Seismic Vulnerability Assessment

Supplementary Topics: Storage, Water Quality, Benefit Cost, Service Goals, Emergency Planning, Hydraulics, SCADA

Prepared for:
City of Pasadena
Water Department

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1.0 Introduction

This report provides information on several topics related to the overall Seismic Vulnerability Assessment of the Pasadena Water System.

These topics include:

- Additional reservoir storage and pumping plant upgrades
- Reservoir modifications to promote water mixing
- Benefit cost issues to justify the extent of seismic upgrades
- Service goals issues to justify the extent of seismic upgrades
- Emergency planning and response
- Hydraulic analyses of the Eagle Rock, Annandale, Lida and Sheldon pressure zones
- SCADA and instrumentation upgrades

1.1 Key Findings

Table 1-1 summarizes the costs for the various system improvements described in this report.

Item	Section	Cost
Eagle Rock Reservoir Expansion to 1.3 MG	2	$1,150,000
Calaveras Reservoir Mixing	3	$205,400
Emergency Response	6	$2,337,500
Ross Pumping Plant Expansion to 5 MGD	7.1	$1,500,000
Eagle Rock to Sunset Zone High Flow – Pipelines and Regulating Station	7.1	$2,650,000
Devils Gate Pumping Plant	7.3	$37,000
Sheldon East Reservoir	7.4	$2,500,000
San Rafael Regulating Station, Sheldon Zone Flow Control Instrumentation	8	$200,000
Seismic Instrumentation	8	$100,000
	Total	$10,679,900

Table 1-1. System Improvements Costs

The costs in Table 1-1 are over and above the costs for the reservoir, pump station and well seismic upgrades included in the Seismic Vulnerability Assessment (G&E, 2006a).

Water Demands, and Storage and Pumping. Tables 2-1, 2-2, 2-3 and 2-4 summarize the existing and year 2020 water demands and existing reservoir and pumping plant capacities. Based on three different types of water storage calculations, the existing PWP system either has a surplus of storage or a deficit of storage. If no new storage is added, then reliable pumping (quick connects and standby emergency power) could be provided to solve the storage shortfalls for the Annandale and Lida pressure zones. Some new storage (300,000 gallons) should be added to the Eagle Rock zone, in addition to substantially upgrading the Ross pumping plant (more pumps plus standby power). If reliable standby power is provided at the Jones pumping plant, the need for a new Sheldon East reservoir is diminished, but Section 7.4 of this report shows that in-zone pressure issues strongly suggest the addition of a new Sheldon East reservoir.

Our evaluations show that the Arroyo Seco pumping plant needs to be upgraded to increase pumping flow rates. This upgrade has already been addressed in the MWH master plan (2002), so it is not included in the cost items in Table 1-1.

Water detention time in Tanks and Reservoirs. Table 3-1 highlights that certain tanks in the existing water system are subject to long water detention times. The most problematic detention times are in the Mirador, Gould, Sunset, Allen and Don Benito reservoirs. This can be readily cured by re-chlorination at these tanks, which is already recognized and implemented by the Pasadena Water Department. Alternate strategies could help, such as taking one of the two tanks at Gould and Don Benito out of service during winter time months.

Water mixing within Tanks and Reservoirs. Table 3-2 summarizes the time needed to achieve essentially complete mixing of water within each existing reservoir, assuming realistic fill rates. For certain reservoirs, the mixing times are too long, and current operational practices are suggested to achieve full mixing of the water. The Calaveras reservoir cannot achieve fully mixed water by operational practices alone, and modifying the inlet-outlet pipe for this reservoir is recommended.

Benefit Cost Analysis. Four possible levels of seismic upgrades have been considered for the Pasadena Water System. These are called packages P1, P2, P3 and P4, costing \$2.1, \$5.9, \$8.7 or \$17.8 million, respectively. These packages are cumulative, meaning that P2 includes all the elements of P1, etc. The incremental benefit cost ratios of implement any of the four packages (assuming a 5% discount rate) are as follows:

- P1: BCR = 2.59
- P2: BCR = 2.36
- P3: BCR = 1.93
- P4: BCR = 0.20

A BCR greater than 1 means that the upgrades are worthwhile, and the benefits gained exceed the costs.

If a decision as to how much money to spend on seismic upgrades were made solely on benefit-cost results, P3 would be the logical level of upgrade.

The water system in its as-is condition will be severely damaged in a Sierra Madre M 7.2 earthquake, leading to $145 million in losses. By implementing the P3 program (costing $5.9 million), plus the emergency response actions outlined in this report (costing $2.3 million), the losses will be substantially reduced to $31 million. These upgrades will also substantially reduce losses in less severe earthquakes that can affect Pasadena.

Service Goals Analysis. Ten earthquake service goals are suggested for the Pasadena water system. After a major earthquake on the Sierra Madre fault, the as-is system only meets one of these then goals. By implementing the P3 seismic upgrade program, plus the emergency response actions outlined in this report, essentially all the service goals can be met even after large magnitude earthquakes on the Sierra Madre, Raymond or Verdugo-Eagle Rock faults.

Emergency Planning. The seismic upgrades in P3 will help reduce, but not entirely eliminate, damage to the Pasadena water system after large earthquakes. With suitable emergency planning and preparedness, Pasadena can meet its goals, in part, by being ready to "Manage the Damage". Section 6 of the report makes recommendations that include:

- Stockpiling of spare parts
- Available staff for emergency response and repair
- Procurement of suitable lengths and diameters of flexible hose.
- Procurement of five emergency generators, plus availability of more emergency generators and portable pumps via mutual aid.
- The existing Contingency Plan for Pasadena Water and Power should be updated to reflect the findings of the seismic vulnerability assessment.

Hydraulic Analyses. Hydraulic analyses were performed for 4 pressure zones, to help establish the need for in-zone upgrades (either more storage or pipes).

- For the Eagle Rock zone, about 6,950 feet of 16-inch pipe (possibly 8,150 feet) should be added to the zone; plus three new 100 horsepower pumps at the Ross pumping plant. The Eagle Rock reservoir should be expanded by at least 0.3 MG.

- For the Annandale and Lida zones, quick connect couplings and suitable sized emergency generators are a viable and lower cost option than adding additional in-zone storage. The cost of these upgrades is about $0.12 million for the Annandale zone, which is much less than the cost to install additional storage ($2 million). The cost of these upgrades is about $0.04 million for the Lida zone, which is much less than the cost to install additional storage ($1 million).

- For the Sheldon zone, the east side of the zone is not currently functional at maximum day demands strictly under gravity flow. Either a new Sheldon East reservoir should be installed, or reliable pumping (install permanent standby power) must be provided at the Jones pumping plant. Due to the topographic restrictions at the proposed Sheldon East site, coupled with the possible existence of a strand of the active Sierra Madre fault at the site, plus the findings from the hydraulic analyses, the following limitations are placed on the design of any new reservoir at this site:

    - The overflow should ideally not be higher than 1050 feet, unless a flow control valve is placed in the Sheldon zone to effectively split the zone into Sheldon East and Sheldon West. If a higher elevation is chosen, and the zone is not split, it is likely that the new Sheldon East reservoir will preferentially service a large portion of the total Sheldon zone, resulting is lower water turnover in the existing Sheldon reservoirs, thereby impacting water quality in the west side of the zone.

    - The Sheldon East site could likely accommodate a new 2 to 3 MG reservoir. A larger reservoir (4 MG) will require more extensive and costly excavations. Any new reservoir for the site will likely need to be able to accommodate a 2 to 3 meter uplift due to faulting, with damage, but without releasing water in a manner so as to create a life safety threat to downstream people, buildings and infrastructure. The new reservoir does not have to be reliable after a Sierra Madre M 7.2 earthquake. A single open cut reservoir could be installed, or possibly a dual steel tank system; the dual steel tank system could likely be sited in a manner so that at least one of the two tanks would survive a Sierra Madre M 7.2 earthquake. The cost for the new reservoir is $2.5 million. The cost for the additional piping is included in the master plan report by MWH (2002).

SCADA System. All batteries in the system should be verified or replaced so as to provide at least 18 hours (preferably 24 hours) continued operation. All batteries and computer equipment should be adequately restrained. New instruments (flow and pressure) should be installed at the San Rafael pressure regulating station, assuming the Eagle Rock upgrades described elsewhere in this report are implemented ($100,000). Instrumentation for a new rate control station in the Sheldon zone should be included, should the Sheldon East reservoir be constructed ($100,000) and the zone split. Seismic instruments should be installed in the water system at several points ($100,000, lower priority), possibly in conjunction with USGS and ShakeMap efforts. New instruments should be considered for any new 16" diameter or larger pipe that crosses an active fault, should that pipe be designed to be rapidly isolated after an earthquake.

1.2 Acknowledgments

Mr. Farid Niknam of the Pasadena Water Department is the overall project manager of this effort. Many people in the Pasadena Water Department assisted in this effort, and their support is gratefully acknowledged.

This report was prepared by John Eidinger, Donald Duggan, Darlene Holston and Ken Goettel.

1.3 Abbreviations

BCR	Benefit Cost Ratio
C	Hazen Williams coefficient
cfs	Cubic Feet per Second (1 cfs = 0.65 MGD)
FEMA	Federal Emergency Management Agency
FIFO	First In First Out
hp	Horsepower
g	acceleration of gravity (=32.2 feet / second / second)
G&E	G&E Engineering Systems Inc.
gpm	gallons per minute
kW	kiloWatt
M	Magnitude (moment)
MG	Million Gallons
MGD	Million Gallons per Day (1 MGD = 1.55 cfs)
MWD	Metropolitan Water District
MWH	Montgomery Watson Harza
OCLR	Open cut lined reservoir
PGA	Peak Ground Acceleration (measured in g)
P1-P5	Turnout abbreviations from MWD to PWP system
P1-P4	Priority 1, 2, 3 and 4 seismic upgrade packages.
PP	Pumping Plant
PWP	Pasadena Water and Power
RC	Reinforced concrete
SCADA	Supervisory Control and Data Acquisition

1.4 Limitations

The findings in this report are meant for post-earthquake planning purposes for the City of Pasadena. The findings are based on information made available to G&E Engineering Systems Inc.

2.0 Reservoir and Pumping Upgrades

Figure 2-1 shows a schematic layout of the Pasadena water system.

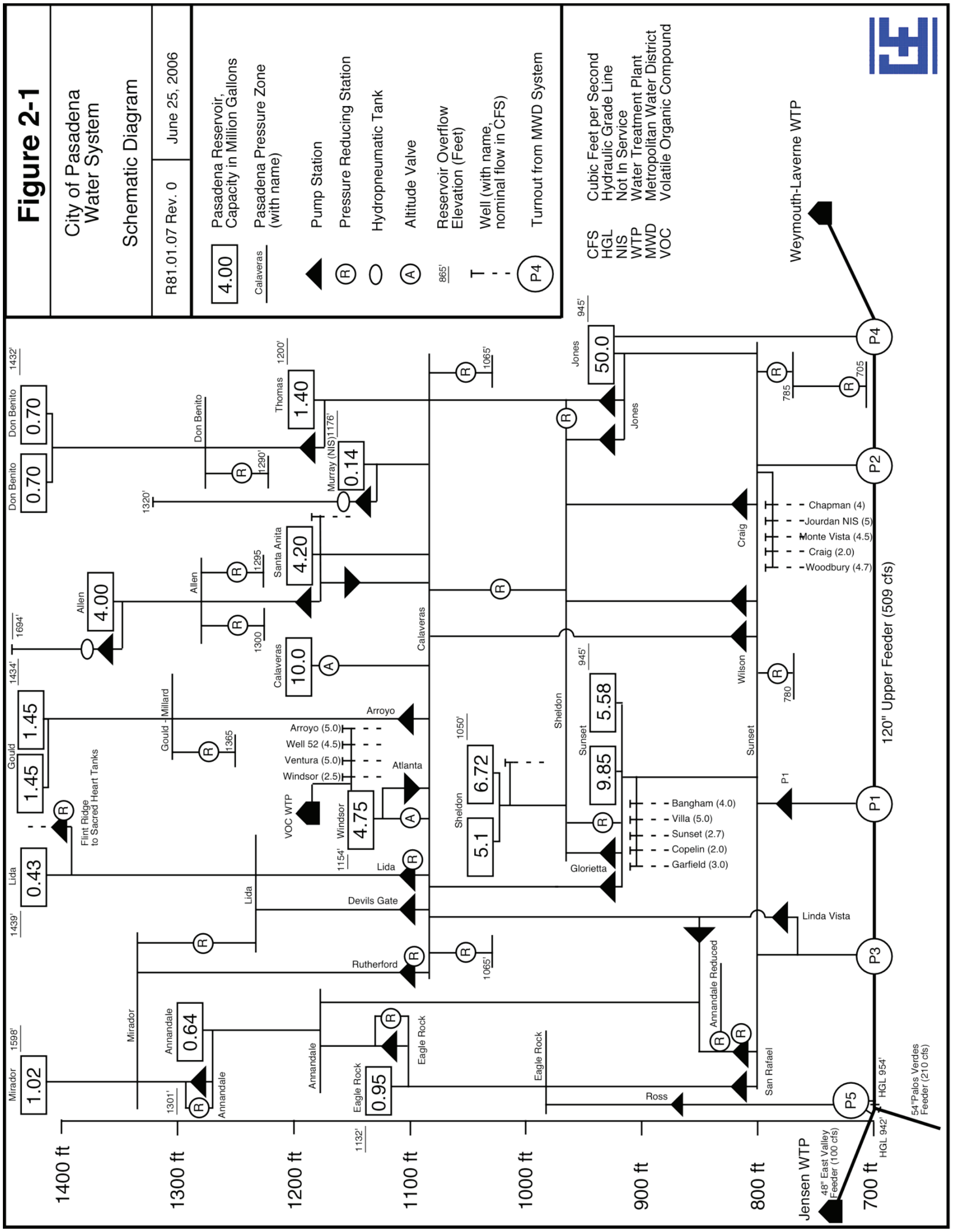

Figure 2-1

City of Pasadena Water System

Schematic Diagram

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2.1 Water Demands

The water demands for Pasadena are estimated for the year 2020. All calculations presented in this report are based on these year 2020 demands.

The water demands are estimated based on data in the MWH report (2002). The demands are allocated within each of ten main pressure zones in the water system. By "main pressure zone", it is meant that regulated pressure zones that draw water from an uphill zone are assumed to be part of that uphill zone, for purposes of estimating reservoir storage and pump sizes for that zone.

Table 2-1 lists the water demands by main pressure zones. Maximum day demands are taken as 1.72 times ADD for each main pressure zone.

Main Zone	Total Zone Storage (gallons)	2002 ADD (MGD)	2002 MDD (MGD)	2020 ADD (MGD)	2020 MDD (MGD)
Gould Millard	2,900,000	0.99	1.70	1.22	2.10
Lida	430,000	0.22	0.38	0.27	0.47
Mirador	1,020,000	0.16	0.28	0.20	0.34
Annandale	640,000	0.51	0.88	0.63	1.08
Eagle Rock	950,000	1.23	2.12	1.52	2.61
Calaveras	20,400,000	8.39	14.43	10.33	17.78
Sheldon	11,820,000	6.70	11.52	8.25	14.20
Sunset	65,430,000	13.65	23.48	16.81	28.92
Allen	4,000,000	0.83	1.43	1.02	1.76
Don Benito	1,400,000	0.28	0.48	0.34	0.59
Total	108,990,000	32.96	56.69	40.60	69.83

Table 2-1. Water Demands by Main Pressure Zone

MWH (2002) considered fire flows for purposes of estimating storage volumes. except for Sheldon and Sunset, they assumed fire flows of 3,000 gpm for 3 hours. For Sheldon, they assumed 5,000 gpm for 5 hours; for Sunset, 4,000 gpm for 4 hours.

2.2 Reservoirs

There are 19 water storage reservoirs and tanks in the Pasadena water system. Figure 2-1 shows how the reservoirs serve the system. Table 2-2 lists the reservoir capacities, the overflow level, the bottom elevation, and the basic style of construction. Excluding the Murray reservoir (not in current service), the total storage capacity of all Pasadena reservoirs is about 109 million gallons. (The Sacred Heart tanks are not part of the Pasadena water system, but can provide flow via emergency regulator into the Lida pressure zone).

Reservoir	Minimum Water Level (feet)	Maximum Water Level (feet)	Capacity (MG)	Type	Roof System
Allen	1458	1480	4.00	OCLR	Wood with metal roof
Annandale	1283	1301	0.64	OCLR	Wood with metal roof
Calaveras	1188	1209	10.0	OCLR	Wood with metal roof
Don Benito 1	1402	1432	0.70	Steel	Wood roof
Don Benito 2	1402	1432	0.70	Steel	Wood roof
Eagle Rock	1114	1132	0.95	OCLR	Wood with metal roof
Gould 1	1411.6	1433.6	1.45	Steel	Aluminum dome
Gould 2	1411.6	1433.6	1.45	Steel	Aluminum dome
Jones	917	945	50.0	OCLR	RC walls and roof
Lida	1421	1439	0.43	OCLR	Concrete Roof
Mirador	1577	1598	1.02	OCLR	Wood with metal roof
Murray	1170	1176	0.14	OCLR	Wood
Sacred Heart		1710	0.8		Emergency only
Santa Anita	1186	1207	4.20	OCLR	Wood with metal roof
Sheldon 1	1032	1050	6.72	OCLR	Wood with metal roof
Sheldon 2	1031	1050	5.10	OCLR	Wood with metal roof
Sunset 1	928	945	5.58	OCLR	Wood with RC walls, metal roof
Sunset 2	928	945	9.85	OCLR	Wood with RC walls, metal roof
Thomas	1185	1200	1.40	RC	RC walls and roof
Windsor	1140	1154	4.80	OCLR	Wood with metal roof
Total			109.1		

Table 2-2. Reservoirs (Existing, 2005)

The Murray hydropneumatic tank is 2,500 gallons. The Allen hydropneumatic tank is 3,600 gallons. The Sacred Heart tank serves the Lida zone. The Altadena reservoir, with total storage capacity of 1.2 MG, is owned 2/3 by Foothill MWD and 1/3 by Pasadena, would serve the Calaveras zone by gravity flow.

The required storage can be considered as the sum of three components: equalizing storage, emergency storage, fire flow storage. Storage volumes also consider water detention times with respect to water quality issues. The components are described below:

- Equalizing storage, plus
- Emergency storage, plus
- Fire flow storage.

Various formulae have been used by other water utilities to establish the amount of in-system water storage. For example, for a water utility with very limited storage, the City of Brisbane (California) assumes that in-zone storage should be based on the following formula:

$$Storage = 1.33 * (0.25 * MaxDayDemand + FireFlowDemand) \qquad \text{(Eq. 1)}$$

Using this formula, and considering the entire City of Pasadena as a single zone, and assuming a fire flow demand 1.2 MG, then the local storage requirement would be (year 2020):

- 1.33 x (0.25 * 69.8 + 1.2) = 24.8 MG

The City of Pasadena currently has much more storage (109 MG) than this very limited storage (24.8 MG). The City of Brisbane recognizes that their storage is limited, and in part to increase system-wide reliability, Brisbane has permanently installed emergency generators and/or pumps with permanent standby power at every one of their pump stations.

Other water utilities use different formulae. For example, the East Bay Municipal Utility District (serving 22 cities in the eastern San Francisco Bay Area, California) assumes that in-zone storage should be based on the following formula:

$$Storage = 1.5 * MaxDayDemand + FireFlowDemand \qquad \text{(Eq. 2)}$$

Using this formula, and considering the entire City of Pasadena as a single zone, then the local storage requirement would be (year 2020):

- 1.5 x 69.8 + 1.2 = 105.9 MG

The EBMUD storage capacity is actually applied in a zone-by-zone basis, such that every pumped pressure zone must meet this criteria. In practice, EBMUD has quite a bit more storage (almost 700 MG), and over the past decade or so has been taking older reservoirs out of service in order to improve system-wide water quality. In its pumped pressure zones and in all newer developments, EBMUD only requires storage per (Eq. 2).

The storage requirements accurately adopted by other water utilities usually fall between the two extremes of Brisbane (limited storage) and EBMUD. This was not always the case, and fifty years ago it would not have been uncommon to plan for three (or more) days storage. Over the past decades, as power supplies have become more reliable, and with the implementation of real-time SCADA systems to monitor water levels, the need for very high local storage volumes has decreased. Under normal circumstances, including typical power outages and winter storms, EBMUD's pumped zones (lacking standby power) have had no water outages.

MWH (2002) proposed a storage requirement per pressure zone of 0.8*MDD + fire flows.

$$Storage = 0.8 * MaxDayDemand + FireFlowDemand \qquad \text{(Eq. 3)}$$

In consideration of emergency situations like common power outage, the amount of storage for Pasadena should consider the following issues:

- There should be sufficient local storage to carry Pasadena without impact to customers should there be typical outages due to power outage (common winter storm); regional power outage (summer time load imbalance or storm); or a not too uncommon water turbidity event in the MWD system. A minimum time for such types of outages would be 8 hours; EBMUD assumes 36 hours. It is likely that having sufficient water for 24 hours should be able to carry Pasadena through most "normal" disruptions; and a total water outage anywhere in Pasadena due to a lack of water supply would not occur much more than once every 50 to 200 years (barring a large earthquake).

It is therefore concluded that for purposes of Pasadena, a reasonable water storage criteria would be as follows:

- City Wide: 1.5 times maximum day demand plus fire flow. The City already more or less meets this criteria, assuming year 2020 maximum day demand.

- Pumped pressure zones, without standby power. Provide (ideally) 1.5 times (maximum day demand for that zone plus local area fire flow).

- Pumped pressure zones, with reliable standby power. Provide (minimum) 0.33 times maximum day demand for that zone plus 1.33 times local area fire flow; plus the ability to pump the required fire flow using permanent standby power.

In Pasadena, the high fire risk areas where there is limited water storage and small diameter water pipes are the Don Benito, Mirador, Annandale, Lida and Eagle Rock pressure zones. Under adverse conditions (high winds and low humidity in the dry September – October time frame), it is possible that a small ignition, if not controlled rapidly, could lead to a conflagration. It is doubtful that a water system upgrade could cost-effectively provide sufficient water supply to control a large conflagration in these areas. (One upgrade alternative would be to upgrade all these zones to be able to provide fire flows of 1,500 gpm simultaneously at two separate fronts for 4 hours, while simultaneously allowing for water loss through open service connections). It is more likely that alternative strategies (rapid ignition detection and response; active fuel management; fire department training, etc.) might provide a better overall strategy.

Using the above criteria, we estimate the storage needed for each main pressure zone. To do this, we use the water demands in Table 2-1, plus the following fire flows: for all the smaller pressure zones, the fire flows were assumed to be 1,500 gpm for 2 hours; for Calaveras 3,000 gpm for 4.33 hours; for Sheldon and Sunset, 3,000 gpm for 3.33 hours.

The results from these calculations are provided in Table 2-3. The calculations in MWH (2002) rely on somewhat different fire flows and zone demands.

Main Zone	Total Zone Storage (MG)	Surplus Brisbane (MG)	Surplus EBMUD (MG)	Deficit Brisbane (MG)	Deficit EBMUD (MG)	Deficit MWH (MG)
Gould Millard	2.90	1.96			0.43	
Lida	0.43	0.04			0.45	1.10
Mirador	1.02	0.67	0.33			
Annandale	0.64	0.04			1.16	1.67
Eagle Rock	0.95			0.16	3.14	2.74
Calaveras	20.40	13.45			7.04	
Sheldon	11.82	6.30			10.07	3.50
Sunset	65.43	55.02	21.45			
Allen	4.00	3.18	1.18			
Don Benito	1.40	0.96	0.33			
Total	108.99	81.62	23.29	0.16	22.29	9.01

Table 2-3. Water Storage by Pressure Zone (2020)

Before deciding whether or not a particular pressure zone needs additional storage, one should also consider the type of water supply available to that zone (via gravity or pumping), whether there is additional water supply available from upper zone storage via pressure regulator, system hydraulics, and earthquake reliability factors.

From Table 2-3, only the Eagle Rock zone shows some amount of deficit of storage when using any of the three methods of calculation. We recommend that the Eagle Rock reservoir be increased in storage capacity by 300,000 gallons. This can be achieved by removing the reservoir roof, installing short height walls around the reservoir, and then reinstalling the reservoir roof. The upgrades would meet the latest seismic criteria (G&E 2006c). After the upgrade, the reservoir will still be essentially invisible to neighbors, and will provide better fire protection for the area. The cost of this upgrade is estimated to be $1,150,000, including construction, engineering, planning and inspection.

It can be seen that the EBMUD criteria results in more local storage than either the MWH or Brisbane criteria. The much lower storage suggested using the Brisbane criteria requires that every pumping plans have permanent standby power; the EBMUD criteria assumes that no pumping plant has any standby power. It is apparent that there is a trade-off between storage and pumping as two sources of water for a pressure zone, and that some reduction in local storage seems reasonable if there is more reliable water available from pumping. For design of new elevated pressure zones, it is not uncommon that no local-in zone storage is provided, (addressing the topography, land available and "view" issues voiced by neighbors) should the pump station be outfitted with variable speed pumps, and the ability to pump the fire flows, without the need for offsite power.

As is recommended in the Seismic Vulnerability Assessment (G&E 2006a), several pumping plants should be retrofitted to include quick connect couplings (or bypass pumping tees), with the ability of have available within a short time (8 or less for hillside zones, 16 hours or less for the Calaveras and Sheldon zones) suitable portable / permanent emergency generators or portable pumping, or reliable power (reliable meaning power is restored within these time periods after a major earthquake on the any of the Sierra Madre, Verdugo-Eagle Rock or Raymond faults) delivered by the city-wide electric system, to push water from lower to upper zones before those zones are likely to go "dry" after a major earthquake. The primary reason for this equipment is that very large nearby earthquakes are likely to cause long term power outages for essentially the entire City of Pasadena for up to 36 to 72 hours (G&E 2006b); although with some limited mitigation efforts to the Pasadena power system, City-wide power outages can be reduced by half (these mitigation activities are described in G&E 2006b). In the interim time, water demands from consumption, fire flows and leakage through broken pipes can lead to complete loss of water supply from storage in the smaller up-hill pressure zones within about 8 hours; and the lower elevation large zones (Calaveras, Sheldon and Sunset) within about 16 hours. Thus, it is important to be able to draw water from lower elevation zones (or MWD if available) and pump the water uphill within these time frames.

In a major earthquake on the Sierra Madre fault, it is possible that the MWD Upper Feeder will be damaged for 90 days or longer, due to fault offset through tunnel portions of that conduit. In this case, it is important to restore power to Pasadena's wells within a few hours after the earthquake, so that there will be sufficient water within the city. The Seismic Vulnerability Assessment (G&E 2006a) describes the quick connect upgrades needed for the wells.

For these reasons, upgrades to pump stations and wells are recommended to have a reliable way of restoring water supply and pumping within a few hours after any earthquake that includes a City-wide power outage.

2.3 Pump Stations

There are 21 pump stations (also called booster stations) in the Pasadena Water System. Figure 2-1 shows how these pump stations function to move water between pressure zones. Table 2-4 provides key operational capacities of the pump stations. (Source data for Table 2-4 from annual year books, supplemented by data from MWH (2002)).

Pump Station	Pump Number	Pump Rated Capacity, horsepower	Pump Rated Capacity, gpm	Discharge Head, feet	Zone Served
Allen	#1	7.5	110	110	Allen Hydro
	#2	40	457	216	Allen Hydro
	#3		400	180	Allen Hydro
Annandale	#1	40	321	325	Mirador
	#2	40	299	317	Mirador
Arroyo	#2	40	317	295	Millard / Gould
	#3	40	750[1]		Millard / Gould
Atlanta (5.9)	#3	60	2,700	70	Calaveras
	#4	100	3,620	69	Calaveras
Craig	#2	125	1480	149	Sheldon East (Brigden)
	#3	40	1002	130	Sheldon East (Brigden)
	#4	40	1002	130	Sheldon East (Brigden)
Devils Gate	#1	60	575	316	Lida
	#2	60	550	321	Lida
Eagle Rock	#1	30	320	280	Annandale
	#2	40	420	220	Annandale
Flint Ridge	#1	60	550	320	Sacred Heart
	#2	60	550	320	Sacred Heart
Glorietta	#1	300	4,600	360	Calaveras
	#2	400	4,500	309	Calaveras
	#3	150	3,580	134	Sheldon
Jones	#2	150	1,677	262	Thomas / Calaveras
	#3	50	1,100	124	Sheldon
	#4	50	396	278	Thomas / Calaveras
	#5	150	1,898	284	Thomas / Calaveras
	#6	125	2,200	155	Sheldon

Table 2-4. Pump Stations (Part 1)

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[1] One of the two pumps at Arroyo was upgraded in 1999 from 307 gpm to 750 gpm, per MWH 2002.

Pump Station (Report Section)	Pump Number	Pump Rated Capacity, horsepower	Pump Rated Capacity, gpm	Discharge Head, feet	Zone Served
Lida	#1	50	400	270	Lida
	#2	50	400	270	Lida
Linda Vista	#1	200	2,250	290	Calaveras
	#2	20	360	145	Annandale
Murray	#1	20	250	150	Murray Hydro
	#2	20	250	167	Murray Hydro
P1	#1				Sunset
Ross	#1	50	744	198	Eagle Rock
	#2	50	748	201	Eagle Rock
Rutherford	#1	40	280	405	Mirador
	#2	40	280	405	Mirador
San Rafael	#1	40	400	240	Eagle Rock / Annandale
	#2	100	1,200	214	Eagle Rock
	#3	75	1,200	214	Eagle Rock
Santa Anita	#1	125	1,340	299	Allen
	#2	250	2,200	220	Allen
	#3	250	2,200	220	Allen
Thomas	#3	100	1,000	238	Don Benito
	#4	100	1,000	238	Don Benito
VOC			3,500		Windsor Reservoir
			3,500		Windsor Reservoir
Wilson	#1	200	4,150	165	Sheldon
	#2	200	4,495	152	Sheldon
	#3	200	2,420	282	Calaveras
	#4	200	2,275	280	Calaveras
	#5	200	2,345	280	Calaveras

Table 2-4. Pump Stations (Part 2)

We examined the possible need to upgrade pump stations (booster stations) to increase pumping capacity. Table 2-5 considers only booster pump stations (all water supply from MWD), and assumes that the largest pump serving a zone is out of service.

In Table 2-5, we assume that the preferred water source for Mirador zone is via the Rutherford pumping plant.

Pressure Zone to be Supplied	Year 2020 MDD (MGD)	Supply Booster Stations	Pumping Rate with largest pump out of service (MGD)	Pumping Rate with largest pump out of service (gpm)	Time to pump 2020 MDD[2] (hours)
Don Benito	0.59	Thomas	2.88	1,000	9.9
Gould / Millard	2.10	Arroyo	0.46	317	110.3
Lida	0.47	Lida, Devils Gate	1.61	1,121	6.9
Mirador	0.34	Annandale, Rutherford	1.24	859	6.6
Annandale	1.08	San Rafael, Eagle Rock, Linda Vista 2	1.58	1,080	16.4
Eagle Rock	2.61	Ross, San Rafael	3.88	2,692	16.1
Eagle Rock + Annandale	3.69	Ross, San Rafael, Linda Vista 2	4.39	3,052	20.2
Eagle Rock + Annandale + Mirador	4.02	Ross, San Rafael, Linda Vista 2, Rutherford	5.20	3,540	18.6
Allen + Allen Hydro	1.81	Santa Anita	5.10	3,540	8.5
Sheldon	14.2	Wilson, Jones, Craig, Glorietta	20.90	14,514	16.3
Calaveras	17.78	Atlanta, Glorietta, Jones, Linda Vista, Wilson	34.68	24,080	12.3
Calaveras + Don Benito + Allen + Gould + Lida + Mirador	22.97				15.9

Table 2-5. Time to Pump Maximum day Demand

As seen in Table 2-5, the Gould / Millard zone cannot be supplied at year 2020 Maximum Day Demand rate (estimated at 2.1 MG) using just the existing Arroyo pumps,

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[2] The pump flows are based on available pump capacity information, generally assuming only one pump turned on in the zone at a time. When multiple pumps are turned on, each becomes somewhat more inefficient, due to rising head losses with increased water velocity in the pipe network. Therefore, the time to fill values may be low.

assuming one out of service, as it would take 110 hours to supply 24 hours worth of water. Year 2000 ADD for the Gould / Millard zone is about 1.70 MGD, so even with both pumps on, the year 2000 maximum day demand cannot be met by pumping alone.

At present time, this shortfall can be met via supply from the in-zone Gould tanks (as long as maximum day demands abate within a few days) and in emergency, via interconnects 14 and 18 with the Lincoln Avenue Water Company (see MWH page 134 Figure 4-1).

EBMUD sizes its pump stations to be able to pump maximum day demand within 18 hours, assuming the largest pump out of service. The "18 hour" target duration was set for two reasons:

- Many power companies establish provide time-of-use schedules that provide lower cost electricity should no power be used during peak demand times, generally in the late afternoon. This ultimately saves money for the water company, by lowering peak electric power demands on the power company. In Pasadena, the water department currently does not have such a rate schedule, although it might be considered in the future.

- Being able to pump the maximum day demand within 18 hours provides a further factor of safety in the overall design of the water system.

As can be seen from Table 2-5, the Gould / Millard zone is clearly deficient in terms of pumping capacity. Table 2-5 also shows that the Eagle Rock zone including its higher elevation supported zones (using the combined pumps at Ross, San Rafael, Linda Vista and Rutherford pumping plants) is moderately short on pumping capacity when using the EBMUD criteria.

MWH (Page 7-31) recommends abandoning the Annandale PP. They report that the pumps are seldom used due to a cycling problem with the automatic controls, and water hammer; and instead, the Rutherford pump station is commonly used to fill the Mirador reservoir. From an earthquake risk reduction point of view, using the Annandale pump station is useful to push water from MWD turnouts P5 to the Mirador zone, after a Sierra Madre earthquake (MWD turnouts P4 and P2 will be unavailable, and depending on damage pattern, MWD turnouts P1 and P3 may not be able to get water from the East Side feeder), therefore avoiding the need to re-pump the water and lessening the high flow rates from the Eagle Rock zone into the Sunset zone via the regulating station at the San Rafael pumping plant. MWH noted it would cost about $650,000 to rehab the Annandale pump station. From an earthquake point of view, a portable pump placed at the Annandale pump station would serve much the same purpose, so in an earthquake emergency causing long term loss of the Upper Feeder, it would be suitable to maintain the site with (at least) the ability to do bypass emergency pumping (keep space available to leave the portable pump, and a lower pressure and high pressure fire hydrants for hookup).

Ross PP. As described in the SVA (G&E 2006a), the Ross PP should be upgraded from its current 2 MGD (3 cfs) rate to at least 5 MGD (8 cfs) (ideally upgraded to 8 MGD) to be able to supplement local wells should there be a long term outage of the Upper Feeder (likely in a large Sierra Madre earthquake event).

Arroyo PP. To meet the EBMUD pumping criteria (pump MDD in 18 hours), a total of 2.79 MGD pumping capacity would be required, not including the largest pump. Currently, there are two 310 gpm pumps (MWH reports one 310 gpm pump and one 750 gpm pump). The discharge head for Arroyo Seco pump station is relatively high (about 300 feet). As the Gould zone already has sufficient in-zone storage, even using EBMUD criteria, then it might be acceptable to relax the pumping criteria to something like meeting MDD in 24 hours, with the largest pump out of service. Thus, the target pump station size for Arroyo Seco is three 750 gpm (= 1.08 MGD = 1.7 cfs) pumps (one existing plus two new). In comparison, MWH proposes that the pump station be upgraded from the existing 0.7 cfs + 1.7 cfs pumps to 2.4 cfs + 1.7 cfs + 2.4 cfs, which would provide a reliable pumping capacity of 4.1 cfs (= 2.7 MGD). MWH assumes a somewhat higher peaking factor for the Gould / Millard zone that does G&E, resulting in somewhat different calculations. Table 2-6 summarizes the findings:

Arroyo Pump	Existing (MGD)	G&E Recommended Year 2020 (MGD)	MWH Recommended Year 2002 (MGD)	MWH Recommended Year 2020 (MGD)
2	0.46	1.08	1.55	1.94
3 (horizontal)	1.08	1.08	1.08	1.08
4	-	1.08	1.55	1.94
Reliable Capacity	0.46	2.16	2.63	3.02

Table 2-6. Arroyo Seco Pump Station

3.0 Reservoir Mixing Time Evaluations

We examined the water mixing characteristics of the water reservoirs and tanks, with the intent to help decide whether the inlet-outlet piping to these reservoirs should be altered as part of the overall seismic improvements.

The MWH 2002 Master Plan goes into detail about the need to make various water system upgrades to address pressure, fire flows, pipe age and other factors. In Section 3 of this report, we address *only* the issue of water mixing within each existing reservoir, and given these issues, make recommendations as to how to modify inlet-outlet pipes (or reservoir operations) in order to promote better mixing of water within the reservoirs.

Water quality within the Pasadena water system has more to do than just mixing of water within the reservoirs. For example, to maintain high water quality, as measured by chlorine levels, travel times of water in the distribution system should be kept as short as possible. Network travel times are affected by many factors such as the spatial and temporal distribution of demands, pipe sizes, pipe wall characteristics and network geometry. In addition to the transit time through the pipes, water is often stored in tanks to reduce pumping costs or maintain fire protection levels. Tank/reservoir detention (residence) times may be long and can negatively impact water quality in the overall system. Poor mixing and long detention times in tanks/reservoirs can lead to loss of disinfectant residual, microbial re-growth, and the formation of disinfection by-products. The hydraulics of mixing of waters within tanks/reservoirs must be understood to correctly represent the effect of tank/reservoirs detention times on overall system water quality.

Once water enters a tank / reservoir, the internal water flows and constituent distribution can be modeled by a number of approaches. The most complex is computational fluid dynamics modeling that includes a detailed physical tank description. A simpler model can be used for preliminary evaluation; this simpler model considers how water entering each tank might stir the existing water within the tank. With sufficient stirring, the water quality essentially everywhere in the tank will be about the same. Another level of refinement considers movement of the water in the tank as uniform layers assuming different types of plug flow. This report relies upon these simpler models to consider water detention times.

To introduce spatial variability within a tank, the tank can be partitioned into several compartments to represent the flow patterns and mixing zones within the tank. Such systems are conceptual descriptions rather than fully portraying the complete physical processes, and ideally they should be formulated and calibrated with field data.

Flow to many tanks/reservoirs is provided with sufficient momentum that causes the water to be nearly completely mixed. Under this assumption, at a given instant, the water in the tank is a uniform blend of all waters that have entered the tank/reservoir over time.

Each reservoir and tank in the Pasadena system can be thought of as being in one of four styles of mixing:

- Complete Mixing. This assumes that all water enters a tank and is instantaneously and completely mixed with all water already in the tank. This is the simplest behavior to assume in hydraulic analyses. This assumption seems to apply quite well to a large number of facilities that operate in a fill-and-draw fashion. For example, complete mixing assumption is reasonable under current operating conditions for the existing Don Benito (both tanks), Lida, Annandale, Mirador, Murray, Thomas (both basins), Allen and Santa Anita reservoirs.

- Two Compartment. This assumes that the tank operates into two compartments, both of which are completely mixed. The inlet-outlet pipe of the tank only fills or draws water from the first compartment, where it is completely mixed. If the first compartment is full, then water overflows into the second compartment, where it is completely mixed. Water leaves the first compartment, which, if full, receives an equivalent amount of water from the second compartment. The second compartment represents water in "dead" zones. for example, the Calaveras reservoir appears to currently operate with "two compartments", with sufficient mixing occurring near the inlet-outlet pipe, but not at locations far away from the inlet-outlet pipe.

- FIFO Plug Flow. This assumes that the water that is "first in (FI)" is the same water that is "first out (FO)". This assumes that there is no mixing of water within the tank; instead, all the water moves through the tank in a segregated fashion. This approximates a tank with internal baffles with one inlet pipe and a separate outlet pipe, with simultaneous inflow and outflow. For example, the Eagle Rock, Gould (both tanks), Windsor, Sunset (both basins) and Jones reservoirs normally operate with FIFO plug flow.

- LIFO Plug Flow. This assumes that the water that is "last in (LI)" is the same water that is "first out (FO)". This assumes that there is no mixing of water within the tank. Instead, each "plug" of water enters the tank from the inlet pipe, and the water parcels stack up on one another, with water entering and leaving the tank from the bottom. This type of model might apply to a tall, narrow standpipe with an inlet-outlet pipe at the bottom of the tank, and where the water enters the tank with low momentum flow. There are no tanks or reservoirs in the Pasadena system that currently approximate this condition.

Using the storage volumes and pressure zone demands described in Section 2, we first evaluated the average detention times for (totally mixed) water in each reservoir. the results are in Table 3-1.

Zone	Storage	Winter 2020	ADD 2020	MDD 2020	Winter	ADD	MDD
	Gallons	Gal per Day	Gal per Day	Gal per Day	Days	Days	Days
Gould Millard	2,900,000	914,609	1,219,478	2,097,502	3.17	2.38	1.38
Lida	430,000	203,246	270,995	466,112	2.12	1.59	0.92
Mirador	1,020,000	147,816	197,087	338,990	6.90	5.18	3.01
Annandale	640,000	471,162	628,216	1,080,532	1.36	1.02	0.59
Eagle Rock	950,000	1,136,332	1,515,109	2,605,988	0.84	0.63	0.36
Calaveras	20,400,000	7,751,077	10,334,769	17,775,803	2.63	1.97	1.15
Sheldon	11,820,000	6,189,775	8,253,034	14,195,218	1.91	1.43	0.83
Sunset	65,430,000	12,610,513	16,814,017	28,920,109	5.19	3.89	2.26
Allen	4,000,000	766,793	1,022,391	1,758,512	5.22	3.91	2.27
Don Benito	1,400,000	258,677	344,903	593,233	5.41	4.06	2.36
Total	108,990,000	30,450,000	40,600,000	69,832,000	3.58	2.68	1.56

Table 3-1. Water Detention Times, Assuming Complete Mixing Daily (Year 2020)

Table 3-1 lists the average detention times for all the reservoirs in each pressure zone, assuming year 2020 demands, and assuming that the tanks are completely mixed each day. Year 2020 demands are assumed to be about 17% higher than demands in the 2000 to 2002 time frame. As can be seen, the existing storage and year 2020 demand patterns suggest the following:

- Mirador Reservoir. In the winter time, water demand is so low that the reservoir will commonly have water in it for about 7 days. Even if completely mixed, this is a long time. Re-chlorination (sweetening) in Mirador reservoir is likely needed.

- Gould Tanks. The 3.17 day turnover in the Gould Tanks during the winter time can be readily reduced to half this level, by taking one of the two tanks out of service during the winter months (December 1 through March 31), corresponding to low fire threat season. The water remaining in one of the two Gould tanks is sufficient to meet normal electric power outages in the winter time, while maintaining about 1 day supply plus fire flows for the zone.

- Sunset. The 5.19 day turnover for the Sunset 1, 2 and Jones reservoirs is slow for winter time demands. This can be somewhat reduced by lowering the operating level of the Sunset and Jones reservoirs in the winter time; re-chlorination (sweetening) in these reservoirs is likely needed.

- Allen. The 5.22 day turnover for the Allen reservoir is slow for winter time demands. Re-chlorination (sweetening) in this reservoir is likely needed.

- Don Benito Tanks. The 5.41 day turnover in the Don Benito Tanks during the winter time can be readily reduced to half this level, by taking one of the two tanks out of service during the winter months (December 1 through March 31), corresponding to low fire threat season. The water remaining in one of the two Don Benito tanks is sufficient to meet normal power outages in the winter time, while maintaining about 1 day supply plus fire flows for the zone. Re-chlorination (sweetening) in Don Benito tanks is likely needed.

As described in the MWH report (2002), PWP has noticed high nitrite levels in the Sunset, Jones, Sheldon, Mirador, Lida and Gould reservoirs and the southwest portion of the Sunset pressure zone (MWH p. 7-60). One of the major sources of nitrification problems is the mixing of MWD water, which is chloraminated (chlorine plus ammonia), and Pasadena well water, which is disinfected with free chlorine. Mixing of free chlorine and chloramines eliminates both disinfectants.

The high nitrite levels observed at Lida and Sheldon are not only due to long average detention times from in-zone water. Lida water must first be detained in the Calaveras zone. Sheldon water must first be detained in the Sunset zone.

PWP has developed a Nitrification Control and Monitoring Plan. This plan provides early detection and elimination of conditions that would promote nitrification. During summer months, PWP staff test nitrite levels in the reservoirs daily, less often in other months. If nitrite (NO2) levels are above 5 mg/L two days in a row, action is taken immediately.

Disinfectant levels reduce over time, with chloramines residuals dropping to negligible levels in about a week. Reservoirs with low turnover (such as Mirador, Lida and Gould) are prone to nitrification due to longer detention times, as the water has already flowed through several other reservoirs. Operationally, low disinfectant levels in Mirador, Annandale and Lida reservoirs have been addressed by using water from MWD connection P3 (at Linda Vista PP) and "deep cycling" the reservoirs. "Deep cycling" consists of draining the reservoir to one-half to one-quarter full, and then turning on all the pumps to re-fill with water at higher quality and higher disinfectant level.

MWD water is delivered to PWP with a chloramine concentration of about 2.5 mg/L. Water from PWP wells is chlorinated and is blended at the A basin, making the concentration about 1.0 mg/L within Sunset reservoir. This low concentration has led to nitrification in the southwest part of the Sunset pressure zone. This has been partially offset by dropping water from P5 (via Ross PP, Eagle Rock reservoir and the PRV at San Rafael PP) into the Sunset zone, with a concentration of about 2.5 mg/L.

Jones reservoir is typically a FIFO Plug reservoir, with water from P4 entering at the north end, and leaving at the south end (FIFO). Normally in the summer time, Jones gets chlormainated water from P4. In the winter time, if little MWD water is purchased at P4, then chlorinated well water may enter Jones, resulting is loss of residual.

Typical solutions to these issues include: evaluation of reservoir detention times; reservoir cycling (mixing or pumping water through the reservoir), or disinfectant sweetening (adding additional chlorine to increase the disinfectant in the reservoir). Distribution system flushing can also be used to remove water in dead-end locations.

Following the methods in Rossman and Grayman (1999), the time needed to achieve essentially complete mixing of water in each reservoir was calculated. Table 3-2 summarizes the time it would take under assumed conditions to get full mixing for each existing reservoir.

Reservoir	Capacity (MG)	Fill rate, gpm	Mixing Time (hours)	Cycle range (percent)	Recommendations to improve mixing
Allen	4.00	670	14.0	28.1	Use larger Santa Anita pumps
Annandale	0.64	145	15.1	20.5	Operate Eagle Rock pumps preferentially
Calaveras	10.0	1,500	18.2	16.4	Modify inlet-outlet pipes to create FIFO plug flow; install 16" or 20" nozzles; create two basins; increase fill rate
Don Benito 1	0.70	500	4.6	19.9	
Don Benito 2	0.70	500	4.6	19.9	
Eagle Rock	0.95	744	3.8	18.0	
Gould 1	1.45	158	23.9	15.6	Take one tank out of service in the winter, operate Arroyo 3, upgraded Arroyo PP
Gould 2	1.45	158	23.9	15.6	
Jones	50.0	5,500	14.4	9.6	
Lida	0.43	400	2.8	15.7	
Mirador	1.02	280	10.7	17.6	
Murray	0.14	396	1.0	17.0	
Santa Anita	4.20	2,275	6.7	21.9	
Sheldon 1	6.72	1790	9.8	17.2	
Sheldon 2	5.10	1790	8.2	15.6	
Sunset 1	5.58	3372	5.3	19.9	
Sunset 2	9.85	3372	7.8	16.5	
Thomas	1.40	1677	4.4	15.8	
Windsor	4.80	3,500	3.2	13.9	

Table 3-2. Time Needed to Get Complete Mixing, At Assumed Fill Rate

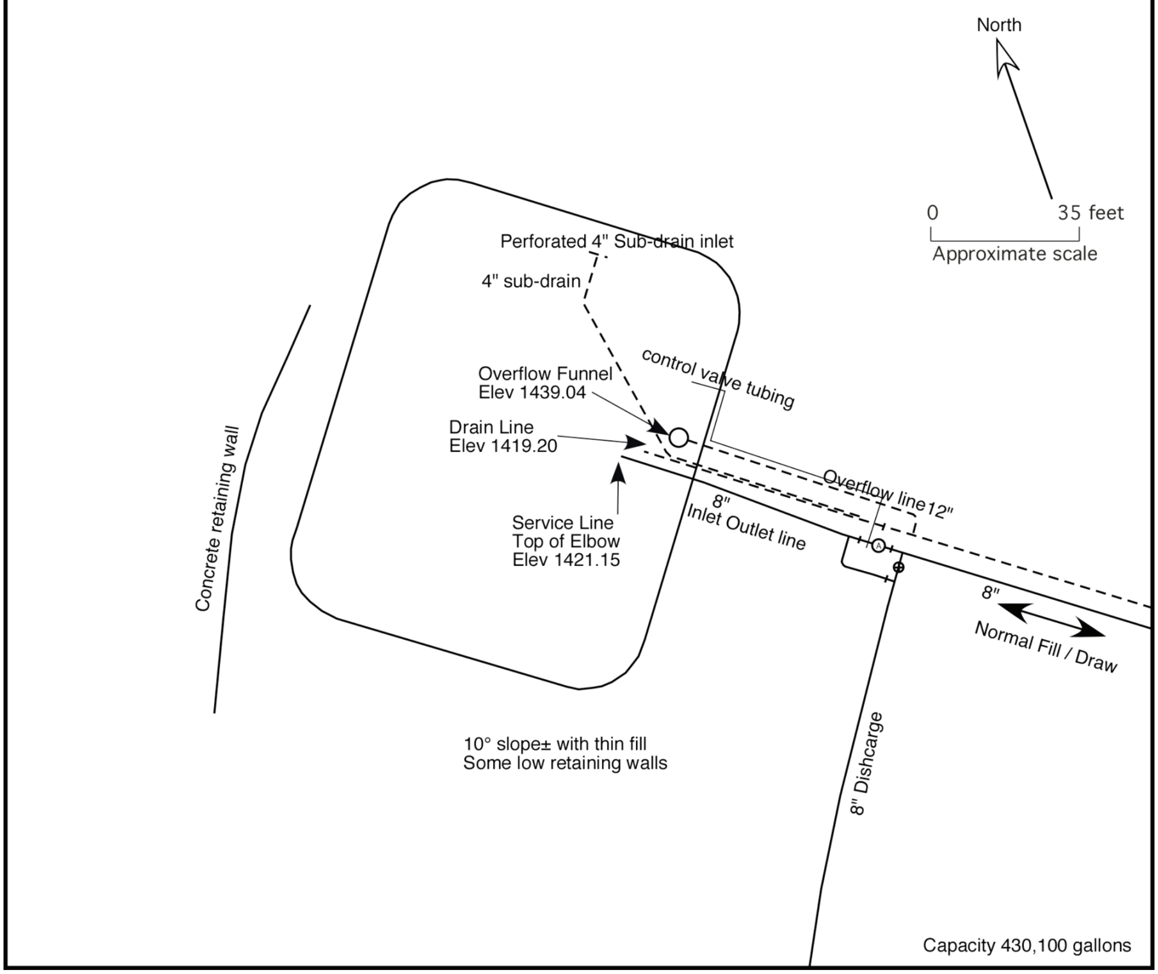
In Table 3-2, the fill rate is the fill rate (gpm) for each reservoir, or basin within a reservoir, as described in the text for each reservoir in the following sub-sections. The fill rate was taken as the lowest pumping rate available for the primary pumps to that reservoir, assuming negligible in-zone demand at the time of pumping; or at the assumed MWD fill rates described in Section 3.8 (Sunset Reservoir) and Section 3.15 (Jones Reservoir).

Sections 3.1 through 3.15 summarize the issues for each reservoir.

3.1 Lida Reservoir

Figure 3.1-1 is a plan view of the Lida Reservoir. The normal fill/draw is via a 8-inch inlet/outlet pipe. The 8-inch discharge line shown in Figure 3.1-1 leads to an emergency connection with another water company, and is rarely used.

Figure 3.1-1 Lida Reservoir



The pumps available to push water into the Lida reservoir are at the Lida pumping plant and the Devils Gate pumping plant. Assuming the smallest pump turned on at a time with near zero in-zone demand (say, in the early morning hours from midnight to 4 am), then with an 8-inch inlet pipe, complete mixing in a full reservoir should occur in about 2.8 hours.

Thus, most likely, the reservoir operates as complete mixing. Thus, no changes in inlet-outlet pipes are recommended.

3.2 Mirador Reservoir

Figure 3.2-1 is a plan view of the Mirador Reservoir.

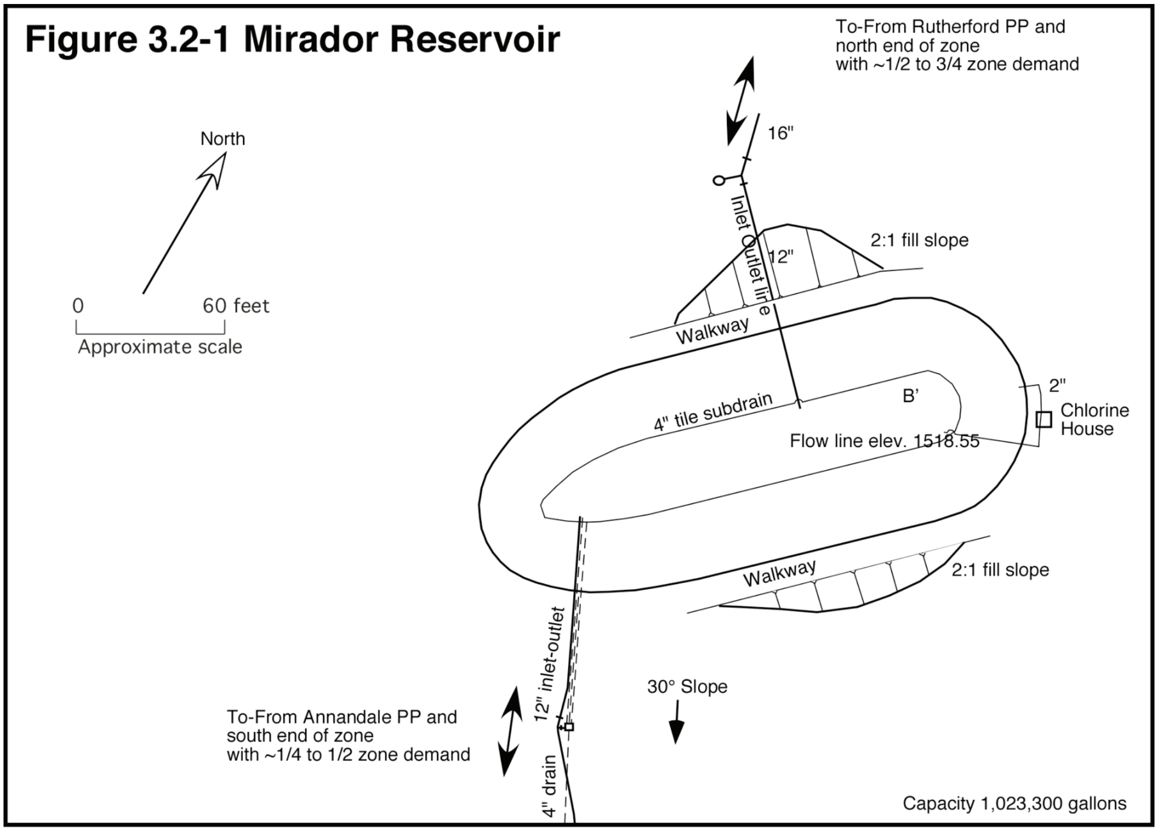


Figure 3.2-1 Mirador Reservoir

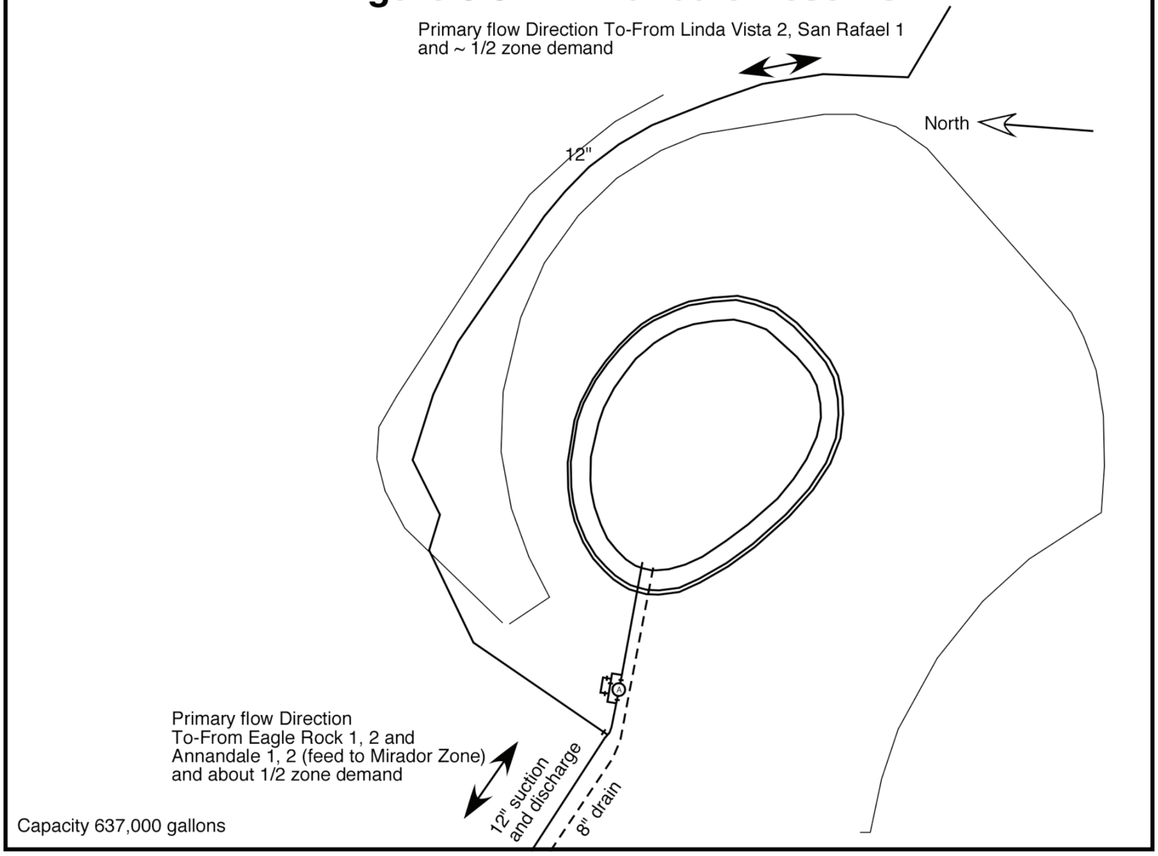
The Mirador reservoir can be filled from either the Annandale or Rutherford pumping plants. Under current normal operations, only the Rutherford pumping plant is in regular use to fill the Mirador Zone. The water normally enters the reservoir from the north inlet-outlet pipe, but leaves via both the north and south inlet-outlet pipes. There are no bypass pipes in the network to allow water form the Rutherford pumping plant to serve the south end of the Mirador zone, so water must traverse through the reservoir.

Assuming just one Rutherford pump is turned on (280 gpm), it would take 10.7 hours to achieve a mixed tank; 5.3 hours if both Rutherford pumps are turned on. Given that a portion of the water acts in FIFO flow to serve the south end of the zone, it is likely that the tank is commonly fully mixed. Thus, no changes in inlet-outlet pipes are recommended.

3.3 Annandale Reservoir

Figure 3.3-1 is a plan view of the Annandale Reservoir.

Figure 3.3-1 Annandale Reservoir



The Annandale reservoir can be filled from either the Eagle Rock, San Rafael or Linda Vista pumping plants. The water enters the reservoir from the single inlet-outlet pipe.

Assuming just the Linda Vista #2 pump is turned on (145 gpm), it would take 15.1 hours to achieve a mixed tank; 6.8 hours if just the Eagle Rock #1 pump is turned on. Thus, no changes in inlet-outlet pipes are recommended; but it is recommended that the zone be filled preferentially using the Eagle Rock pumps, then supplemented by the San Rafael pump and lastly the Linda Vista pump.

3.4 Eagle Rock Reservoir

Figure 3.4-1 is a plan view of the Eagle Rock Reservoir. The Eagle Rock reservoir can be filled by either the Ross #1 and #2 pumps, or the San Rafael #2 and #3 pumps. For purposes of water detention times, the existing Ross pumps are assumed. When filling the reservoir from the Ross PP, the valves can be set to create FIFO plug flow (all water enters via the northwest inlet and leaves via the south inlet-outlet pipe), or FILO (all water enters and leaves via the south inlet-outlet pipe).

Assuming just the Ross #1 pump is turned on (744 gpm), it would take 3.8 hours to achieve a mixed tank; less time if either San Rafael pump is turned on. It is likely that the tank is commonly fully mixed. Thus, no changes in inlet-outlet pipes are recommended.

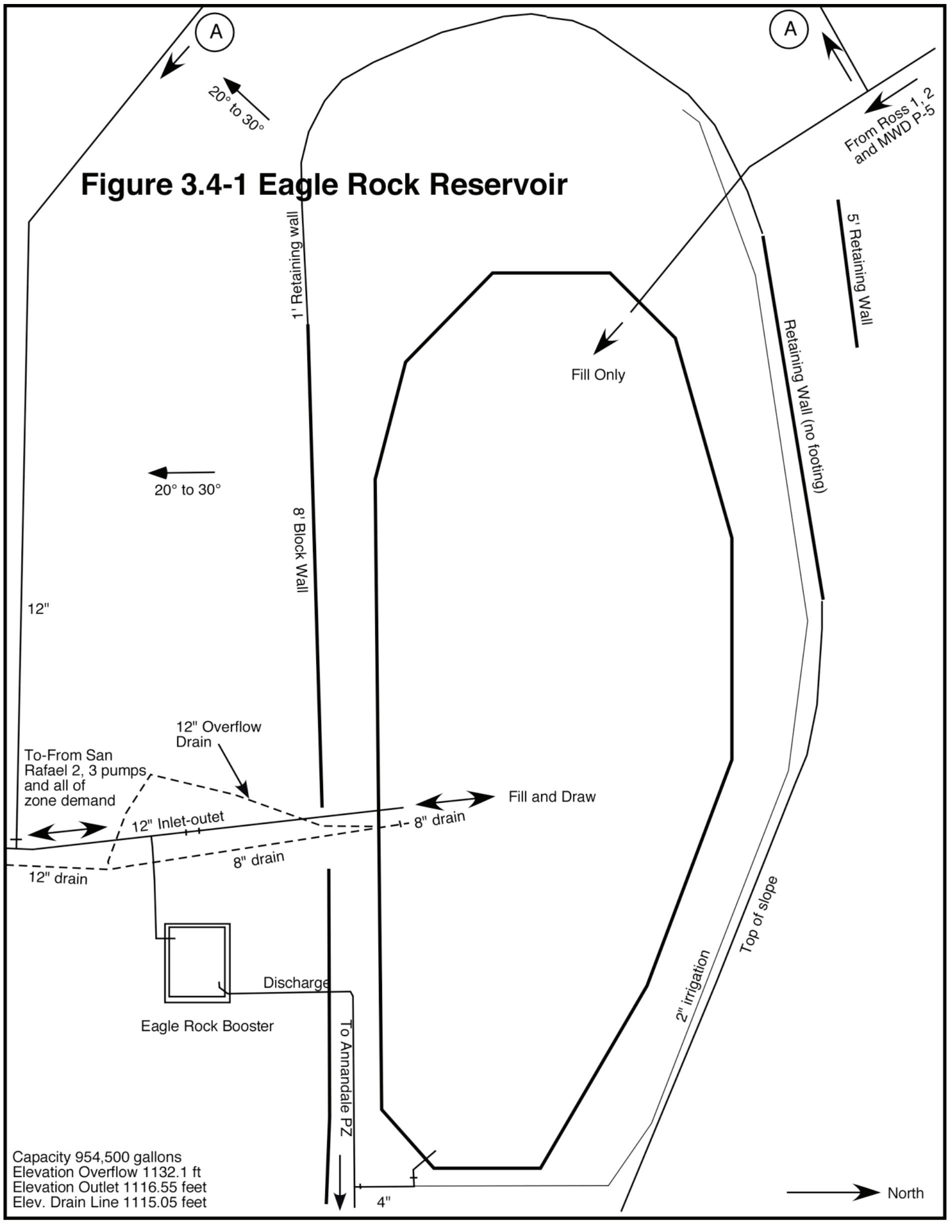


Figure 3.4-1 Eagle Rock Reservoir

3.5 Gould Tanks

Figure 3.5-1 is a plan view of the Gould Tanks.

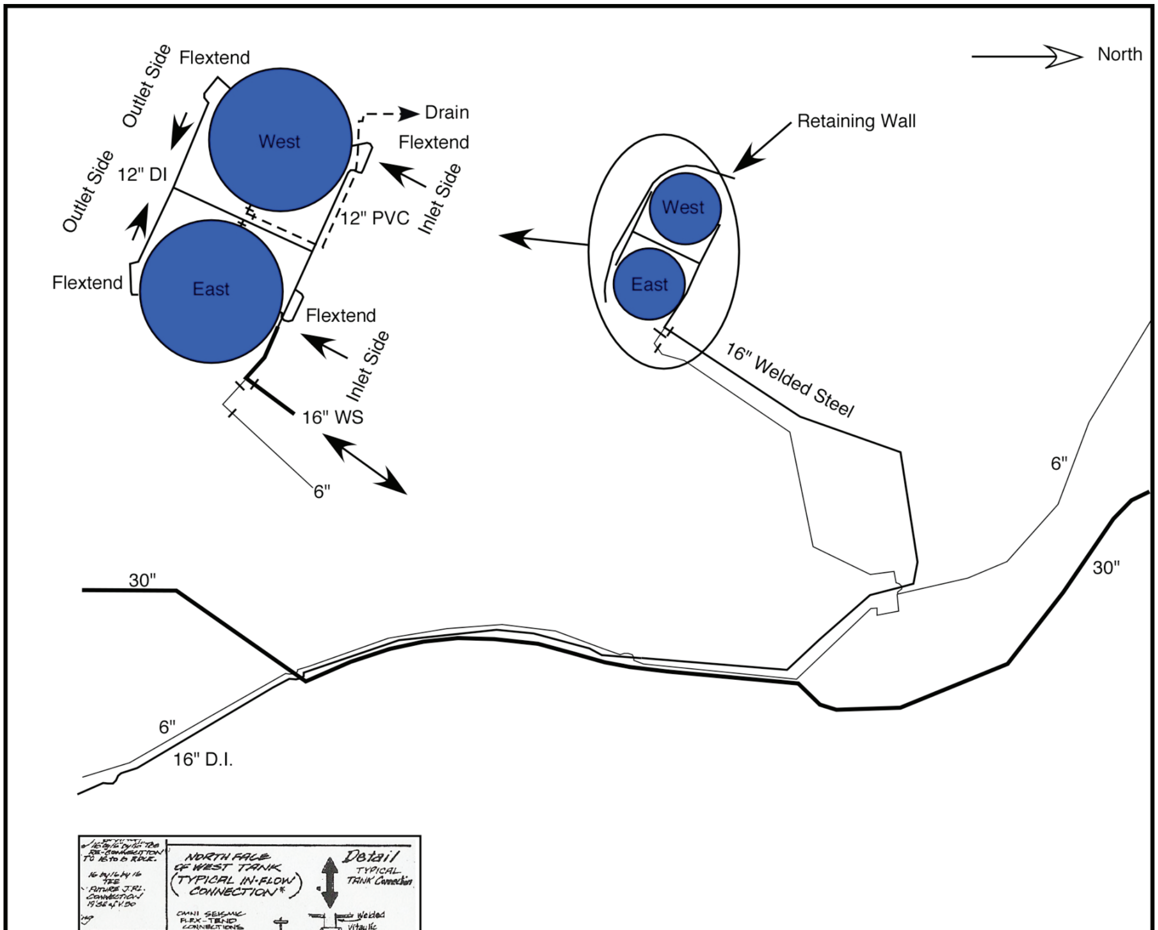


Figure 3.5-1 Gould Tanks

The Gould Tanks can be filled by the Arroyo #2 or #3 pumps. During current winter time demand, there is need for only one Gould tank in order to maintain sufficient in-zone storage one average daily demand plus fire flows. During summer time, both tanks should be kept in service.

The existing inlet and outlet pipes are set up using check valves so that water enters the northeast side of each tank, and leaves from the southwest side of each tank. Thus, the tanks are normally operated in FIFO flow.

For purposes of water detention times, the existing Arroyo #2 (317 gpm) and #3 (750 gpm) pumps are assumed. When filling just one tank using Arroyo #2, complete mixing is reached in 11.90 hours (somewhat long). When filling just one tank using Arroyo #3, complete mixing is reached in 5.0 hours. When filling both tanks using Arroyo #2, complete mixing is reached in 23.9 hours (not acceptable).

To achieve complete mixing in the winter time, when demands in the Gould / Millard zones are currently about 0.75 MGD, water detention times in the two tanks can reach 2.9/0.75 = 3.9 days. To shorten the detention time in the winter time, it is recommended that one of the two Gould tanks be taken out of service from about December 1 through March 31 of each winter season. If both tanks are kept in service in the winter time, then the larger Arroyo #3 pump should be run preferentially to improve mixing in the tanks.

3.6 Windsor Reservoir

Figure 3.6-1 is a plan view of the Windsor Reservoir.

When the reservoir is in use, it is normally filled from the VOC WTP. In turn, the VOC WTP gets water from the Arroyo / Well 25, Well 52, Ventura and Windsor, wells. The rated pump flow[3] for these four wells is 4.5 cfs, 4.5 cfs, 4.0 cfs and 2.5 cfs, respectively. The rated pump flow[4] for these four wells as used in hydraulic models by MWH is 2,600 gpm, 2,800 gpm, 2,500 gpm and 1,320 gpm, respectively. The VOC WTP has two pumps, each rated at 3,500 gpm, to pump the accumulated well water into the Windsor Reservoir.

At the current time (2006), the reservoir is out of service, pending resolution to the water quality issues associated with the four wells that normally fill it.

Water from the VOC normally enters the reservoir via the sand box, located in the northwest corner of the reservoir. A k-rail wall (about 3 feet high, resting on the gunite floor of the reservoir) is installed on the floor of the reservoir, presumably to force FIFO type operation of the reservoir when it is filled for the first quarter (or so) of its capacity. Once water reaches over the height of the k-rail wall, then the reservoir acts like one large basin, with the k-rail acting to promote mixing of the water going over the sandbox weir.

The Behner WTP is no longer in service, so there is no longer any inflow of water from that source.

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[3] Well flow rates in cfs taken from PWP SCADA system.

[4] Well flow rates in gpm taken from MWH hydraulic model.

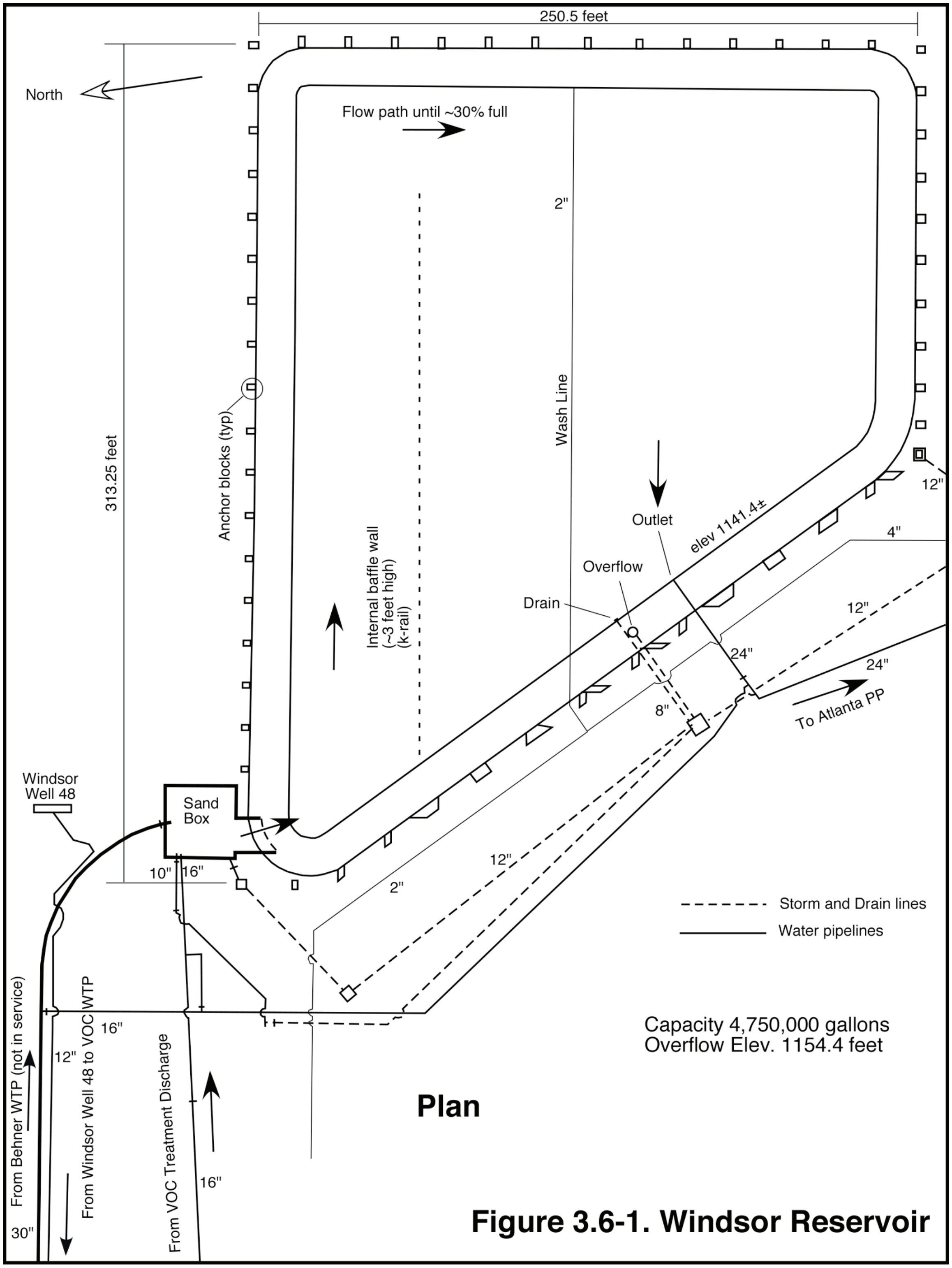


Figure 3.6-1. Windsor Reservoir

The water entering the sand box comes from a 16-inch diameter pipe from the VOC. The water entering the reservoir from the sand box is at essentially the same rate as water entering the sand box (except at start up or change of rate), but spread out over a wider area, as it enters the top of the Windsor reservoir over a weir wall. According to PWP staff, the bypass pipe from the 16-inlet pipe to the 24-inch outlet pipe is never used.

If one assumes that the reservoir is nearly full under normal operations, and one assumes water entering the reservoir has the momentum provided via a 16-inch diameter pipe at a 7.8 cfs rate (=3,500 gpm), then the time needed to achieve mixing would be 3.2 hours.

Water from the Windsor reservoir is normally pumped into the Calaveras pressure zone via the Atlanta pumping plant. The Atlanta pumping plant has two pumps, one rated at 2,700 gpm, and one rated at 3,620 gpm. Thus, the Atlanta pumping plant is sized large enough to be able to withdraw water from Windsor reservoir at approximately the rate of either VOC pump pumping into Windsor reservoir. If left unfilled with new well water, the Atlanta pumping plant could pump out the entire contents of a full Windsor reservoir in about 13 hours.

Given the FIFO operation of the Windsor when being filled, and the short 3.2 hour time to achieve mixing under idealized conditions, and the ability to empty the reservoir within 13 hours, it is likely that there is no need to change the existing inlet-outlet pipes to address water quality issues.

3.7 Sheldon Reservoir

Figure 3.7-1 is a plan view of the Sheldon Reservoir. This reservoir has two basins (east and west), which can be operated separately or together.

Under normal conditions, Sheldon Reservoir is filled with pumped flow from the Sunset zone, via the Glorietta pumping plant. Some flow from the Wilson, Craig and Jones pumping plants might also fill Sheldon Reservoir, especially if operated in the early morning hours when the demand within the Sheldon zone is lowest.

Prior to construction of the Upper Feeder, it was common to fill the Sheldon reservoir from the Calaveras pressure zone by gravity flow. This reflects the time when much of Pasadena's water was drawn from the wells and surface water in Arroyo Seco. Today (2006), the surface water from Arroyo Seco is no longer available (the Behner WTP has been taken out of service), and the water from the Monk Basin wells (Arroyo / Well 25, Well 52, Ventura and Windsor wells) with a combined rate limited to about 3,500 gpm when using one pump at the VOC WTP, is normally totally used by customers in the Calaveras and higher elevation pressure zones. Thus, plug FIFO flow from the Calaveras zone inlet pipes (north end of basins) to the Sheldon zone outlet pipes (south ends of basins) is not the common operating mode anymore.

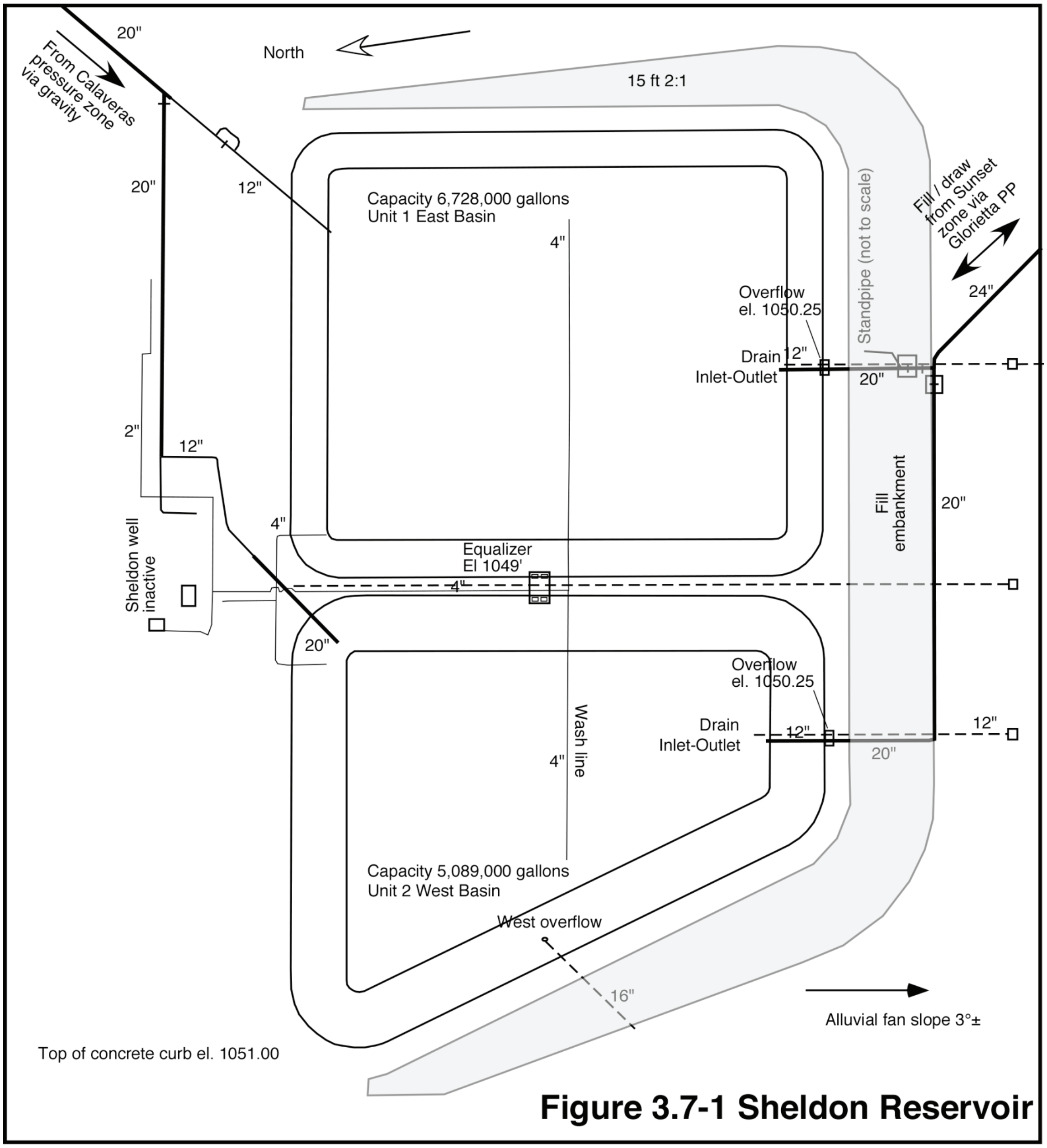


Figure 3.7-1 Sheldon Reservoir

Up to the point where the water elevation in the basins reaches 1049 feet (over 90% full), water does not mix between the east and west basins. When water reaches 1049 feet, water can mix between the two basins via the equalizer. The equalizer is like a set of concrete box culverts that allow flow from one basin to the other; there are no flow controls (valves or gates) in the equalizer.

Assuming that only one basin is in use, and assuming Glorietta #3 pump operating to fill the reservoir in the early morning hours, then mixing is achieved in 4.9 hours (east basin) or 4.1 hours (west basin). This mode of operation is marginally acceptable during winter months, when in-zone demand is about 6.2 MGD. However, during summer time, Sheldon zone demands are about 14.2 MGD, so both basins should be kept in service. In this case, assuming that flows from Glorietta Pump #3 is split equally between the two basins, the mixing time would be 9.8 hours (east basin) or 8.2 hours (west basin). This appears to be marginally acceptable, with each fill cycle filling the reservoir by about 16 to 17% of capacity, within the normal range of cycling the reservoir on a daily basis. In the summer time, either alternate the basins for filling (close the outlet valve in each basin on alternate days, but this is not recommended without addition of remotely operated valves), or run Glorietta and Wilson pumps simultaneously for short periods of time rather than filling the zone on a more gradual basis, with the objective or achieving a net inflow of about 2,000 gpm (or more) when filling either basin.

3.8 Sunset Reservoir

Figure 3.8-1 is a plan view of the Sunset Reservoir. Sunset reservoir has 2 main basins. Basin number 1 is oval, and subdivided into two sub-basins. Basin number 2 is an irregular polygon.

The A basin is a small mixing tank located between Basins 1 and 2. In older times, the A basin was use to aerate the incoming water (hence "A"). Today, MWD water aeration is no longer needed, and the A basin acts as a mixing chamber to blend water from the local wells with MWD water.

Under normal operation, water from MWD is directed into the A basin, where it then leaves in two flumes. Each flume is a rectangular concrete channel. One flume heads east to fill Basin 1, spilling over the walls and into either sub-basin. The other flume heads north to fill Basin 2.

The water then moves as FIFO plug flow with mixing to the outlet pipes, where the water goes into the Sunset pressure zone, or to the Glorietta pumping plant.

In Figure 3.8-1, a valve is labeled as the "no well" isolation valve. It is understood that this valve is commonly left closed. If it were opened, then PWP would lose the ability to blend much of MWD water in the A basin, and the basins would operate largely as fill-and-draw rather FIFO plug flow with mixing.

The flow rate from MWD to Pasadena is variable over the course of the year, depending in part on whether PWP would rather take the water at P1 (Sunset reservoir), P4 (Jones reservoir) or at some combination at P2, P3 and/or P5. If one assumes that, on average, wells provide 10 MGD into the system, with an average day demand of 33 MGD, then, on average, PWP draws 23 MGD from the MWD. Assuming that one-third of this amount is taken at P1 (Sunset) and the bulk of the remaining two thirds at P4 (Jones), then the average inflows of MWD water are about 7 MGD (Sunset) and 14 MGD (Jones), with the remaining at P2, P3 and P5. Assume also that on average, one well is operating to fill the Sunset Reservoirs (say Copelin, at a 3 MGD rate). Say at night time, when demand in the Sunset zone is low, and pumps at the Glorietta pump station are on, that all of this water (10 MGD) enters the reservoir via the A basin. Assume the equivalent diameter of the flumes can be set at 2 feet. Then, the time to achieve mixing is 5.3 hours (Basin 1) or 7.8 hours (Basin 2).

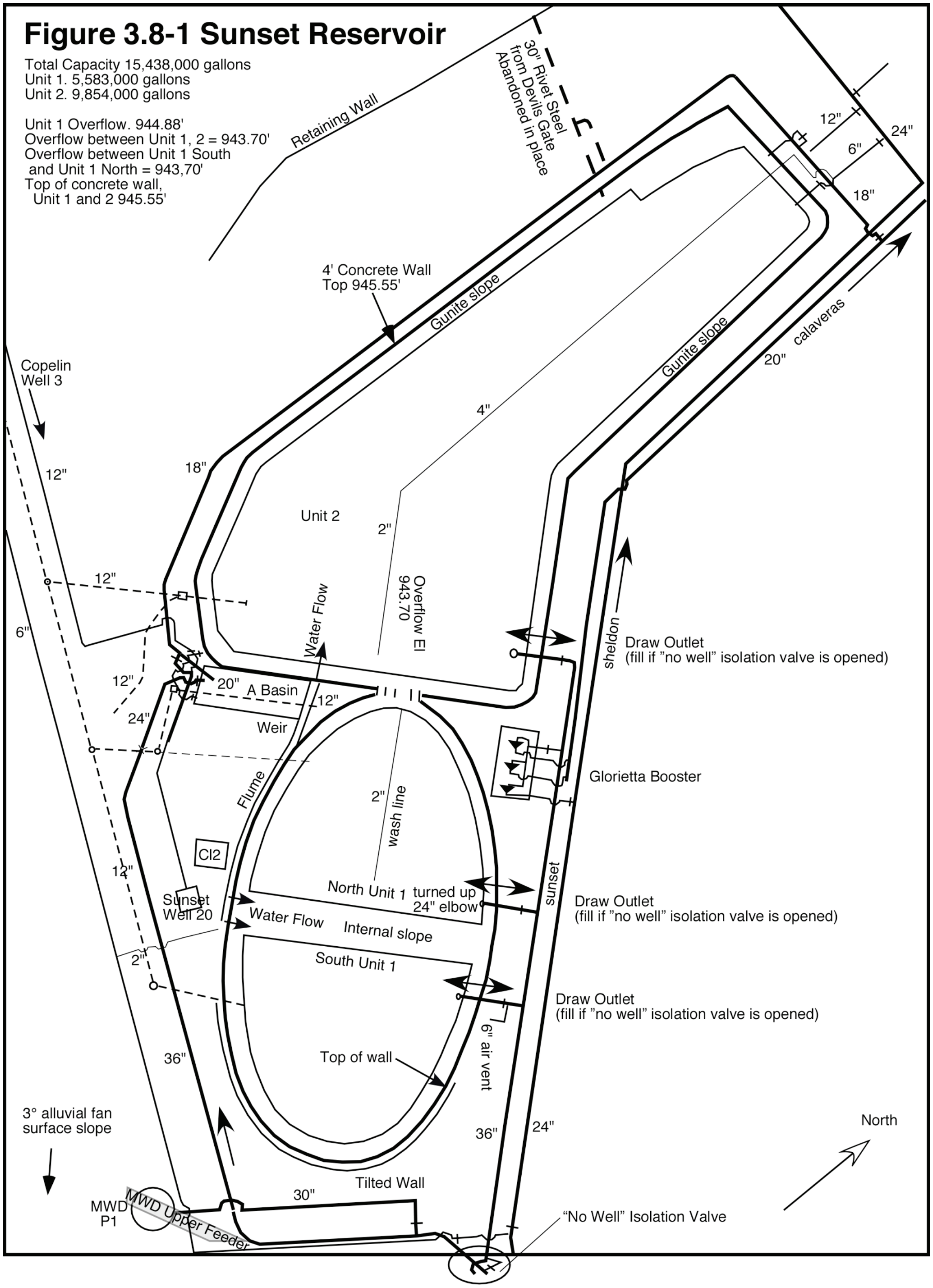


Figure 3.8-1 Sunset Reservoir

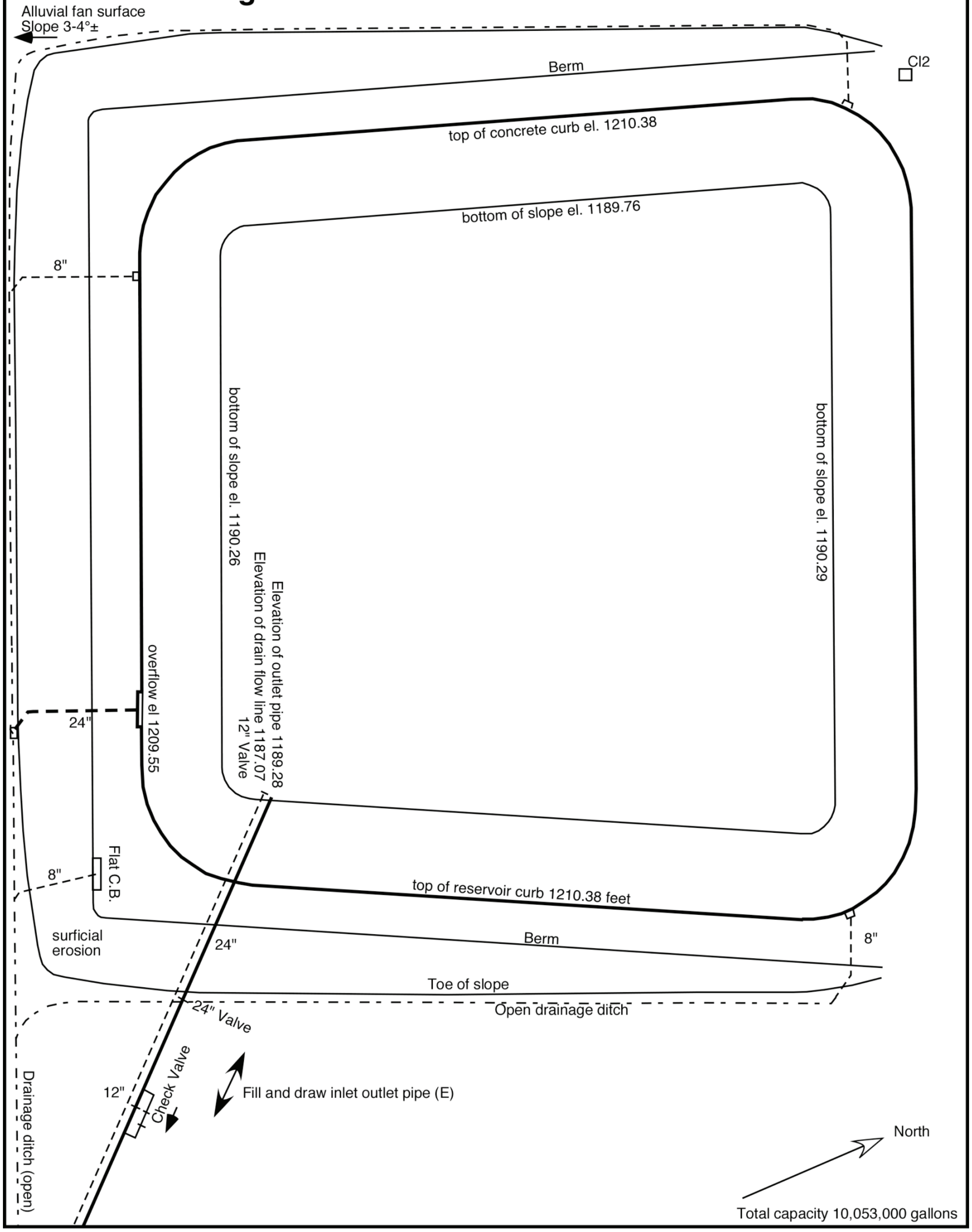
Total Capacity 15,438,000 gallons
Unit 1. 5,583,000 gallons
Unit 2. 9,854,000 gallons

Unit 1 Overflow. 944.88'
Overflow between Unit 1, 2 = 943.70'
Overflow between Unit 1 South
and Unit 1 North = 943,70'
Top of concrete wall,
Unit 1 and 2 945.55'

3.9 Calaveras Reservoir

Figure 3.9-1 is a plan view of the existing Calaveras Reservoir.

Figure 3.9-1 Calaveras Reservoir



The Calaveras reservoir is normally filled with water from the Atlanta pumping plant (if well water is being produced from the Monk basin), or by the Glorietta #1 and #2 pumps or by the Wilson #3, #4 and #5 pumps. The main pipelines and flow paths (when filling) are shown in Figure 3.9-3. If in-zone demand is extremely low, Calaveras reservoir can also receive water from the Linda Vista #1 pump or the Jones #2, #4 and #5 pumps, but this is not likely under normal operations. If one assumes that only one of the Glorietta pumps is used to fill Calaveras reservoir, while other pumps are used to maintain Calaveras zone demands (or fill Santa Anita an Thomas reservoirs), then the mixing time is 6.1 hours.

However, as detailed network models of the Calaveras zone have not been performed, it is obvious form the overall network that only a portion (say 1,500 gpm) of the Glorietta water will reach the Calaveras reservoir; the rest being used by in-zone demand. With the rather large inlet pipe, momentum of water entering the reservoir at one corner could lead to inadequate mixing, taking 18 hours to achieve complete mixing. A more reasonable target fill cycle time is 6 hours. Further, PWP staff has reported that there is a dead water problem with Calaveras reservoir, further supporting the idea that typical fill rates are not as high as 4,500 gpm.

To improve functionality for the reservoir, three possible upgrades are considered:

- Figure 3.9-2a. Subdivide the reservoir into two basins. Use inlet 20" nozzle. Force FIFO flow. Fill at 1,500 gpm rate.
- Figure 3.9-2b. Use pipes to try to create FIFO flow. Use inlet 16" nozzle. Fill at 1,500 gpm rate.
- Modify operations to increase fill rate to 4500 gpm over a 6 hour period. This increased fill rate may be sufficient to improve reservoir mixing, without modifying internal pipes in the reservoir.

The upgrade in Figure 3.9-2a will be more expensive than the one in Figure 3.9-2b

- Install an interior baffle wall. We recommend a reinforced concrete baffle wall without berms, so as to reduce the loss of storage volume to a minimum. The wall will require a new foundation under the existing liner. The wall will have to be designed to take unbalanced hydrostatic loads (one basin full, the opposite basin empty), as well as extra hydrodynamic loads from seismic forces. To prevent damage to the baffle wall, the hydrodynamic forces should be based the higher of PGA = 0.55g with I=1.25 (normal 475 year earthquake motion); or PGA = 0.98g with I=1.0 (2,475 year motion, which will result in somewhat larger forces).
- The top of the baffle wall, except at weirs, should be the same as the current overflow, or 1209.55 feet.

- The new baffle wall can be placed in the north-south direction, about mid-way between two lines of roof girders; or under a girder line. At completion of construction, the girder's redwood support posts should be about the same length as they are currently (this is to avoid creating "stiff" spots in the roof).

- The new baffle wall will create an "east basin" and a "west basin". The east basin can be filled and drained with the existing inlet-outlet pipe and drain line. The east basin can use the existing overflow.

- The new west basin will require modification of the bottom liner to accommodate a suitable drain. To provide the flexibility to drain the west basin without draining the east basin, a new drain pipe will need to be installed. It is recommended that the new drain pipe be routed to connect with the old drain pipe; and that the existing drain pipe gate valve be moved (and cleared/replaced) a few feet to accommodate the new drain pipe.

- The existing inlet-outlet pipe should be modified such that it has a branch just where it enters the reservoir's east basin; and then add a gate valve on the branch for the east basin, and a run of pipe to the west basin with an additional gate valve. In this manner, the existing 24" inlet-outlet pipe can be used to fill and drain the east basin by itself; the west basin by itself; or valved to flow into the east basin and withdraw from the west basin. Alternately, the existing 24" inlet-outlet pipe and 12" drain line can be removed and replaced with four pipes (two drains, two inlet-outlets) to the extent that they can be placed within the original 6-foot-wide by 5.5-foot deep access tunnel; the access tunnel is concreted closed, so it was not possible to assess the condition of the tunnel (it should be empty except for several concrete bulwarks). The main advantage of re-using the tunnel and placing new pipe through it is that the various valves to control the inlet-outlet pipes can be kept outside the reservoir, and there would be not be the need to access internal-basin valves via roof-top operators. Any new 12" or larger pipes inside the reservoir should be supported atop the thickened 14-inch thick slab along the edges of the reservoir floor, and designed to take full hydrodynamic loads.

- The new baffle wall should have two overflow weirs at elevation 1209 to allow mixing of the two basins in the top 1.38 feet of the reservoir. The weirs should be at either end of the baffle wall. Each weir should be 4 feet long, which should provide over 10 square feet of flow area (combined) when the reservoir is near full.

- The baffle wall should also have a slide gate (3 feet by 3 feet) at the north end of the wall, to promote mixing between the two basins when the west basin is used for in-flow and the east basin is used for outflow, and when the water levels are blow 1209 feet. The bottom of the slide gate opening would be at about elevation 1191 feet and the top at elevation 1194 feet. For maintenance purposes, a parallel

20-inch diameter pipe placed at 1191 feet at the south end of the baffle wall will provide an alternate flow path should the slide gate require maintenance (or vice versa).

- The existing chlorination system will need to be modified to allow the independent operation of either basin, or the flow-through operation of the two basins working as detention ponds.

With the conceptual upgrades shown in Figure 3.9-2a, and using 20" nozzles, and still assuming a fill rate of 1,500 gpm, then the mixing time in the west basin would be 9.6 hours, or about half the time as for the reservoir in its current condition. The improvements allow the reservoir to be operated as two independent basins, each with fill/draw operation, or as two compartments with FIFO plug flow with mixing.

The cost to install this baffle wall, along with the associated pipe modifications, is $892,000. This cost includes changing the chlorine system for two basins, draining the reservoir, installing the baffle wall, installing the new pipe and drain lines, providing a roof level walkway to gain access to the operating valves, and leak testing and patching of the liner after the work is complete. See the engineering description for the second alternative (below) for recommended water quality / mixing tests to be done as part of the design process for any alternative.

Figure 3.9-2b shows the second alternative approach to upgrade the reservoir. In this case, the 24" diameter inlet-outlet pipeline is extended around the perimeter of the reservoir, supported on the 14"-thickened slab at the edges. Check valves are inserted in the pipes to force fill from the southeast corner and draw from the northwest corner. A fill nozzle of 16" diameter is included to increase the velocity of water entering the reservoir, thereby improving mixing. The draw nozzle is left at 24" (same size as pipe), as mixing is not an issue during drawdown. By setting up the pipes in this manner, and still using a slow fill rate of 1,500 gpm, mixing time is reduced to 12.1 hours, and the spatial location of the fill and draw locations should promote FIFO conditions, even if the pumps do not fill the reservoir for the full 12.1 hours. The longer length of pipe will create some minor head loss under static operation conditions (no pumps on), but should be satisfactory. The 16" nozzle will impose some extra pumping costs under normal operations.

The cost to implement the second alternative is $205,400, broken down as follows:

- 420 feet new 24" pipe at $12/inch-foot installed: $121,000.

- Two new walkways atop roof to provide access to the valves. Assume wood planking atop wood beams, small operator platform, all attached to underlying wood roof system; replace galvanized sheet metal sheathing. Say each walkway is 120 square feet @$60/square foot installed = $7,200 x 2 = $14,400.

Figure 3.9-2a Calaveras Reservoir with Full Upgrade

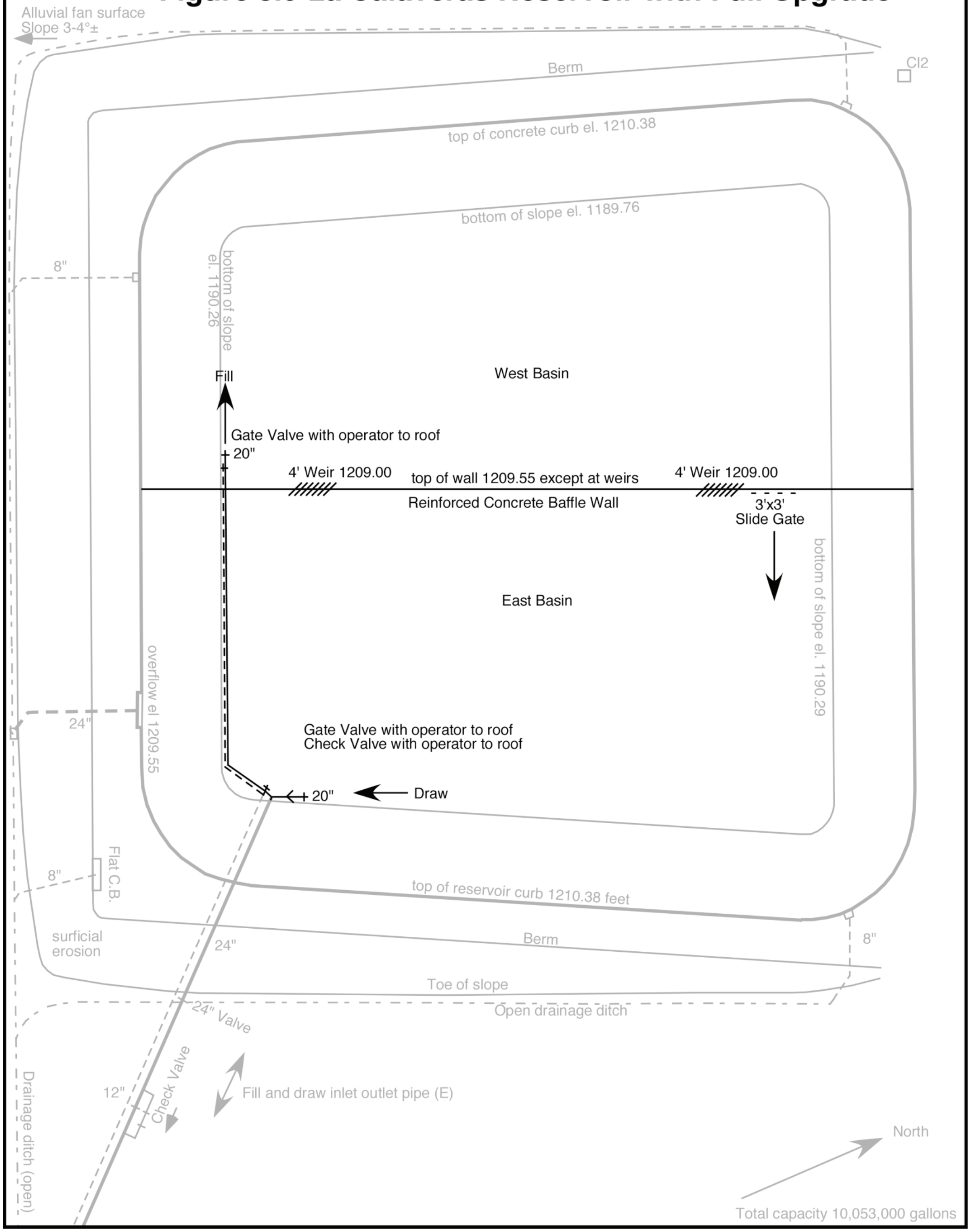
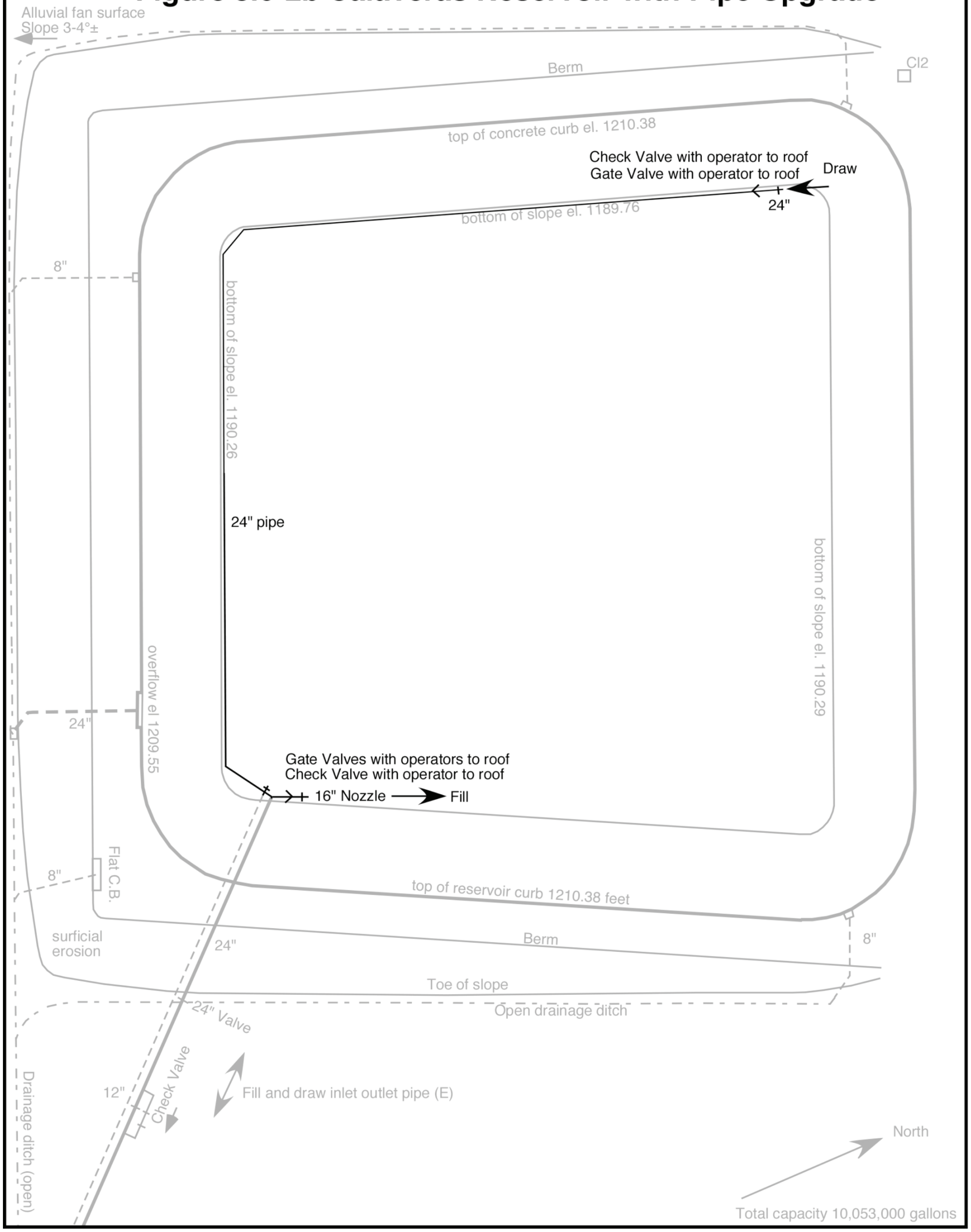


Figure 3.9-2b Calaveras Reservoir with Pipe Upgrade



- Two new walkways atop roof to provide access to the valves. Assume wood planking atop wood beams, small operator platform, all attached to underlying wood roof system; replace galvanized sheet metal sheathing. Say each walkway is 120 square feet @$60/square foot installed = $7,200 x 2 = $14,400.

- Liner test, liner patches and contingency: $35,000.

- Final design, including pressure zone hydraulic checks, structural design: $35,000.

- As part of the design process, it is recommended to conduct some water quality sampling tests at different points within the reservoir, over two 24-hour time periods. In the first 24-hour time period, fill the reservoir under current winter time demand operations. In the second 24-hour time period, attempt to fill the reservoir under very high pumping rates when demand is low (midnight to 6 am) to see if the reservoir can be filled at a 4,500 gpm rate for 6 hours in its current condition, and then left to be drawn down during the next 18 hours period. The final design of the pipes and nozzles in the reservoir should then be selected based on the least cost approach to force water mixing and turnover in the reservoir, and limiting energy costs needed to fill the reservoir.

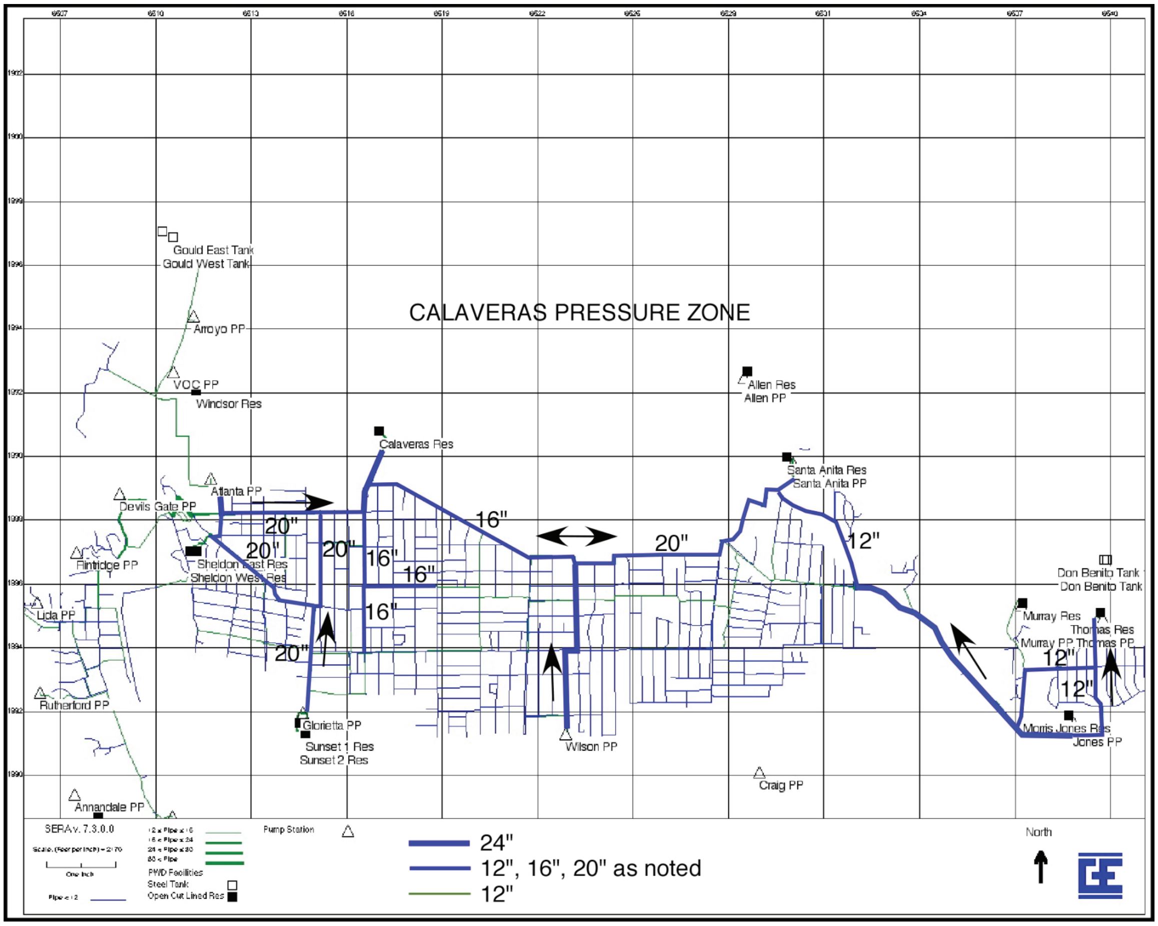
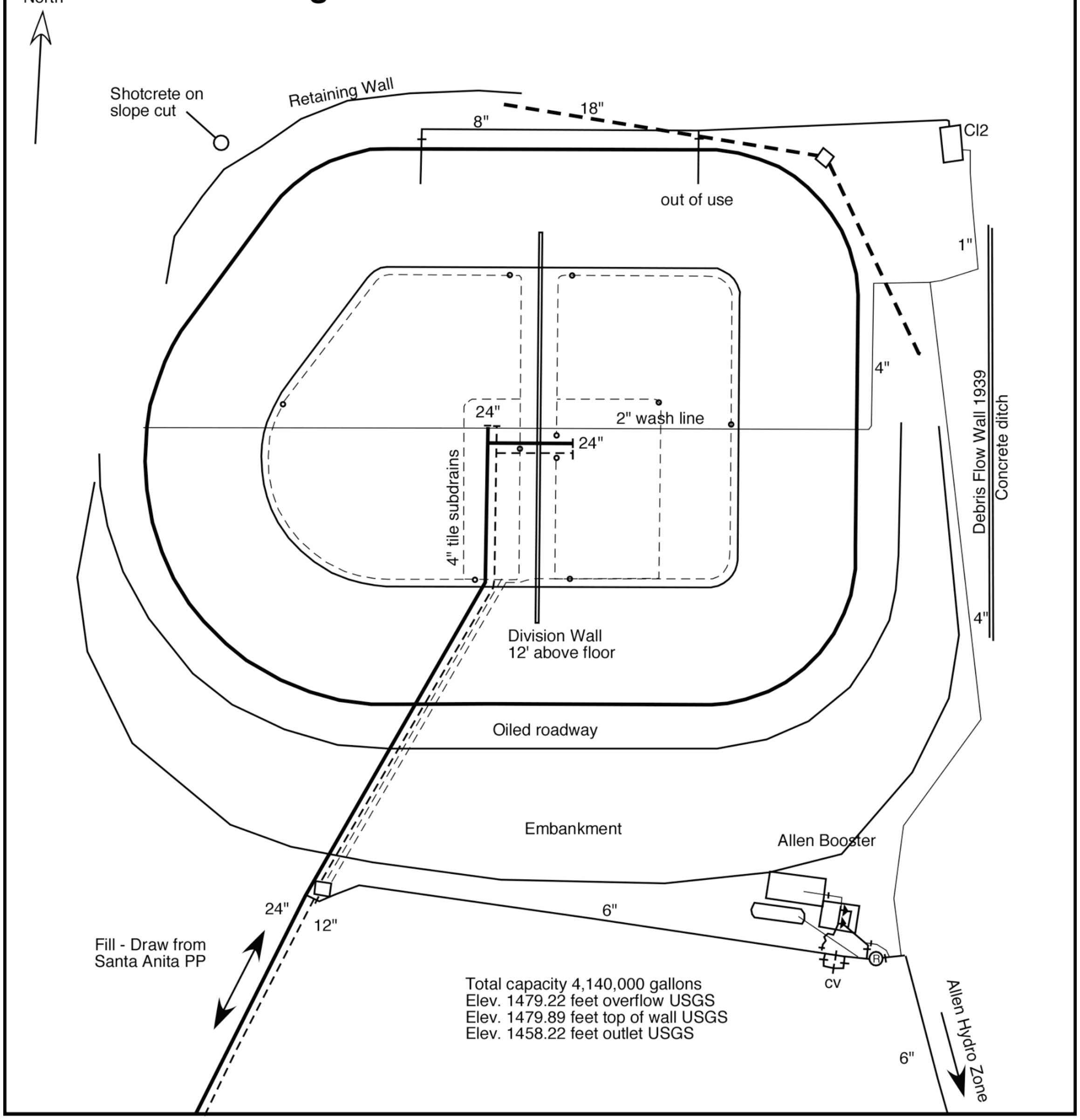


Figure 3.9-3. Calaveras Pressure Zone Main Flow Paths

3.10 Allen Reservoir

Figure 3.10-1 is a plan view of the Allen Reservoir. The reservoir is filled via a 24" inlet-outlet fill-draw pipe, with all water coming from the Santa Anita PP. Within the reservoir itself, there are two basins, with separate 24" diameter inlet-outlet pipes to each basin. The basin dividing wall is 12 feet high, allowing the reservoir to be operated as two separate basins until it is about half full, and then one large basin once the reservoir reaches its fill level, and water goes over the internal division wall.

Figure 3.10-1 Allen Reservoir



Total capacity 4,140,000 gallons
Elev. 1479.22 feet overflow USGS
Elev. 1479.89 feet top of wall USGS
Elev. 1458.22 feet outlet USGS

Assuming operation of just the smallest Santa Anita #1 pump, with both inlet-outlet pipes open to each basin, then the time to achieve mixing is 14 hours if the reservoir is cycled between ~67% to ~95% full; or 8.5 hours if using one of the larger Santa Anita pumps.

To reduce the mixing time and reduce the turnover in the reservoir needed to achieve complete mixing, then change the two 24" outlets in the reservoir to 12" outlets. This would increase momentum of water going into the reservoir, reduce mixing time to about 7 hours by using the smaller Santa Anita pump, cycling the reservoir from 81% full to 95% full, and drop pressure in the zone by about 4 psi.

Given these issues, it is recommended to use either the larger Santa Anita pumps #2 or #3 to fill the Allen reservoir.

3.11 Santa Anita Reservoir

Figure 3.11-1 is a plan view of the Santa Anita Reservoir. It is a fill/draw reservoir, with one 24-inch diameter inlet-outlet pipe.

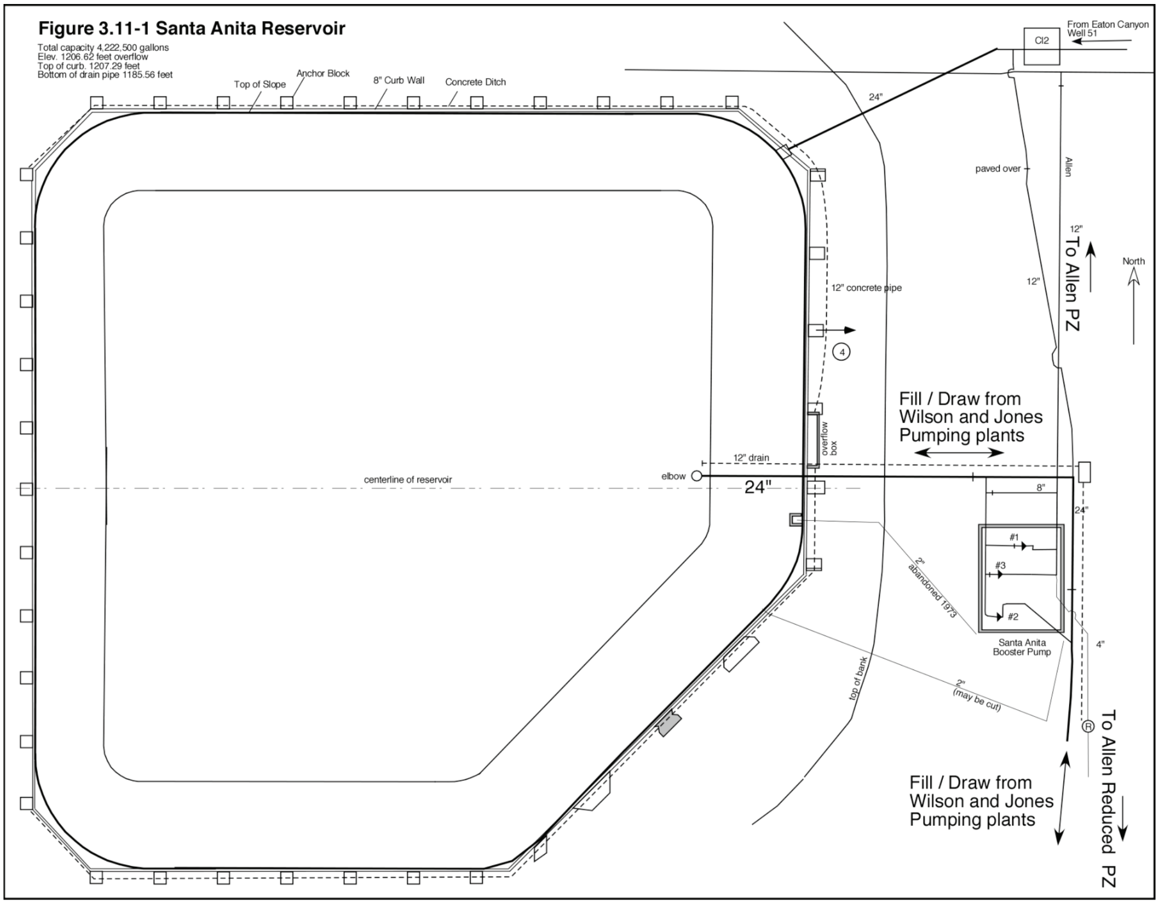


Figure 3.11-1 Santa Anita Reservoir

Santa Anita reservoir is normally filled by the Wilson pumping plant. It can also be filled by the smaller pumps at the Jones pumping plant. Assuming it is filled daily using one

Wilson pump when system demand is low, mixing time is about 6.7 hours. If dead zones are suspected, then the reservoir can be filled using two Wilson pumps (supplemented by Jones pumps) turned on at the same time; no physical changes are therefore recommended.

3.12 Murray Reservoir

Figure 3.12-1 is a plan view of the Murray Reservoir. This reservoir is currently not in service; the reservoir overflow elevation is too low so it does not float well in the Calaveras zone; it is small capacity; and reportedly the liner leaks (unconfirmed).

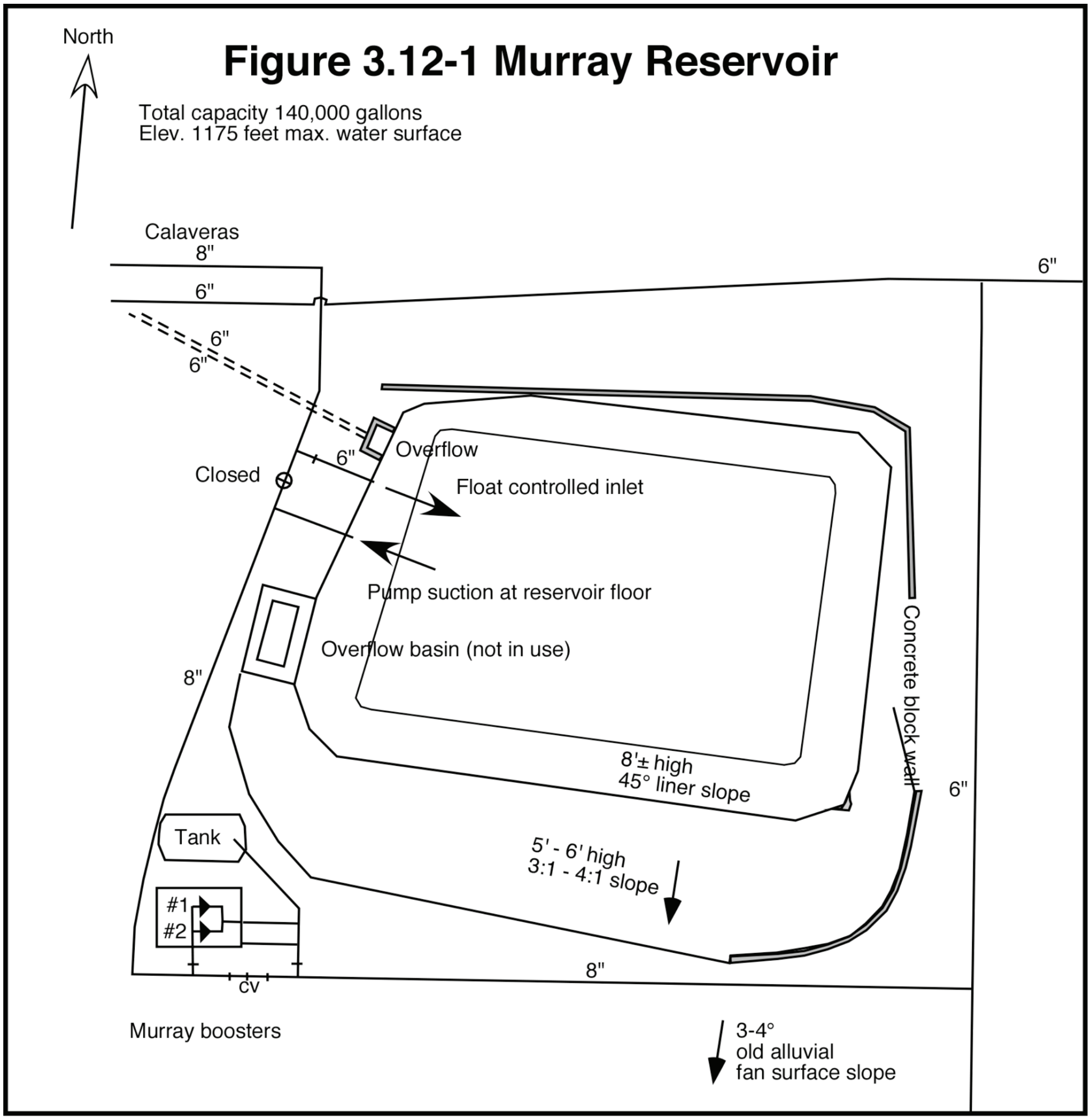


Figure 3.12-1 Murray Reservoir

Should Murray reservoir be returned to service, then the following observations are made about mixing times. The reservoir would be normally filled via a 12-inch pipe from the

Jones PP, with water entering the reservoir via a 6" inlet pipe. A float device is used to shut-off inlet flows once the reservoir is filled. Water is drawn out of the reservoir from a nearby outlet pipe, going to the Murray pump station to serve the higher pressure Murray Hydropneumatic tank zone.

Assuming an inflow rate of 396 gpm, complete mixing would be achieved in about 1 hour.

3.13 Don Benito Tanks

Figure 3.13-1 is a plan view of the Don Benito Tanks.

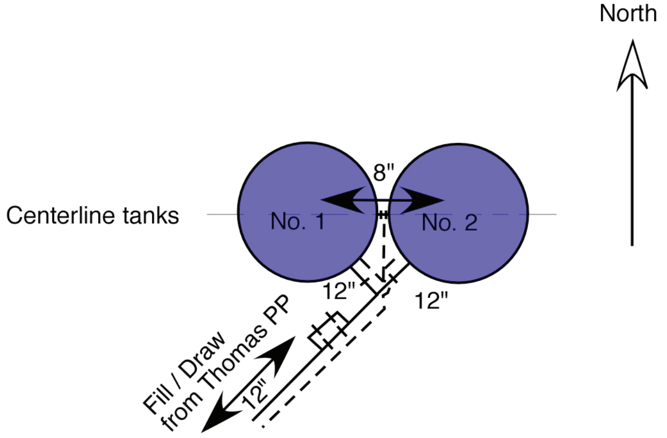


Figure 3.13-1 Don Benito Tanks

The existing pipeline arrangement allows the tanks to be operated either in fill-draw operation for each tank separately, or as a combined fill-draw operation. based on available drawings, there are no check valves to allow the tanks to be operated in FIFO plug flow (such as water fills Tank 1, goes to Tank 2, and then draws only from Tank 2).

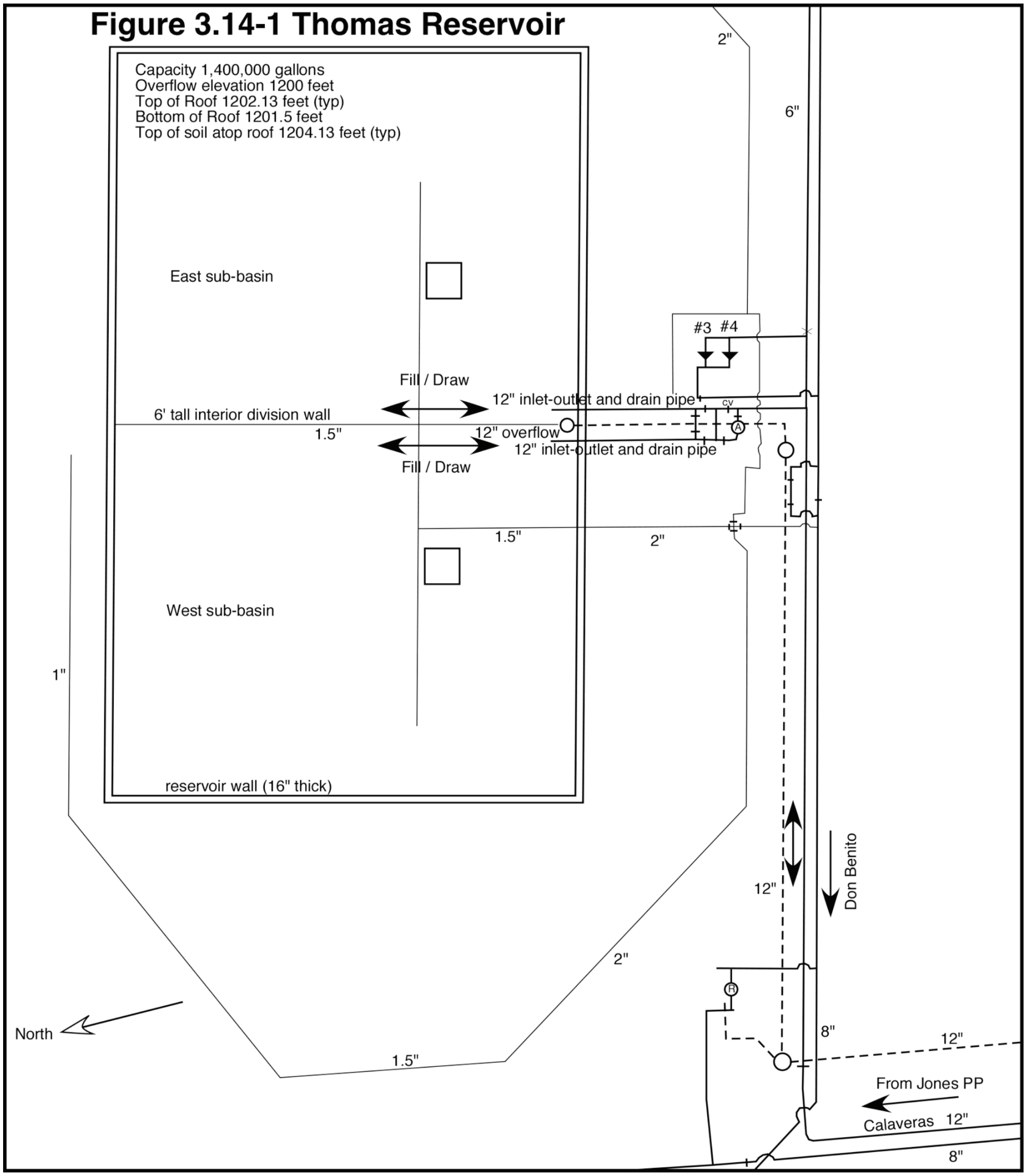
The Don Benito tanks are filled using either pump at the Thomas Pumping Plant. Assuming that only one pump is turned on, and that water is split into the two tanks (both under fill/draw operation), the mixing time is 4.6 hours.

It appears that the existing hardware is adequate for mixing purposes, and no upgrades are suggested.

3.14 Thomas Reservoir

Figure 3.14-1 is a plan view of the Thomas Reservoir. Under normal operations, Thomas reservoir is filled via the Jones Pumping Plant (see Figure 3.9-3) with water drawn from the Jones Reservoir. There is a 6-foot tall dividing wall in the reservoir, allowing it to be operated as two individual separate sub-basins until the reservoir is about half full. Once the water level is higher than the dividing wall, water can mix between the two sub-basins. There are no existing check valves to create a FIFO plug flow arrangement where water can enter one sub-basin, mix, and then leave via the other sub-basin.

Figure 3.14-1 Thomas Reservoir



Capacity 1,400,000 gallons
Overflow elevation 1200 feet
Top of Roof 1202.13 feet (typ)
Bottom of Roof 1201.5 feet
Top of soil atop roof 1204.13 feet (typ)

Assuming that either the Jones #2 or Jones #5 pumps are used, and assuming the entire reservoir acts as one fill/draw basin, then the time to achieve mixing would be about 4.40 hours (when pumped at times of low in-zone demand). This suggests that no upgrades are needed to improve mixing.

3.15 Jones Reservoir

Figure 3.15-1 is a plan view of the Jones Reservoir. Under normal operation, water fills Jones Reservoir from the MWD turnout (P4) at the north side of the reservoir, and then leaves the reservoir at the southwest corner, where it enters either the Sunset zone (gravity flow) or is pumped into the Sheldon and Calaveras zones. If P4 must be closed, then Jones Reservoir can be filled via MWD turnout P2, located just west of the reservoir, where the water would enter the 36" pipeline between Jones and Sunset Reservoirs; this mode of operation is rare.

The fill rate from P4 can be as low as zero (no water purchased from MWD) to as high as 25 MGD (nominal). Under normal operations, the actual rate of purchase of MWD water at P4 (see Figure 2-1 for location of MWD turnouts) is assumed to be in the 8 MGD range (low range) to 15 MGD (high range). Assuming an 8 MGD rate of inflow, then mixing in the reservoir should occur in 14.4 hours. Since the reservoir is normally operated in FIFO plug flow when water enters at the north end and leaves at the south end, there should be adequate mixing. However, should P4 be closed, then mixing at 8 MGD rate will be difficult to achieve when using just the inlet-outlet pipes at the south end unless the main inlet-outlet pipe is closed, and only the smaller 14" pipe is used.

In summary, assuming FIFO plug flow from PWD P4 to the southwest draw line, there should be adequate mixing when water is purchased at an 8 MGD rate or higher.

If the water purchased from MWD is reduced to much below 5 MGD rate, (possible in the winter time, when many wells are in operation), and P2 is open and P4 is closed, then water mixing cannot be achieved using the normal inlet-outlet pipes in the southwest corner of the reservoir.

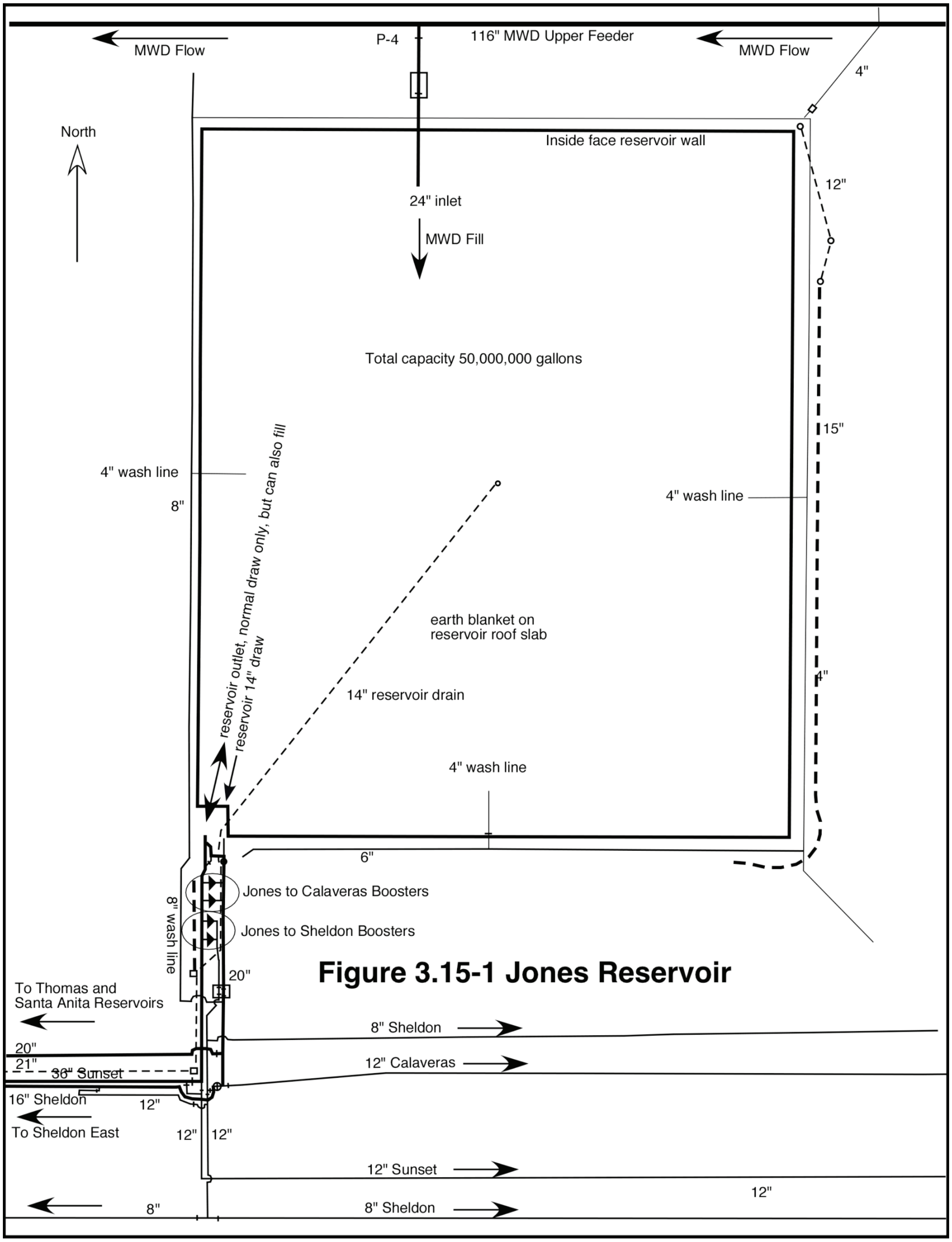


Figure 3.15-1 Jones Reservoir

3.16 Summary, Mixing and Detention Times in Reservoirs

Sections 3.1 through 3.15 discuss the issue of mixing water within each reservoir. Table 3-3 summarizes the issues for each reservoir and highlights the actions needed to improve mixing in the reservoirs.

Table 3-3 also provides the recommended hardware upgrade and costs for improving mixing in Calaveras reservoir.

Reservoir	Mixing Time Suitable?	Recommendations to Improve Mixing	Hardware Cost to Improve Mixing
Allen	Possible	Operate Santa Anita #2 or #3 pumps preferentially	$0
Annandale	Possible	Operate Eagle Rock pumps preferentially	$0
Calaveras	No	Modify inlet-outlet pipes to crate FIFO plug flow; install 16" inlet nozzles	$205,400
Don Benito 1	Yes		$0
Don Benito 2	Yes		$0
Eagle Rock	Yes		$0
Gould 1	No	Take one tank out of service in the winter, operate Arroyo #3 pump, upgraded Arroyo PP	$0
Gould 2	No		
Jones	Possible	Fill at minimum 8 MGD rate from P4	$0
Lida	Yes		$0
Mirador	Possible	Operate Rutherford #1 and #2 pumps	$0
Murray	Yes		$0
Santa Anita	Yes		$0
Sheldon 1	Possible	Operate Glorietta and Wilson pumps to achieve 2,000 gpm inflow during fill cycles	$0
Sheldon 2	Possible		
Sunset 1	Possible	Fill at 10 MGD rate at night time while Glorietta pumps are on	$0
Sunset 2	Possible		
Thomas	Yes		$0
Windsor	Yes		$0

Table 3-3. Actions to Improve Mixing

4.0 Benefit-Cost Analysis

4.1 Overview

The Seismic Vulnerability Assessment (G&E 2006a) for the Pasadena Water System presented four alternative seismic capital improvement packages: P1, P2, P3, and P4. These four packages vary significantly in their scope and cost and thus also vary significantly in their effectiveness in reducing the impacts of future earthquakes on the Pasadena Water System.

In evaluating and choosing between these alternatives, one of the key questions for decision makers is whether or not the increased costs associated with the higher cost packages are worth it. That is, are the reductions in impacts of future earthquakes large enough to justify the extra costs of the high cost packages? What is the "optimum" upgrade alternative for the Pasadena Water System?

Benefit-cost analysis is a powerful tool for exploring these questions quantitatively and can provide a rational, defensible basis for choosing among these alternative packages. Benefit-cost analysis of water system upgrades is based on quantitative calculations of expected damages and losses in the as-is condition of the systems and after implementing each alternative upgrade. This explicit, quantitative evaluation of system performance allows decision makers to compare the relative effectiveness of different upgrade options on improving system performance.

4.2 Benefit-Cost Analysis of Upgrade Packages

The effects of earthquakes on a water system include not only damages to a system's physical infrastructure but also economic impacts on the utility and on customers. For benefit-cost analysis, we consider the following categories of damages and losses:

Impacts on Utility

- Physical damage to reservoirs
- Physical damage to wells and pump stations
- Revenue Loss

Impacts on Customers

- Damages from inundation
- Damages from fire following earthquake
- Economic impacts of loss of water service
- Economic impacts of loss of potability

Physical damages (i.e., the cost to repair or replace) for reservoirs are estimated based on the size of reservoir, type of reservoir, and the seismic fragility of each reservoir.

Physical damages to wells and pump stations (including buildings) are estimated based on replacement value of buildings and equipment, and the seismic fragility of each component.

Revenue losses are estimated based on the average value of water sold and the number of system days of lost service estimated for each scenario earthquake.

Damages from inundation are estimated based on the seismic vulnerability and storage capacity of each reservoir, along with local topography and the value of buildings and contents in downslope areas subject to inundation if damage to a reservoir results in release of stored water.

Damages from fire following earthquake are estimated for the first 24-hours after an earthquake using a simplified FEMA methodology which calculates typical losses per capita of $38.56 (for "dry" climates, as appropriate for Pasadena) associated with lost water supply.

The economic impact of complete loss of water service is calculated on a per capita per day basis, then combined with the number of system days of lost service and the number of customers served. The FEMA per capita per day economic impact for loss of water service is $113.47. This value takes into account the relative importance of water service for each major economic sector and the economic impact of lost time for residents.

The economic impact of loss of water potability is also calculated on a per capita per day basis, on the same basis as above for complete loss of water service. The FEMA per capita per day economic impact for loss of potability is $47.37. For Pasadena, some types of damage such as collapse of reservoir roofs result in longer durations of loss of potability than durations of loss of water service. For economic calculations, loss of potability is assumed only for time periods after water service is restored, but water is not potable.

For benefit-cost analysis of the upgrade packages for the Pasadena Water System, scenario damages and losses for the seven categories of damages and losses listed above (considering impacts on both the utility and on customers) were evaluated for seven scenario earthquakes:

- San Andreas M 7.9
- Sierra Madre M 7.2
- Raymond M 6.5
- Verdugo – Eagle Rock M 6.9
- Upper Elysian Park M 6.4
- Upper Elysian Park M 6.0
- Puente Hills M 7.0

For benefit-cost analysis, the scenario damages and losses for each earthquake (that is, the calculated damages and losses when earthquake occurs) were converted into annualized damages and losses by dividing by the return period of the earthquake. Dividing by the return period is equivalent to considering the annual probability of the specific scenario earthquake.

Damage and loss estimates for the above seven scenario earthquakes, along with the annualized damages and losses are summarized in the following tables.

Tables 4-1 (part 1) and 4-1 (part 2) show the scenario and annualized damages for the seven scenario earthquakes. Figure 4-1 graphs the total losses due to each scenario earthquake.

Table 4-2 illustrates the relative contributions to the total earthquake risk (the potential for damages and losses) for the Pasadena Water System from the various scenario earthquakes and from other earthquakes. We estimate that about 2/3rds of the total seismic risk arises from the seven specified scenario earthquakes, with about 1/3rd of the seismic risk arising from “other” earthquakes. Other earthquakes include potential earthquakes on the specified faults other than the characteristic earthquakes. Thus, for example, the San Andreas fault could produce a M 6.5 or M 7.0 earthquake as well as the characteristic M 7.9 earthquake. The other earthquake category also includes potential impacts from earthquakes on other known or unknown earthquake faults.

As seen in Table 4-2, of the total risk from the seven scenario earthquakes, most of the risk arises from the Sierra Madre M 7.2 and the Raymond M 6.5, which together contribute about 50% of the total seismic risk for the Pasadena Water System. These faults contribute much of the risk because of the combination of relatively large size, short return periods, and proximity to Pasadena.

Earthquake Event	Return Period (years)	System Impacts, Damages and Economic Losses	Impact of Earthquake Event				
			As-Is	P1	P2	P3	P4
San Andreas M7.9	**100**	System Hours of No Water	1.23	1.1	0.55	0.24	0.18
		Economic Impact of No Water	$1,085,120	$970,432	$483,452	$210,743	$158,798
		System Hours of Non-Potable	6.12	5.54	2.86	0.75	0.00
		Economic Impact of Non-Potable	$2,254,007	$2,040,392	$1,054,080	$276,639	$0
		Fire Following Earthquake Losses	$287,812	$248,837	$195,412	$140,368	$86,943
		Physical Damage - Reservoirs	$2,497,016	$2,122,464	$998,806	$374,552	$124,851
		Wells and Pump Stations	$100,000	$20,000	$10,000	$10,000	$10,000
		Lost Revenue	$3,857	$3,449	$1,718	$749	$564
		Total Scenario Damages + Losses	$6,227,811	$5,405,574	$2,743,468	$1,013,051	$381,156
		Annualized Damages + Losses	$62,278	$54,056	$27,435	$10,131	$3,812
Sierra Madre M7.2	**300**	System Hours of Lost Service	106.49	73.06	42.44	25.30	22.03
		Economic Impact of No Water	$93,946,667	$64,454,348	$37,442,806	$22,316,343	$19,435,112
		System Hours of Non-Potable	18.25	19.63	14.92	5.56	0.00
		Economic Impact of Non-Potable	$6,721,507	$7,229,763	$5,494,326	$2,049,260	$0
		Fire Following Earthquake Losses	$4,865,819	$1,801,822	$1,700,908	$1,596,936	$1,496,022
		Physical Damage - Reservoirs	$31,858,349	$27,079,597	$12,743,340	$4,778,752	$1,592,917
		Wells and Pump Stations	$1,200,000	$240,000	$120,000	$120,000	$120,000
		Lost Revenue	$333,891	$229,074	$133,073	$79,313	$69,073
		Inundation Loss	$4,244,750	$3,608,038	$1,697,900	$636,713	$212,238
		Casualty Loss	$2,310,000	$1,963,500	$924,000	$346,500	$115,500
		Total Scenario Damages + Losses	$145,480,983	$106,606,141	$60,256,353	$31,923,818	$23,040,862
		Annualized Damages + Losses	$484,937	$355,354	$200,855	$106,413	$76,803
Raymond M6.5	**300**	System Hours of Lost Service	32.73	24.92	11.95	4.69	3.31
		Economic Impact of No Water	$28,874,772	$21,984,702	$10,545,952	$4,140,252	$2,920,119
		System Hours of Non-Potable	15.5	13.87	9.10	3.05	0.00
		Economic Impact of Non-Potable	$5,708,677	$5,108,345	$3,350,073	$1,122,201	$0
		Fire Following Earthquake Losses	$2,467,387	$1,855,787	$1,350,227	$829,348	$323,788
		Physical Damage - Reservoirs	$19,790,458	$16,821,889	$7,916,183	$2,968,569	$989,523
		Wells and Pump Stations	$800,000	$160,000	$80,000	$80,000	$80,000
		Lost Revenue	$102,622	$78,135	$37,481	$14,715	$10,378
		Inundation Loss	$594,187	$505,059	$237,675	$89,128	$29,709
		Casualty Loss	$150,000	$127,500	$60,000	$22,500	$7,500
		Total Scenario Damages + Losses	$58,488,103	$46,641,417	$23,577,591	$9,266,712	$4,361,018
		Annualized Damages + Losses	$194,960	$155,471	$78,592	$30,889	$14,537
Verdugo - Eagle Rock M6.9	**1000**	System Hours of Lost Service	53.53	45.32	26.12	15.37	13.32
		Economic Impact of No Water	$47,224,764	$39,981,810	$23,043,356	$13,557,821	$11,751,053
		System Hours of Non-Potable	17.46	15.85	11.12	3.93	0.00
		Economic Impact of Non-Potable	$6,430,549	$5,837,583	$4,095,515	$1,448,162	$0
		Fire Following Earthquake Losses	$3,037,015	$2,557,328	$1,973,610	$1,372,203	$788,485
		Physical Damage - Reservoirs	$22,005,657	$18,704,809	$8,802,263	$3,300,849	$1,100,283
		Wells and Pump Stations	$850,000	$170,000	$85,000	$85,000	$85,000
		Lost Revenue	$167,839	$142,097	$81,897	$48,185	$41,764
		Inundation Loss	$942,824	$801,400	$377,130	$141,424	$47,141
		Casualty Loss	$270,000	$229,500	$108,000	$40,500	$13,500
		Total Scenario Damages + Losses	$80,928,647	$68,424,528	$38,566,770	$19,994,144	$13,827,225
		Annualized Damages + Losses	$80,929	$68,425	$38,567	$19,994	$13,827

Table 4-1. Scenario and Annualized Earthquake Damages and Losses (Part 1 of 2)

Earthquake Event	Return Period (years)	System Impacts, Damages and Economic Losses	Impact of Earthquake Event				
			As-Is	P1	P2	P3	P4
Upper Elysian Park M6.4	3000	System Hours of Lost Service	1.41	1.37	0.71	0.34	0.27
		Economic Impact of No Water	$1,243,918	$1,208,629	$626,370	$300,305	$238,197
		System Hours of Non-Potable	6.12	5.54	2.88	0.76	0.00
		Economic Impact of Non-Potable	$2,254,007	$2,040,392	$1,060,709	$279,762	$0
		Fire Following Earthquake Losses	$266,826	$230,693	$195,128	$158,485	$122,920
		Physical Damage - Reservoirs	$7,137,755	$6,067,091	$2,855,102	$1,070,663	$356,888
		Wells and Pump Stations	$275,000	$55,000	$27,500	$27,500	$27,500
		Lost Revenue	$4,421	$4,296	$2,226	$1,067	$847
		Total Scenario Damages + Losses	$11,181,926	$9,606,100	$4,767,035	$1,837,782	$746,351
		Annualized Damages + Losses	$3,727	$3,202	$1,589	$613	$249
Upper Elysian Park M6.0	100	System Hours of Lost Service	1.41	1.37	0.71	0.34	0.27
		Economic Impact of No Water	$1,243,918	$1,208,629	$626,370	$300,305	$238,197
		System Hours of Non-Potable	6.12	5.54	2.88	0.76	0.00
		Economic Impact of Non-Potable	$2,254,007	$2,040,392	$1,060,709	$279,762	$0
		Fire Following Earthquake Losses	$266,826	$230,693	$195,128	$158,485	$122,920
		Physical Damage - Reservoirs	$3,765,421	$3,200,608	$1,506,168	$564,813	$188,271
		Wells and Pump Stations	$140,000	$28,000	$14,000	$14,000	$14,000
		Lost Revenue	$4,421	$4,296	$2,226	$1,067	$847
		Total Scenario Damages + Losses	$7,674,592	$6,712,617	$3,404,601	$1,318,432	$564,234
		Annualized Damages + Losses	$76,746	$67,126	$34,046	$13,184	$5,642
Puente Hills M7.1	3000	System Hours of Lost Service	1.41	1.37	0.71	0.34	0.27
		Economic Impact of No Water	$1,243,918	$1,208,629	$626,370	$300,305	$238,197
		System Hours of Non-Potable	6.12	5.54	2.88	0.76	0.00
		Economic Impact of Non-Potable	$2,254,007	$2,040,392	$1,060,709	$279,762	$0
		Fire Following Earthquake Losses	$266,826	$230,693	$195,128	$158,485	$122,920
		Physical Damage - Reservoirs	$4,582,119	$3,894,801	$1,832,848	$687,318	$229,106
		Wells and Pump Stations	$180,000	$36,000	$18,000	$18,000	$18,000
		Lost Revenue	$4,421	$4,296	$2,226	$1,067	$847
		Total Scenario Damages + Losses	$8,531,290	$7,414,810	$3,735,280	$1,444,937	$609,069
		Annualized Damages + Losses	$2,844	$2,472	$1,245	$482	$203

Table 4-1. Scenario and Annualized Earthquake Damages and Losses (Part 2 of 2)

Earthquake Event	Return Period	Annualized Damages + Losses	
		As-Is	Percent
San Andreas M7.9	**100**	$ 62,278	4.58%
Sierra Madre M7.2	**300**	$484,937	35.67%
Raymond M6.5	**300**	$194,960	14.34%
Verdugo - Eagle Rock 6.9	**1000**	$80,929	5.95%
Upper Elysian Park M6.4	**3000**	$3,727	0.27%
Upper Elysian Park M6.0	**100**	$76,746	5.64%
Puente Hills M7.1	**100**	$2,844	0.21%
Plus 50% for Other Earthquakes	n/a	$453,210	33.33%
Total Annualized Damages	n/a	**$1,359,631**	100.00%

Table 4-2: Relative Contributions of Various Earthquakes to Total Seismic Risk

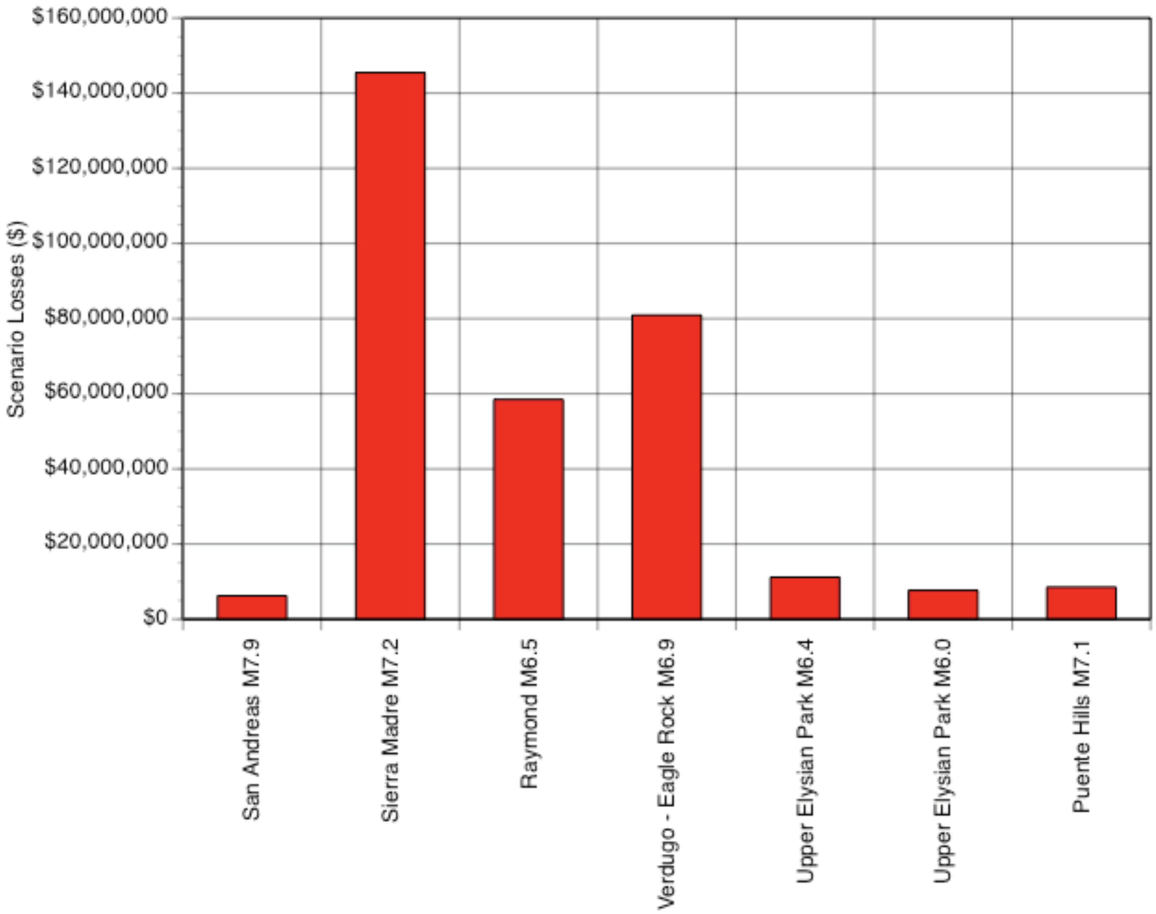


Figure 4-1. Scenario Losses in Pasadena due to Scenario Earthquakes

Figures 4-2 and 4-3 show the breakdown of the losses in Pasadena, given the occurrence of four scenario earthquakes, for the system in its as-is and potentially upgraded conditions.

The reduction in losses in Figure 4-3 assume implementation of the P3 seismic upgrade program plus the emergency response items listed in this report, and assume no surface faulting through the Allen, Santa Anita reservoirs or south of the Don Benito tanks in the Sierra Madre M 7.2 earthquake. If the recommended subsurface investigations for the Allen, Santa Anita and Don Benito sites indicate that more extensive upgrades are required to address the surface faulting hazard, then the P4 costs would be required to justify the reduction in losses in Figure 4-3 for the Sierra Madre M 7.2 earthquake.

Comparison of Figures 4-2 and 4-3 shows that by implementing the seismic upgrade program, losses will be reduced by about 80% to 90%, although not entirely eliminated. The bulk of the residual losses occur due to damage pipelines; the seismic upgrade program does not recommend pipe replacement to reduce this damage, as this is generally not cost effective; instead, somewhat more rapid repairs can be made by implementing the emergency response activities recommended in this report.

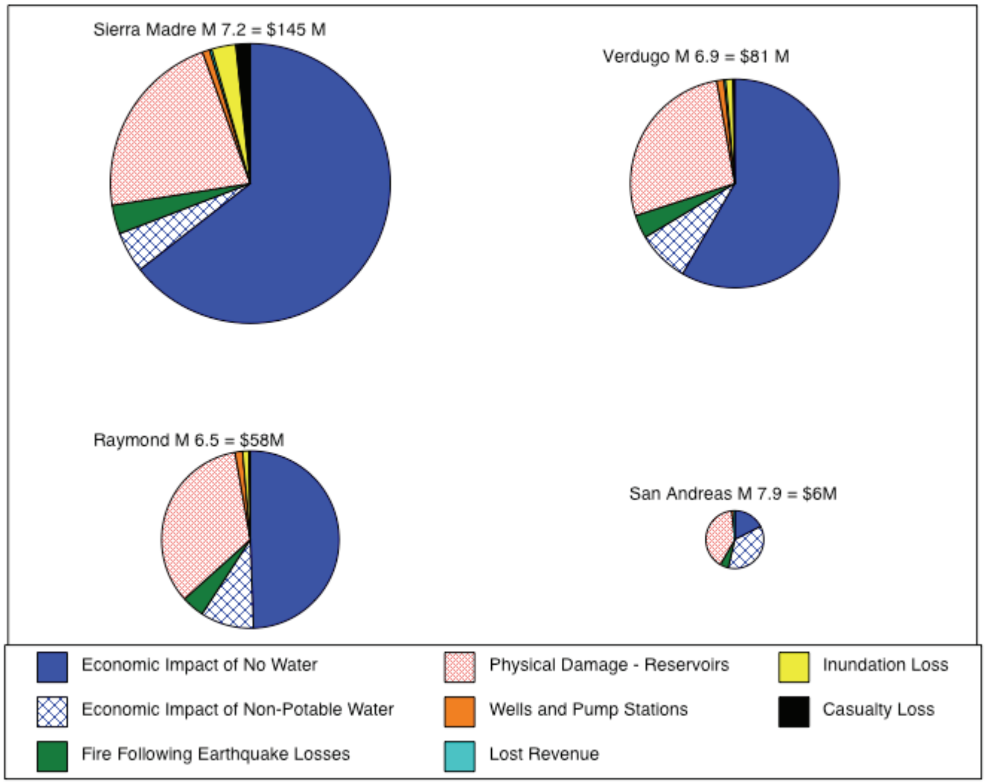


Figure 4-2. Scenario Losses in Pasadena due to Scenario Earthquakes (As Is System)

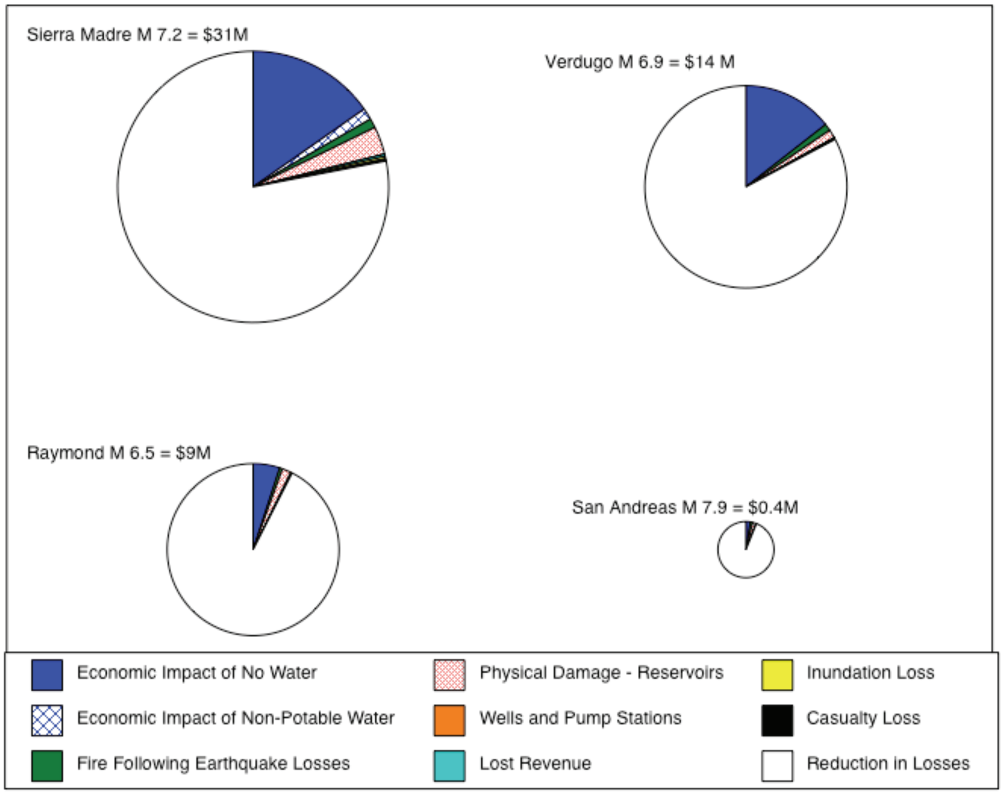


Figure 4-3. Scenario Losses in Pasadena due to Scenario Earthquakes (Upgraded System)

4.3 Benefit-Cost Results and Interpretation

Summary benefit-cost results are shown in Table 4-3. The results shown above in Table 4-3 are for a 5% discount rate, which is the midpoint of plausible discount rates (3% to 7%). The calculation of the net present value of benefits depends strongly on the discount rate selected. The sensitivity of the calculated net present value of benefits and thus of benefit-cost ratios to variations in discount rate is shown below in Table 4-4.

For Benefit-cost calculations take into account the time value of money. In simple terms, the costs of mitigation projects such as a seismic upgrade program are incurred upfront at the time of construction, while the benefits of mitigation (reduced damages and losses) accrue statistically over the useful lifetime of the CIP upgrades. For infrastructure upgrades a useful lifetime of 50-years is commonly assumed.

Earthquake Event	Return Period	Annualized Damages + Losses				
		As-Is	P1	P2	P3	P4
San Andreas M7.9	**100**	$ 62,278	$ 54,056	$ 27,435	$ 10,131	$ 3,812
Sierra Madre M7.2	**300**	$484,937	$355,354	$200,855	$106,413	$76,803
Raymond M6.5	**300**	$194,960	$155,471	$78,592	$30,889	$14,537
Verdugo - Eagle Rock 6.9	**1000**	$80,929	$68,425	$38,567	$19,994	$13,827
Upper Elysian Park M6.4	**3000**	$3,727	$3,202	$1,589	$613	$249
Upper Elysian Park M6.0	**100**	$76,746	$67,126	$34,046	$13,184	$5,642
Puente Hills M7.1	**100**	$2,844	$2,472	$1,245	$482	$203
Subtotal Annualized Damages	n/a	$906,421	$706,105	$382,328	$181,705	$115,073
Plus 50% for Other Earthquakes	n/a	$453,210	$353,053	$191,164	$90,852	$57,536
Total Annualized Damages	n/a	$1,359,631	$1,059,158	$573,492	$272,557	$172,609
Reduction from As-Is (Benefits)	n/a	n/a	$300,473	$786,139	$1,087,074	$1,187,022
Net Present Value of Reduction[1]	n/a	n/a	$5,485,415	$14,351,694	$19,845,534	$21,670,190
CIP Cost (rounded)	n/a	n/a	$2,120,000	$5,880,000	$8,730,000	$17,840,000
Benefit-Cost Ratio[1]	n/a	n/a	**2.59**	**2.44**	**2.27**	**1.21**

Table 4-3: Benefit-Cost Results

For direct comparison to costs, future benefits are discounted to net present value, taking the time value of money into account, by using a "discount rate." For benefit-cost analysis, the proper discount rate is a real discount rate, not considering the impacts of future inflation (which are unknown).

For FEMA-funded mitigation projects, FEMA regulations require use of a 7% discount rate. However, for internally-funded or bond-funded programs, Pasadena would most likely wish to use a lower discount rate. As an example, if a bond were issued at 6% annual interest, and the current annual inflation rate is about 3%, then the real cost of the bond is 3% per year, which corresponds to a real discount rate of 3%. Thus, for bond costs in the range of 5% to 6%, appropriate discount rates would be in the range of 2% to 3%.

Present value coefficients various discount rates (50-years)	PVC
3%	25.73
4%	21.48
5%	18.26
6%	15.76
7%	13.80

Discount Rate	P1	P2	P3	P4
	BCR for Various Discount Rates			
3%	3.65	3.44	3.20	1.71
4%	3.04	2.87	2.67	1.43
5%	2.59	2.44	2.27	1.21
6%	2.23	2.11	1.96	1.05
7%	1.96	1.85	1.72	0.92

Table 4-4. Sensitivity of BCRs to Various Discount Rates

For discount rates of 3% to 6%, all of the upgrade packages have BCRs greater than one, and thus may be deemed economically justified. For the FEMA-mandated discount rate of 7%, P1, P2 and P3 are economically justified while P4 is not (that is, the BCR for P4 is 0.92, which is less than 1.0).

4.4 Interpretation of Benefit-Cost Results

Benefit-cost results provide an important basis for decision making about what level of upgrade program may be appropriate for Pasadena. However, benefit-cost results should not be over interpreted, and other factors may also influence the final decision about which level of upgrade is appropriate.

P1 is a relatively low cost package which addresses obvious and major deficiencies in the as-is water system. Given these attributes and the high benefit-cost ratios, implementation of P1 clearly makes sense. P2 and P3 also have benefit-cost ratios above 1.0 as does P4 (for some discount rates). Further insight into the economic viability of these packages can be obtained by comparing the incremental benefits and incremental costs in going from P1 to P2, from P2 to P3 and from P3 to P4. These results are shown below in Table 4-5.

On the basis of incremental benefits and incremental benefit-cost ratios, going from As-Is to P1 to P2 to P3 are all cost-effective, regardless of discount rate. Going from P3 to P4 is not cost effective, regardless of discount rates because the incremental costs ($9.1 million) are much larger than the incremental benefits ($1.8 million).

The conclusion, drawn from the incremental benefit-cost results, is that P3 clearly makes sense, but a-priori, P4 does not make sense.

Category	Incremental Costs and Benefits			
	As-Is to P1	P1 to P2	P2 to P3	P3 to P4
Benefits	$5,485,415	$14,351,694	$19,845,534	$21,670,190
Incremental Benefits[1]	$5,485,415	$8,866,279	$5,493,840	$1,824,655
Incremental Costs	$2,120,000	$3,760,000	$2,850,000	$9,110,000
Incremental BCR[1]	**2.59**	**2.36**	**1.93**	**0.20**

[1] 5% discount rate, 50-year project useful lifetime

Discount Rate	Incremental BCR for Various Discount Rates			
	As-Is to P1	P1 to P2	P2 to P3	P3 to P4
3%	3.65	3.32	2.72	0.28
4%	3.04	2.77	2.27	0.24
5%	2.59	2.36	1.93	0.20
6%	2.23	2.04	1.66	0.17
7%	1.96	1.78	1.46	0.15

Table 4-5 Incremental Benefit-Cost Results

If a decision were made solely on benefit-cost results, P3 might be a logical level of upgrade. On the other hand, there are certainly valid factors beyond those considered in benefit-cost analysis. P4 provides a greater reduction in future damages and losses from rare (2,475-year return period) earthquakes and includes budget to deal with the possibility that surface faulting might be a realistic hazard for some reservoirs. A better decision to spend any money for items in the P4 budget will be gained after some additional site investigations are done at the Allen, Santa Anita and Don Benito sites.

5.0 Service Goals

This section of the report describes service goals for the Pasadena water system after earthquakes. Where appropriate, the goals are distinguished between rare Maximum Earthquakes (like a Sierra Madre M 7.2 earthquake) or more common but less severe earthquakes like the 1933, 1971, 1987, 1994 earthquakes or a future San Andreas event that can affect the Pasadena area. The numbering of the goals (1 to 10) is for convenience, and does not indicate that an individual goal is more important than another.

Service goals are a method by which to benchmark how well a water system will perform in earthquakes against deterministic goals. There are no code requirements per se to meet these goals. However, service goals similar to the ones presented in Tables 5-1 and 5-2 are commonly used by other water utilities in California, and have been used as a yardstick to help decide whether or not to upgrade their water systems.

Section 5.1 describes the services goals for the Pasadena water system. Section 5.2 describes how well the as-is water system meets these goals. Section 5.3 describes how well the water system would meet these goals, assuming various seismic upgrade programs are adopted.

5.1 Service Goals Described

1. Minimal Secondary Damage and Risk to the Public

Damage to the infrastructure should pose minimal risk to the public. For example, chlorine releases should not occur, and occupied buildings should not collapse.

2. Limit Extensive Damage to System Facilities

Undue amounts of damage to Pasadena's own facilities could result in the inability for the Maintenance Department to respond after an earthquake. Damage to critical facilities with post-earthquake emergency function should be avoided (such as the designated areas for emergency operations coordination). Damage posing credible life safety threat to Pasadena's own personnel should be avoided.

3. All Water Introduced into the Pasadena System Minimally Disinfected

All water entering the Pasadena water distribution system from the Metropolitan Water District should be at least minimally disinfected prior to introduction, immediately after the earthquake. This means that no "untreated" water should be introduced. Minimal disinfection would include chlorination / chloramination.

4. Provide Limited Fire Service at Fire Hydrants for the First 24 Hours After the Earthquake

This service goal reflects that, after an earthquake, there may be multiple fires on Pasadena. This will be compounded by damage within the Pasadena distribution system, cutting off parts of the water distribution system from the source of water and depleting water in the storage tanks through pipeline breaks.

Maximum Earthquake: The target goal is to be able to provide limited fire flow service throughout most of the service area, for the first 24 hours after the earthquake. The first 24 hours is when most of the fire outbreaks usually occur after earthquakes. By limited, it is meant that 75% of the area served by Pasadena will be within 2,000 feet of a serviceable hydrant. A serviceable hydrant is one with a minimum of 1,000 gpm at 20 psi residual pressure, with consideration of concurrent distribution system leak rates and alternative reliable water supplies. In coordination with the Fire Department, emergency fire flows can be established at any location within 2 to 8 hours after the earthquake.

Probable Earthquake: The target goal is to be able to provide limited fire flow service throughout most of the city, for the first 24 hours after the earthquake. The first 24 hours is when most of the fire outbreaks usually occur after earthquakes. By limited, it is meant that 90% of the area served by Pasadena will be within 2,000 feet of a serviceable hydrant (minimum of 1,000 gpm at 20 psi residual pressure) with consideration of concurrent distribution system leak rates. In coordination with the Fire Department, emergency fire flows can be established at any location within 2 to 8 hours after the earthquake.

5. Provide Normal Fire Service to All Hydrants Within 10 Days After the Earthquake

Maximum Earthquake: This service goal reflects that the City should be able to restore its normal capacity to deliver water to almost all (99%+) fire hydrants, within 10 days after any earthquake.

Probable Earthquake: This service goal reflects that the City should be able to restore its normal capacity to deliver water to all fire hydrants, within 3 days after a probable earthquake.

6. Critical Care, Emergency Relief Facilities: Potable Water Via Distribution System or Truck or Accessible Locations Within 1 Day

The Pasadena water department should be able to deliver (or be confident that others will deliver) potable water to any functioning critical care or emergency relief facility (shelter) within Pasadena within 1 day after any earthquake.

This will require an ability to prioritize repair and restoration activities to restore water deliveries via the distribution system to priority customers. Should sufficient damage occur that precludes the restoration of water service by the usual underground pipe network, alternative water delivery approaches should be available.

It is likely that some Pasadena area residents will be unable to get potable water via their normal water distribution system following large earthquakes. This will include people who are forced out of their homes because of damage to those structures and due to damage to the underground water distribution network. Suitable delivery points for distribution of potable water should be identified as part of an emergency response plan. Suitable facilities should be available to allow water tanker trucks to be filled from reliable sources of potable water. Potable water hose bibs should be available at several locations throughout the Pasadena service area.

7. Critical Care, Emergency Relief Facilities: Impaired Service Within 3 Days.

Impaired service is defined as the delivery of some amount of water (enough to meet winter time demands, allowing for mandatory halt of irrigation if necessary) via the buried pipe transmission system. Occasional pressure fluctuations or brief outages are possible. For probable earthquakes, within 2 days.

8. Critical Care, Emergency Relief Facilities: Normal Service Within 5 Days.

Normal service is defined as the delivery of amount of water at the same level of reliability as under "normal" pre-earthquake conditions. For probable earthquakes, within 3 days.

9. Impaired Service to Other Customers Within 7 Days

Impaired service is defined as the delivery of some amount of water (enough to meet winter time demands, allowing for mandatory halt of irrigation if necessary) via the buried pipeline system to at least 98% of all customers. Occasional pressure fluctuations or brief outages are possible. For probable earthquakes, within 4 days.

10. Normal Service to Other Customers within 10 Days

Normal service is defined as the delivery of amount of water at the same level of reliability as under "normal" pre-earthquake conditions. For probable earthquakes, within 5 days.

Service Category	Maximum Earthquake	
General	1	Minimal secondary damage and risk to the public
	2	Limit extensive damage to system facilities
	3	All water introduced into the distribution system minimally disinfected
Fire Service	4	Provide limited fire service to 75% of fire hydrants for first 24 hours after the earthquake.
	5	Normal fire service to almost all (99%+) hydrants within 10 days
Critical Care and Emergency Relief Facilities	6	Potable water via distribution system or truck within 1 day.
	7	Impaired service within 3 days
	8	Normal service within 5 days
Other Users	9	Impaired service within 7 days
	10	Normal service within 10 days

Table 5-1. Pasadena Water System Service Goals - Maximum Earthquake

Service Category	Probable Earthquake	
General	1	Minimal secondary damage and risk to the public
	2	Limit extensive damage to system facilities
	3	All water introduced into the distribution system minimally disinfected
Fire Service	4	Provide limited fire service to 90% of fire hydrants for first 24 hours after the earthquake.
	5	Normal fire service to all (99%+) hydrants within 3 days
Critical Care and Emergency Relief Facilities	6	Potable water via distribution system or truck within 1 day.
	7	Impaired service within 2 days
	8	Normal service within 3 days
Other Users	9	Impaired service within 4 days
	10	Normal service within 5 days

Table 5-2. Pasadena Water System Service Goals - Probable Earthquake

Minimally Disinfected	Chlorination or better
Limited Fire Service (Maximum EQ)	Provide fire flows to cover 75% of the service area for the first 24 hours after earthquake with allowance for distribution leak rates, damaged distribution storage, and alternate reliable water supplies.
Limited Fire Service (Probable EQ)	Provide fire flows to cover 90% of the service area for the first 24 hours after earthquake with allowance for distribution leak rates, damaged distribution storage, and alternate reliable water supplies.
Impaired Service	Provide water (adequate to meet winter time demands), possibly at lower pressure than normal to 98%+ of customers
Normal service	Provide water at the same level of reliability as under "normal" pre-earthquake conditions to 99%+ of customers

5.2 Service Goals Met – As Is Water System

Table 5-3 compares how the Pasadena water system, in its current condition, compares with the performance goals after a Maximum Earthquake.

Service Category	Goal	Sierra Madre M 7.2	Verdugo Eagle Rock M 6.9	Raymond 6.5	Upper Elysian Park M 6.4	Puente Hills M 7.1
General	1	No	Yes	Yes	Yes	Yes
	2	No	No	No	Mostly	Mostly
	3	Yes	Yes	Yes	Yes	Yes
Fire Service	4	No	No	No	Yes	Yes
	5	No	No	Yes	Yes	Yes
Critical Care	6	No	No	No	No	No
	7	No	No	No	Yes	Yes
	8	No	No	No	Yes	Yes
Other Users	9	No	No	Mostly	Yes	Yes
	10	No	No	Yes	Yes	Yes
Goals Met		1	2	4+	8+	8+

Table 5-3. Existing System Versus Goals (Maximum Earthquake)

Goal 1. Goal 1 is not met for the Sierra Madre M 7.2. In this event, there is some possibility that surface faulting will result in sudden release of water from reservoirs at the Allen, Santa Anita and Don Benito tank sites. Water releases could result in secondary damage, including inundation and erosion impacts. Release of water at the Allen and Santa Anita reservoirs could result in some risk to the public.

Goal 2. The Sierra Madre, Verdugo – Eagle Rock and Raymond scenarios all result in very strong ground shaking in Pasadena. the high level of shaking will result in significant damage to several reservoir roof systems (very costly to fix); damage to certain well buildings (could impact well operations); and damage to unanchored electrical equipment.

Goal 3. Goal 3 is met in that Pasadena has already seismically upgraded all its chlorine facilities. Assuming that power is available, these facilities should be reliable. Also, water from MWD is assumed to be suitable treated after any earthquake.

Goal 4. Goal 4 is not met for any of the three large nearby earthquakes. The percentage of fire hydrants without water in the first 24 hours is significant after the Sierra Madre M7.2, Verdugo Eagle Rock M 6.9 or Raymond M 6.5 earthquakes. This loss of water is due to damage to the Upper Feeder; loss of power for pumping; and breakage of distribution pipelines that leads to drops in pressure and rapid drawdown of existing storage reservoirs.

Goal 5. Goal 5 is not met for the Sierra Madre and Verdugo-Eagle Rock events, but is met for the others.

Goal 6. Table 5-3 lists "no", as it is assumed that Pasadena is not currently trained to distribute water via tanker truck to critical care facilities within 24 hours after any earthquake. This goal can be improved via suitable training and incorporation into emergency response plans.

Goal 7. Goal 7 is not met for any of the three large nearby earthquakes. This is chiefly due to loss of power supply, loss of Upper Feeder water, pipeline damage, and lack of emergency response directive to dedicate repair crews to restore water to critical care facilities on a priority basis. Providing backup power capability and improved training will largely serve to meet this goal.

Goal 8. Goal 8 is not met for any of the three large nearby earthquakes. This is chiefly due to loss of power supply, loss of Upper Feeder water, and pipeline damage. Providing backup power capability and improved training will largely serve to meet this goal.

Goal 9. Goal 9 is not met for the Sierra Madre and Verdugo – Eagle Rock earthquakes. This is chiefly due to loss of power supply, loss of Upper Feeder water, pipeline damage and limited repair crew size. Providing backup power capability, and expanding the ability to rapidly take on extra pipe repair crews through mutual aid will largely serve to meet this goal.

Goal 10. Goal 10 is not met for the Sierra Madre and Verdugo – Eagle Rock earthquakes. This is chiefly due to loss of power supply, loss of Upper Feeder water, pipeline damage and limited repair crew size. Providing backup power capability, and expanding the ability to rapidly take on extra pipe repair crews through mutual aid will largely serve to meet this goal for the Verdugo – Eagle Rock earthquake. For the Sierra Madre earthquake, either the Upper Feeder must be made more reliable (an MWD project), or there needs to be increased capacity to draw high volumes of water from the East Valley Feeder / Santa Monica Feeder.

Table 5-4 compares how well the as-is Pasadena water system compares to the service goals for the two Probable earthquake scenarios. As can be seen, the as-is system already meets most of the goals.

Service Category	Goal	San Andreas M 7.9	Upper Elysian Park M 6.4
General	1	Yes	Yes
	2	Mostly	Mostly
	3	Yes	Yes
Fire Service	4	Mostly	Mostly
	5	Yes	Yes
Critical Care	6	Yes	Yes
	7	Yes	Yes
	8	Yes*	Yes
Other Users	9	Yes	Yes
	10	Yes*	Yes
Goals Met		8+	8+

Table 5-4. Existing System Versus Goals (Probable Earthquake)

Goal 2. The existing infrastructure, with just a few exceptions, is expected to have at most none or minimal damage in the two probable scenario earthquakes.

Goal 4. Goal 4 is mostly met expect that there may be short term (a few hours) outage in a few hillside pressure zones due to power outages combined with concurrent pipeline damage due to landslides that leads to rapid depletion of in-zone storage.

Goal 8. Goal 8 is likely to be met after probable earthquakes. Providing backup power capability and improved post-earthquake emergency training will largely serve to increase confidence in meeting this goal.

Goal 10. Goal 10 is almost met for the San Andreas M 7.9 earthquake. Providing backup power capability and improved post-earthquake emergency training will largely serve to increase confidence in meeting this goal.

5.3 System Performance – Upgraded Water System

Figures 5-1 through 5-4 show the projected post-earthquake service within Pasadena assuming the occurrence of the scenario earthquakes, under three conditions:

- As-is system (2006).
- As-is system plus implementing seismic upgrade program P1.
- As-is system, plus implementing seismic upgrade program P3 plus the emergency response issues outlined in this report. The performance shown assumes that surface faulting in the Sierra Madre M7.2 scenario does not go through the embankments of the Allen, Santa Anita reservoirs; or south of the Don Benito reservoirs. Subsurface exploration recommended for these reservoirs may show

this not to be the case, in which case the cost to achieve the improvement in Figure 5-1 will be higher (the P4 upgrades for those reservoirs would then be required).

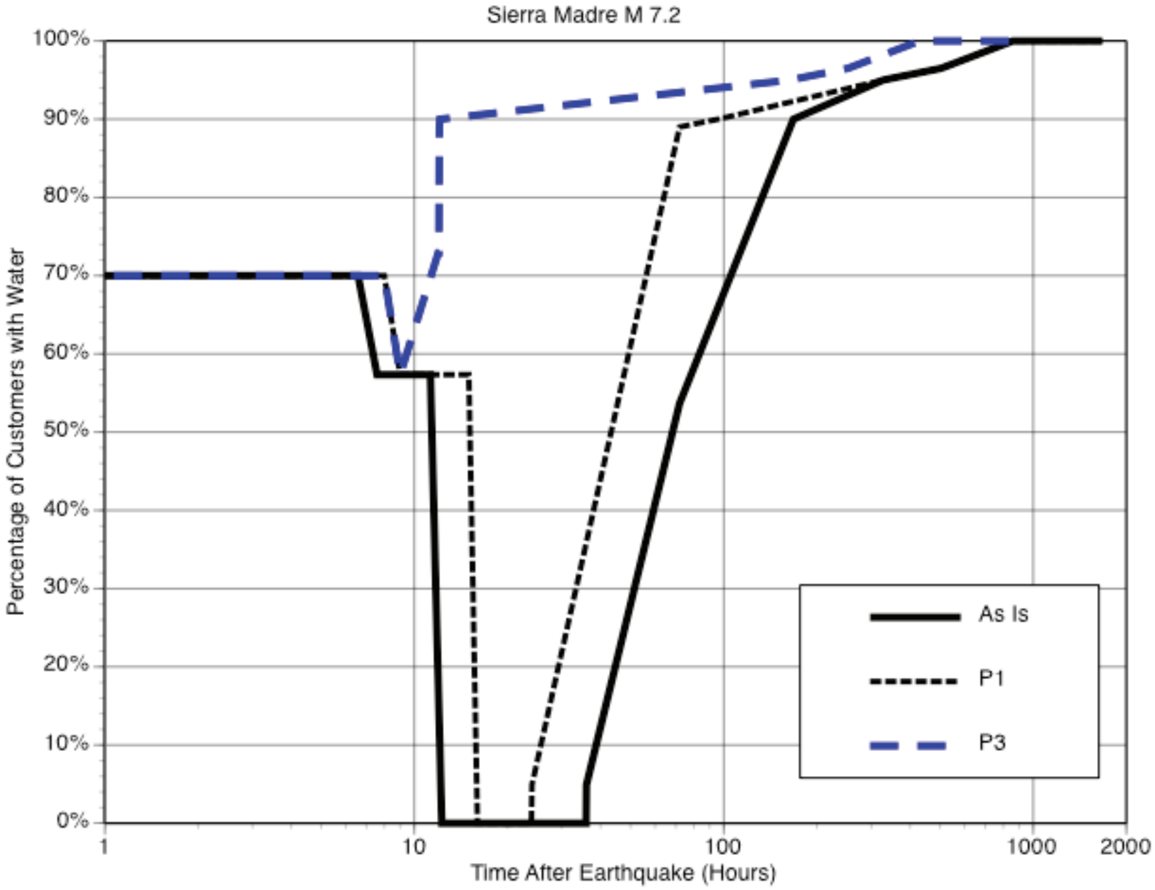


Figure 5-1. System Performance After Sierra Madre M 7.2 Earthquake

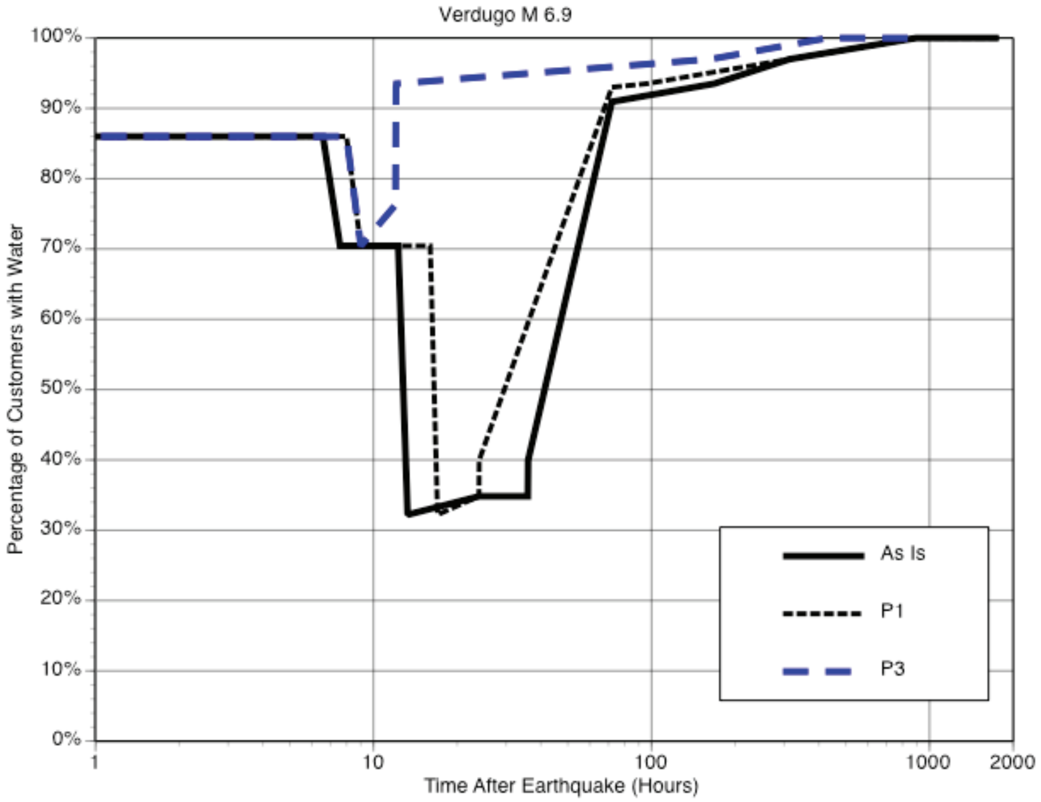


Figure 5-2. System Performance After Verdugo – Eagle Rock M 6.9 Earthquake

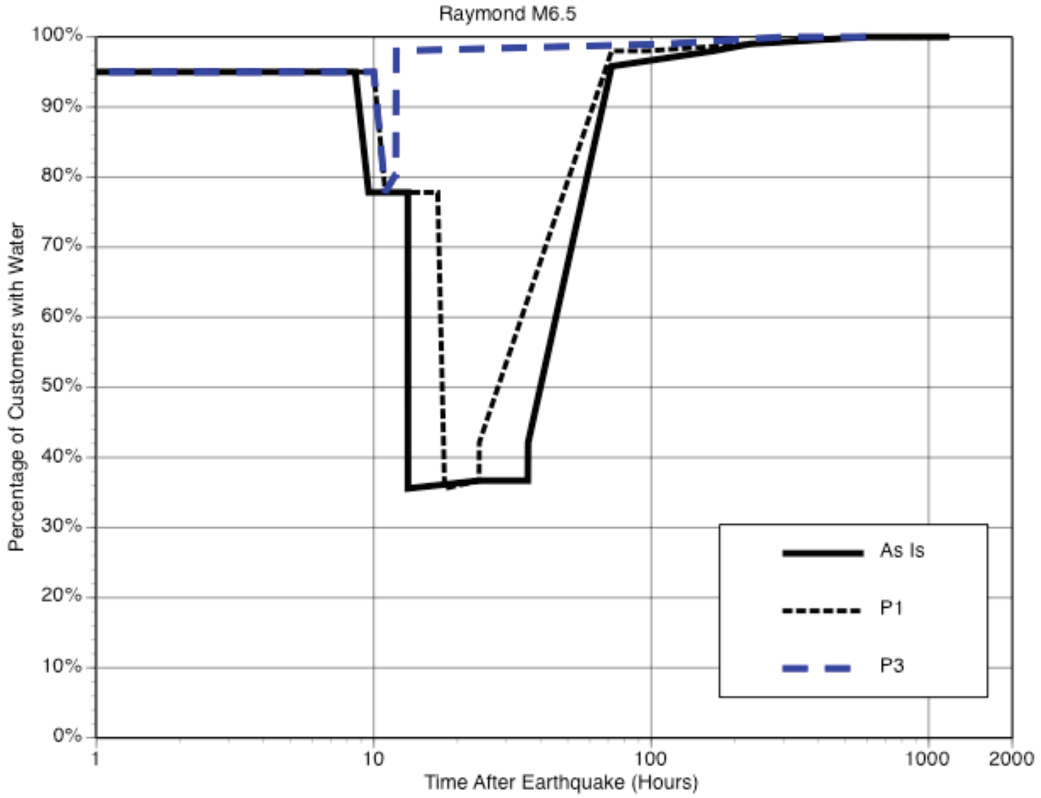


Figure 5-3. System Performance After Raymond – M 6.5 Earthquake

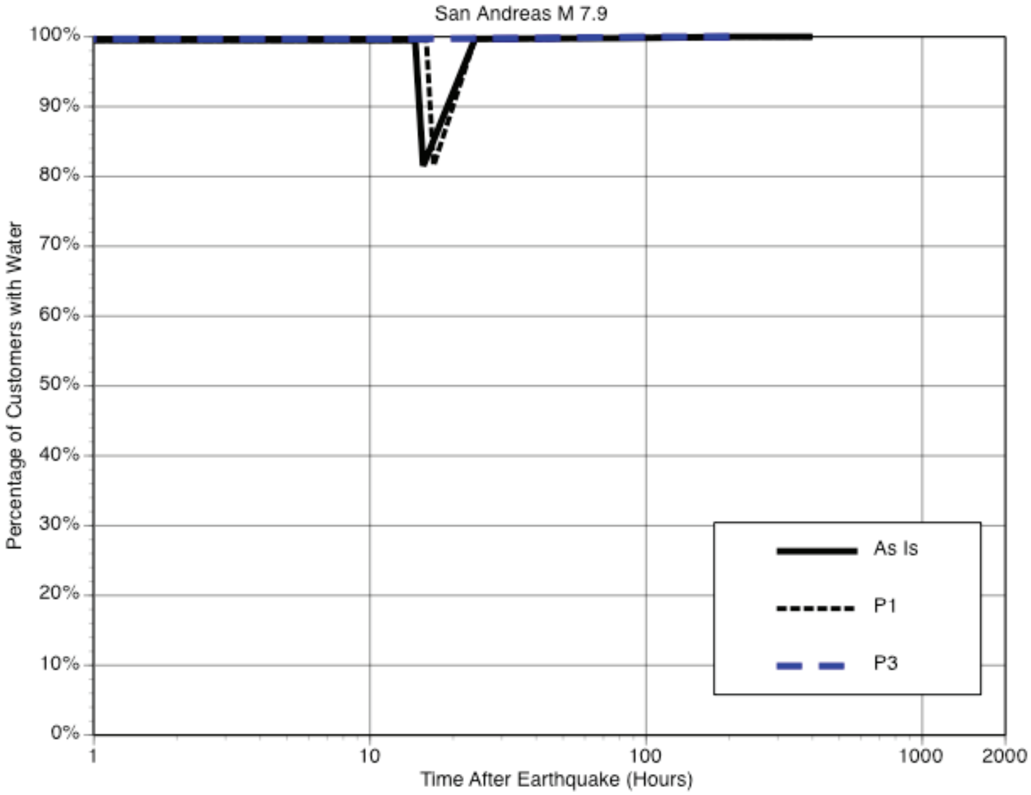


Figure 5-4. System Performance After San Andreas – M 7.9 Earthquake

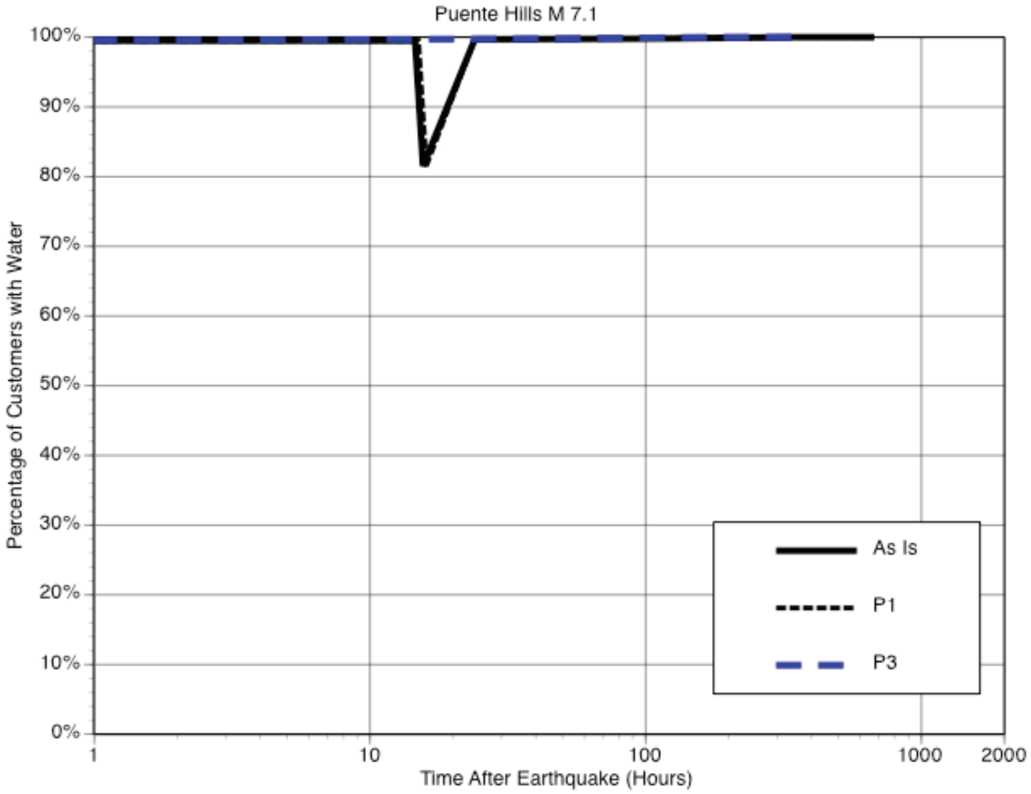


Figure 5-5. System Performance After Puente Hills– M 7.1 Earthquake

6.0 Emergency Planning

Section 6 of the report describes recommended actions to enable Pasadena Water and Power to be better prepared to respond to an earthquake.

6.1 Planning Scenario

Potential damage from seven scenario earthquakes is described in detail G&E (2006a). Because the Sierra Madre M 7.2 event is the scenario earthquake with the largest total earthquake risk to the Pasadena water supply system (see Figures 4-2, 4-3 and 5-1), it is chosen as the primary planning scenario for emergency response. The Verdugo – Eagle Rock M 6.9 scenario earthquake produces somewhat more pipe damage, especially due to fault offset, and this earthquake is also considered in the planning process.

6.2 Estimated Damages

The Sierra Madre M 7.2 earthquake scenario would result in:

- 124 pipeline repairs based on summer conditions. The breaks will occur in all sizes of distribution pipe, and all types of construction, except, possibly, butt-welded, and double-lap welded pipe. Table 6-1 shows the expected breaks by earthquake scenario. Table 6-2 breaks down the damage by pipe type and diameter.
- There will be about 10 to 20% more pipe repairs if the earthquake occurs during winter time (saturated soil) conditions, owing to the increased chance of landslides in hillside pressure zones.
- These total pipe repairs can vary by ±50% from the totals in Tables 6-1 and 6-2, owing to uncertainty and randomness in earthquakes.

The Verdugo – Eagle Rock M 6.9 earthquake scenario would result in about 15% more pipeline damage, with more pipes damaged due to fault offset.

Scenario Earthquake	Total Repairs	Repairs due to Ground Shaking	Repairs due to Liquefaction	Repairs due to Landslide	Repairs due to Fault Offset
San Andreas M 7.9	29	28	0	1	0
Sierra Madre M 7.2	124	103	0	19	2
Raymond M 6.5	76	76	0	7	6
Verdugo-Eagle Rock M 6.9	140	110	0	22	8
Upper Elysian Park M 6.4	50	48	0	2	0
Upper Elysian Park M 6.0	27	26	0	1	0
Puente Hills M 7.1	54	51	0	3	0

Table 6-1. Pipe Repairs Due to Scenario Earthquakes (Summer Time Conditions)

Pipe Diameter	Cast Iron	Ductile Iron	Other
4	10		
6	51	3	3
8	39	3	2
12	3	2	
16		2	
18	1		
30	1		
Total	105	10	5

Table 6-2. Pipe Repairs Due to Sierra Madre M 7.2 Scenario Earthquake

- 4 to 18 pumping plants non-functional due to various causes (2 buildings extensively or completely damaged; 6 pump sets damaged; 18 electrical panels / switchgear / transformers damaged; 11 miscellaneous equipment damaged; and offsite power outages throughout the service area for more than 24 hours)
- Possibly 2 steel tanks that fail and lose all water (meaning none available for fire flows or consumption)
- 4 to 14 open cut lined reservoirs with various types of roof damage, resulting in debris in the water, making water non-potable
- Likely Loss of MWD water supply at P1, P2, P3 and P4.
- Loss of electric power to pumps and wells.
- Failure of several well buildings, damaging the wellhead equipment.

6.3 Planning Assumptions

Repair estimates are divided into short term (temporary bypass to restore service) and long-term (restoring component to its pre-earthquake condition).

The following pipeline repair needs are assumed:

Pipe repair crew (each):

- 1 foreman
- 2 plumbers
- 1 heavy equipment operator (e.g., back hoe operator, heavy dump truck operator, etc.)

Pipe repair equipment (per crew):

- 1 heavy dump truck
- 1 service truck
- 1 backhoe (heavy crane for large pipes)
- 1 pickup truck
- 1 small compactor

Pipeline repair man hours (per pipe repair):

- 321 man hours (48 to 60 inch diameter pipe and larger)
- 241 man hours (24 to 42 inch diameter pipe)
- 95 man hours (12 to 20 inch diameter pipe)
- 38 man hours (10 inch and under diameter pipe, service connections, hydrants)

The pipe repair man hour estimates are based on historical averages of actual efforts by field crews to make pipe repairs. Since recent California earthquakes have been only moderately disruptive to water utilities and their communities as a whole, the above repair estimates reflect potential inefficiencies that may be encountered under very disruptive earthquakes, including poorer than normal communications, non-optimal use of manpower, use of mutual aid crews, etc.

Repair procedure:

- Short term repair and temporary bypass. Locate the damaged pipe. Isolate the damage by closing upstream and downstream valves. Dig up the street to expose the pipe (no trench wall system for most locations). De-water the site. Examine the pipe. Assess type of repair needed (clamp, new pipe, etc.). Install hardware to make the repair. Restore water service to the pipe and verify the pipe works. Leave the street open (with markers) until higher priority repairs are made. If the damage is on a backbone transmission pipeline (a pipeline that has no redundancy and serves hundreds to thousands of customers who will be out of water due to lack or rapid drainage of local storage), install a temporary flex hose bypass pipe between isolated hydrants either side of the fault offset / pipe break, in order to restore backbone transmission of water (at a rate of at winter time demand) while repairs to the transmission pipeline are made,

- Long term repair. Return to site of short term repair. Bury the pipe in suitable backfill. Compact the fill. Close the street. Restore pavement.

Under normal conditions, the entire pipe repair procedure would be done at one time. Breaking the repair procedure into two steps reflects the assumed urgency in restoring water service to as many customers as possible in as short a time frame as possible, given a large earthquake. For small earthquakes where the extent of customer service disruptions is relatively small (under 10% of all customers) and service disruption restoration times are relatively short (under 3 days), permanent repairs may be made at each pipe site in one step; this would reduce the average repair effort (man hours) per pipe break, but increases the total customer outage times.

Under emergency conditions, repair crews would be placed on 12 hour shifts, 7 days per week on a 24-hour cycle until the transmission system is completely restored; thereafter, repair crews would work 8 hour shifts, 5 days per week.

For temporary bypass needs, the average distance between isolated hydrants will be 750 feet. Assume that six large diameter bypasses will be sufficient to restore the bulk of transmission capacity. Assume that ultra large diameter flex hose (12-inch diameter) is used for the bypass. This type of hose is available from suppliers like Angus, and others. The cost of such hose is currently about $55 per foot, plus additional costs for spare parts and deployment vehicles (flaking boxes on trailers pulled by pickups). The estimated cost for Pasadena to procure such equipment is:

- 4,500 feet of 12-inch hose. $247,500
- Flaking boxes, transport vehicles, spare parts, hydrant adapters. $140,000.
- Total. $387,500.

6.4 Recommendations

The following emergency planning issues are addressed:

1. Materials, equipment and personnel for pipe repair
2. Modifications to wells and pumps to allow quick connection of emergency generators and/or bypass pumps
3. Fixed emergency generators and fuel.
4. Mutual Aid from/to neighboring municipalities.
5. Modifications to the existing Water Delivery Business Unit Contingency Plan dated September 12, 2002

6.4.1 Pipe Repair

While the City maintains an inventory of pipe of various sizes, couplings and other spare parts, Water and Power staff assumes that current inventories would not be sufficient to repair the number of estimated pipeline breaks for the scenario earthquake. Therefore, it must be assumed that additional pipe, couplings and other parts would need to be obtained from vendors or mutual aid sources.

Prior to the 1994 Northridge earthquake, the Metropolitan Water District of Southern California (MWD) placed cargo containers with extra pumps, emergency generators and miscellaneous items such as flashlights, gloves, etc. at critical field locations. Its experience responding to this earthquake indicated that most needed parts and equipment, including specialized parts, could have been delivered overnight from anywhere in the country. Consequently, MWD determined that maintaining large stockpiles of supplies and equipment was not necessary.

We recommend that Pasadena Water and Power maintain a minimum inventory of spare parts sufficient to make pipe repairs for three days after any major earthquake. During the first three days, the City will be concentrating on repairing the largest diameter pipelines in most cases; the City should have on hand sufficient spare parts to make about 4 repairs to medium-large diameter pipelines (16-inch to 36-inch diameter) and 40 repairs to small diameter pipelines (4-inch to 12-inch diameter).

We have not made a detailed inventory of available spare parts owned by Pasadena. For planning purposes, provide an allowance of $50,000 to procure and then maintain this minimum level of inventory of pipe repair parts.

Crew Availability

Assuming that a majority of Pasadena’s field personnel are able to report to work following the scenario earthquake, an adequate number of personnel would be available in the first 24 to 48 hours to secure the water system and initiate emergency repairs. However, in order to meet its service restoration goal to all customers, the City should pre-plan the use of mutual aid crews as soon as practical following the earthquake.

Once the system has been secured, 12-hour shift work should be implemented to perform the most critical repairs to the water system as rapidly as feasible. It is recommended that a City foreman be assigned to supervise each mutual aid crew.

As part of its earthquake planning, Pasadena should pre-assign its field personnel to 12-hour A and B shifts, based on job classifications and geographic residence locations (e.g., those living closest to department facilities should be assigned to A shift). Mutual aid crew leaders should also be pre-designated.

The types of repairs to which mutual aid crews would be assigned should be predetermined, and mutual aid crew packets should be developed. The crew packets should include local maps, PWP contact information, meal and/or housing vouchers, lists of local hotels, motels and restaurants, and similar reference information. These preparations will facilitate the timely and effective use of mutual aid crews.

A budget of $200,000 is recommended to plan for rapid crew ramp-up and mutual aid; prepare training manuals for crews to use for rapid pipe repair efforts; and purchase supplementary communication hardware for crew deployment.

6.4.2 Emergency Generators

Tables 6-3 and 6-4 shows the recommended addition of emergency generators for the pumping plants and wells.

Overall, we recommend that five sources of water (Ross pumping plant and four wells) have standby power sources available on site at all times. As the exact location of power outages cannot be known with certainty, these emergency generators should be portable (trailer mounted), so that they can be transported to other sites as needed.

For smaller pumping plants and wells, it is likely that suitable-sized emergency generators (4 to 8 additional) and portable pumps (one large 2500 gpm 200 foot lift and one small 400 gpm 300 foot lift) can be obtained within a few hours via mutual aid.

Pumping Plant	Quick Connects	Standby Power	Procure (P) or Mutual Aid (M)	Cost
Ross	Yes	Portable, On Site	P	$500,000
Linda Vista	Yes		M	
Santa Anita	Yes		M	
San Rafael				
Glorietta	Yes		M	
Lida				
Thomas				
Murray	Yes		M	
Atlanta				
Jones	Yes		M	
Eagle Rock	Yes		M	
Allen	Yes		M	
Annandale	Yes		M	
Flint Ridge				
Wilson	Yes		M	
P1				
Devils Gate	Yes			
Rutherford				

Notes:
P = procure
M = mutual aid / contractors or relocate from another site if necessary

Table 6-3. Standby Power Recommendations for Pumping Plants

In Table 6-4, it is suggested that four wells be outfitted with standby portable (trailer mounted) emergency generators. These four wells were selected primarily based on their size (larger flow rates) and locations (three on the eastern part of the system which is more likely to lose MWD water supply in the Sierra Madre M 7.2 earthquake). However, the final decision as to which wells should have the four standby portable generators will also have to take into account site security, local noise issues, site access or other factors. These four emergency generators should be sufficient to provide 10 to 12 MGD flow into the system within a few minutes after a power outage. If Pasadena can supply normal power to these wells, then they can be relocated to the other wells that do have power outages, and hooked into those wells using the quick connect couplings.

For purposes of this report, we have not sized the actual power needs for each well, but this will be done in the design step. For purposes of initial planning and cost estimating, we assume that the larger wells will require large emergency generators (600 kW to 1000 kW range). Emergency generators in this range are commonly available for about $300,000 each (open market), more if purchased new. Given the relatively rarity of large scale power outages, we think that procuring several used emergency generators might be more cost effective than buying a fewer number of new units, if financial resources are limited.

The smaller wells (typically 1 to 1.5 MGD flow rates) can likely be powered using emergency generators (250 kW to 500 kW range) from mutual aid / contractors, so pre-purchase of those is not suggested.

Well	Quick Connects	Standby Power	Procure (P) or Mutual Aid (M)	Cost
Chapman	Yes	Portable, On Site	P	$300,000
Jourdan				
Woodbury	Yes		M	
Monte Vista	Yes	Portable, On Site	P	$300,000
Craig	Yes	Portable, On Site	P	$300,000
Arroyo	Yes	Portable, On site	P	$300,000
52 Well	Yes		M	
Ventura				
Copelin	Yes		M	
Garfield	Yes		M	
Villa	Yes		M	
Sunset	Yes		M	
Windsor	Yes		M	
Bangham	Yes		M	

Notes:
P = procure.
M = mutual aid / contractors or relocate from another site if necessary

Table 6-4. Standby Power Recommendations for Wells

6.5 Fixed Emergency Generators and Fuel

All five new portable emergency generators should be diesel powered, and sufficient fuel to be stored on location for 72 hours continuous operation. If a standby power source is permanently installed, then it can be either diesel- or propane powered.

6.6 Mutual Aid

Most public and private water agencies in California participate in the Water Authority Response Network (WARN), which provides mutual aid personnel and equipment resources on a voluntary basis.

In order to ensure the expeditious receipt of mutual aid resources, it is recommended that Pasadena Water and Power pre-identify potential sources for the numbers and types of personnel and specific equipment that would be needed. In the case of portable pumps, it is further suggested that Pasadena ensure that appropriate connectors will be available to allow for rapid hook-ups. Planning should consider the following:

- Number of pipe repair teams (including vehicles and equipment) available within 12 hours, 24 hours and 48 hours.
- Materials: pipe, welding supplies, gaskets, flex hose, etc., including specifications to ensure compatibility.
- Emergency generators (size) with compatible quick-connects.
- Bypass pumps (size).
- Fuel for generators.
- Communications protocols.
- Home/cell phones/pagers/radio communicators for key personnel.
- Joint Training exercises and drills to identify any mismatches in equipment and/or supplies.

6.7 Revisions to Existing Contingency Plan

The existing Contingency Plan for Pasadena Water and Power, Water Delivery Business Unit, (September 12, 2002) does not currently contain the information needed to respond effectively to the scenario earthquakes. Specifically, the plan does not describe earthquake-specific procedures for activation, notification, damage assessment, status reporting, action planning, resource deployment and tracking, mutual aid, expenditure tracking, or deactivation.

The California Governor's Office of Emergency Services, in concert with the California Utilities Emergency Association and the American Water Works Association, has prepared "Emergency Planning Guidance for Public and Private Water Utilities" (1998). This document provides excellent planning guidance and function checklists which could be customized by Pasadena Water and Power.

The Contingency Plan for Pasadena Water and Power, Water Delivery Business Unit, September 12, 2002, should be updated as described above including the following:

- A new scenario should be added for earthquakes. The scenario should include an immediate assessment of system damage through pressure and flow measurements.
- The plan should be specific on which supplies are located where (see 6.4.1, above). For example, if pipe, cutting equipment and fittings are to be staged at multiple locations in the district, the locations and supplies should be specified.
- The Mutual Aid Agreements (including WARN) should be included in the Plan, including communications, command and control, and types of aid to be provided or received.
- The California Office of Emergency Services should be included as a contact in the plan.
- Interface protocols with the Pasadena Fire Department should be described.

- Interface with Pasadena Power, Southern California Edison and Los Angeles Department of Water and Power should be established for the purpose of identifying locations with power outages, likely power outage restoration times, and prioritizing power restoration efforts for critical water department wells or pump stations.

6.8 Summary Emergency Response Costs

Table 6-5 summarizes the items to be done as part of emergency response capability.

Item	Section	Cost
Ultra Large diameter 12" Flex Hose	6.3	$387,500
Spare Parts – Pipe Repair Kits	6.4.1	$50,000
Emergency Response Plans	6.4.1	$200,000
Standby Power Supply – Pumping Plants	6.4.2	$500,000
Standby Power Supply – Wells	6.4.2	$1,200,000
	Total	$2,337,500

Table 6-5. Emergency Response Costs

7.0 Hydraulic Analyses

A series of hydraulic analyses were performed to assess the hydraulic issues within the Eagle Rock, Annandale, Lida and Sheldon pressure zones.

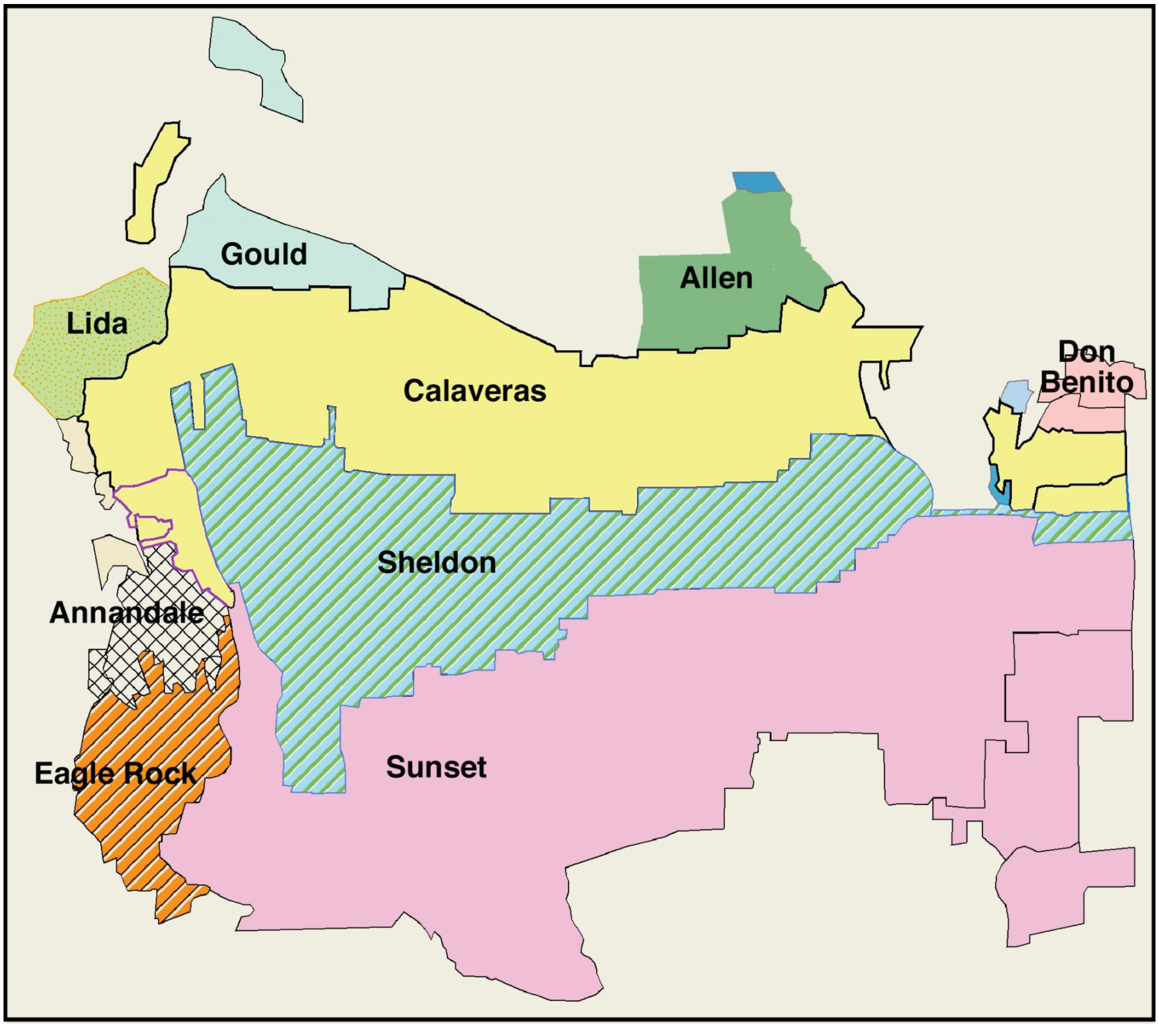


Figure 7-1. Main Pressure Zones in Pasadena Water System

7.1 Eagle Rock Pressure Zone

The Eagle Rock pressure zone is located in the southwest part of the Pasadena water system. The main facilities serving the zone, along with those in adjacent zones, are shown in Figure 7-2.

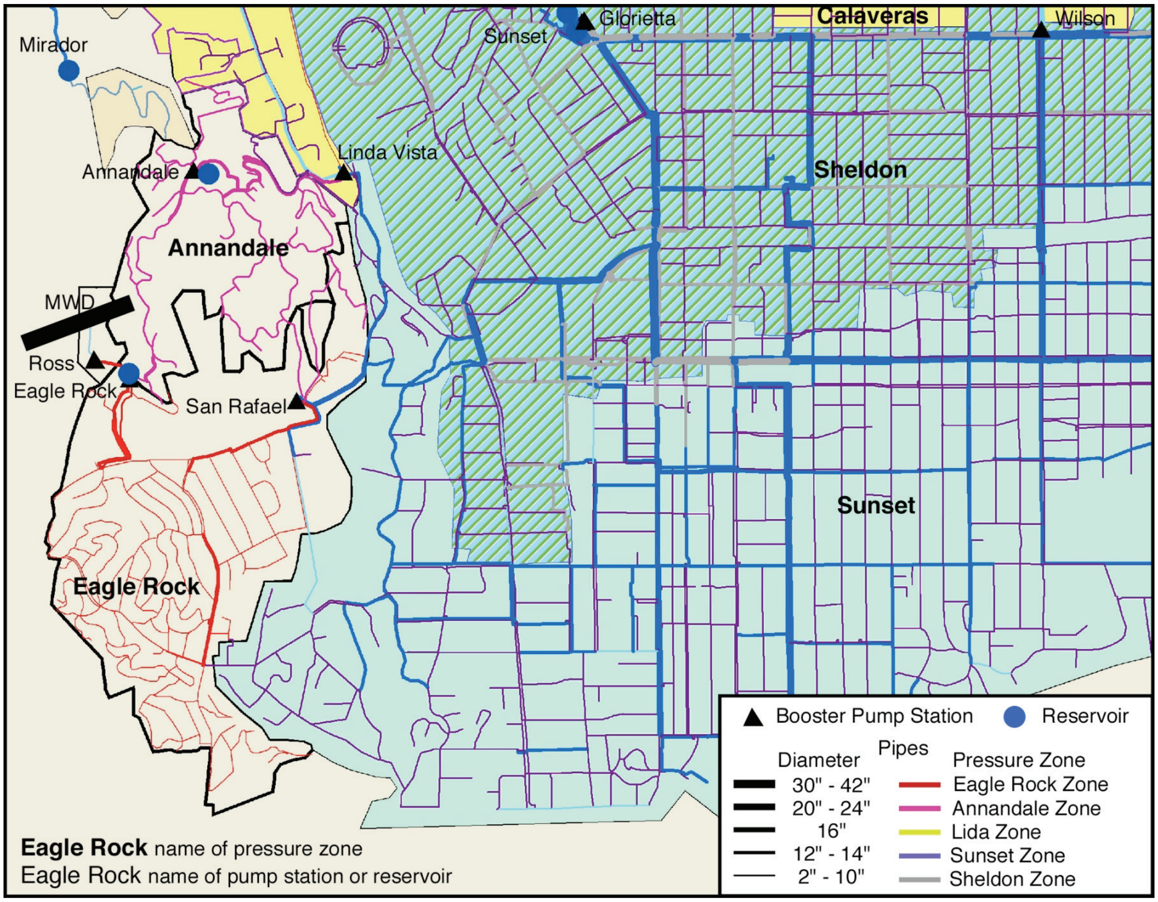


Figure 7-2. Pipes in and Near the Eagle Rock Zone

Hydraulic analysis was performed for the Eagle Rock Zone. The primary purpose of the analyses was to establish what upgrades would be needed in the Eagle Rock zone in order to move between 5 to 8 MGD flow into the Sunset pressure zone, from MWD turnout P5 next to the Ross pumping plant.

The transmission piping from the MWD P-5 turnout and Eagle Rock reservoir was modeled. Approximately 420 feet of 12-inch piping was modeled from the P-5 turnout to the Ross Pumping Plant. Hydraulic loss factors (Hazen Williams C values) were taken from MWH (2002) without adjustment; these factors were assumed to be reasonably calibrated by MWH, to reflect the age of the in-situ pipe. Where we specify new pipes, we assume C values consistent with modern installed lined welded steel, ductile iron or PVC pipe (C=130). The Ross Pumping Plant currently has two 50 horsepower pumps. Up to 5 additional pumps were used for the analysis, each having 100 horsepower useful output.

Base Case. For the base case, in-zone maximum day demands (MDD) for the year 2020 were used. Specific nodal demand data were not available, so equal demand was placed on the 143 nodes below Patrician Way. Pump curves reflecting in-situ conditions for the Ross #1 and Ross #2 pumps were used in the model. With both pumps operating, we found that the head loss was such that the two pumps could not supply the in-zone demand. The pumps can supply a total of approximately 1525 gpm or 2.20 MGD. The 2020 maximum day demand for the zone is 2.60 MGD. Therefore, the Ross Pumping Plant alone is not capable of keeping the Eagle Rock reservoir full at year 2020 MDD.

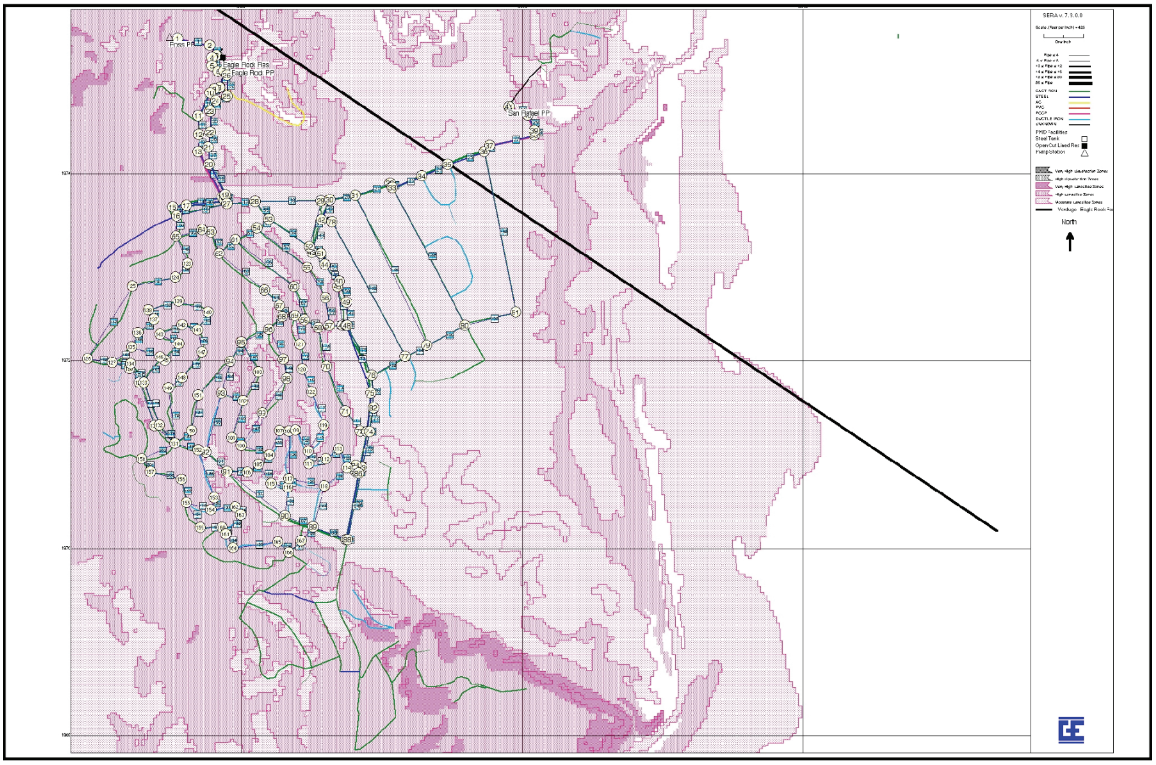


Figure 7-3. Pipes Eagle Rock Zone (Black line is approximate location of Eagle Rock fault, shaded areas show landslide hazard zones of varying severity)

The hydraulic grade line at the P-5 connection was taken as 943 feet. The maximum overflow height of 1132 feet at the Eagle Rock reservoir was used. Losses in the existing Eagle Rock zone piping results in a hydraulic grade of 1074 feet at the San Rafael Pumping Plant, where water can be supplied to the Sunset zone via a pressure reducer. Water can also be supplied to the Sunset zone in the southeastern corner of the zone, at the corner of Avenue 64 and La Loma. The hydraulic grade at this point is 1073 feet.

5 MGD Case. The second hydraulic analysis case applied the year 2020 average day demand (ADD) for the Eagle Rock zone (1.51 MGD), plus drew out another 5 MGD to the Sunset zone. This extra 5 MGD would correspond to a situation where the Upper Feeder was out of service, and all MWD water into Pasadena must be taken at P5. The Eagle Rock-to-Sunset pressure regulator station at the San Rafael Pumping Plant drew 4.5 MGD, and the southeast corner drew 0.5 MGD (see Figure 7-4 for location of zone interconnections). The analysis was first run with the as-is piping, assuming that additional pumps at the Ross pumping plant would be added to make up the additional demand. If two 100 hp pumps are added, the flow will be about 100 gpm short of the target, or 0.14 MGD. The analysis was performed with three 100 hp pumps to supply the additional 5 MGD to the Sunset zone.

In the as-is configuration, the hydraulic losses in the zone are high, yielding a hydraulic grade of only 566 feet at the San Rafael pumping plant, which is impossibly low. In addition, much of the piping is at negative pressure, which is clearly unacceptable. Therefore, additional piping is needed to transmit the additional water to the Sunset zone via a pressure regulator at the San Rafael pumping plant to preserve the service pressure in the existing system. A 16-inch diameter parallel pipe, of approximately 2150 feet, was added down Patrician Way, as previously recommended by Montgomery Watson (MWH, 2002). Another 16-inch diameter parallel pipe, of approximately 4800 feet, was also assumed to be installed along Colorado Boulevard and up to the San Rafael pumping plant.

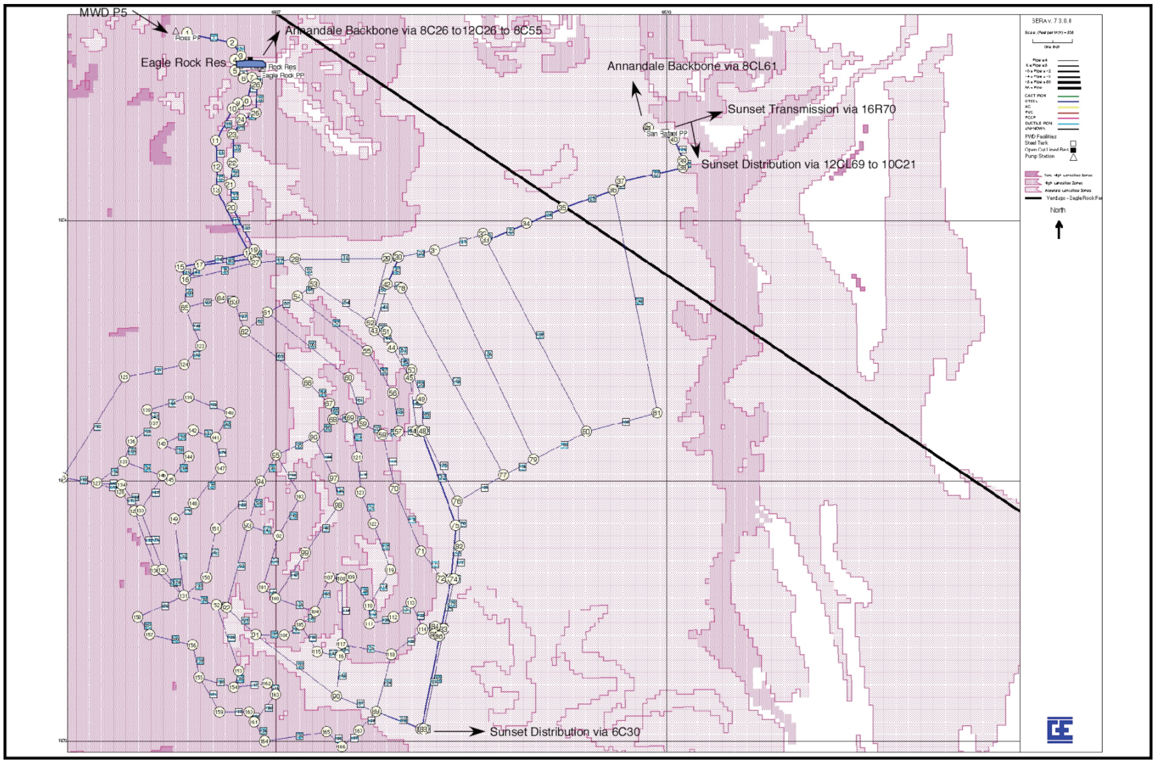


Figure 7-4. Eagle Rock Zone – Hydraulic Model

The addition of the 6950 feet of 16-inch pipe results in an improved hydraulic grade line in the zone. The final hydraulic grade is 1082 feet at the San Rafael pumping plant and 1080 feet at the southeastern corner of the zone. The pressures in the service area appear reasonable; in fact, they are about 5 to 6 feet (2 psi) higher than under current operating conditions.

The pressure in the 12-inch suction pipe between the Ross pumping plant and MWD turnouts is very slightly negative when all 5 pumps are run, due to the high flow in the 12-inch pipe. If Ross Pumps #1 and #2 are turned off, and only the 3 new pumps run, the flow from the MWD turnout will be adequate to supply the demand, plus the pressure in the inlet pipe to the pumping plant will be positive. Flows in the 12-inch pipe are on the order of 13 to 14 fps, which is high but tolerable for the periods of time where the high demand would be in effect. Therefore, for an additional 5 MGD supply to the Sunset zone, it may not necessary to upgrade the piping between the MWD turnout and the top of Patrician Way, but this should be investigated in final design. With the very high flow rates, water hammer forces should be checked in the pipes between the MWD turnouts and the Eagle Rock reservoir; and likely the discharge water under high flow rate should be directly into the Eagle Rock reservoir.

8 MGD Case. The third hydraulic analysis case applied the year 2020 ADD for the Eagle Rock zone, plus another 8 MGD for the Sunset zone. The pressure regulating station at San Rafael pumping plant drew 7 MGD, and the southeast corner drew 1 MGD. First, the upgraded condition for the 5 MGD case was considered. Two additional pumps were added (making 5 additional 100 hp pumps at the Ross pumping plant) to achieve the desired flow through the 12-inch pipe from the MWD turnout. The head loss is so high in the 12-inch pipe that the original two 50 hp pumps are ineffective, and the remaining 5 new pumps must provide the flow. Additionally, there are negative pressures in the pipe between the MWD turnout and the Ross pumping plant, and the velocities in the 12-inch pipe between the MWD turnout and the top of Patrician Way are on the order of 20 fps.

Clearly the 12-inch pipe is too small to transmit the desired flow. Since the right-of-way is too narrow to allow placement of a parallel pipe, the 12-inch pipe was assumed to be replaced by a larger pipe in the hydraulic model. If a larger diameter pipe is used, the hydraulic losses are reduced, allowing more efficient pumping, and fewer pumps can also be added. After a few iterations, the final configuration consists of a 16-inch pipe to replace the 12-inch pipe from the MWD turnout through the top of Patrician Way (where the 16-inch parallel pipe added for the 5 MGD case starts), for approximately 1200 feet. No additional pumps are needed, above the three added for the 5 MGD case. Flows in the 16-inch replacement pipe are on the order of 11 fps, which is acceptable for the limited periods of high flow.

The replacement of the 1200 feet of 12-inch pipe with 16-inch pipe results in a reasonable hydraulic grade line in the zone. The final hydraulic grade is 1054 feet at the San Rafael Pumping Plant and 1053 feet at the southeastern corner of the zone. The pressures in the service area are also reasonable.

Table 7-1 summarizes the recommended upgrades to the system to accommodate the 5 MGD and 8 MGD to the Sunset zone. Figure 7-5 shows the hydraulic grade lines for the various analyses.

Case	No. 100-hp pumps	Length of pipe (ft)	Diameter of pipe (in)
5 MGD	3	6950	16
8 MGD	3	8150	16

Table 7-1. Recommended Upgrades

Given the overall system needs, it would appear that upgrading the Ross pumping plant by an increment of 5 MGD is feasible. Required upgrades will include about 6,950 feet of 16-inch diameter pipe; expanding the pumping plant by adding three 100 HP pumps; and possible allowances for upgrading the pressure regulating station at the San Rafael pumping plant to allow up to 5 MGD flow rates from the Eagle Rock zone to the Sunset zone at that location. The upgraded Ross pumping plant will require provision for emergency standby power (the cost for standby power is covered in Section 6.4.2). To be verified in final design, some allowance for pressure transients should be considered, probably by installing a suitable pressure relief valve at the upgraded Ross pumping plant. It may also be necessary to upgrade the suction pipe from P5 to the Ross pumping plant.

In all these analyses, the additional storage for the Eagle Rock reservoir, as recommended in Section 2, is assumed.

The cost to make these upgrades includes:

- 6,950 feet of 16" pipe at $15 per inch foot (installed). $1.7 million
- Ross pumping plant upgrades. $1.5 million
- Additional in-zone storage. $1.15 million.
- Pressure regulating station upgrade. $0.2 million
- Contingency $0.75 million
- Total $5.30 million (

Of these upgrades, the MWH report (2002) includes 2,150 feet of 16" pipe, so some of this cost is already budgeted in the MWH report.

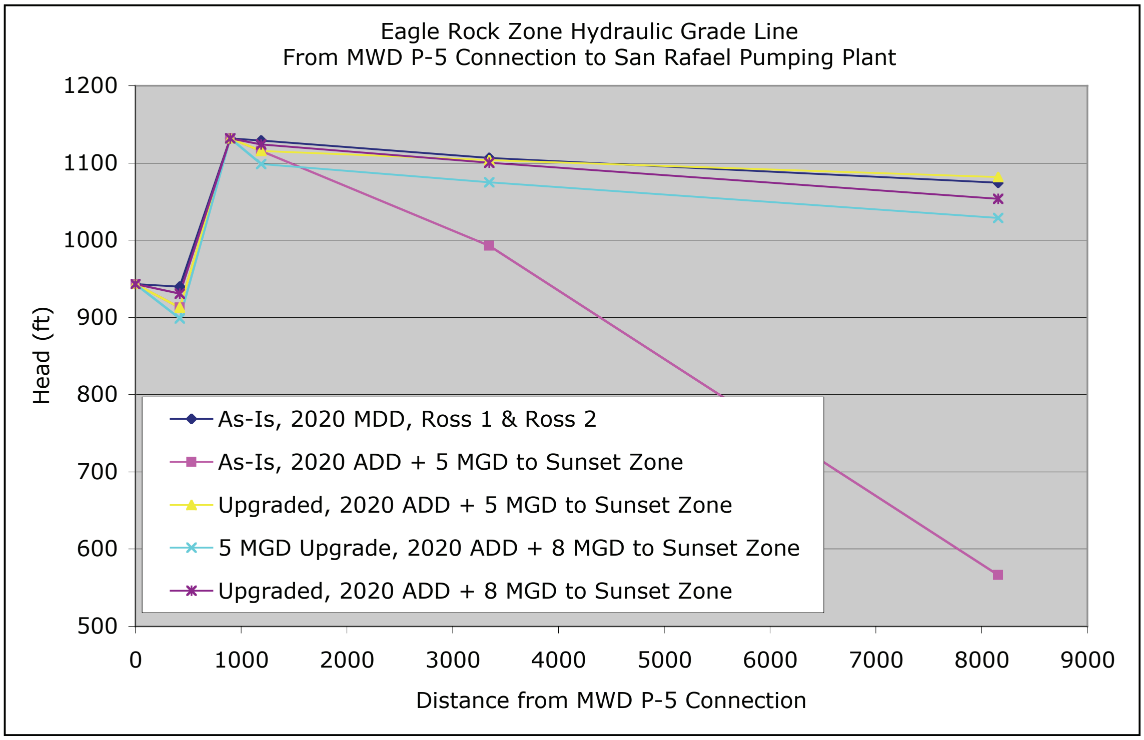


Figure 7-5. Hydraulic Grade Lines

7.2 Annandale Pressure Zone

The Annandale pressure zone is located in the southwest part of the Pasadena water system. The main facilities serving the zone, the hydraulic model nodes and pipes, along with the geologic hazards, are shown in Figure 7-6.

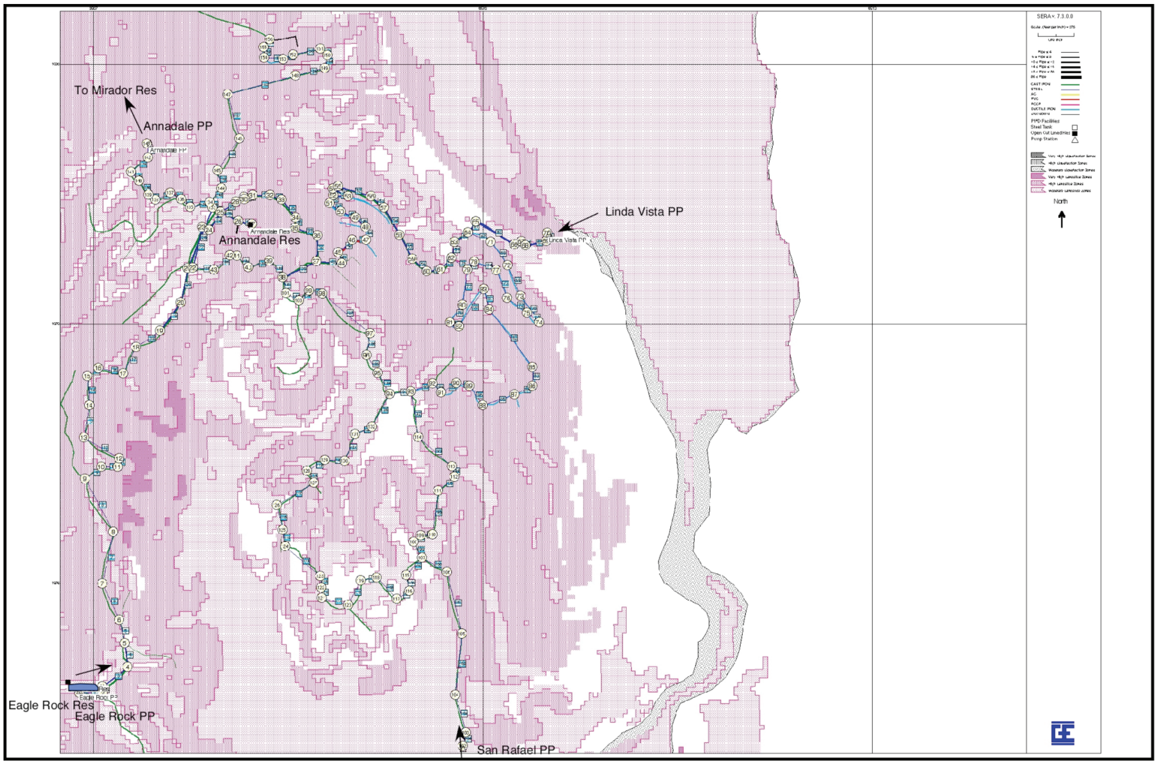


Figure 7-6. Hydraulic Model, Annandale Zone

Hydraulic analysis was performed for the Annandale zone in the as-is configuration. The zone has one reservoir, Annandale, at overflow elevation of 1301 feet. There are three pumping plants which supply the zone. The Eagle Rock pumping plant has one 30 hp and one 40 hp pump and pumps from the Eagle Rock Zone. The Linda Vista Pump #2 supplies the Annandale Zone from the Calaveras Zone and is rated at 20 hp. The San Rafael pump #1 supplies the Annandale zone from the Eagle Rock zone.

In-zone maximum day demands (MDD) for the year 2020 were used. The 0.96 MGD Annandale demand, plus the 0.12 MGD Annandale Reduced demand (total of 750 gpm) was spread evenly on 148 nodes in the model.

Iterative analysis was done to determine the head and flow at the San Rafael pumping plant. Hydraulic analysis on the Eagle Rock zone was performed with an applied demand at the San Rafael pumping plant. The head at the pumping plant was applied in the Annandale hydraulic model, and the resulting flow in the San Rafael pump #1 was checked against the demand applied to the Eagle Rock model. The final flow was about 200 gpm, with a head of 1059 feet.

With all the pumps turned on, the Annandale reservoir fills at a rate of 528 gpm (0.76 MGD). The reservoir has a capacity of 0.64 MG. The Eagle Rock pumping plant puts out 556 gpm (0.80 MGD). The Linda Vista pump #2 puts out 536 gpm (0.77 MGD). The San Rafael pump #1 puts out 185 gpm (0.27 MGD). The head in much of the Annandale zone is about 1300 feet. The head is about 1400 feet in the vicinity of the

Eagle Rock pumping plant and decreases to 1300 feet as the pipe heads up Kenworthy and Patrician Way.

Under gravity feed from the Annandale reservoir (no pumps on), the head remains relatively unchanged for most of the zone, except in the vicinity of the Eagle Rock pumping plant, where the head drops about 25 feet.

Facility	Flow at Year 2020 MDD	Flow at Year 2020 MDD
San Rafael Pump 1	200 gpm	0.29 MGD
Eagle Rock Pumps 1 + 2	556 gpm	0.80 MGD
Linda Vista 2	536 gpm	0.77 MGD
Less Zone Demand	(750 gpm)	(1.08) MGD
Reservoir Fill	528 gpm	0.76 MGD

Table 7-2. Flow Rates Annandale Zone

As described in Section 2 of this report, the Annandale zone has either a surplus of 0.04 MG in storage (using Brisbane formula) or a deficit of between 1.16 MG to 1.67 MG (EBMUD and MWH formula). If reliable standby power is provided to all the pump stations, then it is feasible to provide reasonably reliable service to the Annandale zone, even under maximum day demand (year 2020) combined with a single in-zone structure fire (assuming 0.18 MG storage volume set aside for fire flows). Under this situation, it would take about 8 hours to drain the Annandale reservoir (assuming it was full at the start of the fire, or a drawdown rate of 972 gpm assuming fire flows of 1,500 gpm), which is more than enough time for the fire department to control a typical single structure (or even a single block) fire. Even if the largest pump serving the Annandale zone were out of service at the time of the fire, the drawdown rate would increase to about 1,252 gpm, and it would take about 6 hours to drain the Annandale reservoir under similar assumptions (4.9 hours if the reservoir is 80% full at the start of the fire).

As described in Table 6-3, quick connect couplings are recommended to be installed for the San Rafael, Eagle Rock and Lida Vista pumping plants. The cost to procure several large emergency generators is included in Tables 6-3 and 6-4, and additional emergency generators and portable pumps can be reliably procured from equipment vendors / mutual aid within 2 hours after a major (but non-spreading beyond the first block) fire; or 8 hours after a major earthquake. The Pasadena emergency response plan must address the rapid (under 2 hour) relocation of its emergency generators to pumping plants serving the Annandale zone should a large fire occur in this area.

The cost to install a quick connect at the three pumping plants is included in the seismic upgrade program (G&E 2006a), costing about $113,000 for these three pumping plants. The alternative of adding about 1.16 MG to 1.67 MG storage at the existing Lida reservoir site is likely on the order of $2 million, likely involving the construction of a new partially buried and partially above ground tank to fit within the footprint of the site. To construct such a tank will likely require draining the existing reservoir, installing standby power at the Linda Vista and Eagle Rock pumping plants, installing a temporary bolted steel tank (or similar) at the site to provide some measure of gravity flow while the old tank is removed/replaced. It is clear that it would be less expensive to rely upon standby power for reliable pumping, even if the cost of procuring emergency generators is considered.

7.3 Lida Pressure Zone

The Lida pressure zone is located in the western part of the Pasadena water system. The main facilities serving the zone and adjacent zones are shown in Figure 7-7. Figure 7-8 shows the hydraulic model for the Lida zone, along with the geologic landslide hazards in the hillside area.

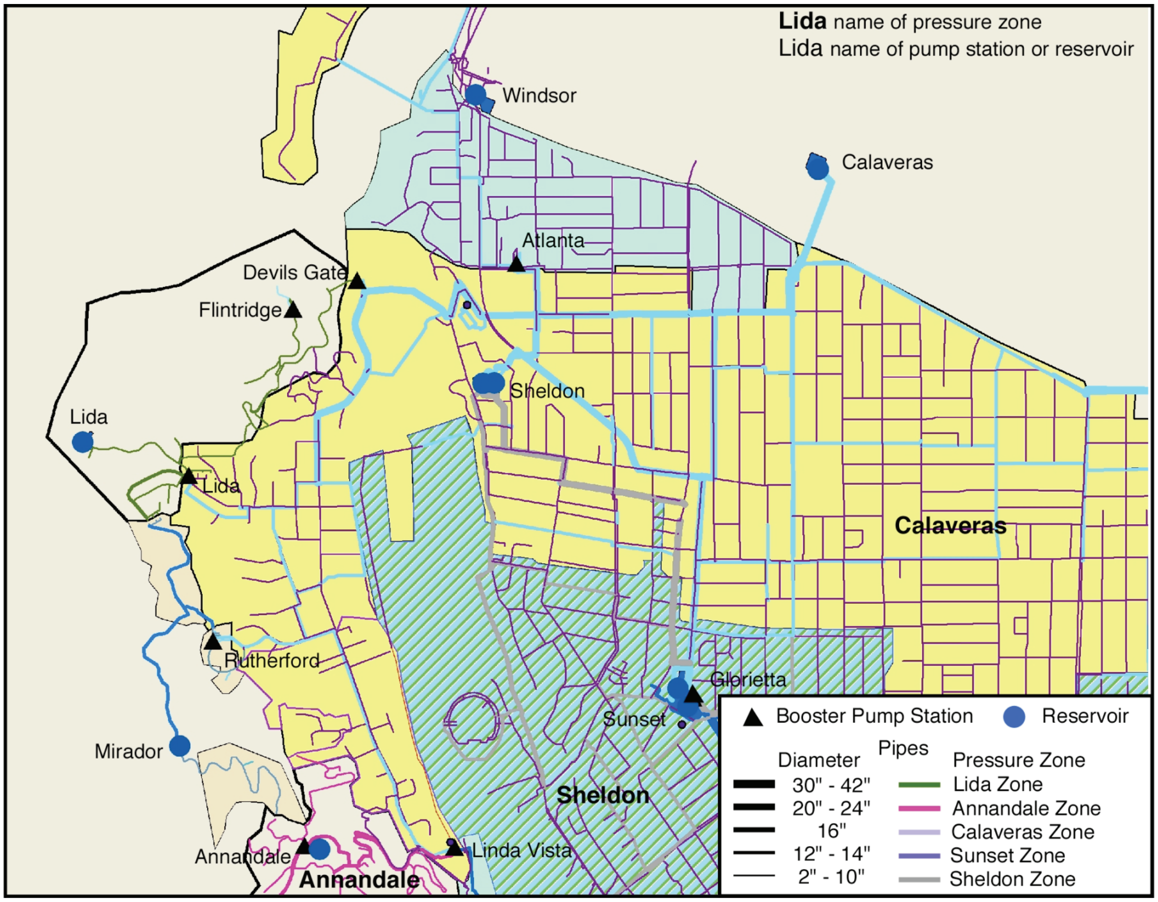


Figure 7-7. Pipes and Facilities, Lida, Sheldon West and Adjacent Zones

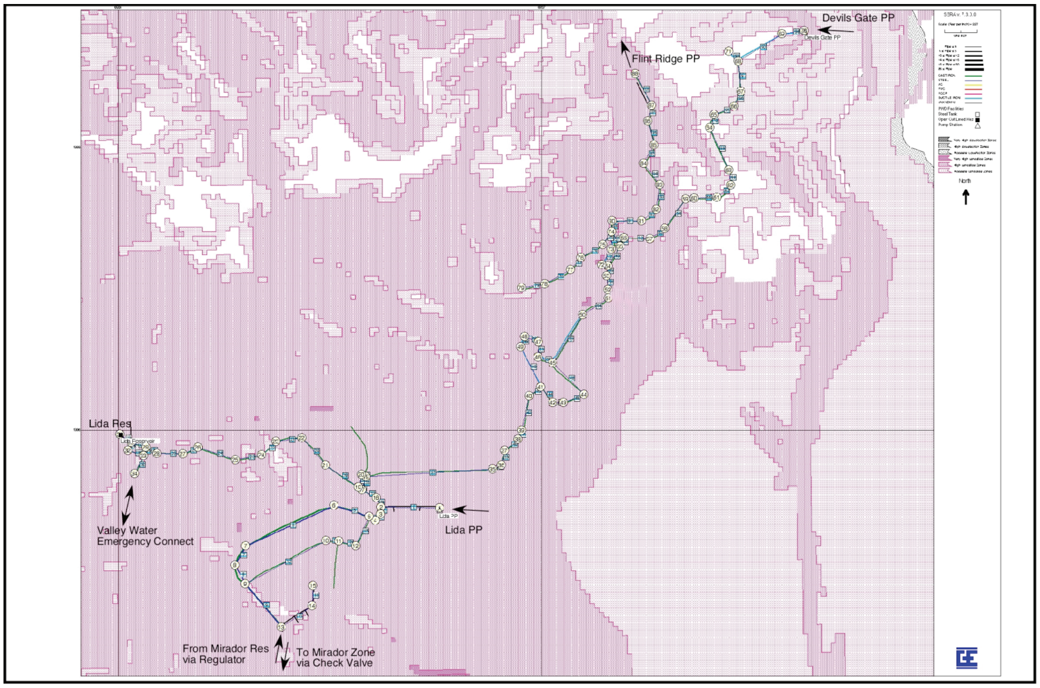


Figure 7-8. Hydraulic Model, Lida Zone

Hydraulic analysis was performed for the Lida zone in its as-is configuration. The zone has one reservoir, Lida, at overflow elevation of 1439 feet. There are two pumping plants with two pumps each which supply the zone, Lida and Devil's Gate. The Lida pumping plant has two 50 hp pumps. The Devil's Gate pumping plant has two 60 hp pumps. Both pump from the Calaveras zone.

In-zone maximum day demands (MDD) for the year 2020 were used. The 0.46 MGD demand (319 gpm) was spread evenly on 71 nodes in the model. Two analyses were run to bound the hydraulic profile of the zone. The first analysis was done with gravity flow from the Lida reservoir supplying the demand. This is the lower bound case (minimum head in the system). The second analysis was done with all four pumps turned on.

Under gravity feed, the zone has fairly constant head throughout the system. The head values range from 1439 feet in the area around the reservoir to 1425 feet in the areas farthest from the reservoir (around the Devil's Gate pumping plant).

With all pumps turned on, the Lida reservoir fills at a rate of 732 gpm or 1.05 MGD. The reservoir has a capacity of 0.43 MG. The Lida pumping plant puts out 165 gpm (0.24 MGD), and the Devil's Gate pumping plant puts out 886 gpm (1.28 MGD). The pressures in the system increase significantly with all pumps on, with the head near the Devil's Gate pumping plant at 1593 feet. Head near the Lida reservoir is 1451 feet, and the head is1483 feet near the Lida pumping plant.

Facility	Flow at Year 2020 MDD	Flow at Year 2020 MDD
Lida Pumps 1 + 2	165 gpm	0.24 MGD
Devils Gate Pumps 1 + 2	886 gpm	1.28 MGD
Less Zone Demand	(319 gpm)	(0.46) MGD
Reservoir Fill Rate	732 gpm	1.05 MGD

Table 7-3. Flow Rates Lida Zone

As described in Section 2 of this report, the Lida zone has either a surplus of 0.04 MG in storage (using Brisbane formula) or a deficit of between 0.45 MG to 1.10 MG (EBMUD and MWH formula). If reliable standby power is provided to all the pump stations, then it is feasible to provide reasonably reliable service to the Lida zone, even under maximum day demand (year 2020) combined with a single in-zone structure fire (assuming 0.18 MG storage volume set aside for fire flows). Under this situation, it would take about 9 hours to drain the Lida reservoir (assuming it was full at the start of the fire, or a drawdown rate of 768 gpm assuming fire flows of 1,500 gpm), which is more than enough time for the fire department to control a typical single structure (or even a single block) fire. Even if the largest pump serving the Lida zone were out of service at the time of the fire, the drawdown rate would increase to about 1,200 gpm, and it would take about 6 hours to drain the Lida reservoir (if full at the start of the fire) or 4.7 hours (if 80% full at the start of the fire).

As described in Table 6-3, quick connect couplings are recommended for the Devils Gate pumping plant. A cost allowance is provided herein to install a quick connect coupling at this pumping plant. The Lida pumping plant already has provision for bypass pumping. The cost to procure several large emergency generators is included in Tables 6-3 and 6-4, and additional emergency generators and portable pumps can be reliably procured from equipment vendors / mutual aid within 2 hours after a major (but non-spreading beyond the first block) fire; or 8 hours after a major earthquake. The Pasadena emergency response plan must address the rapid (under 2 hour) relocation of its emergency generators to pumping plants serving the Lida zone should a large fire occur in this area.

The cost to install a quick connect at the Devils Gate pumping plant is on the order of $37,000. The alternative of adding about 0.45 MG to 1.1 MG storage at the existing Lida reservoir site is likely on the order of $1 million, likely involving the construction of a new partially buried and partially above ground tank to fit within the footprint of the site. To construct such a tank will likely require draining the existing reservoir, installing standby power at the Devils Gate pumping plant, installing a temporary bolted steel tank (or similar) at the site to provide some measure of gravity flow while the old tank is removed/replaced. It is clear that it would be less expensive to rely upon standby power for reliable pumping, even if the cost of procuring an emergency generator is considered.

7.4 Sheldon Pressure Zone

The Sheldon pressure zone is a major pressure zone in the Pasadena water system. It stretches from Jones Reservoir in the east to the base of the San Rafael hills in the west. The main facilities serving the zone and adjacent zones are shown in Figures 7-9 and 7-10. Figure 7-11 shows the hydraulic model for the Sheldon zone, along with the geologic landslide hazards in the hillside area.

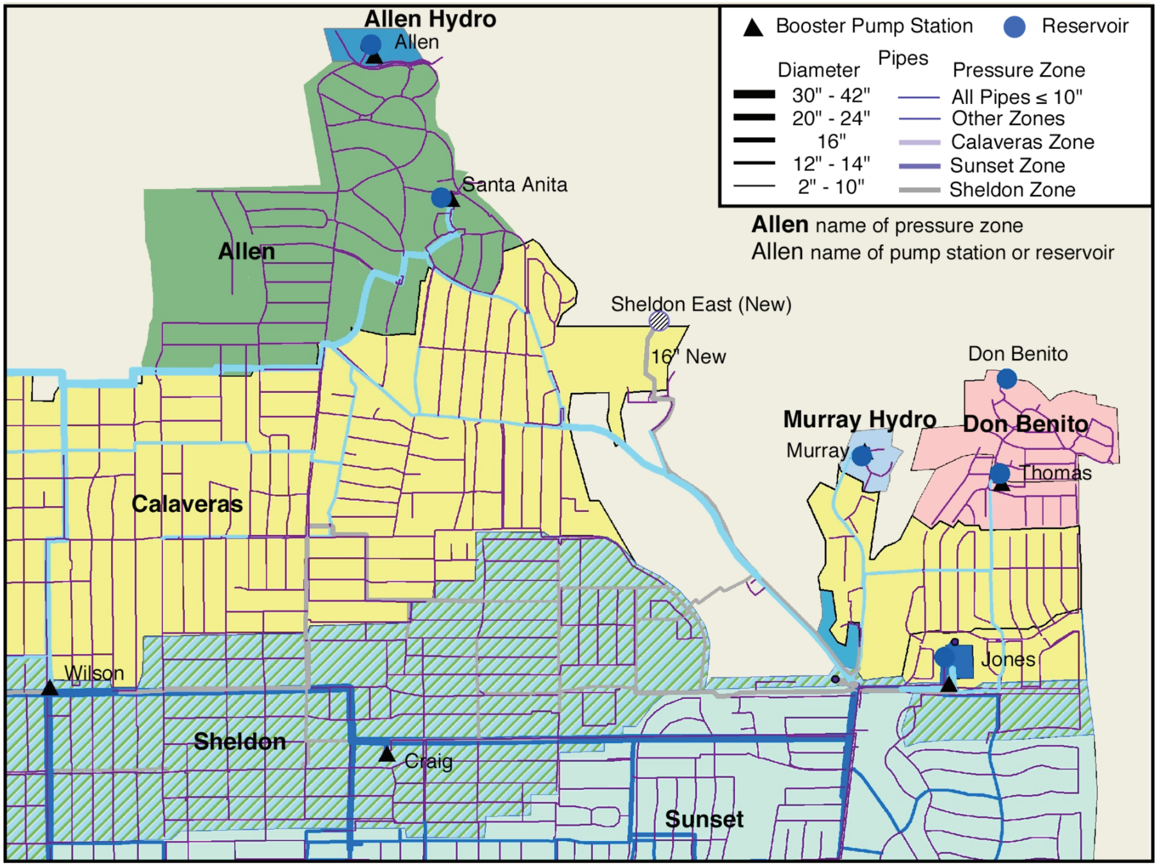


Figure 7-9. Pipes and Facilities, Sheldon East and Adjacent Zones

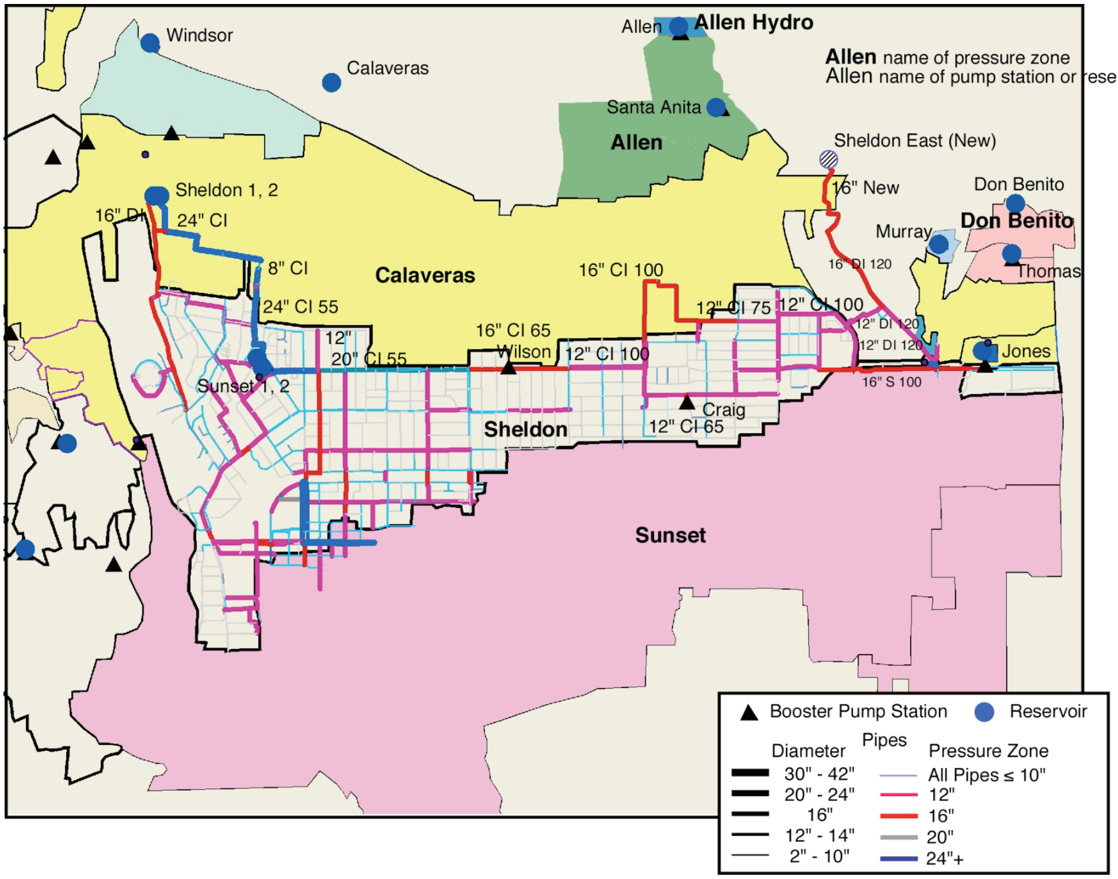


Figure 7-10. Pipes and Facilities, Sheldon Zone

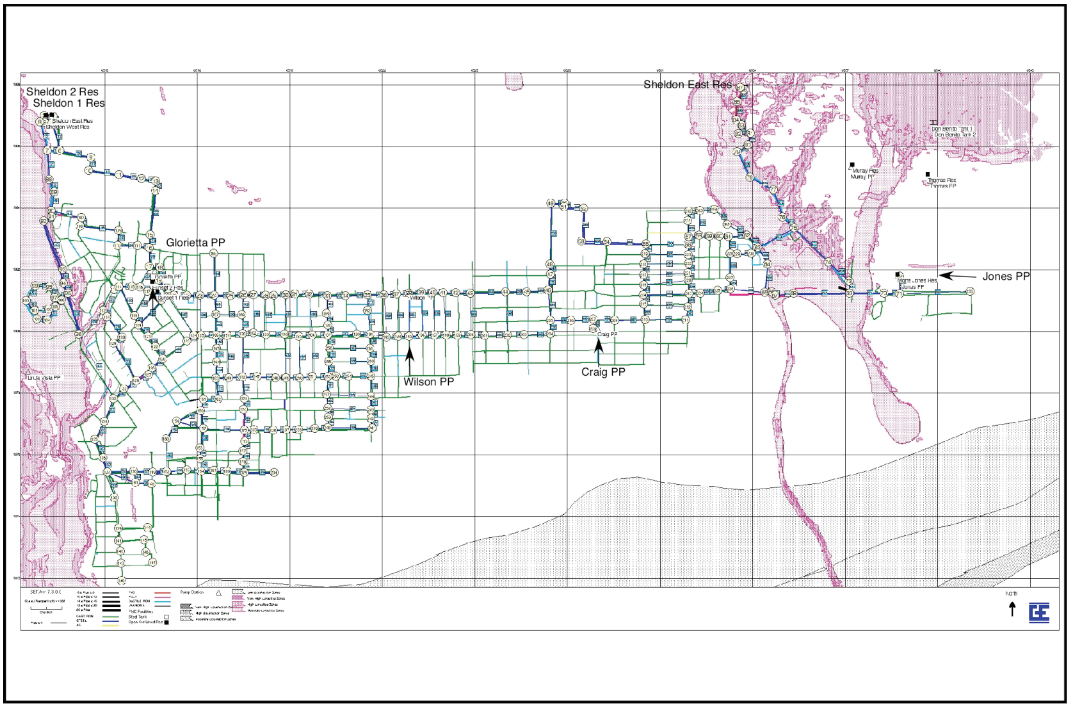


Figure 7-11. Hydraulic Model, Sheldon Zone

In order to better understand the hydraulic considerations of installing a new Sheldon East reservoir, hydraulic analysis was performed for the Sheldon zone. The existing zone has two reservoirs on the western extreme of the zone, Sheldon 1 and 2, at overflow elevation of 1050 feet. There are four pumping plants which supply the zone. The Jones pumping plant on the east side has one 50 hp (Jones #3) and one 125 hp pump (Jones #6) which supply the Sheldon zone. The Craig pumping plant has two 40 hp pumps (Craig #3 and #4). The Wilson pumping plant has two 200 hp pumps (Wilson #1 and #2) which supply the zone. The Craig and Wilson pumping plants are in the center of the zone. The Glorietta pumping plant is in the western part of the zone and has one 150 hp pump (Glorietta #3) which supplies the zone. All pumping plants pump from the Sunset zone. The Sheldon zone can also be supplied from the higher elevation Calaveras zone, but this is rarely done anymore.

In-zone maximum day demand (MDD) for the year 2020 of 14.17 MGD (9840 gpm) was used in the analyses. Specific nodal demand data were not available, so equal demand was placed on 242 nodes in the zone.

Base Case. For the base case, gravity flow from the existing Sheldon reservoirs 1 and 2 was considered. There were negative pressures in much of the zone due to head losses along the substantial length of the transmission path from west to east. This indicates that the zone cannot supply the 2020 MDD demand without concurrent pumping.

When both Jones #3 and Jones #6 pumps were turned on, the pressures in the zone improved substantially, with head in the zone ranging between 1017 feet and 1087 feet. The Jones pumps supply 4010 gpm (5.77 MGD), and the reservoirs supply 5830 gpm (8.40 MGD).

When all the pumps serving the zone are turned on, the head in the entire zone increases well above the 1050 overflow level of the existing reservoir. In the vicinity of the pumping plants, the head is between 1060 feet (at Glorietta pumping plant) and 1127 feet (at Jones pumping plant). The fill rate of the existing reservoir is 1844 gpm (2.66 MGD). This indicates that the existing pumping plants that fill the zone are somewhat too small to support the 2020 MDD demand. Note: once the wells from the Monk basin are returned to service, the Calaveras zone can also be used to supply the Sheldon zone.

Sheldon East Case. To increase reliability under hot summer days, it is advantageous to be able to operate the Sheldon zone by gravity only. An additional reservoir is proposed on the east side of the zone to improve pressure and flow in the zone. An analysis including the proposed Sheldon East reservoir was performed, without pumping. The elevation of the new reservoir was set at 1050 feet, the same elevation of the existing Sheldon 1 and 2 reservoirs. The hydraulic grade line in the zone was greatly improved, with most of the zone with hydraulic grade line between 1000 feet and 1050 feet. The flow rate from the three reservoirs was on the same order: 3676 gpm from Sheldon 1, 3163 gpm from Sheldon 2, and 3000 gpm from Sheldon East. This is somewhat undesirable, as the Sheldon East reservoir is planned to be significantly smaller than

Sheldon 1 and 2. The flow rates indicate that the turnover in Sheldon East will be greater than that of Sheldon 1 and 2, and reservoir turn over and water quality on the west side of the zone will not be as good as on the east side of the zone. Additionally, the hydraulic grade in the middle of the zone is somewhat low (about 1000 feet). If the level of Sheldon East is increased, it will improve the grade line in the middle of the zone, but it will also increase flow from the Sheldon East reservoir.

A few studies were made to see if the addition of pumping could improve the hydraulic grade line in the zone as well as balance out the flow between the existing Sheldon and the proposed new Sheldon East reservoirs. The base case of Sheldon East at overflow elevation of 1050 feet was used. If either of the Jones pumps are turned on, the head in the middle of the zone increases to between 1010 and 1025 feet. In addition, the flow rate from Sheldon East is decreased to 530 and 1700 gpm for Jones #6 and Jones #3, respectively. Another alternative is to add check valves in the east-west transmission pipe to limit the flow from the Sheldon East Reservoir westward.

One additional analysis was performed to bound the hydraulic grade line for the system with the Sheldon East reservoir. The analysis was performed with all pumps turned on to maximize the pressure in the system. Figure 7-12 compares hydraulic grade lines going from west to east for the system without Sheldon East and with Sheldon East.

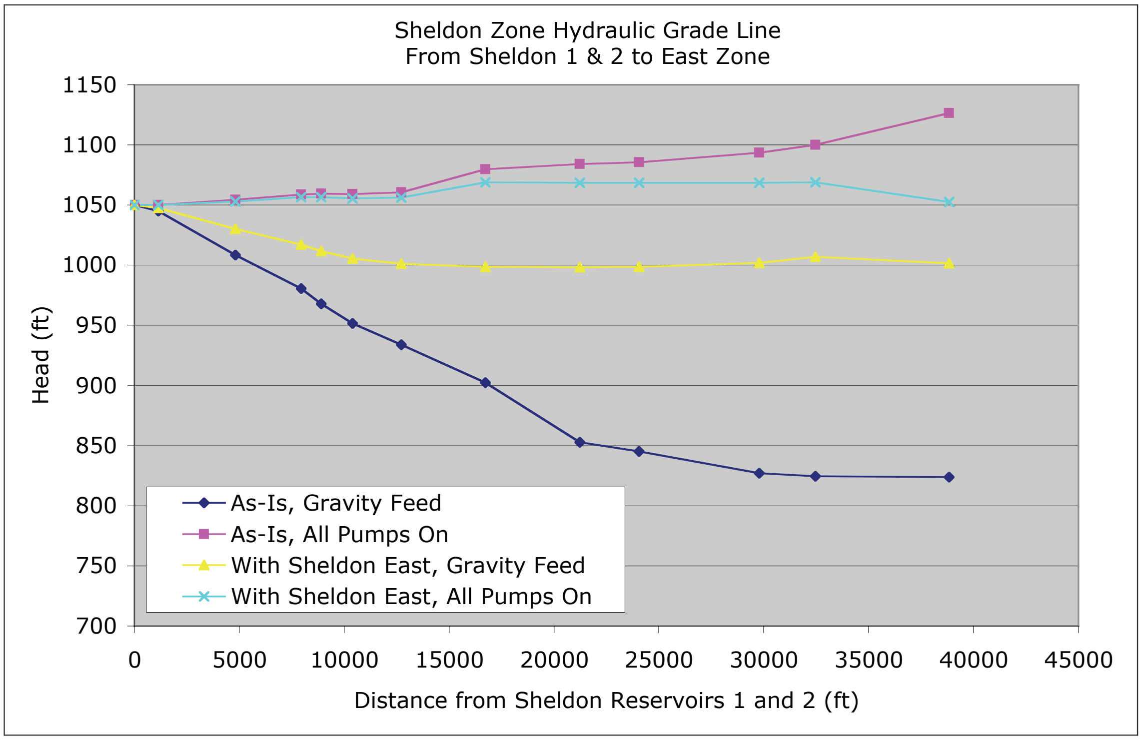


Figure 7-12. Hydraulic Grade Line for Sheldon Zone

Based on these exploratory hydraulic analyses, we make the following observations about the design needs for the new Sheldon East reservoir.

- The acceptable range of hydraulic grade line throughout the Sheldon zone needs to be defined. While we think that keeping the grade line between 1000 and 1050 feet at all locations under winter to summer time demands is likely acceptable, this will need to be confirmed.

- Setting the overflow elevation for the new Sheldon East must consider the topography of the available Sheldon East site, the desired size of the new reservoir, the location of the Sierra Madre fault at the site, and the net hydraulic flows from the new reservoir. If the overflow elevation is set high (as will be the case for a larger reservoir), then water will preferentially flow from the new Sheldon East reservoir (and not the older Sheldon reservoirs), resulting in possible water quality issues on the west side of the zone. Currently, with 11.8 MG total in-zone storage, water turnover ranges from 0.83 days to 1.91 days (see Table 3-1), which should be adequately short; the time needed to pump into the existing Sheldon reservoirs to achieve full mixing is about 8 to 10 hours (Table 3-2) which is a bit long, but likely acceptable.

- Ideally, the new Sheldon East reservoir overflow should be placed at an elevation so that there is no net flow between the existing and new Sheldon reservoirs, when all pumps are turned off, and the outflow from each reservoir should be approximately in the ratio of the volume of the reservoirs, under typical demand situations. In practice, meeting all of these targets might only be achievable by changing the diameter of the inlet-outlet pipe of the new Sheldon East reservoir, or possibly by placing a remotely-operated flow control valve somewhere in the zone along a major east-west pipeline, so that the gradient in the zone can be somewhat modified in near real time so that the Sheldon East reservoir will not over-supply the zone demand. A possible convenient location to place this valve would be near the Wilson pump station, owing to the proximity of a place where switchgear and telemetry for the new rate control station can be placed.

- Final design for the new Sheldon East reservoir should take into account all the hydraulic pipeline upgrades proposed by MWH (2002) for the zone, and to be adopted by PWP.

- The existing site can accommodate a 2 MG Sheldon East tank, with overflow about 1050 feet, while providing a reasonable fault offset design. If a larger Sheldon East reservoir is desired (say 4 MG), then either there will have to be more extensive excavation to make place for a suitably sized reservoir, but this will be partially negated in terms of reliability should the reservoir cross over the fault. The sense of fault offset at this site is likely reverse movement, meaning that fault offset will manifest itself by upward (vertical) offsets, with amount of likely vertical offset as much as 2 to 3 m for a Sierra Madre M 7.2 earthquake. The reservoir would have to be designed to either accommodate this offset (unlikely), avoid the offset (site might be too small, and subsurface investigations may prove inconclusive), or allow a release of water in a way so as to avoid any life safety / inundation potential (possibly the best way to design in this case).

Since the new Sheldon East reservoir is not essential to operate after a Sierra Madre earthquake, as long as there is reliable pumping available into the Sheldon zone, then allowing slight to major damage under this earthquake scenario, while not ideal, might be acceptable.

- Given the current site configuration and topology, a 110 feet x 184 feet x 20 feet deep (overflow about 1050 feet, bottom about 1030 feet) open cut reservoir could hold about 2.5 MG or so. However, this footprint (GeoSoils 1992) might cut through a trace of the Sierra Madre fault. Due to existing soil conditions, it is likely that a large cut into the site will be needed, in order to remove poorly-placed fills that exist. It is conceivable that two circular steel tanks could be placed at the site, with bottom elevation about 1025 feet, and overflow about 1050 feet, and still provide about 2 to 3 MG total storage. The multiple steel tank solution may be better than the single open cut basin, in that it is more likely that at least one tank could be designed to reliably survive a Sierra Madre M 7.2 earthquake.

Given these issues, and even though the Sheldon East site has been investigated and is possibly subject to surface faulting from the Sierra Madre fault, a new 2 million gallon steel tank could be placed at the site, without undue risk; the design would include certain fault-tolerant features. Alternately, the Sheldon east zone could be reliably served (to avoid the pressure fluctuations) by suitable pumping from the Wilson and Jones pumping plants. A third solution is to provide suitable regulating valves to drop water into the east-end of Sheldon zone from the higher elevation Calaveras zone. For purposes of this report, we include an allowance for a new Sheldon East 2 million gallon steel tank reservoir, to be designed with fault tolerant features, costing $2,500,000.

8.0 SCADA

The Supervisory Control and Data Acquisition system (SCADA) in the PWP system includes a number of instruments in the file to measure pressure and flow, level transmitters, security devised, etc.

MWH (2002) provides a list of recommended upgrades to the SCADA system for purposes of normal operations. This report does not duplicate the MWH recommendations, but concentrates only on seismic aspects of the system.

Seismic Ruggedness. As part of the Seismic Vulnerability Assessment (G&E 2006a), we visited essentially all PWP well and pump station and reservoir sites. We found, in general, that the SCADA RTU hardware to be solid state, and therefore not particularly vulnerable to earthquake motions. Also, most enclosure cabinets were bolted to walls, meaning that by definition the cabinets withstand 1g vertical down forces from gravity; past experience suggests that few, if any, of such wall-mounted installations are dislodged in large earthquakes, unless they are mounted on unreinforced masonry walls.

However, we did not find any such installations, so the risk of this type of damage is considered very small, in any scenario earthquake.

Many times, the RTU hardware includes a small battery, whose purpose is to provide continued signal to the hardware, should offsite power be lost. These batteries are often sized to provide perhaps 8 hours of operation, sometimes more. As these batteries get older, their capacity to supply power is often diminished. so that loss of RTU signal will occur sooner than if with a new battery. Also, we observed some batteries to be prone to rattling within their enclosure cabinets; for lead-acid type, the battery could prematurely fail in earthquakes. G&E (2006a) provides a list of facilities where we observed unrestrained batteries, and a budget to go and restrain all such batteries throughout the system.

We did not verify the projected lifetime of batteries of the RTU system. However, G&E (2006b) suggests that in large scenario earthquakes, the offsite power outage could last 18 to 36 hours, even with some minor seismic upgrades to the power system. For most pumping plants and wells, we recommended installation of quick connect couplings, but use of emergency generators only for those sites where pumping water is most critical (i.e., not at all sites). Therefore, even if the existing batteries are restrained, it is likely that telemetry will be lost within 8 hours or so after a major earthquake, leaving PWP operators uncertain as to the operating status of the system. further, the SCADA computers at the Corporate Yard site were unrestrained (monitors) and had unrestrained UPS units; all these should be restrained, and budget for this was provided in G&E (2006a). As batteries are replaced in the system, it is recommended that all batteries be sized for at least 18 hours (preferably 24 hours) service, including those batteries at RTU sites, and the batteries needed to operate the main SCADA computers. All SCADA information on computers should be preserved permanently for the 72 hours after the earthquake, for any earthquake with epicenter within 5 miles of downtown Pasadena with magnitude 6 or larger.

Assuming a long term loss of the Upper Feeder, PWP will need to draw water from MWD P5 turnout for extended times. As described earlier in this report, up to 5 MGD is recommended to be transferred through the Eagle Rock zone, and into the Sunset zone via a pressure regulating station at the San Rafael pumping plant location. We recommend that a new set of SCADA instruments be installed at this site, to report back the upstream and downstream pressures and flow rate going through the pressure regulating station at this location. These instruments should be installed as part of the upgrade of this pressure regulating station described elsewhere in this report. Allow $100,000 for this instrumentation (high priority).

The operation of the Sheldon zone, with (or without) the Sheldon East reservoir has large flows moving east to west. It might be useful to install a flow meter someplace mid-way in the zone (possibly near Wilson pumping plant) to get real time readings of the flow and pressure. These instruments would probably be included with any rate control valve that might be included as part of the Sheldon East reservoir, described earlier in this report. Allow $100,000 for this instrumentation (high priority).

Additional instruments that could be considered would include accelerometers placed at a few locations within the water system. Possibly, these could be paid for and maintained by USGS as part of their overall ShakeMap effort. In any case, these accelerometers can provide very useful information for actual recorded ground motions in small to large earthquakes, helping PWP understand the actual performance of its water system components. Other utilities, such as Bonneville Power Administration, Bay Area Rapid Transit District, etc. have allowed for such instrumentation. Allow $100,000 for this instrumentation (lower priority).

The San Francisco Public Utilities District and the East Bay Municipal Utility District routinely installs accelerometers, pressure and flow sensors at critical pipelines (usually 42 inches and larger) where they cross faults, so that they can tell whether or not they should remotely actuate valves to shut off pipes where they might be damaged at fault offset. The PWP has no such large diameter pipes that cross faults, but conceptually this could be done as part of any new pipes (16 inches or larger) crossing the Sierra Madre fault zone to try to isolate leaking pipes before they adversely depressurize the remaining parts of the water system. The cost for this instrumentation would be included with the design of the new pipelines. At this time, there are no clear locations in the PWP system where such instrumentation need be installed to existing pipes.

9.0 References

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