gradually deepening alluvial deposits. Figure 3 illustrates how stream planform and profile respond to changes in topography and geology as the stream moves from the bedrock dominated upper zone into the alluvial intermediate zone. Because the stream periodically flows over bedrock outcrops in the alluvium, the channel of the Creek can vary from shallow and wide with a uniform bed as it flows across deep alluvium to steep and narrow with numerous pools as it cuts through the bedrock.

Local soils data provide important clues regarding the physical processes that define the character of Marsh Creek and its floodplain in the intermediate zone. In the steeper upstream reaches of this zone Marsh Creek flows through the Zamora soil series. This series, common to narrow valley floodplains, is well-developed with depths to bedrock greater than 5 feet. The soil texture is generally a fine-grained silty clay loam with occasional gravel layers found in the lower horizons. The fine-textured soils were deposited in floodplain environments, while the gravel layers were deposited as the streambed moved back and forth across the valley bottom. These Zamora







CONFINED REACH

Shallow bedrock and steep channel walls confine Marsh Creek and offer very little room for lateral migration. In this steep-sloped topography, the dominant geomorphic process is erosion and the stream develops little to no floodplains. Because stream energy cannot dissipate by spreading over a floodplain, the energy is focused on the bed and banks and erodes the bedrock channel. Differential erosion rates on various exposed rock formations and strata alignments cause the stream profile to vary, resulting in the creation of both deep bedrock pools and shallow riffles.

SEMI-CONFINED REACH

In the semi-confined reaches, Marsh Creek is less restricted by narrow canyon walls and the channel migrates laterally within the confines of the broader valley floor. These broader valley floors facilitate the development of alluvial floodplains typified by Zamora series soils in the more confined areas and Brentwood series soils in the less confined areas. Another important component of the semi-confined reaches is the periodic outcrops of shallow bedrock that confine the stream and often create bedrock pools supported by extruded groundwater. The channel profile consists of runs and riffles across coarse-grained alluvium, punctuated by bedrock pools.

UNCONFINED REACH

Below the current-day location of the Marsh Creek Dam, the channel enters a large alluvial fan that stretches north to the Delta and east-west from Big Break to the Old River. Prior to channelization, the wide, gently sloping topography and deep alluvial soils allowed the channel to meander across the entire fan. These alluvial soils can be hundreds of feet deep and bedrock outcroppings are virtually non-existent. The stream profile slopes gradually and slight changes in gradient control the configuration of the channel and texture of the channel bed. The only prominent non-alluvial soils along this fan are the Delhi sand dunes that are derived from eolian processes and control the westward migration of the channel in the lower watershed near the City of Oakley.

Figure 3 – Range of Marsh Creek Confinement

Figure 4 – Rancho Los Meganos

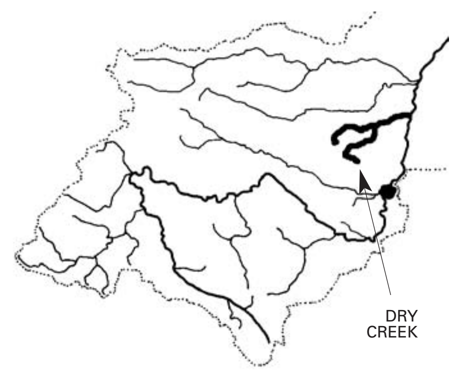
A panoramic landscape of Rancho Los Meganos and the John Marsh House, painted by Edward Jump in 1865. Courtesy of the Bancroft Library.

soils are also known to maintain near surface (4–12 inches deep) moisture from November to April, and thus experience wetting and drying characteristic of wetland/floodplain soils. The channel and floodplains in the downstream reaches of the intermediate zone are composed mainly of Brentwood soils. These alluvial soils are also greater than 5 feet deep but finer-textured than the Zamora soils and have higher clay content. Brentwood soils are common in alluvial fan settings, and like the Zamora soils, they maintain shallow moisture throughout the rainy season. Historical ecology research indicates that Brentwood soils were commonly associated with mature valley oak woodlands (Jones and Stokes Associates, 1994). The Zamora and Brentwood soils confer a propensity for lateral channel migration, which is manifested in the increased sinuosity of Marsh Creek in these reaches dominated by deep (greater than 5 feet) alluvial material. Interspersed between the alluvial Zamora and Brentwood soils are much shallower soils of the Millsholm and Los Gatos series that form over bedrock outcrops. The Millsholm and Los Gatos soils are made up of fine-grained materials that range from very shallow (less than 10 inches to bedrock) to moderately shallow (10–40 inches to bedrock).

Current land uses in this zone include recreation, ranchette development, grazing, and agriculture. Most of the agriculture is in the lower portion of this zone and consists primarily of orchard crops in the rich alluvial soils. With the exception of a few hundred feet of stream channel in Round Valley Regional Park and the flood control easement at the Reservoir, Marsh Creek's channel runs through privately owned land in this zone. Substantial development has yet to occur on the privately held land in this zone, but some parcels along the Creek corridor have been sub-divided into ranchettes and this land use conversion, if continued, could have a major impact on watershed processes. Although the majority of the lands in this zone are currently under private ownership, the Trust for Public Land and its regional partners recently helped protect 4,000 acres of the Cowell Ranch Property, now owned by California State Parks. This property protects vast acreages of annual grassland, blue oak-savannah, riparian woodlands, and vernal pools in the intermediate zone (Figure 1).

The Lower Zone

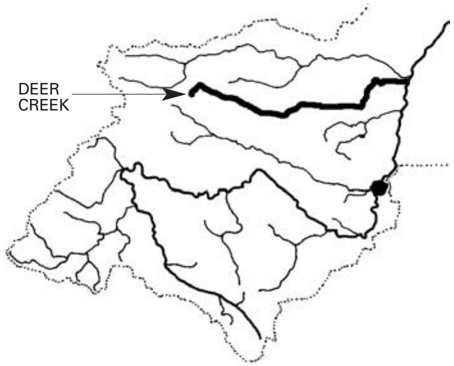
The lower zone of the watershed extends approximately 11 stream miles from the outfall of the Marsh Creek Reservoir through the cities of Brentwood and Oakley and into the western Delta at Big Break. In this zone, Marsh Creek flows due north at a relatively gentle slope of approximately 0.3% or 15 vertical feet per mile of stream. Directly below the Marsh Creek Dam, at the upstream end of the lower zone of the watershed, sits the historic John Marsh House. Built by Marsh in 1856, this ranch house was the centerpiece of what became one of the largest cattle ranches in the area. Figure 4, a painting of Rancho Los Meganos and the John Marsh House, depicts the character of the stream and its floodplain a full century before the Marsh Creek Dam was constructed.



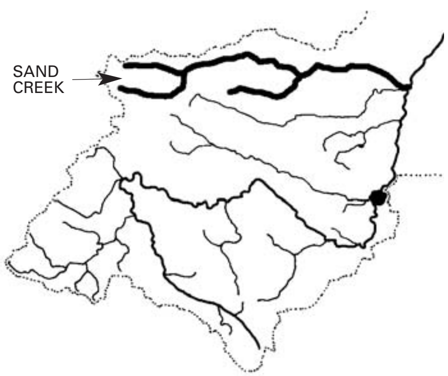
The lower zone of the watershed contains Marsh Creek's confluences with Dry, Deer, and Sand creeks. These sub-watersheds function as important conduits of surface flow, sediment, agricultural return flow, and urban runoff into lower Marsh Creek. Dry Creek flows seasonally and has two branches draining approximately 3.5 square miles. Although Dry Creek's watershed is relatively small in area, the steepness of its topography (>2%) and the channel's rapid descent into Marsh Creek creates a flashy hydrology characterized by short periods of high flows during storms followed by long periods of no flow the remainder of the year. In order to control the flash floods that periodically emanated from the Dry Creek watershed, the second largest flood control dam in the watershed, the Dry Creek Dam, was built less than 1.5 miles upstream of its confluence with Marsh Creek.

Deer Creek, the next tributary to empty into Marsh Creek, drains 6.6 square miles of foothill and floodplain. Unlike Dry Creek, Deer Creek flows for approximately one stream mile through flat floodplain lands before its confluence. Deer Creek is a seasonal stream and is perhaps the most severely altered tributary of Marsh Creek.

Historic maps and aerial photos indicate that for much of the past 75 years the channel was disconnected from Marsh Creek. Today, its lower reaches are straightened, channelized, diverted, and forced underground into culverts before it resurfaces and enters Marsh Creek.



Sand Creek, the largest of the lower zone tributaries, drains 14.4 square miles from its headwaters in Black Diamond Mines Regional Park to its confluence with Marsh Creek approximately 700 feet downstream of the Deer Creek confluence. Sand Creek appears to have seasonal flow in its more natural upland reaches, and perennial flow supported by agricultural return flows in the lowland reaches. Sand Creek, between its urban boundaries with Antioch and Brentwood and Black Diamond Mines Regional Park, contains intact aquatic and riparian habitat. Moreover, recent observations indicate that upper Sand Creek contains perennial pools, which function as vital dry season habitat for resident aquatic species and potential habitat for anadromous fish such as steelhead trout (Kanagaki, pers. com). In addition, Sand Creek, as the name implies, flows through deep sandy soils in its lower reaches and is therefore likely to be a major sediment source for lower Marsh Creek and Big Break.



Below the Reservoir, Marsh Creek gradually drops out of the hills and flows into a wide floodplain. Unlike in the upper zones of the watershed, in the lower zone Marsh Creek is not confined by bedrock or valley walls as it flows across the expansive alluvial fan and floodplain before draining into the Delta. The deep alluvial soils in the lower Marsh Creek watershed were deposited over millions of years by Marsh Creek and its tributaries as well as by floodwaters from the San Joaquin River. The soils underlying the current location of the Marsh Creek channel are dominated by the Sorrento series, an alluvial soil series that is known to support wetland vegetation and is commonly associated with sycamore riparian woodlands (http://www.statlab.iastate.edu/soils/osd/dat/S/SORRENTO.html). In addition to the Sorrento soils, the Marsh Creek fan is a mosaic of deep alluvial deposits including the Capay, Rincon, and Brentwood soils. In the northwestern section of the watershed, eolian (wind deposited) sand dunes were deposited on top of the alluvial soils. These dunes are composed of the Delhi soils that were formed in the early Holocene (approximately 8,000–10,000 years ago). Scientists speculate that these inland dunes were built during a period when sea level was significantly lower and large amounts of glacier-carved sediments were being washed out of the Sierran rivers. Due to a lower sea level, the Sacramento and San Joaquin rivers flowed more rapidly all the way to Suisun Bay where they entered the gradually rising seawaters. During flood events they dropped huge amounts of sand along their banks near present day Pittsburgh. These sands were then transported by winds through the Carquinez Straits and deposited as sand dunes on top of existing alluvium in present day Antioch and Oakley.

Below the Marsh Creek Reservoir, Marsh Creek once migrated widely over the lower zone, creating a broad alluvial fan over thousands of years. Figure 5 maps the extent and orientation of Marsh Creek's alluvial soils (Sorrento, Brentwood, Capay, and

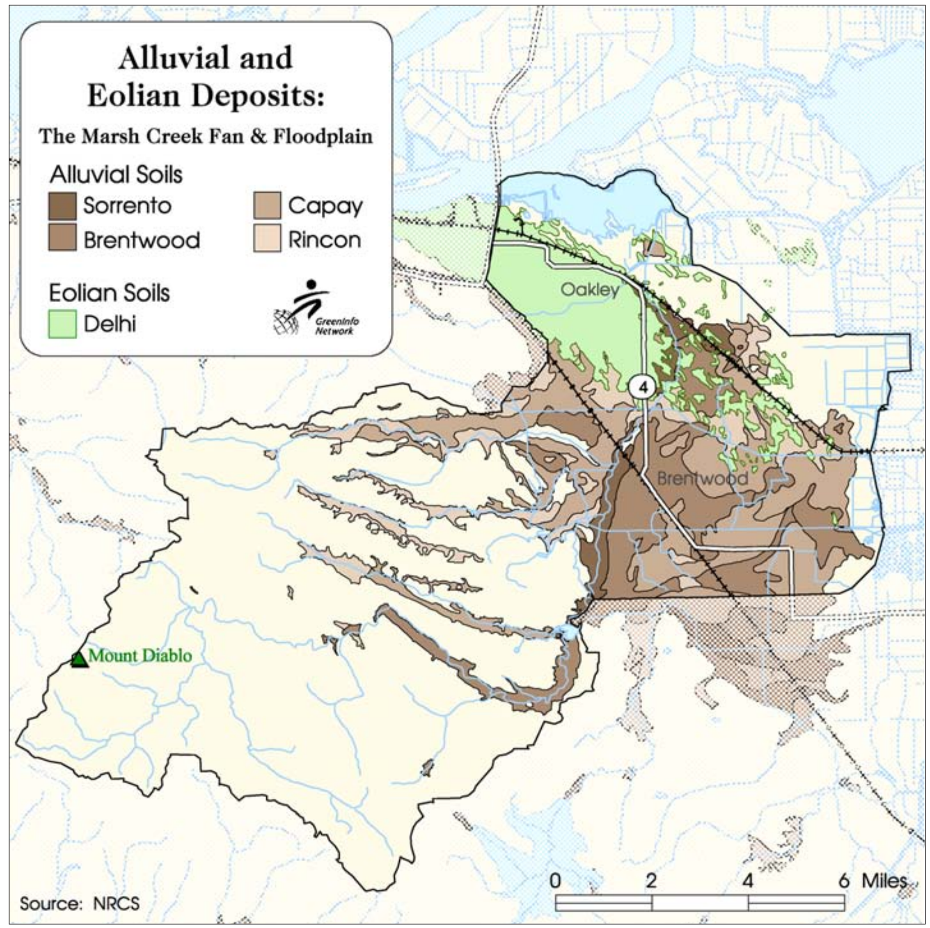


Figure 5

Rincon) and eolian sands and illustrates the current and prehistoric locations of the Marsh Creek channel. Historically, as Marsh Creek exited the constrained valleys of the intermediate zone, the primary channel migrated widely across its fan and may have flowed as far east as Kellogg Creek into what is now Discovery Bay, and as far west as Big Break. Marsh Creek probably would not have moved farther west than Big Break because its path would have been obstructed by the inland sand dunes in the northwestern portion of the lower zone.

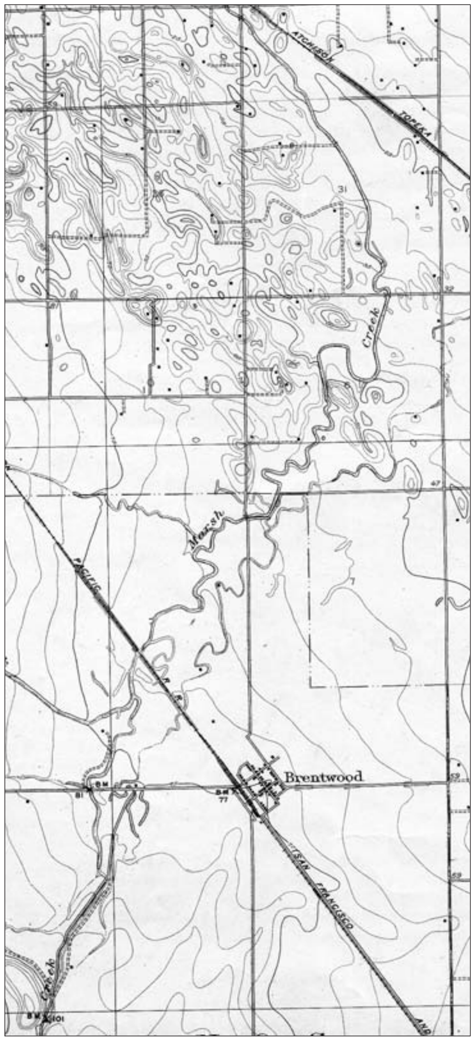


Figure 6 – USGS 1914
Marsh Creek near Brentwood, 1914. Courtesy of the United States Geological Survey.

Prior to construction of the Marsh Creek flood control channel, the combination of deep, erodible soils and gently sloping fan topography resulted in extensive meanders, multiple channels, and regular channel migration. Although land conversion has greatly altered both the topography of the Marsh Creek fan and the mobility of Marsh Creek, historic US Geological Survey (USGS) maps from 1914 provide a glimpse into the historic planform of the Creek as it flowed through the lower zone (Figure 6). These meanders and multiple channels created a mosaic of deposition and erosion across Marsh Creek's fan and floodplain. The periodic reworking of the alluvial surfaces likely resulted in a patchwork of riverine wetlands ranging from mature valley oak woodlands to seasonal wetlands.

The character of Marsh Creek may have looked very different as the Creek channel flowed through the eolian Delhi sands. Unlike its character in alluvial soils, as Marsh Creek flowed through the unstable sand flats along the eastern edge of the dunes it would have historically functioned as a distributary system, dropping out the sand-enriched sediments and rapidly losing surface water to the ground via infiltration. The extremely high infiltration rates associated with the Delhi soils and the resulting loss of surface water to groundwater is illustrated by historic maps depicting the terminus of perennial surface flow in Marsh Creek along this eastern edge of the inland dune system (Figure 7) (State Geological and US Surveys, 1871; McMahon, 1908).

Flooding and Flood Control

The tendency of Marsh Creek to meander across the gently sloping topography of the lower watershed and regularly inundate its broad floodplain was not compatible with agricultural and urban development. Due to the easterly slope of the floodplain, flooding issues have historically been most acute along the northeastern boundary of the watershed. Beginning at the turn of the century, humans began to confine the channel to its present location and build levees to protect the rich farmland on the eastern side of the channel. As Brentwood and Oakley grew and more homes, fields, and businesses were built in Marsh Creek's floodplain, flood damage to property and structures increased. Flood control efforts throughout this century straightened and confined the lower 9 miles of Marsh Creek and the lower reaches of Dry, Sand, and Deer creeks. Figure 8 documents the effects of human flood control efforts on the channel of lower Marsh Creek and its tributaries from 1914 to the present. These images show snapshots of the position and character of the various channels during four different periods of development. This series was created from a combination of historic USGS maps and aerial photographs. In the early 20th century, Marsh Creek apparently flowed in at least two channels (Figure 8a), the first near Marsh Creek's present location and the second channel located to the east closer to downtown Brentwood. Where Marsh Creek enters the wide floodplain, at its confluence with Deer Creek, the channel was characterized by sinuous meanders. These meanders conjure up images of a lower watershed floodplain full of oxbow ponds, backwaters, and seasonal marshes all sustained by periodic flood inundation. Between 1914 and the late 1950s orchards expanded across the fertile floodplain soils and the town of Brentwood began to grow. Aerial photographs taken in 1939 show that Marsh Creek had been routed into a single channel by the late 1930s (Fairchild Aviation, 1939). These photographs indicate that the secondary channel shown on early maps was removed and the land was converted to agriculture. The photo record also suggests that the removal of significant stands of floodplain vegetation and the elimination of associated off-channel wetlands accompanied these channel manipulations. By the late 1930s, expansion of agriculture had reduced the riparian corridor along Marsh Creek to a fringe of trees no more than 50 feet wide on either side. The aerial photographic and map records from the 1940s are scarce, but it does appear that the position of the Creek underwent some further alterations during that time period. USGS Quad Maps from 1954 (Figure 8b) reveal some straightening of Marsh Creek and Dry Creek as well as the disconnection of Deer

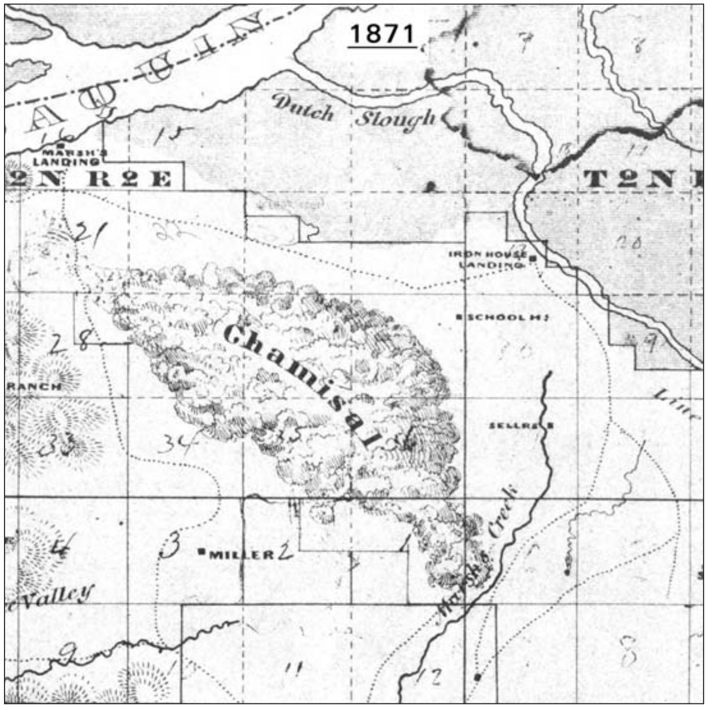


Figure 7a – 1871
Figure 7b – 1908
Historic maps of lower Marsh Creek depicting the seasonality of surface flow. Courtesy of State Geological and US Survey (1871) and McMahon (1908).

Creek from Marsh Creek. The position and sinuosity of Marsh Creek below Sand Creek indicates that the stream was still free to meander in the alluvial reaches well into the 1950s.

As Brentwood grew and more floodplain lands were converted to both agriculture and suburban/commercial use, the effects of frequent flood events began to have significant financial impacts in the lower zone of the Marsh Creek watershed. Contra Costa County's 1959 Watershed Work Plan cites flooding as the major problem facing the watershed.

> "Damaging floods have occurred, on the average, once in three years, with three of the worst since January 1952. It is not uncommon to have several floods in the same year, as happened in the winter of 1955–1956 and again in 1958. When such events occur, some damage is suffered to roads, bridges and stream banks in the middle reaches of the creek. The great bulk of the damage however, takes place on the flood plains of Marsh and Kellogg creeks. In the case of Marsh Creek, floodwater leaves the inadequate channel at various points but is prevented by topographic conditions from returning... Such flows have inundated as much as 4,900 acres to depths of four feet." (Eastern Contra Costa Soil Conservation Service et al., 1959)

The 1959 Work Plan lists the extent of damage to orchard crops, residences, and commercial buildings. Figure 9 illustrates the extent of flooding from the major flood in 1955. Although this flood was originally calculated by the flood control district to have a 96-year return interval, the current period of record indicates that the return interval may be substantially lower. The floodwaters from this and other storms had a particularly devastating effect on the agricultural lands in the Knightsen area, at the northeastern corner of the watershed where floodwaters ponded at depths of 5 feet or more, due to the easterly slope of the floodplain.

The series of flood events in the 1950s compelled the County flood control district and the Soil Conservation Service to implement a major flood control program that channelized lower Marsh Creek and constructed two flood control dams on Marsh Creek and Dry Creek. These flood control improvements straightened and confined the existing channel, removed all of the existing near channel riparian vegetation, and increased the channel cross section to efficiently convey floodwaters through the lower zone into the Delta. These improvements stabilized Marsh Creek and the near-confluence portions of its tributaries, preventing the natural tendency of the channel to migrate laterally. Channel clearing and excavation increased the amount of water the channel could carry, thereby preventing high flows from inundating the nearby floodplain and the associated riparian and wetland habitats. Figure 8c illustrates the configuration and character of Marsh Creek and its tributaries following these improvements and the construction of the Marsh Creek Dam. Notice the reduc-

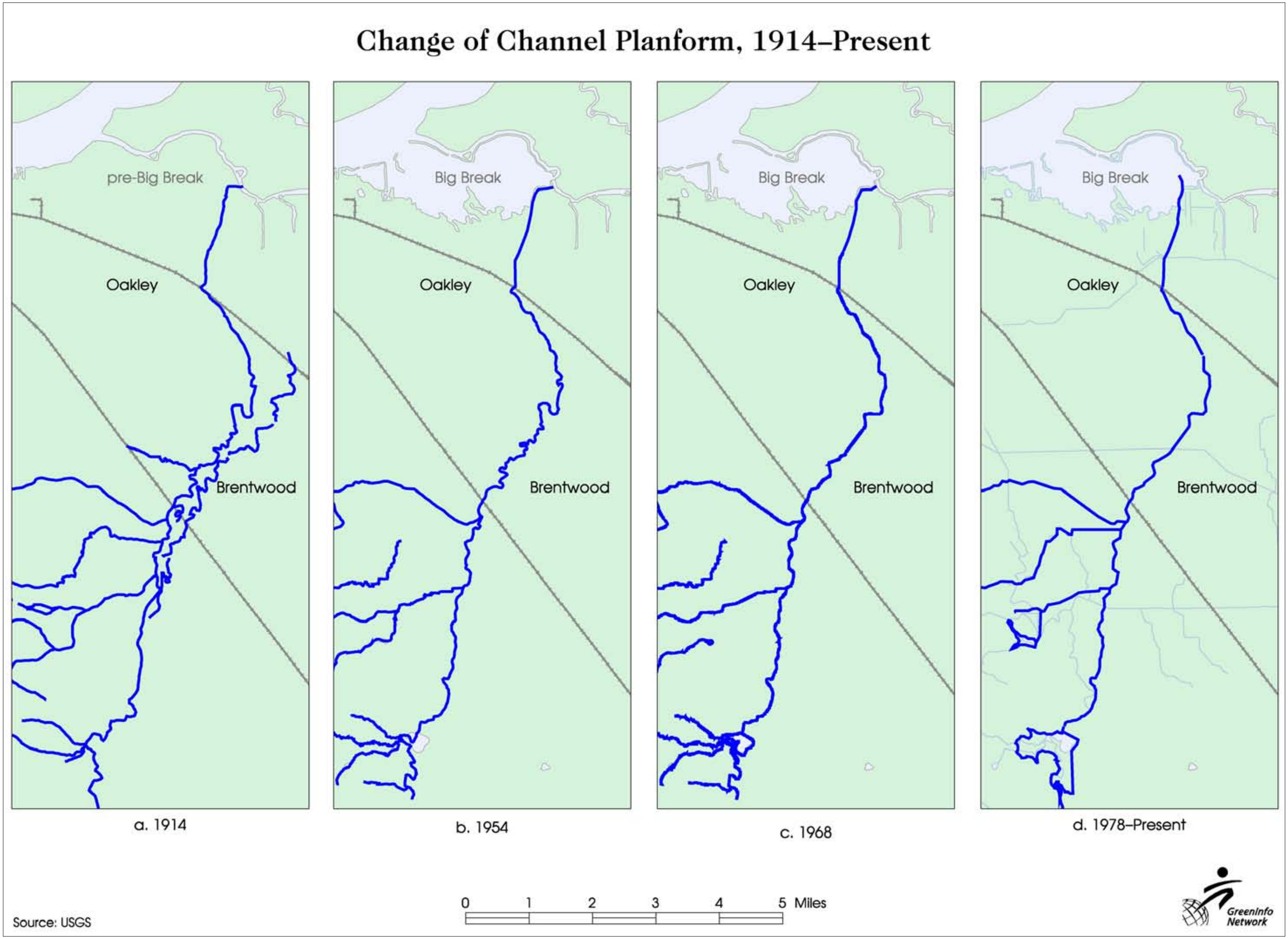

Change of Channel Planform, 1914–Present
pre-Big Break
Oakley
Brentwood
a. 1914
Big Break
Oakley
Brentwood
b. 1954
Big Break
Oakley
Brentwood
c. 1968
Big Break
Oakley
Brentwood
d. 1978–Present
0 1 2 3 4 5 Miles
Source: USGS
GreenInfo Network

Figure 8

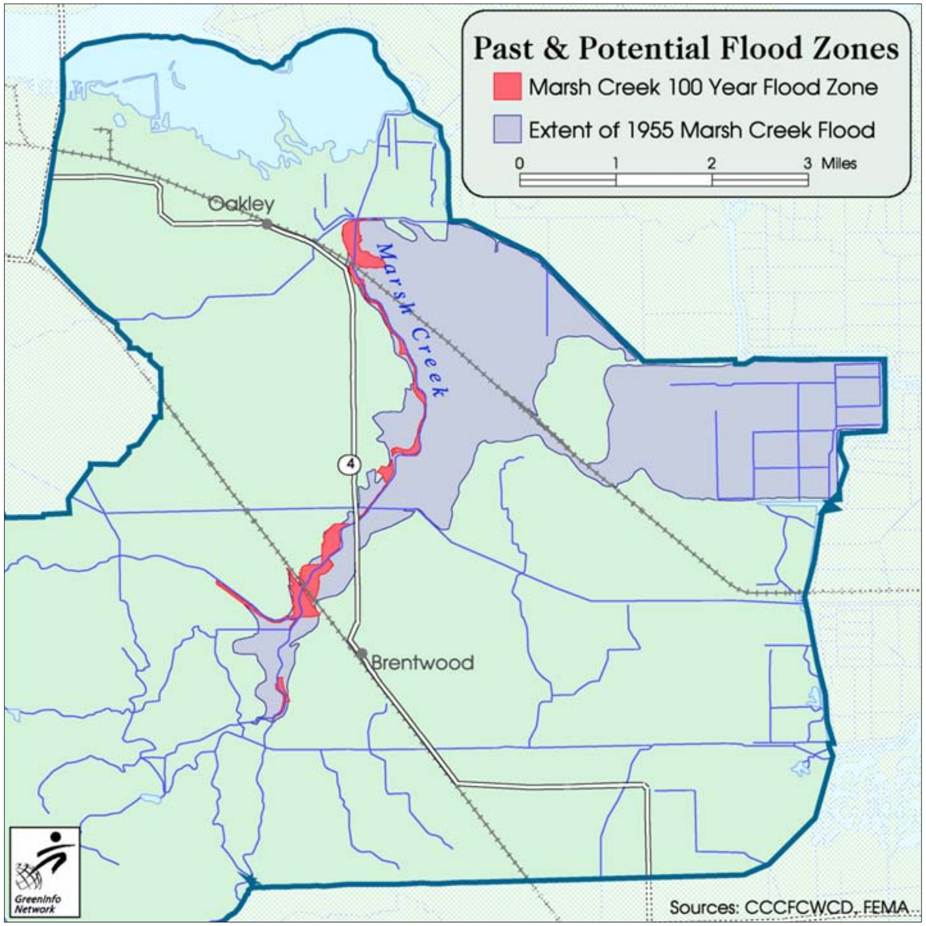


Figure 9 – Flood Map

tion of sinuosity along Marsh Creek below Sand Creek and the straightening of Dry Creek at its confluence with Marsh Creek. By the early 1970s the series of flood control improvements started a decade earlier were completed. Figure 8d shows the current planform of Marsh Creek and the lower reaches of Dry, Deer, and Sand creeks. The changes evident here are the full footprint of the Marsh Creek and Dry Creek dams, the linear realignment of lower Sand Creek, and the reestablishment of Deer Creek's connection with Marsh Creek via a straight channel.

Channel excavation, clearing, and straightening over the past century has resulted in the loss of more than 50%[1] of the total stream channel length in the lower zone. Similarly, these flood control improvements have eliminated nearly all the riparian and floodplain habitat that once flourished along the margins of Marsh Creek. Habitat in the stream channel itself has been further impacted by the loss of natural complexity associated with a meandering stream channel. Prior to the flood control improvements, the channel form was highly variable with pools, gravel riffles, gentle bars, and steep cut-banks. To increase the amount of floodwater that the channel could carry, the flood control improvements eliminated these channel habitat features and created an enlarged, trapezoidal flood control channel with a flat bottom and uniformly sloped banks devoid of vegetation. The County flood control district eradicates any vegetation that becomes established along the flood control channel with herbicides in a management technique known as "chemical mowing" to maintain sufficient channel capacity to convey the 50 to 100-year flood.

Trapezoidal flood control channels are specifically designed to reduce the potential for regular floodplain inundation. Without regular inundation, floodplain species are deprived of the life sustaining nutrients, moisture, and disturbance regimes with which they have evolved. Aerial photographs from the 1960s document the complete destruction of the remnant riparian corridor along Marsh Creek from the Dry Creek confluence to Big Break. Today, flood protection activities such as levee maintenance, channel dredging, and vegetation removal have transformed the creeks of the lower Marsh Creek watershed from dynamic living systems to static, confined, and ecologically impoverished water conveyance structures.

Historically, the channel was considerably smaller with an uneven bottom and irregular banks. A comparison of the historical and existing creek channel cross sections (Figures 10a and 10b) illustrates how the 1958 surveys conducted for the 1959 Work Plan enlarged the channel and made it more uniform. Enlarging the channel entailed removing large sections of stream bank that contained riparian vegetation and wildlife habitat. The historic channel had a considerably more heterogeneous form that was shaped and maintained in part by the dense riparian vegetation along its banks. Although the historic channel cross sections depicted in Figures 10a and 10b are relatively steep, the historic channel form meandered between steep "cut banks" with overhanging vegetation and gently sloping, unvegetated sand and gravel bars. This is illustrated in the topographic map of the historic channel (Figure 11). The flood control channel design shows the 1959 Work Plan for straightening and enlarging the channel after the 1955 floods, and the existing cross section depicts the shape of the channel today.

The lower Marsh Creek channel where it enters the Delta was bordered by natural levees built up from sediments deposited when the stream periodically over-topped its banks (Figure 10b). Over thousands of years the Creek shifted back and forth depositing mineral soils along its banks and forming a broad delta more than a mile

[1] Measurements were conducted with a map wheel and include the loss of the secondary channel in the 1914 USGS quad and the loss of stream length from the 1950s' flood control improvements.

[2] Over the last several thousand years, the mouth of Marsh Creek alternated between its current location and points farther south near Discovery Bay as illustrated by the soil patterns depicted in Figure 5.

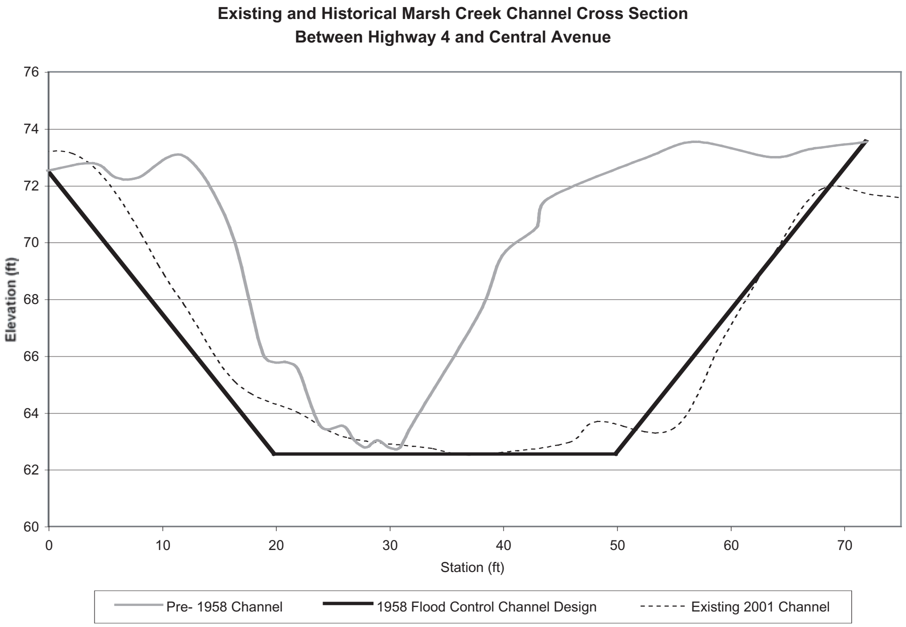


Figure 10a

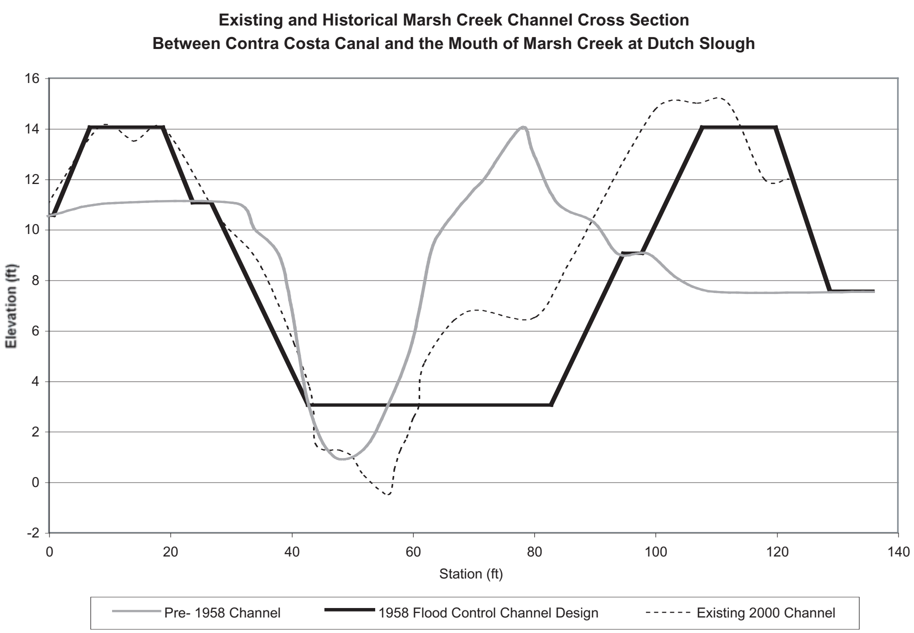


Figure 10b

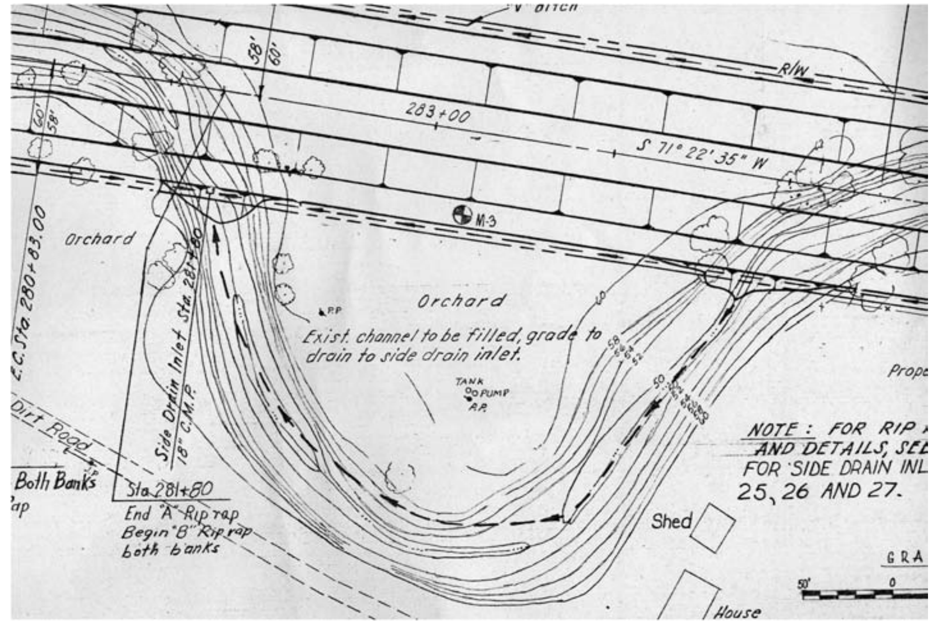


Figure 11 – Excerpt of 1958 Flood Control Channel Design to Straighten Marsh Creek

wide – from the current location of Marsh Creek eastward to Sellers Avenue[2]. These rich deltaic soils supported a mosaic of riparian forest and wetlands before settlers cleared them for agriculture. Today the channel near the Delta at Big Break has been enlarged and confined by larger artificial flood control levees that are never overtopped by floodwaters, and the flood control district eradicates any tree seedlings that become established on these levees.

Construction of the flood control channel not only changed the shape and size of the channel's cross section, but it also significantly changed the gradient of the stream channel from Brentwood to the Delta (Figures 12a and 12b). Contra Costa County and the Soil Conservation Service surveyed the stream channel in 1958 and the Natural Heritage Institute (NHI) resurveyed it in 2001 with the help of students from the Department of Landscape Architecture and Environmental Planning (LAEP) at UC Berkeley. Historically, the stream gradient in Marsh Creek abruptly flattened below its confluence with Sand and Deer creeks due to the large amount of sediment deposited by these tributaries. These abundant natural sediments from Sand Creek periodically clogged the channel, causing Marsh Creek to frequently overtop its banks and bifurcate into two channels below its confluence with Sand Creek, as shown in the 1914 channel map in Figure 8a. In its attempt to transport the large sediment loads delivered from Sand Creek, Marsh Creek historically assumed a highly sinuous meandering pattern downstream of Sand Creek. The flood control channel

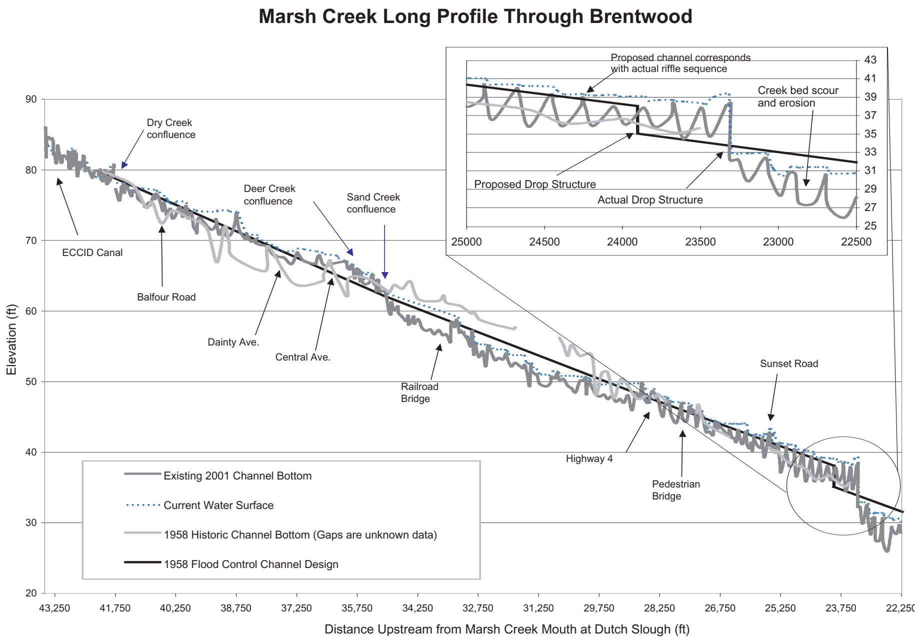


Figure 12a

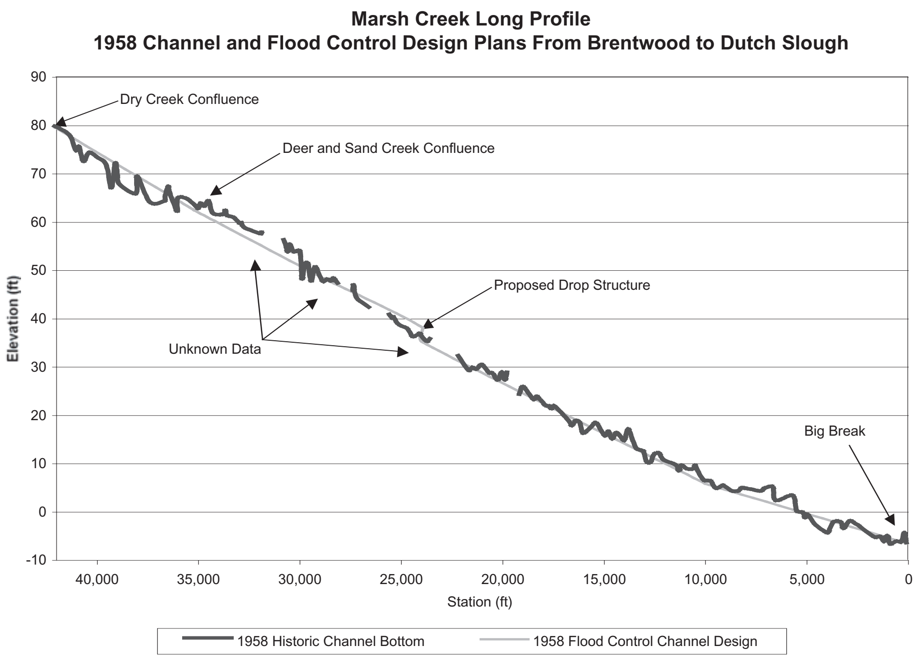


Figure 12b

Figure 13 – The Marsh Creek Grade Control Dam Upstream of the Brentwood Wastewater Treatment Plant

Figure 14 – Grade Control Structures in the Marsh Creek Channel

"improvements" were designed to straighten out these meanders, excavate the excess sediment, and increase the channel gradient through this reach with the objective of preventing Marsh Creek from flooding. To accommodate the increased stream gradient, the Soil Conservation Service and the County constructed a grade control dam or "drop structure" near the Brentwood Wastewater Treatment Plant where water cascades over a concrete check dam (Figures 12a and 13).

The stream gradient also flattened abruptly where it entered the Delta near the Contra Costa Canal (Figure 12b). Here the stream deposited its sediment load that formed the historic delta of Marsh Creek. Although historic maps are inconclusive, Marsh Creek probably branched into a network of dispersed channels to carry water and sediment across its low gradient delta, as is the case with other deltas. Since 1914, however, Marsh Creek has been confined to a single, stable channel due to the construction of the Contra Costa Canal, which only provides one narrow gap for the Creek to flow. The construction of the Canal across the Marsh Creek delta blocked floodwaters and exacerbated the flooding of Knightsen during the first half of the twentieth century. The 1958 flood control channel was designed to excavate a steep gradient through this historical delta of Marsh Creek to reduce the frequency of floods.

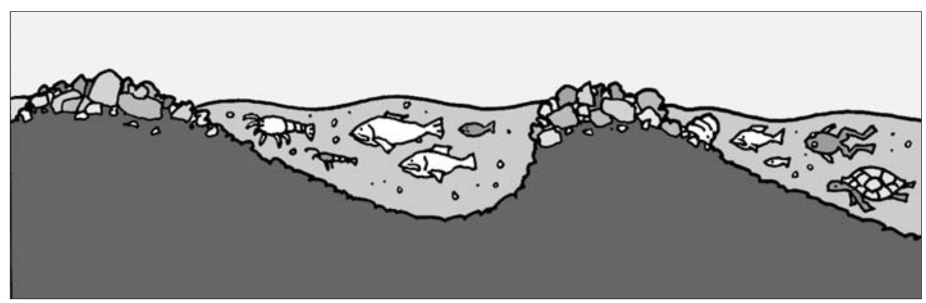


Figure 15 – Habitat Formed by Pools and Riffles
Not to scale.

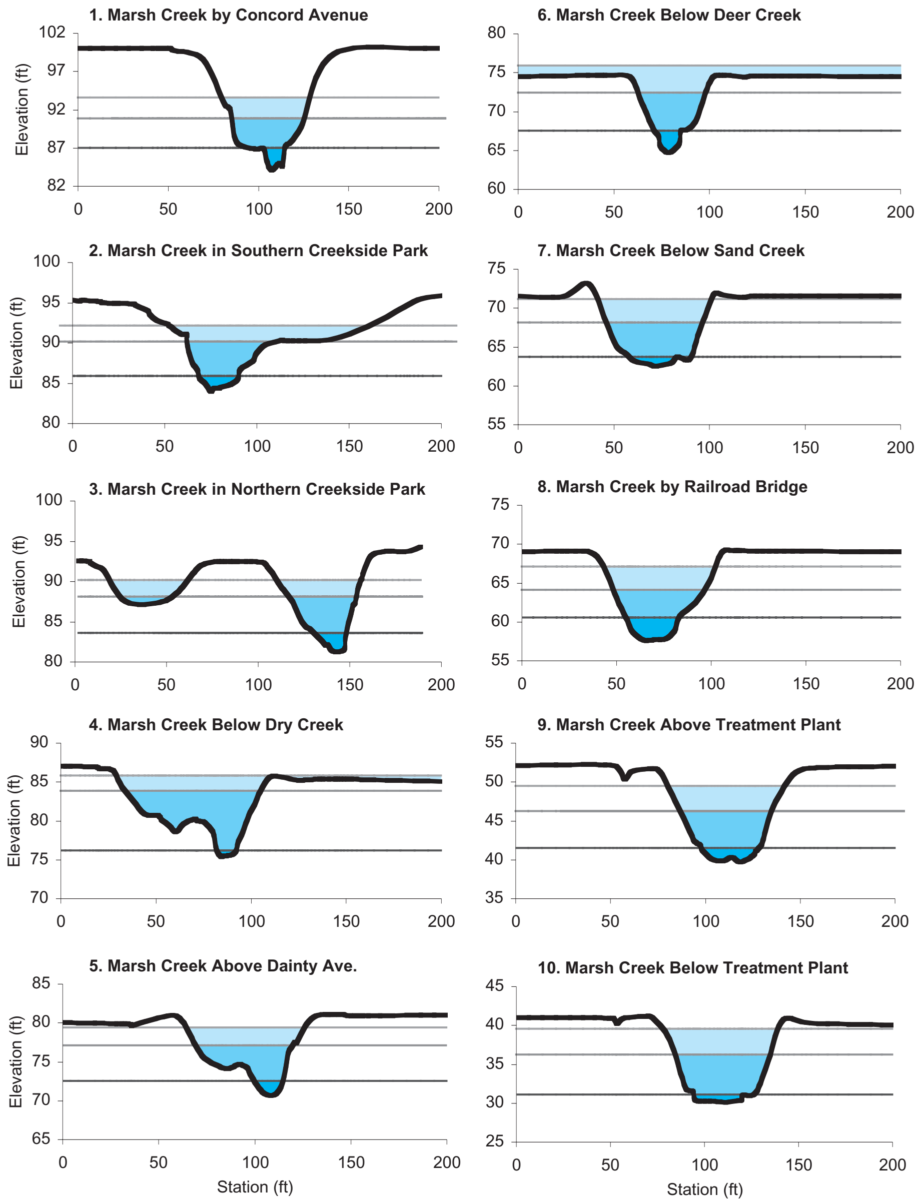


Figure 16 – Marsh Creek Cross Sections

Following the cross sections down the left column and then down the right column shows the changes associated with the Creek as it flows through Brentwood from north to south. The three horizontal lines represent water surface elevations associated with the 100-year flood (source: CCCFCD report), the two-year flood and the observed flow rate at the time of the survey (source: UC Berkeley LAEP students).

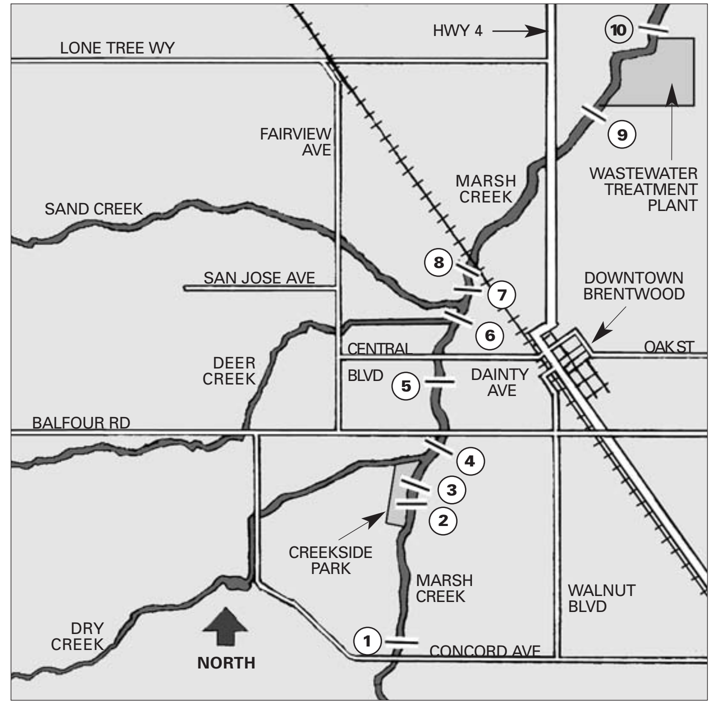


Figure 17 – Map of Marsh Creek Cross Sections through Brentwood

Measurements taken in Fall 2001 by NHI and UC Berkeley LAEP students.

A comparison of the 1958 and present day channel profile illustrates other interesting changes to the Marsh Creek channel. The 1958 channel survey depicts a series of large pits near Central and Dainty Avenues that are most likely the result of local borrow pits mined for sand and gravel to build roads and other infrastructure (Figure 12a). Downstream of the Highway 4 crossing, the present stream profile is characterized by a series of pools formed by engineered grade control structures constructed from imported rock (Figure 14). These structures were designed and built to force the flood control channel to maintain an even gradient. Although artificial, these structures create a series of pools and riffles that provide habitat for aquatic species (Figure 15 and see Chapter 4). The present day flood control channel bottom undulates far more than the flood control channel design bottom, which is shown as perfectly straight. These undulations are the result of both the graded control structures and changes in the channel bottom since the flood control channel was built. The present channel profile appears to be more locally complex than the historical channel profile, but this is probably an artifact of the difference in resolution of the two surveys. The survey by NHI and UC Berkeley measured channel bottom elevation every 20–50 feet, while the 1958 survey measured the channel topography more generally for the purposes of developing a grading plan. In reality, the historic channel profile was probably more complex than the existing channel profile.

Construction of the flood control project altered the riverine ecosystem in the lower zone of the watershed and accomplished the desired effect of protecting commercial, residential, and agricultural lands from all but the most extreme flood events. Figure 9, shows the 1996 Federal Emergency Management Agency (FEMA) 100-year flood map of lower Marsh Creek overlain on the 1955 flood map. According to the FEMA data, the 100-year flood zones are now restricted to small isolated pockets adjacent to the Creek. The juxtaposition of today's 100-year flood zones with the flooded area map from 1955, a flood that represents far less than a 100-year return interval, illustrates the effectiveness of flood control activities. It should be noted that FEMA maps do not account for the effects of future urbanization and therefore might already be out of date for a rapidly urbanizing region like the lower Marsh Creek watershed. Nonetheless, it is clear that where the water flows has changed dramatically over the past century. Lower Marsh Creek has been changed from a meandering and migrating stream connected to a rich and vital floodplain to a confined, straightened stream disconnected from its floodplain.

Although far more uniform than it was historically, the shape of the lower Marsh Creek channel still varies significantly between its upper reaches by Concord Avenue and downstream reaches near the Brentwood Wastewater Treatment Plant (Figure 16). NHI and students from UC Berkeley surveyed several cross sections through the City of Brentwood in 2001 (Figure 17). The channel downstream of Dainty Avenue is a more uniform trapezoidal flood control channel with steep banks compared to the channel between Dainty Avenue and Creekside Park. Downstream of Dainty Avenue the flood control district eradicates all woody vegetation to maintain enough channel capacity to convey the 100-year flood. Riparian vegetation in the channel reduces the amount of flow the channel can convey without flooding. Immediately below the confluence of Deer Creek, the channel is relatively small and unable to convey the 100-year flood even in the absence of riparian vegetation. Downstream of Sand Creek the channel is wider with steeply sloped banks in order to convey the additional floodwater inputs from Sand Creek, but it is not large enough to accommodate both floodwater and riparian vegetation.

Upstream of Dainty Avenue, the channel generally has a small floodplain that supports a modest band of riparian vegetation. These floodplains are inundated by the modest floods that occur, on average, every two years. Periodic inundation of the floodplain cycles nutrients, sustains riparian vegetation, and creates conditions favorable for aquatic species. Between Dainty Avenue and Creekside Park approximately 1 mile of channel was widened when the surrounding lands were developed in the last decade. Here the channel has a small floodplain and is large enough to accommodate both floodwaters and limited riparian vegetation. The channel cross section in northern Creekside Park encompasses a secondary overflow swale that was constructed when Creekside Park was developed, and conveys floodwaters into the Dry Creek detention basin. From Creekside Park upstream to the Marsh Creek Reservoir, the Creek was never channelized for flood control and still has a relatively natural shape and mature riparian vegetation. Nevertheless, the channel is somewhat entrenched either naturally or due to incision prompted by trapping of the natural sediment supply behind the Marsh Creek Reservoir a mile upstream. The cross section by Concord Avenue is particularly entrenched but this is probably due to its location immediately below a bridge crossing.

The upstream cross sections are more varied and often have a two-stage channel with a small floodplain surface that accommodates riparian vegetation. Marsh Creek above Dry Creek, which enters Marsh Creek at the north end of Creekside Park, is generally wider than downstream sections even though it conveys less floodwater. Flood control districts are required to manage the channel to contain all water during a 100-year flood, a flood that has a likelihood of occurring once every 100 years. However, in some sections of the Creek the 100-year floodwater surface elevations are above the top of the channel, such as on Marsh Creek below Dry Creek and below Deer Creek. Most of the year the water surface elevation is very low and large peak flows that shape the channel are much smaller than the 100-year flood and typically occur every two years.

Chapter 2

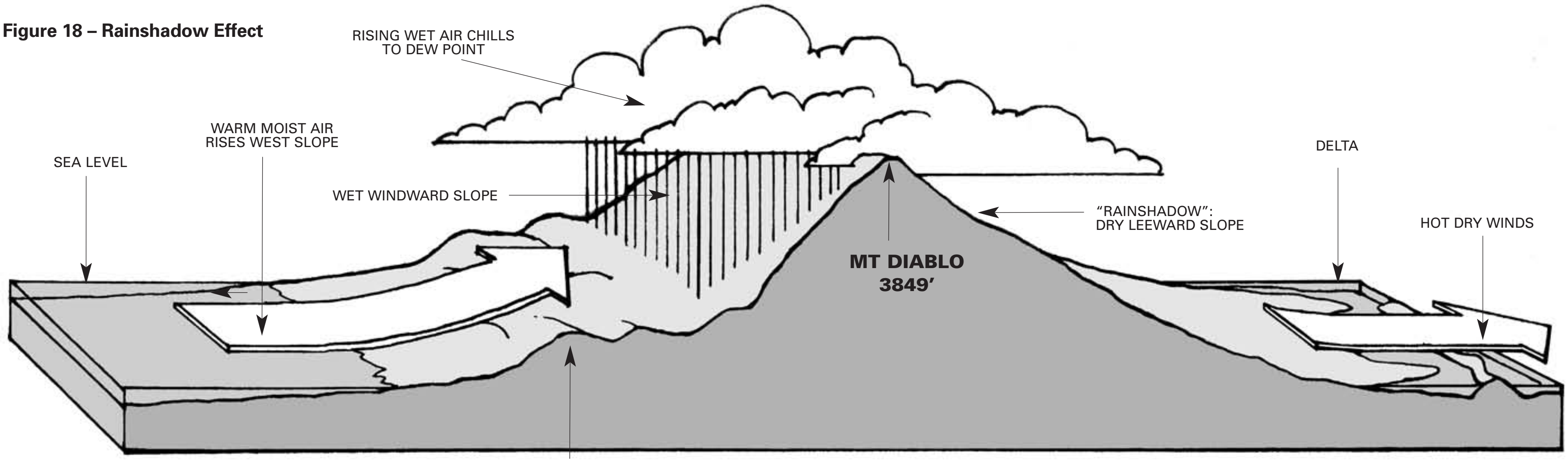
When It Flows

Streamflows in Marsh Creek and its tributaries are directly related to regional climatic patterns and fluctuate sharply in response to winter storms and summer droughts. The timing and magnitude of rainfall and the resulting streamflows are often in direct conflict with human land uses. For example, winter floods may portend financial ruin for businesses built in Marsh Creek's floodplain and regular summer drought severely limits local water supply for agricultural and municipal users. This chapter discusses climate and the resulting hydrologic patterns that control the flow of Marsh Creek and chronicles how human settlement and development have changed those hydrologic patterns.

Climate

The climate in eastern Contra Costa County is "Mediterranean," characterized by mild to moderately cold, wet winters and hot, dry summers. Mt. Diablo represents the border between the cool summer climate type found along the Pacific coast and the hot summer climate type found in the Central Valley (Bowerman, 1944). The absence of the summer fog in eastern Contra Costa County leads to higher average summer temperatures than in areas further west in the San Francisco Bay Area. Although summer fog is not common in the Marsh Creek watershed, marine winds, locally known as the "Delta Breeze," blow through the Golden Gate and up the Carquinez Straits, moderating summer temperatures in the low-lying regions (Soil Conservation Service, 1977). Furthermore, winter "Tule Fog," a common climatic condition in the Central Valley, occasionally blankets portions of the watershed. According to data compiled by the Western Regional Climate Center, Mt. Diablo Junction, located in the upper zone of the watershed, experiences the coldest temperatures in January with average monthly lows and highs of 36.7°F and 53.6°F respectively. In contrast, the warmest temperatures were recorded in July and monthly average lows and highs ranged from 60.1°F–86.6°F. Although temperature records for the cities of Brentwood and Oakley were not readily available, climate data for nearby Antioch showed the same pattern as Mt. Diablo Junction with the coldest average monthly temperature in January and the warmest in July. The main difference between the Antioch data and the Mt. Diablo Junction data was an increase in average monthly temperature of approximately 3°F. Lastly, because average monthly low temperatures in January at Mt. Diablo Junction are just above freezing, the Mt. Diablo highlands are one of the only climate zones in the San Francisco Bay Area to receive regular, albeit ephemeral, winter snow (Soil Conservation Service, 1977).

Figure 18 – Rainshadow Effect



The Marsh Creek watershed is located in the rainshadow of Mt. Diablo, and thus it receives less precipitation than do watersheds in the western portion of Contra Costa County. As frontal storms swing in from the Pacific Ocean, the Coast Range forces moisture-laden clouds to rise, wringing out precipitation as they cool. Conversely, as the airmass passes over the mountains and descends, the warming airmass, already moisture-depleted and better able to retain the remaining moisture as humidity, produces far less rainfall (Figure 18). The rainshadow effect explains why the town of Orinda receives 30–32.5 inches of rain annually while Brentwood, 25 miles to the east, receives 10–12.5 inches annually (Soil Conservation Service, 1977). Rainfall also decreases as one moves east and downslope from Mt. Diablo (Figure 11). The average annual rainfall at Mt. Diablo Junction is 24.10 inches (period of record 1952–2000) and 13.07 inches at Antioch (period of record 1955–2000). These data illustrate the significant variation in rainfall moving from the higher elevations in the southwest of the watershed to the lower elevation regions in the northeast.

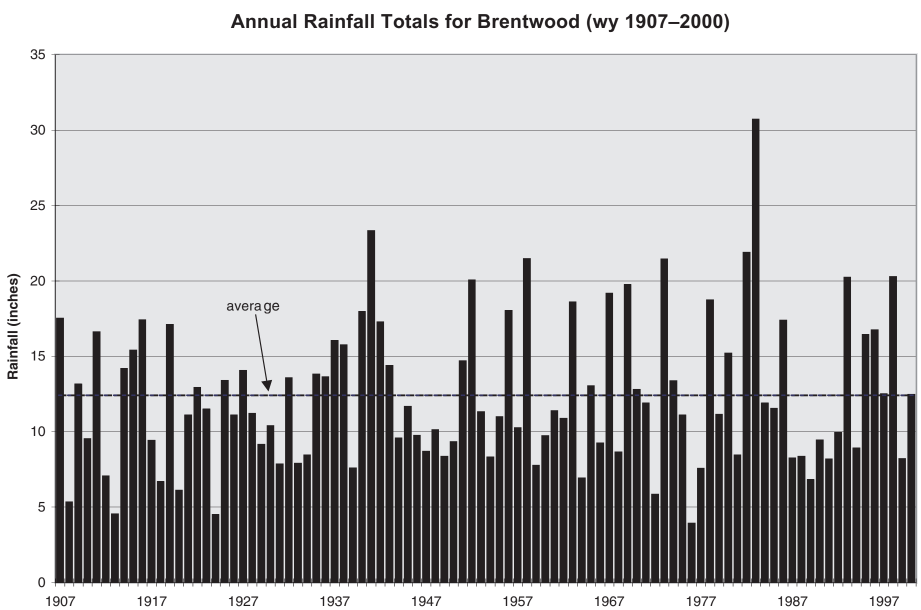


Chart 1

In the Marsh Creek watershed, 90% of all rainfall occurs between November and April (Soil Conservation Service, 1977). Figure 19 displays the data from rain gauges at Mt. Diablo Junction, the Morgan Territory, and Brentwood. All three of these graphs reflect a normal "bell curve" distribution with the highest mean monthly precipitation occurring in the month of January. It is also the month of greatest precipitation variability from year to year. For example, 25th and 75th percentile January rains at Mt. Diablo Junction range from 1.47 inches to 8.09 inches.[1]

Annual rainfall varies considerably from year to year. This variability is illustrated in Chart 1, which shows the total annual rainfall for the City of Brentwood over a 93-year precipitation record (1907–2000). This rainfall record, provided by the Contra Costa County Flood Control and Water Conservation District (2001), shows that although the average annual rainfall for Brentwood is approximately 12.41 inches, only 3 years

[1] The 25th and 75th percentiles represent the minimum amount of rain that falls in at least 25% or 75% of years.

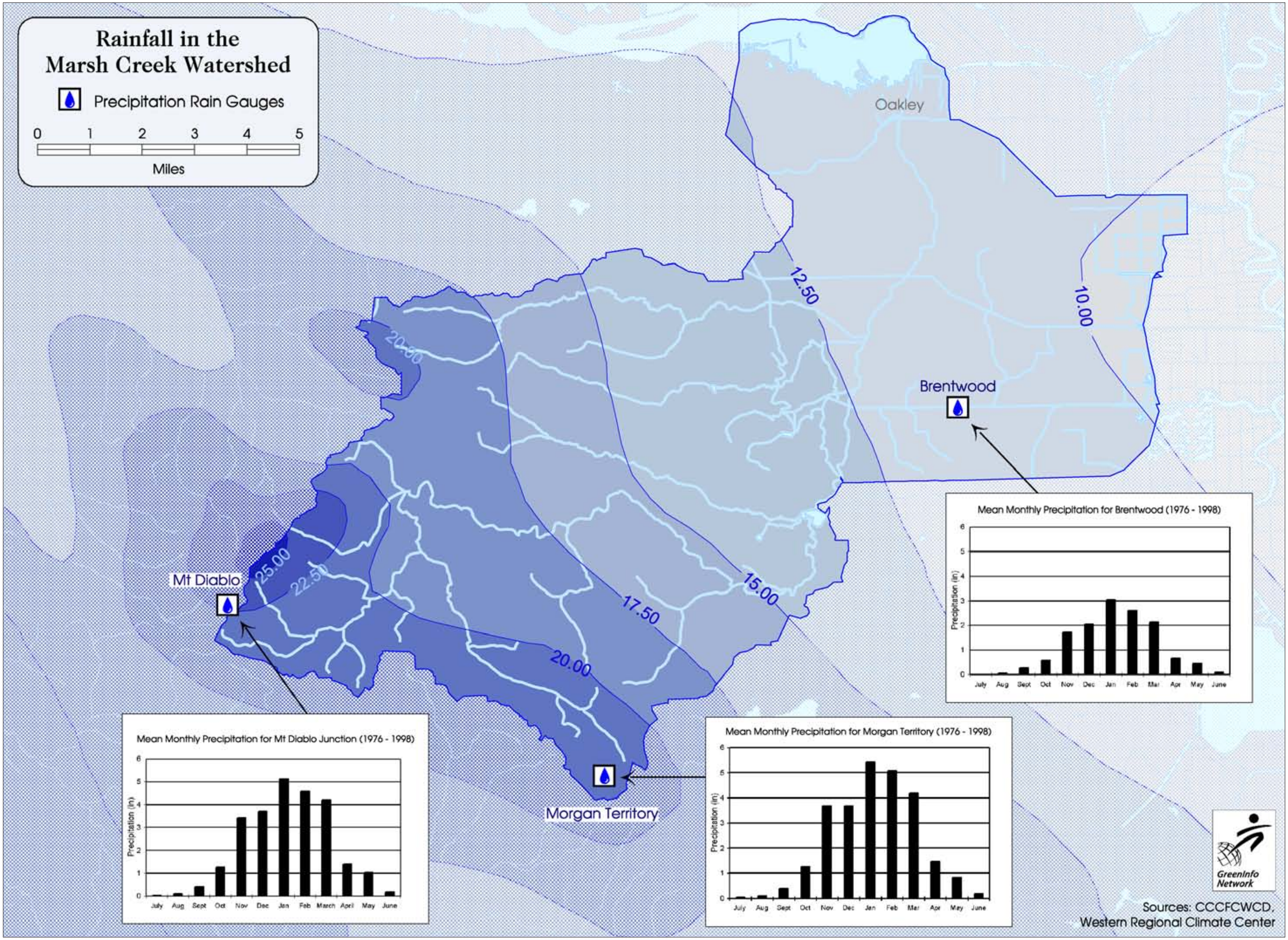

Rainfall in the Marsh Creek Watershed
Precipitation Rain Gauges
0 1 2 3 4 5
Miles
Oakley
Brentwood
Mt Diablo
Morgan Territory
25.00
22.50
20.00
17.50
15.00
12.50
10.00
Mean Monthly Precipitation for Brentwood (1976 - 1998)
Mean Monthly Precipitation for Mt Diablo Junction (1976 - 1998)
Mean Monthly Precipitation for Morgan Territory (1976 - 1998)
Precipitation (in)
July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June
GreenInfo Network
Sources: CCCFCWCD, Western Regional Climate Center

Figure 19

in the record have annual rainfall between 12 and 13 inches. This extreme variability in inter-annual rainfall is illustrated by the fact that eight times as much rain fell during 1983, the wettest year on record, than in 1976, the driest year on record. Because these data reflect variability during extreme years, we also calculated the 25th percentile and 75th percentile annual precipitation to provide a less extreme indication of the variability. The 25th percentile annual rainfall (the amount of rain that falls in at least 75% of the years) is 8.67 inches and the 75th percentile (the amount that falls in at least 25% of the years) is 15.66 inches. Therefore, the range between the 25th and 75th percentiles is 6.99 inches versus a range of 26.8 inches between the driest and wettest years on record.

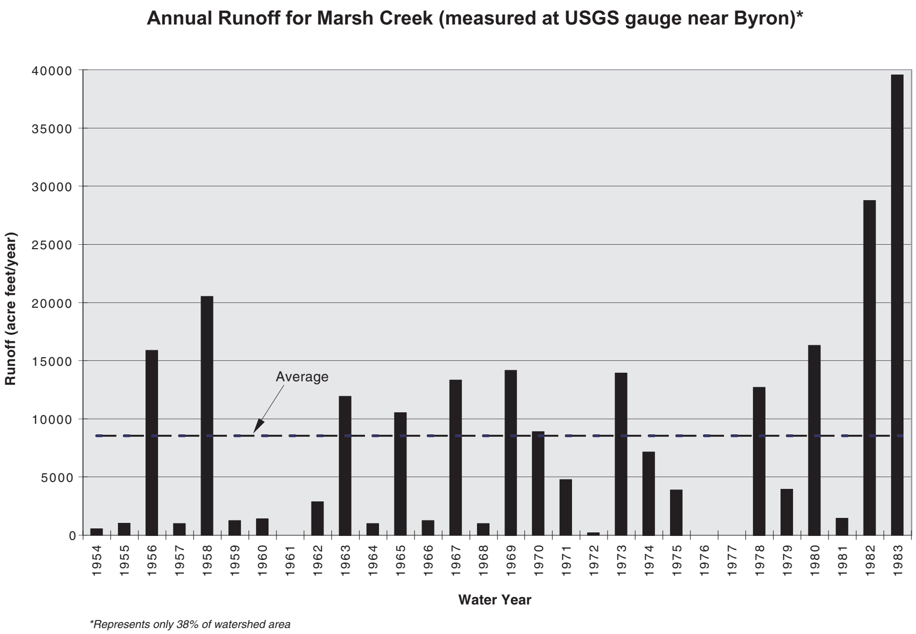


Chart 2

Streamflow

Wide variation in annual rainfall results in large variability in annual runoff – the amount of water flowing through Marsh Creek during a given water year. All flows in Marsh Creek were measured by the US Geological Survey at the Marsh Creek Reservoir from 1954 to 1983. Chart 2 graphs annual runoff at the historical Marsh Creek gauge.[1] This gauge measures runoff in the upper 42.6 square miles (38%) of the watershed and does not account for runoff entering the system from Briones Creek and tributaries that join Marsh Creek in the lower watershed. These data show that annual runoff is even more variable than annual rainfall. This extreme variability in annual runoff is expressed by a mean annual runoff rate of 8,525 acre-feet per year (af/yr) and 25th percentile and 75th percentile annual runoff amounts of 992 af/yr and 13,158 af/yr respectively. Thus, the 75th percentile is more than an order of magnitude larger than the 25th percentile. The highest rainfall year on record, 1983, represents the highest annual runoff with nearly 40,000 af/yr. On the other hand, 1976, the driest year on record, shows an annual runoff rate below the detectable limit of the gauge.

The annual hydrograph is a record of streamflow over a one-year period and illustrates how daily streamflow changes throughout the seasons of a given year. Chart 3 illustrates Marsh Creek's annual hydrograph at the gauge upstream of the Marsh Creek Reservoir for water year 1970, a year with both average rainfall and runoff. This hydrograph again shows that, similar to rainfall, most of the streamflow occurs in January. Perhaps more importantly, there was no measurable surface flow from approximately June 1st to the middle of December.

The annual hydrograph indicates that much of Marsh Creek upstream of the Reservoir only flows seasonally. Nevertheless, there are a number of perennial pools and springs in the upper watershed that provide essential habitat for fish, amphib-

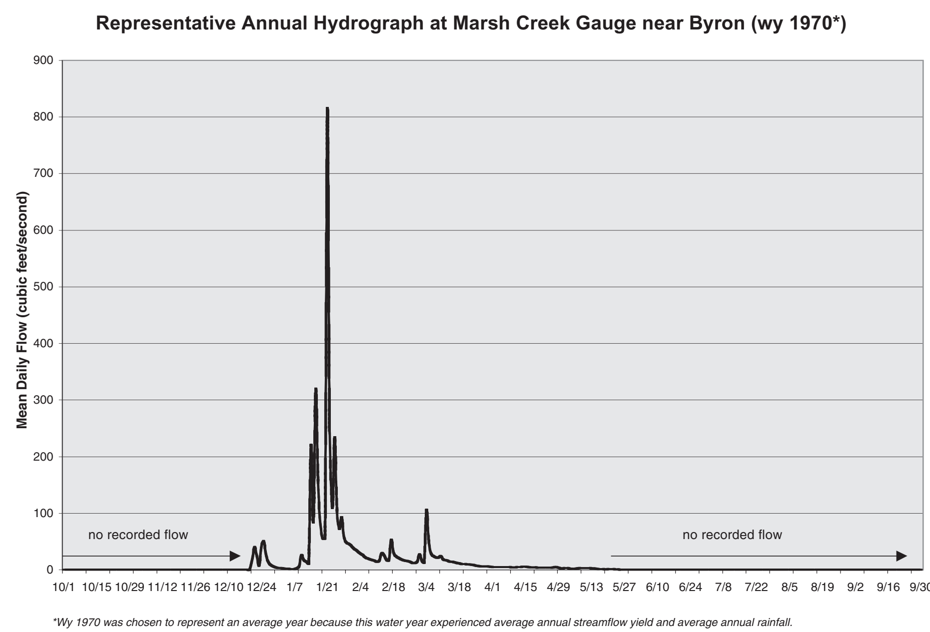


Chart 3

[1] On February 4, 2001, a new real-time streamflow gauge was installed by the USGS on Marsh Creek downstream of its confluence with Sand Creek. In the future these data will provide us with a more precise tool for analyzing streamflow for more than 80% of the watershed.

Stream	Specific Location	Watershed Area (sqmi)*	Mean Season Precipitation*	1997 Conditions– 100 year flow*
Marsh Creek				
	At dam outflow	52.3	19.4	1490
	Above jct w/Dry Cr.	53.43	19.3	1502
	Above jct w/Deer Cr.	59.59	18.6	1926
	Above jct w/Sand Cr.	66.2	18.2	2573
	Below jct w/Sand Cr.	80.62	17.7	3526
Dry Creek				
	At dam outflow	2.87	14	29
	At confluence w/Marsh Cr.	3.52	13.7	279
Deer Creek				
	At dam outflow	4.16	15	198
	Deer Cr. basin outflow	6.4	14.5	–
	At confluence w/Marsh Cr.	6.62	14.4	770
Sand Creek				
	At upper Sand Cr. basin outflow	11.13	16	2422
	At lower Sand Cr. basin outflow	14.2	15.4	–
	At confluence w/Marsh Cr.	14.42	15.3	2427

**All data provided by the Contra Costa County Flood Control and Water Conservation District*

Table 1 – Watershed and Sub-watershed Climate and Modeled Hydrology Data

ians, and other aquatic species. These pools are fed by springs that emanate from bedrock fractures. During the winter storms, some rainfall percolates into the bedrock and flows slowly through porous sandstone layers and fractures in the bedrock before emerging months or years later at seeps, springs, and pools along Marsh Creek. Although these springs do not yield enough water to maintain a continuously wetted channel throughout the dry season, they play a vital role in maintaining isolated pools within the stream by slowly releasing groundwater throughout the year. All the aquatic species in the upper watershed depend on these cool bedrock pools that remain wet even as vast stretches of stream go dry. Not only do these pockets of moisture provide refugia for aquatic species, but they also function as essential water sources for a variety of other animals.

Flood control engineers, hydrologists, and geomorphologists are particularly interested in annual peak flow events – the maximum instantaneous flow in a given year. These events cause the most flooding problems and shape the channel form. Hydrologists and geomorphologists believe that the large peak events that occur every 1.5 to 2 years on average determine the size of the stream channel. All smaller events are thus conveyed by the channel while large events, such as the 5-year flood, overflow the stream banks and inundate the floodplain. Similar to many of the other hydrologic variables already discussed, instantaneous peak flows are tremendously variable from year to year. In some years, Marsh Creek appears not to experience any peak flows large enough to be recorded and in other years there can be as many as 12 peaks flows recorded. The highest instantaneous peak flow on record for Marsh Creek was on January 5, 1982 and measured 5,920 cubic feet per second (cfs).

Peak flow data for Marsh Creek were collected at the Marsh Creek gauge upstream of the confluence with Briones Creek and the Marsh Creek Reservoir. Thus data from the gauge do not account for the major flow inputs from Briones, Dry, Deer, and Sand creeks, which represent more than half of the watershed. Table 1 displays the watershed area, average annual precipitation, and modeled 1997 conditions 100-year flood flow values at specific locations along Marsh Creek and its tributaries below the Dam.

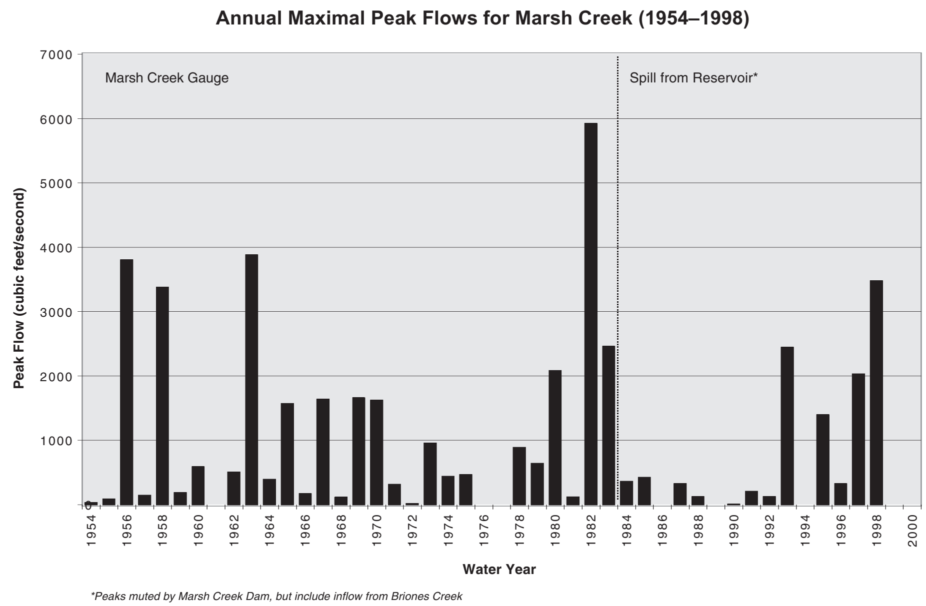


Chart 4

The USGS gauge on Marsh Creek was discontinued in 1983 and thus the hydrologic record for Marsh Creek covers a limited period of time (1952–1983). As such, this record represents only a limited picture of the true variability in peak flows. In order to extend this record to represent a longer period of record, NHI has utilized Reservoir level data from the Contra Costa County Flood Control District to estimate peak Reservoir outflow from 1983 to the present. Chart 4 shows peak flow data for

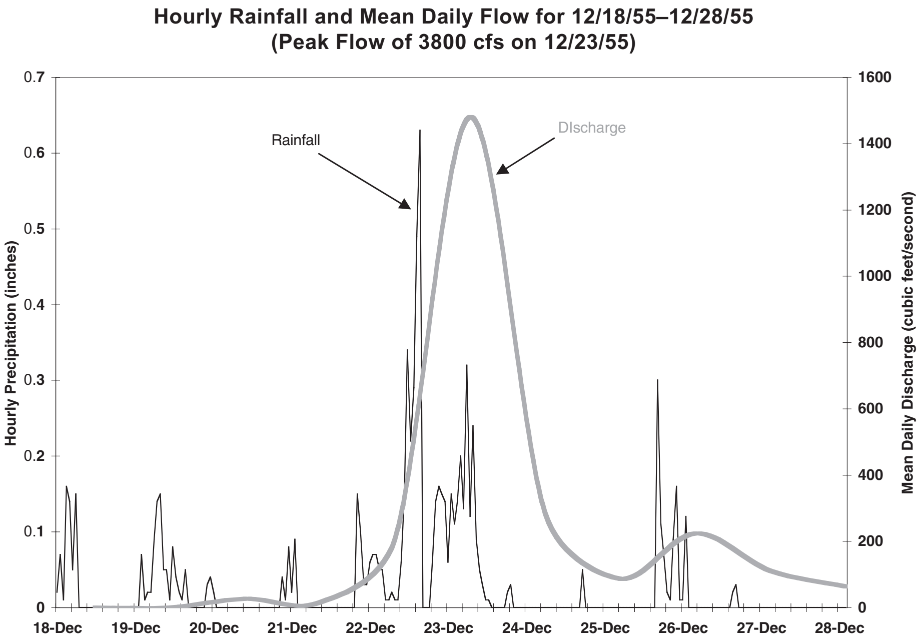


Chart 5

the entire period of record, including the 19 years since the Marsh Creek gauge has been discontinued. Peak flow data prior to 1983 represent flow past the Marsh Creek gauge. Peak flow data after 1983, as depicted on Chart 5, represent outflow from the Reservoir, including runoff from Briones Creek, which enters the Reservoir downstream of the gauge. We can assume that peak flows into the Reservoir were larger than Reservoir outflow, because the Reservoir significantly dampens peak events. If peak flows occurred when the Reservoir was full, however, the outflow from the Reservoir would be just as great as the inflow. Even with the dampening effect of the Reservoir, peak Reservoir outflows measured as high as 3,475 cfs in 1988 and exceeded 2,000 cfs several times in the past 15 years.

A storm hydrograph illustrates the change in creek flows during a storm event. By carefully analyzing both the storm hydrograph and rainfall during the storm, it is possible to measure how quickly flows increase as a result of precipitation. Chart 5 illustrates the relationship between hourly rainfall and mean daily discharge at the USGS gauge station on Marsh Creek during a major flood event in December of 1955. This chart shows that although moderate intensity rains began as early as the 18th of December, it took until the 20th before the first measurable increase in streamflow was detected. Once the soil became saturated, the vast majority of the on-going precipitation was directly transported into Marsh Creek and its tributaries via surface runoff.

The time between peak rainfall intensity and peak streamflow is called lag-time. The concept of lag-time is clearly illustrated in Chart 5 where the ascending limb of the flood hydrograph does not crest until 8–12 hours after the highest intensity rainfall. We see this same pattern again with rain intensity picking up on the night of the 25th and morning of the 26th, resulting in increased flow approximately 8–12 hours later. Due to the lack of hourly flow data, we were unable to calculate the exact lag-time for Marsh Creek above the Reservoir.

Hydrologic Alterations

Below Marsh Creek Reservoir, human activities have undoubtedly changed the timing and flow of water in the channel. Unfortunately, there are no hydrologic data to quantify the extent to which flows have changed over the last century. Based on a com-

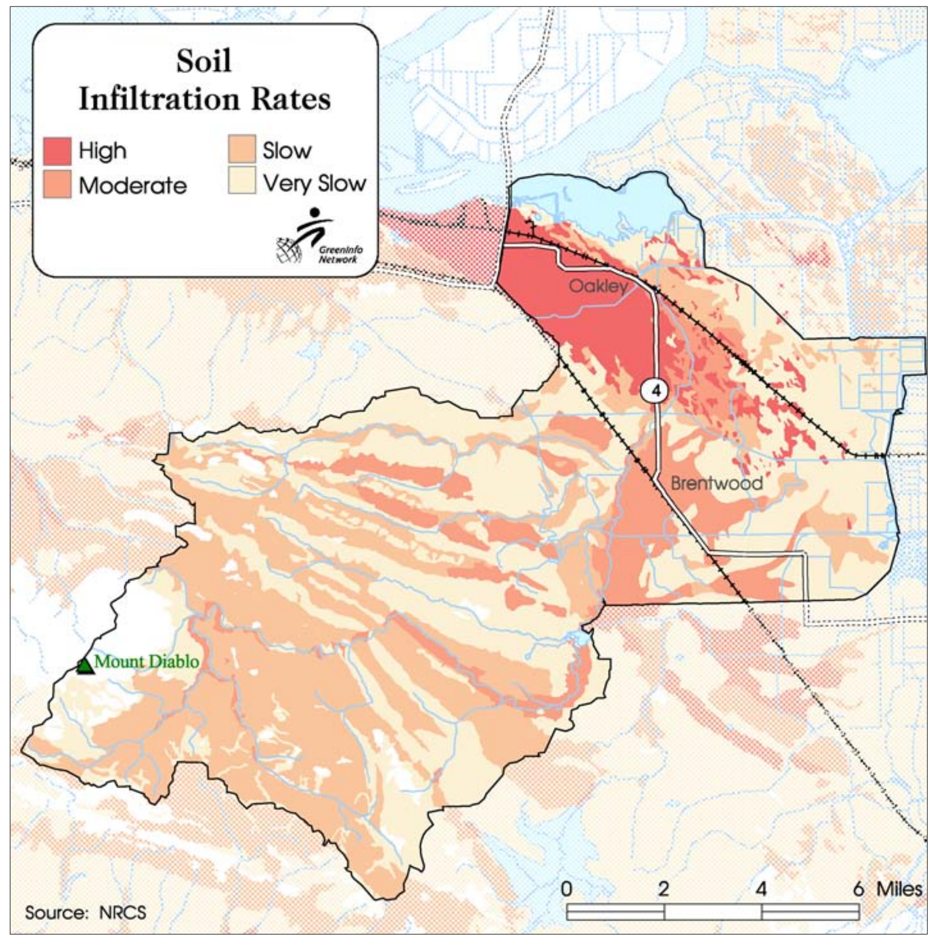


Figure 20

bination of hydrologic principles, understanding of the environmental setting, and deductive reasoning, we can qualitatively describe how the hydrology has changed.

Before urbanization laid claim to much of lower Marsh Creek's floodplain, the deep alluvial soils, varied topography, and natural vegetation slowed runoff rates and increased infiltration of rainfall. Figure 20 illustrates that the infiltration rates for the floodplain soils in the lower zone range from moderate to high, while the soils in the upper zone and much of the intermediate zone have infiltration rates ranging from slow to very slow. These data are particularly interesting because the lower zone of Marsh Creek has experienced extensive suburban, commercial, and industrial development. Although there is natural variability in the infiltration rates across the floodplain of the lower zone, under natural conditions average rates ranged from a low of 0.4 inches/hour for finer-grained soils to a high of 13 inches/hour for Delhi sands. Under developed conditions, where the ground is covered by impervious surfaces such as buildings, paved roads, and parking lots, average infiltration rates drop as low as .01 inches/hour (Soil Conservation Service, 1977).

An increase in impervious surfaces decreases infiltration and increases runoff. Figure 21 illustrates the relationship between percent impervious surface and the fate of rainfall. The illustrations (Figure 21a) provide a quantitative description of infiltration versus runoff across a continuum of development, while the graph (Figure 21b) displays the resulting impact on the magnitude of flood peaks and the duration of the lag-time. This exponential change in infiltration rates that occurs as lands are converted from natural cover to impervious surface has profound effects on local hydrology especially on the extremely high-infiltration Delhi sands. In essence, as the Marsh Creek watershed continues to develop, rainfall will be more rapidly transported into the stream channels, resulting in shorter lag-times and higher peaks.

Figure 22 depicts the explosion of urban development in the lower Marsh Creek watershed. Although the cities of Brentwood, Oakley, and Antioch grew slowly through the early part of the century, during this era much of the arable land in the lowland floodplains was converted to agriculture and protected from flooding by the construction of earthen levees. By the 1950s, urbanization along Marsh Creek and intense agricultural development throughout the lower watershed led to significant changes in local hydrology and placed existing and future development interests on a collision course with natural floodplain processes.

After the financial damage resulting from the December 1955 flood event and two subsequent events in 1958, the Contra Costa County Flood Control District modeled the magnitude of a 50-year flow to design appropriate flood control measures for the developing watershed. This exercise resulted in both the construction of the Marsh Creek Reservoir and a major channel "improvement" effort focused on rapid water evacuation through increased channel capacity and decreased roughness and sinuosity.

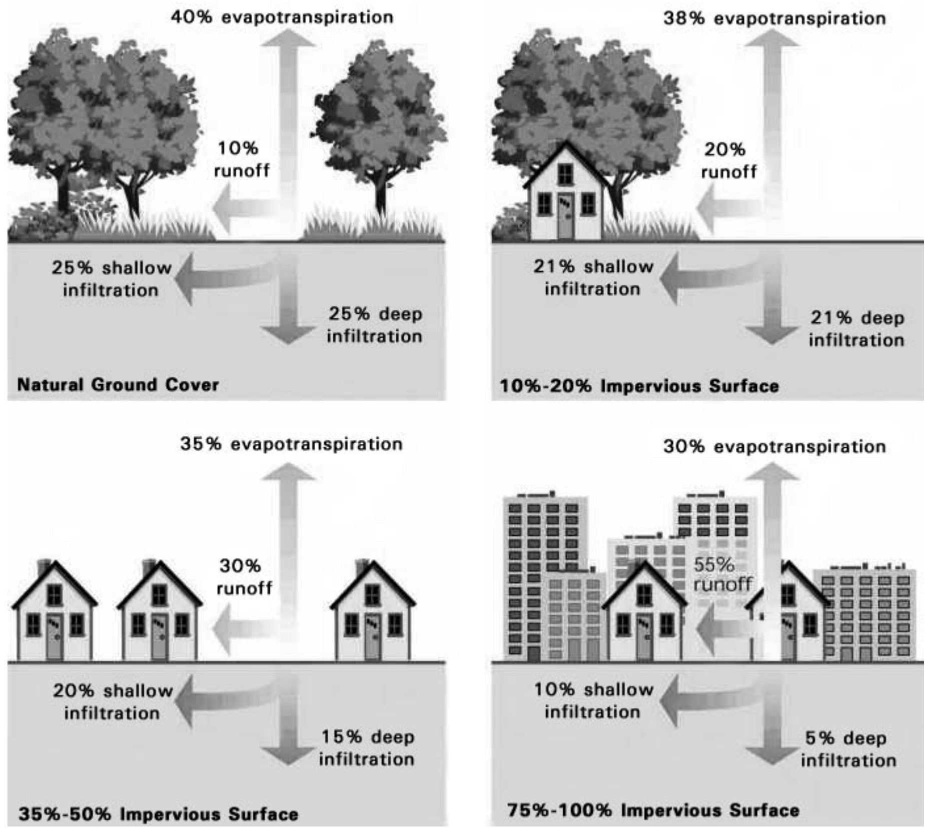


Figure 21a

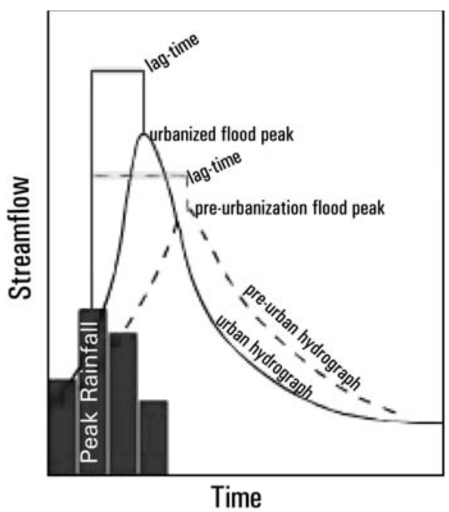


Figure 21b

Figures 21a /21b

The effects of increased impervious surfaces, a proxy for urbanization, on the fate of rainfall. Notice the increase in runoff rates with increasing impervious surface (a) and how increased runoff rates result in shorter lag-times and higher peak flows (b). Courtesy of US EPA and Leopold.

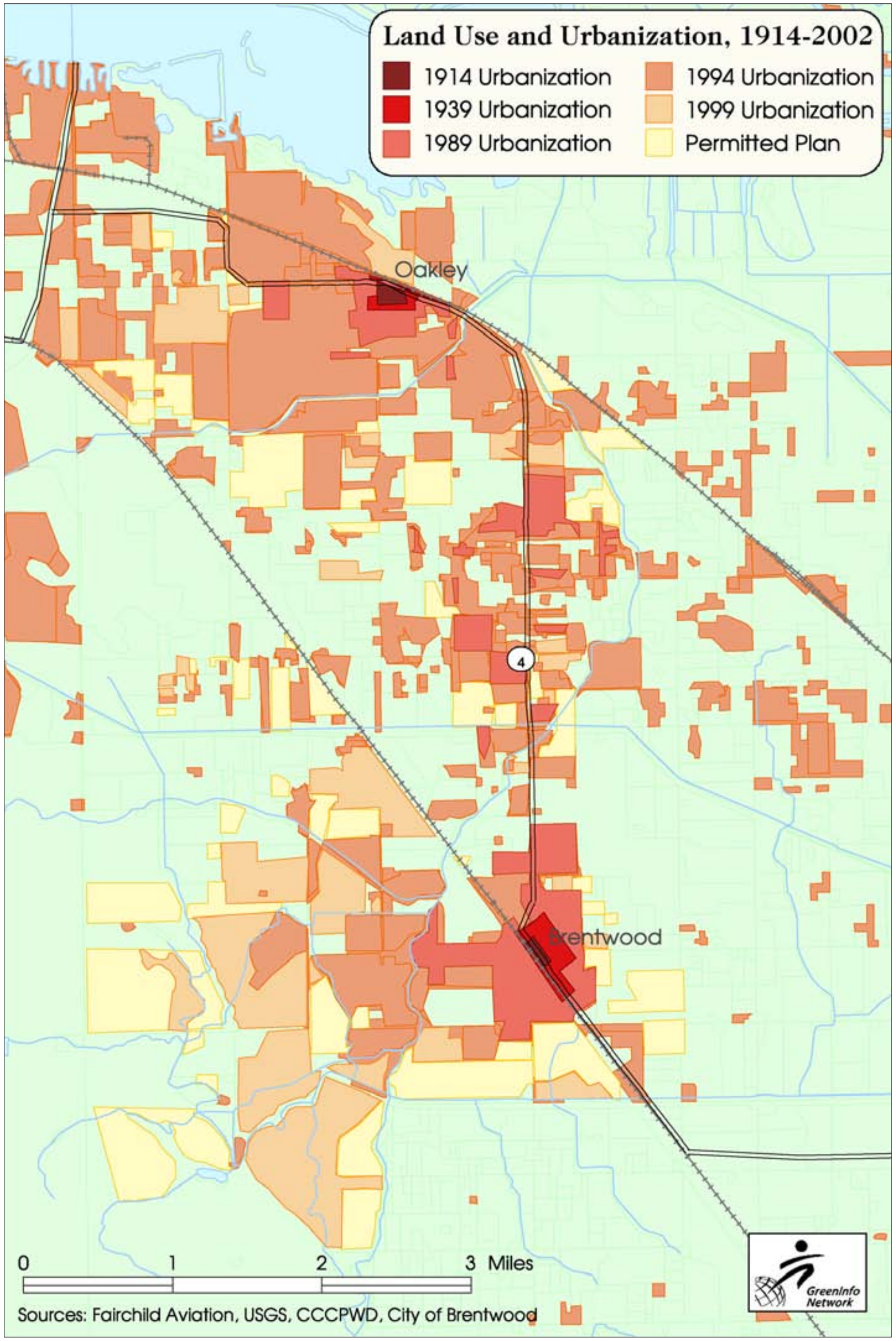


Figure 22

Although urban development proceeded slowly through the 1970s, by 1996 the lower watershed contained a high percentage of impervious surfaces with the heart of the growth centered in Oakley and Antioch. Moreover, the late 1990s have seen an unparalleled development boom in Brentwood, resulting in the conversion of thousands of acres of agricultural lands and wildlands to residential and commercial development.

Agricultural development over the last century has almost certainly increased summer flows in the lower watershed. As previously discussed, historical maps of Marsh Creek from the late 1800s and early 1900s indicated that the Creek dried out before it reached the Delta. This historical terminus of Marsh Creek was located near Oakley, where the Creek intercepts the sandy Delhi soils. These sands may have absorbed the surface flow of water during low flow periods, preventing it from reaching the Delta. The current situation is quite different. Today, lower Marsh Creek is a perennial stream fed by a variety of natural and human sources including rainfall, canal leakage, irrigation return flows, golf courses, urban landscaping runoff, agricultural tail water, slow leakage from detention basins, emptying of pools and spas, and releases of treated wastewater. Farmers apply irrigation water delivered from the Delta via the East County Irrigation District canal on agricultural fields throughout the lower watershed. Some of this irrigation water percolates into the aquifer, raising the water table in the lower watershed sufficiently to maintain a constant flow in Marsh Creek throughout the summer all the way to the Delta.

In order to accommodate the hydrologic alterations associated with increased urbanization, the flood control district has adopted a two-pronged strategy focused on 1) minimizing the instantaneous peaks by controlling the timing of flows from the upper watershed, the tributaries, and storm drains and 2) improving conveyance of high flows via increased channel capacity. Because the majority of development has taken place in the lower zone, in addition to widening the channel and removing vegetation from the lower 11 miles of stream, a series of flood control dams and detention basins have been constructed along Marsh Creek and its tributaries. Table 2 lists the existing flood control facilities currently in operation and the proposed additions and expansions to this flood control network. Although these structures effectively mitigate flood damage in urban areas by muting major peaks, they also mute the peaks of smaller flood events causing a serious disruption to natural hydrologic, geomorphic, and biological processes.

According to the Contra Costa County Flood Control and Water Conservation District (1999), Marsh Creek now has two different peak flows. Flood flows contributing to the "local peak" are created by runoff from areas downstream of the dams on Marsh Creek, Dry Creek, and Deer Creek plus the spillway discharges from these dams. The second peak is derived from long-duration, high-intensity storm events that fill the dams and existing detention basins and stormwater exits via the emergency spillways. These emergency spillway flows combine with residual local flows and create a second peak several hours after the "local peak."

Facility	Existing Capacity (acre-ft)	Proposed Capacity (acre-ft)
Marsh Creek Reservoir*	4300	5700
Dry Creek Reservoir*	365	356
Deer Creek Reservoir*	200	350
Existing DA 107 North Basin	15	15
Existing DA 107 South Basin	50	50
Future DA 107 Basin	0	50
Dry Creek Basin	25	25
Deer Creek Basin	70	100
Upper Sand Creek Basin	50	850
Lower Sand Creek Basin	50	250
DA 30C North Basin	70	70
DA 30C South Basin	0	80
DA 30A Upper Basin	30	30
DA 30A Lower Basin	50	50

These facilities include dams.

Table 2 – Existing and Proposed Flood Control Facilities

CHAPTER 3
WHAT'S IN IT

As rainfall hits the ground and moves through a watershed, it picks up various types of sediments, chemicals, and woody debris along the way. Water flowing over a rocky hillside may pick up sand, gravel, small clods of soil, or organic debris and transport these materials into the nearest stream. Likewise, water flowing through city streets could pick-up anything from carelessly littered plastic bags to drops of engine oil deposited by a leaking car. All of these materials can be carried through a watershed via runoff and streamflow and will affect both the shape of stream channel and the quality of associated habitats.

Natural Processes

It is natural for streams to erode, transport, and deposit materials as they flow through a watershed. In fact all watersheds have three sediment transport zones: the zone of erosion, the zone of transport, and the zone of deposition. In the Marsh Creek

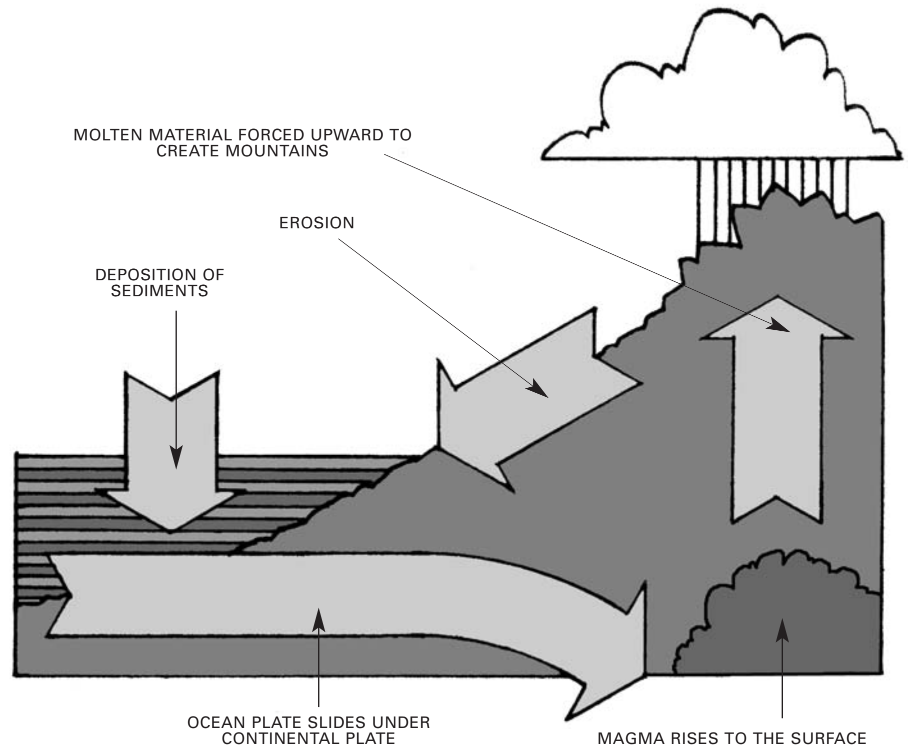


Figure 23 – Geochemical Cycle

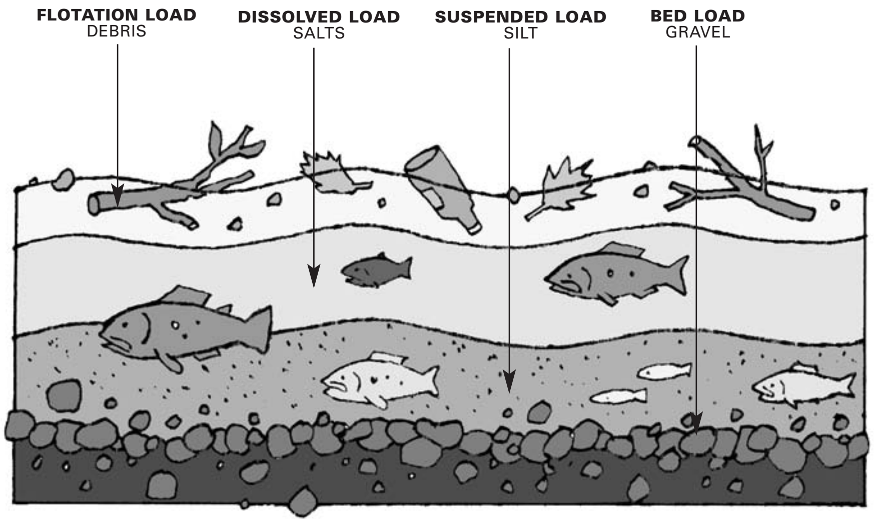


Figure 24 – Categories of Transported Materials in a Stream

watershed, materials eroded from the upper zone are transported downstream through the intermediate zones and deposited along the floodplains and streambed of the lower zone or into the Delta at Big Break. These transport processes are part of what scientists call the geochemical cycle. Figure 23 is a schematic illustrating how, over long periods of time, nutrients and minerals eroded in the upper watershed are transported and deposited in the lower watershed and then gradually moved into Big Break, the Delta and ultimately the ocean where these materials are recycled over geologic time.

Depending on the mass of the material, steepness of the streambed, and velocity of water flowing through it, materials are transported through the watershed as flotation load, suspended load, bedload, or dissolved load (Figure 24). The flotation load is made up of logs, branches, leaves, or other debris that float on the water's surface. The suspended load is composed of particles that remain in the water column, such as clay and silt. Bedload is composed of heavier materials, such as sand, gravel, and cobbles that travel along the bed by rolling, sliding, or saltation (Gordon et al., 1992). In addition to the visible materials that the stream carries, a wide variety of chemicals, nutrients, and minerals are transported as dissolved load.

Erosion, transport, and deposition of various materials are natural processes important for maintaining instream and riparian habitat. The essential minerals, nutrients, and chemicals that form the foundation of the aquatic food web enter and move through the watershed via these processes. Examples of these processes include: woody debris carried in the flotation load that comes to rest in the streambed, providing cover for fish and other aquatic species; nutrients bound in fine sediments in the suspended load that are deposited on the floodplains, fertilizing the productive riparian and wetland habitats that drive the productivity of the ecosystem; coarse gravels that accumulate in bars along the creek, thus providing a well-oxygenated environment for spawning fish and the aquatic insects they feed upon; and dissolved minerals in the stream like magnesium and calcium, which foster the growth of aquatic organisms at the base of the food chain, increasing the overall productivity of the aquatic ecosystem.

Although natural sediment transport processes and the materials they carry are crucial to maintaining productive aquatic ecosystems, unusually high or low concentrations of these materials can be detrimental to the local biota. For example, increased concentrations of metals that naturally occur in local bedrock can be toxic to stream biota, and decreases in bedload and suspended load can lead to increased downstream erosion and channel incision.

Human Alterations

Human alterations to the Marsh Creek watershed have significantly changed the rates and types of materials eroded, transported, and deposited throughout the system. In the upper and intermediate zones of the watershed (those areas upstream of the Marsh Creek Dam) mining activities, livestock grazing, and road development have altered the natural biogeochemical processes of erosion and transport. Below the Marsh Creek Dam, intensive agricultural and suburban development are the factors responsible for driving the biogeochemical changes to the lower zone of Marsh Creek. Moreover, the Marsh Creek Dam itself has a profound impact on transport of materials between the upper/intermediate zones and the lower zones.

The upper and intermediate zones of Marsh Creek function as zones of erosion and transport. As rains weather the steep and highly erodible sandstone hillsides, sediments are washed down hillslopes and gullies and carried into the channel. Erosion is not limited to the exposed hillslopes, but also regularly occurs along the banks and bottom of the channel in this steep bedrock-confined region. These erodible materials are then transported downstream to areas with gentler slopes where the streambed is composed of alluvial sand and gravels, not bedrock. Historically, Marsh Creek transported material all the way down to the flat alluvial floodplain surrounding Brentwood and Oakley. Today, however, much of this material is trapped behind the Marsh Creek Dam in the Reservoir.

Erosion of exposed portions of the Mt. Diablo Ophilite in the upper zone has led to the weathering of naturally occurring cinnabar and the resulting release of mercury into the environment. Although these natural processes account for elevated background levels of mercury in many watersheds draining the Coast Range, large deposits of cinnabar in the rocks of Mt. Diablo's North Peak and in Perkins Canyon significantly increased the amount of mercury exposed to weathering and, therefore, the rates of release into the environment (Mt. Diablo Interpretive Association, 2000). Mercury mining from the 1860s to the 1950s increased the rate of mercury released into the watershed through two primary processes: (1) Mine shafts increased the total surface area of exposed mercury containing rocks. Now, in addition to the natural erosion of exposed hillsides, rainfall flowing through mine shafts is eroding rocks that would otherwise not be exposed to erosive forces; (2) As cinnabar was extracted from the hillsides and crushed to extract mercury, mercury-rich waste rocks or tailing where thrown into nearby creeks or left in piles to slowly erode. More than 50 years have elapsed since active mercury mining ended in the watershed, yet tailings sites remain a major contributor of mercury to the system.

Research documenting the extent and bio-availability of mercury in the Marsh Creek watershed confirms that surface soil contamination, eroding tailings sites, and abandoned mine shafts have increased the concentration and transport of various forms of mercury into Marsh Creek (Slotton et al., 1996, 1997, and 1998). According to UC Davis researchers (Slotton et al., 1998), stream invertebrates and resident fish living directly downstream of the abandoned mine sites had significantly higher levels of mercury in their tissues than invertebrates and fish upstream of the abandoned mine sites. Mercury concentrations in the stream invertebrates increased from background levels of <0.03 parts per million (ppm) in nearly pristine upstream waters to 4–50 ppm in Dunn Creek below the mines. Whole body mercury concentration in native stream fish such as California roach, hitch and three-spined stickleback, showed a 5- to 6-fold increase in specimens below the confluence with Dunn Creek as compared to specimens upstream of the confluence. Slotton et al. (1998) also found that 85% of fish sampled between the Dunn Creek inflow and the Marsh Creek Reservoir contained mercury concentrations above the California Department of Health consumption guideline levels. In addition, the research showed that mercury levels in fish and stream macro-invertebrates declined along a gradient moving downstream from Dunn Creek to the Marsh Creek Reservoir. Although mercury concentrations in the sampled biota declined along the downstream gradient, mercury-laden sediments originating from the abandoned mine sites are accumulating behind the Marsh Creek Dam resulting in the contamination of Reservoir's fishery (Slotton et al., 1998).

Livestock grazing is the dominant land use throughout the upper and intermediate zones of the watershed. Although grazing can be managed to achieve conservation goals and minimize impacts on local resources, poor grazing practices can increase soil compaction and decrease infiltration rates (Liacos, 1962; Gifford and Hawkins, 1978). These alterations, in turn, lead to changes in runoff rates and result in increased soil loss through erosion. In addition to the changes in the soil resource, over 200 years of livestock grazing in California has led to the wholesale conversion of perennial bunchgrass grassland to annual grassland, further increasing runoff and erosion. Because of differences in above ground plant structure and below ground root development, bunchgrasses are more effective at slowing the velocity of surface runoff and holding the topsoil than are their annual counterparts. Lastly, intense livestock grazing along stream banks can lead to the destruction of riparian vegetation and subsequent destabilization of stream banks, again resulting in increased erosion and transport of sediments.

Like livestock grazing, road building can have a major impact on watershed hydrology and greatly increase erosion rates. Both dirt roads and paved roads that cut across hill slopes concentrate rainwater and speed its movement and erosive power. On the uphill side of a road cut, concentrated runoff can undercut hillsides, leading to increased erosion via slumping and landslides. On the downhill side of a road cut, concentrated flow is usually directed off the road and onto adjacent lands via stormwater culverts. Flow spilling from these culverts often form eroding gullies that transport sediments into the nearest stream channel.

While erosion is clearly a natural process, land use activities such as livestock grazing and road building can greatly increase erosion rates, resulting in degraded habitat, loss of property and infrastructure, declining groundwater levels, and increased floods. Excessive erosion clogs stream channels, reducing flood conveyance capacity and smothering the oxygen-rich environment of natural streambed gravels. Clean, well sorted stream gravels are not only important as spawning habitat for numerous native fish, but are also essential habitat for a host of aquatic invertebrates that are the food supply for fish and amphibians. Sedimentation of streambed gravel destroys the food supply that drives the aquatic ecosystem and thus reduces the number and diversity of aquatic fauna. Increased erosion of the stream banks can erode private property and undermine infrastructure. Lastly, increased erosion from the upper watershed increases the flow of sediment into the Marsh Creek Reservoir, slowly reducing reservoir capacity and flood protection over time.

Although historic and current land uses in the upper and intermediate zones have increased erosion rates and altered what flows with the water, the Marsh Creek Dam functions as a sediment trap impeding the flow of sediment and other material to the lower watershed. As Marsh Creek enters the Reservoir, stream velocity decreases and the majority of the materials it has been carrying are deposited in the Reservoir, leaving the outflow with little or no sediment load. The clear, sediment-free waters flowing from the Marsh Creek Reservoir are more erosive. These sediment "hungry" waters appear to have eroded the channel below the Reservoir. As a result, the channel bottom has incised, or cut down, slightly between the Reservoir and Brentwood since the Reservoir was built. Material eroded from the channel bottom in this process has apparently been carried downstream, perhaps all the way to Big Break.

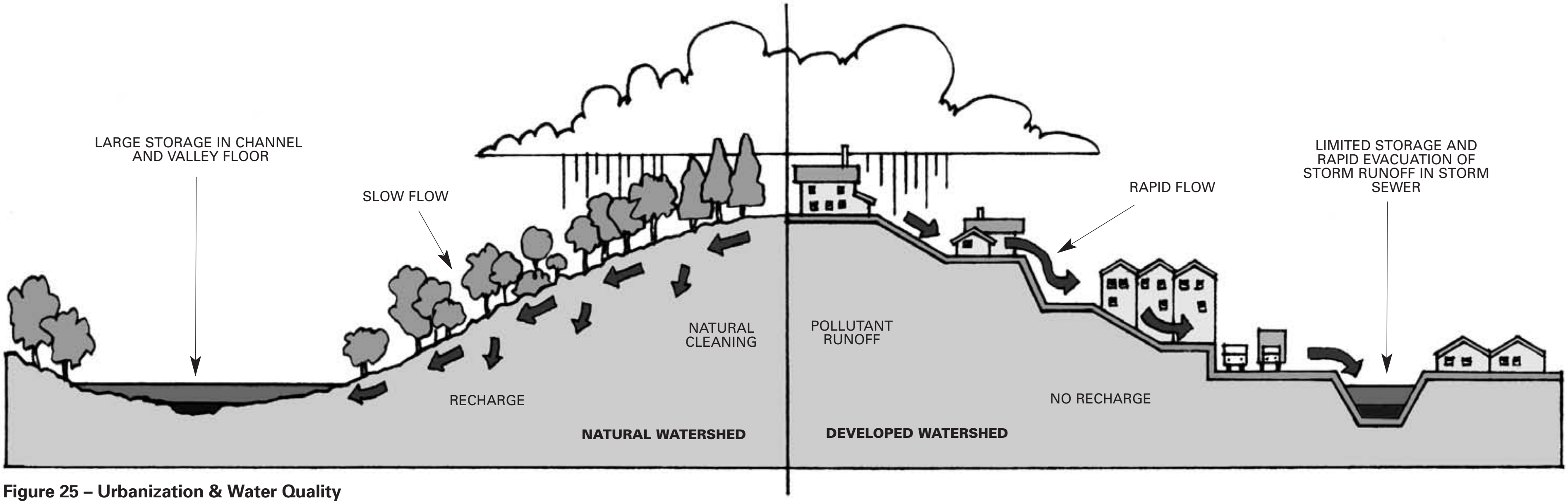


Figure 25 – Urbanization & Water Quality

Because the Dam disrupts the natural transport of materials downstream, it may also play a critical role in limiting the mobility of mercury contaminated sediments into the lower watershed. Research shows that although mercury-laden sediments appear to be accumulating in the Reservoir and causing high levels of toxicity, mercury does not appear to be accumulating to a significant level in the lower watershed or Big Break (Slotton et al.,1998).

The broad low-gradient floodplain in the lower zone of Marsh Creek was historically a zone of sediment deposition. Historically, flood flows carrying large amounts of sediments overflowed the stream banks and deposited fine sediments on floodplains and in backwater areas. Prior to flood control facilities and channel widening, floodwaters would have washed over the floodplain, losing energy and depositing nutrient-rich sediments to nourish floodplain vegetation.

The construction of the flood control channel and dams have changed lower Marsh Creek from a zone of deposition to a zone of erosion and transport. The flood control reservoirs have trapped sediment above the Dam and increased erosion below the Dam with sediment-free "hungry water." The trapezoidal shape of the flood control channel along with the lack of vegetation has increased stream velocities, facilitating the downstream transport of sediments. Historically, the complex meandering channel slowed water and sediment transport, inducing sediment deposition. When the stream overflowed its banks, as it did frequently, its waters slowed abruptly, depositing fine sediments on the floodplain. Today the flood control channel almost never floods its banks, precluding the once common process of floodplain deposition.

Due to its relatively steep gradient, Dry Creek probably contributed coarser-grained sediments to Marsh Creek than did either Deer Creek or Sand Creek. Since the creation of the Dry Creek and Marsh Creek dams, sediment yields from Dry, Deer, and Sand creeks have played a more crucial role in the sediment budget for lower Marsh Creek. It is likely that increased sedimentation from agriculture and construction of new urban developments along lower Marsh Creek and its tributaries have partially offset the reduction in sediment loads caused by the construction of the Marsh Creek Dam. But most of the sediment inflow from construction sites is fine sediment that will choke the channel as opposed to coarse sediments such as gravels that provide important habitat for aquatic fauna. As the watershed is urbanized, the increased area of paved surfaces along with new sediment detention basins on lower Marsh Creek and its tributaries will further reduce the amount of sediment entering Marsh Creek, leading to a new cycle of erosion as sediment-free runoff from paved surfaces washes through Marsh Creek.

Although Slotton et al. (1996, 1997, 1998) found significantly lower mercury levels in aquatic biota downstream of the Reservoir, he warned that this reduction in bioavailable mercury does not mean that mercury has not been transported through the lower reaches of Marsh Creek. He cautions that due to the lack of depositional surfaces in lower Marsh Creek, it is likely that if and when mercury is transported though the system it may instead accumulate in the depositional environments within the Delta.

Extensive agriculture and rapid urbanization have also resulted in an array of water quality problems in lower Marsh Creek. Under natural conditions, riparian and wetland vegetation along Marsh Creek's floodplain filtered out many potential pollutants. Research (Skinner et al., 1999) demonstrates that higher levels of surface water toxicity are generally associated with watersheds containing more developed land surface and less open space. Today, agricultural and urban development in the Marsh, Dry, Deer, and Sand creek floodplains and legitimate flood control management practices are facilitating the rapid transport of pollutants into surface waters (Figure 25).

Contaminants such as pesticides, heavy metals (including Cd, Cr, Cu, Pb, Ni, and Zn), dioxin, and n-nitroso compounds are common constituents in stormwater draining developed watersheds and have been correlated with developmental toxicity in a variety of aquatic organisms (Wisk and Cooper, 1990; Pillard, 1996; Skinner et al., 1999; Wenning et al., 1999). Research indicates that the impacts of polluted runoff may be especially significant if contaminated surface waters empty into an enclosed area such as a bay or estuary (Katznelson et al., 1995). Thus, increases in polluted runoff from the Marsh Creek watershed could inflict large and potentially irreversible ecological harm to Big Break due to its relatively closed configuration.

Students in environmental science and chemistry classes at Freedom High School have been sampling water quality in Marsh Creek since in the fall of 2001 (Figure 26). The students sampled water quality at several locations along the Creek: below and above the discharge point of the Brentwood Wastewater Treatment Plant, upstream and downstream of the confluence of Marsh Creek with Deer and Sand creeks, and at Creekside Park. Students measured a variety of physical and chemical parameters as well as the presence and diversity of aquatic invertebrates (Table 3). While measurements of physical and chemical parameters provide a "snapshot" of water quality conditions at the time of sampling, invertebrate sampling enables scientists to

Figure 26 – Students from Freedom High School Taking Water Quality Samples

Locations	Creekside Park	CF-2	CF-1	ST-1	Trail Bridge
Time	10:15AM	10:25AM	11:45AM	12:25PM	12:25PM
Parameter					
Temperature, degrees C	15.9	13.9	14.5	14.9	14.9
Dissolved Oxygen, mg/l	6	7.4	11.8	10.6	10.6
Conductivity, us	745	935	784	707	707
pH	8	8.7	8.9	8.7	8.7
Total Alkalinity, mg/l	430	420	480	550	550
Phosphate, mg/l	4.5	0.2	0.1	0.1	0.1
Ammonia Nitrogen, mg/l	0	0	0	0	0
Nitrate Nitrogen, mg/l	n/a	n/a	n/a	n/a	n/a
Total Chlorine, mg/l	0.1	0.1	0.1	0.1	0.1
Free Chlorine, mg/l	0.1	0.1	0.2	0.2	0.2
Sulfide, mg/l	0.2	0.2	0.2	0.2	0.2
Total Hardness, mg/l	315	310	430	400	400
Calcium Hardness, mg/l	152	129	220	200	200
Invertebrates	None	Minimal	Lots of worms and mollusks	Few worms and mollusks	Water too high

Description of Locations	
Creekside Park	Downstream from bridge across Marsh Creek within the park
CF-2	Upstream of confluence of Marsh Creek with Sand and Deer Creeks
CF-1	Downstream of confluence of Marsh Creek with Sand and Deer Creeks
ST-1	Marsh Creek, downstream of effluent from City of Brentwood Wastewater Treatment Plant
Trail Bridge	Bridge over Creek downstream of crossing with Water Plant Intake

Table 3 – Field Water Quality Sampling Data from Marsh Creek
Measured by Students From Freedom High School on May 3, 2003.

characterize water quality conditions over longer periods of time. Although water quality may be adequate most of the time, periodic discharges of pollutants from storm drains or agricultural fields can eliminate whole populations of invertebrate species. The presence or absence of invertebrates and their diversity can provide an indication of short-term water quality problems resulting from short-term discharges of pollutants and toxins into the stream.

Based on the parameters analyzed, the students, under the guidance of their instructor Tom Lindemuth, concluded that the water quality was acceptable to aquatic health, but that there are some problems that make conditions for aquatic species difficult. Specifically, depressed dissolved oxygen may contribute to the absence of invertebrates in some sections of the Creek, as the students observed in the spring of 2003 in Creekside Park. Low dissolved oxygen levels can be caused by excess nutrients, a condition that is sometimes caused by sewage discharge or runoff from fertilized agricultural fields. Elsewhere in the Creek, the student survey of invertebrates measured an abundance of worms and mollusks, invertebrates with a high tolerance for pollution, but did not find any aquatic insect nymphs from the pollution intolerant mayfly and caddisfly families. The water quality in the 2 miles downstream of Creekside Park, in the vicinity of the Brentwood Wastewater Treatment Plant, was relatively good compared to water quality at upstream sites and did not appear to pose a threat to fish or other aquatic species. The students also measured elevated pH levels generally throughout the Creek, which may be caused by human factors or from the natural geology of the watershed.

The water in Marsh Creek and its tributaries is influenced by its location in a developed urban and agricultural zone. Dr. Darell Slotton of UC Davis sampled a diversity of invertebrate and fish species in the relatively undeveloped upper watershed above Marsh Creek Reservoir where stream flow is discontinuous and intermittent. Downstream of the Reservoir the Creek flows continuously year-round due to an elevated water table caused from agricultural and landscape irrigation. Dr. Slotton observed that water quality near Oakley in 1996, 1997, and 1998 “was so degraded, apparently from local agricultural and urban discharges, that typical aquatic insect fauna were essentially absent” (Slotton et al., 1997).

In order to address existing and potential water quality problems, all the waters contributing to Marsh Creek need to be managed to reduce the transport of mercury and to filter out agricultural and urban pollutants. The City of Brentwood has begun to install grease-traps in its urban storm drains (Stevenson, pers. com.). These mechanisms, if properly installed and maintained, will decrease the amount of urban pollution entering Marsh Creek and the western Delta. In addition, the City of Brentwood is also embarking on an innovative plan to restore riparian wetlands and some floodplain surfaces along Marsh Creek and Sand Creek. If water quality objectives are factored into these designs, this program could represent a major step toward remediating urban and agricultural water pollution. Although the primary function of the Contra Costa County flood control district’s detention basins program is to decrease peak flows and limit flood damage, these basins could also play a potential role as artificial filtration wetlands.

Chapter 4
Who's in It

The stream and wetland habitats of Marsh Creek from Mt. Diablo to the Delta once supported a large and diverse number of species, many of which used the Creek as a migration corridor between the Delta and the Coast Range. Floodwaters from winter storms regularly inundated rich floodplains, maintaining a mosaic of riparian wetlands that supported an abundance of birds, amphibians, and mammals. During the dry summer months, cool groundwater-fed pools provided habitat for resident aquatic species as well as essential water for the terrestrial biota of the watershed.

Since the mid-1800s, humans have also occupied a growing percentage of the Marsh Creek watershed and been influenced by Marsh Creek. Marsh Creek used to be a popular retreat destination and people came from many miles to enjoy fishing, swimming, and the natural setting available at the Creek (Kim Vogley Associates, 1991). The suburban population that makes up the watershed today enjoys the trails and the few remaining natural areas along Marsh Creek. The dynamic nature of Marsh Creek and its floodplain have often conflicted with human land uses, resulting in extensive alterations of the Creek. Most notably, lower Marsh Creek has been changed from a meandering and migrating stream to a confined, straightened stream disconnected from its floodplain. Its waters are polluted and perennialized by continuous inputs of dry season irrigation waters. Flood control structures have impeded upstream fish passage and altered both the velocity and chemistry of the water. And significant removal of riparian vegetation along the Creek has resulted in higher water temperatures, increased sediment loads, and loss of riparian habitat. All of these changes have reduced habitat for native species, leading to a significant decline in their numbers. Some of the changes, particularly increased summer flows in lower Marsh Creek, have created habitat favored by exotic species such as bullfrogs *(Rana catesbeiana)* and bluegills *(Lepomis macrochirus).*

Although we have limited historic information on the biota of Marsh Creek, we can surmise that pre-development Marsh Creek provided essential habitat for a wide diversity of native species during various stages of their life cycles (Fairchild Aviation, 1939; California Department of Fish and Game, 2002). Due to its proximity to the Delta and its expansive fertile floodplain, lower Marsh Creek probably supported the highest species diversity in the watershed. It is also here, on the rich floodplain soils of the lower watershed, that the majority of agricultural and urban development has occurred, resulting in the loss and fragmentation of essential habitat for once-abundant populations of native species. Recent biological surveys sup-

San Joaquin Kit Fox *(Vulpes macrotis mutica)*

subspecies of the Kit Fox *(Vulpes macrotis)*

The San Joaquin kit fox is a casualty of intensive agricultural, oil, and urban development in California's fertile San Joaquin Valley. It once inhabited native grasslands and scrublands throughout most of the Valley. By 1930, its range had been reduced by half, largely as a result of agricultural expansion. Continued loss of native valley habitats over the next several decades necessitated formal listing under federal and state endangered species acts; this kit fox is federally endangered and state-listed as threatened. Currently, less than 7,000 individuals are thought to survive, the majority of them patchily distributed throughout western and southern portions of the Valley and surrounding foothills. Current threats to the species include habitat loss and fragmentation, predation by coyotes, competition and predation by non-native red foxes, starvation, and automobile-caused deaths.

Small and elusive, the kit fox is the smallest member of the dog family in North America. It is active year-round and primarily nocturnal. The San Joaquin kit fox prefers to forage in sparsely vegetated saltbush scrub habitats and grasslands for its main prey – rodents, hares, and other small mammals.

Average home range for an individual is 1–2 square miles, but may be as large as 12 square miles where prey is scarce. Within its home range, a kit fox may use between 3 and 24 different dens throughout the year for housing and protection. Kit foxes can construct their own dens in loose, deep soils, or may opportunistically enlarge or modify burrows constructed by ground squirrels, badgers, and other ground-dwelling creatures. In urban settings, they have been known to den in human-made structures such as culverts or abandoned pipes.

The San Joaquin kit fox may live up to seven years, but average lifespan in the wild is likely much lower. Kit foxes reach sexual maturity at 1 year of age. Adult pairs remain together year-round but may use separate dens. Most breeding occurs early January, with litters of 2 to 6 pups born in late February or early March. Pups emerge from dens after weaning at about 1 month of age. After 4 to 5 months, usually in August or September, the young begin dispersing. Like most predators, reproductive success of San Joaquin kit foxes is related to prey abundance. Survival of pups is usually low; less than 25% live to 8 months.

Sources

California Department of Fish and Game [http://www.delta.dfg.ca.gov/gallery/kitfox.html]

California State University Endangered Species Recovery Program [http://arnica.csustan.edu/esrpp/sjkfprof.htm]

Lowe, D.W. (managing ed.), J.R. Matthews and C.J. Moseley (eds.). c1990–c1994. The Official World Wildlife Fund Guide to Endangered Species of North America. Washington, D.C.: Beacham Pub.

Schlorff, R. 2001. Outdoor California (March–April): 32-35. [http://www.dfg.ca.gov/coned/ocal/kitfox.pdf]

port this presumption – only small remnant populations of native species such as river otters *(Lutra canadensis),* burrowing owls *(Athene cunicularia ssp. hypugaea),* and western pond turtles *(Clemmys marmorata)* have been observed in the lower watershed. Although native wildlife populations are severely confined by the lack of available habitat in the lower watershed, the intact riparian corridor and freshwater tidal marsh at the mouth of Marsh Creek still support a wealth of native biota. Recent bird surveys recorded the presence of sensitive species including the state-listed California black rail *(Laterallus jamaicensis),* tricolored blackbird *(Agelaius tricolor),* yellow-breasted chat *(Icteria virens),* white-tailed kite *(Elanus leucurus),* and northern harrier *(Circus cyaneus)* (Ibis Environmental, 2000). In addition to the habitat at its mouth, the riparian areas and adjacent uplands in the upper and intermediate zones of the watershed represent quality habitat for a range of terrestrial species including the federally listed San Joaquin kit fox *(Vulpes macrotis)* and Alameda whipsnake *(Masticophis lateralis euryxanthus).* The cool perennial pools of upper and intermediate Marsh Creek are also important summer habitat for a wealth of native species, especially fish and amphibians that otherwise would not survive the region's long dry season, when vast stretches of stream dry up. A variety of terrestrial species similarly congregate around these isolated watering holes in ever-increasing numbers during the dry season. The high density of wildlife in and around these pools during the dry season has unfortunately also attracted the attention of human poachers and collectors. Protection of these dry season oases from human disturbances and development should be a key aspect of any system-wide conservation plan for the Marsh Creek watershed.

Marsh Creek and its tide waters near Big Break provide habitat for a number of native fish whose populations have been in serious decline over the last several decades. For example, recent sampling efforts have indicated that the tidal waters at the mouth of Marsh Creek and Big Break provide habitat for the federally threatened Sacramento splittail *(Pogonichthys macrolepidotus)* and Delta smelt *(Hypomesus transpacificus).* A comprehensive survey of splittail determined that Big Break, where Marsh Creek enters the Delta, is one of only three locations where adult splittail congregate in large numbers (Meng and Moyle, 1995; Baxter, 1996). Figure 27 displays the locations of various native fish recorded during sampling events between 1996 and 2002.

Marsh Creek also appears to support reproducing runs of Chinook salmon. One published study, several observations, and numerous anecdotal accounts provide evidence that salmon migrate up Marsh Creek and successfully reproduce. NHI scientists observed adult Chinook salmon on at least three occasions in the fall of 2001 congregating below the furthest downstream fish barrier on Marsh Creek (Robins and Cain, pers. obs.). On one of those visits NHI scientist, Jim Robins, photographed a salmonid that appeared to be a steelhead trout *(Oncorhynchus mykiss)*

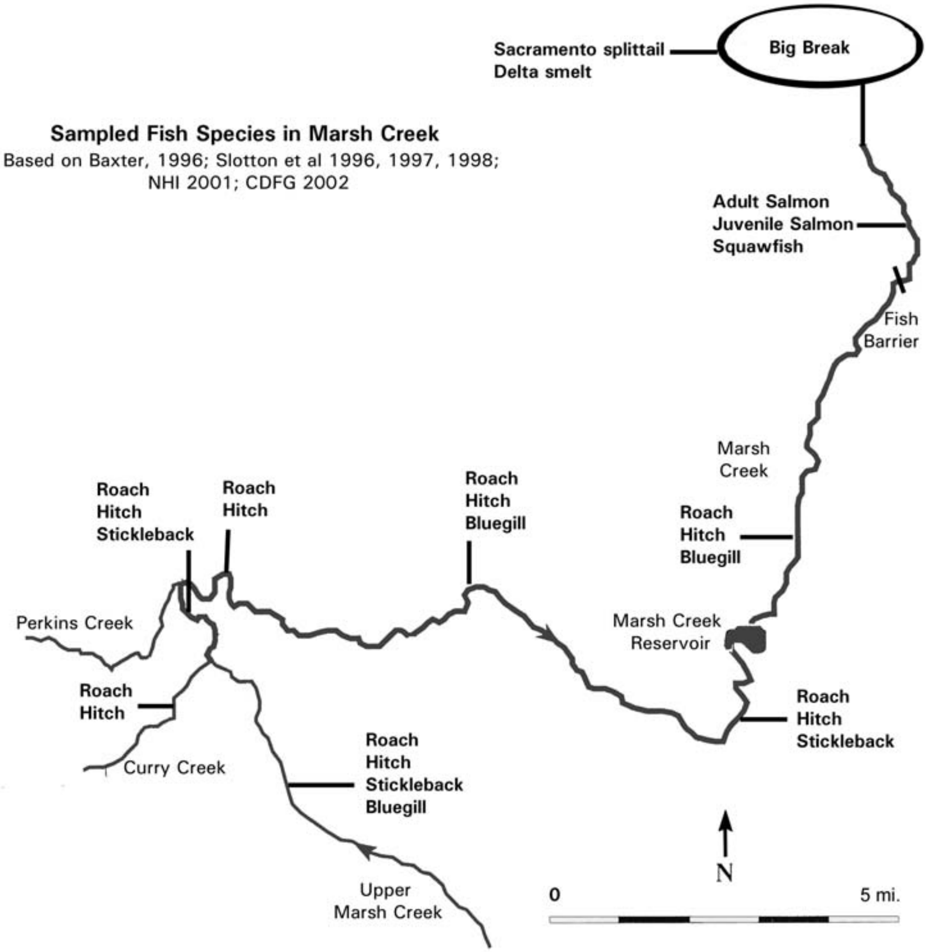


Figure 27

just below the downstream barrier. NHI scientists also interviewed local fishermen along the banks of Marsh Creek, who estimated the size of the salmon run to be in the hundreds of individuals (Cain, pers. com.; Robins, pers. com.) and who reported that the salmon have returned in similar numbers for at least five years. In the fall of 2002, NHI, the Delta Science Center, and the East Bay Regional Park District organized a community effort to look for and monitor spawning adult salmon in lower Marsh Creek. Volunteers from the community were trained how to look for salmon and were given surveys to fill out if they observed salmon while using the Creek on a regular basis. Groups of more than twenty adult Chinook salmon were observed on more than three occasions. Two Chinook exhibiting spawning behavior were photographed in Marsh Creek in the reach between Cypress Road and the drop struc-

Fall-run Central Valley Chinook salmon *(Oncorhynchus tschawytscha)*
Central Valley/Central Coast Steelhead Trout *(Oncorhynchus mykiss)*

Chinook salmon and steelhead trout are both highly valued by sport and commercial fishermen. Like other anadromous

Steelhead Trout

species, the adult fish migrate from the ocean to spawn in the gravels of creeks and rivers. After the fry emerge from the gravels, the young fish rear in freshwater before returning to the ocean as adults. Fall-run Chinook salmon return to their natal streams to spawn and die between October and December. In the Central Valley, the salmon typically emerge from their gravel nests or "redds" within 2 to 3 months and will spend the better part of the next 4–6 months migrating to the ocean. Unlike salmon, steelhead trout do not necessarily die after spawning and may spawn more than once, returning to the sea after each spawning event. Also unlike fall-run Chinook salmon, juvenile steelhead spend at least one summer season in their natal stream before migrating to the open ocean and thus require cool summer water temperatures to successfully complete their life cycle.

Populations of both salmon and steelhead have suffered major declines over the last century due to a combination of over fishing and human induced changes in habitat, such as siltation of spawning gravels, high water temperatures, low dissolved oxygen, loss of stream cover, reductions in river flow, and instream barriers that prevent adult migration to spawning grounds. These impacts are primarily caused by dams, water diversions, flood control projects, destruction of riparian forest, and land-use practices that increase erosion.

Under the direction of the Endangered Species Act, the US Fish and Wildlife Service listed the Central Coast steelhead trout as federally threatened in 1998 and proposed the fall-run Central Valley Chinook salmon as a candidate for federal listing in September of 1999.

Chinook salmon

Sources

Emmett, R.L., S.L. Stone, S.A. Hinton, and M.E. Monaco. 1991. Distribution and Abundance of Fishes and Invertebrates in West Coast Estuaries, Volume II: Species Life History Summaries. ELMR Rep. No. 8 NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD.

US Fish and Wildlife Service. Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates, Species Profiles, 1983–1989. US Fish and Wildlife Service Biol. Rep. (11). US Army Corps of Engineers, TR EL-82-4, Washington, D.C.

Figure 28 – Spawning Chinook Salmon in Marsh Creek

One of a pair of salmon seen just above the Brentwood Wastewater Treatment Plant discharge in September 2002. Photo by Tom Lindemuth.

Figure 29 – Chinook Salmon in Shallow Water in Marsh Creek

Photo by Tom Lindemuth.

ture near the Brentwood Wastewater Treatment Plant (Figures 28 and 29). Freedom High School students regularly observed salmon while conducting water quality sampling (Figure 30). These observations and interviews support several anecdotes from reliable sources that reported similar runs of salmon in recent years. These observations have been substantiated by limited biological surveys. Dr. Darell Slotton of UC Davis measured five juvenile Chinook salmon *(Oncorhynchus tschawytscha)* between 60 and 80 mm in lower Marsh Creek during water quality sampling in 1995 (Slotton et al., 1996). More recently, field surveys by biologists from the California Department of Fish and Game identified 13 juvenile Chinook salmon between 60 and 80 mm just downstream of the drop structure (Cleugh, unpublished).

Although the reach of Marsh Creek downstream of the existing fish barrier is channelized and appears to lack suitable spawning gravel habitat, the presence of juvenile salmon sampled in both the spring of 1995 and the spring of 2002 suggests that salmon are successfully reproducing in Marsh Creek. Although there is little information on historic salmonid runs in the Marsh Creek watershed, field reconnaissance indicates that there are multiple reaches containing spawning gravels suitable for fall-run Chinook salmon both above and below Marsh Creek Dam (Robins, pers. obs.). Hence, if the current lower Marsh Creek barrier were to be modified or removed to enable fish passage, Chinook may be able to utilize this habitat. Unlike fall-run Chinook salmon, which die after they spawn, steelhead trout spend the summer in their natal streams and return to the ocean the following year. Thus, this species requires cold perennial pools to sustain juveniles and adults throughout the hot dry summer. Numerous perennial pools exist in Marsh Creek and its tributaries in the intermediate and upper zones of the watershed. However, even if steelhead could pass through lower Marsh Creek, the Marsh Creek Dam represents a major barrier to upstream migration and access to the perennial pools. Although steelhead cannot currently access this habitat, existing populations of rainbow trout *(Oncorhynchus mykiss)* in the upper watershed indicate that suitable habitat conditions do exist in this region. Moreover, recent observations indicate that perennial pools exist in the upper reach of Sand Creek in Black Diamond Mines Regional Preserve. There are two existing migration barriers on Sand Creek, both of which could be redesigned for fish passage and thus open up suitable habitat for steelhead trout.

Figure 31 displays data from the California Department of Fish and Game's Natural Diversity Database on the distribution of endangered species throughout Marsh Creek watershed. These species fall into two main regions, one near the mouth of Marsh Creek and the other spread across the open space of the watershed's intermediate and upper zones. In addition to the wealth of faunal biodiversity near the mouth of Marsh Creek at Big Break, recent rare plant surveys located populations of rare species such as Suisun marsh aster *(Aster lentus)* and Mason's lilaeopsis *(Lileaeopsis masonii)* (Vollmar Consulting, 2000). In addition, the relic sand dunes near the mouth of Marsh Creek and Big Break are home to the federally endangered Antioch dune evening primrose *(Oenothera deltoids ssp. howellii),* recently observed within the boundary of the watershed, and Contra Costa wallflower *(Erysimun capitatum var. angustatum)* (California Department of Fish and Game, 2002).

Figure 31 illustrates that there are still a wealth of rare species existing in both the public and private open space in the intermediate and upper zones of the watershed. This region is an integral component of the known range of four federally listed faunal species – the Alameda whipsnake, California red-legged frog *(Rana aurora draytonii),* San Joaquin kit fox *(Vulpes macrotis),* and vernal pool fairy shrimp *(Branchinecta lynchi).* In fact, this portion of the watershed is considered to be so important to the survival of the California red-legged frog that the US Fish and Wildlife Service has designated large portions of the watershed as critical habitat for this species. Other sensitive faunal species found in the upper watershed include the California tiger salamander *(Ambystoma californiense),* Swainson's hawk *(Buteo swainsoni),* western burrowing owl, and western pond turtle.

Figure 30 – Freedom High School Student With Dead Salmon in Marsh Creek

This salmon, found dead in the Creek, most likely died naturally after spawning.

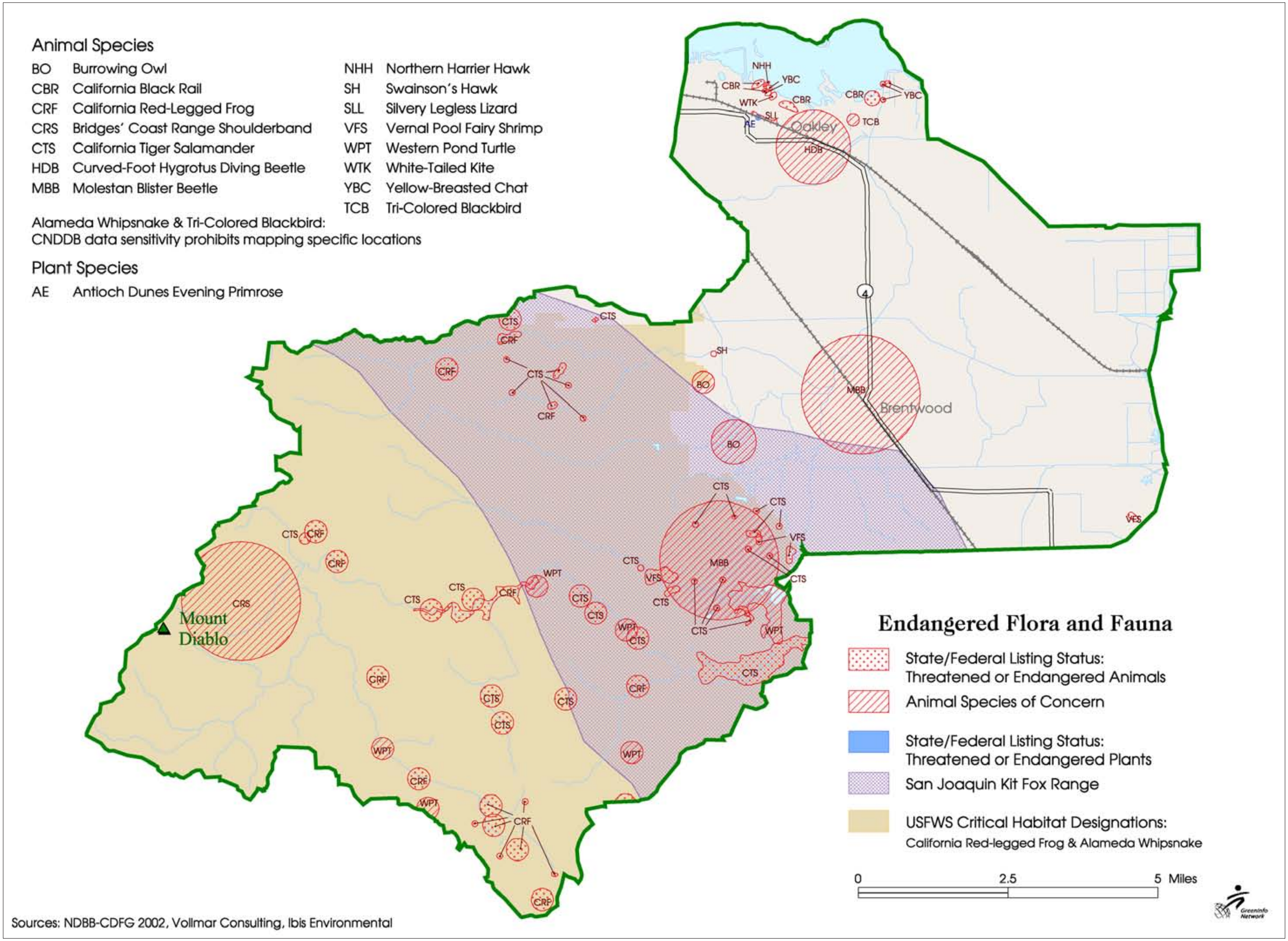

Animal Species
BO Burrowing Owl
CBR California Black Rail
CRF California Red-Legged Frog
CRS Bridges' Coast Range Shoulderband
CTS California Tiger Salamander
HDB Curved-Foot Hygrotus Diving Beetle
MBB Molestan Blister Beetle
NHH Northern Harrier Hawk
SH Swainson's Hawk
SLL Silvery Legless Lizard
VFS Vernal Pool Fairy Shrimp
WPT Western Pond Turtle
WTK White-Tailed Kite
YBC Yellow-Breasted Chat
TCB Tri-Colored Blackbird
Alameda Whipsnake & Tri-Colored Blackbird:
CNDDB data sensitivity prohibits mapping specific locations
Plant Species
AE Antioch Dunes Evening Primrose
Oakley
Brentwood
Mount Diablo
Endangered Flora and Fauna
State/Federal Listing Status: Threatened or Endangered Animals
Animal Species of Concern
State/Federal Listing Status: Threatened or Endangered Plants
San Joaquin Kit Fox Range
USFWS Critical Habitat Designations:
California Red-legged Frog & Alameda Whipsnake
0
2.5
5 Miles
Sources: NDBB-CDFG 2002, Vollmar Consulting, Ibis Environmental

Figure 31

Western Burrowing Owl *(Athene cunicularia hypugaea)*
subspecies of the Burrowing Owl *(Athene cunicularia)*

This semi-colonial ground-dwelling owl with its disproportionately long legs and daytime perching habits is one of California's more conspicuous residents of special concern. Burrowing owls are most often found in open grasslands and semi-desert habitats with high visibility and suitable nest burrows, usually excavated by ground squirrels, prairie dogs, badgers, or other burrowing creatures. Habitat destruction and widespread poisoning of ground squirrels and prairie dogs (thus loss of nest burrows) have markedly reduced burrowing owl numbers over the past half century and, in California, particularly within the past 5 years. In 1971, the burrowing owl was included in the National Audubon Society's first Blue List of bird species suffering population declines and severe habitat loss. It is presently listed as a federal species of concern and a California species of special concern.

The western burrowing owl, active at twilight and sunrise, is found in western North America from Canada to Mexico and east to Texas. Burrowing owls are year-round residents or migratory, depending on location. California is believed to be the most important US state for wintering burrowing owls in addition to hosting its own year-round residents throughout the state up to elevations of 1600 m.

Much of the burrowing owl's activity is centered around its nest burrow, which provides protective cover in all seasons, especially the critical pre-fledging season for young chicks. Peak nesting activity occurs in April and May. In the burrow, the female owl incubates her clutch of 5 to 6 eggs for almost one month. During this time and the subsequent nestling stage, the male will bring food for the mother and chicks. Insects and small mammals make up the majority of the owl's diet. The presence of nearby productive foraging grounds and raised hunting perches greatly enhances nesting success. Chicks are fully capable of flight by 6 weeks of age and remain near their parents' nest burrow until they fledge in fall. Burrowing owls are reproductively active at 1 year of age. Average lifespan is unknown, but maximum known lifespan in the wild is almost 9 years.

Sources

California Department of Fish and Game
[http://www.delta.dfg.ca.gov/gallery/burowl.html]

Institute for Bird Populations
[http://www.birdpop.org/burrowin.htm]

Sacramento Regional County Sanitation District
[http://www.srcsd.com/casebur.html]

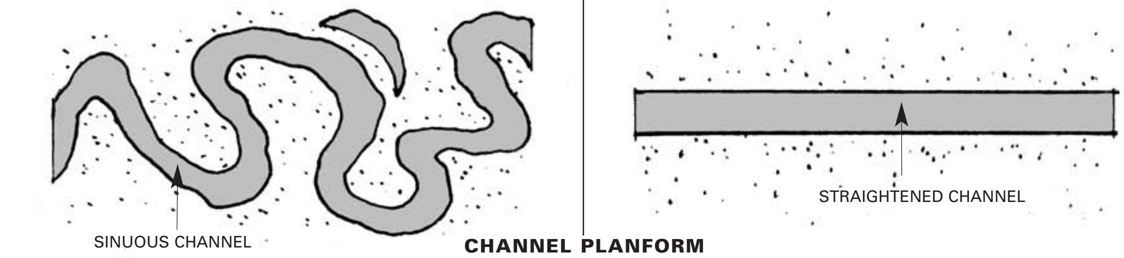
It is no surprise that recorded sightings of the species listed above have been rare in recent decades, in Marsh Creek and elsewhere in their ranges. The decline of these native species, many of which were once abundant throughout the Delta and its associated habitats, can be largely attributed to human activities that have resulted in widespread habitat loss, degraded water quality, and the introduction of predatory or highly competitive exotic species.

Habitat Loss

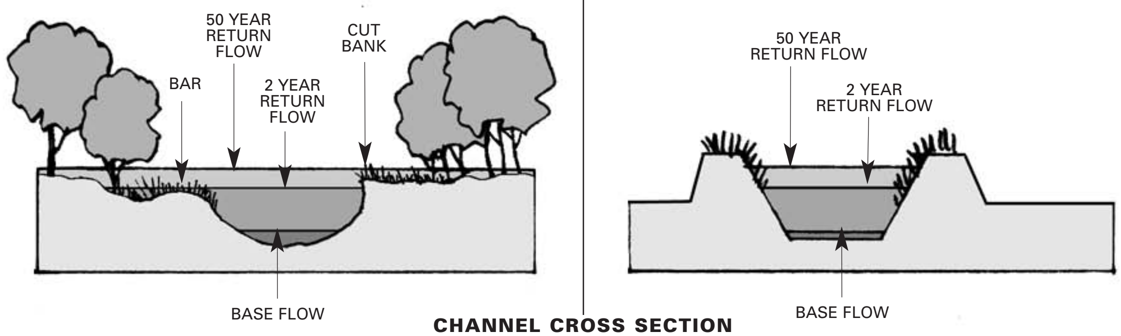
The destruction and alteration of riverine habitat by flood control improvements as well as urban and agricultural development have dramatically reduced both the area of riparian and wetland habitat and the species that depend upon them. In the Marsh Creek watershed, rich floodplains have been converted to croplands, golf courses, and residential neighborhoods. Dams, levees, and channel widening ensured that floodwaters were efficiently conveyed through lower Marsh Creek, eliminating the seasonal marshes and pools that once contributed to the diversity of the aquatic and riparian ecosystem. Sacramento splittail and Chinook salmon have been greatly impacted by such developments in Marsh Creek and throughout the Delta. Splittail use the shallow, vegetated habitats of inundated floodplains for spawning and rearing, and juvenile salmon use them for rearing. For the Sacramento splittail, annual recruitment is closely tied to the availability of spawning habitat, which is greater in wet years when floodwaters may overwhelm flood control structures. In the upper and intermediate watershed of Marsh Creek, barriers like the Marsh Creek Dam further reduce habitat availability for salmon and other anadromous fish by cutting them off from upstream spawning habitat. Conversion of marshes and wetlands has also reduced habitat for a host of native riparian and wetland species, including tricolored blackbirds and California black rails. Figure 32 summarizes major physical changes to stream habitats that have resulted from human activities along Marsh Creek and its tributaries, and why these changes have been so profound for native fauna and flora.

The significant near-total destruction of riparian vegetation that accompanied floodplain development and flood control activities in the watershed has had important consequences for both aquatic and terrestrial biota. In the early 1960s, the remnant riparian corridor along Marsh Creek from the Dry Creek confluence to Big Break was completely eliminated (Figures 33a, 33b). Today, remnant stands of riparian vegetation above the flood control channel (upstream of the Dry Creek confluence) offer clues to the diversity of riparian species that once lined the waterways of lower Marsh Creek. A recent survey of a 1,000 foot stretch of Creekside Park in Brentwood, the downstream extent of the existing riparian corridor, documented at least 8 species of native riparian woody plants, including blue elderberry *(Sambucus mexicana),* box elder *(Acer negundo),* California bay laurel *(Umbellularia californica),*

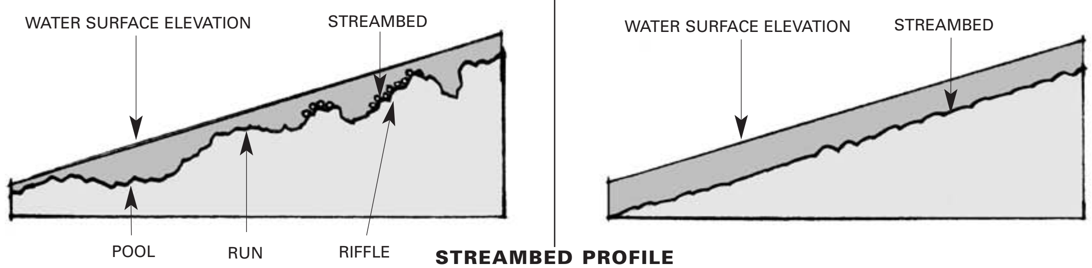
NATURAL CHARACTER OF LOWER MARSH CREEK	CURRENT CHARACTER OF LOWER MARSH CREEK	WHY ARE THESE IMPORTANT?



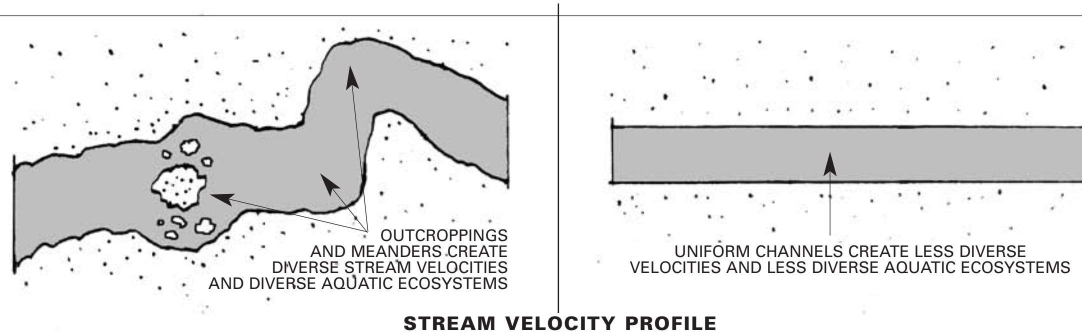
A sinuous stream will naturally meander back and forth across its floodplain. As it meanders, new floodplain surfaces are built-up along the inside of channel bends while older floodplain surfaces are eroded away along the outside of channel bends. Because meandering streams are gradually building new floodplains and eroding older ones, they maintain a mosaic of different habitat types including: mature riparian forests on older floodplain surfaces; newly created depositional bars with riparian seedlings and forbs; oxbow lakes resulting from cut-off meanders; and seasonal marshes in streamside depressions.



A natural stream cross section facilitates connectivity between the stream channel and its floodplain. During high flows, floodplains are inundated creating ideal habitat for spawning and rearing of aquatic species. In addition, floodplain vegetation slows the velocity of flowing water resulting in the deposition of sediments, organic matter, and pollutants in the water. Floodplains function to filter out contaminants and increase downstream water quality, while at the same time nourish the local biotic community with nutrients and moisture. Furthermore, canopy from riparian trees helps maintain cool water temperatures by shading the stream and adds carbon to the aquatic food web via litterfall.



Streambed or stream profile heterogeneity increases available habitat niches for stream insects, fish, and amphibians. These niches range from deep slack water pools to fast moving shallow riffles. Streambed diversity also increases surface water turbulence, which, in turn, increases dissolved oxygen for aquatic organisms.



A stream's velocity profile is directly related to sinuosity, cross section, and profile. The velocity profile affects both instream habitat quality and quantity as well as sediment transport. Different aquatic species and specific life stages within species are adapted to survival at various stream velocities. Thus, a varied velocity profile will foster a diverse aquatic ecosystem. In addition, a natural velocity profile ensures the presence of both depositional and erosional environments within a given stream reach. This, in turn, further increases both instream and riparian habitat complexity and diversity.

Figure 32 – Changes in Physical Channel Properties

Alameda Whipsnake *(Masticophis lateralis euryxanthus)*

subspecies of the California Whipsnake *(Masticophis lateralis)*

The Alameda whipsnake, also known as the Alameda striped racer, is a slender, fast-moving, diurnal snake that inhabits northern coastal shrub and chaparral habitats of western and central Contra Costa and Alameda counties. Urban sprawl and major highways have fragmented the originally continuous range of the Alameda whipsnake into five effectively isolated population centers, making this species highly vulnerable to extinction. It is now listed as threatened under both state and federal endangered species acts. The whipsnake is found in habitats of intermediate shrub density and canopy cover, which provide protection from predators while permitting thermoregulation to maintain body temperature. Threats to populations include human activities that reduce the availability of these intermediate habitats, including certain grazing practices that reduce shrub and grass cover; housing developments, golf courses, and other developments that eliminate existing habitat and fragment remaining habitats; and fire suppression, which promotes closed canopy structures.

Although its 5–20 acre home range is centered in shrub communities, the Alameda whipsnake often uses riparian and other vegetated corridors to foray into surrounding grasslands, oak savanna, and occasionally oak-bay habitats for periods ranging from a few hours to several weeks at a time. The purpose and importance of these ventures and adjacent habitats has not been determined, but may include foraging activities, mate-searching, and egg-laying. Movements are usually less than 50 m from shrub habitat. Within the overlapping home ranges of this species, preferred habitat characteristics include south-facing slopes, partially open (<90%) canopy cover, and small mammal burrows or rock outcrops for protective cover, temperature regulation, and winter hibernation shelter. Lizards, particularly the western fence lizard, make up the bulk of the whipsnake's diet, which also includes small mammals, other snakes, and nesting birds.

Little is known about the life history of this species. However, Alameda whipsnakes are believed to generally hibernate through the winter months (November–March), emerging in spring to mate. Females lay clutches of 6 to 11 eggs between May and July. Young hatch in late summer to early fall.

Sources

US Fish and Wildlife Service. 62(234) Fed. Reg. 64306-64329 (December 5, 1997) "final rule"

US Fish and Wildlife Service. 65(192) Fed. Reg. 58933-58962 (October 3, 2000) "final rule, critical habitat"

Figure 33a – 1939

Figure 33b – 1999

This stretch of Marsh Creek is near the current day location of the Brentwood Wastewater Treatment Facility. In 1939, Marsh Creek still has its sinuosity and although much of its floodplain has been cleared for agriculture the immediate riparian corridor remains densely vegetated (a). By 1999, the Creek has been straightened and all of the woody vegetation has been removed. Notice how the property lines in the northwestern portion of the aerial photograph still mirror the historic bend in the Creek (b). Courtesy of Fairchild Aviation and the City of Brentwood.

California walnut *(Juglans californica),* Fremont cottonwood *(Populus fremontii),* Oregon ash *(Fraxinus oregona),* valley oak *(Quercus lobata),* and various species of willow (*Salix* spp.) (Robins and Walkling, pers. obs.).

Riparian corridors such as these are utilized by many semi-aquatic species for nesting, hibernation, dry season estivation (summer hibernation), foraging, and dispersal, among other activities. In the Marsh Creek watershed, riparian corridors are used by California red-legged frogs and western pond turtles for occasional dispersal between watercourses, thus promoting genetic diversity in local populations. Both species may also spend winter months hibernating or summer months estivating in the thick leaf litter of vegetated riparian corridors. During the summer, female western pond turtles deposit their eggs in underground nests excavated in open upland habitats, often several hundred meters from the watercourse. There is much concern that although western pond turtles are present in Marsh Creek, there is little or no recruitment into the population because nests are unwittingly trampled, flooded (e.g., by irrigation waters), or otherwise destroyed during the incubation period, which may last through September. For this reason, it may be important not only to protect riparian corridors, but also terrestrial habitat adjacent to corridors and within several hundred meters of the Creek.

Many terrestrial species, including the San Joaquin kit fox and Alameda whipsnake, also use riparian corridors for dispersal and movement between habitats. Historically, the riparian corridor of Marsh Creek connected two biologically rich regions, the Delta and Mt. Diablo. Mammals, reptiles, and birds traveled back and forth from the highlands of Mt. Diablo to the wetlands of the Delta in search of food. As the ecosystem within this riparian corridor was degraded by vegetation removal and channel straightening, this essential terrestrial migration route was destroyed. Today, migration through the watershed is severely limited by the absence of woody riparian vegetation in the lower 7 miles of stream. The fragmentation of habitat resulting from the loss of this migration corridor has led to a major constriction in the ranges of the remnant populations of terrestrial wildlife still existing in the watershed.

Degraded Water Quality

Although students at Freedom High School have conducted preliminary water quality sampling, comprehensive water quality measurements have not yet been conducted in either Marsh Creek or Big Break. However, numerous studies on the effects of both urban and agricultural runoff and bio-available mercury on water quality suggest that elevated concentrations of pollutants in Marsh Creek and Big Break could be

California Red-legged Frog *(Rana aurora draytonii)*

subspecies of the Red-legged Frog *(Rana aurora)*

When Mark Twain wrote *The Celebrated Jumping Frog of Calaveras County* in 1865 – the short story that launched him into literary fame – the California red-legged frog was one of the most abundant and the largest of native frogs in the western United States. Since then, the title character of Twain's legendary tale has disappeared from 70% of its historical range, which once stretched from northern California to Baja California at elevations below 1,500 m. It is now found only in isolated pockets of the Sierra Nevada and portions of the San Francisco Bay area and the central California coast. Having lost nearly 90% of its total population over the past century, the California red-legged frog is federally listed as threatened and is a California species of special concern.

The decline of the California red-legged frog is attributed to widespread habitat loss, degradation, and fragmentation (which precludes dispersal between populations); the spread of exotic predators such as bullfrogs and predatory fish; and alterations to the natural hydrograph. Research also indicates that toxic air pollutants such as windborne agricultural pesticides may be playing a role in the decline of this species.

Ideal habitat for red-legged frogs is characterized by dense, shrubby riparian vegetation along the fringes of deep (≥ 0.7 m), still or slow-moving waters, and a near-permanent water source. However, these frogs are also found in and breed in a variety of habitats that do not fit the definition of ideal. Juveniles seem to favor open, shallow aquatic habitats with dense submergent vegetation. During the dry season, California red-legged frogs may seek refuge in small mammal burrows, moist leaf litter, or other protective landscape features within densely vegetated riparian corridors, typically within 60 m of the water. In cooler areas, these terrestrial features also provide critical hibernation habitat.

The diet of the California red-legged frog is highly variable, but primarily consists of invertebrates and small vertebrates for adults; algae for larvae. Sexual maturity is attained at 2–3 years of age, and breeding occurs between November and March. Females deposit masses of 2,000–5,000 eggs on emergent aquatic vegetation during or shortly after large rainfall events in late winter or early spring. The eggs hatch in 6–14 days, and tadpoles develop into frogs between July and September (3.5–7 months after hatch). California red-legged frogs can live 8 to 10 years, but the average life span is likely much lower.

Sources

Center for Biological Diversity

[http://www.biologicaldiversity.org/swcbd/species/rlfrog/rlfrog.html]

Davidson, C., H.B. Shaffer, and M.R. Jennings. 2001. Declines of California red-legged frogs: climate, UV-B, habitat, and pesticides hypotheses. Ecological Applications 11(2): 464-479.

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.

Hayes, M.P. and M.R. Tennant. 1985. Diet and feeding behavior of the California red-legged frog, *(Rana aurora draytonii)* (Ranidae). The Southwestern Naturalist 30(4): 601-605.

Jennings, M. R. and M. P. Hayes. 1994. Amphibian and Reptile Species of Special Concern in California. Final Report submitted to the Department of Fish and Game Inland Fisheries Division under contract No. 8023. 255 pp.

US Fish and Wildlife Service. 66(49) Feg. Reg. 14626 (March 13, 2001) "final rule"

[http://www.r1.fws.gov/crithab/crlf/crfcrithab1.pdf]

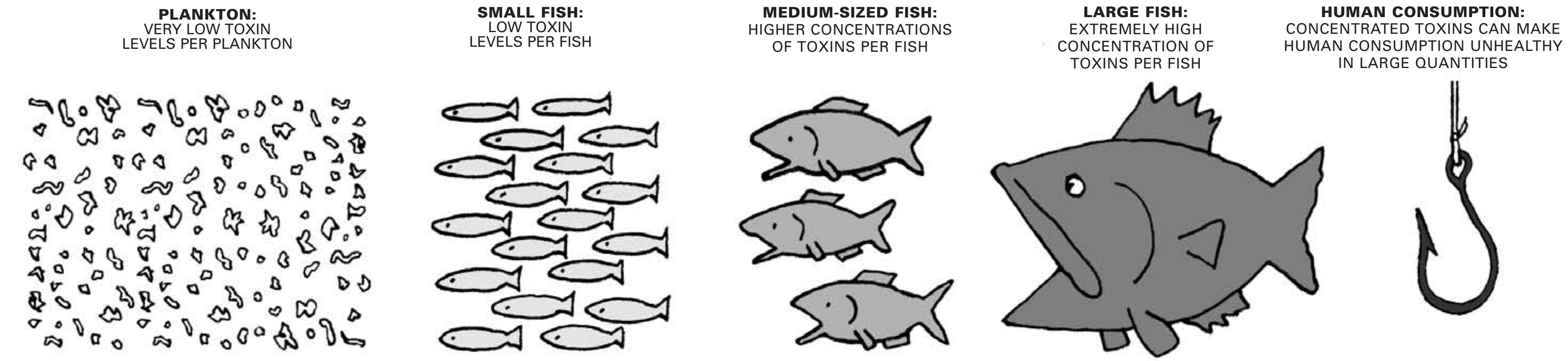


Figure 34 – Biomagnification of Toxins

As larger species consume smaller ones, toxins accumulate and concentration levels increase.

harming endangered fish and leading to the long-term degradation of aquatic habitats (Pillard, 1996; Slotton et al., 1996, 1997, and 1998; Magaud et al., 1997; Hinton, 1998; Fisher et al., 2000). Several factors have contributed to Marsh Creek's water quality problems including mercury mining activities beginning in the middle of the 19th century, followed by extensive agricultural development and rapid urbanization of the watershed. These activities have increased the concentration of naturally occurring substances such as mercury and nitrogen, added synthetic toxins such as the active chemicals in pesticides and herbicides, and reduced freshwater inflows that could otherwise dilute contaminants.

The impact of toxic substances is further compounded by the loss of wetland floodplain vegetation. This vegetation would have acted as a filter, capturing and immobilizing many of the contaminants currently spilling into Marsh Creek before they entered the Delta. As water gradually spread across the vegetated floodplain, contaminants would have settled out of the water column and into the sediments where they could have been bound by charged clay particles, altered chemically by oxidation or reduction, or taken up by plants. All of these potential fates would have removed the contaminants from the stream ecosystem.

Fish and other species higher in the food chain, including humans, are most susceptible to the toxic effects of pesticides, heavy metals, and other contaminants in Marsh Creek, through the naturally occurring processes of bioaccumulation and biomagnification. Bioaccumulation refers to how pollutants enter a food chain and biomagnification refers to the tendency of pollutants to concentrate as they move up the food chain from one trophic level to the next. Together, these phenomena explain how even small concentrations of chemicals in the environment can find their way into organisms in high enough dosages to cause problems.

Bioaccumulation is the process by which "persistent" contaminants – those that are not easily broken down through digestion – are "eaten" and concentrated by organisms at the lowest trophic levels, such as algae. As contaminants are continually ingested and accumulated, their concentrations inside the organism become greater than in the environment. Animals higher in the food chain eat large quantities of organisms lower in the food chain, and thereby accumulate even higher concentrations of persistent contaminants in their systems. Biomagnification is the process in which each successively higher trophic level accumulates and concentrates the contaminants collectively stored in all ingested organisms from lower trophic levels. Figure 34 illustrates the processes of bioaccumulation and biomagnification in an aquatic ecosystem. These processes explain how the concentration of a toxic chemical in animals at the top of the food chain can be high enough to cause death or adversely affect reproduction, while ambient contamination levels in the air, water, or soil are well below levels deemed to be "dangerous" by regulatory agencies.

The effects of mercury bioaccumulation and biomagnification on Marsh Creek's fauna deserve special mention, both because upper Marsh Creek was home to nearly a century of historic Delta mercury mining activities and because mercury's toxicity in aquatic systems is relatively well-studied and understood. Since the mid-1980s, the Marsh Creek Reservoir has been closed to fishing due to the dangerously high concentrations of mercury found in fish both in and upstream of the Reservoir. Mercury-laden sediments originating from historic mine sites in upper Marsh Creek have been deposited and accumulated in the slack water of the Marsh

Creek Reservoir. In the Reservoir sediments, anaerobic conditions and naturally occurring microbial populations transform, or methylate, less toxic forms of mercury into highly toxic and bioavailable methylmercury. Planktonic algae and freshwater macrophytes, which form the base of most aquatic food webs, have a high capacity to bioaccumulate methylmercury directly from the water. Methylmercury is also quickly concentrated up the aquatic food chain, through ingestion from water and food, as well as maternal transmission via eggs. Biomagnification of mercury in aquatic systems can result in large, predatory fish with mercury concentrations over a million times higher than those in the surrounding waters (Eisler, 1987).

Mercury is lethal at high concentrations – fish-eating species (such as birds, aquatic mammals, and humans) are at greatest risk of acute mercury poisoning. At sublethal concentrations, mercury primarily affects the reproductive system and brain development. Mercury toxicity has been cited for low reproductive success in fish-eating birds and aquatic mammals such as river otters; high mortality and deformity rates in frog and fish embryos; and impaired growth and development in fish and fish-eating mammals. In humans, unborn babies are most susceptible to mercury's harmful effects, which may be transmitted from mother to fetus and usually result from a woman's consumption of contaminated fish during her pregnancy. Affected babies may suffer brain damage, mental retardation, blindness, seizures, and inability to speak. For this reason, the US Food and Drug Administration (FDA) sets a maximum permissible level of 1 part of methylmercury per million parts of seafood (1 ppm) consumed by humans. Approximately 80% of advisories that are issued in the United States to warn against consumption of fish or wildlife in a region are due at least in part to mercury contamination in animal tissues. Between 1993 and 2000, mercury advisories increased 149% to a record 2,242 issued in 2000 (United States Environmental Protection Agency, 2001).

Water quality issues in an aquatic ecosystem are defined by more than just the concentration of contaminants. Over the past half century, water quality in Marsh Creek has also been negatively impacted by higher water temperatures, lower dissolved oxygen levels, and increased sediment loading. Before widespread clearing of vegetation in the 1960s for flood control purposes, riparian vegetation along Marsh Creek played an important role in maintaining the aquatic conditions favored by salmon and other fauna. Shade from riparian trees kept water temperatures cool and moderated dissolved oxygen and pH. These factors are important for the survival and proper development of numerous native aquatic species.

Riparian vegetation also controls sediment loading from erosion by armoring stream banks and reducing stream velocities. In the absence of adequate riparian vegetation or other erosion control measures, fine sediment loading increases turbidity of water and reduces sunlight penetration. Without sunlight, phytoplankton

Western Pond Turtle *(Clemmys marmorata)*

The western pond turtle includes two subspecies – the northwestern and southwestern pond turtles – which overlap in range just south of the San Francisco Bay Area. Historically, this species was abundant from Puget Sound to Baja California, with isolated inland populations. Its current distribution is limited to suitable parts of California, Oregon, and Washington. The western pond turtle is a California species of special concern.

Pond turtles are habitat generalists, found in fresh to brackish permanent or ephemeral aquatic habitats with deep, slow water and access to underwater refugia and emergent basking sites (logs, boulders, emergent vegetation). Hatchlings are relatively poor swimmers and tend to seek areas with slow, shallow, warmer water, often with dense submergent and emergent vegetation. Pond turtles are omnivorous with a preference for live animal matter such as small insects, aquatic invertebrates, and fishes.

Although they may be active throughout the year, in the northern part of their range pond turtles often spend the winter months largely inactive in pond bottoms or, more often, in thick leaf litter of terrestrial habitats up to 500 m from the watercourse. Terrestrial habitats are also used by this species for dispersal, to escape high water flows, for aestivation where aquatic habitats are ephemeral, and for egg-laying.

Egg-laying generally occurs between May and July. Females travel several hundred meters upland to excavate nests in south-facing areas with sparse, low vegetation, little slope, and dry compact soil. Clutches average 4–7 eggs. Incubation takes approximately three months. Hatchlings emerge in early fall or, in cooler climes, overwinter in nests to emerge in March or April. Western pond turtles reach sexual maturity at 8–10 years of age. Most females reproduce in alternate years and exhibit high nest-site fidelity. Average life span is uncertain, but likely in the range of 30–40 years.

The greatest threats to survival of this species are habitat loss, disturbance of nesting habitats during critical incubation or hatchling overwintering periods, and introduction of exotic species – especially bullfrogs and largemouth bass – that prey on hatchlings. In addition, raccoons and coyotes, which have increased in number as their predators have been driven out by human influences, are major predators on western pond turtle eggs.

Sources

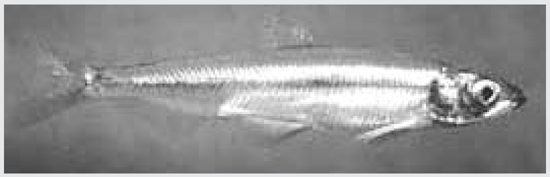
Holland, D.C. 1991. A synopsis of the ecology and status of the western pond turtle *(Clemmys marmorata)* in 1991. Prepared for the USFWS, National Ecology Research Center, San Simeon Field Station.

Holland, D.C. 1994. The western pond turtle: habitat and history. CDFG final report.

Reese, D. A. 1996. Comparative demography and habitat use of western pond turtles in Northern California: The effects of damming and related alterations. Unpublished Ph.D. Dissertation, University of California, Berkeley. 253 pp.

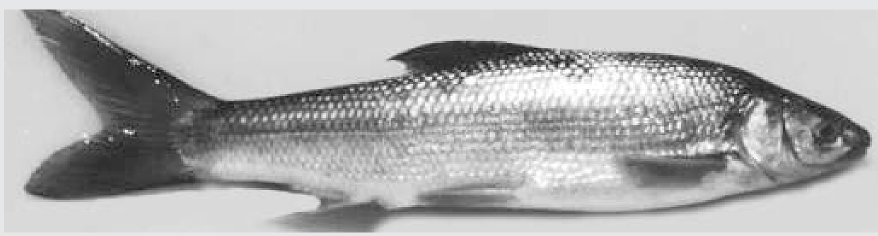
Delta Smelt *(Hypomesus transpacificus)*
Sacramento Splittail *(Pogonichthys macrolepidotus)*

Due to its short 1-year lifespan and relatively low fecundity, the 3-inch Delta smelt is widely regarded as an important indicator species for the health of the Sacramento-San Joaquin estuary (the Delta). Sacramento splittail, which were once popular among anglers as bait fish, are longer-lived (5–7 years) and more fecund. Despite life history differences, both California endemic species have suffered similar declines in the Delta where they were once abundant. By 1993, delta smelt abundance was 10% of historic values, earning the species both federal and state threatened listing. Sacramento splittail populations are currently estimated at 35–60% of 1940 levels. The Sacramento splittail is a California species of special concern. It was also federally listed as threatened in 1999, but that status is currently under review as a result of legal actions.



Smelt

Delta smelt and Sacramento splittail occur primarily in low-salinity zones (2–7 ppt) of the Delta and Suisun Bay during much of the year. In late winter and early spring, smelt move into freshwater sloughs and shallow edge-waters of channels in the western Delta to spawn; splittail migrate to inundated floodplains, such as the Yolo and Sutter Bypasses. Individual female smelt lay 1,200–2,600 eggs, which attach to rocks, gravel, and other hard substrates. For the prolific splittail (a single female may produce over 100,000 adhesive eggs), evidence suggests that spawning occurs over shallow, flooded vegetation. Eggs hatch in several days (splittail) to two weeks (smelt). Larvae feed near spawning sites as their swimming abilities increase over the next few weeks, after which they migrate or are washed downstream to low-salinity rearing grounds in the Delta and Suisun Bay.



Splittail

Delta smelt abundance and Sacramento splittail recruitment success fluctuate greatly from year to year, partly in response to changes in annual freshwater outflow to the Delta. In moderately (but not extremely) high outflow years, the low-salinity zones favored by smelt are located close to or in the broad, shallow Suisun Bay, where nutrients and prey are abundant. When freshwater outflow is low (due to drought and/or high rates of water diversion), low-salinity zones are located in deep, narrow channels of the Delta, where there is less available habitat area and increased risk of diversion to export pumps. Splittail, which have higher salinity tolerance (up to 29 ppt) than smelt, rely on Delta outflow more for its influence on the availability and extent of flooded vegetation for spawning, particularly in the Yolo Bypass. In addition to low Delta outflow, both species are threatened by habitat loss and alteration, entrainment in Delta export pumps, toxic pollutants, and loss of prey to competing exotics.

Sources

California Department of Fish and Game. [http://www.delta.dfg.ca.gov/gallery/dsmelt.html]

Meng, L. and P.B. Moyle. 1995. Status of Splittail in the Sacramento-San Joaquin Estuary. *Trans. Amer. Fish. Soc.* 124:538–549.

Moyle, P.B. Inland Fishes of California (2nd ed.). unpubl.

Moyle, P. B., R. M. Yoshiyama, J. E. Williams and E. D. Wikramanayake. 1995. Fish Species of Special Concern in California. Final Report submitted to the Department of Fish and Game Inland Fisheries Division under contract No. 2128IF. 272 pp.

Sommer, T., W. Harrell, M. Nobriga and R. Kurth. Floodplain as Habitat for Native Fish: Lessons from California's Yolo Bypass. unpubl.

US Fish and Wildlife Service. 58 Fed. Reg. 12854 (March 5, 1993) "final rule" [http://endangered.fws.gov/r/fr93492.html]

and other photosynthetic organisms that form the foundation of the stream food web cannot survive. Moreover, suspended fine sediments may be deposited in low-gradient reaches, clogging gravels that are essential for successful spawning of anadromous fish.

Removal of riparian vegetation affects the trophic structure and overall health of riverine ecosystems in other ways as well. In vegetated reaches, twigs, leaves and other plant materials that enter the creek provide the basic carbon and nitrogen essential for growth and maintenance of primary consumers, such as aquatic insects, which represent a major food source for secondary and tertiary consumers. Not surprisingly, surveys of aquatic insects and other macroinvertebrates (Slotton et al., 1996, 1997, and 1998; Hagelin, 1998) in unvegetated reaches of lower Marsh Creek have found a disturbingly low insect diversity – a grim portent for the survival of native riparian and aquatic species that depend on aquatic insects for their food supply. In response to these findings, the Delta Science Center has initiated a comprehensive volunteer water quality-monitoring program involving students and faculty from Oakley's Freedom High School, Bentwood's Liberty High School, and California State University in Hayward. The long-term monitoring effort is expected to determine the specific contaminant issues impacting the biotic communities of Marsh Creek and Big Break, particularly at lower levels of the aquatic food web.

Exotic Species

In the highly modified environment of Marsh Creek, native species specially adapted to seasonal flow, regular floodplain inundation, cool water, and specific niches no longer present are often out-competed by opportunist non-native species. Indeed, limited biological surveys on the lower zone of Marsh Creek (Hagelin, 1998) indicated that the existing aquatic community is dominated by exotics. Introduced fish species, crayfish, and bullfrogs thrive in the warm perennial flows of lower Marsh Creek and prey on or compete against the larval, juvenile, or adult developmental phases of many sensitive native species. Bullfrogs are particularly notorious for their voracious appetites. This single species has been cited as a major factor in the decline of numerous native Delta species, including the California red-legged frog, western pond turtle, and California tiger salamander. Exotic fish such as largemouth bass *(Micropeterus salmoiders)* and bluegill predate the native species listed above and compete with or prey upon other fish, including Sacramento splittail, juvenile Chinook salmon and steelhead trout, California roach, and hitch. The presence of significant populations of exotic species has led to the decline or complete extirpation of many sensitive species from waterways of the Marsh Creek watershed's lower topographic zone.

Perennialization of lower Marsh Creek is one of the primary factors that has permitted the survival of exotics in this aquatic ecosystem. Dry season irrigation of croplands, golf courses, and urban landscaping has converted waterways in the lower topographic zone from seasonal to perennial systems. This enabled the intrusion and subsequent success of bullfrogs, whose young metamorphose over a period of two years and would not survive in a seasonal aquatic habitat. Unlike the anadromous fish native to Marsh Creek, largemouth bass and many other predatory non-natives also depend on year-round waters for successful habitation and recruitment of young. Perennialization of lower Marsh Creek has eliminated the one habitat factor that favored natives such as California red-legged frogs, western pond turtles, and juvenile Chinook salmon over the exotic generalists that have come to dominate Marsh Creek.

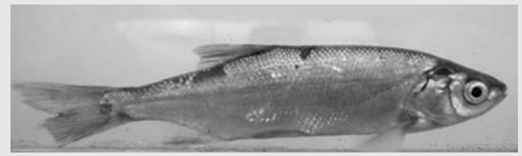
The Changing Human Community

Over the last ten years, there has been a population explosion in the Marsh Creek watershed. Approximately one quarter of the population in the watershed moved into their current residences between March 1999 and 2000[1]. Between January 1, 2000 and 2003 the population of Brentwood increased from approximately 23,000 to

[1] Interpreted from the 2000 Census Data for Tracts 3020, 3031 and 3032.

Hitch *(Lavinia exilicauda)*
California Roach *(Hesperoleucus symmetricus)*

Hitch and California roach are closely related California native freshwater fishes. Although both are classified as minnows, the hitch can actually exceed 13 inches in length. Both hitch and roach are important



Juvenile Hitch

forage fish in warm inland waters. Where they co-occur, they can hybridize to produce fertile young. Several geographically isolated subspecies have been identified for both the hitch (3) and California roach (6–8). Many of these subspecies are still abundant, but threatened to some degree by increasing water diversions, which reduce instream flow; dams and other artificial barriers, which isolate populations and may block upstream access for spawning; decreased water quality; and (especially for California roach) predation by non-native fishes such as green sunfish and largemouth bass. California has granted protected status to the following subspecies: *Endangered* – Red Hills roach; *Species of Special Concern* – Clear Lake hitch, Pit roach; *Watch List* – Monterey roach, Navarro roach, Tomales roach, Gualala roach.

Hitch are omnivorous open-water feeders commonly found in warm (27–29 C) low-elevation lakes, sloughs, and streams. They have scattered populations throughout the Central Valley, in Clear Lake, and in the Russian River. The hitch spawns mainly in streams, swimming up small creeks during early spring rains. A single female may deposit anywhere from 3,000 to 110,000 nonadhesive eggs, which sink to clay or gravel substrate or in submerged vegetation. Larvae hatch within a few days and soon congregate in shallow vegetated areas and shaded pools, which serve as nursery grounds and shelters. Juvenile hitch usually remain in the same habitat as the larvae. Hitch reach sexual maturity at 1–3 years of age (2–3 for females) and may live 4–6 years.

The omnivorous California roach is a habitat generalist, most often found in small, warm intermittent streams in the Sierra foothills and in Coast Range streams of the Sacramento-San Joaquin drainage system. Spawning for this species occurs March–early July, with schools of fish seeking shallow waters with moderate flow and gravel/rubble substrate. On average, a single female lays 300 adhesive eggs, which hatch in 2–3 days. Once free-swimming, larvae move into shallow pools or stream edges. Juvenile roach reside in the deeper pools and main body of a creek, maturing in 2–3 years. Roach generally live 3 years.

Sources

Moyle, P.B. Inland Fishes of California (2nd ed.). unpubl.

Moyle, P. B., R. M. Yoshiyama, J. E. Williams and E. D. Wikramanayake. 1995. Fish Species of Special Concern in California. Final Report submitted to the Department of Fish and Game Inland Fisheries Division under contract No. 2128IF. 272 pp.

California Department of Fish and Game

[http://www.dfg.ca.gov/hcpb/species/ssc/sscfish/sscfish.shtml]

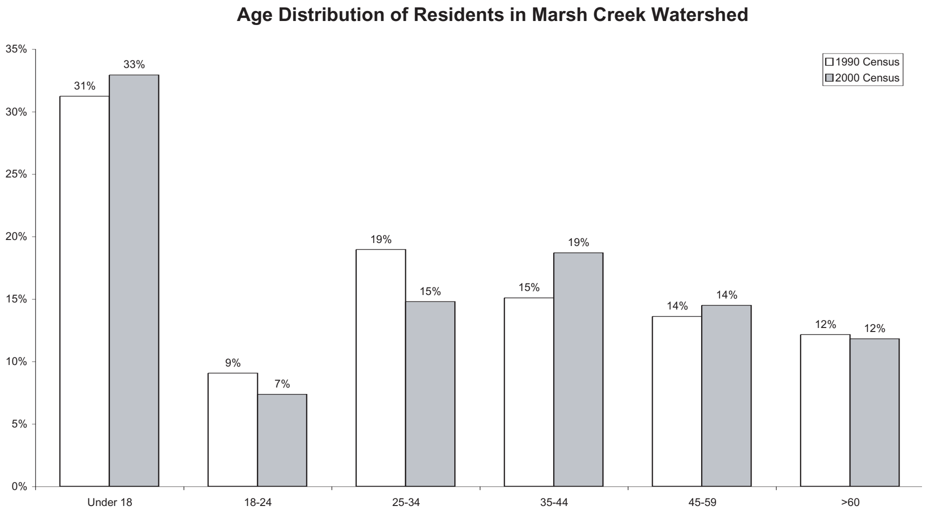


Chart 6

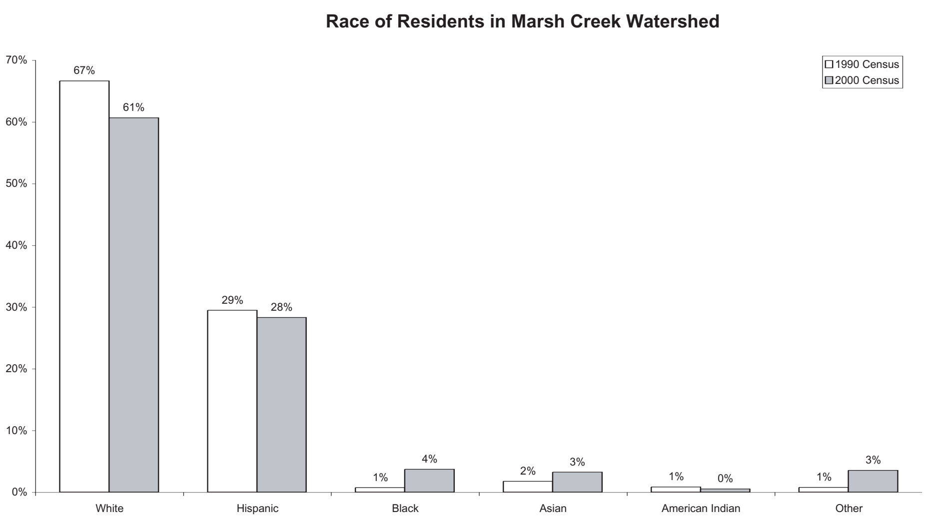


Chart 7

33,000 people[1]. The City had a population of approximately 7,500 in 1990 according to the US Census data. In addition to an increase in population, Brentwood has changed from an agricultural community to a predominantly residential community. The percentage of residents (over 16 years old) employed in agriculture dropped from 6.5% in the 1990 Census to 1.3% in 2000. Growth is expected to continue into the future. Projects are currently under construction or approved to accommodate approximately 26,000 new residents in the City of Brentwood[2].

So who are these new residents? There are more kids under 18 years old and more adults between the age of 35 and 44 in 2000 than there were in 1990, as shown in Chart 6. The population has become slightly more diverse with an increase in Black and Asian populations and a 6% decrease in Whites (Chart 7).

Both the newcomers to the community and the residents who have lived in Brentwood for generations highly value Marsh Creek. Most think it is an ugly little creek in desperate need of repair, but they value it nonetheless. It is not a surprise to hear that some people don't know that Marsh Creek is really a creek and think it is only an irrigation canal or ditch. In 2002, the City of Brentwood and NHI, in partnership with the University of California, Berkeley and the Delta Science Center, sent out 2,000 surveys to households located within a quarter mile of Marsh, Sand, Deer, and Dry creeks to determine how residents value and use the Marsh Creek watershed. The results of the survey were analyzed by Chia-Ning Yang from UC Berkeley. The survey found that residents use Marsh Creek to walk, bike, and jog to work and school, and for recreation and exercise. Kids enjoy playing in the Creek with their parents and other kids. Residents enjoy sitting, relaxing, and enjoying the natural beauty of the Creek and watching wildlife. Most people think there should be less garbage and more trees and want to take action to enhance their community by taking care of and improving the Marsh Creek watershed.

About 18% of the recipients responded to the Brentwood survey, a high response rate compared to the 1% return expected with most unsolicited mailings. Most of the people who responded were females and middle-aged residents, and probably cared more about the Creek than people who did not respond. The questionnaire was in English, which may have deterred some Hispanic residents from responding. UC Berkeley is in the process of translating the survey into Spanish.

When asked what features people value in or around Brentwood, residents responded that they value Marsh Creek nearly as much as surrounding farms and orchards, Mt. Diablo, regional and city parks, and the Delta. Interestingly, they valued Marsh Creek far more than the local golf courses (Chart 8). When choosing what factors most influenced residents to move to Brentwood, the natural environment was second only to housing costs, and ranked higher than social environment and children's education (Chart 9). When asked specifically what they value about the Creek, the majority of residents said they appreciate the natural environment (Chart 10). They value the accessibility of the Creek because it is conveniently located near their homes and flows through their community. The trails were also highly valued as an opportunity to exercise and recreate in a natural setting near their homes.

[1] Data from the 2000 Census and the State Department of Finance.

[2] Data from Summary of Residential, Commercial and Industrial Activity Within the City of Brentwood as of April 1, 2003 assuming 3.1 residents per household, according to the 2000 Census Data.

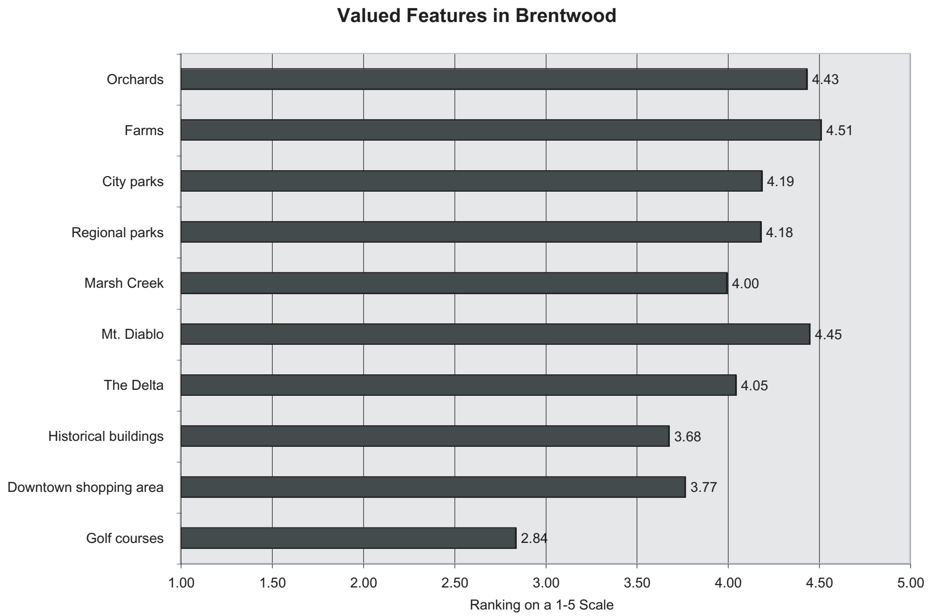


Chart 8

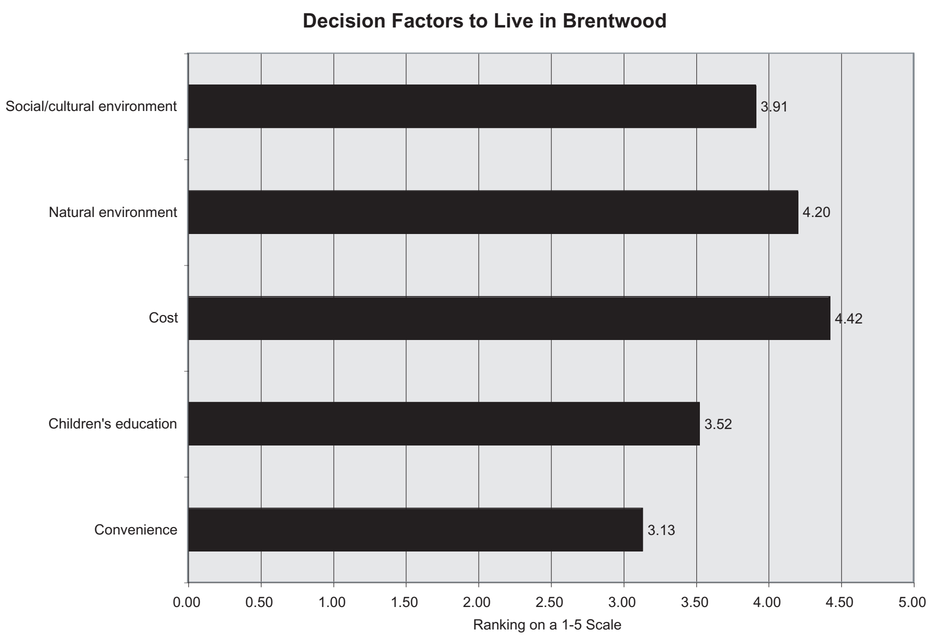


Chart 9

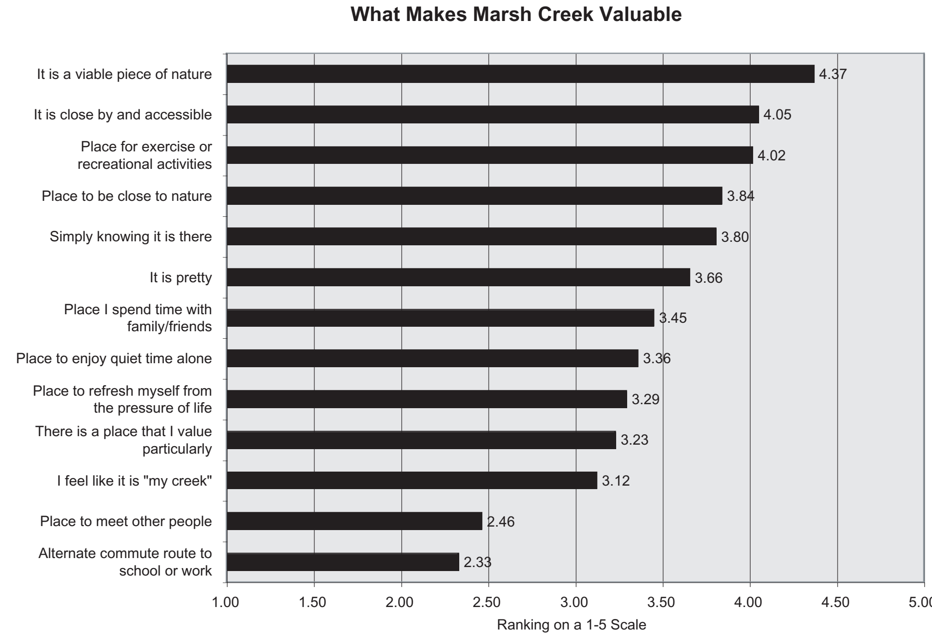


Chart 10

Marsh Creek provides a highly valued opportunity to view wildlife, walk along the trail and relax by the water. Most of the activities on Marsh Creek involve residents moving along the trail (Chart 11), especially walking, biking, jogging, roller-blading, and skating (Chart 12). Although barren and lacking vegetation in some sections of the Creek, Brentwood residents value the natural aspects of the Creek, such as interacting with fish, crawdads, frogs, tadpoles, and bugs, bird watching, and exploring water, rocks, and trees. Residents also enjoy quiet time sitting, relaxing, watching the water, and listening. Although people use the creek primarily for exercise, respondents answered that their most memorable experiences along the trail often involve interacting with nature, and spending quiet time by the Creek (Chart 13). Residents particularly enjoy watching birds and spending time at the creek with their children. One respondent wrote that her most memorable experience was watching a flock of egrets land in the Creek by Creekside Park on a sunny day.

Despite the heavy use of and appreciation for Marsh Creek, residents thought the Creek had many problems. They wanted to see improvements and changes, and take action to help make these changes. When residents were asked what area of the Creek they would like to see improved, one third said “all of it”. They thought the biggest problem facing the Creek was cleanliness, specifically dumping and garbage (Chart 14). Unfortunately it is common to see shopping carts, tires, and lots of trash along the banks of Marsh Creek. Lack of shade was another problem and residents

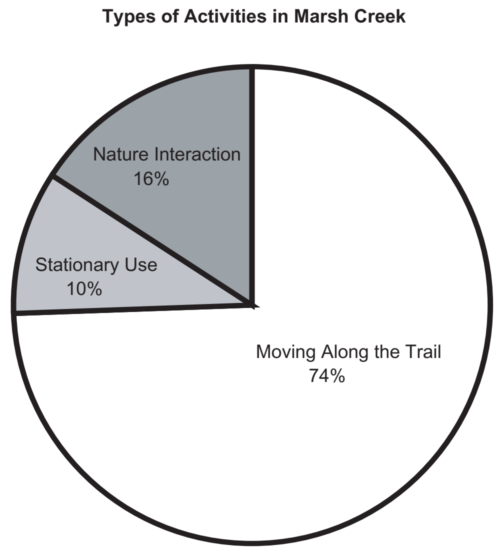


Chart 11

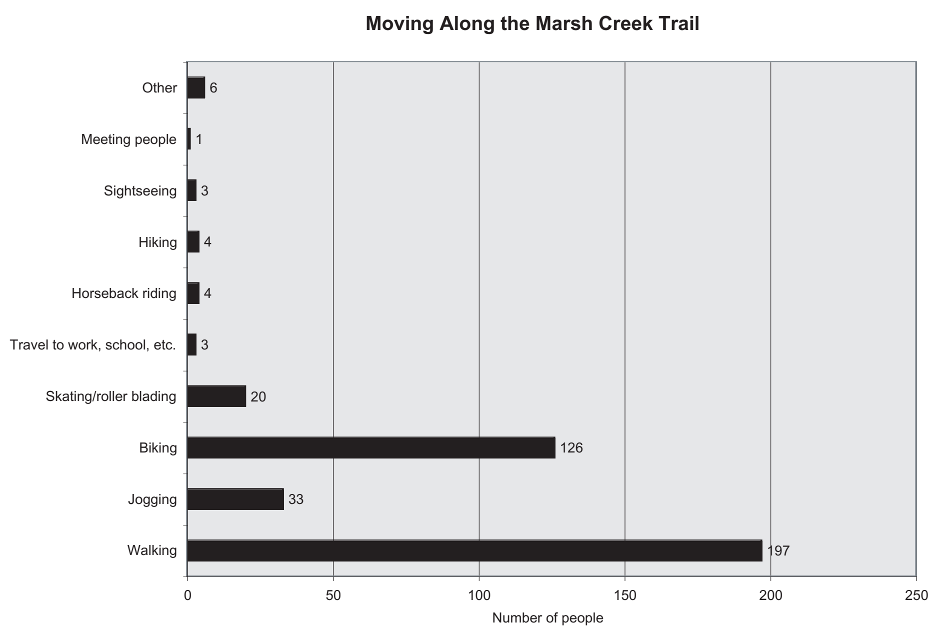


Chart 12

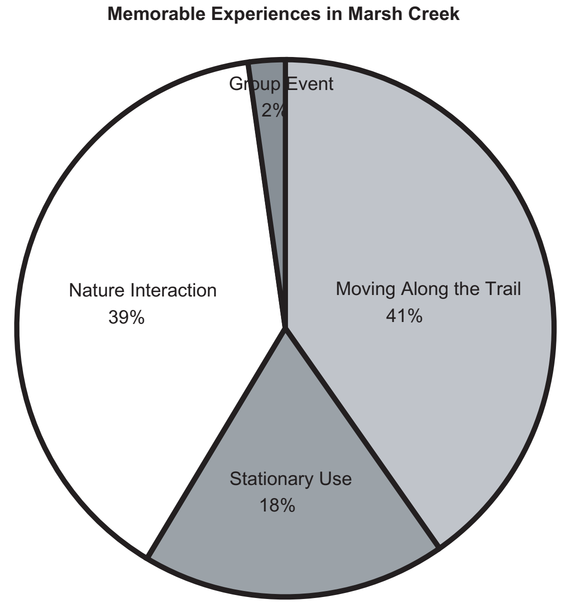


Chart 13

thought the Creek could be improved or changed by planting more vegetation and trees, and fewer grasses and weeds (Chart 15). There are large stretches of the Creek adjacent to the trail that completely lack streamside vegetation and protection from intense sun on a hot summer day. A more natural-looking creek integrated with the neighborhood, with shady trees, clean water, and better trails and facilities, was preferred. Respondents wanted to see natural, woodsy areas where kids could have adventures.

In order to improve the condition of Marsh Creek, 95% of the people who responded to the survey said they were willing to do something to help. A majority of the respondents were interested in receiving information about the Creek or participating in Creek clean-up events (Chart 16). More than one third of the respondents said they would vote for a local funding initiative to enhance the Creek. It is clear that Brentwood residents value and use Marsh Creek and are ready to take action to make it better.

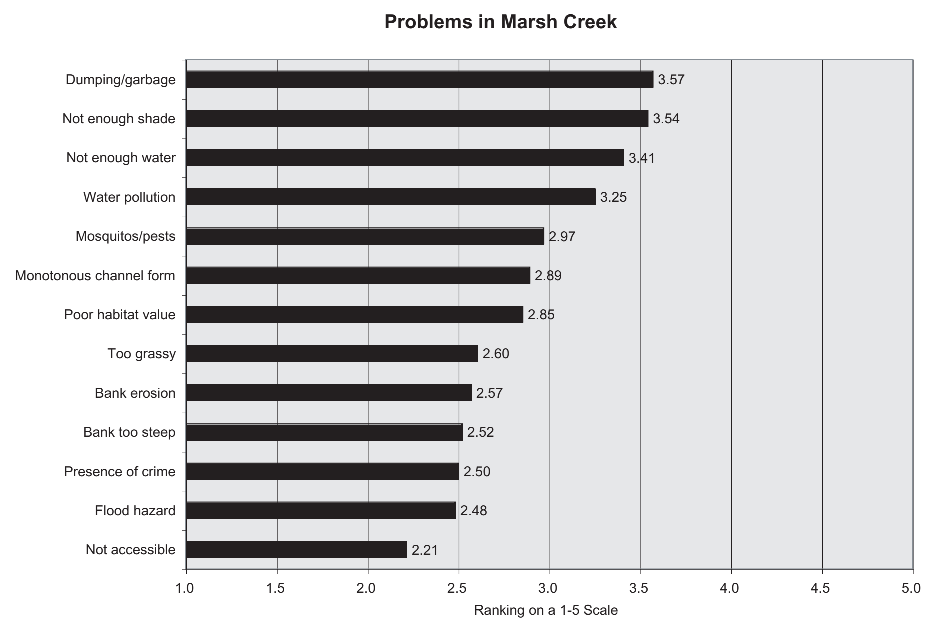


Chart 14

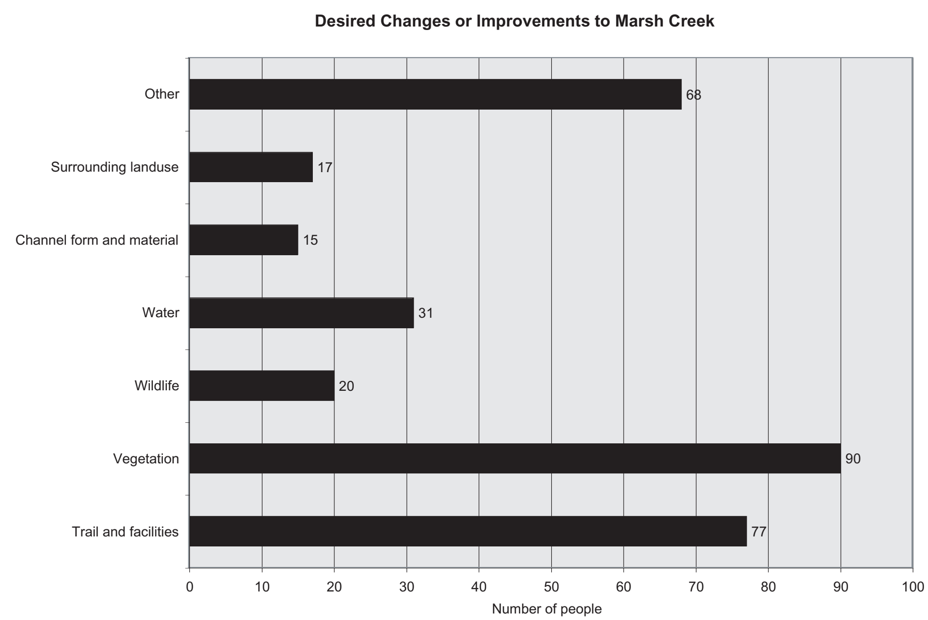


Chart 15

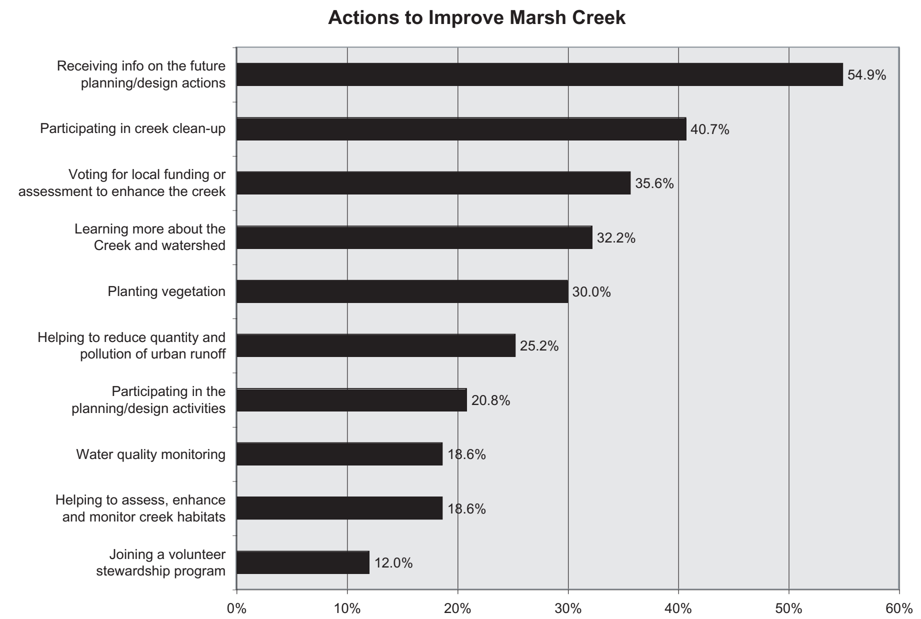


Chart 16

Chapter 5
Now What?

The Natural Heritage Institute and the Delta Science Center have spent three years working to better understand the past and present condition of the Marsh Creek watershed. Together with many collaborators, we have pursued numerous leads and sources to piece together a contemporary image of Marsh Creek composed of ancient natural processes juxtaposed with more modern human changes. But recent changes throughout the watershed are quickly obliterating over 10,000 years of biological and geological processes that once defined Marsh Creek. Rapid urbanization and the channelization of lower Marsh Creek are transforming an important asset into a lifeless, polluted ditch that will be a liability for generations to come. Fortunately, there is a window of opportunity now to protect and restore stream corridors, clean water, shady forests, diverse wildlife, safe recreational opportunities, and great civic pride. Without public involvement, and we dare say love, Marsh Creek will continue to deteriorate, depriving people and the balance of nature of a special gift. Problems in the lower watershed through Brentwood, Oakley, and parts of Antioch have already created an apathy and sense of helplessness among some residents who now view beautiful creek settings as a vacation destination point, not a backyard gift. We can change the Creek by becoming active stewards and restoring what we love about the Creek. The balance of this report is a roadmap for getting there. A lot has already been accomplished, but we have only just begun.

Residents commonly tell us that too much of Marsh Creek is just plain "ugly" and many people don't even know that the ditch that runs through their community is a creek. As residents, we all owe a great debt of thanks to the flood control engineers from decades past for protecting us and our properties from recurrent, devastating floods. They did the best they could with what they had, but in the process they gutted a natural creek and left us with rip-rapped storm drains destined for the Delta. The greatest consequence of the flood controls was to put the creeks out of sight, out of mind. People lost visual, visceral, and aesthetic connections to the creeks, and by a logical extension began treating them as open sewers and convenient garbage sites. If you have ever done a community creek clean-up, you know what that means. And like graffiti on a wall, once it gets going it steamrolls.

This mind-set, which can contaminate us all, has gradually stripped away, piece by piece, all the riparian vegetation and the rich, natural edges of life between the waterscape and landscape. This loss of habitat translates to a poor environment, now dominated by invasive weeds and vermin that are comfortable living among us. The richness is gone, and with it our desire to even care. Maybe it just prompts us to look the other way. But in east Contra Costa County there is no time left to look away or ignore the change. The speed and rapidity of urbanization in Antioch, Brentwood, and Oakley have made front page news repeatedly for the fastest growth in the state. As agricultural lands have lost ground to housing developments, the pressures on the edge of Marsh Creek have intensified, replacing orchards with concrete and fences – further disconnecting the Creek from the community it should adorn.

Even if we can rationalize this loss of habitat and a gain of ugliness as necessary sacrifices for building our cities and communities, we still have a responsibility to pass on clean water to future generations and people downstream. Every activity in the watershed, be it a bird pooping or a person washing their car, finds its way to water. Gone with the riparian habitat and the lush edges are the Earth's natural filters, leaving behind conduits for pollutants directly headed for the Delta, which provides drinking water for thirty million Californians. Agricultural, industrial, and urban runoff are increasingly serious threats to our health and the health of the whole ecosystem. Marsh Creek in its current configuration is not helping us. It needs to be restored and protected, piece by piece, so you will want to dip your feet into Marsh Creek on a warm summer day.

One of the most troublesome issues in Marsh Creek is the presence of mercury and its toxic impact on fish and the people who consume them. Like many streams in California, Marsh Creek is associated with an abandoned mercury mine that continues to leach heavy metals into the food chain. Mercury can be so toxic that efforts to remediate these sites have foundered because of liability issues. In other words, by trying to fix it you might make the situation worse. But ignoring mercury is no longer a solution either. You've seen the reports warning and advising you and your family not to eat fish. They are scary.

Another important issue in Marsh Creek is the survival of native fish. Fish are a great barometer of environmental health. While native fish have declined in the Creek, there are reasons for optimism. Miraculously, a few Chinook salmon return each year to spawn in lower Marsh Creek. With a little help from their human friends, the removal of one small check dam downstream of Brentwood could restore access to miles of former upstream spawning habitat. In the upper watershed, the Creek still provides habitat to a number of unique native fish and amphibians.

With commitment and foresight it is still possible to transform Marsh Creek into an economic and ecological asset we can all take pride in and enjoy. We can create a new future for Marsh Creek by pursuing five simple goals:

1) Establish and protect a corridor of undeveloped land along the urbanizing edges of Marsh Creek;
2) Design and construct new residential and commercial developments slated for the creekside properties to feature the Creek as a valued natural amenity;
3) Restore native vegetation to create wildlife habitat and shaded trails along Marsh Creek and its tributaries;
4) Improve water quality currently degraded by agricultural and urban runoff in the lower watershed and mercury tailings in the headwaters; and
5) Involve students and everyone in the watershed with educational opportunities and hands-on restoration.

The goals are pretty straightforward, and the tools now exist to implement them, if the public wants a transformed Marsh Creek and gives it the priority it deserves. It will take time and a lot of hard work, but the good news is that it is now possible based upon win-win strategies and designs that meet the needs of all participants. The toolkit for putting Marsh Creek's nature back into our lives has and continues to grow substantially. Reshaping the Creek may be expensive, but isn't it worth it? People are the main reason for our optimism. We have a very progressive flood control district with already tested two-stage channel designs that protect property, restore habitat, and improve water quality. We have local governments that, in spite of the huge pressures for growth, realize and acknowledge with actions and deeds how Marsh Creek and its Delta confluence deserve meticulous care in planning for the future. We have new residents who want not only affordable housing but nearby jobs and a quality of Delta living that is the envy of the Bay Area. We also have government agencies and private funders supporting this effort in lean economic times because we have built a level playing field of collaborators who are doing good work and getting it done on time.

It is time to move forward on to the golden opportunities that outline the work and accomplishments of this second edition of the Marsh Creek watershed report.

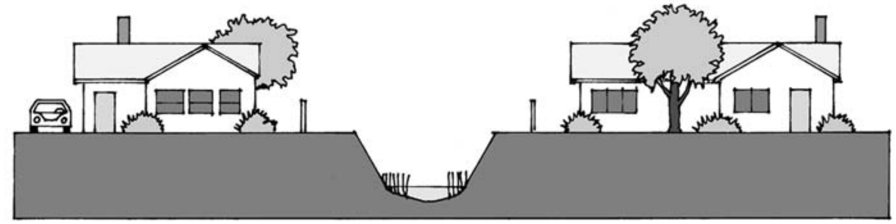
Golden Opportunity

The relatively large amount of undeveloped land along creeks in the Marsh Creek watershed is a golden opportunity to protect and restore these creeks through the rapidly growing communities of Brentwood and Oakley. Once the lands along Marsh Creek become developed, it will be extremely difficult and prohibitively expensive to improve the habitat, aesthetics, and water quality of the Creek and its tributaries. In most urban areas where development has been allowed up to the edge of creeks, the result is a dangerous, dirty ditch relegated to moving polluted floodwater downstream. By protecting undeveloped corridors along creeks, some cities such as San Luis Obispo have created beautiful and functional linear parkways used by people and wildlife, and valued as amenities by businesses and developers. The City of

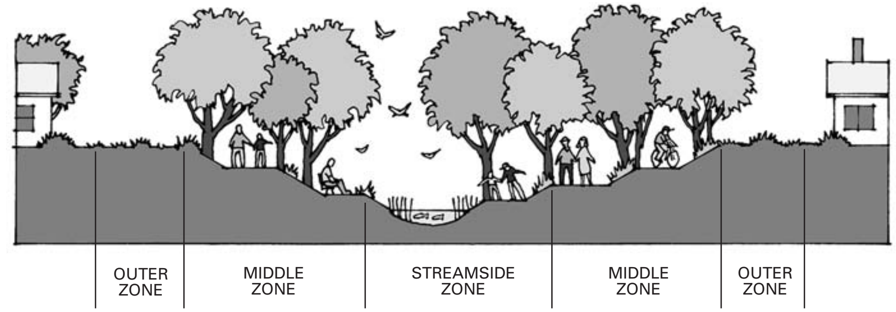
Brentwood's Creekside Park is an example of enlightened development along Marsh Creek. Figure 35 shows the difference between what a typical section of Marsh Creek looks like today with no shade and steep banks, and what Marsh Creek could look like with a wider channel and a buffer of shady trees, habitat for wildlife, and more recreational opportunities. In less constrained areas, more vegetation and broader terraces for increased water conveyance, habitat, and recreational trails are possible. In the more constrained areas, less restoration is feasible.

With good planning and a commitment to protect and restore Marsh Creek, the cities of Brentwood and Oakley have the opportunity to avoid the fate of most urban creeks by setting aside an undeveloped corridor along their creeks. A relatively wide corridor of undeveloped land along the creeks is necessary to provide enough room for the variety of functions an urban stream parkway can and should provide. Currently lower Marsh Creek looks like a ditch because the only benefit it is designed to provide is flood control. The existing flood control corridor along Marsh Creek is not wide enough to provide both flood control and allow tree planting along the Creek to create wildlife habitat and shaded trails. Planting trees and riparian vegetation along the existing narrow channel would conflict with flood control by reducing the channel's flood conveyance capacity. A wider channel with more gently sloped banks is necessary to maintain enough room for flood control while also accommodating tree plantings along the Creek (Figure 35). The resulting shade and gently sloped banks would create a more inviting, safer environment for people of all ages who use and enjoy the Creek. Leaving room between the Creek and new creekside development is an essential first step for transforming Marsh Creek from an ugly flood control channel to an amenity valued by residents and businesses alike.

Fortunately, there are large areas of undeveloped land along Marsh Creek that provide an excellent opportunity to protect a relatively large corridor as the cities of Brentwood and Oakley inevitably grow. Due to the rapid pace of development, a corridor won't get protected and restored along Marsh Creek without enlightened planning and timely action by city officials. To protect a corridor along creeks, city officials need to develop policies that require and encourage developers to maintain a buffer between development and creeks. These requirements need not be onerous new regulations on development but rather incentives for creating higher value developments that benefit both city residents and developers. For example, in Brentwood developers are currently required to set aside land for city parks, so if these parks are configured as linear greenbelts along the creeks they can provide for both recreation and protection of creeks without any new requirements on developers. In other cases, state bond funds are widely available to purchase and preserve land along creeks, allowing creekside landowners to receive market value for their land without



CREEK WITHOUT PROTECTED CORRIDOR



CREEK WITH PROTECTED CORRIDOR

Figure 35 – Creek With and Without Protected Corridors
The creek with a protected corridor broadens the creek channel in order to increase flood capacity, habitat value, and visual appeal. The creek without a protected corridor only provides flood control.

selling to a developer. These win-win opportunities will be far easier to realize if they are pursued within the context of an official city corridor protection plan.

Maintaining a properly designed and managed forested corridor along streams results in several benefits including:

- Providing an aesthetically pleasing landscape;
- Removing sediment and chemicals from stormwater runoff before it reaches the stream;
- Providing protection from large flood events;
- Providing recreational opportunities such as trails, parks, and open space;
- Preserving or creating wildlife habitat and migration corridors;
- Preventing soil erosion and improving bank stability;
- Providing connectivity between wildlife areas and between civic spaces;
- Allowing vegetation planting on streambanks while maintaining flood protection;

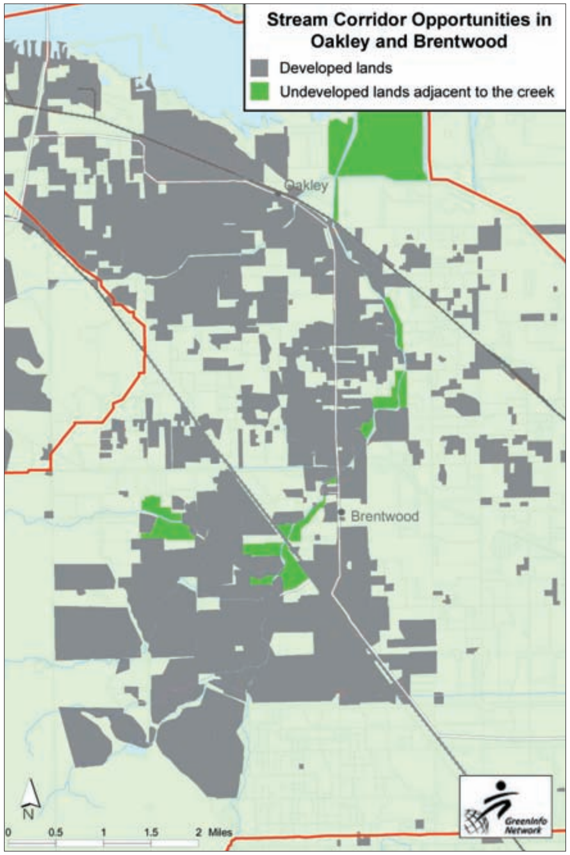


Figure 36

- Moderating temperature in and around the stream and trails; and
- Providing room for streams to naturally meander and change over time.

A well-designed stream corridor should typically have three zones on either side of a creek: a streamside zone, a middle zone, and an outer zone. As shown in Figure 35, the three zones transition from the creek up a gently sloping vegetated bank planted with trees, shrubs, and grasses, to the desired land use, such as a housing development, outside the creek corridor. The *streamside zone* protects the physical and ecological integrity of the stream ecosystem. This forested corridor provides shade, nutrients, leaf litter, woody debris, erosion protection, and habitat for fish, turtles, river otters, and other animals that live in the creek. The *middle zone* acts as a transition and buffer between the forested streamside zone and other land uses. It can be forested or grassy and is usually where walking and biking trails are located. This area is also used for flood control, which complements recreational use because there is little damage if trails and parks are flooded. The middle zone also removes sediment and nutrients from urban stormwater runoff and subsurface flows. The middle zone usually includes the 100-year flood zone and any riparian wetlands in need of protection and restoration. The *outer zone* is generally an additional 15–25 feet between the middle zone and any concreted, paved, or permanent structures. It is typically a grassy strip designed to encourage infiltration (MSU, 1998; Cacho, 1998).

The Natural Heritage Institute prepared the *Corridor Width Report, Parcel Inventory and Conceptual Stream Corridor Master Plan for Marsh, Sand, and Deer Creeks in Brentwood, CA* (Corridor Width Report) and has partnered with the City of Brentwood, the Delta Science Center, and the Coastal Conservancy on how to create corridors along Marsh Creek in Brentwood. The Corridor Width Report summarizes the existing condition of stream protection in Brentwood and the current science of setback width requirements for urban creeks. The findings include:

- In general, approximately 50 feet on either side of Brentwood's creeks is currently protected;
- To re-vegetate the channel with trees and other riparian plants, and still provide protection from the 100-year flood, the Marsh Creek channel must expand by roughly 200 feet;
- In order to improve water quality in Brentwood creeks, the City must protect an additional 50–200 feet on either side of the stream; and
- In order to improve habitat in and along Brentwood creeks, the City must protect 100–300 feet on either side of the stream and provide patches that are several acres large.

The Corridor Width Report recommends a variable width stream corridor that varies with the objectives and the opportunities at any given site along the stream. At a minimum, the City should protect 100 feet on either side of the stream to improve water quality. On public lands, or on lands that have not yet been developed, the City should require a 100–200 foot setback to allow for channel expansion, flood protection, and habitat benefits.

In order to achieve these recommendations three strategies have been identified to create corridors within the Marsh Creek watershed:

1) Create corridors on existing public land;
2) Purchase vacant land or conservation easements along creeks to maintain corridors; and

3) Work with developers on the City's park set-aside program to incorporate creeks into new developments in a manner that maintains corridors along creeks and creates linear parks.

There are several publicly owned lands along Marsh Creek in Brentwood that present opportunities for creek restoration. The City, Contra Costa County Flood Control and Water Conservation District, Brentwood Union School District, and the East Bay Municipal Utility District currently own approximately 170 acres of land adjacent to Marsh, Sand, or Deer creeks. These parcels include approximately 14,000 feet of stream frontage. A good example of a healthy creek corridor along Marsh Creek on public land is the City of Brentwood's Creekside Park. Creekside Park has approximately 180 feet of trees and open space between the channel and the nearest houses. The playing fields in the park also act as retention basins for large flood flows.

Despite the heavy development pressure in the Marsh Creek watershed, there is still vacant land adjacent to the Creek to develop corridors (Figure 36). The City of Brentwood and the Natural Heritage Institute have worked together to raise money to acquire a property at the confluence of Marsh, Deer, and Sand creeks dedicated to the protection of these creeks and public recreation. The purchase of conservation easements on undeveloped parcels is another way to protect corridors and restore creeks. A conservation easement is a set of restrictions a landowner voluntarily places on his or her property in order to preserve its conservation values and/or existing land use. The easement is conveyed to a government agency or nonprofit conservation organization qualified to hold and enforce easements (e.g. the City of Brentwood or the Brentwood Agricultural Land Trust). Each conservation easement is unique, specifically tailored to the particular land being protected as well as to the particular situation of the landowner.

Instead of building traditional parks in the center of a planned community, detached from the Creek, developers can help to enhance Marsh Creek, link neighborhoods, and create recreational areas by building linear parks along the Creek corridor and incorporating the Creek into their development. The City of Brentwood is pursuing an innovative strategy of including stream setbacks and channel modifications as conditions for development. The City has already identified the Ponderosa Tract and Special Planning Area D by the Highway 4 Bypass as likely candidates for this strategy of restoration and enhancement. All developers within the City of Brentwood are also required to set aside land for parks when they subdivide land for development. Residential developers are required to pay fees for development of parks and trails, construct the facilities, or do a combination of both. The General Plan broadly identifies the location of future parks and trails. The Growth Management Element of the General Plan (Policy 1.3 and Action Program 1.3.6) calls for provision of at least five acres of parkland citywide per 1,000 people. The Parks, Trails, and Recreation Master Plan provides more specific direction on location and design of future parks.

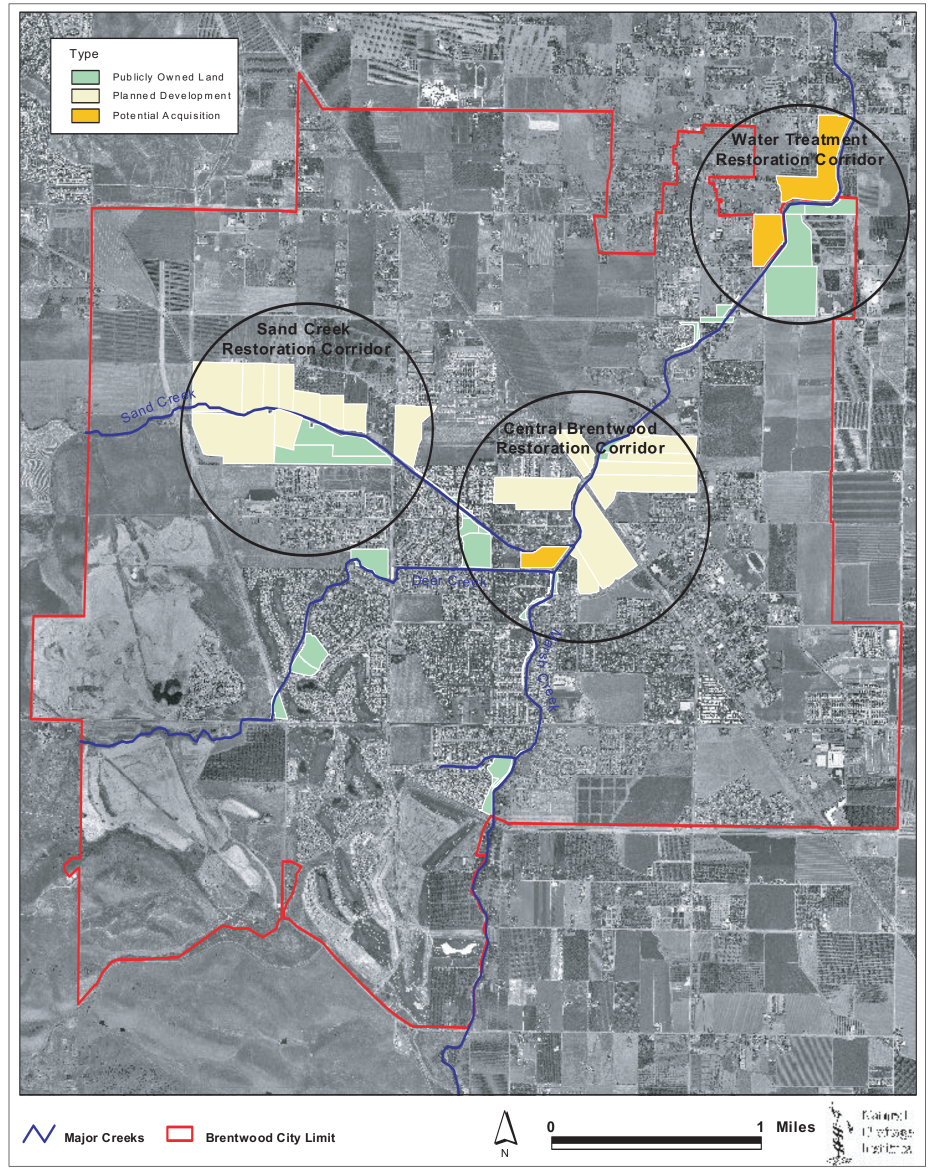


Figure 37 – Opportunities to Restore Stream Corridors on Brentwood Creeks

The City's development fee program specifies the fees due from residential developers for parks. The timing and size of parks is generally determined on a case-by-case basis by the City Council and/or Planning Commission and is sometimes addressed through the conditions of approval for specific development projects (Rhodes, pers. com.).

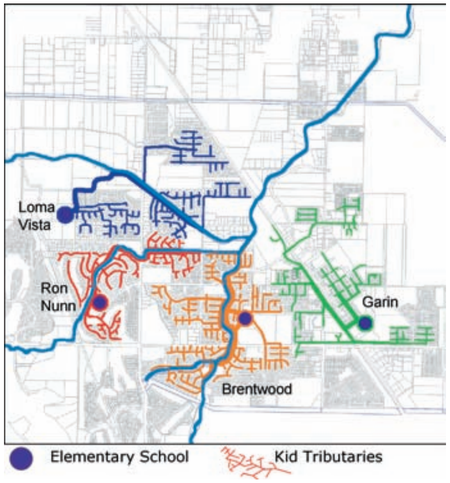


Figure 38 – The "Kidshed" Master Plan
Design by Joy Glasier, Matt Haynes, Carey Knecht, and Steve Rasmussen-Cancian, UC Berkeley LAEP students.

Three distinct corridor zones were identified in the Corridor Width Report where the combination of public lands, impending development, and stream character present excellent opportunities for stream restoration: the Central Brentwood Restoration Corridor, Sand Creek Restoration Corridor, and the Water Treatment Restoration Corridor (Figure 37).

Integrating Development

New residential and urban development is inevitable in the growing communities of Brentwood, Oakley, and Antioch, but development does not have to be incompatible with protecting and restoring Marsh Creek for people and wildlife. With enlightened planning and development policies, new construction can be integrated into a healthy Marsh Creek watershed. Traditional residential and commercial development patterns are generally oriented away from the creek with fences and walls separating houses and buildings from the creek making it difficult to access, police, or view. These developments literally turn their back to the creek relegating it to a neglected fragment of the urban landscape that becomes a liability for neighboring landowners. Innovative development patterns that are oriented toward the creek can transform the creek into an amenity that is valued by residents and businesses. Rather than turning away from the creek and fencing it off, these innovative subdivisions and business parks face the creek and provide ample paths and trails to access the creek. This way residents and workers view the creek from their homes and businesses and regularly visit the creek, which quickly becomes a meeting place and source of community pride.

In the fall of 2001, students and professors from a graduate class in UC Berkeley's Department of Landscape Architecture and Environmental Planning (LAEP) spent a semester in Brentwood developing a series of plans and designs that illustrated how to integrate the creek into future residential and commercial developments. A summary of their work titled *Envisioning Brentwood's Creeks: A Green Resource for the Future* can be viewed on the web at www.n-h-i.org. Their efforts focused on four strategies for transforming the creek into an amenity that serves the community:

- Develop a natural network of trails along Brentwood's creeks;
- Orient new development toward the creek;
- Plant trees and restore habitat along the creek; and
- Implement new drainage best management practices to improve water quality in the creek.

A creek system with trees and trails along its banks can be a welcome feature of the city: a place of dappled shade, wildlife, trickling water, spring bloom, and fall color that every resident of the watershed can be proud of and experience in their own neighborhood.

Marsh, Dry, Deer, and Sand creeks pass through many of Brentwood's neighborhoods and Marsh Creek links the communities of Brentwood and Oakley. Local cities and the East Bay Regional Park District have developed an integrated trails plan that would follow these stream courses linking together the various neighborhoods and natural areas throughout the watershed. When complete, this natural network of creeks and trails will provide safe routes for kids to ride their bikes to school, and for people in the community to walk their dogs and meet up with their neighborhood friends. The trails will also provide an opportunity to hike, walk, or bike directly from people's houses within the community to Mt. Diablo and the Delta, and the system of parks and open spaces in between. These trails along the creeks will create a place where people can view wildlife and enjoy nature in their everyday lives.

The Marsh Creek Regional Trail is the only trail that has yet to be developed along the creeks. The trail is currently about 6.5 miles long and connects Creekside Park in Brentwood with the Delta at Big Break and several other community parks along the trail. The East Bay Regional Park District, who manages the trail, plans to make the trail 14 miles long and connect the Delta with Morgan Territory Regional Preserve and Round Valley Regional Park, east of Mt. Diablo State Park. Additional plans include connecting the Marsh Creek Trail to the Delta De Anza Regional Trail, which follows the Contra Costa Canal connecting the cities of Concord, Bay Point, Pittsburg, Antioch, Oakley, and Brentwood to Mt. Diablo State Park, Black Diamond Mines Regional Preserve, Contra Loma Regional Park, Los Medanos Community College, and the Pittsburg/Bay Point BART station.

Figure 39 – Creekside Trail Connection Linking Downtown Brentwood and Marsh Creek
Design by UC Berkeley LAEP students.

The UC Berkeley students' thorough survey and exploration of Brentwood's creeks revealed that creekside trails could provide a safe route to and from schools (Figure 38). Many schools in the City of Brentwood are located near creeks and creek trails. The "Kidshed" master plan (Figure 38) shows the path traveled by children on their way to and from schools and explores the possibility of directing more foot and bike traffic along creekside trails. By formerly developing a trail network along the creeks and providing better access to it from the neighborhoods, the City can provide a safe route for children to walk and bike to and from school, away from traffic and fast-moving cars. Strategically placed bridges across the creeks and safe routes across busy roads, will allow residents of all ages to travel safely by bike or foot throughout their community. Trails will also provide an opportunity for kids and adults to stay healthy by playing, riding bikes, and walking along their neighborhood creeks.

The students' analysis also identified the opportunity and need to link downtown Brentwood to the creek trail network. The plan in Figure 39 designs an inviting bike and pedestrian trail along the railroad tracks to connect downtown Brentwood and Marsh Creek. This trail would provide a safe route for high school students traveling between school and home and shoppers and workers moving between home and downtown.

The UC Berkeley students developed a number of designs for integrating new development into a restored network of creeks. These designs orient commercial and residential developments toward the creeks, showcasing these creeks as a natural amenity and fostering a sense of place that could distinguish Brentwood from the homogeneity that typifies many suburban developments. A plan for retail shops and a business park along Sand Creek (Figure 40) near the new Highway 4 Bypass spans both sides of the Creek, so that the Creek itself becomes the central mall. The design calls for widening and replanting the Creek with native riparian vegetation. It proposes airy barn-like building for shops, restaurants, and businesses and suggests that developers preserve an existing or replant a new almond orchard so that shoppers might park among trees when they visit the mall.

Clean water is a key component of a healthy, safe creek. As land is paved and developed, more water runs off roofs, lawns, and paved surfaces, picking contaminants

Figure 40 – Sand Creek Retail and Business Mall
Design by Toby Minear, Jessie Kupers, Michelle Dubin, and Daphne Edwards, UC Berkeley LAEP students.

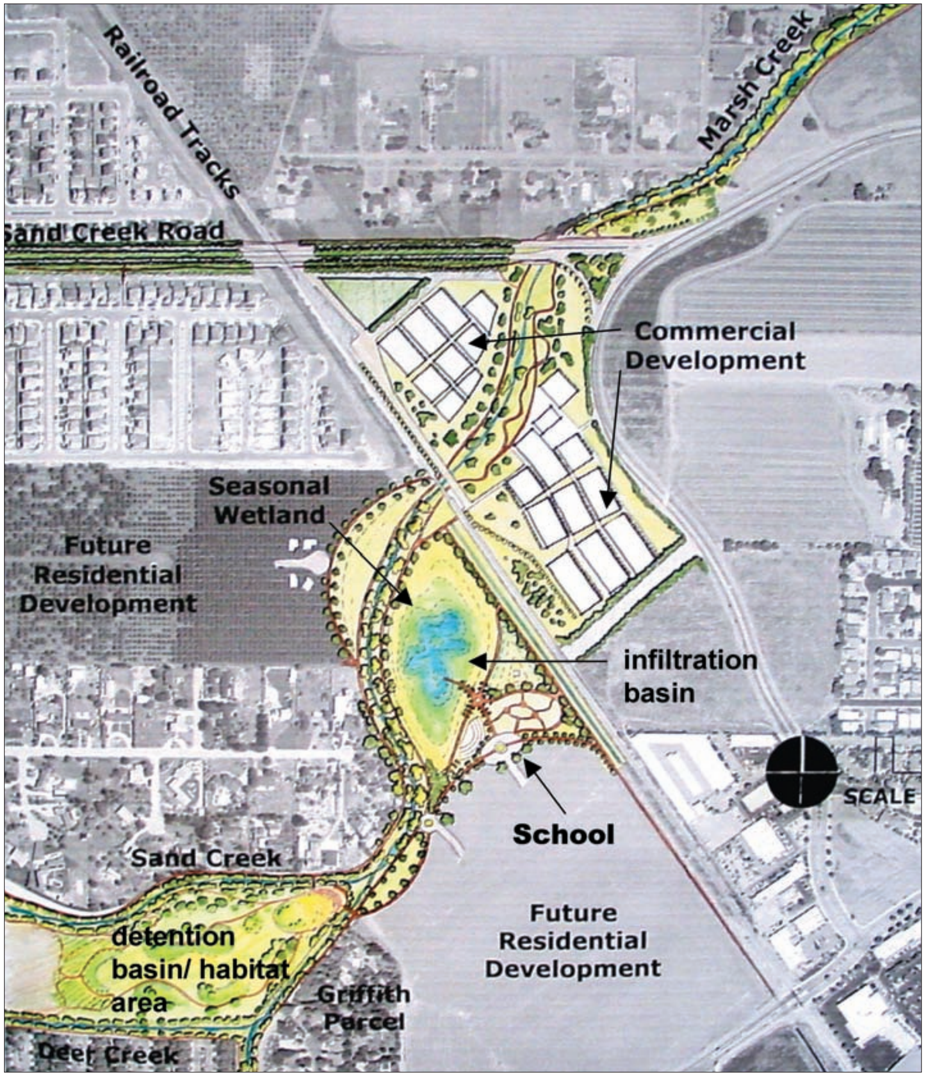


Figure 41 – Design to Reduce Polluted Runoff from New Development
Design by UC Berkeley LAEP students.

(like fertilizer, oil, and heavy metals) along the way. Increased urban runoff not only results in water pollution but can also increase the risk of flooding. There are a number of techniques for stormwater management and stream restoration to mitigate increased runoff and improve water quality. Filters, vegetated swales, and riparian buffer zones help cleanse polluted runoff as it flows toward the creeks. To decrease the quantity of runoff and floodwaters during storms, schools, businesses, homeowners, cities, and developers can build with permeable pavement in driveways and parking lots to allow more water to infiltrate the soil instead of running off into the creeks. They can also construct cisterns to "harvest" roof runoff during rainstorms for later use watering lawns and gardens.

Figure 41 illustrates a plan to develope detention and infiltration basins along Marsh Creek to prevent and mitigate the negative flood and water quality impacts of new development. Detention basins are designed to hold water during peak storm events and release it slowly after floodwaters from the storm recede. Infiltration basins are designed to filter out pollutants and percolate clean water into the groundwater. Swales are shallow, linear, vegetated channels designed to capture and filter surface runoff and pollution, and decrease erosion. Both swales and basins can use specialized plants that filter and remove pollutants for stormwater runoff.

Reducing polluted runoff from urban areas is mandated by the Regional Water Quality Control Board (Regional Board), the state agency charged with implementing the federal Clean Water Act. The Regional Board has been progressively developing increasingly stringent regulations to reduce the amount of polluted runoff entering streams and bays. Innovative techniques for reducing runoff from new developments will probably cost developers more money, but in the long run they will save taxpayers the costs of cleaning up the problem later. The Regional Board is mandated to improve water quality in "impaired" waterways such as Marsh Creek. If new developments increase the amount of polluted runoff into a creek, they will require city and county governments and local districts to clean up the problem. Innovative and preventative strategies described for reducing the amount of polluted runoff entering Marsh Creek will be far less expensive then attempting to clean up the problem later.

Progress and Partnerships

Numerous groups and agencies such as the Natural Heritage Institute, cities of Brentwood and Oakley, Delta Science Center, private landowners, neighbors and community members, Contra Costa County Resource Conservation District, Natural Resources Conservation Service, East Bay Regional Park District, California Department of Fish and Game, American Rivers, Trust for Public Land, California Costal Conservancy, Department of Water Resources, Conservation Fund, California Department of Parks and Recreation (State Parks), CALFED, and others have all been involved in some capacity to improve the Marsh Creek watershed. Land acquisition, wetland restoration, a watershed plan, creek monitoring programs, and a dam removal are just a few of the ambitious projects that have been undertaken from the Delta to the upper watershed. This section describes some of the success stories that have affected the Marsh Creek watershed.

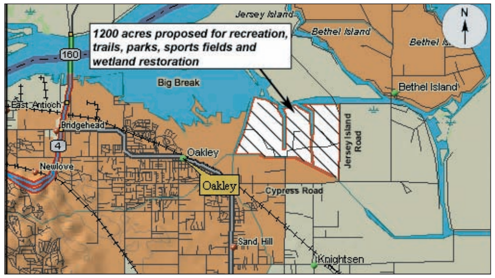


Figure 42 – Map of the Dutch Slough Restoration Project

Dutch Slough

At the mouth of Marsh Creek on the San Joaquin-Sacramento Delta, the CALFED Bay-Delta Program provided approximately $30 million in the summer of 2002 to acquire and restore approximately 1,200 acres known as the Dutch Slough Restoration Project (Dutch Slough) (Figure 42). Such a large amount of public funding was contributed to this region and project because this site is the only site in the central and western Delta with the topographic elevation necessary for large-scale tidal marsh restoration. The restoration of 1,200 acres, over six miles of shoreline and the potential to restore over thirty miles of edge habitat will provide major benefits for endangered fish species that congregate or migrate through the Delta. A large wetland at the mouth of Marsh Creek will provide rearing habitat for salmon that spawn in Marsh Creek or elsewhere in the Bay-Delta watershed.

NHI formed a number of partnerships to secure funding for Dutch Slough and recreational amenities for the community. The Natural Heritage Institute, California Coastal Conservancy, Department of Water Resources, Conservation Fund, and three landowners worked closely with CALFED and public officials to secure the millions of dollars needed to purchase this property and restore wetlands at the site. The Dutch Slough team worked closely with the City of Oakley and local residents and groups to plan for a community park, four miles of shoreline trails along Delta sloughs, safe fishing access, a canoe and kayak launch, sports fields, picnic grounds, wildlife viewing, and other educational and recreational opportunities centered around a large-scale wetland restoration project.

Fish Barrier Modification

A grade control dam located approximately three miles from the mouth of Marsh Creek (near the Brentwood Wastewater Treatment Plant) prevents salmon from reaching several miles of suitable spawning habitat in lower Marsh Creek and its tributaries. In October and November of 2002, NHI's citizen salmon monitoring program observed as many as 45 salmon at a time congregating immediately below this drop structure.

The removal of the fish barrier would provide access to approximately seven miles of lower Marsh Creek, Deer Creek, and Sand Creek, including approximately three miles of suitable spawning gravels and shaded riparian stream downstream of and in the Cowell Ranch property.

The City of Brentwood has included removal of the barrier and restoration of the creek immediately downstream in its Department of Parks and Recreation Master Plan. Similarly, NHI included the same actions in its restoration master plan for lower Marsh Creek developed cooperatively with the City of Brentwood. The Marsh Creek Watershed Coordinated Resource Management Program Group (Marsh Creek Watershed Group) is now considering including these actions in its watershed plan due in September 2003.

Since July 2002, the City of Brentwood, Contra Costa County flood control district, American Rivers, Marsh Creek Watershed Group, Natural Resources Conservation Service, Department of Water Resources (DWR), and NHI have been meeting regularly to plan and design the removal of the fish barrier and the restoration of the stream immediately downstream. Currently, the designs are at the conceptual level and will continue to increase in detail, as we are able to conduct additional surveys of the project site in the upcoming months.

DWR's engineers and biologists will work collaboratively with the Contra Costa County Flood Control and Water Conservation District engineers to further design, model, and obtain permits for the project. The general design employed by the alternatives under consideration would meet all relevant fish passage criteria developed by the California Department of Fish and Game and National Oceanic and Atmospheric Administration Fisheries, and similar designs have been successfully allowing fish to pass at former barriers throughout California and the Pacific Northwest.

In conjunction with providing fish passage, the project will restore creek and riparian habitat diversity by converting more than 1,000 feet of uniform, trapezoidal channel into a more diverse, two-stage channel capable of supporting riparian vegetation.

The potential benefits of this project to the local community are numerous and significant. First, it will aid the City of Brentwood in implementing its parks and recreation master plan. Second, at a time when California communities are increasingly deprived of meaningful connections to their natural world, this project will offer an opportunity for residents of a rapidly urbanizing area to observe and facilitate one of nature's marvels – the completion of a salmon's epic journey back to natal spawning grounds. Third, through the cooperation of the East Bay Regional Park District, the project will provide the local community trail access through what will be one of the few natural creek settings in the lower reaches of Marsh Creek. Although the project reach is small relative to the entire Creek, it is our hope that this will be only the beginning of a larger project to restore more of the Creek habitat. Lastly, the project will provide a unique living laboratory for the local schools to learn first hand about creek restoration and salmon issues, including Tom Lindemuth's environmental science class at Freedom High School.

Three Creeks

The Three Creeks Parcel is located at the confluence of Marsh, Sand, and Deer creeks. In 2002, the Department of Water Resources and California State Parks separately awarded a total of $1.2 million to acquire land and restore the creeks at and near this confluence.

In addition to being a priority flood control improvement reach for the local flood control district, the Three Creeks Parcel represents the best restoration opportunity in lower Marsh Creek. All three creeks are currently denuded of vegetation and disconnected from the confluence zone floodplain. Plans call for expanding the channel cross section on all three creeks to accommodate woody riparian vegetation and regrading the floodplain to restore periodic inundation. This restoration is a high priority because confluences are ecologically important features and the mosaic of riparian wetlands, backwater floodplains, and meandering channels provide key habitat for a wealth of sensitive aquatic and riparian species.

Not only does this site offer tremendous flood control and habitat restoration potential, but it also offers opportunities to improve water quality. Rapid upstream development coupled with existing agriculture has led to the degradation of water quality in the Creek and its receiving waters in the western Delta. The restoration plan calls for the use of bio-filtration wetlands to mitigate urban stormwater pollution in the winter and agricultural return water in the summer.

Due to its central location, the project will showcase the promise of riparian restoration and serve to galvanize local residents interested in watershed stewardship. Three local schools are located within walking distance of the site and will be able to use it for education programs. A number of Brentwood and Oakley high school students are already involved in the Delta Science Center's high school water quality monitoring program at the site, and restoration will allow students to measure changes in water quality before and after restoration.

Cowell Ranch

In the winter of 2002, an approximately 4,000-acre parcel in the upper Marsh Creek watershed known as Cowell Ranch was permanently protected as public open space (Figure 1). The Trust for Public Land and many public officials worked to purchase the land from the Cowell Foundation to be managed by California State Parks as part of Mt. Diablo State Park. The California Coastal Conservancy, Caltrans, State Parks, Wildlife Conservation Board, and US Bureau of Reclamation provided funding to protect Cowell Ranch. The upper reaches of Marsh Creek flow through Cowell Ranch and into the Marsh Creek Reservoir and by the John Marsh House.

If this area had not been become a park, Cowell Ranch would have included 5,000 single-family residences, a golf course, and possibly a school and business park. Such heavy development in the upper reaches of any watershed negatively affects water quality in downstream reaches. Protection of the upper watershed of Marsh Creek will help to maintain better water quality in the Creek, preserve an important corridor for wildlife, and provide valuable recreational opportunities for people in the neighboring communities and the regional Bay area.

Marsh Creek Coordinated Resource Management Program

The Contra Costa Resource Conservation District initiated the Marsh Creek Watershed Coordinated Resource Management Program Group (Marsh Creek Watershed Group) in the summer of 2001 to address the concerns of landowners and stakeholders in the Marsh Creek watershed. The Marsh Creek Watershed Group meets monthly to voice concerns about the creeks and discuss policies and other issues affecting the watershed. In the fall of 2003 the Marsh Creek Watershed Group is scheduled to complete a catalogue summarizing these issues and concerns. The community, public officials, and other stakeholders can use this catalogue to enforce and create policies or take action to address these issues and concerns facing the Marsh Creek watershed.

Next Steps and Recommendations

The movement to protect and restore Marsh Creek has only just begun. Achieving the vision of a healthy, living creek that enriches the lives of people throughout the watershed will require new collaboration and progress on several fronts. Most importantly, the future of Marsh Creek is dependent on residents stepping forward to advocate for the Creek in future land management decisions. People working together at the local level to articulate and work for a new vision of the future are the best hope for Marsh Creek. We hope that this report can provide local residents and officials with information and analysis necessary to develop a long-range and detailed action plan for Marsh Creek. In light of the rapid pace of development in the watershed, however, action is needed now to maintain the option for protecting and restoring the Creek, and more funding and study is necessary develop and implement a plan. Based on our work and analysis to date, we suggest that local residents and officials focus on the following actions for transforming Marsh Creek into a treasured amenity valued by businesses and residents alike:

- Establish a protected corridor of undeveloped land along Marsh Creek and its tributaries through Brentwood, Oakley, and Antioch;

- Work in collaboration with the cities to acquire funds to strategically purchase vacant parcels along creek corridors from willing landowners;
- Acquire funds to plant riparian vegetation along creek corridors;
- Acquire funds to improve, maintain, and open new trails and bridge crossings along creek corridors;
- Implement best management practices in new developments to reduce and filter polluted stormwater runoff;
- Monitor creeks to identify sources of water quality problems, such as mercury, and solutions to remedy these problems;
- Design new development to feature Marsh Creek as an important natural amenity;
- Work with cities and developers to implement existing park set-aside programs in a manner that creates a greenbelt along creeks; and
- Work in collaboration with developers to regrade and expand the existing creek channels for restoration as development proceeds.

Citations

Baxter, R.1996. Distribution and relative abundance of splittial *(Pogonichthys macrolepidotus)* in the Sacramento and San Joaquin rivers and delta during August 1994. Working Paper submitted to The Resident Fishes Project Workteam of IEP.

Bowerman, M.L. 1944. Flowering Plants and Ferns of Mt. Diablo, California. The Gillick Press, Berkeley, CA.

Cacho, M. 1998. A Conceptual Model for the Design of Buffer Zones. PhD Dissertation, University of California, Berkeley. 180pp.

Cain, J.R. 2001. Natural Heritage Institute. Personal Communication.

California Department of Fish and Game. 2002. California Natural Diversity Database.

Cleugh, E. 2002. Unpublished CDFG data from salmonid surveys of lower Marsh Creek.

Contra Costa County. 1990. Draft Environmental Impact Report: The Marsh Creek Watershed Regional Drainage Plan. County File #CP 88-69.

Contra Costa County Flood Control and Water Conservation District. 1953. Marsh and Kellogg Creek Watershed Programs for Soil Conservation and Flood Control.

Contra Costa County Flood Control and Water Conservation District. 1998. Marsh Creek Capacity Study-Brentwood, Contra Costa County, California. Flood Control File 3108-05.

Contra Costa County Flood Control and Water Conservation District. 1999. Drainage 107-Brentwood Area: Hydrology-Hydraulic Analysis for Proposed Detention Basins. Prepared by M. Kubicek and M. Weston.

Contra Costa County Flood Control and Water Conservation District. 2001. Annual Rainfall Data (1907–2000) for Brentwood, CA.

Eastern Contra Costa Soil Conservation Service, Contra Costa Soil Conservation District, and Contra Costa County Flood Control and Water Conservation District .1959. Watershed Work Plan: Marsh-Kellogg Watershed.

Eisler, R.1987. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. US Fish and Wildl. Serv. Biol. Rep., 85(1.10). 90 pp.

Fairchild Aviation. 1939. Aerial Photographic Series of Contra Costa County. Scale = 1:24,000.

Fisher, D.S., J.L. Steiner, D.M. Endale, J.A Stuedemann, H.H. Schomberg, A.J. Franzluebbers and S.R. Wilkinson. 2000. The relationship of land use practices to surface water quality in the upper Oconee watershed of Georgia. Forest Ecology and Management, 128(1-2): 39-48.

Gifford, G.F. and R.H. Hawkins. 1978. Hydrologic impacts of grazing on infiltration: A critical review. Water Resources Research, 14: 305-313.

Gordon, N.D, T.A.McMahon and B.L. Finlasyon. 1992. Stream Hydrology: An Introduction for Ecologists. John Wiley and Sons, New York.

Hagelin, C. 1998. Monitoring Program Report for Marsh Creek near Big Break.

Hinton, D. E. 1998. Multiple stressors in the Sacramento River watershed. Fish Ecotoxicology, 303-317.

Ibis Environmental. 2000. Wildlife Surveys at the Lauritzen Property, Contra Costa County, CA. Prepared for the Natural Heritage Institute and the Delta Science Center.

Kanagaki, B. 2002. East Bay Regional Park District. Personal Communication.

Katznelson, R., W.T. Jewell, and S.L. Anderson. 1995. Spatial and temporal variations in toxicity in an urban-runoff treatment marsh. Environmental Toxicology and Chemistry, 14(3): 471-482.

Kim Vogley Associates with Richard A. Bigler Associates. 1991. City of Brentwood Creek Trails and Revegetation Master Plan. Prepared for the City of Brentwood.

Liacos, L.G. 1962. Water yields as influenced by degrees of grazing in the California winter grasslands. Journal of Range Management, 15: 34-42.

Magaud, H., B. Migeon, P.Morfin, J.Garric, and E. Vindimian. 1997. Modeling fish mortality due to urban storm runoff: Interacting effects of hypoxia and un-ionized ammonia. Water Research, 31(2): 211-218.

McMahon, T.E. 1908. Official Map of Contra Costa County. Scale = 1:63,360.

Meng, L. and P.B. Moyle. 1995. Status of splittail in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society, 124(4): 538-549.

Mississippi State University. 1998. Stream Corridor Restoration - Principles, Practices and Processes.

Mt. Diablo Interpretive Association. 2000. The Mt. Diablo Guide. Berkeley Hills Books, Berkeley, CA.

Pillard, D.A. 1996. Assessment of benthic macroinvertebrate and fish communities in a stream receiving stormwater runoff from a large airport. Journal of Freshwater Ecology, 11(1): 51-59.

Rhodes, W. 2003. City of Brentwood. Personal Communication.

Robins, J.D. 2001. Natural Heritage Institute. Personal Observations.

Robins, J.D. and R.P. Walkling. 2001. Natural Heritage Institute. Personal Observations.

Skinner, L., A. de Peyster, and K. Schiff. 1999. Developmental effects of urban stormwater in medaka *(Oryzias latipes)* and inland silverside *(Menidia beryllina)*. Archives of Environmental Contamination and Toxicology, 37(2).

Slotton, D.G. S.M. Ayers, and J.E. Reuter. 1996. Marsh Creek Watershed 1995 Mercury Assessment Project. Final Report for Contra Costa County, CA.

Slotton, D.G. S.M. Ayers, and J.E. Reuter. 1997. Marsh Creek Watershed 1996 Mercury Assessment Project. Final Report for Contra Costa County, CA.

Slotton, D.G. S.M. Ayers, and J.E. Reuter. 1998. Marsh Creek Watershed Mercury Assessment Project. Third Year (1997) Baseline Data Report with 3-YR Review of Selected Data. Final Report for Contra Costa County, CA.

Soil Conservation Service. 1977. Soil Survey of Contra Costa County.

State Geological and US Surveys. 1871. Topographic Map of Contra Costa County. Scale = 1:63,360.

Stevenson, J. 2001. City of Brentwood. Personal Communication.

United States Environmental Protection Agency Fact Sheet. April 2001. National Listing of Fish and Wildlife Advisories. Available at http://www.epa.gov/waterscience/fish/advisories/factsheet.pdf.

United States Geological Survey. 1914. Brentwood Topographic Quadrangle Map. Scale = 1:36,800.

United States Geological Survey. 1994. Preliminary Geologic Map Emphasizing Bedrock Formations in Contra Costa County, CA: A Digital Database. Open File Report # 94-622. Compiled by Graymer, Jones and Brabb.

Vollmar Consulting. 2000. Big Break Marsh Project: Vegetation, Wetland and Botanical Studies. Prepared for the Natural Heritage Institute and the Delta Science Center.

Wagstaff and Associates. 1996. Draft Environmental Impact Report: Cowell Ranch Project General Plan Amendment and Related Actions. Prepared for Contra Costa County. County File #1-92-CO.

Wenning, R., D. Mathur, D. Paustenbach, M. Stephenson, S. Folwarkow, and W. Luksemburg. 1999. Polychlorinated dibenzo-p-dioxins and dibenzofurans in stormwater outfalls adjacent to urban areas and petroleum refineries in San Francisco Bay, California. Archives of Environmental Contamination and Toxicology, 37(3): 290-301.

Wisk, J D and K.R. Cooper. 1990. The stage specific toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin in embryos of the japanese medaka *(Oryzias latipes).* Environmental Toxicology and Chemistry, 9(9): 1159-1170