Appendix C
Surface Water Yields and Spreading Details

C.1 Introduction

Surface runoff from the San Gabriel Mountains is a water supply source for the City of Pasadena Water and Power Department (PWP). PWP owns water rights to divert instantaneous runoff from Arroyo Seco up to 25 cubic feet per second (cfs) and Eaton Canyon up to 8.9 cfs. These water rights are not typically realized due to limitations of PWP's existing facilities as well as discounts for groundwater recharge taken when applying Raymond Basin Management Board (RBMB) spreading credit methodology. The WIRP evaluates several options to enhance yield from existing surface runoff water rights and potential projects to increase recharge and reduce overdraft in the Raymond Basin. In addition, the WIRP includes several options to capture urban runoff during dry and wet conditions for recharge in the Raymond Basin.

The capture and recharge of surface runoff from mountain canyons and urban landscape must be considered in the same framework, because theses source of water could be stored and recharged in existing and/or potential new spreading facilities. The storage and recharge capacity of spreading facilities is limited therefore; it may not be technically feasible to capture all runoff that is available from each source. A mass balance model was developed to simulate daily capture and overflow of surface runoff from Arroyo Seco, Eaton Wash, and urban subwatersheds in the City of Pasadena and La Canada Flintridge. The model accounts for surface runoff inflows (from Arroyo Seco, Eaton Wash, or urban runoff), surface storage, supply resulting from recharge within spreading basins or direct delivery (i.e. treatment plant), transfer of runoff from Arroyo Seco to Eaton spreading grounds, recharge losses within Devil's Gate reservoir, and environmental flow needed in downstream segments of Arroyo Seco (Figure C-1).

Surface runoff is available over short time periods and is non-uniform. Most of the time, there is not sufficient surface runoff supply to provide source water to fully utilize existing or proposed facilities. Facilities that are not used during these periods provide reserve capacity for use during larger wet weather events, when surface runoff availability constraints are temporarily removed. As a result, the yield from a single supply option depends upon the operation of existing facilities and potential new supply options (Figure C-2). The model uses a hierarchical structure to facilitate simulation of surface runoff yield with a set of supply options that are arranged in order of preference. Thus, during low flow periods, it may be only the most preferred option that receives any surface runoff supply.

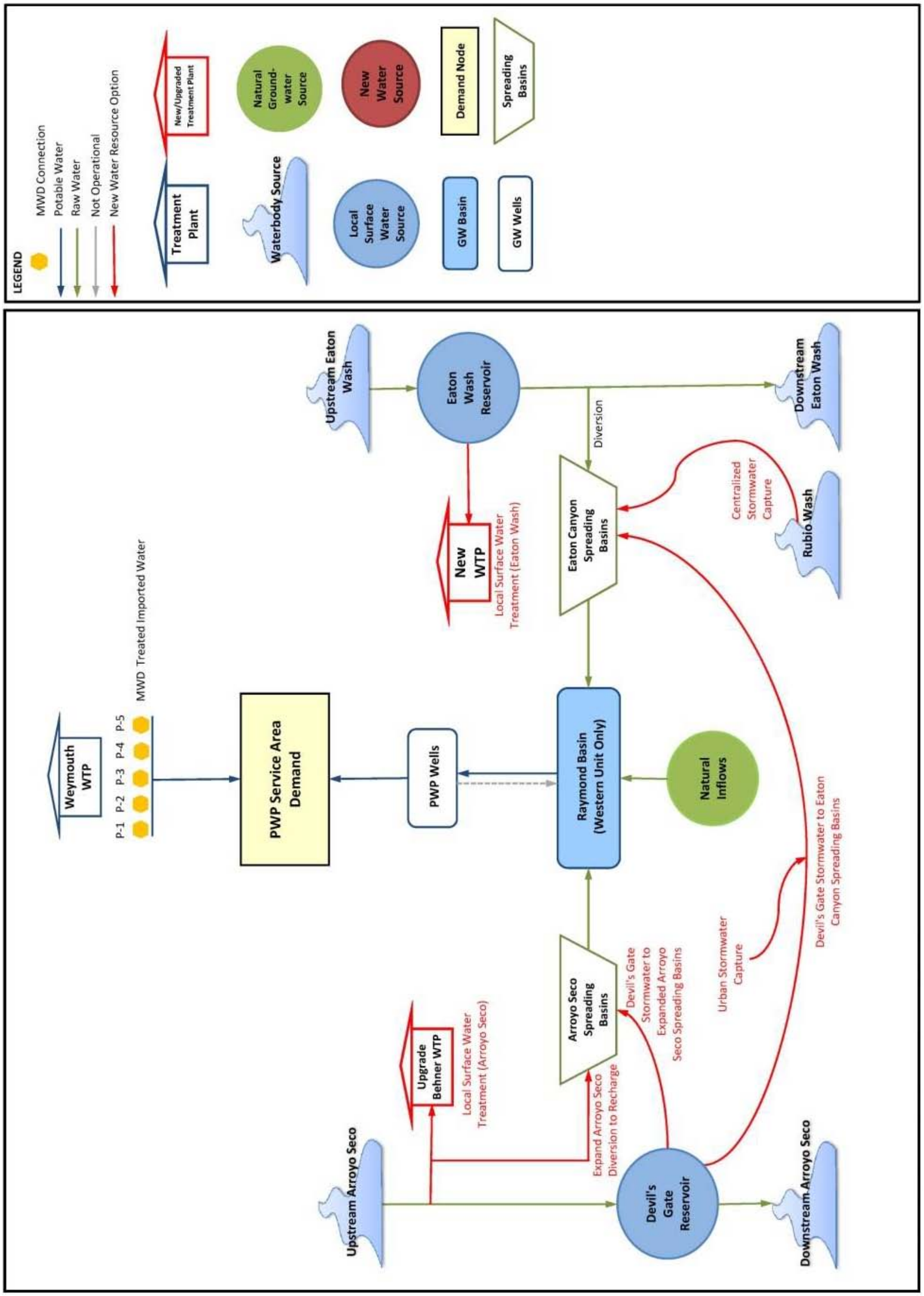

Figure C-1
Flow Schematic Highlighting Surface Runoff (Arroyo Seco, Eaton Wash, and urban stormwater) Options

Given this approach, there are multiple potential scenarios within a proposed portfolio of supply options, which involve different operational hierarchies. For the WIRP, best professional judgment and discussions with PWP staff guided development of appropriate operational hierarchies. For example, if surface runoff treatment were to be implemented, then it would make sense that a higher preference would be given to a new water treatment plant (WTP) than to groundwater recharge, because treated water is not subject to spreading credit formulas and WTP operations.

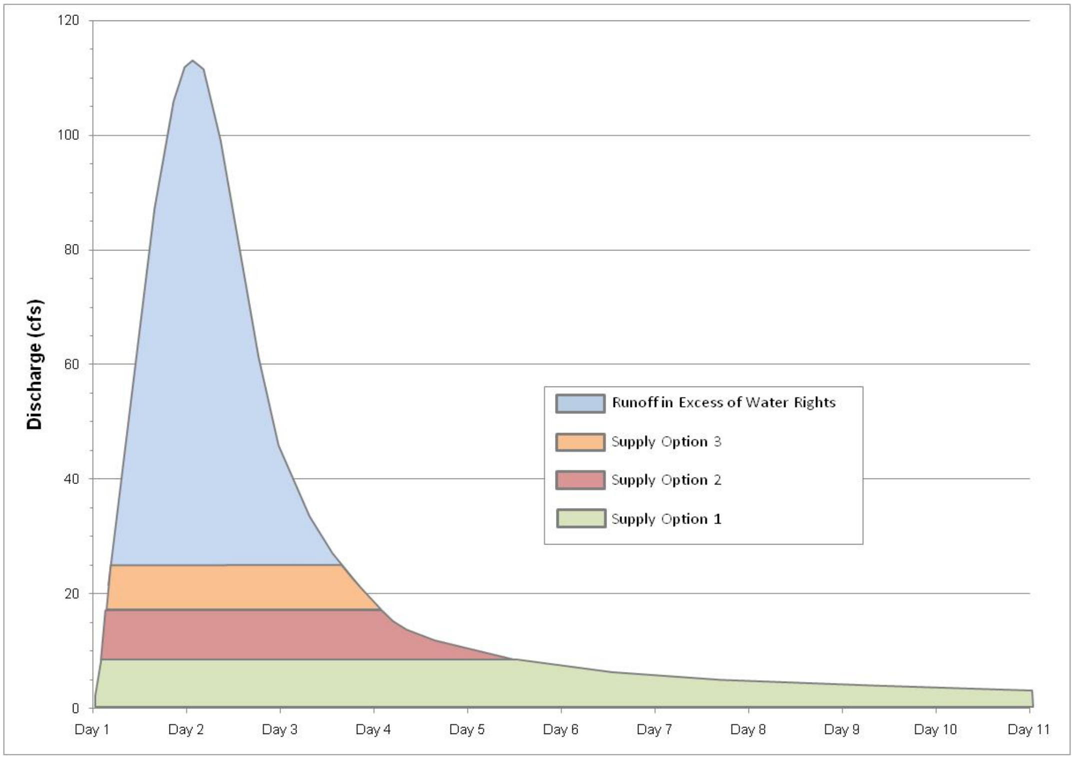

Figure C-2
Varying Yield for Supply Options with Equal Capacity due to Hierarchical Operation

C.2 Hydrologic Period of Record

Flow gauge data and precipitation data was collected to estimate potential yields for the surface water options. A summary of the hydrological data sources is shown in Table C-1.

The period of record used in the surface runoff analysis is from 1999 to 2009. This period was selected primarily due to (1) completeness of data, and (2) recent hydrologic data is more reflective of current facility practices, such as operations of the spreading basins and management of the dams. Precipitation during the 1999 to 2009 had significant variation and the period contains a broad range of hydrologies. Figure C-3 compares the long-term distribution of surface runoff in the Arroyo Seco with the simulation period used in the WIRP. Overall, flows remain less than 5,000 AFY nearly 75 percent of the time, with most of the simulation years falling in this range. One simulation year is representative of a very wet year.

Table C-1
Hydrological data sources

Data	Units	Period of Record	Use in WIRP analysis	Source
Diversion and Spreading in Arroyo Seco and Eaton Spreading Grounds	Monthly Volume (ac-ft)	1980 – 2010	Evaluate effectiveness of existing diversions and spreading facilities	RBMB Annual Reports, Appendix C
Devil's Gate Dam Outflow	Daily discharge (cfs)	1980 – 2010	Boundary condition for estimate of flow from Flint Wash; Comparison of Central Arroyo Seco flow duration changes with enhanced runoff capture	LACDPW Flow Gauge Site ID F277
Eaton Wash Dam Outflow	Daily discharge (cfs)	1988 – 2010	Estimate of runoff available for spreading in Eaton Wash Spreading Grounds	LACDPW Flow Gauge Site ID F318
Arroyo Seco near Pasadena	Daily discharge (cfs)	1910 – 2010	Estimate of runoff available for spreading in Arroyo Seco Spreading Grounds (scaled up to account for DA between gauge and diversion point)	USGS Flow Gauge Site ID 11098000
Devil's Gate Dam Precipitation	Hourly rain (in/hr)	1996 – 2010	Input data for SWMM model of Flint Wash subwatershed	LACDPW Meteorological Station ID 453

RBMB: Raymond Basin Management Board
LACDPW: Los Angeles County Department of Public Works
USGS: United States Geological Survey
SWMM: Storm Water Management Model
DA: drainage area

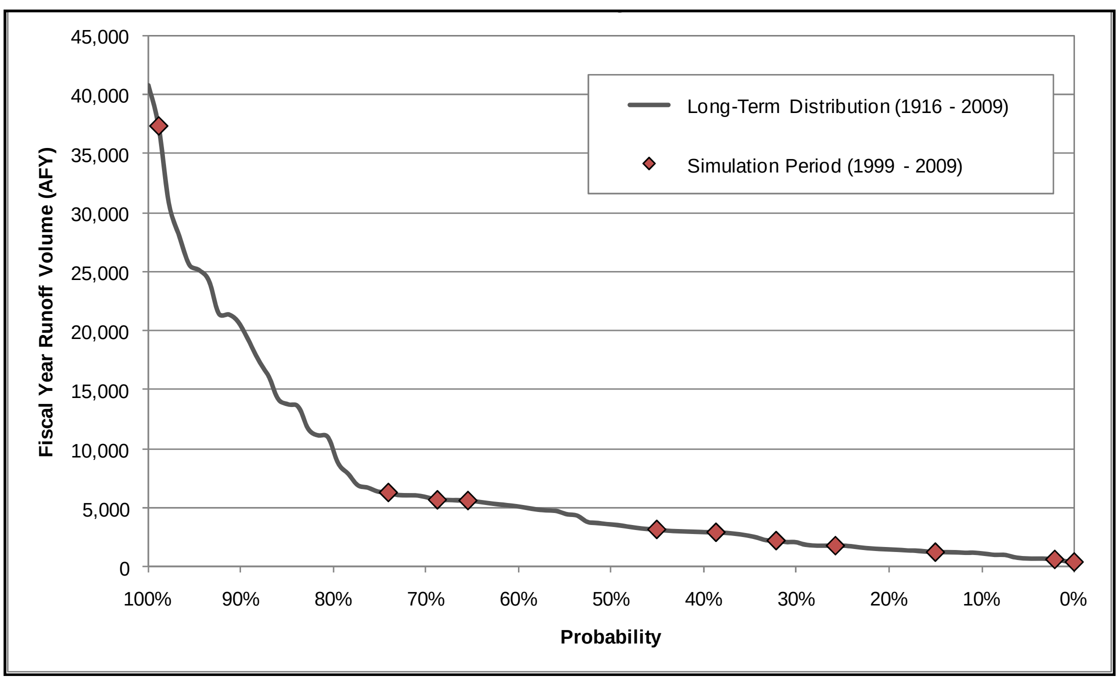

Figure C-3
Hydrologic Conditions during Analysis Period Compared with Long-Term Runoff in Arroyo Seco

C.3 Arroyo Seco Watershed

Runoff in the Arroyo Seco ranges drastically and is most dependent upon climatic patterns. In wet years, such as 2004-2005, annual runoff can exceed 40,000 AFY, most of which is lost to the Pacific Ocean via the Los Angeles River. Conversely, in dry years such as 2003-2004, runoff is limited to less than 1,500 AFY. Therefore, evaluations of surface runoff options must consider the significant temporal variability in surface runoff. In addition to year-to-year variation, runoff in Arroyo Seco is highly seasonal. In the dry season, runoff is typically an order of magnitude below PWP's water rights.

The City water rights from Arroyo Seco are up to 25 cfs of instantaneous diversion from the stream. In recent years, since PWP took ownership of the spreading grounds from Los Angeles County Flood Control District (LACFCD), spreading of surface runoff has ranged from 1,000 to 4,000 AFY. The City's diversion structure and pipeline was designed to provide sufficient capacity to capture this flowrate to be sent to the Behner WTP and Arroyo Seco Spreading Grounds. Sedimentation behind the dam that impounds water at the diversion structure has degraded the capacity of the diversion facility.

The Arroyo Seco spreading grounds currently have capacity to recharge up to 18 cfs of runoff from Arroyo Seco, which is less than the 25 cfs water right. In recent years, PWP has improved operation of the spreading grounds to maximize use of this capacity; however, the effectiveness of the diversion structure has degraded, which limits the diversion of runoff to the spreading grounds. An upstream USGS flow gauge (Gauge 11098000) provided an estimate flow in Arroyo Seco at the diversion point. Daily runoff at the gauge was scaled by a factor of 1.1 to account for ungauged drainage area between the USGS station and diversion point downstream. Figure C-4 compares the monthly volume of surface runoff at or below 25 cfs in Arroyo Seco upstream of the diversion structure with historical diversions.

Over the past 10 years, the difference between annual runoff volume below 25 cfs and actual spreading (before credits) has averaged approximately 1,300 AFY. This is the incremental volume of Arroyo Seco surface water that could be captured and used with new facilities. Two options are available for PWP to maximize its use of water rights in Arroyo Seco, including:

- Upgrade existing Behner WTP to provide direct delivery of Arroyo Seco surface runoff diversions
- Expand existing Arroyo Seco diversion structure and spreading grounds to enhance recharge capacity

Current spreading in the Arroyo Seco spreading grounds has also been subject to a pumping credit formula, which reduces the volume of spreading that can be pumped from PWP wells. Surface runoff yield from Arroyo Seco runoff can also be improved by constructing new spreading capacity, with a more favorable pumping credit formula, or by using a surface water treatment facility, which is not subject to any reductions.

Runoff from Arroyo Seco above 25 cfs at the PWP diversion point flows into Devil's Gate reservoir. Capture and use of this surface runoff for the benefit of the region is an additional supply option. Analysis of the yield for this option is described in Section C.5 (Devil's Gate Reservoir) of this appendix.

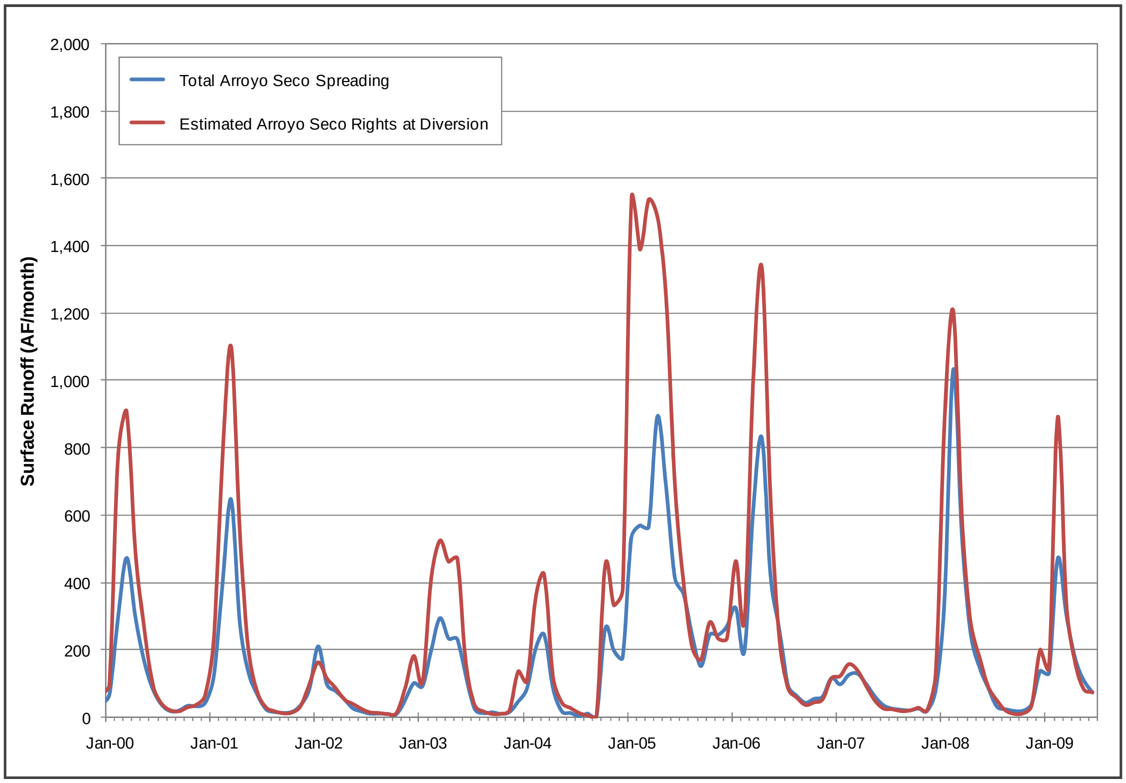

Figure C-4
Historical Spreading by PWP Compared with Runoff up to 25 cfs of Water Diversion Rights in Arroyo Seco

C.3.1 Upgrade Behner Water Treatment Plant

The Behner WTP is owned by PWP was shut down in 1993 because the existing treatment process (Hardinge Filter) is not capable of producing water that meets more stringent Stage 2 Disinfectants and Disinfection Byproduct Rule (State 2 D/DBPR) and the Long Term 2 Enhanced Surface Water Treatment Rule (LT2 ESWTR). The existing Behner WTP was constructed to treat 10 cfs of runoff. Evaluation of long-term runoff in Arroyo Seco determined the frequency of full WTP utilization at varying capacities (Figure C-5). This chart shows that the frequency of full WTP operation is greatly reduced as potential capacity increases. The proposed project was recommended at a capacity of 2 cfs. This would result in full operation about one third of the time.

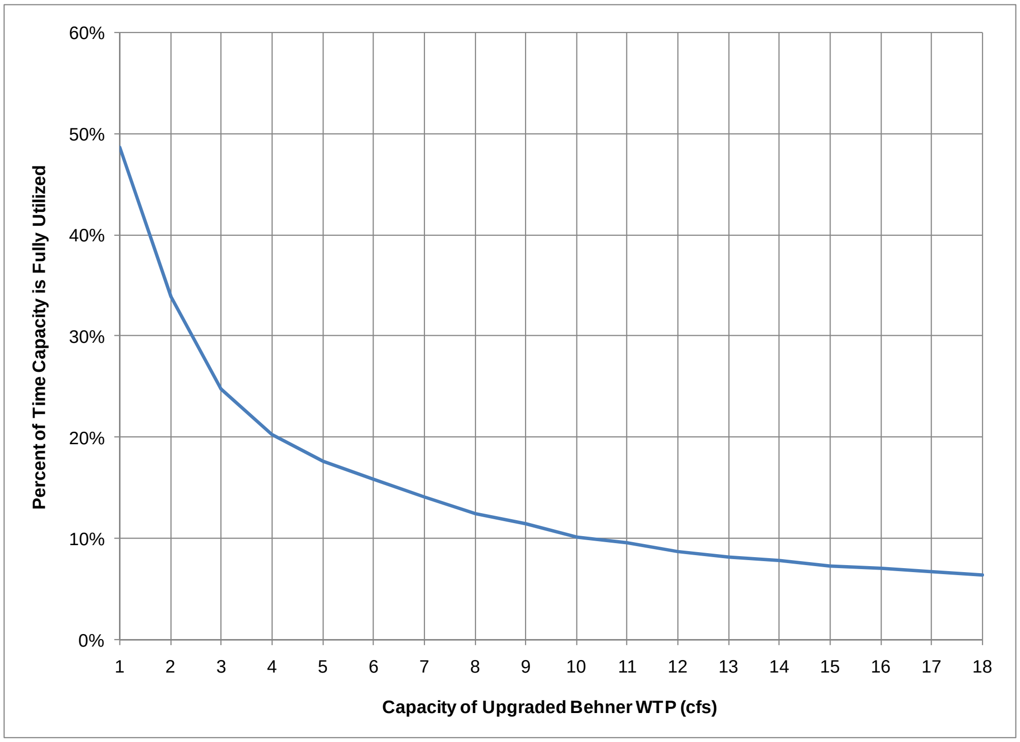

Figure C-5
Percent of Time Potential Upgraded Behner WTP is Fully Utilized for different Sizing Capacities

Assuming this project would be given highest priority (water rights are sent to Behner WTP before any other facility), estimation of the supply yield is simply the sum of daily runoff in Arroyo Seco up to the capacity of the Behner WTP. For a potential capacity of 2 cfs, the average (1999-2009) annual yield to the plant is ~860 AFY. In a dry year (2003), lower runoff from Arroyo Seco results in a reduced yield of ~575 AFY to the plant. Any water rights in excess of plant capacity are sent to existing spreading basins. On average, the amount of water to spreading would be 1,759 before credits are applied (1,055 after credits). The combined yield is approximately 413 AFY over current levels of average annual spreading credit.

C.3.2 Expand Arroyo Seco Spreading Grounds

The 2002 *Hahamongna Watershed Master Plan* includes projects to expand spreading basins on the east side and add new spreading basins on the west side of Arroyo Seco. The expansion of spreading basins on the east side of Arroyo Seco is projected to add 6.7 cfs of recharge capacity and 20 acre-feet of storage volume. New spreading basins proposed on the west side of Arroyo Seco are projected to add 7.7 cfs of recharge capacity and 32 acre-feet of storage volume. Using the existing spreading grounds, PWP obtains pumping credits for ~60 percent of surface runoff spreading. In new or expanded facilities, PWP would obtain ~80 percent pumping credit for surface runoff spreading. Therefore, the WIRP evaluation incorporates variable pumping credits to compare supply options and increase spreading yields in Arroyo Seco over baseline conditions.

Estimation of supply yield from spreading of diverted surface runoff involves a daily mass balance of diversion, storage, and recharge. If the east and west side spreading grounds are constructed and given the highest priority (water rights are sent to new spreading grounds before any other facility), the supply yield is approximately 2,800 AFY and credit is ~2,160 AFY. This represents an approximately 660 AFY increase from current levels of average annual spreading credit. Table C-2 summarizes the modeled yield in each of the proposed basins as well as from existing spreading grounds.

Table C-2
Supply Yield and Spreading
Credit for Potential Arroyo Seco Spreading Ground Expansion Projects

Supply Option	Capacity (cfs)	Supply Yield (AFY)		Spreading Credit (AFY)	
		Average (1999 - 2009)	Dry Year (2003- 2004)	Average (1999 - 2009)	Dry Year (2003- 2004)
New Eastside Spreading Grounds	6.7	1,641	813	1,313	650
New Westside Spreading Grounds	7.7	660	168	528	134
Existing Spreading Grounds [1]	17.6	539	139	323	83
Total	32	2,840	1,119	2,164	868

1) Water rights in excess of the new spreading capacity is captured in existing spreading grounds

The estimated yields and credits in Table C-2 include both PWP's 25 cfs of water rights in Arroyo Seco and Lincoln Avenue Water Company's (LAWC) 6.9 cfs of water rights from Millard Canyon, a tributary to Arroyo Seco. LAWC uses the Arroyo Seco spreading grounds to capture a portion of its water rights. To provide sufficient capacity to maximize use of both PWP and LAWC water rights it would be necessary to construct both the east and west spreading basins for capture and recharge of up to 32 cfs of Arroyo Seco runoff. Table C-2 shows that the existing spreading grounds have sufficient capacity to recharge the remaining water rights in excess of the new spreading capacity.

Should new spreading basins be pursued in the future, it is recommended that the site locations of new spreading areas be further evaluated with regard to potential sediment and habitat issues.

C.4 Eaton Wash Watershed

The option to construct a new surface WTP in Eaton Wash may not result in a measurable increase in long-term supply yield. Currently, the Los Angeles County Department of Public Works (LACDPW) operates Eaton Wash Dam and the Eaton

Wash spreading grounds, which have the ability to store wet weather runoff from large storm events. Eaton Wash Dam is located upstream of the spreading grounds, which allows for controlled releases to the Eaton Wash spreading grounds for recharge after a storm event. Conversely, a surface WTP at the diversion point upstream of Eaton Wash dam would have limited storage to capture runoff from high flow events that exceed the plant capacity. Due to limited data upstream of Eaton Wash Dam, the USGS flow gauge (Gauge 11098000) in the Arroyo Seco was used to estimate daily runoff at PWP's Eaton Wash diversion point. These watersheds are very similar in land cover, topography, and rainfall. To account for differences in drainage area, the runoff at this gauge was scaled by a factor of 0.4. Figure C-6 compares the approximated monthly volume of surface runoff at or below 8.9 cfs in Eaton Wash with historical diversions after PWP credits have been discounted. The largest differences occur during very large runoff events, when overflows from the spreading grounds result in subtractions from PWP pumping credits. However, on an average annual basis, there is limited benefit to developing a new supply option in Eaton Wash at the diversion point.

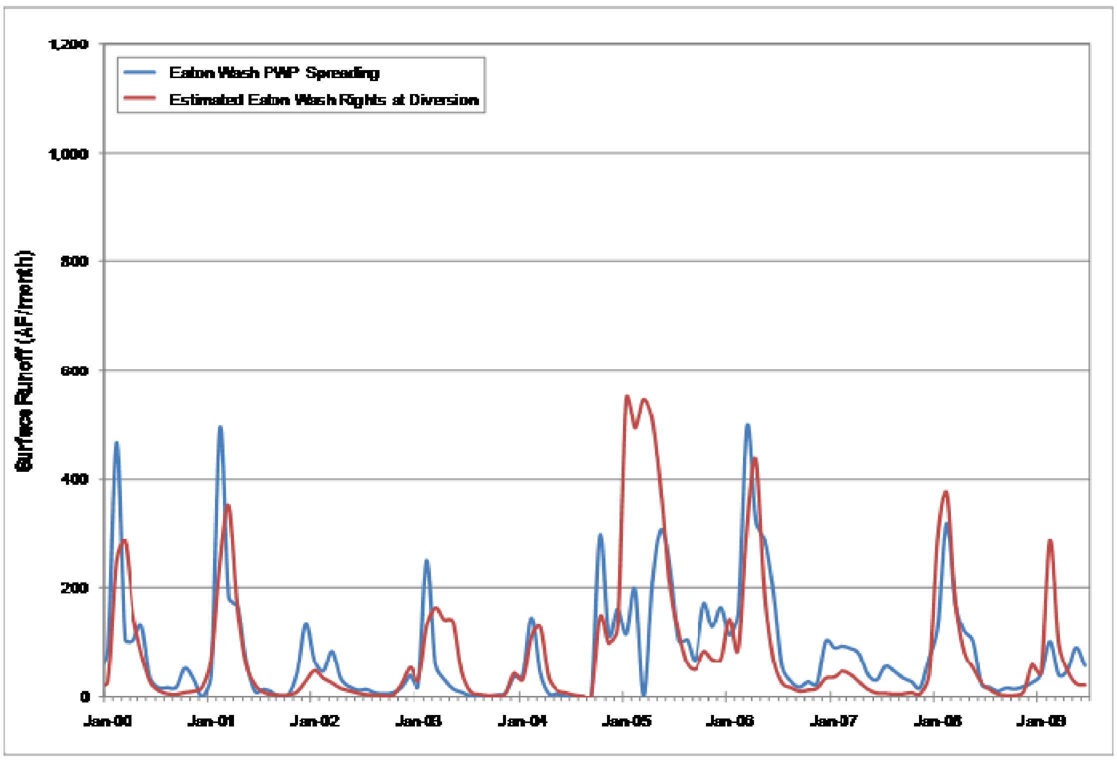

Figure C-6
Historical Spreading by PWP Compared with Estimate of Runoff up to 8.9 cfs of Water Diversion Rights in Eaton Wash

C.5 Devils Gate Reservoir

Devils Gate Reservoir is located behind Devil's Gate Dam which is owned by LACFCD. The dam was originally constructed to provide detention of large storm events in the Arroyo Seco. However, under current operating conditions, all runoff flows through Devil's Gate Dam (with no storage) and ultimately to the Pacific Ocean. The main sources of water entering Devil's Gate Reservoir include

- Surface runoff from the Arroyo Seco not diverted into spreading basins
- Stormwater runoff from Flint Wash
- Dry weather flow from Flint Wash

The daily mass balance of runoff in Arroyo Seco computes the volume of water that is in excess of diversions to the Arroyo Seco spreading grounds associated with PWP's water rights. The remaining volume flows into Devil's Gate Reservoir. The capacity of the Arroyo Seco spreading grounds are sufficient to capture most small storms in the watershed, therefore overflows to Devil's Gate reservoir are limited to larger storm events. Over the ten-year period of the simulation, overflows occurred on ~150 wet weather days (long-term average of ~15 days/yr). While infrequent, the volume of runoff on these days was very large relative to capture in the Arroyo Seco spreading grounds. A portion of this runoff could be captured in Devil's Gate reservoir to recharge the Raymond basin, by infiltration through the Devil's Gate reservoir bottom, and also pumping to the Eaton Wash spreading grounds.

In addition to these wet weather events, more consistent runoff enters Devil's Gate reservoir from Flint Wash. Most of the stormwater runoff from the City of La Canada Flintridge flows into Flint Wash and then into Devil's Gate reservoir. There are no existing facilities to capture and recharge this source of water. The Stormwater Management Model (SWMM) runoff module was used to simulate historical wet weather stormwater runoff from Flint Wash into Devil's gate reservoir. Hourly rainfall data from an LACDPW meteorological station (Station 453) at Devil's Gate Dam was the primary input to the model. Simulation results show that annual wet weather runoff volume is 2,600 AFY in an average rainfall year, and ranges from 800 to 6,500 AFY due to temporal variability in annual rainfall (Table C-3).

In addition to wet weather runoff, dry weather flows are persistent in Flint Wash, mostly from nuisance runoff from outdoor water uses in the City of La Canada Flintridge. Several watershed plans in southern California have evaluated dry weather runoff generation from urban drainages (e.g., City of Los Angeles Integrated Resources Plan (2001); Inland Empire Utilities Agency (IEUA) and Orange County Water District (OCWD) Chino Creek Integrated Plan (2006)). These studies show that dry weather runoff rates from urban watersheds can range from zero to 300 gal/acre/day. The midpoint of this range, 150 gal/acre/day is used to estimate the portion of gauged flows, which could be attributed to nuisance runoff, e.g., from excess landscape irrigation, car washing, or other uses of water in the City of La

Canada Flintridge during dry weather. This urban runoff generation rate equates to a maximum dry weather flow from Flint Wash of 0.8 cfs. Under current operating conditions, dry weather runoff from Flint Wash flows through Devil's Gate Dam, and then passes a LACDPW gauging station (Station F277-R). The only other source of dry weather runoff in Arroyo Seco below Devil's Gate Dam is tunnel outflow. More information about tunnel flows can be found in Appendix E, Fact Sheet on Tunnel Flows.

Table C-3
Rainfall and Simulation Runoff for Flint Wash Drainage Area to Devil's Gate Reservoir (1997-2009)

Fiscal Year	Annual Rainfall (in)	Annual Runoff (AF)
1997-1998	22.7	3,479
1998-1999	10.7	1,637
1999-2000	16.6	2,557
2000-2001	17.2	2,619
2001-2002	5.1	782
2002-2003	15.2	2,315
2003-2004	12.9	1,955
2004-2005	42.3	6,445
2005-2006	17.5	2,684
2006-2007	5.2	809
2007-2008	23.1	3,555
2008-2009	14.6	2,248
Average(1997-2009)	16.9	2,600

Under current operating conditions, all runoff flows through Devil's Gate Dam to the Los Angeles River and ultimately to the Pacific Ocean. LACDPW is proposing a project that would provide conservation storage for stormwater and surface runoff within Devil's Gate Reservoir for recharge in the Raymond groundwater basin. The LACDPW project concept also includes pumping of water stored in Devil's Gate reservoir to the Eaton Wash spreading grounds for additional recharge. The decision to transfer stored water from Devil 's Gate reservoir (Arroyo Seco watershed) to Eaton Wash spreading grounds is driven by two key factors. First, recharge capacity within the reservoir bottom and/or the Arroyo Seco spreading grounds may not allow for the drawdown within a sufficient timeframe to allow for detention storage in the event of a back to back flooding scenario. Secondly, groundwater level decline is more severe in the eastern portion of the Raymond groundwater basin which would be replenished by spreading in the Eaton Canyon.

The mass balance model of surface runoff simulates daily storage and recharge within Devil's Gate Reservoir (S_{dg}) under a LACDPW proposed conservation storage scenario. The proposed project would allow for conservation storage of up to 1,400 acre-feet in Devil's Gate Reservoir. Above this volume, runoff is lost from the system via overflow of Devil's Gate Dam. A large component of this new groundwater recharge would consist of stormwater from Flint Wash (R_{fw}), because of diversions to Arroyo Seco spreading basins upstream of Devil's Gate Reservoir. However, Arroyo Seco runoff that passes the diversion point (R_{as}) is a major inflow to Devil's Gate Reservoir during larger storm events. The mass balance model simulates the storage of water in Devil's Gate reservoir as the sum of inflows and outflows on a given day, as follows;

$$S_{dg} = \left[R_{fw} + R_{as}\right]_{t-1} - \left[I_{dg} + P_{ew}\right]_{t-1} - ENV_{as}\,, \qquad S_{dg} < 1{,}400$$

where:

S_{dg}: Storage in Devil's Gate reservoir (acre-ft)
R_{fw}: Recharge from Flint Wash (acre-ft/day)
R_{as}: Runoff from Arroyo Seco (acre-ft/day)
t: timestep (day)
I_{dg}: infiltration losses from Devil's Gate reservoir (acre-ft/day)
P_{ew}: Pumping to Eaton Wash Spreading Grounds (acre-ft/day)
ENV_{as}: Arroyo Seco environmental flows (acre-ft/day)

A key outflow from Devil's Gate Reservoir is environmental flow needed to sustain the central and lower Arroyo Seco restoration projects downstream of the dam. Although environmental demands have yet to be determined, they were assumed to be 3 cfs, whereby all flows into Devil's Gate Reservoir up to a threshold of 3 cfs is released to maintain downstream flows during and after storm events. Other outflows include infiltration losses within Devil's Gate Reservoir (I_{dg}) and pumping to Eaton Wash spreading grounds (P_{ew}) and environmental flows to maintain adequate water for Arroyo Seco (ENV_{as}). To estimate infiltration losses within Devil's Gate Reservoir, the following assumptions were employed to develop an estimate of recharge capacity of ~24 cfs within the reservoir bottom:

- Wetted area for active recharge is 25 acres on average (given storage-area curves were not available at time of analysis)
- Daily recharge rate of 1.9 ft/day (estimated values for new spreading grounds on the west side of Arroyo Seco)
- Maximum residence time in Devil's Gate Reservoir of 14 days following a storm event

Pumping from Devil's Gate Reservoir to Eaton Wash spreading grounds provides new recharge within the Raymond groundwater basin. However, the storage capacity within Eaton Wash spreading grounds (S_{ew}) to accept transfers from Devil's Gate Reservoir is limited during large storm events. Runoff from Eaton Wash (R_{ew}) routed to the Eaton Wash spreading grounds for recharge (I_{ew}) is given first priority in the mass balance model. LACDPW operates a flow gauge (Station F318) downstream of Eaton Dam that is used to estimate the daily runoff available for routing into the Eaton Wash spreading grounds. The recharge capacity within the Eaton Wash spreading grounds is approximately 14 cfs. While this rate is similar to the current Arroyo Seco spreading grounds capacity, the Eaton Wash spreading grounds have substantially larger storage capacity, which is currently at 525 AF. The storage capacity allows for more capture of wet weather runoff for recharge over a longer period following the storm event.

The mass balance model computes pumping from Devil's Gate Reservoir to Eaton Wash (P_{ew}) as a function of daily storage capacity in both Devil's Gate Reservoir and Eaton Wash spreading grounds;

$$S_{ew} = [R_{ew} - I_{ew}]_{t-1} + P_{ew} \quad , \qquad S_{ew} < 525$$

where:

S_{ew}: Storage in Eaton Wash spreading grounds (acre-ft)
R_{ew}: Runoff from Eaton Wash (acre-ft/day)
I_{ew}: Infiltration in Eaton Wash spreading grounds (acre-ft/day)

The results of this analysis show long-term average annual flows from Devil's Gate to Eaton Canyon of 1,250 AFY and 950 AFY in dry year from the proposed project (Table C-4). Additionally, the mass balance model computed recharge within Devil's Gate Reservoir of approximately 2,100 AFY for long-term average and 1,400 AFY in a dry year.

Table C-4
Normal and Dry Year Yields of Devil's Gate Reservoir and Stormwater Harvesting Options

Supply Option	Estimated Recharge (AFY) [1]	
	Normal Year (2000 - 2001)	Dry Year (2003 - 2004)
Devil's Gate Reservoir – recharge behind dam	2,100	1,400
Pumping from Devil's Gate Reservoir to Eaton Wash	1,250	950
Storm Drain Connection to Pumpback Pipeline	518	250

1) Values shown are projected groundwater recharge volumes and do not represent expected supply credits for PWP

C.6 Stormwater Runoff

Stormwater is runoff within municipal separate storm sewer systems (MS4s) generated by wet and dry weather sources of overland flow in urbanized drainage areas. In the City of Pasadena, discharge of stormwater runoff to flood control channels results in a large volume of fresh water lost to the Pacific Ocean. Capture and reuse of this water resource is a practice that is becoming more popular for water purveyors in Southern California, as access to new groundwater or imported water is limited. Captured stormwater can be used to recharge groundwater or treated for use as a non-potable water supply. For the PWP WIRP, stormwater runoff options fall into two categories; on-site and centralized. On-site stormwater capture involves use of low-level water conservation BMPs such as rain barrels or rain gardens, which can reduce runoff leaving a property as overland flow and instead provide groundwater recharge. Centralized stormwater runoff capture involves diversion of stormwater runoff at a point downstream within the MS4 or from a receiving surface water body. PWP's centralized stormwater capture options exist for Flint Wash, Rubio Wash, and MS4 drainages in the northern part of the City. The option to capture stormwater from Flint Wash is described in the previous section on Devil's Gate Reservoir.

C.6.1 Storm Drain Connection to Pumpback Pipeline

One option for capturing stormwater runoff is to connect storm drains in northern Pasadena and Altadena to the proposed pipe from Devil's Gate Reservoir to Eaton Wash ("pumpback" pipeline). Three storm drain pipelines were identified that could potentially be reconnected to the pumpback pipeline, and are shown in Figure C-7 along with an approximate tributary area.

Hourly flow data from a downstream LACDPW flow gage (F82C-R, Rubio Wash Glendon Way) was scaled downward by the ratio of the tributary area of the centralized stormwater location to the tributary area of the flow gage, which is approximately 0.2. This analysis is similar to the one used for the centralized stormwater option, but only simulates runoff volume from the site and does not include pump stations or storage calculations as it assumes gravity flow is sufficient. This analysis also assumes that there is sufficient pipe capacity to capture all runoff generated from the tributary area is routed to storm drains and that there is sufficient storage for the runoff at the spreading basin. Results show the tributary area north of the pipeline from Devil's Gate to Eaton Wash generates 518 AFY on average, and 250 AFY during a dry year (Table C-4).

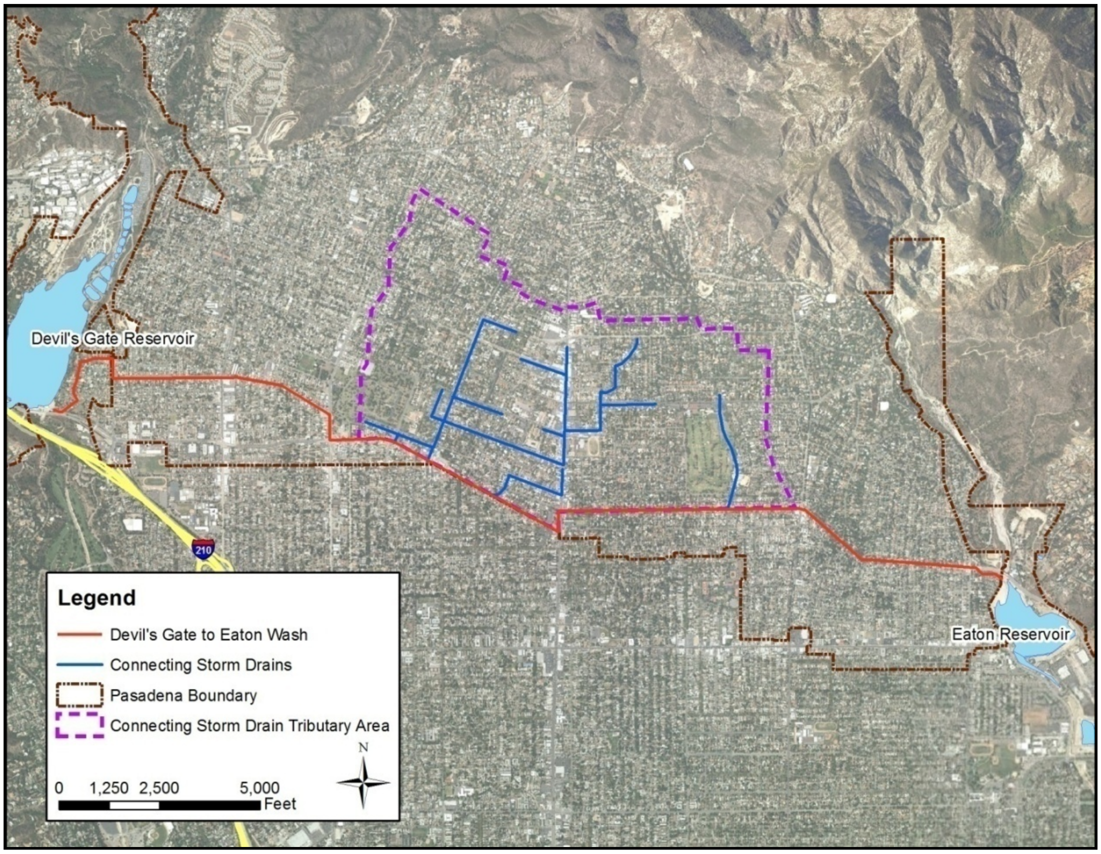

Figure C-7
Storm Drain Connection to Pumpback Pipeline

C.6.2 Rubio Wash Centralized Stormwater

This option collects runoff from the storm drain system at a centralized location and pumps it to Eaton Wash (Figure C-8). The benefits of implementing this project would increase infiltration at Eaton Spreading Grounds, and reduce pollutant loading for Rubio Wash. One potential location for a potential diversion from Rubio Wash is next to San Marino High School. Rubio Wash is owned by LACFCD. Coordination between the City of Pasadena, City of San Marino, LACFCD, RBMB, and other potential stakeholders would be required to implement this option.

Note that the tributary area for the Storm Drain Connection to Pumpback Pipeline in the previous section overlaps with 26% of the tributary area of this option. If both options are implemented, reduction of total runoff capture is not expected because both projects are more limited by the capacity of their respective facilities to capture runoff than the volume of runoff available in the stormwater system. Excess water is generated during storm events for both options to reach capacity. The primary limiting factor for yield for both options is not runoff from storm events but the number of storm events that occur each year.

Hourly flow data from a downstream LACDPW flow gage (F82C-R, Rubio Wash Glendon Way) was scaled downward by the ratio of the tributary area of the centralized stormwater location to the tributary area of the flow gage, which is approximately 0.75. Using these data as inputs a mass-balance model was developed to simulate Rubio Wash runoff capture, pumping to Eaton Wash spreading grounds, storage, and overflow. Multiple scenarios of varying storage and conveyance capacity at the diversion point evaluated the most effective facilities for this centralized stormwater option. Generally, technically feasible scenarios showed that runoff capture is limited compared with total runoff volume. Thus, the limiting factor becomes the siting of facilities. It was determined that pumping and transmission pipelines with a conveyance capacity of 2 cfs could be technically feasible given the site constraints. Implementation of these facilities would provide significant water quality benefits for the upstream stormwater agencies by capturing the first flush of wet weather runoff, and result in average annual capture and recharge of an additional 421 AFY within the Raymond Basin.

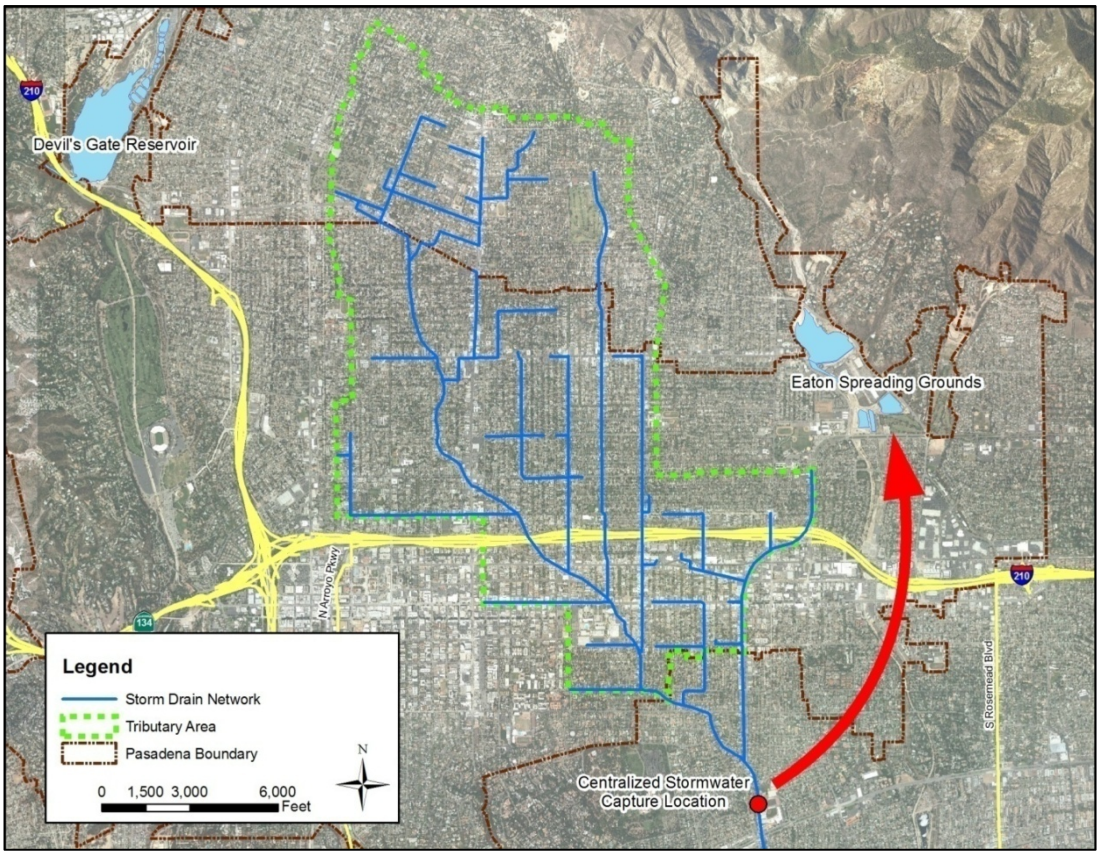

Figure C-8
Rubio Wash Centralized Stormwater Capture

C.7 On-Site Stormwater Harvesting

This option is to provide incentives for homeowners and businesses to install or construct runoff collection systems on their properties. Wet and dry weather runoff captured from residential or commercial properties can be utilized to offset existing on-site non-potable water demands or to provide additional recharge to the Raymond Basin. Four on-site stormwater harvesting options were evaluated:

- Residential Rain Barrels for Non-Potable Demand
- Residential Downspout Disconnection to Rain Gardens for Recharge
- Residential Infiltration strips/bioswales for Recharge
- Commercial Infiltration strips/bioswales for Recharge

Rain barrels are installed to capture runoff from rooftops for use in non-potable water demands, such as irrigation. For residential rain gardens, rooftop runoff is routed through downspouts into gardens designed to infiltrate the water. These gardens have the benefits of reducing off-site runoff and provide aesthetic benefits to the property, but captured runoff cannot be stored and used to offset existing non-potable demands. Bioretention strips on single family residential lots collect not only rooftop runoff, but also any drainage from the property and overwatering. This type of option would be implemented on a neighborhood scale, usually constructed between the road and the residential properties. Bioretention strips for commercial properties would collect runoff from parking lot areas and other available open spaces. A summary of each of the options and their respective yields for normal and dry year is shown in Table C-5.

Table C-5
Normal and Dry Year Yields of Stormwater Harvesting Options

Supply Option	Estimated Yield (AFY) [1]	
	Normal Year (2000 - 2001)	Dry Year (2003 - 2004)
Centralized Stormwater Capture - Rubio Wash	421	200
Residential Rain Barrels	32	11
Residential Raingardens	106	24
Residential Infiltration Strip / Bioswale	256	122
Commercial Parking Lot Swales	321	152

1) Values shown are projected yield volumes and do not represent expected supply credits for PWP resulting from groundwater recharge (pertains to all except rain barrels).

C.7.1 Wet Weather Runoff Capture

Runoff volume capture during wet weather for each of the evaluated options was simulated for BMP installations on a single representative property (residential and commercial) using the CDM developed software NetSTORM. This hourly storage routing model simulates runoff in response to input rainfall and estimates the volume capture of a downstream facility with known storage and treatment capacity. The water supply benefit of widespread on-site stormwater harvesting was estimated by extrapolating simulated yields across the entire City. Implementation of on-site stormwater harvesting was assumed for 25 percent of single-family residential (SFR) parcels and 30 percent of commercial (COMM) parcels.

During a storm event, the capture volume for rain barrels, rain gardens, and bioretention strips primarily depends on the following parameters;

- Tributary area to BMP- The tributary area ranges from as small as a typical SFR rooftop (average of 800 ft^2) for SFR rain barrels and downspout disconnection options to entire SFR parcels (average of 2,700 ft^2) for SFR bioretention strips to entire COMM parcels (average of 17,100 ft^2) for COMM bioretention strips. The entire parcel tributary areas include a reduction factor of 0.9, to account for areas of the property that may not drain to an on-site BMP. Parcel sizes were estimated from GIS data provided by the City of Pasadena, which allowed for calculation of citywide averages of parcel area and building footprint.

- Runoff coefficient for tributary area – Runoff coefficients of 1.0 for the two options, which capture runoff from SFR rooftops only. For SFR and COMM bioretention strips, runoff coefficients of 0.4 and 0.7, respectively, are applied for the entire property area (Ackerman and Schiff, 2003).

- Storage capacity of BMP – For SFR rain barrels a typical household rain barrel of 100 gallons is assumed, with a 3-day drawdown period. For the other options, storage volume is a function of the BMP footprint, and the depth and porosity of media, as summarized in Table C-6.

- Rate stored runoff is emptied from BMP by either infiltration into underlying soils in the case of raingardens and bioretention strips, or application for irrigation of on-site landscaping in the case of rain barrels. These rates are summarized in Table C-6.

The BMP footprint for typical rain garden and bioretention strip BMPs was calculated using a target rainfall capture depth of 0.75 inches. This rainfall depth is equivalent to the sizing criteria for Standard Urban Stormwater Mitigation Plans (SUSMPs) per the local Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) Permit (Permit CAS004001 Order 01-182). The following equations provide an approximate footprint for the potential raingarden or bioretention BMPs per the Los Angeles County Stormwater BMP Design and Maintenance Manual (LACDPW, 2010):

$$A = \frac{(V_{design})(l)}{(t)\left(P_{design}/12\right)(d+l)}$$

Where A = area of rain garden (acres)
V_{design} = design runoff volume (cubic ft)
t = drawdown time
P_{design} = infiltration rate
d = ponding depth
l = planting media depth

$$V_{design} = A_{trib} \times D_{WQ}$$

Where A_{trib} = tributary area to rain garden (acres)
D_{WQ} = water quality depth per storm event (in)

Table C-6
Summary of On-Site Stormwater Harvesting BMP Sizing and Extrapolated Water Supply Benefit Estimates

BMP Characteristics	SFR Rain Barrel	SFR Downspout Disconnection	SFR Bioretention Strip	COMM Bioretention Strip
Unit drainage area (ft^2/project)	800	800	2,700	17,100
Bioretention Footprint (ft^2)	n/a	29	96	611
Storage volume (gallons/project)	100	374	1,262	7,994
Capture rate (gallons/day/project)	14	125	421	2,665
Wet-weather runoff capture (in/yr) [1]	2.4	7.9	4.7	6.6
Potential # of BMP projects [2]	35,182	35,182	35,182	4,600
Implementation rate	25%	25%	25%	30%
Treated drainage area (acres)	162	162	545	542
Wet- weather flow capture (AFY)	32	106	211	298
Dry weather flow capture (AFY) [3]	n/a	n/a	45	22
Long-term average capture (AFY)	32	106	256	321

1) Results of NetSTORM modeling run for representative SFR and COMM parcels
2) Number of parcels in City of Pasadena within SFR and COMM land use categories
3) Estimate is based on assumed irrigation excess generation of 150 gallons per irrigated acre per day

Soil infiltration rates were extracted from the LACDPW database, which is based on modified Natural Resources Conservation Service soil series boundaries and recent double ring infiltration testing. For this analysis, the soil infiltration rate was reduced by 25% to account for soil compaction in developed landscapes. Infiltration of soils within the City of Pasadena are relatively favorable, exceeding 1.0 in/hr in most areas, therefore an infiltration rate (P_{design}) of 0.25 in/hr was used to estimate the footprint of potential raingarden and bioretention BMPs.

Other properties of raingardens and bioretention strips were set to typical values. This includes storage depth of 3 feet, media porosity of 50 percent, allowable ponding of 0.5 feet, and drawdown time of 72 hours. The BMP sizing shown in Table C-6 is based on these assumed BMP sizing criteria.

C.7.2 Dry Weather Flow Capture

Findings of a recent study conducted by the Municipal Water District of Orange County and Irvine Ranch Water District on residential runoff reduction, facilitated the translation of number of properties into dry weather flow (DWF) reductions

(Jakubowski, 2008).[1] This study evaluated DWF from residential drainage areas with and without use of weather based irrigation controllers. This study estimated that dry weather runoff from excess irrigation is approximately 170 gal/irrigated acre/day. To be conservative, a value of 150 gal/irrigated acre/day was used for this analysis. This rate is used to estimate the annual volume of excess irrigation that may be routed to a raingarden or bioretention strip, assuming there are 300 irrigation days in an average year. The results show that dry weather flow capture can provide additional recharge of 45 AFY for SFR parcels and 22 AFY for COMM parcels, with effective routing of irrigation excess to bioretention strips.

[1] Jakubowski, S. 2008. Effectiveness of runoff reducing weather based irrigation controllers (SmartTimers). Presentation to the WaterSmart Innovations Conference, Las Vegas, NV, October 8, 2008.