APPENDIX E: WATER RESOURCES TECHNICAL REPORT

The Arroyo Seco Watershed Restoration Feasibility Study

Water Resources

By Tim Brick

- **A Brief History of Water Development in the Arroyo Seco**
- **The Water System – How It Works**
- **Watershed Management**

Flowing Waters, Fruitful Valley
A Brief History of Water Development in the Arroyo Seco

Geographically and historically the Arroyo Seco has played an important role in the development of water resources in Southern California.

The Natural History

Geology divided the Arroyo Seco into three distinct sections with very different hydrologic characteristics: 1) the precipitous upper mountain watershed; 2) the Raymond Basin area including Pasadena and surrounding communities; and 3) the region below the Raymond Dyke in South Pasadena and northeast Los Angeles.

About half the length of the Arroyo Seco lies in the upper mountain watershed. This is the front range of the Sierra Madre or San Gabriel Mountains, well known for harsh conditions and landslides. Fierce rainstorms and raging forest fires periodically attack the steep erosion-prone slopes in this relatively small upper watershed (32 square miles) to create the conditions for substantial floods that occasionally roar into the heavily populated communities below.

As the Arroyo Seco emerges from the San Gabriel Mountains, its steep descent slows and the waters cut through an alluvial plain. Beneath this region, which includes La Cañada-Flintridge, Altadena, Pasadena, Sierra Madre and part of Arcadia, lies the Raymond Basin – a massive bowl of alluvial sand and gravel filled with water. The south rim of the basin is the Raymond Dyke, a geological fault that runs from Highland Park to Raymond Hill at Pasadena's southern boundary with South Pasadena and then through San Marino just north of Huntington Drive to Santa Anita Canyon on the east side of Arcadia.

Flowing water and rich soil conditions endowed the Arroyo Seco communities with a rich natural heritage. In La Cañada streams flowed out of the mountain canyons and across the foothills and flatlands into what is now Flint Wash, which enters the Arroyo Seco just to the north and west of Devil's Gate. Altadena streams also feed the Raymond Basin but only Millard Canyon on the west flows to the Arroyo Seco. Rubio, Las Flores, Eaton Canyons and others all flow to the east eventually to join the Rio Hondo and San Gabriel Rivers. While most of Pasadena also tilts away from the Arroyo Seco to the Rio Hondo, hundreds of years ago abundant springs and streams lined the western part and the southern rim of that city. Below the Raymond Dyke, which lines the southern boundary of Pasadena, more springs bubbled from the ground on the Arroyo ridges as the main Arroyo stream flowed for five more miles to the Los Angeles River. Highland Park and Garvanza were so rich in springs that pioneers thought it sat on a "sea" of underground water.

The Early Settlers

Water was the attraction that brought the first settlers and succeeding generations to the Arroyo Seco. While the Spaniards dubbed the watershed Arroyo Seco or "dry riverbed," the Tongva or Gabrielino Native Americans referred to the region between the Los Angeles and San Gabriel Rivers as Hahamongna, "the land of flowing waters, fruitful valley." They settled on bluffs overlooking the stream that linked the San Gabriel Mountains to the Los Angeles River. At the mouth of Millard Canyon, the Gabrielinos established one major settlement. Further south were three minor settlements: a village on the banks of a brook on the east side of Raymond Hill, one more at Los Robles Canyon in Oak Knoll and a third at Garfias Springs on the banks of the Arroyo. Just west of the confluence of the Arroyo Seco and the Los Angeles River in what is now Elysian Park, they established another major village, Maungna, on a bluff overlooking the Arroyo Seco.

The Mission Era & Rancho Eras

The combination of substantial runoff from nearby high mountains, large alluvial volumes to absorb the flood flows and a natural underground dyke that forced groundwater to the surface resulted in perennial springs and artesian wells that were used by the early Native Americans. Lacy Park in San Marino lies at the base of the Raymond Dyke and was once a natural lake resulting from these artesian conditions. The padres of the San Gabriel Mission and the Spanish and Mexican settlers of the early 1800s tapped these rising waters for such purposes as operating a mill, a sawmill, and a tannery in addition to domestic uses. Springs flowed in the canyons cutting south across the terrace until wells sunk in Pasadena lowered the water table of the Raymond Basin.

At what is now 1120 Old Mill Road in San Marino, Padre Jose Maria de Zalvidea built the first water-powered gristmill in California in 1816. The Old Mill, *El Molino Viejo*, harnessed the flows from Mill and El Molino cañons to grind grain for the San Gabriel Mission. The Mill's output helped establish San Gabriel's reputation as the richest of the Missions. During Zalvidea's administration, nearby Mission Lake (later Wilson Lake) was dammed and used for irrigation of orchards, vineyards and other crops.

In 1819 Joseph Chapman, the first Anglo settler in southern California, found lumber to build the old Plaza church and much of the early pueblo Los Angeles in what he called "Church Canyon," later known as Millard Canyon, a tributary of the Arroyo Seco. Chapman established the first sawmill on the west coast there, indicating the forested nature of the mountains at that time.

The region's earlier settlers referred to Pasadena as a mesa, as it sits atop the Raymond Basin higher then the rest of the San Gabriel Valley. The name they chose for their community, Pasadena, is a Chippewa word for "crown of the valley".

Settlers entering the region followed the Tongva practice of locating near the Arroyo or near the flowing springs. Don Manuel Garfias, the last Mexican landholder of the Rancho San Pasqual, placed his hacienda at Garfias Springs on the edge of the Arroyo at 433 Arroyo Boulevard near the historic Cathedral Oak in what is now South Pasadena.

Because the natural rainfall was insufficient to maintain agricultural crops on a year-round basis, settlers soon discovered how to tap the springs along the Arroyo that flowed perennially. The first orchards, subdivisions, and settlements were made possible by piping water from the numerous springs along this water table or by pushing horizontal tunnels back into the hills to tap the waters held in the immense bed of gravels that fed the aquifer beneath.

The Indiana Colony

In the 1860s, Benjamin Eaton, who moved to the Rancho San Pasqual a few years before, experimented by growing grapes without irrigation, something that had never been done before in Southern California. Eaton's grapes flourished, and their wine was so delicious that residents from throughout the region clamored for it. Realizing the limitations of dry farming, though, Eaton in 1867 helped Benjamin Wilson and William Griffin, the owners of the ranch, to build "Wilson's Ditch," the first attempt to export water from Devil's Gate in the Arroyo Seco to the mesa lands of their rancho.

In 1873 Eaton gave Daniel Berry, representative of the California Colony of Indiana in Indianapolis, the grand tour of Rancho San Pasqual. Berry wrote back enthusiastically to his backers: "Found tract of 2,800 acres at $10 an acre about four miles from town, about 500 acres, a wooded and watered canyon, suitable for wood and cattle grazing. The wood is plenty, the water delicious and cool, leaping out of the rocks on the side in little cascades." (note source)

When the pioneers of the Indiana Colony arrived at Rancho San Pasqual the next year, Eaton laid out their water system. He brought water all the way from Devil's Gate in the Arroyo Seco through three miles of pipe to a 3,000,000-gallon reservoir located a few hundred feet north of the present intersection of Colorado Street and Orange Grove Avenue on the hill that is now home to the Pasadena Historical Museum. From there the pipeline ran south on Orange Grove Avenue to the lower Indiana Colony lands extending into what is now South Pasadena.

Eaton's pipeline was a bold departure from the primitive water distribution systems in place in southern California at that time. Open ditches, known by their Spanish name of zanjas, were the standard. William Mulholland, the Irish immigrant who would build Los Angeles' water system, began his service to that city as a lowly zanjero or ditch-tender at about this time.

The Indiana Colony incorporated the San Gabriel Valley Orange Grove Association, whose main task came to be the development of an adequate water system. When the association sunseted after ten years, three land and water companies assumed responsibilities for developing Pasadena and its water system: 1) the Pasadena Land & Water Company (west of Fair Oaks), the Lake Vineyard Land & Water Company (east of Fair Oaks), and the North Pasadena Land & Water Company (2000 acres of north Pasadena between Lake and the Arroyo).

In 1881 the first wells were drilled in the Raymond Basin just north of the Raymond Dyke.

In 1883 John D. Yocum built a water wheel that he used to bring water to the Linda Vista area west of the Arroyo. Despite the streets and water system Yocum built, the area remained primarily a ranch with sheep and vineyards until the 1920s.

In 1887 C. W. Scoville built the first major dam for irrigation in the Arroyo Seco, a six foot rock wall dam and bridge where the Colorado Street Bridge is now located. Water from the pond behind the dam was pumped to the land above, where groves of oranges and avocados flourished. Portions of the dam still can be seen today by the diversion structure under the bridge.

Less than a mile south, at the base of the La Loma Bridge, another windmill pumped water up to irrigate the Campbell-Johnstone lands in the San Rafael section of southwest Pasadena.

In 1891 the Pasadena Land and Water Company began a series of tunnels in the Devil's Gate area. A major tunnel, 4730 feel long, and several smaller spurs were cut through alluvium and provided a major supply to the growing community. Between 1897 and 1904 a subsurface dam was built at the Devil's Gate to increase percolation of mountain runoff and the flow in these tunnels. Between 1913 and 1919 the tunnels yielded an average of 3400 acre-feet of water per year, an amount which declined in later years due to the construction of Devil's Gate Dam and the sedimentation of the flood basin.

Pioneers of Watershed Management

It is noteworthy that two of the most vigorous early apostles of watershed management, forest protection and the development of a national forest system hailed from the Arroyo Seco Watershed – Abbot Kinney, noted architect, and Theodore Lukens. Kinney, who established his home at Kinneloa in the Altadena foothills, was president of the Southern California Forests and Water Association and vice-president of the American Forestry Association in the 1880s. Later Kinney went on to develop the canals of Venice.

Theodore Lukens, who was mayor of Pasadena in 1894, saw a direct link between the mountain watershed and water resources. "During the summer of 1896," he wrote, "the Watershed from which Pasadena drew its water supply was burned. The next year our supply had so shrunken as to nearly cause a famine. We were compelled to sink wells and pump in order to live." Lukens, motivated by his view that local watersheds needed healing, made a personal crusade of reforesting the San Gabriel Mountains. "It is a fact not conceded by many," he said, "that our Southern California mountains were in a great measure well-clothed with trees, only a small portion of which were utilized, but were recklessly burned; leaving only a few remnants of the once useful tree covering on steep, rocky places."

Lukens watched the mountain watershed above his city and knew that protecting it was key to the health and growth of his city. In 1911 he stated "Pasadena does not need to look elsewhere for water now or in the future, if she will take care of the watershed from which her supply of water now comes."

The Strain on Local Supplies

Renowned engineer J. B. Lippincott had a very different view. Lippincott, who along with Mulholland played a key role in developing Los Angeles' Owens Valley supply, was hired in 1898 by Pasadena to assess local water resources. He warned city officials that local sources were being rapidly depleted and stressed the need to develop outside sources promptly.

As pumping increased to meet the needs of a growing population, groundwater levels continued to fall By 1908 there were 141 wells in operation in the Pasadena area. In 1914, after consolidating the three land and water companies that had developed Pasadena's early water system into the municipal water department, Pasadena began a spreading program in the Arroyo Seco and along the foothills to replenish the Raymond Basin by percolating storm runoff through the gravel beds. The spreading continued until 1924 when the program was discontinued in the midst of a drought, replenishing the basin with more than 20,000 acre-feet.

During this period Pasadena also began buying up Arroyo Seco land to protect its water rights and quality. Eventually Pasadena bought the entire stretch from the South Pasadena boundary up into the Angeles National Forest. Pasadena bought several thousand acres extending up into the mountain watershed and by the 1940s evicted the settlers there to ensure water quality.

Following torrential floods in 1914 and again in 1916, the Los Angeles County Flood Control District built Devil's Gate Dam in 1920 at the southern end of the flood basin at the mouth of the Arroyo Seco. The 100-foot-tall concrete arch dam had a dual purpose of flood protection and water conservation.

By the early 1920s water had become a critical problem for most southern California cities. Pasadena was particularly hard-hit and aggressive in its pursuit of new supplies. The water level in the Raymond Basin was falling 10 feet per year. When the Copelin well was drilled during the drought of 1899, the drillers found water at 154 feet. By 1924 the level had fallen to 190 feet; by 1929 it was at 240 feet. Local pumping was draining the Raymond Basin by 10,000 acre feet each year.

While pumpers in the Raymond Basin observed the water table receding, they did not fully understand the effects of their actions on each other and on the basin. There was no complete description of the basin's geology and underground storage characteristics until the California Division of Water Resources (DWR) published Bulletin No. 45 in 1934.

The Raymond Basin Adjudication

In 1935 Pasadena officials called together all the pumpers in the Raymond Basin in an effort to reduce pumping to a sustainable level, but this effort was not successful. In 1937 Pasadena initiated legal proceedings against Alhambra and other major Raymond Basin water users. The action sought to end the annual overdraft by legally dividing or adjudicating water rights in the basin. *City of Pasadena v. City of Alhambra et al.,* was the first basin wide adjudication of groundwater rights in California and the first to use the California DWR to determine of water rights.

After an extensive investigation of the "safe yield" of the Raymond Basin, in 1943 most of the 20 parties involved in the action agreed to a stipulation which provided: 1) an admission that taking water was adverse to the claims of other parties; 2) allocation of the basin's safe yield; 3) declaration and protection of each party's rights; and 4) arrangement for the exchange of pumping rights among parties. The agreement was based on a process called mutual prescription. Instead of honoring only senior water rights and cutting off pumpers with more recent claims, each party agreed to reduce its annual pumping and take a percentage of the Basin's safe yield. Judge Frank Collier accepted the determination of the parties of a "present unadjusted right," defined as the highest amount of water continuously produced during a five-year period prior to the filing of the lawsuit. Each party owned this right by prescription, and the rights were of equal priority. Judge Collier then defined a "decreed right" for each party, which was that party's present unadjusted right adjusted downward about one-third so that the sum of all parties' decreed rights matched the estimated safe yield of the basin.

On December 23, 1944 Judge Frank Collier signed the judgment adopting the stipulated agreement worked out by the parties. California DWR became the watermaster for the basin, charged with policing the adjudication. In 1949 the California Supreme Court affirmed *Pasadena v. Alhambra.* The decision validated mutual prescription as a basis for resolving groundwater overdraft problems and establishing water rights.

In 1955 the estimated safe yield was adjusted to 30,622 acre-feet. In 1984 the Raymond Basin Management Board, made up of representatives of the local parties, assumed watermaster responsibilities for managing the basin. The Raymond Basin Management Board (RBMB) has been a cooperative mechanism for local management of groundwater resources, while retaining the safe yield concept of the original adjudication.

In 1974 a second modification to the judgment allowed parties credit for spreading canyon diversions in the vicinity of the Arroyo Seco, Eaton Was and Santa Anita Creek Canyon. This modification allows member agencies the right to divert and spread surface water and protects their right to recapture a percentage of that water.

In the early 1990s, the RBMB established long term storage policies and allocated storage capacity to the basin parties, an important step in allowing all parties to benefit from the storage potential of the basin.

In the early 1980s contamination of the wells in the Devil's Gate area was detected. Industrial solvents such as Trichloroethylene (TCE) and Perchloroethylene (PCE) had seeped into the groundwater. Four wells had to be closed because the water did not meet health standards. In 1990 a closed aeration system treatment plant was installed on the east side of the Hahamongna basin across from Jet Propulsion Laboratory(JPL). JPL is now finalizing long term cleanup plans.

Below the Raymond Dyke

Below the Raymond Dyke, the Arroyo Seco enters a canyon bounded by the Monterey and Montecito Hills on the east and Mount Washington on the west. While there were numerous historical springs and wetlands in the area, there is no significant groundwater basin. The Arroyo stream and its underground flow proceed directly to the confluence with the Los Angeles River and then flow to its outlet in Long Beach.

The Highland Park area was particularly rich in a hydrologic sense. A major tributary of the Arroyo Seco, called the North Branch, flowed for six miles through northeast Los Angeles from the Annandale area of the San Rafael Hills near Poppy Peak. The stream flowed along Figueroa Street to Branch Street and then Aldama Street, flowing into the Arroyo Seco at Sycamore Grove Park. The North Branch was fed by a series of healthy springs including Springvale and Glen Rock Springs. There were also numerous springs in the area about York Boulevard and Figueroa Boulevard and along Sycamore Grove Park.

The Arroyo Seco was instrumental in determining the location of the early pueblo of Los Angeles. In the late 18th century, settlers strategically sited the pueblo to avoid the floods from the San Gabriel Mountains that would pour in through the Arroyo Seco adding substantially to the ferocity of the Los Angeles River in flood periods as it wound around Griffith Park and the Glendale Narrows.

The Arroyo provided a major water supply for the growing city. In 1870 the Buena Vista Reservoir was built in the hills of Elysian Park immediately west of the confluence of the Arroyo Seco and the Los Angeles River. In the 1880s the reservoir was expanded and other facilities were constructed to tap the river for a rapidly growing population. In 1904 William Mulholland and Los Angeles built the southernmost of this series of diversion facilities, the Narrows Gallery, to squeeze every available drop out of the river. A 1,178 foot tunnel was drilled at a depth of 115 feet through the bedrock beneath the Los Angeles River up the Arroyo Seco. Nine wells were drilled to allow water to percolate into the tunnel where it was then collected and conveyed through the Zanja Madre to downtown Los Angeles.

The Narrows Gallery and similar facilities at the Headworks near Burbank and the Crystal Springs in Griffith Park drained the subsurface flow of the Los Angeles River and decisively demonstrated that the river had reached its limits as a water supply for a burgeoning city. It was that same year that Mulholland wrote of the Los Angeles River, “This is certainly a noble stream to be found running in the semi-arid country after a long success of dry years, and speaks volumes for its constancy and reliability as a source of municipal supply. The time has come, however, when we shall have to supplement its flow from some other source. Earnest and immediate steps are necessary to produce additional water.” The Los Angeles Department of Water and Power abandoned the Narrows Gallery more than fifty years ago after developing new sources from the Owens Valley and the Colorado River.

Los Angeles grew to be one of the largest cities in the U.S. in size and population largely due to its tight hold on water supplies. Los Angeles staked out an exclusive “pueblo” water rights claim to the Los Angeles River. In 1899 the Arroyo Seco communities of Highland Park and Garvanza voted to annex to Los Angeles for this reason. Within a few years the community of Arroyo Seco followed. Later, when the river supply proved insufficient, communities such as Eagle

Rock were forced to annex to LA to obtain the imported supplies from the Owens Valley. Mulholland's vision was of one great city in Los Angeles County from the mountains to the sea. Only the formation of the Metropolitan Water District in 1928, a unique partnership led by Pasadena and Los Angeles to bring the Colorado River to Southern California's coastal plain, ended LA's annexation stranglehold on nearby cities.

Imported supplies from the Owens Valley, the Colorado River and later the State Water Project eventually relieved the strain on local water supplies such as the Arroyo Seco but have not diminished their historic and current importance.

Table: Historic Springs in the Arroyo Seco.	
Thibbets Springs	Just to the north and east of Devil's Gate
Ivy Springs	Near Flint Canyon just to the north and west of Devil's Gate
Sheep Corral Springs	At the foot of reservoir hill at the south end of Brookside Park
San Rafael or Johnson Springs	On the west bank of the Arroyo opposite California Street was a bog or cienega with continuous water.
Johnson Lake (also Beaudry Lake)	A natural spring that was dammed to supply irrigation for agriculture. Some water was piped to the Highland Park area through the Beaudry Tunnel. In San Rafael canyon there is a small but pretty waterfall – Puddingston Falls -- with a fine specimen of a pot hole at its foot.
Baker's Springs	On Grand Avenue just above West Columbia on the east side of the Lower Arroyo near the Raymond Fault.
San Rafael Creek	The outlet for Johnson Lake and south San Rafael hills to the Arroyo Seco (just south of the San Rafael bridge and above the South Pasadena city limits.
Garfias Springs	On the edge of the Arroyo in South Pasadena, this site near the Cathedral Oak was the home of Manuel Garfias, the last of the Mexican rancho landholders.
Springvale Springs	Just west of North Figueroa street at Springvale drive, this major spring was the source of the North Branch of the Arroyo Seco.
Glenn Rock (Milwaukee) Springs	This was a large spring that fed the North Branch of the Arroyo Seco in Highland Park at the head of Milwaukee Avenue.
Garvanza Springs	Springs at the site of the present reservoir behind Luther Burbank Middle School and Garvanza Elementary near Avenue 64 and York Blvd. Here there was a deep ravine that drained into the Arroyo Seco. Later it was the site of Los Angeles' oldest reservoir still in use.
Arroyo Verde Springs	On the east side of the Arroyo near York Blvd. and Pasadena Avenue near the equestrian stables was a rich spring at the ford across the Arroyo on the path from Pasadena to Los Angeles.
Yosemite Springs	These springs, right on the edge of the Arroyo bluff at 226 S Avenue 54, are still in production, operated by Yosemite Waters bottling company.
Casa de Adobe Springs	Beginning in 1915 this spring near Casa de Adobe at 4605 Figueroa was used for a bottling operation.
White Rock Spring	At 4835 Figueroa Street across from Sycamore Grove Park, next to the Hiner House and the Alternative School, this spring was home to the White Rock or Rose Spring Water bottling operation. It is now a private home.
Sparkletts (Indian Head) Springs	Just over the ridge into the Verdugo Wash drainage on the former Glassell estate are major springs that have made Sparkletts famous and are still being tapped by the Hinkley-Schmidt bottling operation.

The Water System – How It Works

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Introduction

As described in the project's goals and objectives (Chapter I), Goal 4 is to "Better Manage/Optimize/Conserve Water Resources." To meet this goal, six objectives were proposed:

Objective 2.1:	Review existing storm drain structures
Objective 2.3:	Develop sediment management strategy
Objective 2.5:	Increase ground water percolation
Objective 2.6:	Reduce volume and velocity of storm water runoff
Objective 2.7:	Restore the quality and quantity of water recharge to the Raymond Aquifer
Objective 2.8:	Reduce dependence on imported water

To study ways to meet these objectives, the technical study for water resources examines the Arroyo Seco and its management to determine whether it is possible and productive to augment local water supplies.

The research presented herein focuses on three areas: characteristics and nature of the watershed, history of local water development, and methods that could be used to increase local water supply. The *ASWRFS* is committed to an integrated watershed management program that coordinates the multiple objectives of our study, including water resources and quality, habitat enhancement, stream and flood management, and recreational improvements. Any expansion of water resources will not come at the expense of these other objectives, but shall be coordinated with them for an optimized ecosystematic solution.

Description of the Watershed

The Arroyo Seco stream, a major tributary of the Los Angeles River, drains an area of 47 square miles, beginning at Red Box in the San Gabriel Mountains of the Angeles National Forest and proceeding through Pasadena, South Pasadena and northeast Los Angeles to join the Los Angeles River near Elysian Park. Figure WS1 illustrates the Arroyo Seco's location within the larger Los Angeles River watershed. The upper watershed is contained in the transverse front range of the San Gabriel Mountains, historically referred to as the Sierra Madre Mountains, immediately north of Pasadena, northwest of Altadena and northeast of La Cañada-Flintridge, approximately 15 miles north of downtown Los Angeles. This mountain watershed contains 32 square miles of steep, erosion-prone terrain that drain into Hahamongna Watershed Park and the Devil's Gate Dam basin at the mouth of the Arroyo Seco near JPL. Here the County of Los Angeles built its first flood control and water conservation dam in 1920. The upper watershed extends north into the San Gabriel Mountains for five miles and then cuts across the front range for another six miles towards Mount Wilson. Millard Canyon, the major easterly tributary, extends for about four miles into the mountains before cutting to the east behind Las Flores and Rubio Canyons.

Most of the mountain watershed lies within the Angeles National Forest and is owned and managed by the U. S. Forest service. A small portion (less than five percent) is located within the City of Pasadena. Private land owners control less than one percent of the upper watershed. This mountain watershed is primarily managed for recreation, watershed protection and wildlife conservation. It is largely undeveloped and contains few potentially significant sources of contamination. An extensive network of hiking trails provides access to the upper watershed for various recreational uses such as hiking, mountain bicycling and horseback riding. The Gabrielino National Recreation Trail follows the Arroyo Seco and is heavily used.

The upper watershed contains roadless area of 5,000 acres with great scenic, recreational and wildlife habitat value. Approximately fourteen miles of the Angeles Crest Highway, (CA Highway 2) – a major scenic route that crosses the San Gabriels – are located within the watershed.

Topography

The upper watershed is rugged and erosion-prone with a network of more than 20 deeply incised V-shaped canyons. The slopes within the Angeles National Ford are shown in Table ???. Elevations in the upper watershed range from 990 above sea level at the base of Devil's Gate Dam to 1160 feet immediately north of NASA's Jet Propulsion Laboratory to 6164 feet at Strawberry Peak, the watershed's highest point.

Table: Canyon Tributaries of the Arroyo Seco			
Bear	Little Bear	Brown Mountain	Cloudburst

Mt. Lawlor	Ladybur	Daisy	Colby
Long	Dark	Twin	Brown
Pine	Falls	Niño	Agua
Fern	Raccoon	El Prieto	Millard

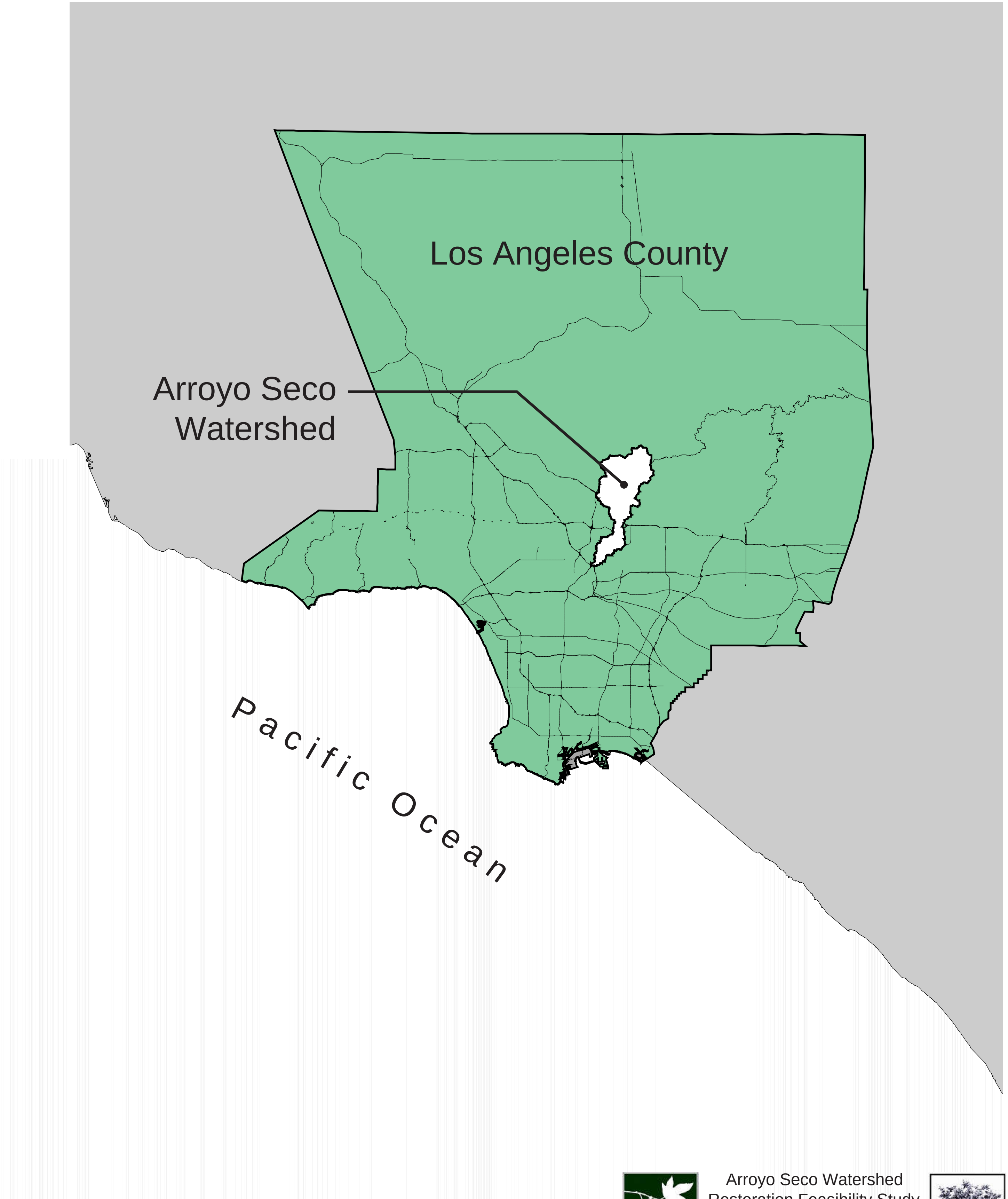
Table: Slope Distribution in the Arroyo Seco	
Slope	**Percent**
0-20%	4.0
21-40%	4.0
41-60%	25.0
Over 60%	67.0

The lower half of the watershed is distinctly different from the upper watershed. Near Jet Propulsion Laboratory, the Arroyo Seco emerges into the alluvial plain of the San Gabriel Valley. Most of the Pasadena mesa flows easterly to the Rio Hondo and the San Gabriel River, but the Arroyo Seco cuts a deep gorge through the western edge of Pasadena and through the Raymond Fault as it enters South Pasadena and Northeast Los Angeles. Thus the Arroyo Seco is a major tributary of the Los Angeles River.

In La Cañada-Flintridge, the northwest corner of the watershed, several canyons including Hay Canyon, Gould Canyon and Winery Canyon flow into the Arroyo Seco by way of Flint Wash. The canyons further west including Hall Beckley Canyon, Webber Canyon, Snover Canyon and Pickens Canyon all flow to Verdugo Wash, although water from these canyons percolates into the Monk Hill subarea of the Raymond Basin. There is also a tunnel system in these canyons that extends far into the mountains to collect water. Before settlement, streams would flow in these canyons and across La Cañada virtually all year long. After the devastating New Year's Flood of 1934, debris basins were built at 1700-1900 feet elevation in each of these canyons at the residential edge, and the streams were channelized and buried. Flint Wash begins near Descanso Gardens area and runs along the toe of the San Rafael Hills in the Flintridge area, carrying all the flow from these canyons as well as street runoff into Hahamonga where it enters just west and north of Devil's Gate Dam.

Table: La Cañada Canyons		
Canyon	**Surface Flow**	**Groundwater**
Hay	Arroyo Seco (Pasadena)	Raymond Basin
Gould	Arroyo Seco	Raymond Basin
Winery	Arroyo Seco	Raymond Basin
Hall Beckley	Verdugo Wash (Glendale)	Raymond Basin
Webber	Verdugo Wash	Raymond Basin
Snover	Verdugo Wash	Raymond Basin
Pickens	Verdugo Wash	Raymond Basin

As we move easterly across the foothills, Millard Canyon is tributary to the Arroyo Seco, but Las Flores, Rubio and Eaton Canyons and most of Pasadena and Altadena are tributary to the Rio Hondo.



Arroyo Seco Watershed
Restoration Feasibility Study

Location Map
1:1,000,000

Figure 1

Table: Pasadena/Altadena Canyons		
Canyon	**Surface Flow**	**Groundwater**
Arroyo Seco	Arroyo Seco	Raymond Basin
Millard Canyon	Arroyo Seco	Raymond Basin
Las Flores	Rio Hondo	Raymond Basin
Rubio Canyon	Rio Hondo	Raymond Basin
Eaton Canyon	Rio Hondo	Raymond Basin

Below JPL, the Arroyo Seco is highly urbanized. This stretch of the Arroyo is also eleven miles long extending from the San Gabriel Mountains to the Los Angeles River. In the Pasadena region, the Arroyo has cut three major basins: the Hahamongna/Devil's Gate basin (1.5 miles) at the foot of the mountains, the Central Arroyo (2.5 miles), which includes Brookside Park and the Rose Bowl, and Pasadena's Lower Arroyo (1.5 miles), which extends from the Colorado Street Bridge to the South Pasadena boundary just south of the Raymond Fault.

Historically natural springs and surface flows dotted the Arroyo Seco. Just north of Devil's Gate gorge, Ivey Springs on the west and Thibbet Springs on the east bubbled to the surface. At the end of that gorge on the east side of the Arroyo, fifteen to twenty feet above the stream bed, were Flutter Wheel Springs, a series of springs that extended for several hundred feet. Two and a half miles south, at the entrance of another gorge that begins just south of Brookside Park and proceeds to the Colorado Street Bridge, Sheep Corral Springs gushed out of the gravels of the Arroyo bed.

San Rafael Springs or Johnson's Spring was located on the west bank of the Arroyo, nearly opposite the foot of California street. Here there was a bog or cienega which yielded a continuous supply of water which was pumped by a waterwheel up into cisterns on top of the arroyo hill.

Just opposite the foot of West Columbia Street, San Rafael creek enters the Arroyo. This creek is the outlet of Johnson's Lake and forms the principle drainage of the lower San Rafael area. In San Rafael canyon there used to be a small but pretty waterfall -- Puddingston Falls -- with a fine specimen of a pothole at its foot.

The Raymond Dyke created a tremendously rich area hydologically. Springs and streams flowed all along the base of the fault from Highland Park through Pasadena, South Pasadena and San Marino. On the west side of Raymond Hill on the rim of the Arroyo in South Pasadena were Garfias Springs. Other springs flowed on the east side of the hill and along its base. Further south were springs at Casa de Adobe near Avenue 54 and extensive wetlands near the confluence with the Los Angeles River.

At the Raymond Fault, the Arroyo Seco stream enters a hill-lined canyon with a wide alluvial wash that travels through South Pasadena and Los Angeles to meet the Los Angeles River across from Elysian Park. In Highland Park the North Branch of the Arroyo Seco flowed from the west side of the San Rafael Hills southwest for six miles to join the Arroyo at Sycamore Grove Park. Streams from canyons in Mountain Washington and from the Monterey Hills and Montecito also joined the Arroyo. The Arroyo Seco Parkway, the flood channel, and residential and commercial developments now have massively altered this 5.5-mile stretch of the lower Arroyo Seco.

Geology

Geologic processes have been forming the rugged San Gabriel Mountains for more than one hundred million years. The San Gabriels stand on a massive block of the earth's crust, in which the Arroyo Seco is found, separated from the surrounding landscape by a network of major faults—the San Andreas Fault on the north, the San Gabriel and Sierra Madre Faults on the south, and the Soledad Fault on the west. The great block itself is also fractured by numerous subsidiary faults.

The San Gabriel Mountains, the northern portion of the Arroyo Seco, and the San Rafael Hills on the west consist of crystalline bedrock assigned to the Wilson diorite, Rubio diorite and unnamed units of quartz monzonite and gneiss. The bedrock is Cretaceous and Pre-Cretaceous (more than 98 million years) in age. Most of the parent bedrock is igneous, but the rocks are highly fractured and weathered – decomposing rapidly when exposed to the elements. At Devil's Gate Dam, the bedrock material is highly weathered, fractured diorite gneiss. In general, surface weathering rates are large and these surfaces are the primary source of the sand and silt being washed out of the canyon during rainfall events.

The Arroyo is underlain by younger and older alluvium and stream channel deposits. The Arroyo lies between the La Cañada Alluvial Fan on the west and the Altadena Alluvial Fan on the east. The fans are underlain by older alluvium. The alluvium is Pleistocene (1.6 million years) to Holocene (10,000 years) in age.

As it leaves the mountains, the Arroyo Seco is a deep gorge cut through an alluvial plain creating three basins or canyons as it passes through Pasadena. When it cuts through the Raymond Fault, it reaches a broad alluvial wash lined by the Monterey Hills, Montecito Heights, Mount Washington and the Verdugo Hills.

Soil

Shallow, coarse textured soils occur extensively throughout the upper watershed. These are recently formed soils that exhibit little profile development. The substratum typically occurs within 20 inches of the surface and may range from very soft, weathered material to hard, but highly fractured rock. In the Raymond Basin area this material often consists of alluvium that transmits water readily and allows it to percolate into the groundwater basin. Figure WS2 shows the distribution of permeable soils within the watershed.

Vegetation

The vegetative cover of the upper mountain watershed is mainly chaparral with islands of oak woodland and conifer occurring in canyons and north-facing slopes. Riparian species commonly found along the Arroyo Seco and its tributaries include willows, white alders, cottonwoods, box elders, big leaf maples and sycamores. Conifer stands generally occur at elevations above 5,000 feet. Seven miles of the Arroyo Seco from Hahamongna to Long Canyon in the upper watershed have been designated critical habitat for the endangered Arroyo toad by the US Fish and Wildlife Service.

Table – Vegetation Communities of the Arroyo Seco
Coastal Sage Scrub and Chamise Chapparal
Mixed and Semi-Desert Chaparral
Conifer Woodland Forest
Pynion-Juniper Forest
Riparian
Forestwide Vegetative Cover

Hydrology

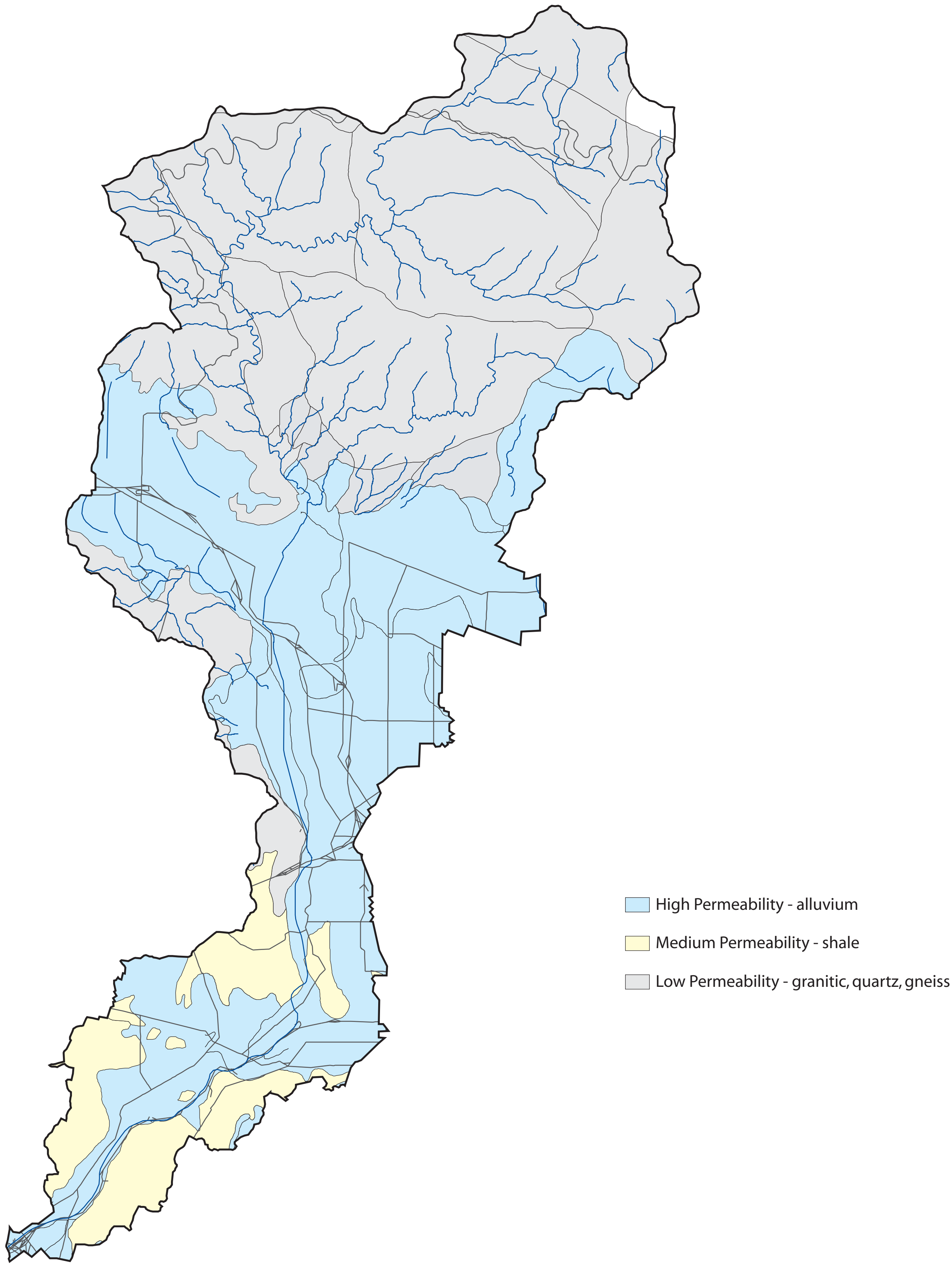
The Arroyo Seco has twenty main tributaries. The presence of a continual streamflow in the upper watershed even during the driest years reveals a significant contribution of groundwater (spring) supplies to the Arroyo Seco stream where these subsurface flows intersect with the surface. Just below the San Gabriel Mountains is the Raymond Basin, a forty-square-mile aquifer. Below the Raymond Fault in South Pasadena and northeast Los Angeles, the Arroyo Seco and a limited underground flow move toward the Los Angeles River.

Precipitation

The lower elevations of the Arroyo Seco watershed have a Mediterranean climate with hot, dry summers and cool, wet winters. Precipitation increases with altitude. Ninety-five percent of the precipitation occurs from November to April with seventy-five percent occurring from December to March. The average annual precipitation is twenty inches (20") in the lower elevations and up to thirty inches (30") in the higher elevations. Figure WQ2 illustrates the average precipitation in the watershed. In most years, however, rainfall deviates substantially from these averages as many seasons of drought and flood occur. Climatic records demonstrate dramatic cyclic variations with little predictability.

Table: Precipitation in the Arroyo Seco

Station	Type		Period of Record in Years	Precipitation in Inches		
	Valley	Mountain		Year 1999	Year 2000	50 Year Mean
Altadena-Rubio Canyon	X		102	10.1	9.04	23.09
Highland Park	X		104	8.66	14.29	18.56
Descanso Gardens	X		87	14.02	18.12	23.18
Chilao Flats		X	64	9.28	8.59	36.40
Oakwilde		X	56	---	---	28.19
Big Tujunga Dam		X	82	11.76	11.07	41.19



Soils

coded by probable permeability

WS2

Pasadena City Hall	X			10.96	17.18	n/a
Sierra Madre Dam	X	X	104	12.96	17.62	25.01
Upper Haines Canyon		X	65	---	---	30.06
Clear Creek City School		X	72	15.80	17.89	27.72
Pasadena Chlorine Station		X	72	---	---	23.40
Valley Stations (Mean)				11.34	15.32	22.46
Mountain Streams				12.45	27.66	30.28

Snowmelt contributes approximately 20 percent of the watershed's total annual flow. The average stream temperature is 55° F (13° C) in the winter and 65° F (20°) C in the summer. Water temperatures in the lower urbanized watershed are significantly higher.

Streamflow

The historic streamflow record contained in the following graphs and tables is taken from the US Geologic Survey gauging station in the Arroyo Seco above Pasadena's diversion facilities.

Table: Historic Streamflow in the Arroyo Seco

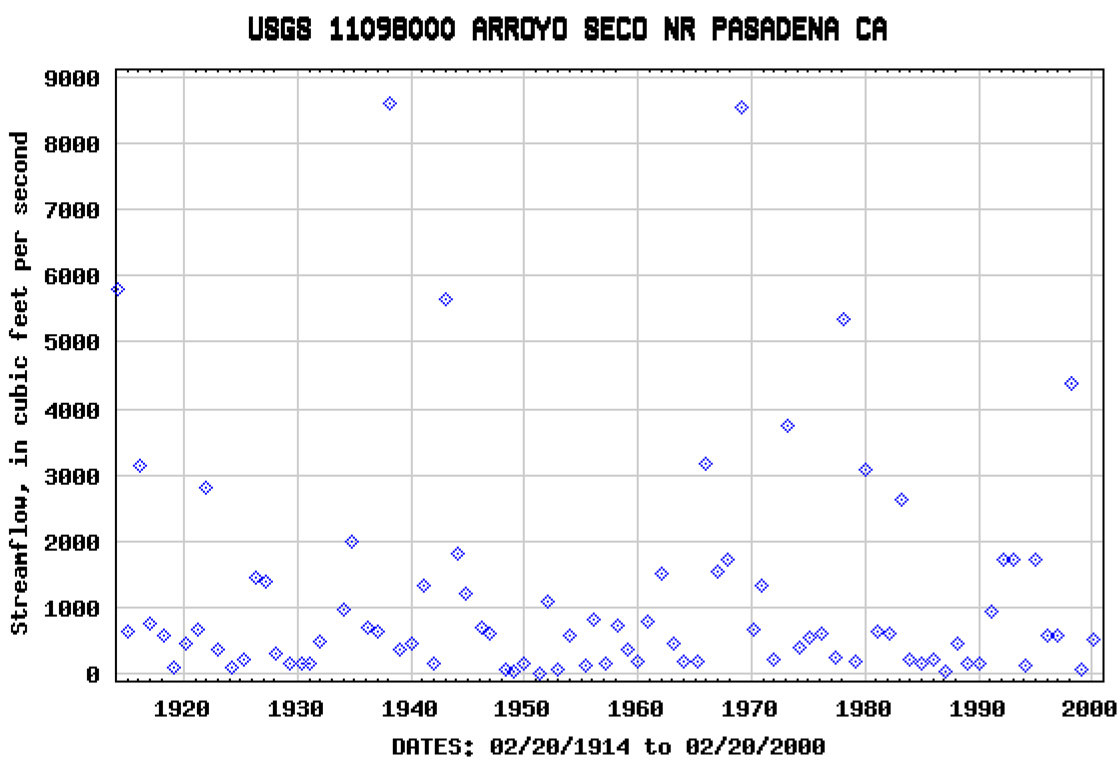


Table: Historic Daily Streamflow Peaks in the Arroyo Seco

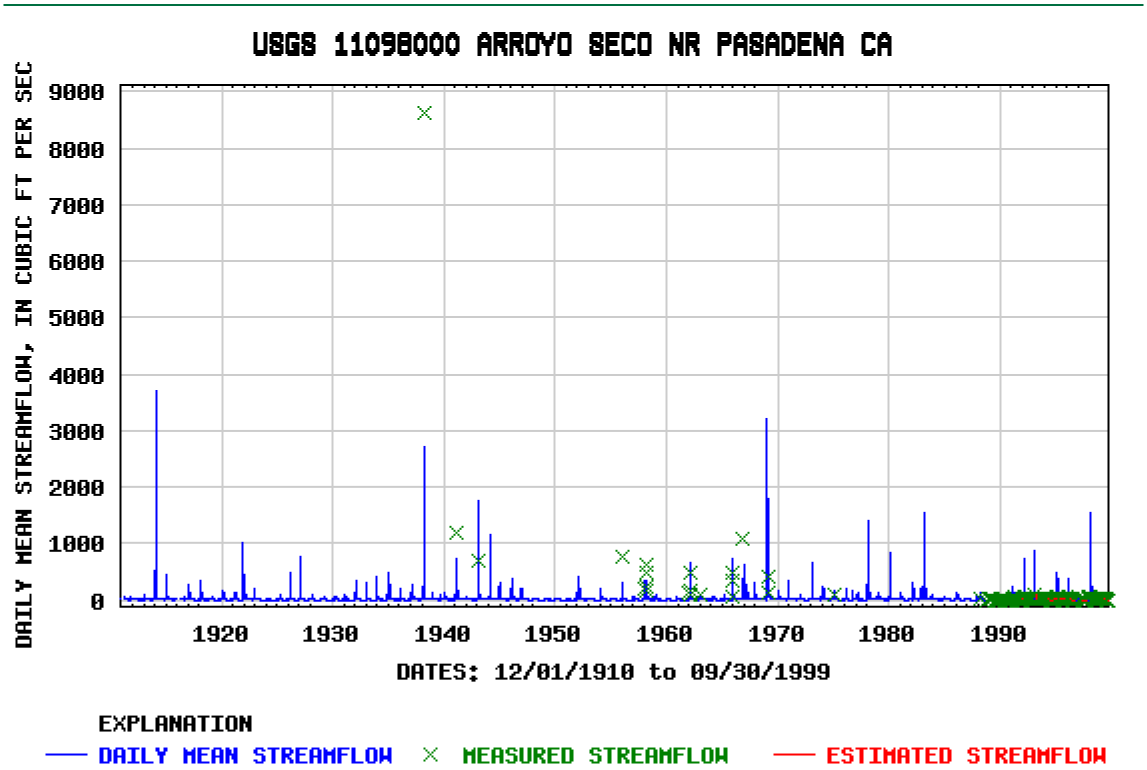


Table: Daily Discharge July 2000 – July 2001

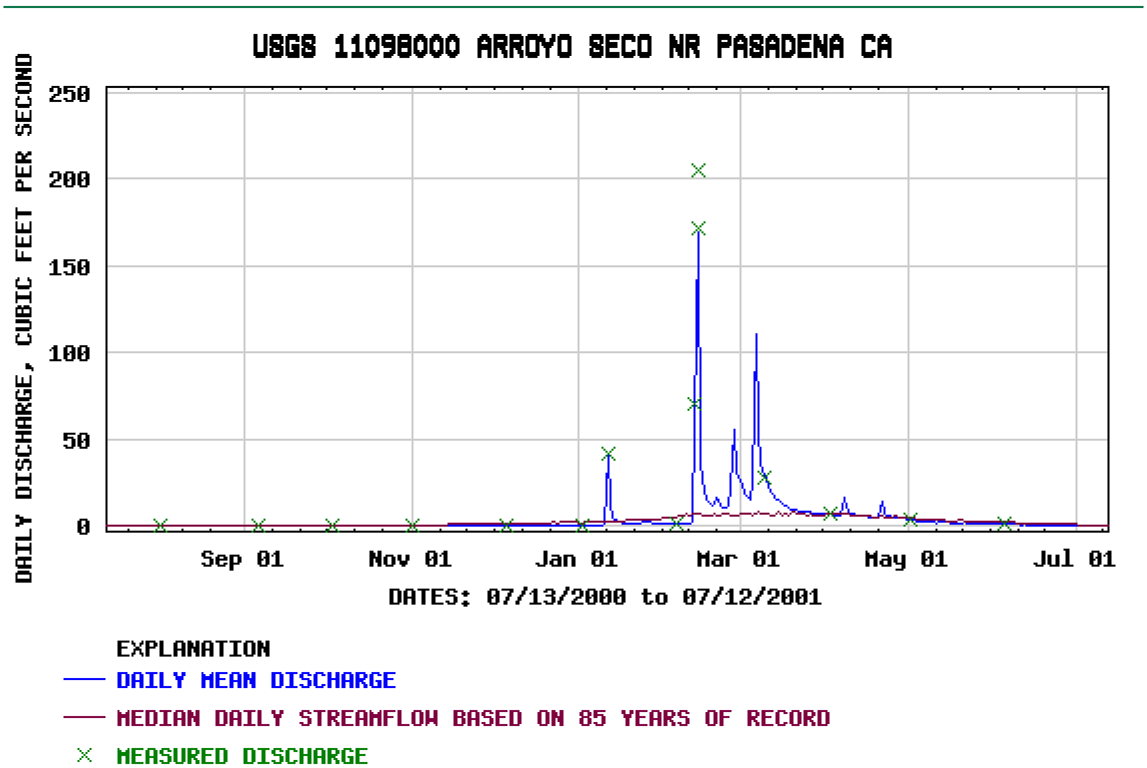


Table: Annual Mean Streamflow in the Arroyo Seco							
Year	**Annual mean streamflow, in ft^3/s**	**Year**	**Annual mean streamflow, in ft^3/s**	**Year**	**Annual mean streamflow, in ft^3/s**	**Year**	**Annual mean streamflow, in ft^3/s**
1914	45.9	**1937**	15.5	**1958**	15.1	**1979**	8.19
1917	5.83	**1938**	32.6	**1959**	2.07	**1980**	30.1
1918	8.19	**1939**	4.10	**1960**	1.51	**1981**	3.26
1919	2.07	**1940**	5.84	**1961**	.90	**1982**	10.7
1920	4.68	**1941**	35.2	**1962**	9.00	**1983**	40.3
1921	15.5	**1942**	2.42	**1963**	2.60	**1984**	3.92
1922	25.5	**1943**	30.6	**1964**	1.89	**1985**	2.43
1923	2.86	**1944**	19.8	**1965**	15.6	**1986**	6.48
1924	1.16	**1945**	7.65	**1966**	13.2	**1987**	2.30
1925	1.47	**1946**	9.67	**1967**	20.8	**1988**	4.61
1926	8.77	**1947**	3.66	**1968**	4.48	**1989**	1.80
1927	9.44	**1948**	1.51	**1969**	58.6	**1990**	.98
1928	1.48	**1949**	2.04	**1970**	7.28	**1991**	5.11
1929	1.75	**1950**	1.76	**1971**	4.41	**1992**	20.5
1930	2.29	**1951**	1.61	**1972**	1.51	**1993**	42.2
1931	2.75	**1952**	15.7	**1973**	11.4	**1994**	2.77
1932	6.48	**1953**	1.39	**1974**	7.12	**1995**	25.0
1933	4.40	**1954**	4.19	**1975**	3.50	**1996**	7.94
1934	7.74	**1955**	1.77	**1976**	3.42	**1997**	4.40
1935	8.39	**1956**	2.93	**1977**	3.29	**1998**	28.4
1936	6.26	**1957**	2.36	**1978**	36.7		

Water Rights

The California DWR defines the Arroyo Seco as a Fully Allocated Stream. Water rights in the Arroyo Seco watershed are clearly defined and carefully regulated. After many years of dispute, water rights in the Raymond Basin were divided by a judicial decree in 1944 that established a safe yield for the basin that would eliminate overdraft and match pumping with replenishment. The decision in the case known as "Pasadena v. Alhambra" is based on "mutual prescription."

The following table lists the adjudications of the Raymond Basin parties:

Table: Raymond Basin Water Rights			
Party	**Decreed Right** Acre feet		**Maximum Storage Allocation**
Alhambra, City of	1031.0	3.37%	3,600
Arcadia, City of			17,000
Pasadena subarea	2118.0	6.92%	

Santa Anita subarea	3526.0	11.51%	
California-American Water Company	2299.0	7.51%	6,900
East Pasadena Water Company	515.0	1.68%	1,600
H.E. Huntington Library & Art Gallery	372.0	1.21%	1,200
Kinneloa Irrigation Water District	516.0	1.69%	1,600
La Cañada Irrigation District	100.0	0.33%	2,300
Las Flores Water Company	249.0	0.81%	900
Lincoln Avenue Water Company	567.0	1.85%	2,200
Pasadena Cemetery Association	91.0	0.30%	300
Pasadena, City of			
Monk Hill Subarea	4464.0	14.58%	13,400
Pasadena subarea	8343.0	27.25%	25,100
Rubio Cañon Land & Water Association	1221.0	3.99%	3,700
San Gabriel County Water District	1091.0	3.56%	3,300
Sierra Madre, City of	1764.0	5.76%	5,300
Sunny Slope Water Company	1558.0	5.09%	4,700
Valley Water Company	797.0	2.60%	34,00
TOTAL	30622.0		96,500

Pasadena, the largest water rights holder, has an adjudicated right to pump 12,807 acre-feet per year from the Raymond Basin. Surface water rights established prior to 1914 decree to Pasadena the right to divert up to 25 cubic feet per second (cfs) or 16.1 million gallons per day (mgd) from the Arroyo Seco streamflow including diversions from Millard Creek.

Because Pasadena is only credited with eighty percent recovery of the water it spreads versus one hundred percent of surface diversions, it loses twenty percent of the water spread.

Local groundwater use makes up forty-nine percent of Pasadena's water supply. Pasadena purchases approximately half of its water from the Metropolitan Water District of Southern California (MWD). La Cañada receives eighty percent of its water supply from the MWD. MWD water is imported from the Colorado River and from northern California through the State Water Project.

Groundwater is currently pumped from 12 active wells located throughout Pasadena. Water from Well 52, Arroyo, Ventura and Windsor wells is pumped through the VOC plant, treated by air stripping and a granular activated carbon (GAC) trap and conveyed to Windsor Reservoir where it is distributed to Pasadena consumers.

Pasadena's Water Diversion System

Local water users have been diverting surface waters from the Arroyo Seco since 1867. In 1914 Pasadena began a spreading program near the mouth of the Arroyo. Water diversion facilities in the Arroyo Seco canyon have developed over the last century. From north to south, the major diversion facilities include the Arroyo Seco Headworks, a submerged dam, the Arroyo Seco Intake, and Millard Stream Intake. Related facilities include a traveling screen, a concrete weir and two settling ponds, and the Behner Water Treatment Plant.

The reinforced concrete weir, completed in November 1995 to replace a breakaway earthen diversion berm, is located approximately ¾ mile north of the mouth of the canyon near JPL. The water is diverted into a series of fourteen percolation ponds that line the eastern edge of the Devil's Gate/Hahamongna basin.

The surface intake structure is located approximately 2200 feet south of the Headworks. The intake structure consists of a submerged dam with adjustable gate boards and a side inlet concrete box. The submerged dam, which is about 14-feet-wide and two-feet-high, was constructed prior to 1897. The intake is located five feet upstream from the dam and consists of a six-foot-wide by ten-foot-high concrete box and a sluice gate. A seven-foot-high chain-link fence completely surrounds the intake and follows the stream course ending approximately 600 feet north of the Headworks.

In January 2001 Pasadena Water and Power completed the construction of the Millard Stream Intake, a concrete structure that diverts Millard Canyon streamflow and complements the Arroyo Seco spreading operations. The Millard steam is located south of the main Pasadena diversion just north of the JPL Bridge and the Behmer Treatment Plan.

From the main Arroyo Seco intake and the Millard Stream Intake, water flows through a series of tunnels, drop structures and old pipe (1929) by gravity directly to a series of spreading basins on the east side of the Arroyo Seco. Currently the water bypasses the Behmer Treatment Plant nestled on a mesa on the east side of the Arroyo directly east of JPL. Until 1993 all diverted water went through a traveling screen, originally designed to remove leaves, twigs, branches and other debris. The traveling screen is located near a liquid chlorination sterilization plant, which was built pre-1939 but became redundant in 1970 when the Behmer Plant was constructed. Water would then flow through a 30" pipe to the Behner Water Treatment Plant, a five million gallon per day (mgd) conventional water treatment plant. Conventional treatment of the surface water includes chemical coagulation, rapid mixing, flocculation and sedimentation followed by filtration. As the result of new water quality standards contained in the Surface Water Treatment Rule of the Safe Drinking Water Act, the Behmer Plant was shut down in June 1993. Diverted streamflow now is routed directly to the spreading basins where it percolates into the Raymond Basin aquifer.

The fourteen nearby settling ponds have a functional capacity of approximately 18 cubic feet per second or 11.6 million gallons per day. They were first developed around 1949 and were improved in 1976. The ponds are scraped out to remove sediment on an as needed basis.

South of the Headworks the Devil's Gate Tunnels begin. A large horizontal tunnel, 4,370 feet long, and two short spur tunnels were originally constructed to collect water percolation from the water-bearing layers of soil just above the bedrock. The tunnel system extends under Devil's Gate Dam. Before the construction of Devil's Gate Dam in 1920, these tunnels captured a major source of supply for Pasadena, providing an average of 3,400 acre-feet per year. After the construction of Devil's Gate Dam in 1920, production in the tunnels declined to 2,300 acre-feet per year. The flood of 1938 filled the basin with sediment and rendered the tunnel water non-potable. Today the relatively small amount of water being produced by the tunnels is used for irrigation at Brookside Golf Course downstream of the dam.

About 150 yards south of Devil's Gate Dam, the Arroyo Seco flood control channel begins. Streamflow from this point all the way to Long Beach travels in a concrete lined channel, with the single exception of the unlined stretch that extends from just south of the Holly Street

Bridge to the Colorado Street Bridge. At that point, much of the Arroyo flow is transported through low-flow streams that travel for half a mile on both sides of the flood control channel. On the west side, the low-flow stream enters the flood channel near the bridge at the archer's shack. On the east side, a pipe conveys water to a weir where the stream zone begins. That water enters a pipe that takes it along the toe of the knoll where La Casita del Arroyo is located. The water is released at another weir just south of this knoll and branches into two streams that travel through the area that contains the parking lot and the casting pond in Lower Arroyo Nature Park. South of the casting pong the two streams merge and are reintroduced to the flood channel just north of the Bird Bath Knoll.

Below the Raymond Fault, a narrow channel lined by steep hills characterizes the Arroyo Seco watershed. In addition to the concrete-lined stream, there is some subsurface flow but no connection to a definable water basin, as the stream flows to the Los Angeles River.

Several water users divert streamflow or springs in South Pasadena and northeast Los Angeles:

- The Arroyo Seco Golf Course in South Pasadena has taken an unmetered diversion from the Arroyo Seco stream since 1955 to irrigate approximately 30 acres.
- The Yosemite Waters Company taps a spring at Avenue 54 for its drinking water supply.
- Near York Boulevard and Eagle Rock Boulevard, just over the ridge that defines the Arroyo Seco, Hinkley Schmidt (formerly McKesson/Sparkletts) uses water from the small Eagle Rock basin for its bottled water business.
- Near the confluence at 451 N. San Fernando Road in Los Angeles, the Angelica Healthcare Services Group, a linen supplier, is pumping groundwater.

The Arroyo Seco enters the Los Angeles River just below Gage F57, which defines the end of the Upper Los Angeles River Area or San Fernando Basin.

Water Use

The upper Arroyo Seco and front range of the San Gabriel Mountains provide a domestic water supply to the cities of La Cañada Flintridge, Pasadena, Sierra Madre, Alhambra and Arcadia.

The following table lists the water use of the Raymond Basin parties.

Table: Water Use in 1999-2000
in acre-feet

Party	Ground Water Extractions	Imported MWD Water	Total Water Use
Alhambra, City of	114.4	3,467.30	3,581.70
Arcadia, City of	6,182.60		6,182.60
California-American Water Company	4,001.60	600.1	4,449.70
East Pasadena Water Company	569.6	311.5	888.30
H.E. Huntington Library & Art Gallery	431.9		431.90
Kinneloa Irrigation Water District	834.9		904.20
La Cañada Irrigation District	43.3	2,996.40	3,168.70
Las Flores Water Company	274.4	738.1	1,012.50

Lincoln Avenue Water Company	1208.5	1146.7	2,520.90
Pasadena Cemetery Association	69.5		69.50
Pasadena, City of	19,095.20	21,105.40	40,405.80
Rubio Canon Land & Water Association	1,374.50	994.7	2,603.50
San Gabriel County Water District	0		0.00
Sierra Madre, City of	2897.1		3,225.90
Sunny Slope Water Company	1916.6		85.60
Valley Water Company	1,308.90	3,327.40	4,636.30
TOTAL	40,323.00	34,687.60	74,167.10

The Raymond Basin

The Raymond Basin is a groundwater aquifer that underlies the cities of Pasadena, Sierra Madre, Arcadia, Altadena, San Marino, and La Cañada-Flintridge. (Refer to Figure WQ3 for the groundwater basins of Los Angeles.) Bound by the San Gabriel Mountains to the north, the San Rafael Hills to the west and the Raymond Fault on the south and the east, the forty square mile basin supplies about 40% of local water supply. The basin slopes to the south, with elevations from 1,500 feet above sea level at the toe of the San Gabriel Mountains to 500 to 700 feet at the Raymond Fault. The basin underlies a highly urbanized, predominately residential region with a semi-arid climate and a long-term mean annual precipitation of about 22.45 inches. The Arroyo Seco, Eaton Canyon and the foothills of the San Gabriel Mountains feed the Raymond Basin. Those ground waters are stored in thick alluvial deposits of fan origin that were laid down on an irregular bedrock topography. The Raymond Basin then is like a bowl of sand and gravel or alluvial material that has washed down from the mountains and is filled with water. The bowl tilts to the southeast where there is some overflow into the Main San Gabriel Basin. Groundwater levels on the north side of Raymond Fault are 200 to 300 feet higher than on the south side of the fault.

The Raymond Basin is divided into three subareas. The northwest of the basin is the Monk Hill Subarea which includes La Cañada-Flintridge, Altadena and northwest Pasadena down to Monk Hill just north of Washington Boulevard. The main basin is the Pasadena Subarea, found under Pasadena. The Santa Anita Subarea makes up the north eastern corner of the basin.

Recharge to the groundwater of the Raymond Basin results from the percolation of streamflows originating in the mountains to the north, deep penetration of rain falling on the alluvial surfaces and returns from delivered water used for irrigation or discharged from cesspools. The basin is fed by the Arroyo Seco including Millard Canyon from the east and Flint Canyon from the west, Las Flores Canyon, Rubio Canyon, and Eaton Canyon. Spreading grounds in the basin are located in the Arroyo Seco, Eaton Wash, Sierra Madre and Santa Anita. The estimated annual capacity of these spreading grounds is about 41,000 acre-feet. These spreading grounds are used to capture local run-off, which averages about 6,000 acre-feet per year over the last 45 years.

The earliest wells just above the Raymond Dyke resulted from artesian conditions. Beginning in 1881 wells were drilled for irrigated agriculture and the expanding municipalities. As more wells were drilled in the basin with the advent of the deep-well turbine pump, the rising waters were dried up and the artesian flows stopped. Alarmed by the progressive lowering of water levels in the basin, the City of Pasadena initiated a spreading program in 1914 and began to seek outside water supplies. In 1937 Pasadena sought to restrain pumping by filing a lawsuit challenging other pumpers. The resulting litigation is referred as Pasadena vs. Alhambra, or the Raymond Basin adjudication.

Water rights in the area overlying the Raymond Basin were a constant source of contention from the first pumping in the basin in the 1880s until 1944. In that year Raymond Basin pumpers achieved the first successful basin wide adjudication of groundwater rights. The original judgment established a safe yield for the basin of 21,900 acre-feet per year and divided the water rights among sixteen users. In 1955 the judgment was modified, resulting in a decreed safe yield of 39,622 acre-feet per year. A 1974 modification of the judgment allows basin parties the right to spread canyon diversions and recapture a percentage of the spread water. In 1984 the judgment was restated and modified with no change in the decreed rights. The Raymond Basin Management Board, composed of representatives of the water rights holders, manages pumping and is overseen by a judge. The California Department of Water Resources measures streamflow and pumping.

Sixteen producers operate more than 50 wells annually. The well yields range up to several thousand gallons per minute. The MWD's Upper Feeder, which serves treated water to six producers, including the city of Pasadena and five agencies of the Foothill Municipal Water District, supplements local water supply.

Water quality in the basin is generally of high quality and superior to other basins in southern California. The level of total dissolved solids is generally below 500 mg/l, ranging from 145 to 1,050 mg/l. Nitrate (NO_3) from previous agricultural activities and septic tank systems ranges up to 85 mg/l and is an area-wide problem in the northwest portion of the basin near the Arroyo Seco. Significant levels of volatile organic contamination have been detected in the Devil's Gate/Hahamongna basin near Jet Propulsion. For more information, refer to the Technical Report on Water Quality.

Water Budget

The unusual geographic and hydrologic characteristics of the Arroyo Seco and the integrated nature of local water systems make it difficult to develop a precise water budget for the watershed. The Arroyo Seco watershed, for instance, feeds the Raymond Basin but only covers a portion of the land overlying the aquifer or of the communities that use it. These communities rely on imported supplies from the Metropolitan Water District to supplement their local supplies. Consumption figures from these communities and from South Pasadena and Los Angeles are not computed according to watershed boundaries. The County of Los Angeles Department of Public Works has developed a hydrology model that can be used to calculate rainfall in the Arroyo Seco, although there is not accurate gauging of storm water flows.

Table: Developing a Water Budget

Puts	Takes
Rainfall	M&I Consumption
Imported Water	Storm Water Discharges

Possibilities for Augmenting or Supplementing Local Supply

Recommendations

The final recommendations for water resources are targeted toward improving the water supply:

- Protect and preserve foothill lands to enhance percolation into the groundwater basin and to prevent aggravated runoff.
- Promote comprehensive conservation and implement best management practices throughout the watershed to improve water quality and reduce consumption.
- Expand water conservation and recycling programs through the watershed.
- Create conjunctive use of groundwater basin for enhanced storage during wet periods and for use during dry periods.
- Develop upper watershed reforestation and revegetation programs to reduce sediment flow and improve local retention.
- Naturalize the stream in Hahamongna for greater percolation and habitat benefits and reconsider the use and expansion of the spreading basins.
- Complete a sediment management study for Devil's Gate Dam basin.
- Review the functionality and effects of the upper basin flood control structures such as debris basins and check dams.

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Suggested llustrations

- Map of upper watershed canyons
- Map of springs
- Map of Indian settlements
- Map of Pasadena's diversion system and water percolation ponds
- WS1 – LA River watershed, Arroyo Seco watershed
- WS2 – permeable soils
- WQ1 – includes precip. info *(add second copy here or just refer to Water Quality section?)*
- WQ3-groundwater basins (add second copy here or just refer to Water Quality section?)

Watershed Management

"*The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased and not impaired in value*." Teddy Roosevelt

Watershed management offers tools to achieve a variety of purposes in a watershed. It can improve habitat, water quality and supply and provide for stream and flood management. The best watershed management plans provide an integrated approach to achieving multiple benefits including habitat, stream and flood management, and water resources.

This section of the ASWRFS will explore the feasibility of several viable alternatives, including structural and non-structural improvements, to increase the water yield in the Arroyo Seco watershed. Key goals are to reduce the sediment yield of the watershed above Devil's Gate Dam, to protect and improve water quality, and to enhance water conservation and flood protection throughout the watershed.

The State of the Watershed

A variety of factors led to a steady deterioration of environmental conditions in the mountain watershed of the Arroyo Seco in the last two centuries:

1) People moving through the mountains on highways, roads and trails have aggravated erosion and pollution;
2) Forest fires, both intentional and accidental, have burned much of the conifer forest that was then replaced by chaparral;
3) Fire control programs have protected chaparral from natural burn cycles and fostered thick mats of vegetation that thwarted other habitat;
4) Mountain debris basins and grade control structures have altered the stream ecology in ways that were not carefully studied; and
5) Exotic vegetation has choked out sensitive riparian environments.

Despite this sustained assault from the growing nearby metropolis, little effort has been expended to repair the steady degradation of the mountain watershed. Fires and floods wreak havoc, and land managers simply wait for the next crisis. The US Forest Service has neither an adequate budget nor experience to deal with a watershed that is so heavily used and impacted by the urban area it abuts. Their recent announcement that they will close the Arroyo Seco ranger station only increases concerns about the stewardship of the local watershed.

The scourge of fires in this region is particularly significant. After two centuries of unchecked fires, air pollution and urban heat island effects on the Angeles National Forest, fires today burn hotter, spread more rapidly and destroy larger areas than natural fires once did. Small fires are contained quickly, and big fires rage uncontrolled over larger areas.

Table: Major Wildfires in the Arroyo Seco Watershed

Year	Acres Burned in Watershed	Percent of Undeveloped Watershed (15,107 acres)
1896	6,385	42

1934	3,743	25
1955	424	3
1959	10,729	71
1975	809	5
1979	1,328	9
Source: LACDPW, Hydraulic/Water Conservation Division, "Devil's Sate Dam & Reservoir Hydrologic Reanalysis," August 1993.		

Local fires interact with floods to compound their effects. Fierce flames from the altered plant mix bake the soil surface at about 700 degrees and result in impervious soil. Next, heavy rains strike the exposed surface, dislodging soil particles. Water that once infiltrated into the mountains and the groundwater basin flows quickly over the ground surface transporting sediment downstream in significantly larger quantities than under historical conditions. Water that infiltrates during prolonged wet periods reduces the stability of steep slopes and leads to land slides, which now occur more quickly because the roots of native vegetation are no longer stabilizing the soil to the rock beneath. These larger masses of sediment are washed out of the canyons sooner, because flood peaks are occurring more quickly as the run-off process shifts toward more surface runoff. Local geology is such that exposed bedrock decomposes rapidly when exposed to the elements to generate new soil, keeping the destructive processes intact. Current management has done little to repair the damage or to enhance habitat in the mountains.

A Watershed Management Program

Watershed management has both environmental and economic benefits. It can restore more natural ecosystems that in turn can be more productive for human needs. By enhancing water conservation and local water retention, watershed management provides measurable real dollar benefits to local entities, particularly the City of Pasadena and other Raymond Basin parties. The high price of imported water, the alternative to optimizing local supplies, sets a clear monetary measure for the feasibility of watershed management program. At current water rates and charges, an investment of up to $650-700 an acre-foot of yield can be justified.

Unlike previous fire and flood control programs, a key goal of watershed management is to slow runoff and increase local retention of rainfall. The steep, denuded nature of much of the Arroyo Seco watershed today aggravates sediment production and flood peaks. This reduces water conservation storage in the mountain watershed and in the Devil's Gate flood basin as well as natural replenishment of the Raymond Basin.

The "Preliminary Economic Feasibility Assessment for the Devil's Gate Multi-Use Project," conducted for the City of Pasadena Water & Power Department in May 1992, contains a conceptual assessment of the elements and goals of such a watershed management program in the Arroyo Seco watershed. It envisions a program that would include a series of tools such as:

Table: Upper Watershed Management Tools	
Fire Management	Reduce combustible biomass, add diversity and reduce the ease with which fires ignite and spread by a carefully planned and systematic program of controlled burns in the Angeles National Forest.
Vegetation Management	Restore healthy natural vegetation in an age and species diverse

	environment to form a stable ecology that also supports native wildlife in the watershed.
Erosion and Sediment Reduction	Reduce water and sediment run-off through revegetation, reforestation, cross furrowing, debris structures and other techniques on slopes carefully chosen to reduce sediment yield. Such a program would identify target areas by slope, soil, vegetative conditions, and potential to contribute to landslides and severe erosion and then utilize control techniques to reduce erosion.
Sediment Management	Establish a maintenance and management program to either trap the sediment in areas where it can be easily processed or to promote its passage through Devil's Gate reservoir and dam downstream
Recreation Facilities Planning and Use Regulation	Concentrate recreational use of the watershed in less fragile areas and at managed facilities. Reasonable regulations must be developed and enforced to protect the watershed lands from overuse, particularly during vulnerable periods such as fire season.
Slope Stabilization	Protect vulnerable slopes and reduce erosion of exposed upland areas that might suffer from sheet erosion and human activity causing rills and gullies; use revegetation techniques with appropriate understory and trees.
Channel Erosion Control	Reduce stream channel scouring and flow gradient to protect the stream and reduce erosion with revetments, small debris dams and other techniques.
Monitoring	All watershed management techniques and policies should be carefully documented and monitored to improve effectiveness and future programs.

The Preliminary Economic Feasibility Assessment recommends several important watershed priorities:

1) "Establish a governance concept where funding and local agencies have a role in decision making, to work with the US Forest service in an effective joint program of watershed management coordinated within a larger program of land and water use.
2) "Concentrate on programs to manage vegetation for fire control and on establishing better cover on source areas for sedimentation reduction, and
3) "Perform studies to determine how human abuse and the effects of pollution are degrading soil productivity, particularly n the more fragile soils, and what management policies can do a better job of protection."

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"Best Management Practices" (BMPs) are practical tools, including streambank revegetation, use of buffer strips, and wetland restoration, that can be utilized to diminish run-off related erosion and chemical pollution and provide adequate water quality for native aquatic species survival. A collaborative approach among landowners and government agencies will be essential.

An effective watershed management program will identify and implement strategies to reduce the flow changes caused by the altered ecology, dams, water diversions, and groundwater pumping. Alterations of natural river flow regimes can greatly impair the ability of many species to fulfill their life cycles, thereby threatening their survival. For example, certain fish require specific flow timing, magnitude and duration to trigger their spawning behavior. The challenge will be finding a balance between human needs for irrigation, drinking water and other purposes, and adequate flows to maintain the river ecosystem's health. It will be important to demonstrate that watershed management techniques can enhance the watershed to make it more productive, not only environmentally and aesthetically, but also for local water production. This will enable water managers and policy makers to see the feasibility of adjusting the patterns of water diversion or dam operations to meet both ecosystem needs and human demands for water.

Monitoring the effectiveness of strategies will be essential. The information gathered during monitoring can be used adaptively to modify strategies and increase the effectiveness of conservation. The results will also document the effectiveness of specific strategies and demonstrate which solutions have broader application in the watershed.

Developing a Watershed Management Programs

While the upper Arroyo Seco watershed will reap the greatest water benefits, actions throughout the Arroyo Seco watershed can contribute to an effective watershed management program.

Table: Watershed Management Techniques	
Watershed Planning	Thorough watershed and subwatershed planning using ecosystematic principles, our community can improve the health of the watershed, reduce the amount and impact of floods, fires and imperious cover and optimize overall watershed objectives.
Land Conservation	Land acquisitions, conservation easements, and protections for critical areas are watershed management tools that can protect special areas such as aquatic corridors, steam zones, percolation areas, and critical habitat. Foothills and hillside protections are particularly important since the foothills act like a sponge absorbing rainfall and streamflow into the alluvial soils and allowing the water to percolate into groundwater basin. Connecting corridors for habitat, wildlife or recreational uses.
Aquatic Buffers	Buffers can physically protect and separate a stream, lake, or wetland from future disturbance or encroachment. For streams, a network of buffers can offer special protection during floods and sustain the integrity of stream ecosystems and habitats.
Site Design	Careful planning can promote a healthier watershed to enrich us all. Ecosytematic standards can reduce impervious cover, pollution and runoff, while conserving water and natural areas and preventing stormwater pollution.
Erosion and Sediment	Erosion and sediment control throughout the watershed is

Control	important. In the upper watershed it includes reforestation, fire management, and other tools. An analysis of the environmental and hydrologic effects of current flood facilities, debris basins and check structures is needed. A sediment management program for Devil's Gate Dam is also vital. Eradication of non-native, invasive species is another key element. In the lower watershed, hillside restrictions and best management practices for construction are critical.
Flood Hazard Mitigation	Flooding poses a significant risk to the safety and property of each community in the Arroyo Seco watershed. Flood hazard mitigation helps communities identify their flooding risks and assists them to become safer. Tools such as mapping, acquisition of vulnerable sites, safety education, elevations and relocations of flood-prone structures, and flood protection facilities can be used to reduce or eliminate risks to safety and property. The key goal is to establish sustainable floodplain management programs to prevent flooding risks from occurring in the future.
Stormwater Management	New construction standards and stormwater retrofits should be applied along with other available watershed restoration strategies to reduce pollutants, restore habitat and stabilize stream morphology as part of an integrated watershed restoration program.
Non-storm Discharges	Three basic kinds of non-stormwater discharges need to be monitored, reduced and controlled: 1) Septic Systems, 2) Sanitary sewers, and 3) industrial and residential NPDES discharges, including urban "return flows" (discharges caused by activities such as car washing and watering lawns), water diversions, and runoff from equestrian stables.
Watershed Stewardship	Involving the community in caring for the Arroyo Seco watershed is key to developing the political support and behavioral changes needed to protect our watershed. Stewardship programs include a wide variety of education and action including volunteer-based programs, incentives for conservation & efficient use, business and consumer programs to reduce water use, regionally appropriate landscape, and water quality monitoring programs.

Other Methods to Augment Local Water Supplies

Pasadena Diversion and Spreading Program

Pasadena's water collection system offers one of the most promising opportunities for enhancing environmental values and expanding water resources. The diversion structure in the Arroyo Seco was established for engineering efficiency many decades ago without taking into account its environmental impact. During much of the year, it captures most of the Arroyo flow and diverts it through pipes to the spreading basins further south. It is a major impediment to fish passage and riparian habitat values in the especially precious transition zone from the mountains to the alluvial plain below.

The Hahamongna Watershed Park Master Plan, now under environmental review, proposes expanding the spreading basins from 13.75 acres on the east side of the basin to 22.5 acres on both sides. The intent of this is to collect more surface runoff from the Arroyo Seco, but it is not clear that expansion of the percolation basins would achieve that goal. "Flood Hazard, Sediment Management, and Water Feature Analysis in Hahamongna Watershed Park" by Phillip Williams & Associates finds that the percolation basins are not an effective mechanism for percolating water into the Raymond Basin. The study finds that a more naturalized stream flowing through the middle of the Hahamongna basin to a conservation pool at Devil's Gate Dam would be more effective in maximizing groundwater percolation by an order of magnitude.

Pasadena Water & Power notes: "Although Philip Williams & Associates may be technically correct that there may be alternatives that will capture and spread greater quantities of surface water than what is presently practiced in the Arroyo Seco, it does not address the critical issue of the rights to protect and extract the spread water by member agencies. There are two critical issues and they do not necessarily mean the same. The first issue is groundwater replenishment, which is diverting and spreading surface water on behalf of the basin as a whole. Its purpose is to prevent or limit the effects of overdraft on the groundwater basin. The second issue is the right to protect and recapture water spread by member agencies for the purpose of supplementing its adjudicated water rights. This is the purpose of the spreading ponds, it distinguishes natural groundwater replenishment from spreading operations for the purpose of recapturing groundwater by member agencies." The County of Los Angeles Department of Public Works comments: " It should also noted that if water was held behind Devil's Gate Dam, the percolation rates would quickly diminish due to sediment deposition in the reservoir."

While the Master Plan envisions "naturalizing" the spreading basins with riparian vegetation, the spreading basins of necessity must be unrelieved sandy basins with only habitat fringes. This is especially regrettable since the area where the basins are contained is the only patch of rare and precious riversidian alluvial scrub habitat, of such great value to a wide variety of important species. This is also the southern tip of the area recently designated by the US Fish and Wildlife Services as critical habitat for the endangered Southwest Arroyo Toad. This habitat needs more space as well as the disturbance of a more natural hydrologic regime.

There is already capacity for spreading 41,000 acre feet per year in the Raymond Basin from current facilities. However, since only 6,000 are spread annually, it is appropriate to reconsider any expansion of the basins as well as their functionality. A more naturalized system could capture more water and provide for a healthier environment. Such an operational change may require a change in the way the Raymond Basin Management Board calculates groundwater credits, but clearly everyone would benefit from the enhanced percolation a natural stream could provide.

By reducing and managing the sediment coming into the Devil's Gate basin, naturalizing the diversion and eliminating the percolation ponds, Pasadena can have a water system that incorporates environmental sensitivity and captures and stores more water for human use.

Groundwater Storage

The Raymond Basin is a tremendous resource for our region. Experts calculate that it has approximately 1,000,000 acre-feet in storage with significant additional storage capacity in the unsaturated zone. In recent years Pasadena and other agencies have developed storage programs that have stored about 50,000 acre-feet in the basin to cushion us in future dry periods.

In the last ten years, Pasadena and Foothill MWD have improved the efficiency of their water systems and promoted water conservation by taking more Winter water when available, and reducing their take of imported water during the Summer. This kind of operational system can help replenish the Raymond Basin and relieve environmental stress to California's water system while also saving money for consumers.

Raymond Basin Conjunctive Use Program

The next step in the historical development of local water resources is the Raymond Basin Conjunctive Use Program (RBCUP). Conjunctive use, the coordinated use of surface supplies and groundwater resources with imported water, is a water resources management technique that can optimize the use of local and imported resources while reducing the environmental stress sometimes associated with water importation. The RBCUP will provide storage capacity of up to 75,000 acre-feet in the Raymond Basin to the MWD to use for regional water reliability. MWD will build facilities necessary to produce up to 25,000 acre-feet from the Raymond Basin in dry years.

Until now, the management of the Raymond Basin has been limited by the quality of Colorado River water being imported into the region. Colorado River water is significantly higher in total dissolved solids (TDS or salts) content than is the local water in the Raymond Basin. The basin management standard, set by the Regional Water Quality Control Board, does not allow Colorado River water to be spread to replenish the basin. Instead groundwater levels can only be fed by the "in-lieu" replenishment method in which local pumpers forego their pumping rights and take surface deliveries of MWD water, allowing the water stored in the basin to build up. While this is an effective technique, it does not allow for the flexibility that a full replenishment program, involving spreading or injecting water into the aquifer, would provide.

In 1997 MWD established a program of blending Colorado River deliveries with lower-salt State Water Projects supplies to meet a salt standard of 500 parts per million (ppm) during Spring and Summer months. This policy improves water quality and facilitates groundwater and reclamation programs, but the 500 part standard still does not allow local MWD agencies such as Pasadena and Foothill MWD to use imported water for groundwater replenishment.

In the Raymond Basin Conjunctive Use Program, MWD would build a 13-mile pipeline to connect its East Valley Feeder in Glendale with Pasadena and FMWD. This pipeline would bring in highly desirable State water (+/- 250 ppm TDS) into our region and for the first time allow the Raymond Basin to be used as a replenishment basin. Injection wells, pumps and other facilities needed to develop storage and production capacity will be built at MWD's expense.

In 1992 and 1993 the Raymond Basin Management Board allocated the unused storage capacity of the Raymond Basin among the basin parties. Taking advantage of this, Pasadena now has about 50,000 acre-feet in storage beyond its pumping rights. An additional 100,000 acre-feet has been set aside for storage programs such as the RBCUP.

The RBCUP would be significant not only to our local region but to all southern California. While MWD has developed groundwater storage programs in other parts of California, this is the first groundwater storage in which MWD agencies have offered to make a portion of their local groundwater resources available for regional benefit.

The MWD board approved the RBCUP in concept in January 2000, and the Raymond Basin parties have approved the program in concept as well. The environmental documentation has recently been initiated, paving the way to a final agreement for this significant program.

Recycling

Because the Los Angeles County Sanitation District handles sanitation for Pasadena, La Cañada-Flintridge and Altadena, it is difficult to develop local wastewater recycling programs. Wastewater from the upper Arroyo Seco area flows to the wastewater treatment plant at Whittier Narrows where some of it is recycled. Now, however, Pasadena is moving ahead with a cooperative program with Glendale to bring reclaimed water from the Los Angeles/Glendale Wastewater Plant into the western part of Pasadena for irrigation purposes. Approximately 1,000 acre-feet per year (2.5% of Pasadena's demand) will be used to irrigate Brookside Golf Course, Annandale Country Club, Brookside Park, Defenders Park near the Colorado Street Bridge, and the Lower Arroyo Nature Park.

Storm Water Retention

Standards recently adopted by the Los Angeles Regional Water Quality Control Board require that new major developments must be designed to retain a ¾" storm in a twenty four hour period onsite. This standard is intended to improve water quality, but it will also have some measurable effect on local water retention as some of this water will percolate into the groundwater basin. Best management practices and storm water retrofits can multiply this benefit.

Appropriate Landscaping and Conservation

Everyone in the Arroyo Seco watershed can help stretch our water supplies by using water wisely. Reducing the amount of outdoor water uses through the use of native plants for landscaping homes and business has the greatest potential for saving water and improving the environment. Plants native to our region, such as Engelmann Oak and Sycamores, have adapted over centuries to local climatic and hydrologic conditions. They can shade and cool our homes and improve habitat for birds and wildlife while reducing demands for irrigation water.
