5 Hydrology

The 11,169 square mile Foothills Area has been evaluated using five geographic subregions corresponding to five of the six subregions of the Sierra Nevada Conservancy Region, grouped by major watersheds. The total land area within each of the five geographic subregions varies, generally increasing in area and percent from north to south (fig. 5-1).

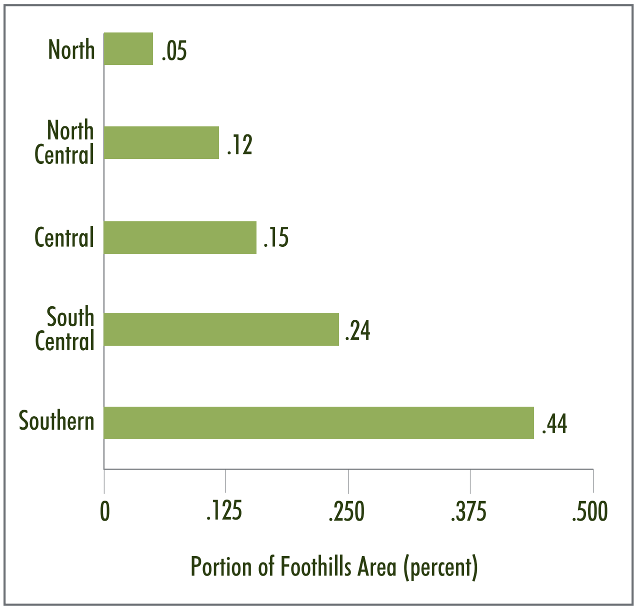


Figure 5-1. Portion of Foothills Area by Geographic Subregion

The Sierra Cascade Foothills Area Conservation Report describes substantial portions of three of California's ten identified hydrologic regions (California Department of Water Resources 2009), including about 40% of the San Joaquin River hydrologic region, 35% of the Tulare Lake hydrologic region, and 25% of the Sacramento River hydrologic region (fig. 5-2). The Foothills Area covers 41% of the Mountain Counties water planning overlay (i.e., portions of Shasta, Tehama, Plumas, Butte, Yuba, Sierra, Nevada, Placer, El Dorado, Amador, Calaveras, Tuolumne, Mariposa, Fresno, Tulare, and Kern counties), coinciding with its lower elevation zone (Department of Water Resources 2009). The portion of the Foothills Area that is within the Mountain Counties overlay varies from north to south (fig. 5-3). The Foothills Area extends in the north from Shasta County south into the Tulare Lake hydrologic region. The Sacramento River and San Joaquin River hydrologic regions are the largest source regions for surface water supply within the state, and the Mountain Counties overlay comprises the foothill and mountainous zones of both regions. The Mountain Counties' watersheds account for about a quarter of California's river runoff and more than half of the snowmelt runoff (Department of Water Resources 2009). The Foothills Area does not include the high elevation source areas of these watersheds, but does span substantial portions of the contributing watersheds, along with reservoirs and river networks critical for storage and conveyance.

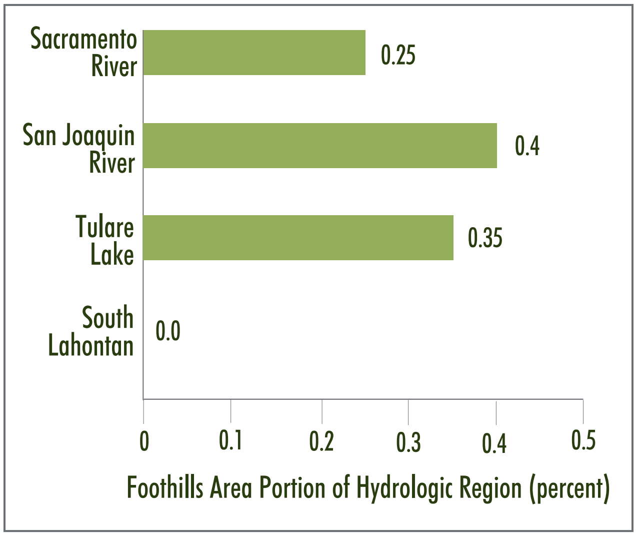


Figure 5-2. Foothills Area as a Portion of California's Hydrologic Regions
Source: DWR 2009, California Water Plan

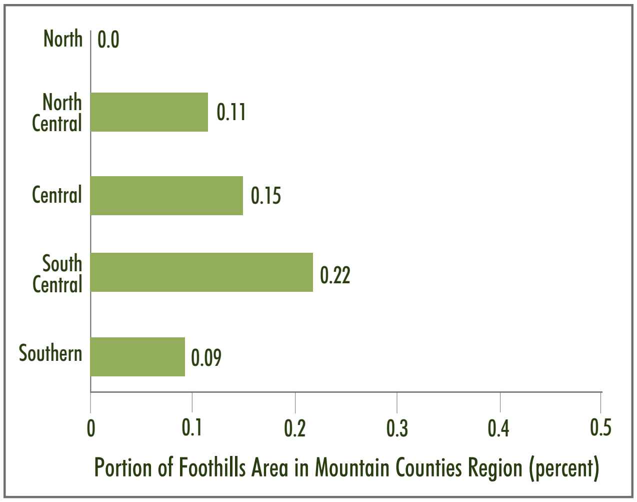


Figure 5-3. Portion of Foothills Area in the Mountain Counties Region
Source: DWR 2009, California Water Plan

The importance of the Sierra Nevada's water to both California and Nevada, its history and role in the region, the risks posed by stresses on those watersheds, and recommendations for action have been described by the Sierra Nevada Alliance (2003 and 2006). These reports highlight impairments to various rivers based on publicly available data, and encourage public and private entities to engage in efforts to protect and restore the watersheds, water bodies, and water quality. The Foothills Area overlies the lower elevation zone of the Sierra Nevada, and as such, includes portions of all the watersheds addressed in the Sierra Nevada Alliance reports.

5.1 Focus Areas

Hydrology focus areas of this Conservation Report include river corridors, major watersheds, surface water bodies, and groundwater. Water use and management, and climate and runoff are also addressed.

5.1.1 River Corridors

The Foothills Area includes the lower elevations of the Sierra Nevada and Cascade Range, and is crossed by numerous river corridors flowing from east to west, draining off the west slope of the mountains towards the Central Valley. Approximately 35 perennial rivers flow through the Foothills Area along with many perennial tributaries (table 5-1).

In addition to these year-round streams, there are intermittent streams (those that flow for periods of weeks to months during the winter) and ephemeral streams (those that only flow during and shortly following storm events). The length of each stream channel category (i.e., perennial, intermittent, and ephemeral) in the Foothills Area varies by geographic subregion (fig. 5-4), as do the proportion of perennial, intermittent, and ephemeral streams within each subregion (fig. 5-5).

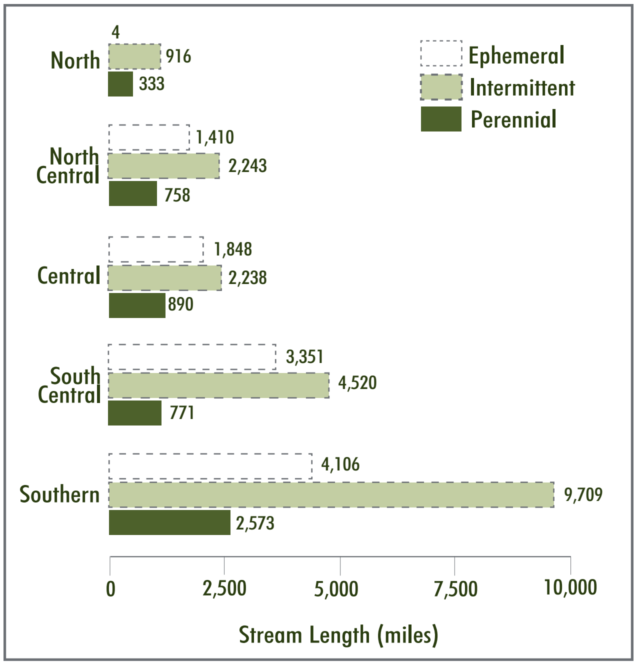


Figure 5.4. Perennial, Intermittent, and Ephemeral Stream Miles in the Foothills

Table 5-1. Perennial Streams within the Foothills Plan Area[1]

Perennial Streams	Perennial Tributaries (if applicable)
Clover Creek (upper)	
Bear Creek (upper)	
Battle Creek (upper)	
Payne Creek	
Little Chico Creek	
Little Butte Creek	
Feather River	Big Kimshaw Creek, North Fork Feather, Middle Fork Feather, South Fork Feather
Honcut Creek	
Dry Creek	
Yuba River	Deer Creek
Dry Creek	
Bear River	Wolf Creek
Coon Creek	
Dry Creek	
American River	North Fork American, Middle Fork American, South Fork American
Cosumnes	Deer Creek, North Fork Cosumnes (upper), Middle Fork Cosumnes (upper), South Fork Cosumnes (upper)
Mokelumne	Sutter Creek (upper), Jackson Creek (upper), Middle Fork Mokelumne
Calaveras River	North Fork Calaveras, South Fork Calaveras
Stanislaus River	Angels Creek, Coyote Creek, Middle Fork Stanislaus, South Fork Stanislaus
Tuolumne River	North Fork Tuolumne; Clavey River
Merced River	Bean Creek, North Fork Merced, South Fork Merced
Mariposa Creek (upper)	
Chowchilla River (upper)	East Fork Chowchilla
Fresno River (upper)	Coarse Gold Creek
San Joaquin River (upper)	Fine Gold Creek, Willow Creek, Stevenson Creek; Big Creek
Kings River (upper)	Big Creek, Dinkey Creek, North Fork Kings (upper); Mill Flat Creek, Tenmile Creek, Mill Creek (upper)
Kaweah River (upper)	Dry Creek (upper), North Fork Kaweah, Marble Fork Kaweah, Middle Fork Kaweah, East Fork Kaweah, South Fork Kaweah
Tule River	North Fork Tule, Middle Fork Tule, South Fork Tule
Deer Creek (upper)	
White River (upper)	
Little Poso River (upper)	
Kern River	Little Kern River, South and North Fork Kern, Kelso Creek
Walker Basin Creek	
Caliente Creek	
Cottonwood Creek	

Note:[1] Table listing is in north-to-south order, not by size or length, and is focused on key named streams; this is not a comprehensive list.

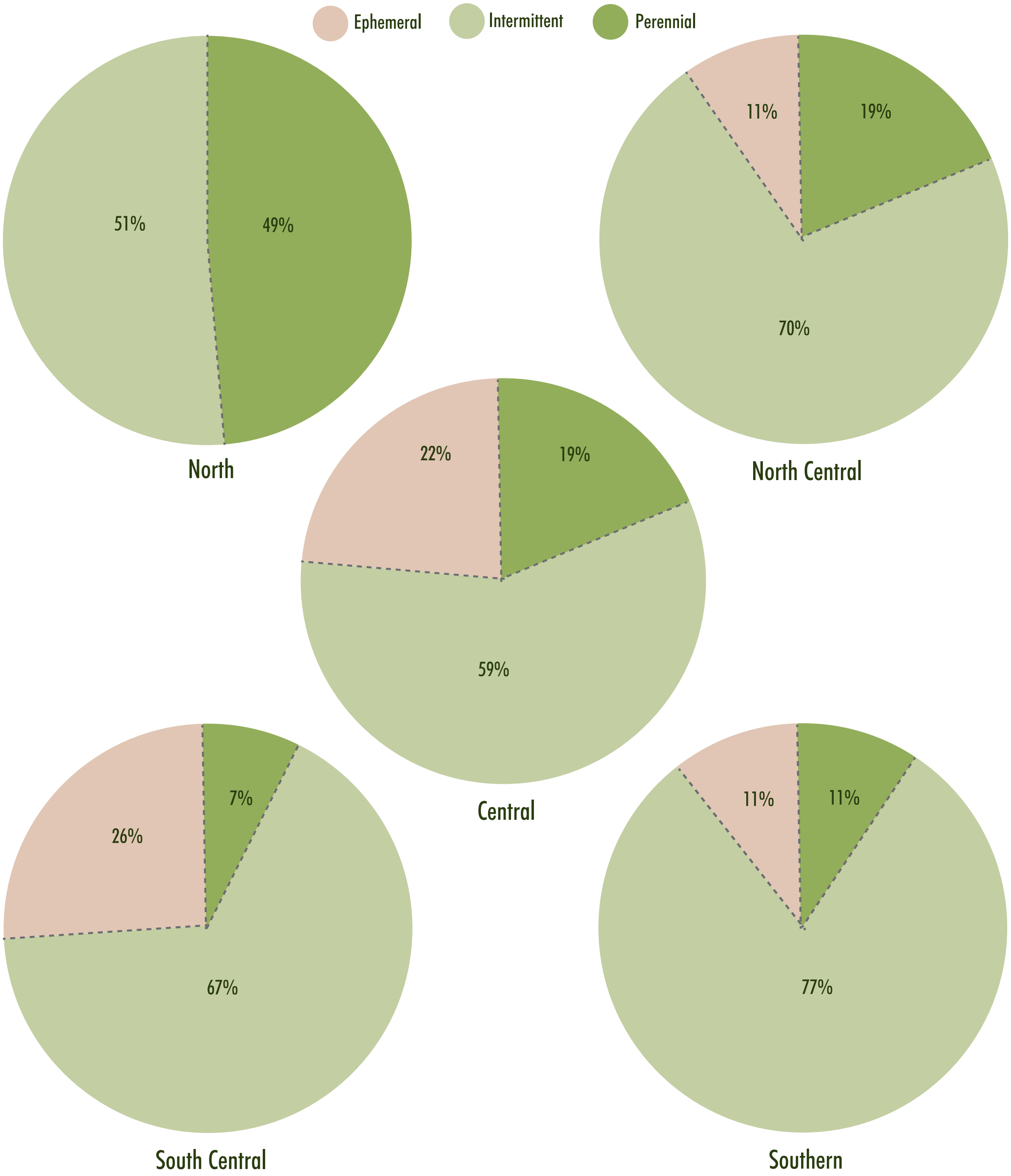


Figure 5-5. Proportion of Perennial, Intermittent, and Ephemeral Streams in Foothills Area Subregions

While perennial channels are generally those commonly thought of as "important," intermittent and/or ephemeral channels comprise much more of the total drainage network throughout the Foothills Area (fig. 5-4). The proportions of perennial, intermittent, and ephemeral streams by subregion reflect general differences in climate, geology, and vegetation. The largest percent of perennial channels is 49% in the north, and decreases below 20% in the other subregions, while the percentage of intermittent and ephemeral channels increases southward (fig. 5-5). The higher proportion of perennial channels in the north likely reflects general climatic trends. The largest total stream length is in the Southern and South Central subregions (fig. 5-4), but the greatest perennial channel length is in the Southern Subregion (2,573 miles).

The length of streams per unit area (channel mile/square mile), or channel density, also is a product of climate, geology, and vegetation. The total channel density is highest in the Southern, North Central and South Central subregions and somewhat lower in the Central and North subregions (fig. 5-6). Perennial channel density is highest in the North (0.62 miles/square mile) and North Central (0.58 miles/square mile) subregions, moderately high in the Southern and Central subregions, but relatively low in the South Central subregion (fig. 5-6). Intermittent channel density is fairly similar throughout the Foothills Area. However, there is a wide range of ephemeral channel density, from nearly zero in the North Subregion to 1.24 miles/square mile in the South Central Subregion. It is beyond the scope of this Conservation Report to determine the relative importance of each controlling factor, but the areas with greater perennial channel density likely reflect wetter climates and thicker weathered rock/soil materials that hold moisture and support summer base flow. The areas with higher ephemeral channel density likely have drier, warmer climates and/or less soil water capacity.

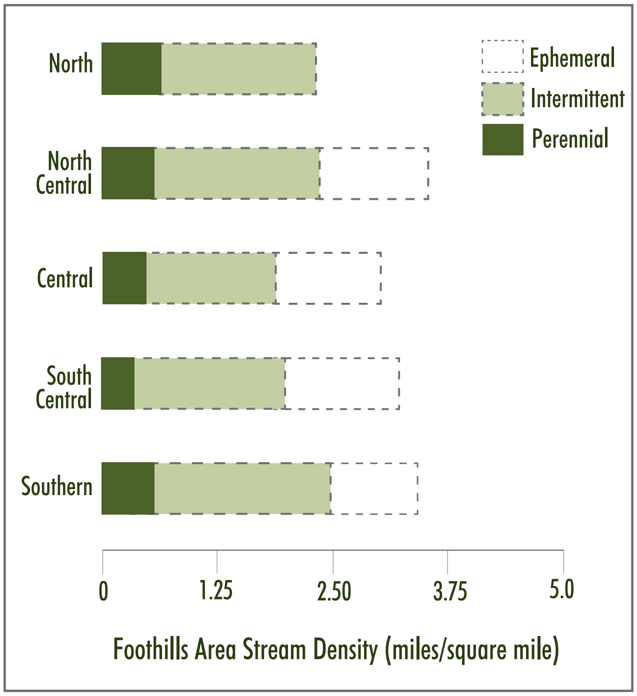


Figure 5-6. Perennial, Intermittent, and Ephemeral Stream Density in the Foothills Area

Additional details regarding stream types, stream lengths and stream densities throughout the Foothills Area are included in Appendix D-I.

5.1.2 Major Watersheds

The stream channels of the Foothills Area function within watershed drainage systems based on topography that dictates the natural flow of water from high elevation headwaters to low elevation areas. These low elevation areas generally either accumulate water (i.e., lakes or basins on the floor of the Central Valley) or ultimately discharge through the Sacramento-San Joaquin Delta to the ocean. Watersheds within the Foothills Area (Map W-1,

Map W-2, Map W-3, Map W-4, and Map W-5) include a couple dozen drainages that are at least 50 square miles, and a few small basins and subbasins. Ten of the foothill watersheds are over 500 square miles. The largest watershed areas within the foothills are the Tule, Kaweah, Kern, and American river basins (table 5-2). There is a wide range in the total watershed area for the rivers flowing through the Foothills Area. Therefore, the portion of each river's total watershed within the Foothills Area ranges from around one quarter (e.g., San Joaquin and Tuolumne) to about 90% of each contributing area (e.g., Kaweah and Calaveras) (table 5-2).

The Foothills Area portion of the contributing watershed areas for rivers flowing through the foothills has some geographic variability (fig. 5-7). The North, Central, and South Central subregions comprise around or a little over one-third of the associated watersheds. However, the Southern and North Central subregions occupy smaller portions of their total contributing drainage basins. In particular, the Feather River and San Joaquin River basins each have large headwater areas upstream of the foothill elevation zones. Watersheds that are largely contained within the Foothills Area would have potential advantages for watershed-scale management

Table 5-2. Largest Watershed Areas within Foothills Area Subregions

Watershed Name	Watershed Area within Foothills (square miles)	Total Watershed Area (square miles)	Percent of Contributing Watershed in Foothills (%)
Tule River	901	1,043	86.4
Kaweah River	835	938	89.1
Kern River	830	2,371	35.0
American River	788	2,050	38.4
Cosumnes/ Mokelumne rivers	712	1,456	48.9
Kings River	711	1,849	38.5
Yuba River	622	1,495	41.6
Feather River	567	3,625	15.6
Chowchilla/Fresno rivers	559	644	86.7
Mill/Deer creeks	509	895	56.9
San Joaquin River	458	1,706	26.9
Tuolumne River	433	1,616	26.8
Merced River	432	1,099	39.3
Calaveras River	376	396	95.0
Upper Clover/ Bear/Battle creeks	369	827	44.6

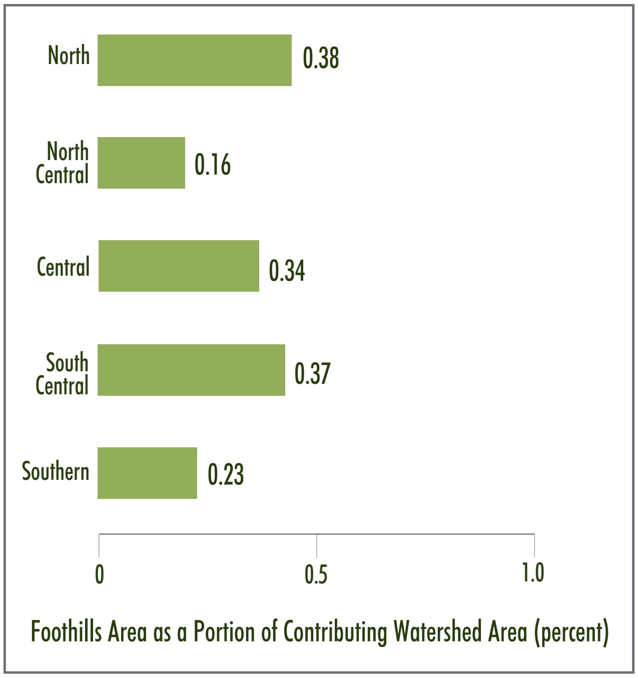


Figure 5-7. Proportion of Total Watersheds within the Foothills Plan Area

practices, but lack the hydrologic support of high elevation crest areas with increased snowpack.

The stream channel density within the Foothills Area varies by geographic subregion (fig. 5-6) and is different than the channel density of the total watershed areas (fig. 5-8). Additionally, the pattern of Foothills Area channel density versus total watershed channel density is not geographically uniform. The North, North Central, and Southern subregions have higher stream density than that of their overall watersheds. In contrast, the Central and South Central subregions have lower stream density than that of their respective watersheds.

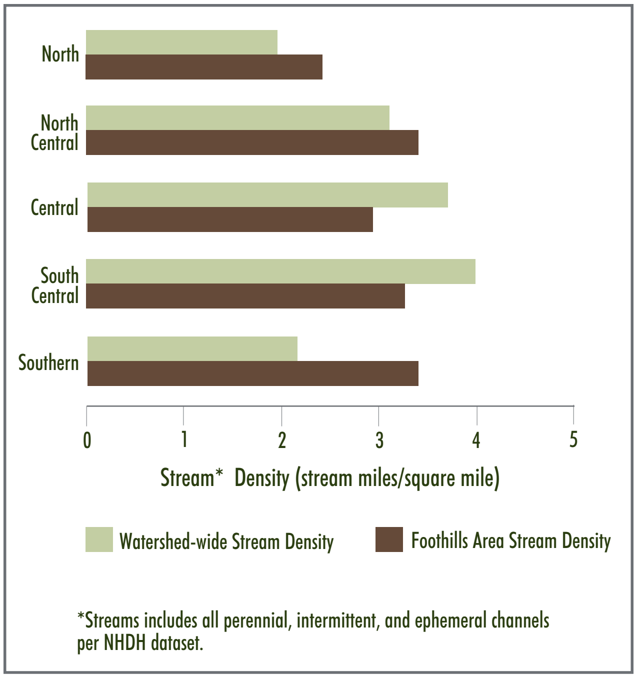


Figure 5-8. Stream Channel Densities

5.1.3 Surface Water Bodies

While there are small natural surface water bodies within the Foothills Area, all of the large water features are artificial (or artificially enlarged) reservoirs. Most major water supply, hydropower, and flood control reservoirs in the Sierra Nevada are located in the middle to low elevations while the natural lakes are typically in the glaciated high elevation zone (Department of Water Resources 2009). About 88% and 90%, respectively, all of the reservoir capacity in the San Joaquin River and Tulare Lake hydrologic regions of California lies within the Foothills Area. In contrast, only 30% of the Sacramento River hydrologic region's storage capacity lies within the Foothills Area, even though the region has some large reservoirs outside of the Foothills Area.

The ten largest reservoirs in the Foothills Area include representative federal entities (U.S. Bureau of Reclamation, U.S. Army Corps of Engineers), state entities (Department of Water Resources), local public entities (Turlock ID, Merced ID, Yuba County WA), and private utility facilities (PG&E); table 5-3. The largest reservoir in the Foothills Area is Lake Oroville, which is the largest reservoir of the State Water Project (SWP) (Department of Water Resources, 2009). Eight federal reservoirs are within the Foothills Area (including five of the largest ten) and several of the local private facilities are also large (table 5-3).

The surface area of reservoirs in the various subregions ranges from zero (North) to 72 square miles (South Central); figure 5-9. If calculated as a percent of the total area of each subregion, the surface area of reservoirs occupies between 2.0% and 2.7% of the total land area in the North Central, Central, and South Central subregions. Reservoirs occupy just 0.8% of the Southern Subregions and there is no measurable reservoir surface area in the North Subregion.

Table 5-3. Ten Largest Surface Reservoirs within the Foothills Area

Water Body*	Storage Capacity (1,000 acre-feet)	Capacity Rank	Surface Area (acres)	Area Rank	Operator
Lake Oroville	3,538	1	15,455	1	DWR
New Melones Lake	2,400	2	12,439	2	USBOR
Don Pedro Reservoir	2,030	3	11,075	3	Turlock ID
Lake Amador	1,308	4	299	29	PG&E
Lake McClure	1,032	5	5,628	7	Merced ID
Pine Flat Lake	1,000	6	5,379	8	USACE
Folsom Lake	975	7	11,063	4	USACE
New Bullards Bar Reservoir	970	8	4,046	10	Yuba County WA
Isabella Lake	568	9	7,731	5	USACE
Millerton Lake	521	10	4,364	9	USBOR

*Listed in order of storage capacity
DWR = California Department of Water Resources; USBOR = U.S. Bureau of Reclamation;
Turlock ID = Turlock Irrigation District; PG&E = Pacific Gas & Electric Company; Merced ID = Merced Irrigation District;
USACE = U.S. Army Corps of Engineers; Yuba County WA = Yuba County Water Agency

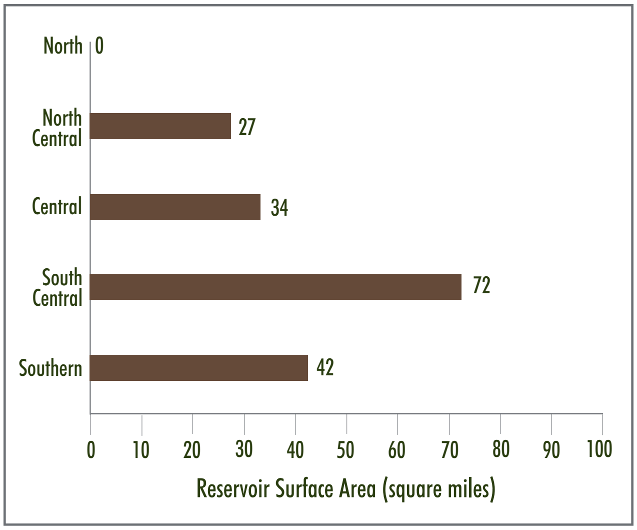


Figure 5-9. Reservoir Surface Areas within the Foothills Area

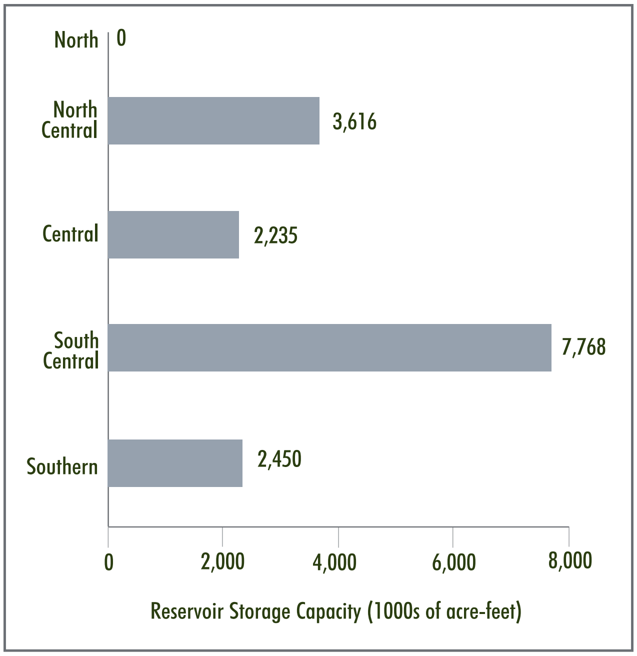


Figure 5-10. Reservoir Storage Capacity within the Foothills Area

While the proportion of Foothills Area occupied by reservoirs is not highly variable by subregion, the differences in reservoir storage capacity are large (fig. 5-10). The South Central and North Central subregions have the largest reservoir volumes (7.8 and 3.6 million acre-feet, respectively), and the Southern and Central subregions have smaller, but similar volumes (2.5 and 2.3 million acre-feet, respectively).

Additional detail regarding surface water reservoirs throughout the Foothills Plan area is included in Appendix D-II and Appendix D-III.

5.1.4 Groundwater

Groundwater conditions throughout the Foothills Area are controlled by the distribution of bedrock versus unconsolidated deposits; primarily in mountainous terrain whose only groundwater-bearing units are in fractured bedrock. Unfortunately, there is limited hydrogeology information available regarding fractured rock regions to ensure the reliability of locating groundwater supplies, and some of these areas have no other local water supply alternatives (Department of Water Resources 2003). Groundwater development in the fractured rocks of the foothills of the southern Cascades and Sierra Nevada is uncertain and difficult to access for community use (Department of Water Resources 2003). Modern groundwater development in the Foothills Area is primarily private wells. There are groundwater quality issues within some fractured hard rock areas due to either natural (e.g., uranium, radon, heavy metals) and human-induced (i.e., bacteria, nutrients) causes (Department of Water Resources 2003).

While most of the Foothills Area lacks major groundwater resources due to the dominance of bedrock, about 575 square miles are within identified groundwater basins. However, this comprises only 5.1% of the Conservation Report study area. The portion of each Foothills Area subregion with identified groundwater basins varies from nearly zero in the Central Subregion to 28.5% in the North Subregion (fig. 5-11).

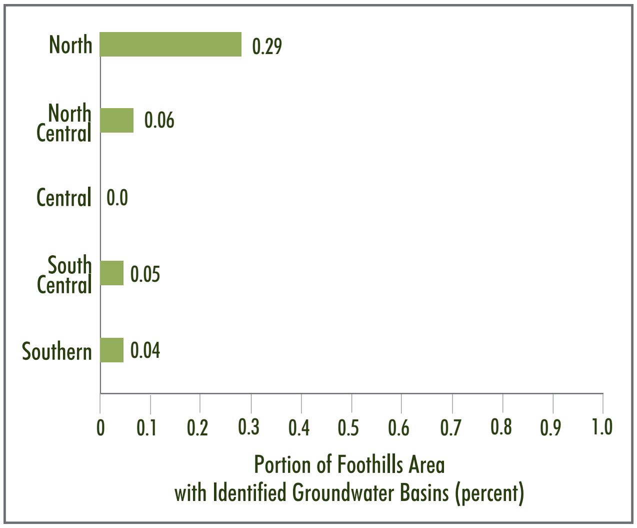


Figure 5-11. Portion of Foothills Area Subregions with Identified Groundwater Basins
Source: DWR 2009, California Water Plan

The North Central and South Central subregions include groundwater basin areas relatively proportional to their portion of the overall Foothills Area. In contrast, the North Subregion has a much higher portion of the total groundwater basin area (27.2%) than its portion of the total Foothills Area (4.9%). The Central and Southern subregions have much lower proportions of the foothill groundwater basin total (34.6% and 0.8%, respectively) than they do of the total Foothills Area (43.8% and 15.5%, respectively).

There are some discrete groundwater basins largely within the Foothills Area in the North Subregion (Millville and South Battle Creek basins) and in the Kern River watershed (Kern River Valley basin); table 5-4. In the vicinity of these small groundwater basins within the Foothills Area, the contributing watershed surface hydrology largely controls recharge, and groundwater resources may be developed and managed for local uses. However, these basins tend to have thin aquifers and generally low well yields; relatively little data regarding storage capacity or specific yield exists for them (Department of Water Resources 2003).

Most of the groundwater basin areas within the Foothills Area are very small, discrete regions along the eastern fringe of vast groundwater basins in the Sacramento and San Joaquin valleys or in structural basins between the Sierra Nevada and Tehachapi Mountains (table 5-4). For those situations, the Foothills Area plays a very minor role contributing to groundwater recharge and has limited groundwater development and management options. The eastern fringe of the Central Valley groundwater basins also has some contaminant issues, due to the shallow, unconfined aquifer exposure to potential impairments by historic land uses (Department of Water Resources 2003). Along the southeastern margin of the Sierra Nevada (i.e. Tehachapi and Fremont valleys), complex combinations of alluvial and lacustrine deposits affect aquifer characteristics (Department of Water Resources 2003).

Groundwater basins along the east fringe of the Sacramento Valley north of Mill/Deer Creek watersheds (Department of Water Resources basins 5-21.53 to .56) have not experienced significant declines in groundwater levels historically, while areas further south and near municipal extraction areas have declined. Along the entire east fringe of the San Joaquin Valley the groundwater basins have been adversely affected by overdraft for decades, resulting in depressed groundwater levels, ground

Table 5-4. Identified Groundwater Basins within the Foothills Area

Department of Water Resources Groundwater ID	Groundwater Basin	Groundwater Sub-basin	Total Basin Surface Area (acres)
5-6.05	Redding Area	Millville	67,900*
5-6.06	Redding Area	South Battle Creek	32,300*
5-21.53	Sacramento Valley	Bend	29,770
5-21.54	Sacramento Valley	Antelope	18,710
5-21.55	Sacramento Valley	Dye Creek	27,730
5-21.56	Sacramento Valley	Los Molinos	33,170
5-21.57	Sacramento Valley	Vina	125,640
5-21.58	Sacramento Valley	West Butte	181,560
5-21.59	Sacramento Valley	East Butte	265,390
5-21.64	Sacramento Valley	North American	351,000
5-22.16	San Joaquin Valley	Cosumnes	281,000
5-22.01	San Joaquin Valley	Eastern San Joaquin	707,000
5-22.04	San Joaquin Valley	Merced	491,000
5-22.08	San Joaquin Valley	Kings	976,000
5-22.11	San Joaquin Valley	Kaweah	446,000
5-22.14	San Joaquin Valley	Kern County	1,945,000
5-25	Kern River Valley	n/a	74,000*
5-26	Walker Basin Creek Valley	n/a	7,670
5-28	Tehachapi Valley West	n/a	14,800
6-45	Tehachapi Valley East	n/a	24,000
6-69	Kelso Lander Valley	n/a	11,200
6-46	Fremont Valley	n/a	335,000

* 75-100% of this basin surface area is within the Foothills Area.
Source: Department of Water Resources 2003. California's Groundwater, DWR Bulletin 118-Update 2003.

subsidence, and loss of aquifer storage capacity (Department of Water Resources 2003). Management efforts, including artificial recharge and water banking (Kern County basin), have supported partial recovery of groundwater levels. In the Tehachapi Valley the groundwater basins are adjudicated (Tehachapi-Cummings County Water District is the watermaster) and artificial recharge programs are in place to help address groundwater declines that were noticed as early as the 1940s (Department of Water Resources 2003).

5.1.5 Water Use and Management

The Foothills Area is a critical element of state-wide water resource use and management, as it comprises over half of the Mountain Counties source area, and contains nearly all of the large and critical reservoirs (outside of the Coast Ranges). Further, its position is key for water conveyance and transfers (e.g., from the South Central Subregion to the San Francisco Bay Area; from the Tulare Lake basin north via the Friant-Kern canal).

In terms of overall water balance (use and supply), the Sacramento River hydrologic region is larger than those of either the San Joaquin River or Tulare Lake hydrologic regions (Department of Water Resources 2009, using 2005 water year as case example), and the magnitude and proportion of uses and sources varies. The extent of irrigated agriculture and urban uses, for example, is relatively similar in all three regions, but forms a very large percentage of total use in the Tulare Lake region as compared to the Sacramento River region. Wild and Scenic River uses (Department of Water Resources 2009) are similar in the Sacramento River and Tulare Lake regions, but lower in the San Joaquin region, while the Sacramento and San Joaquin rivers have instream flows and managed wetland uses much greater than those in the Tulare Lake region. The primary regional difference in use is that a large magnitude and portion of the Sacramento River region is required Delta outflow. The water sources by region also differ somewhat. The magnitude of reuse and instream environmental supply is greatest in the Sacramento region, but all three regions have relatively similar amounts of federal and local project and groundwater sources. The Tulare Lake region differs in having state project water as a source (imported) and a larger reliance on groundwater.

Water resource planning efforts across California have progressed in the last decade, with a growing emphasis on collaboratively managing all aspects of water related issues within the Integrated Regional Water Management (IRWM) process. IRWM crosses jurisdictional, watershed, and political boundaries; involves multiple agencies, stakeholders, individuals, and groups; and attempts to address the issues and differing perspectives of all the entities involved through mutually beneficial solutions. The Integrated Regional Water Management Act (SB 1672, 2002) encourages local agencies to work cooperatively to manage local and imported water supplies, improving quality, quantity, and reliability. Funding through competitive grants for IRWM planning and implementation has been established through Proposition 50 (2002), Proposition 84 (2006), and Proposition 1E (2006). The IRWM Planning Act (SB1, 2008) provides a general definition of an IRWM plan as well as guidance to Department of Water Resources as to what IRWM program guidelines must contain (Department of Water Resources IRWM web page; see References section). All Foothills Area watersheds are within regions identified by the IRWM program (Department of Water Resources IRWM Acceptance Process web page), and in some cases there are overlapping

IRWM planning regions (Appendix D-IV). However, each IRWM group has varied funding levels, participation, and is at a different stage of planning and implementation.

5.1.6 Climate and Runoff

Given the large latitude range and varied relationships to the San Francisco Bay-Delta topographic break in the Coast Ranges, there is some climate variability in the Foothills Area, despite general consistency due to its position along the low elevation zone of the Sierra Nevada and the western slope of the southern Cascade Range. The moderate and low elevation zone of the Sierra Nevada has a Mediterranean-montane climate with cool, wet winters (November–April) and warm, dry summers (May–October). Near the far southern and northern ends of the Central Valley, the lower Foothills Area is isolated from marine air incursions, resulting in hotter summer temperatures and long durations of fog during winter inversion events.

Average annual precipitation in the Foothills Area varies from rather low amounts (less than 12 inches per year) along the San Joaquin valley floor south of Merced County and in the Tehachapi Mountain basins, to moderate amounts (20 to 25 inches per year) along most of the Sacramento Valley margin. The average annual precipitation amounts for the contributing watersheds reflect the elevation distributions and latitude of the watersheds. Average annual precipitation is lowest in the southern watersheds: about 22 inches per year for the Kern River basin, and between 35 to 40 inches per year for the Tule, Kaweah, Kings and San Joaquin river basins (Null et al. 2010). In the South Central Subregion, average annual precipitation for the watersheds varies from 34 inches per year in the Calaveras River basin to 48.5 inches per year in the Mokelumne River basin (Null et al. 2010). The highest precipitation amounts are in the Central and North Central subregions, with annual values from about 48 inches per year in the Bear and Feather river basins to as high as 65.9 inches per year in the Yuba River (Null et al. 2010). Precipitation generally increases moving north, but there is some variability that is influenced by the watershed crest elevations and position relative to regional atmospheric circulation patterns and gaps in the Coast Ranges.

The maximum elevations within the Foothills Area range from under 4,000 feet in the North Subregion to some small areas of nearly 12,000 feet Southern Subregion (fig. 5-12). Although most of the Foothills Area is below 5,000 feet in elevation, Foothills Area watersheds vary in terms of their upstream and upslope extent. These upper watershed source areas have large effects on the overall hydrology and hydrologic regime of the river channels that flow through the Foothills Area portion of each watershed. The crest elevations of the respective watersheds are consistently just over 10,000 feet for the Northern, North Central, and Central subregions (fig. 5-12). The highest crest elevations are those of the contributing areas to the South Central and Southern subregions (13,031 feet and 14,476 feet, respectively); figure 5-12. The elevation ranges and the large north-to-south distance create varied relationships between the Foothills Area watershed elevations, contributing watershed crest elevations, and typical snowline elevations (fig. 5-13).

In the Northern and Central subregions, maximum elevations within the foothills are approximately the same as typical snowline, such that the entire Foothills Area is dominated by precipitation as rainfall, and lacks snowpack effects on local runoff. The North Central and South Central subregions have maximum elevations somewhat higher than typical

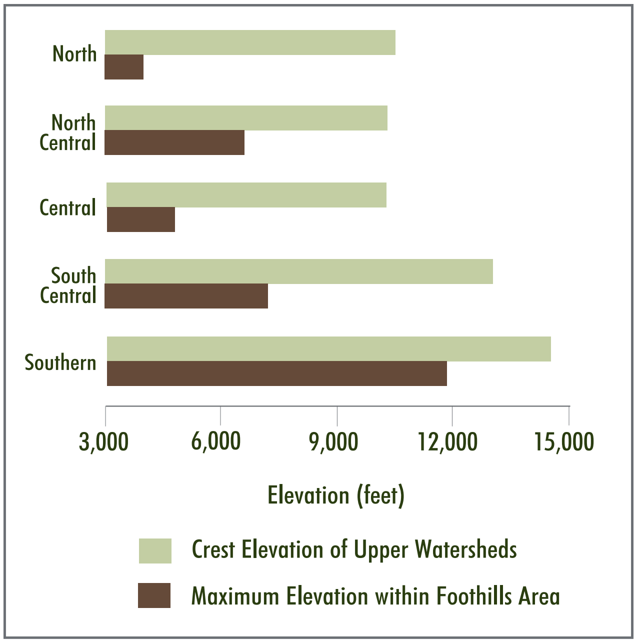


Figure 5-12. Maximum Watershed Elevations

snowline, while the Southern Subregion of the Foothills Area extends far above snowline. These areas would experience increasing proportions of precipitation as snowfall and greater snowpack effects on local runoff.

The relationship of maximum crest elevations in the upper watersheds to typical snowline differs substantially between subregions (fig. 5-13). The crest elevations of contributing watersheds in the Northern, North Central and Central subregions are moderately low, but a few thousand feet above recent snowlines. In contrast, the crest elevations of contributing watersheds in the South Central and Southern subregions are much higher, and about 8,000 to 10,000 feet above historic snowline; "historic" meaning the period of record, which varies by river system and years of climate stations. Very large proportions of a few watersheds are above the snowline near the north and south extremes of the Conservation Report area (i.e., 72% of both the Feather and San Joaquin river basins and 60% of the Stanislaus basin). Several other watersheds have nearly half of their drainage area above snowline (e.g., Yuba, American, Mokelumne, Tuolumne and Merced rivers) (Null et al. 2010). In contrast, the Cosumnes River basin has about one-quarter of its area above snowline and the Bear River basin is nearly all below snowline. These relationships affect modern precipitation and runoff patterns as well as the potential resilience of contributing watersheds in the different subregions against future climate change.

Existing runoff regimes throughout the region are affected not only by natural climate, geology, and land-cover driven factors, but also by numerous water diversion, storage, transfer, and consumptive

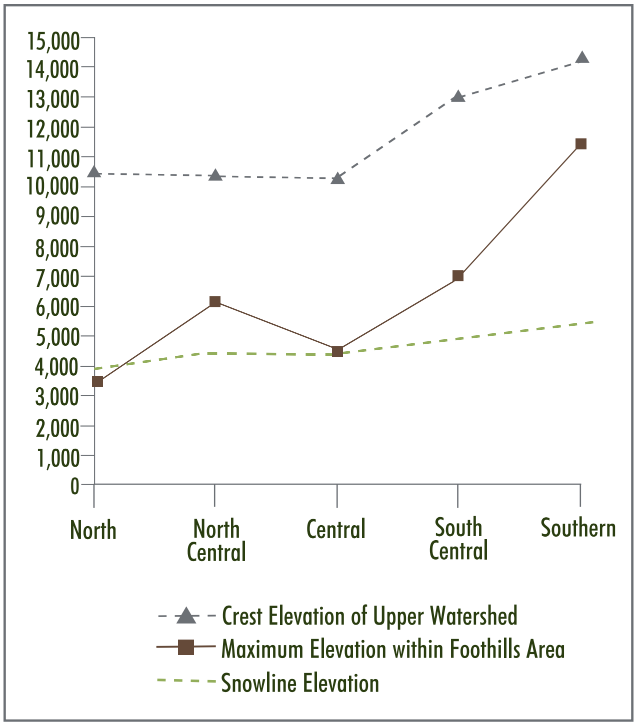


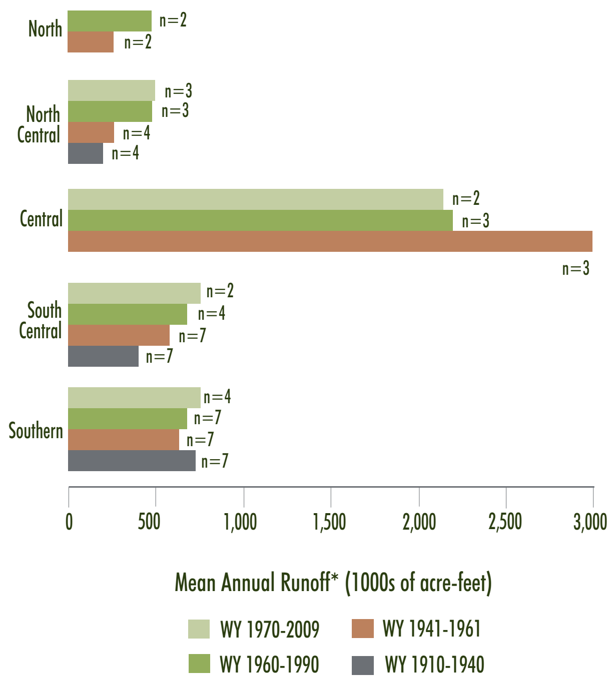
Figure 5-13. Watershed Elevations and Typical Snowline

uses, and flood operation rules. Legal mandates to maintain minimum instream flows during certain seasons and under specific water-year types have been established pursuant to state and federal water rights and endangered species protections, as part of hydroelectric facility license conditions, and as an outcome of specific litigation. Legal mandates to maintain minimum flood storage during certain seasons and forecast runoff conditions require reservoir releases to downstream channels.

Therefore, the seasonal pattern of runoff in Foothills Area streams is a managed system in most of the watersheds. Very few watersheds have limited water development, water storage/flood control systems, or dedicated environmental/recreational flow requirements. These watersheds, primarily in the North and North Central subregions (i.e. Upper Clover/Bear/Battle, Mill/Deer, Chico/Butte Creeks, North Fork American River) and in the South Central Subregion (i.e. Cosumnes River), are largely unregulated and unmanaged, so their flow regimes are "natural." While they provide unique opportunities for preservation and restoration of the ecological systems dependent upon a natural river regime, they may have unusually high vulnerability to future climate change, since they lack infrastructure or policy environments for active management.

The California Department of Fish and Game (DFG) developed lists of perennial streams that are high priority (beginning circa 1980) for instream flow designations, to ensure the viability aquatic-dependent biologic resources (Department of Water Resources 2009). Six of the 21 streams with immediate needs are in the Foothills Area (i.e., Battle Creek, North Fork Feather River, Yuba River, lower American River, lower Mokelumne River, and lower Merced River). Five of the 22 streams with future needs are also in the Foothills Area (i.e., Butte Creek, lower Tuolumne River, Bear River, Deer Creek (tributary of the Yuba River), and Middle Fork Feather River). Historic and existing flow in these streams falls short of biologic objectives in at least some seasons and years. Therefore, these systems likely represent particular challenges in the context of potential runoff response to climate change.

Observed runoff from rivers in the Foothills Area during the historical period of record provides information about both the major rivers and some smaller watersheds (fig. 5-14). These data are not

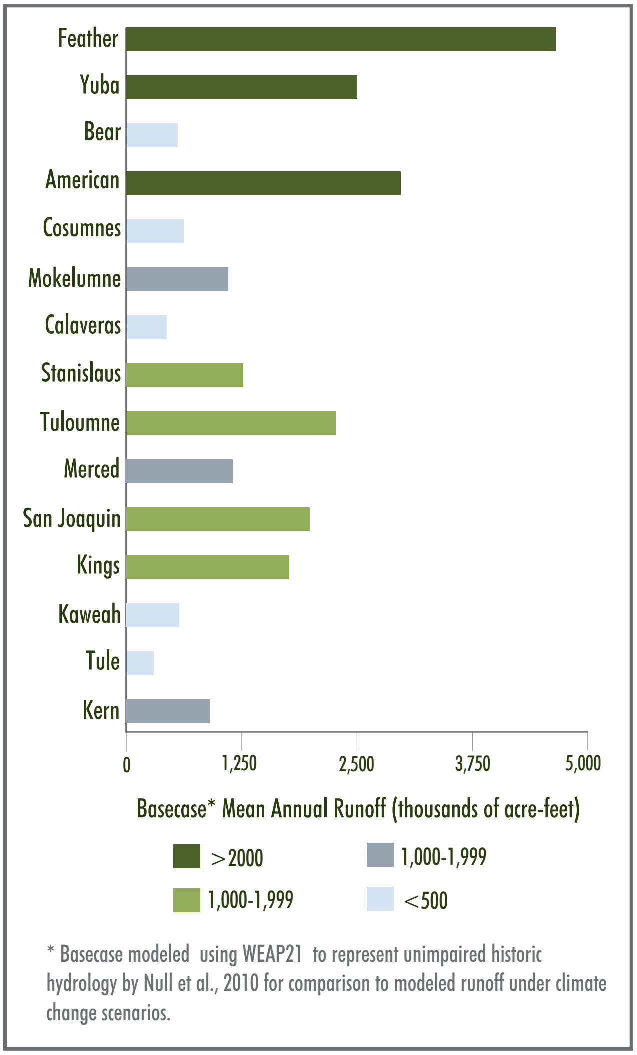


* Based on USGS data for available stations representing watersheds within the foothills region within each geographic area. The data is grouped by time periods for which there are several stations reporting concurrently. The data do not include all watersheds (the number of watersheds reporting for each timer period is listed above as n=#). Additionally, there are a few missing years, and some effects of diversion, storage, or import may not be corrected. The values should be considered approximate.

Figure 5-14. Observed Mean Annual Runoff for Foothills Area Rivers

corrected for the effects of water use and management, such as diversions, loss, and transfers. Therefore, they represent the combination of natural runoff factors and water resource development. The top three observed average annual runoff values are the American, Yuba, and Kings rivers, with moderate runoff observed for the Feather, Stanislaus, Tuolumne, Merced, San Joaquin and Kern rivers (fig. 5-14). These systems have the greatest flows, despite human modifications to their natural networks, storage, seasonality, and loss rates.

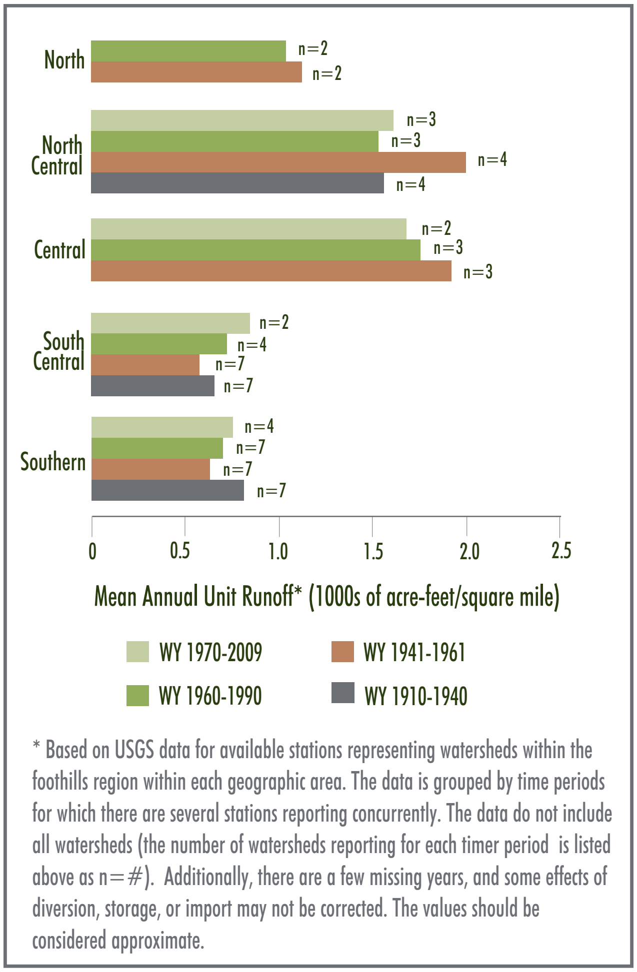
Modeling to 'correct' for the historic use and management provides an estimate of unimpaired natural runoff. The unimpaired historic average annual runoff for major river basins in the Foothills Area ('Basecase' per Null et al., 2010) vary widely from 4,683 thousand acre-feet (TAF) in the Feather River to just 161 TAF in the Tule River (fig. 5-15). Watersheds with larger drainage areas, high crest elevations, and/or northern latitude have the largest estimated natural runoff. The top three watersheds are in the North Central and Central subregions (Feather, American and Yuba rivers). The next four watersheds are in the South Central and Southern subregions (Tuolumne, Stanislaus, San Joaquin and Kern rivers). The remaining eight watersheds have modest runoff estimates due to their smaller drainage areas, lower crest elevations (i.e., Calaveras, Bear) and/or southern location (i.e., Kaweah, Tule). Future management options require consideration of the watersheds' natural runoff generation potential, as well as the historic and future uses that modify runoff quantities.



* Basecase modeled using WEAP21 to represent unimpaired historic hydrology by Null et al., 2010 for comparison to modeled runoff under climate change scenarios.

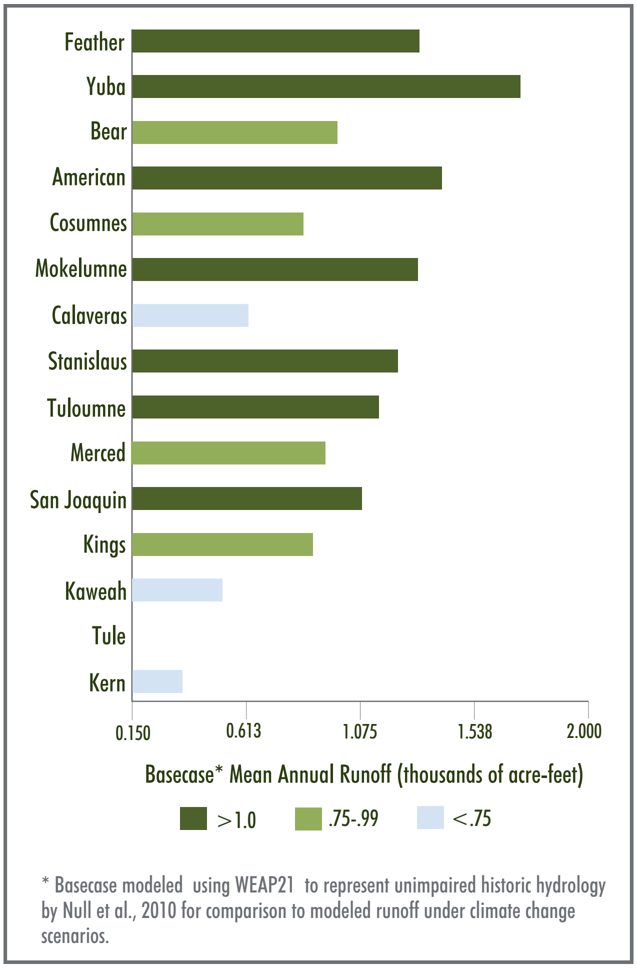
Figure 5-15. Modeled Unimpaired Mean Annual Runoff for Major Sierra Nevada Rivers

When variations in drainage area are accounted for by expressing runoff volume per unit drainage area (TAF/square mile), the effect of latitude on runoff production is more readily noticed in both the observed (fig. 5-16) and modeled (fig. 5-17) runoff data. The highest unit runoff values are in the Northern, North Central and Central subregions of the Foothills Area, decreasing southward. The modeled data (fig. 5-17) does not include as many small streams or low elevation basins, or any streams in the Northern Subregion. However, both sets of data have similar overall



* Based on USGS data for available stations representing watersheds within the foothills region within each geographic area. The data is grouped by time periods for which there are several stations reporting concurrently. The data do not include all watersheds (the number of watersheds reporting for each timer period is listed above as n=#). Additionally, there are a few missing years, and some effects of diversion, storage, or import may not be corrected. The values should be considered approximate.

Figure 5-16. Historic Mean Annual Unit Runoff for Major Sierra Nevada Rivers



* Basecase modeled using WEAP21 to represent unimpaired historic hydrology by Null et al., 2010 for comparison to modeled runoff under climate change scenarios.

Figure 5-17. Modeled Unimpaired Mean Annual Unit Runoff for Major Sierra Nevada Rivers

patterns that demonstrate higher unit runoff values for northern streams and those in the south that have highest elevation headwaters.

The seasonal runoff regime throughout the foothills is somewhat varied based on whether the watersheds are local, lower crest elevation watersheds dominated by rainfall runoff or have high elevation snowpack-driven streamflow patterns. Rainfall-dominated streams typically have annual peak flows during early winter (January–March), such as the Feather River. Snowmelt-dominated streams typically have annual peak flows during late spring (May–June), such as the Merced River.

One representation of the seasonal hydrograph is the runoff centroid (RC): the date by which one half of the annual runoff has flowed past the basin outlet. The estimated RC for existing unimpaired flow conditions, modeled as the 'Basecase' by Null et al. (2010) varies through the major Sierra Nevada watersheds from early February (Bear River) to mid-April (Kings and Kern rivers). The southern watersheds with relatively high to very high crest elevations have the latest RC dates.

The minimum flow magnitude and timing varies somewhat natural due to elevation zone (air temperature), vegetation and riparian corridor conditions (evapotranspiration demand), geology (local seeps, springs), and soils/topography (valley width and thickness of any alluvial aquifer). On perennial streams, the annual minimum flows are typically between August and October. Human influences on minimum flow timing and low flow duration are wide ranging, from direct effects due to diversions and managed flow releases to indirect effects on streamside vegetation canopy or groundwater extraction. Compared to perennial streams, intermittent and ephemeral streams have long periods of weeks to months (respectively) with low or absent surface flow. However, the factors controlling the timing and duration of low flows on intermittent and ephemeral streams are the same as those affecting low flow timing and duration on perennial streams.

The low flow duration (LFD), defined as weeks with streamflow less than 1% of the total annual discharge, was evaluated for major Sierra Nevada rivers by Null et al. (2010). Their modeled Basecase represents unimpaired conditions, which may differ from historic observations on managed rivers, but provides a useful comparison against projected conditions under climate warming (below). The LFDs varied from less than one week (i.e., Feather, Calaveras, San Joaquin, Kings and Kern rivers) to more than five weeks (i.e., American, Cosumnes, Mokelumne rivers).

5.2 Anticipated Changes and Threats

Several very different types of changes and threats are projected to affect hydrologic resources in the Foothills Area, including the following:

- climate change; affecting snowpack, reservoir inflow, and runoff centroid;
- regional water demand and development; and
- local surface and groundwater status.

5.2.1 Climate Change Effects

Various climate change scenarios for California have been investigated in recent years, including those presented by Cayan et al. (2008) based directly on two Global Climate Models (GCMs): the National Center for Atmospheric Research's Parallel Climate Model (PCM), and the National Oceanic and Atmospheric Administrations' Geophysical Fluid Dynamics Laboratory model (GFDL). Climate change scenarios are also based on a range of emissions scenarios (B1 low, A2 medium-high, and Alfi high). The climate models predict significant temperature warming in California and relatively small changes in total precipitation (Cayan et al. 2008). The temperature changes are generally larger in the summer than in the winter, but precipitation continues to occur predominantly in the winter. However, while the average annual precipitation projections show little change (to small decreases), there is a small tendency for increased number and magnitude of large events. Downscaled forcing parameters were used in a variable infiltration capacity (VIC) model to simulate hydrologic response at the 1/8 degree resolution for all of California. This procedure allows the global scale modeling results to be expressed at a regional scale, and translates the predicted changes in basic climatic variables (e.g., temperature, precipitation) into estimates of their effects on streamflow and other hydrologic parameters by an added modeling step that considers regional differences in factors such as topography and soils. Based on this approach, climate warming is projected to reduce snow accumulation due to an increased proportion of precipitation falling as rain versus snow. Additionally, the historical trend of reduced snowpack water equivalent as of April 1 is projected to continue, with earlier melt dates under future climate conditions (Cayan et al. 2008). Snowpack losses are modeled to be substantial over the Sierra Nevada, and to be most severe at the low-middle and middle elevations, with greater potential effect on the central and northern parts of the range due to topographic differences.

Climate change impacts on California hydrology and water resources have been estimated at a regional scale with downscaled output from two GCMs (PCM and HadCM2) under both low and high range (B1 and ALfi) emission scenarios, applied in a VIC model at the 1/8 degree resolution to derive modified historic inflows to watersheds of the Department of Water Resources/USBOR CalSim II water system model (Vicuna et al. 2007). This approach was used to estimate effects of both higher temperatures and modified (increased or decreased) precipitation on water supply deliveries, reliability, reservoir storage, and variables affecting environmental water use (Vicuna et al. 2007).

Predicted hydrologic effects of the range of climate change scenarios on California summarized in table 5-5 include the following:

- severely reduced April 1 snowpack water equivalent (particularly in the lower elevation ranges);
- lower to slightly increased annual inflow to reservoirs;
- consistently diminished April–June inflow to reservoirs; and
- shift in runoff centroid to earlier in the year (especially in the south, but late-spring and summer runoff decreased in all the modeled basins).

Negative impacts to reservoir storage, water supply deliveries and reliability and environmental conditions result under most emissions scenarios. Generally, impacts south of the Delta on water storage are more adverse than north of Delta, because of a greater effect of temperature increases on runoff timing in the south. Simulated conditions for the higher emissions scenarios suggest that there is greater impact during dry periods than for the average years under higher emissions scenarios (Vicuna et al. 2007).

Using the Water Evaluation and Planning System (WEAP21) spatially discrete rainfall-runoff model at the watershed scale on a weekly time step, Null et al. (2010) simulated the hydrologic effects of future air temperature changes indicated by GCMs under varied emissions scenarios. Their runoff estimates for 15 west slope Sierra Nevada watersheds under climatic warming scenarios provides an initial estimate, without assuming specific additional changes in precipitation and/or land cover. The modeled period, water years 1981–2001, covers a wide range of climatic variability including the wettest year on record (1983), the flood year of record (1997), and a prolonged drought (1988–1992). These results indicate an overall trend of reduced runoff volume as a result of higher evapotranspiration losses due to warming. The results for the study watersheds indicate an average of 3%, 6%, and 9% annual flow

Table 5-5. Summary of California Climate and Hydrology Variables under Climate Change Scenarios

Historical			Simulated Change			
Variable	**1961-1990**	**Units**	**2020–2049 (min)**	**2020–2049 (max)**	**2070–2099 (min)**	**2070–2099 (max)**
Average Temperature						
Annual	9.0 °F	°F	2.5	3.6	4.1	10.4
Summer (JJA)	73.0 °F	°F	2.2	5.3	4.0	15.0
Winter (DJF)	45.7 °F	°F	2.1	2.7	3.9	7.2
Average Precipitation						
Annual	21.4 in	in	0.2	(2.8)	1.5	(6.2)
Summer (JJA)	0.8 in	in	0.1	(0.3)	0.2	(1.8)
Winter (DJF)	10.6 in	in	0.2	(2.2)	0.5	(3.6)
April 1 Snowpack Water Equivalent						
3,300 to 6,600 ft	2,919 TAF	%	-56	-66	-97	-65
6,600 to 9,900 ft	5,270 TAF	%	-24	-36	-22	-93
9,900 to 13,100 ft	1,865 TAF	%	4	-15	15	-68
All elevations	10,053 TAF	%	-26	-40	-29	-89
Annual Reservoir Inflow						
Total	17,592 TAF	%	5	-22	12	-30
Northern Sierra	12,323 TAF	%	3	-22	9	-29
Southern Sierra	5,270 TAF	%	10	-23	17	-43
April-June Reservoir Inflow						
Total	7,377 TAF	%	-11	-24	-1	-54
Northern Sierra	4,459 TAF	%	-16	-24	-6	-47
Southern Sierra	2,919 TAF	%	-2	-24	-5	-65
Water Year Runoff Centroid						
Total	April 5	Days	2	-15	-7	-32
Northern Sierra	March 13	Days	3	-16	-3	-24
Southern Sierra	May 1	Days	-7	-19	-22	-43

Source: Vicuna et al. 2007.

Data Source: Null et al. 2010: Comparison of Average Annual Runoff modeled using WEAP21 for the Basecase (historic unimpaired) and three warming scenarios: uniform atmospheric temperature increases of 2°, 4°, and 6° degrees Celsius (T2, T4, T6).

Figure 5-18. Percent Change in Annual Runoff from Basecase under Atmospheric Temperature Increases of 2°, 4°, and 6° Celsius.

reductions under the 2°C, 4°C, and 6°C (3.6°F, 7.2°F, 10,8°F) warming, respectively, although there is variation by watershed (fig. 5-18). When normalized by area, the Bear River had the largest change for a 2°C warming; the American River had the most change for 4°C and 6°C warming. Overall, the watersheds in the northern Sierra Nevada had greater reductions than in the southern high elevation Sierra (Null et al. 2010).

Modeled changes in RC timing (Null et al. 2010) based only on direct climate warming indicate that future runoff will move earlier in the year due to changes in snowpack. The climate warming effect on RC timing is estimated to be three to four weeks for northern watersheds (e.g., Feather, American rivers), but limited to one to two weeks for low elevation watersheds (e.g., Bear, Cosumnes, and Calaveras rivers). The greatest change in RC timing was modeled for the Stanislaus River, but the San Joaquin, Mokelumne, Kings, and Merced rivers would also have RC shifts of up to five or six weeks.

Modeled changes in LFD (Null et al. 2010) due to direct climate warming effects suggest that the Central, and South Central subregions of the foothills may have the most adverse lengthening of low flow periods. The Mokelumne, Merced, Tuolumne, American, and Stanislaus watersheds are estimated to experience the largest increases in LFD (three to four additional weeks). Moderate LFD increases (one to two additional weeks) are simulated for the Yuba, Cosumnes, San Joaquin and Kaweah rivers. These results do not address changes in all factors affecting low flow, and may be conservative, since aspects of climate change other than temperature alone could also adversely affect LFD.

Potential changes in California flood regimes have been analyzed using downscaled GCM output for temperature input parameters to VIC runoff models, along with GCM predictions of changes in future precipitation characteristics of major weather events (e.g., atmospheric rivers) (California Energy Commission 2009). These data indicate that higher snowlines may increase the frequency of flooding and occasionally larger than historical flood magnitude would occur, especially in the higher southern Sierra Nevada. Years with many atmospheric river (AR) storms would become more frequent, but the number of such storms per year may not change.

In basins where rain has not historically reached an entire watershed (those with considerable high elevation zones like the watersheds of the Merced and Kings rivers), warming alone could result in storms with higher than historic flow without any change in the magnitude of storms themselves (California Energy Commission 2009). In watersheds that have historically received rainfall up to the crests (like the American and Feather rivers), the warming may result in increased frequency of flooding without increasing the magnitude of floods (California Energy Commission 2009). The future of "rain-on-snow" events is largely unknown at this time, but the potential for generally synchronous melt of all elevations within a watershed is likely to increase in the Sierra Nevada (California Energy Commission 2009). Atmospheric River (AR) storms have been the source of most of the largest floods in California and GCMs predict more years with many AR days and fewer years with fewer AR days; winter-flood AR storms may also increase. It is possible that the seasonality of AR storms will expand and that some may be more intense in the future (California Energy Commission 2009).

Climate change is having a profound effect on California's water resources and will continue to modify water supply in the form of runoff and snowpack, as well as water quality; affecting water temperatures and contaminent concentrations. Climate change will also affect hydropower and water delivery via operations conflicts and decreased reliability of water resources. Flooding is expected to become more frequent and extensive, drought will be more frequent and/or severe, and there are expected to be warming effects on water demand (Department of Water Resources 2009). All of these water-related elements of climate change pose particular challenges for the Foothills Area of the Sierra Nevada, although they have different levels of risk by subregion and/or watershed. For example, reduced total runoff may be particularly adverse for environmental/aquatic resources in the American, Yuba, Bear, Mokelumne and Cosumnes rivers (Null et al. 2010). Low flows in the foothills that are in part a function of high elevation mountain meadow systems that support summer base flows and are most vulnerable to degradation by climate warming in the American, Mokelumne, Merced, and Tuolumne watersheds (Null et al. 2010). Interestingly, some of the same watersheds most valued for their existing, largely unmanaged hydrology (e.g., Mill, Deer, Chico and Butte creeks; North Fork American; Cosumnes River) may be adversely affected by climate change without any facilities or infrastructure in place that could be used to ameliorate adverse changes or an adverse rate of change.

5.2.2 Regional Water Demand and Development

The California Water Plan 2009 Update (Department of Water Resources 2009) formulated three future scenarios for estimating water demand within the context of climate change: current trends; slow and strategic growth; and expansive growth. The Sacramento River region is forecast to have relatively large demand increases for either the current trends or expansive growth scenarios, and these increases would be magnified by climate change. Only under the slow and strategic growth scenario would the demand in the Sacramento River region be expected to drop, and climate change could counteract that to result in modest net demand increases. The San Joaquin River and Tulare Lake regions both have demand forecast patterns that are similar: reduced demand under all scenarios, but climate change could result in net demand increases for the current trend (minor increase possible) or expansive growth (moderate increase possible) scenarios. The water demand stays the same or decreases in the San Joaquin River and Tulare Lake regions in the absence of climate change, because of declining acreages of irrigated crops as urbanization replaces agriculture and better water conservation is achieved. The future demand increases for all Central Valley areas are highly sensitive to the warmer, drier conditions possible under several of the climate change scenarios, as compared to other areas of California (Department of Water Resources 2009).

Many of the dams and reservoirs within the Foothills Area are components of hydroelectric generation projects regulated by the Federal Energy Regulatory Commission (FERC). These projects typically operate under 30–50 year licenses issued by the FERC that set conditions including mandating minimum downstream flow releases and modified conditions under various water-year types. Several FERC projects in the Sierra Nevada have recently completed relicensing but many others will be going through FERC relicensing over the next decade. Under present regulations, the effects of climate change are not considered during relicensing, and it is uncertain whether and when these processes will incorporate such analysis in setting operation conditions. Based on the geography of existing hydroelectric generation capacity, the Kings, San Joaquin, Stanislaus and Tuolumne rivers' power supply roles are most vulnerable to changes in runoff timing (Null et al. 2010).

Reservoirs within the Foothills Area are an existing resource and attraction, and future land use patterns may continue to focus on them. However, it is possible that natural hydrology changes and modified operations under climate change will highly alter reservoir conditions in the future. Balancing the needs for additional water storage volumes, seasonal differences in hydropower opportunities and demand, and potential conflicts with desired flood storage capacity may result in water surface elevations and reservoir margin environments very different from historic patterns.

5.2.3 Local Surface and Groundwater Status

Future development pressure on local water sources within the Foothills Area is a serious concern, particularly due to limited available surface water and difficult or uncertain groundwater conditions. The cumulative effect of groundwater development may reduce the yield of wells, lower the flow of mountain streams, and impact local riparian and aquatic habitat (Department of Water Resources 2003). While the development of regional water supply projects has been suggested as a means to overcome these problems, the development pattern of small, isolated population centers does not lend itself to the kind of financial base necessary to support such projects (Department of Water Resources 2003). When considered in combination with climate change, adverse effects on groundwater recharge and increased evapotranspiration demand, the management of Foothills Area groundwater resources will be particularly challenging.

Throughout the Foothills Area, future development patterns are likely to be tied to existing urban/suburban communities, road networks, stream corridor alignments, and reservoir locations. Areas of growth on the western edge of the Foothills Area may have potential water supply access to regional groundwater supplies and/or combined sources, but most areas would continue to be fairly isolated from such resources. The Central Subregion may have the greatest development pressure and this area includes some of the watersheds relatively vulnerable to hydrologic effects of climate change. Throughout the Conservation Report study area, climate change may reduce some reaches or portions of perennial streams to intermittent channels, and intermittent streams to ephemeral channels, due to direct effects of reduced precipitation and higher temperatures and/or feedback from changes in vegetation patterns. Areas with lower existing stream density (i.e., the Central and South Central subregions) may not have good support for riparian corridors as average runoff decreases in the future. These low stream density areas could experience adverse effects from surface runoff and erosion during flood events due to the relative lack of developed channel networks.