# Attachment 10.1-C

## Model Scenario Water Balance Results – Westside Basin

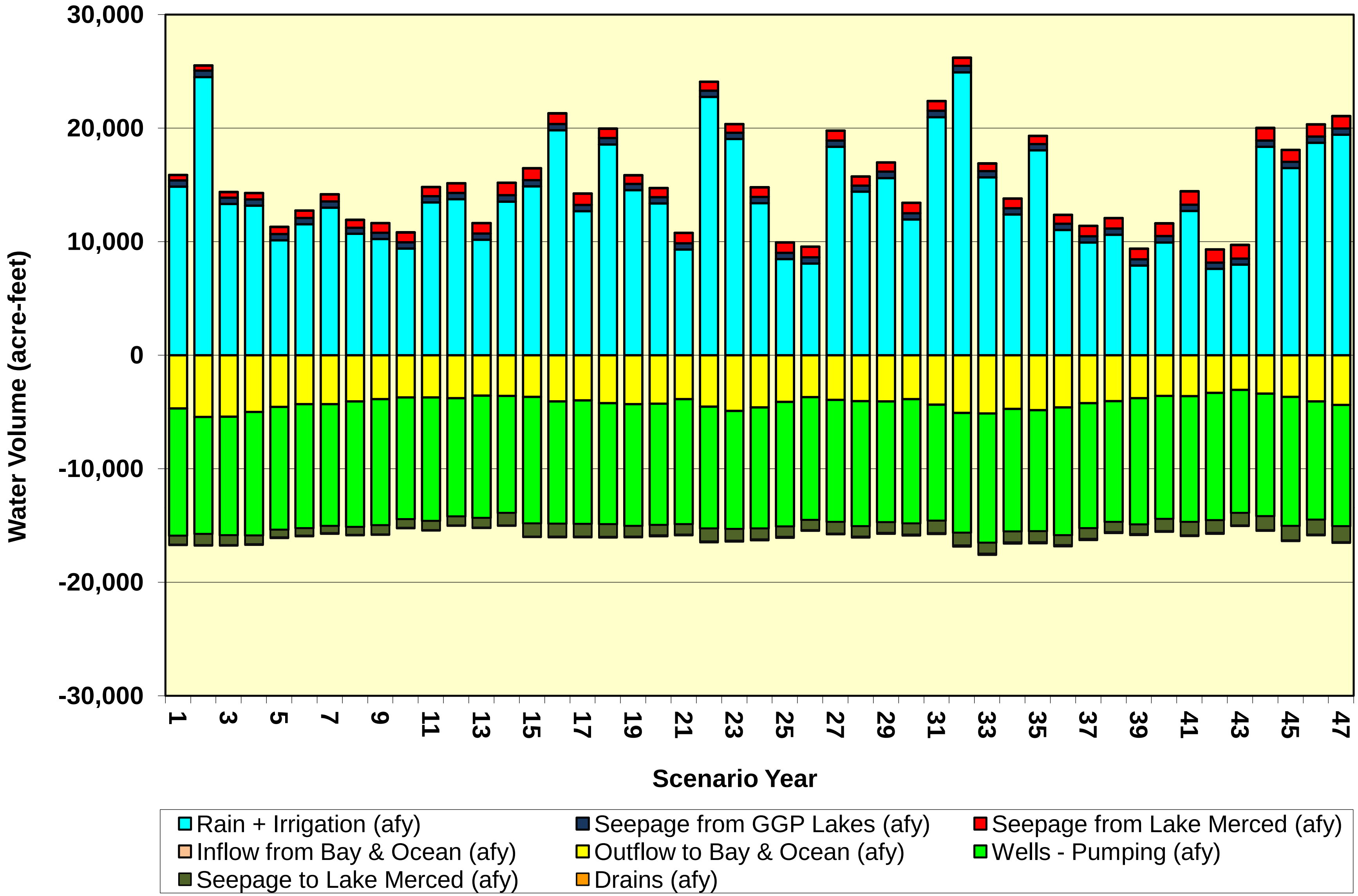
## Scenario 1 Westside Groundwater Basin Water Balance Summary

| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 546 | 14,845 | 464 | -4,684 | -11,229 | -753 | -71 | -877 |
| 2 | 5 | 558 | 24,505 | 456 | -5,439 | -10,299 | -974 | -72 | 8,739 |
| 3 | 5 | 552 | 13,329 | 475 | -5,406 | -10,445 | -858 | -73 | -2,420 |
| 4 | 5 | 549 | 13,169 | 547 | -4,988 | -10,889 | -758 | -74 | -2,440 |
| 5 | 5 | 549 | 10,129 | 623 | -4,561 | -10,804 | -679 | -74 | -4,814 |
| 6 | 5 | 551 | 11,546 | 624 | -4,317 | -10,917 | -653 | -73 | -3,234 |
| 7 | 5 | 552 | 12,988 | 614 | -4,317 | -10,717 | -634 | -72 | -1,580 |
| 8 | 5 | 545 | 10,691 | 671 | -4,064 | -11,064 | -680 | -72 | -3,968 |
| 9 | 6 | 549 | 10,235 | 853 | -3,868 | -11,113 | -788 | -70 | -4,198 |
| 10 | 6 | 554 | 9,386 | 875 | -3,717 | -10,720 | -767 | -68 | -4,451 |
| 11 | 7 | 549 | 13,455 | 807 | -3,710 | -10,879 | -807 | -68 | -647 |
| 12 | 8 | 556 | 13,751 | 820 | -3,780 | -10,420 | -772 | -74 | 89 |
| 13 | 9 | 553 | 10,162 | 915 | -3,568 | -10,761 | -841 | -76 | -3,609 |
| 14 | 10 | 558 | 13,533 | 1,086 | -3,585 | -10,315 | -1,067 | -75 | 145 |
| 15 | 11 | 549 | 14,876 | 1,040 | -3,666 | -11,154 | -1,139 | -81 | 437 |
| 16 | 12 | 556 | 19,804 | 925 | -4,070 | -10,766 | -1,142 | -84 | 5,234 |
| 17 | 10 | 549 | 12,678 | 995 | -3,989 | -10,883 | -1,095 | -88 | -1,823 |
| 18 | 10 | 554 | 18,568 | 828 | -4,225 | -10,663 | -1,102 | -92 | 3,879 |
| 19 | 9 | 553 | 14,531 | 755 | -4,322 | -10,710 | -932 | -96 | -212 |
| 20 | 9 | 556 | 13,363 | 791 | -4,272 | -10,673 | -920 | -100 | -1,245 |
| 21 | 9 | 548 | 9,310 | 896 | -3,869 | -11,010 | -912 | -93 | -5,120 |
| 22 | 10 | 554 | 22,751 | 765 | -4,542 | -10,729 | -1,125 | -94 | 7,591 |
| 23 | 9 | 556 | 19,036 | 745 | -4,914 | -10,402 | -1,014 | -101 | 3,915 |
| 24 | 9 | 549 | 13,397 | 837 | -4,599 | -10,670 | -949 | -105 | -1,530 |
| 25 | 9 | 549 | 8,479 | 893 | -4,123 | -10,963 | -904 | -107 | -6,167 |
| 26 | 11 | 550 | 8,071 | 921 | -3,694 | -10,827 | -871 | -96 | -5,935 |
| 27 | 12 | 552 | 18,354 | 870 | -3,946 | -10,732 | -1,017 | -96 | 3,997 |
| 28 | 12 | 549 | 14,398 | 788 | -4,057 | -11,007 | -911 | -104 | -331 |
| 29 | 12 | 553 | 15,609 | 801 | -4,065 | -10,650 | -921 | -109 | 1,231 |
| 30 | 13 | 550 | 11,960 | 905 | -3,871 | -10,961 | -964 | -112 | -2,479 |
| 31 | 13 | 556 | 20,974 | 840 | -4,352 | -10,230 | -1,076 | -115 | 6,611 |
| 32 | 12 | 556 | 24,922 | 717 | -5,079 | -10,564 | -1,106 | -118 | 9,340 |
| 33 | 12 | 545 | 15,668 | 661 | -5,124 | -11,398 | -951 | -121 | -709 |
| 34 | 11 | 554 | 12,389 | 855 | -4,732 | -10,800 | -955 | -124 | -2,802 |
| 35 | 11 | 553 | 18,045 | 708 | -4,839 | -10,663 | -951 | -128 | 2,737 |
| 36 | 11 | 545 | 11,034 | 780 | -4,601 | -11,255 | -871 | -129 | -4,486 |
| 37 | 11 | 545 | 9,932 | 915 | -4,215 | -11,035 | -919 | -121 | -4,886 |
| 38 | 11 | 554 | 10,605 | 904 | -4,058 | -10,620 | -900 | -114 | -3,618 |
| 39 | 12 | 549 | 7,905 | 926 | -3,789 | -11,119 | -846 | -106 | -6,468 |
| 40 | 15 | 556 | 9,935 | 1,119 | -3,588 | -10,839 | -1,052 | -100 | -3,953 |
| 41 | 17 | 549 | 12,714 | 1,156 | -3,608 | -11,081 | -1,163 | -100 | -1,516 |
| 42 | 22 | 550 | 7,618 | 1,146 | -3,322 | -11,202 | -1,120 | -96 | -6,403 |
| 43 | 28 | 549 | 7,975 | 1,171 | -3,057 | -10,827 | -1,087 | -87 | -5,335 |
| 44 | 31 | 552 | 18,357 | 1,090 | -3,379 | -10,805 | -1,216 | -87 | 4,544 |
| 45 | 29 | 545 | 16,490 | 1,030 | -3,669 | -11,371 | -1,263 | -95 | 1,697 |
| 46 | 27 | 556 | 18,714 | 1,050 | -4,069 | -10,412 | -1,305 | -98 | 4,464 |
| 47 | 23 | 545 | 19,422 | 1,095 | -4,385 | -10,681 | -1,383 | -101 | 4,535 |
| **Average (afy)** | **12** | **551** | **14,034** | **846** | **-4,172** | **-10,814** | **-960** | **-94** | **-597** |
| **Maximum (afy)** | **31** | **558** | **24,922** | **1,171** | **-3,057** | **-10,230** | **-634** | **-68** | **9,340** |
| **Minimum (afy)** | **5** | **545** | **7,618** | **456** | **-5,439** | **-11,398** | **-1,383** | **-129** | **-6,468** |

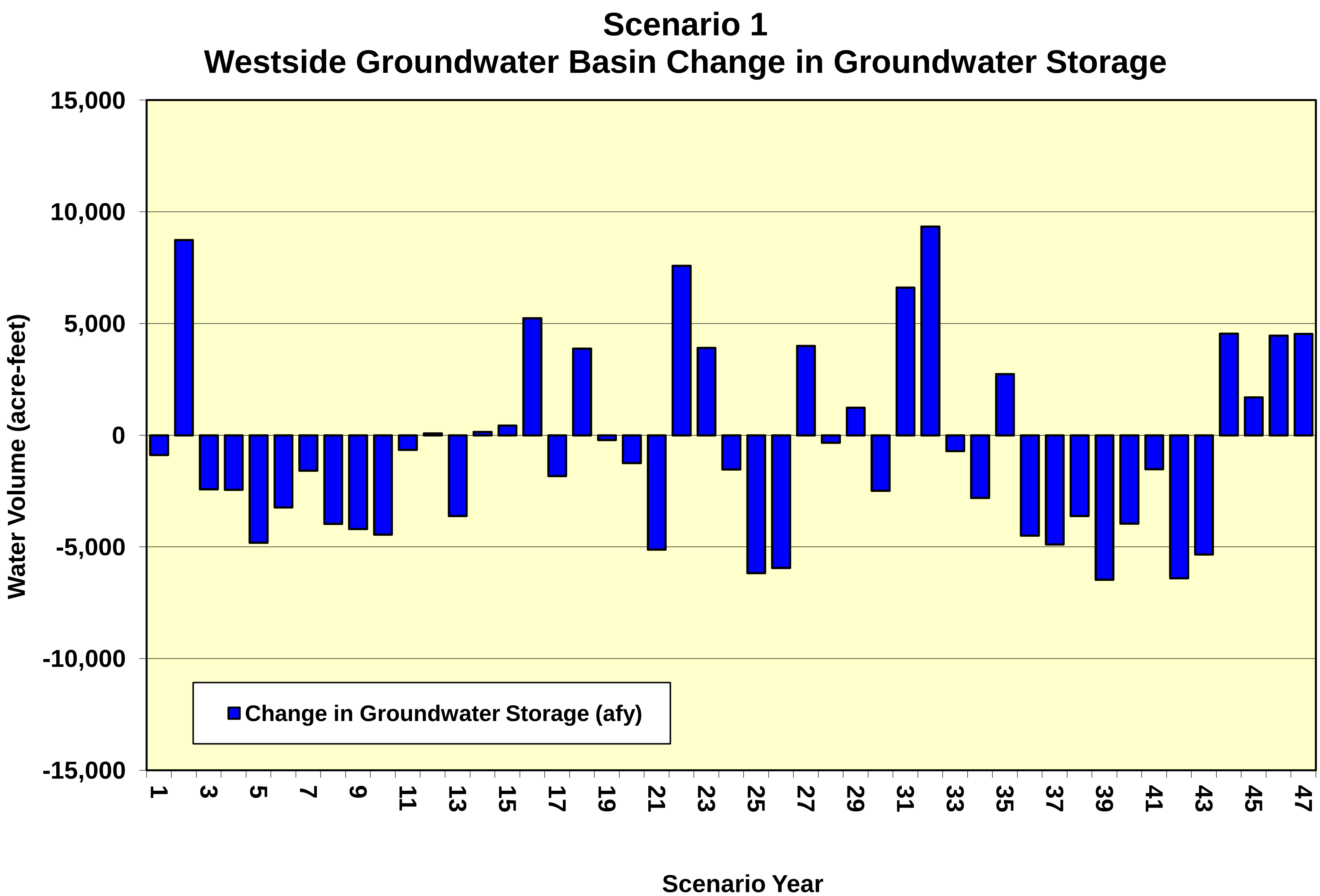
Key:
afy - acre-feet per year
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.

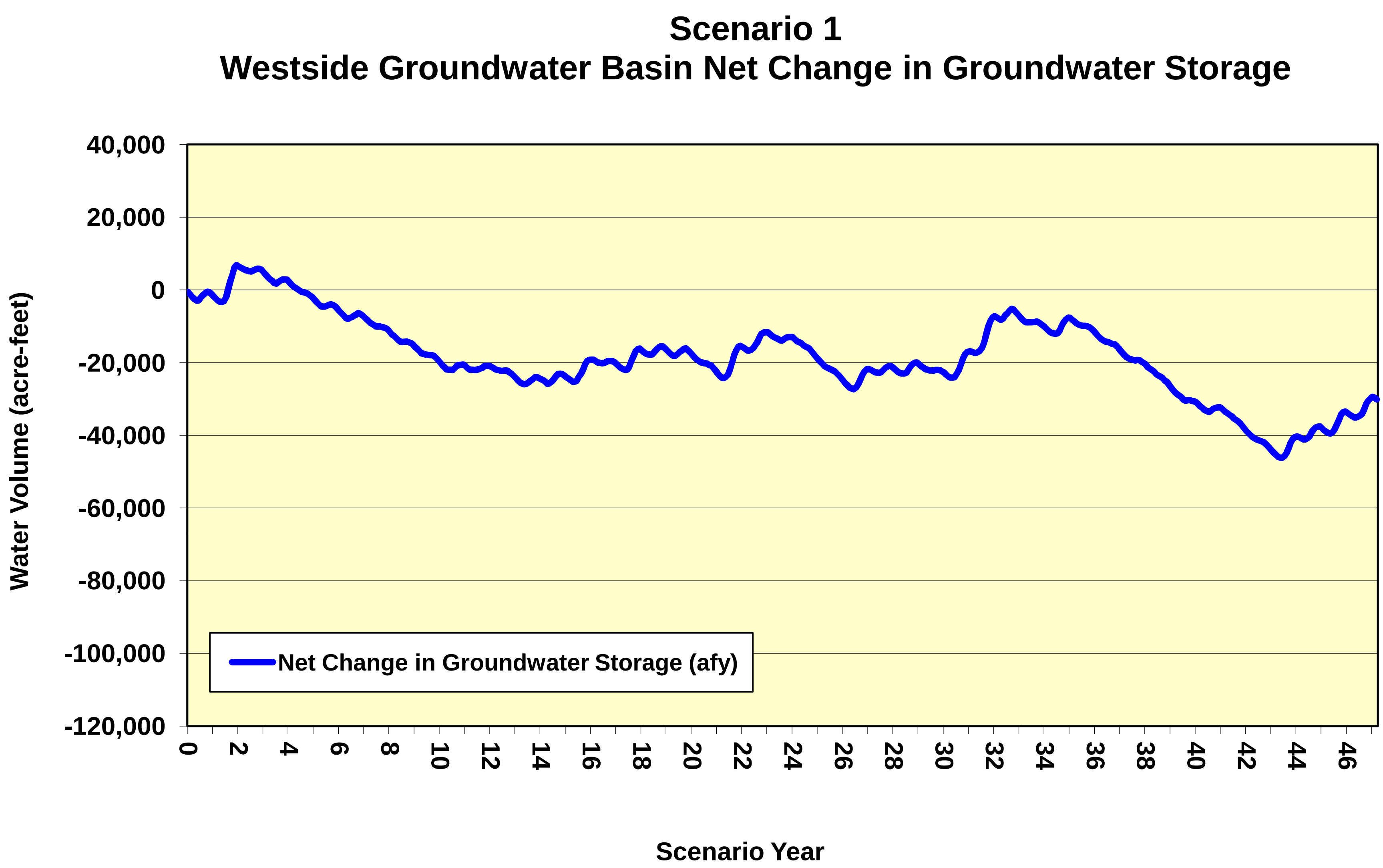
## Scenario 1 Westside Groundwater Basin Water Balance




Note: Volume of some water balance components may be too small to be visible.



Scenario 1
Westside Groundwater Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
Change in Groundwater Storage (afy)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year

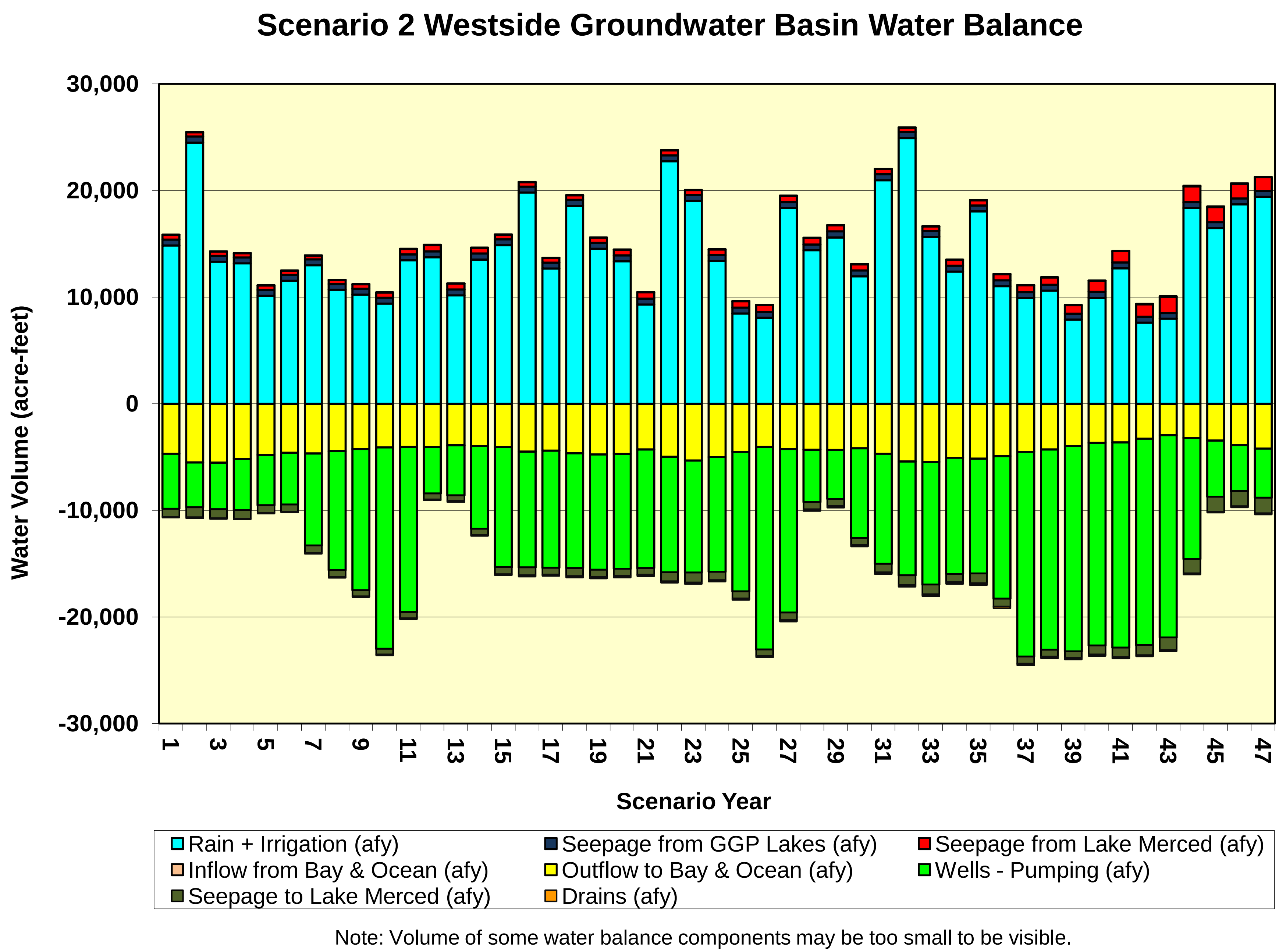

Scenario 1
Westside Groundwater Basin Net Change in Groundwater Storage
40,000
20,000
0
-20,000
-40,000
-60,000
-80,000
-100,000
-120,000
Water Volume (acre-feet)
Net Change in Groundwater Storage (afy)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
Scenario Year

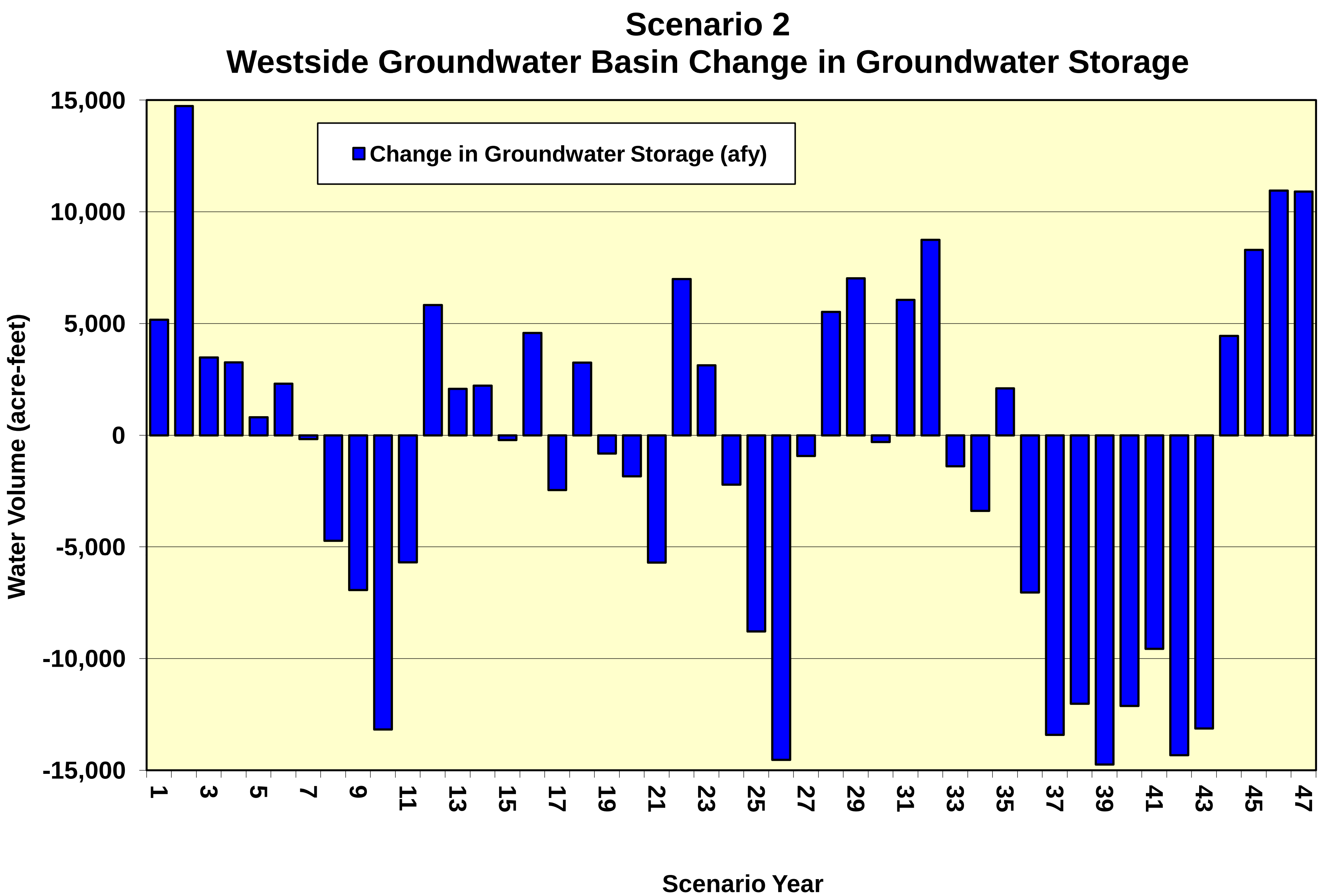
## Scenario 2 Westside Groundwater Basin Water Balance Summary

| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 546 | 14,845 | 452 | -4,698 | -5,157 | -754 | -71 | 5,168 |
| 2 | 5 | 558 | 24,505 | 405 | -5,499 | -4,227 | -931 | -72 | 14,744 |
| 3 | 5 | 552 | 13,329 | 402 | -5,526 | -4,373 | -835 | -74 | 3,480 |
| 4 | 5 | 549 | 13,169 | 395 | -5,165 | -4,817 | -798 | -75 | 3,262 |
| 5 | 5 | 549 | 10,129 | 418 | -4,789 | -4,732 | -698 | -77 | 805 |
| 6 | 4 | 551 | 11,546 | 394 | -4,601 | -4,845 | -667 | -77 | 2,305 |
| 7 | 4 | 552 | 12,988 | 351 | -4,657 | -8,647 | -680 | -78 | -166 |
| 8 | 4 | 545 | 10,691 | 365 | -4,435 | -11,173 | -640 | -81 | -4,723 |
| 9 | 4 | 549 | 10,235 | 425 | -4,252 | -13,237 | -569 | -84 | -6,929 |
| 10 | 4 | 554 | 9,386 | 492 | -4,097 | -18,889 | -529 | -85 | -13,164 |
| 11 | 4 | 549 | 13,455 | 512 | -4,044 | -15,498 | -574 | -87 | -5,683 |
| 12 | 5 | 556 | 13,751 | 575 | -4,081 | -4,348 | -533 | -94 | 5,832 |
| 13 | 4 | 553 | 10,162 | 567 | -3,900 | -4,689 | -522 | -98 | 2,077 |
| 14 | 4 | 558 | 13,533 | 526 | -3,963 | -7,759 | -583 | -99 | 2,218 |
| 15 | 4 | 549 | 14,876 | 448 | -4,070 | -11,262 | -647 | -109 | -213 |
| 16 | 4 | 556 | 19,804 | 419 | -4,482 | -10,874 | -728 | -117 | 4,582 |
| 17 | 4 | 549 | 12,678 | 461 | -4,406 | -10,991 | -624 | -124 | -2,453 |
| 18 | 4 | 554 | 18,568 | 427 | -4,647 | -10,771 | -752 | -130 | 3,253 |
| 19 | 4 | 553 | 14,531 | 486 | -4,749 | -10,818 | -690 | -136 | -819 |
| 20 | 4 | 556 | 13,363 | 530 | -4,702 | -10,781 | -671 | -141 | -1,841 |
| 21 | 4 | 548 | 9,310 | 595 | -4,296 | -11,119 | -611 | -134 | -5,702 |
| 22 | 4 | 554 | 22,751 | 471 | -4,969 | -10,837 | -840 | -135 | 6,999 |
| 23 | 4 | 556 | 19,036 | 442 | -5,333 | -10,510 | -920 | -144 | 3,132 |
| 24 | 4 | 549 | 13,397 | 517 | -4,993 | -10,778 | -762 | -149 | -2,214 |
| 25 | 4 | 549 | 8,479 | 595 | -4,504 | -13,087 | -662 | -151 | -8,778 |
| 26 | 5 | 550 | 8,071 | 644 | -4,053 | -18,996 | -605 | -139 | -14,523 |
| 27 | 6 | 552 | 18,354 | 598 | -4,245 | -15,350 | -706 | -137 | -927 |
| 28 | 7 | 549 | 14,398 | 617 | -4,310 | -4,935 | -663 | -145 | 5,519 |
| 29 | 6 | 553 | 15,609 | 589 | -4,340 | -4,578 | -668 | -149 | 7,022 |
| 30 | 6 | 550 | 11,960 | 567 | -4,184 | -8,404 | -641 | -153 | -299 |
| 31 | 6 | 556 | 20,974 | 489 | -4,688 | -10,338 | -777 | -157 | 6,065 |
| 32 | 6 | 556 | 24,922 | 424 | -5,418 | -10,673 | -908 | -161 | 8,748 |
| 33 | 6 | 545 | 15,668 | 430 | -5,453 | -11,506 | -912 | -166 | -1,389 |
| 34 | 6 | 554 | 12,389 | 558 | -5,053 | -10,908 | -757 | -171 | -3,382 |
| 35 | 6 | 553 | 18,045 | 500 | -5,154 | -10,771 | -902 | -175 | 2,100 |
| 36 | 6 | 545 | 11,034 | 573 | -4,907 | -13,378 | -736 | -176 | -7,040 |
| 37 | 6 | 545 | 9,932 | 648 | -4,503 | -19,204 | -670 | -163 | -13,409 |
| 38 | 7 | 554 | 10,605 | 689 | -4,289 | -18,789 | -645 | -152 | -12,020 |
| 39 | 9 | 549 | 7,905 | 790 | -3,949 | -19,288 | -614 | -140 | -14,738 |
| 40 | 15 | 556 | 9,935 | 1,038 | -3,678 | -19,008 | -842 | -131 | -12,113 |
| 41 | 23 | 549 | 12,714 | 1,048 | -3,631 | -19,250 | -882 | -128 | -9,557 |
| 42 | 36 | 550 | 7,618 | 1,170 | -3,278 | -19,363 | -934 | -121 | -14,321 |
| 43 | 53 | 549 | 7,975 | 1,498 | -2,948 | -18,976 | -1,172 | -108 | -13,129 |
| 44 | 65 | 552 | 18,357 | 1,481 | -3,201 | -11,372 | -1,330 | -103 | 4,449 |
| 45 | 61 | 545 | 16,490 | 1,422 | -3,452 | -5,271 | -1,384 | -107 | 8,303 |
| 46 | 47 | 556 | 18,714 | 1,356 | -3,864 | -4,335 | -1,408 | -107 | 10,960 |
| 47 | 34 | 545 | 19,422 | 1,281 | -4,207 | -4,607 | -1,453 | -107 | 10,906 |
| **Average (afy)** | **11** | **551** | **14,034** | **640** | **-4,418** | **-10,926** | **-784** | **-122** | **-1,013** |
| **Maximum (afy)** | **65** | **558** | **24,922** | **1,498** | **-2,948** | **-4,227** | **-522** | **-71** | **14,744** |
| **Minimum (afy)** | **4** | **545** | **7,618** | **351** | **-5,526** | **-19,363** | **-1,453** | **-176** | **-14,738** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

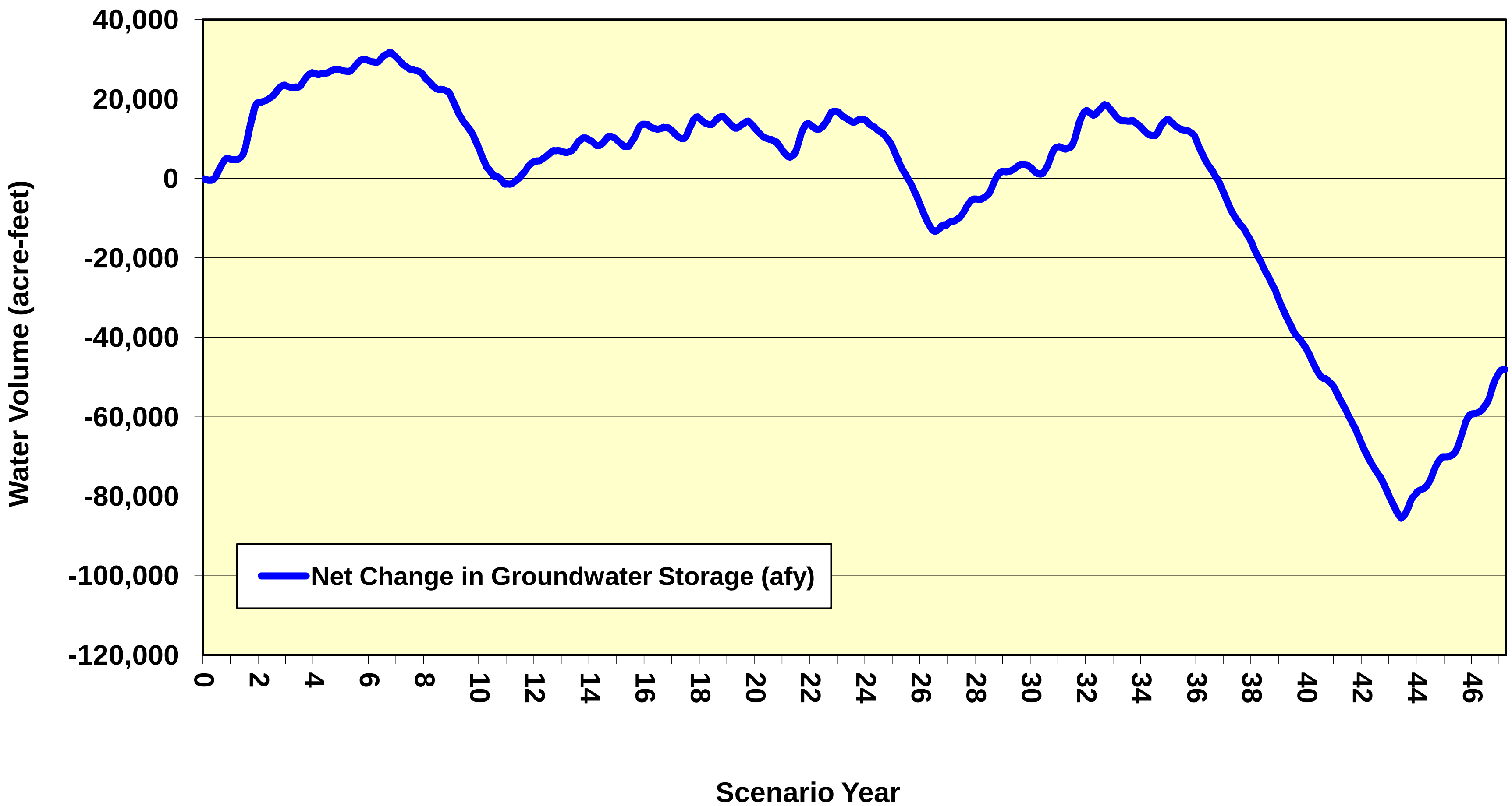
Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.


Scenario 2 Westside Groundwater Basin Water Balance
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from GGP Lakes (afy)
Seepage from Lake Merced (afy)
Inflow from Bay & Ocean (afy)
Outflow to Bay & Ocean (afy)
Wells - Pumping (afy)
Seepage to Lake Merced (afy)
Drains (afy)
Note: Volume of some water balance components may be too small to be visible.



Scenario 2
Westside Groundwater Basin Change in Groundwater Storage
Change in Groundwater Storage (afy)
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year

## Scenario 2
## Westside Groundwater Basin Net Change in Groundwater Storage

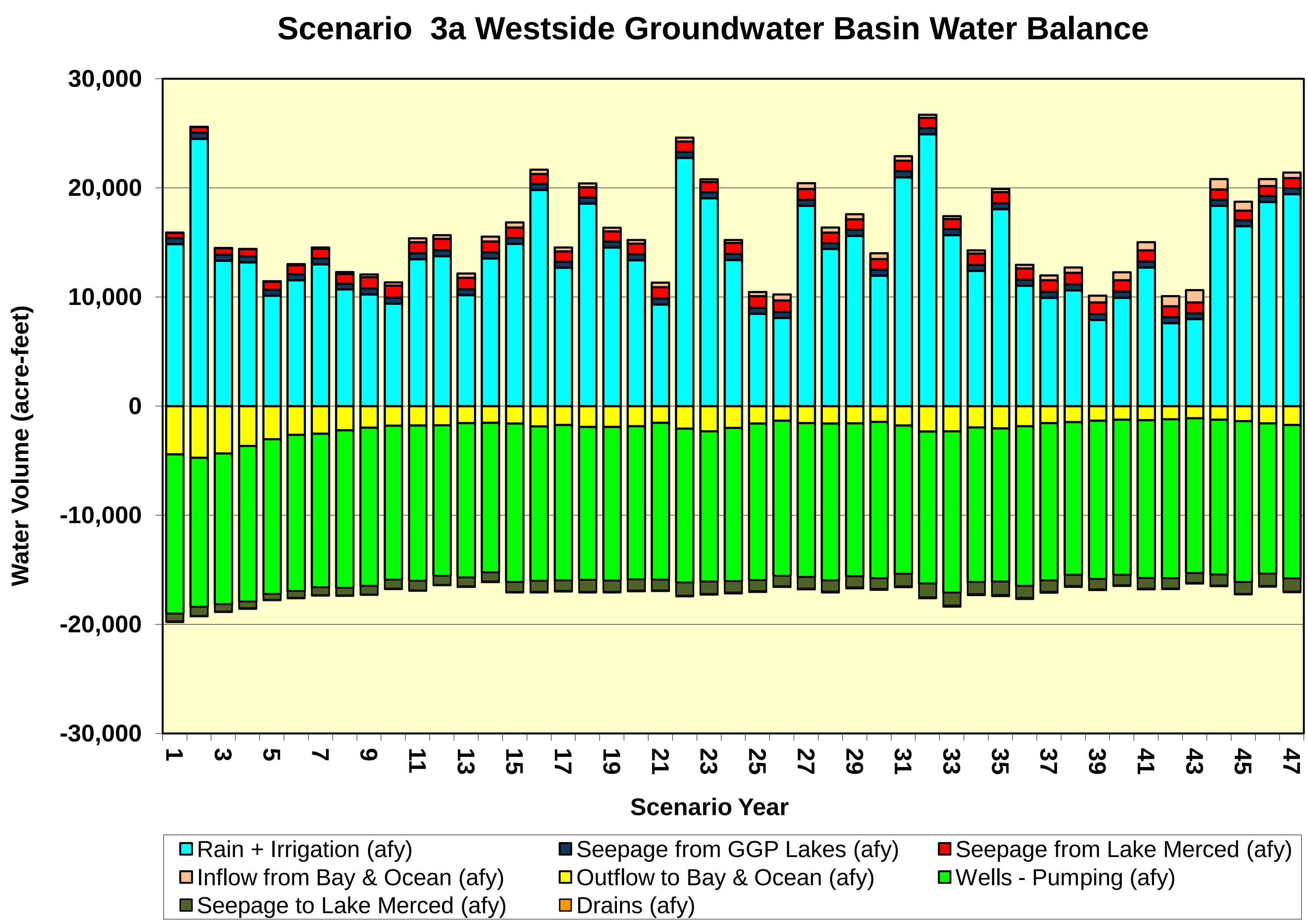


## Scenario 3a Westside Groundwater Basin Water Balance Summary

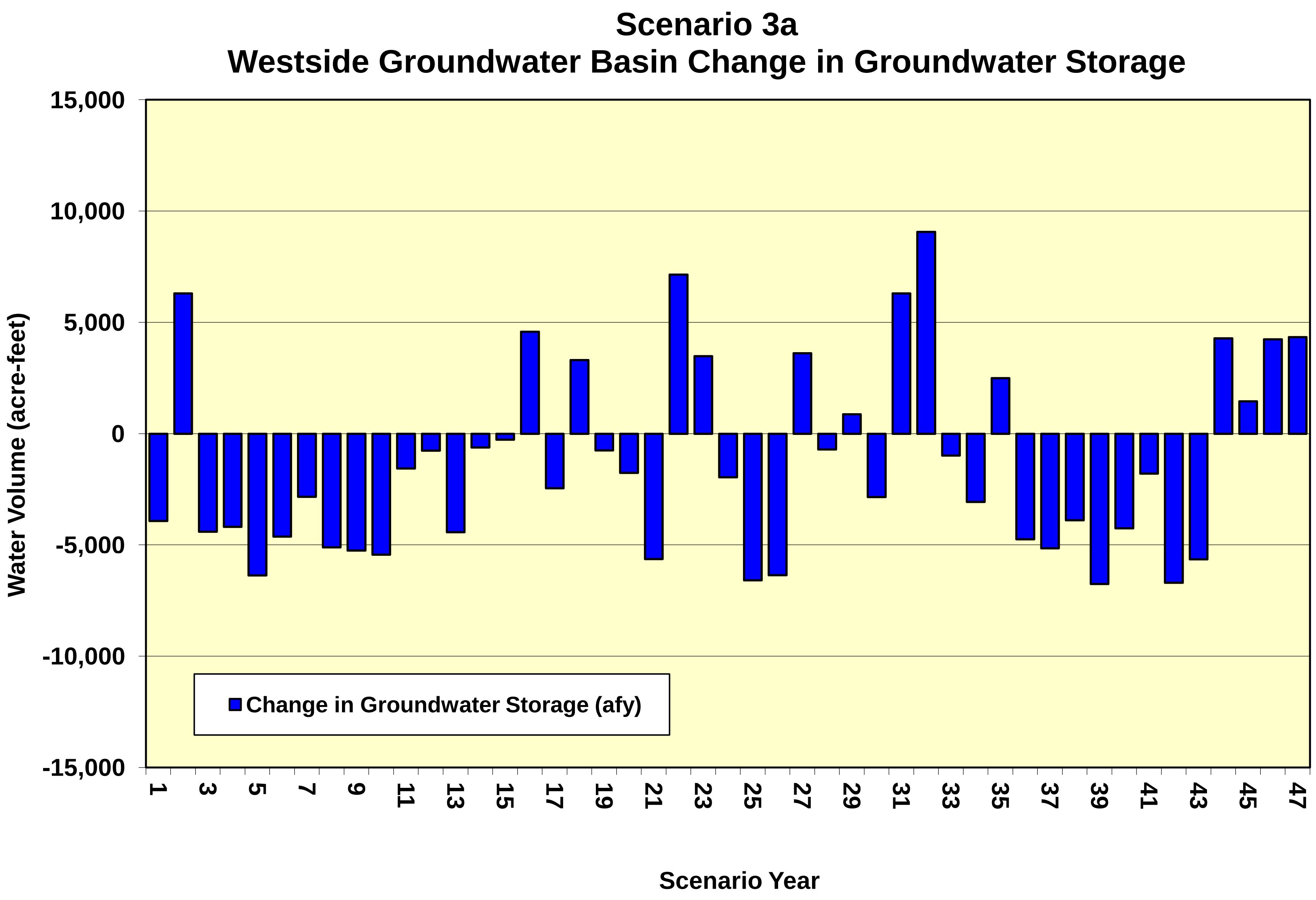
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 546 | 14,845 | 485 | -4,415 | -14,603 | -712 | -71 | -3,919 |
| 2 | 7 | 558 | 24,505 | 517 | -4,731 | -13,674 | -806 | -72 | 6,303 |
| 3 | 11 | 552 | 13,329 | 601 | -4,339 | -13,820 | -661 | -73 | -4,399 |
| 4 | 26 | 549 | 13,169 | 660 | -3,649 | -14,264 | -605 | -74 | -4,188 |
| 5 | 53 | 549 | 10,129 | 718 | -3,023 | -14,179 | -534 | -74 | -6,362 |
| 6 | 93 | 551 | 11,546 | 818 | -2,639 | -14,292 | -628 | -73 | -4,624 |
| 7 | 127 | 552 | 12,988 | 881 | -2,526 | -14,091 | -692 | -72 | -2,833 |
| 8 | 183 | 545 | 10,691 | 874 | -2,213 | -14,439 | -678 | -72 | -5,109 |
| 9 | 243 | 549 | 10,235 | 1,035 | -1,978 | -14,488 | -772 | -70 | -5,247 |
| 10 | 301 | 554 | 9,386 | 1,105 | -1,802 | -14,095 | -814 | -68 | -5,432 |
| 11 | 349 | 549 | 13,455 | 1,031 | -1,765 | -14,254 | -854 | -68 | -1,558 |
| 12 | 335 | 556 | 13,751 | 1,029 | -1,752 | -13,795 | -818 | -74 | -766 |
| 13 | 409 | 553 | 10,162 | 1,035 | -1,558 | -14,136 | -810 | -76 | -4,421 |
| 14 | 431 | 558 | 13,533 | 1,002 | -1,539 | -13,690 | -835 | -75 | -616 |
| 15 | 463 | 549 | 14,876 | 941 | -1,594 | -14,528 | -896 | -81 | -272 |
| 16 | 397 | 556 | 19,804 | 922 | -1,872 | -14,141 | -999 | -84 | 4,585 |
| 17 | 370 | 549 | 12,678 | 951 | -1,721 | -14,257 | -930 | -87 | -2,447 |
| 18 | 361 | 554 | 18,568 | 928 | -1,896 | -14,037 | -1,072 | -92 | 3,313 |
| 19 | 314 | 553 | 14,531 | 943 | -1,905 | -14,084 | -1,011 | -96 | -755 |
| 20 | 327 | 556 | 13,363 | 979 | -1,836 | -14,047 | -1,006 | -99 | -1,763 |
| 21 | 432 | 548 | 9,310 | 1,031 | -1,520 | -14,385 | -957 | -93 | -5,634 |
| 22 | 346 | 554 | 22,751 | 945 | -2,056 | -14,103 | -1,193 | -94 | 7,150 |
| 23 | 253 | 556 | 19,036 | 945 | -2,299 | -13,777 | -1,125 | -101 | 3,489 |
| 24 | 273 | 549 | 13,397 | 1,010 | -1,985 | -14,045 | -1,047 | -105 | -1,952 |
| 25 | 380 | 549 | 8,479 | 1,057 | -1,608 | -14,338 | -1,000 | -107 | -6,589 |
| 26 | 544 | 550 | 8,071 | 1,071 | -1,343 | -14,201 | -955 | -96 | -6,359 |
| 27 | 522 | 552 | 18,354 | 997 | -1,550 | -14,106 | -1,060 | -96 | 3,614 |
| 28 | 469 | 549 | 14,398 | 961 | -1,589 | -14,381 | -1,014 | -104 | -710 |
| 29 | 463 | 553 | 15,609 | 964 | -1,574 | -14,025 | -1,014 | -108 | 869 |
| 30 | 529 | 550 | 11,960 | 980 | -1,435 | -14,335 | -979 | -112 | -2,841 |
| 31 | 425 | 556 | 20,974 | 959 | -1,778 | -13,604 | -1,117 | -115 | 6,301 |
| 32 | 291 | 556 | 24,922 | 933 | -2,327 | -13,939 | -1,246 | -117 | 9,072 |
| 33 | 258 | 545 | 15,668 | 938 | -2,315 | -14,773 | -1,183 | -120 | -982 |
| 34 | 293 | 554 | 12,389 | 1,038 | -1,949 | -14,175 | -1,097 | -124 | -3,068 |
| 35 | 302 | 553 | 18,045 | 1,014 | -2,046 | -14,037 | -1,207 | -127 | 2,496 |
| 36 | 337 | 545 | 11,034 | 1,035 | -1,844 | -14,629 | -1,094 | -128 | -4,745 |
| 37 | 426 | 545 | 9,932 | 1,067 | -1,557 | -14,409 | -1,035 | -120 | -5,151 |
| 38 | 495 | 554 | 10,605 | 1,058 | -1,474 | -13,994 | -1,017 | -113 | -3,885 |
| 39 | 613 | 549 | 7,905 | 1,058 | -1,333 | -14,494 | -948 | -105 | -6,755 |
| 40 | 729 | 556 | 9,935 | 1,037 | -1,255 | -14,213 | -936 | -99 | -4,245 |
| 41 | 757 | 549 | 12,714 | 1,001 | -1,297 | -14,456 | -963 | -98 | -1,793 |
| 42 | 949 | 550 | 7,618 | 974 | -1,204 | -14,576 | -915 | -95 | -6,699 |
| 43 | 1,123 | 549 | 7,975 | 988 | -1,115 | -14,201 | -872 | -86 | -5,640 |
| 44 | 957 | 552 | 18,357 | 943 | -1,250 | -14,180 | -1,006 | -85 | 4,287 |
| 45 | 806 | 545 | 16,490 | 891 | -1,369 | -14,746 | -1,069 | -93 | 1,457 |
| 46 | 637 | 556 | 18,714 | 904 | -1,572 | -13,786 | -1,113 | -96 | 4,243 |
| 47 | 508 | 545 | 19,422 | 938 | -1,734 | -14,055 | -1,184 | -99 | 4,340 |
| **Average (afy)** | **403** | **551** | **14,034** | **940** | **-1,982** | **-14,189** | **-946** | **-93** | **-1,282** |
| **Maximum (afy)** | **1,123** | **558** | **24,922** | **1,105** | **-1,115** | **-13,604** | **-534** | **-68** | **9,072** |
| **Minimum (afy)** | **5** | **545** | **7,618** | **485** | **-4,731** | **-14,773** | **-1,246** | **-128** | **-6,755** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

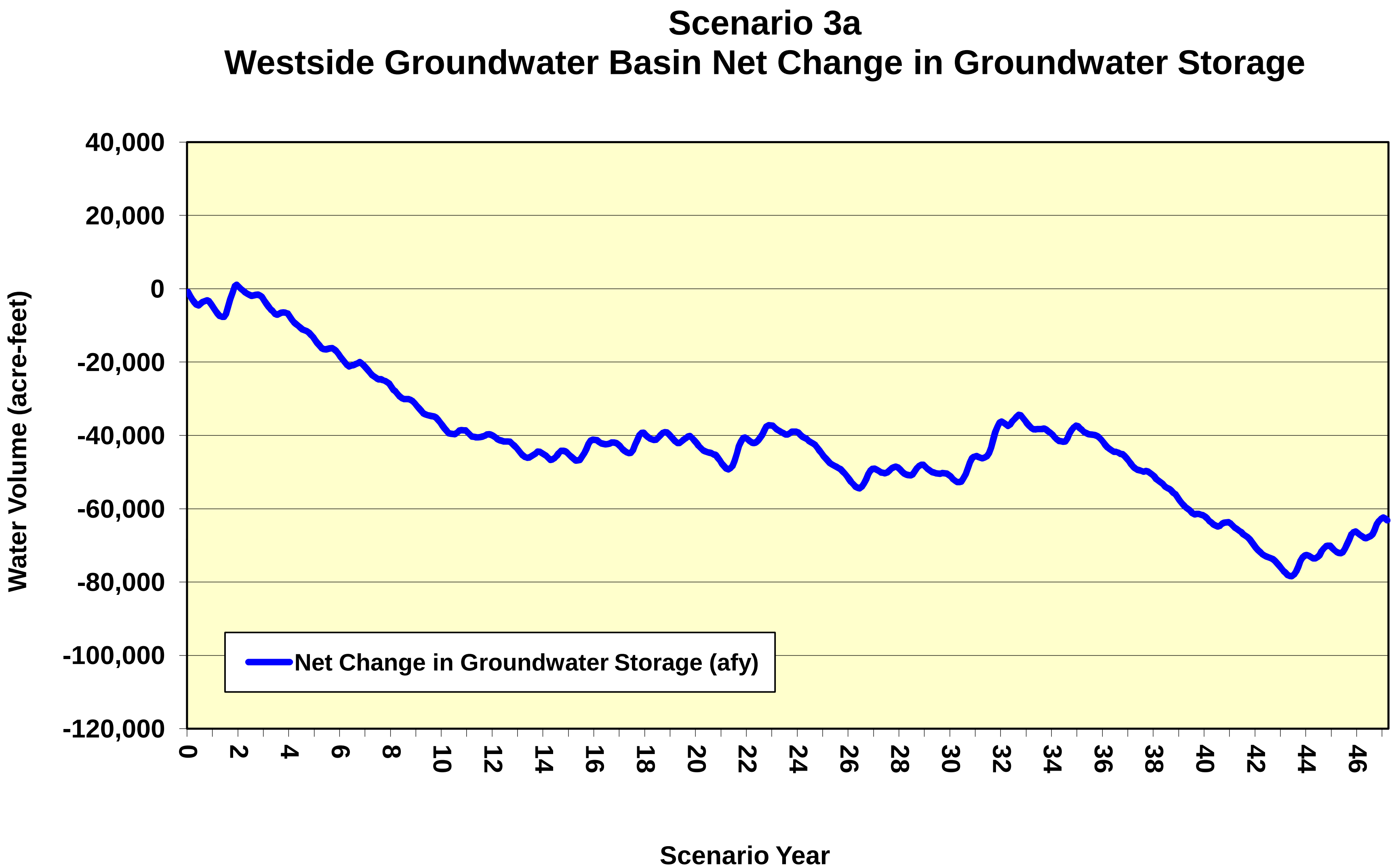
Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.




Note: Volume of some water balance components may be too small to be visible.



Scenario 3a
Westside Groundwater Basin Change in Groundwater Storage
Water Volume (acre-feet)
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Change in Groundwater Storage (afy)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year

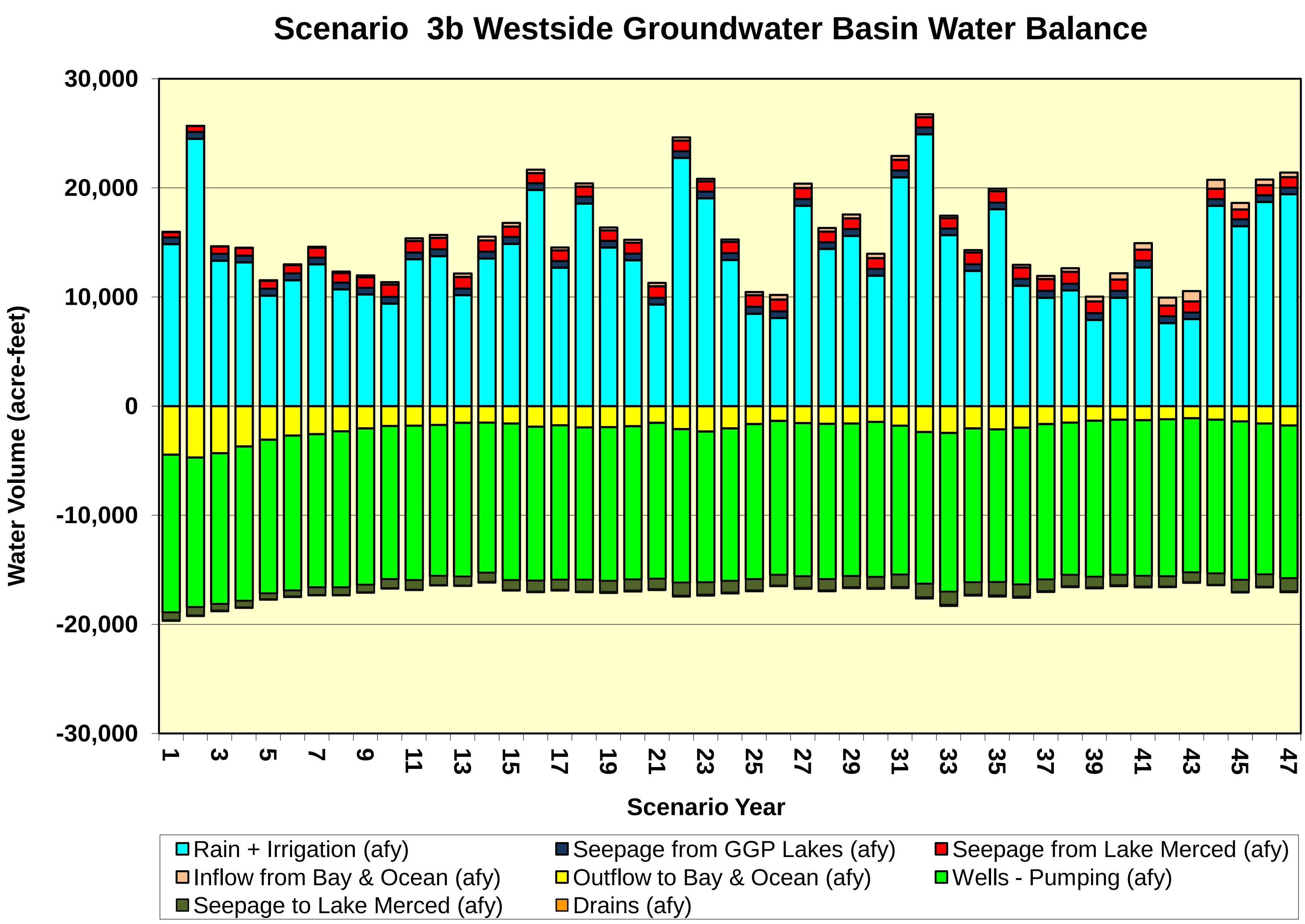

Scenario 3a
Westside Groundwater Basin Net Change in Groundwater Storage
40,000
20,000
0
-20,000
-40,000
-60,000
-80,000
-100,000
-120,000
Water Volume (acre-feet)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
Scenario Year
Net Change in Groundwater Storage (afy)

## Scenario 3b Westside Groundwater Basin Water Balance Summary

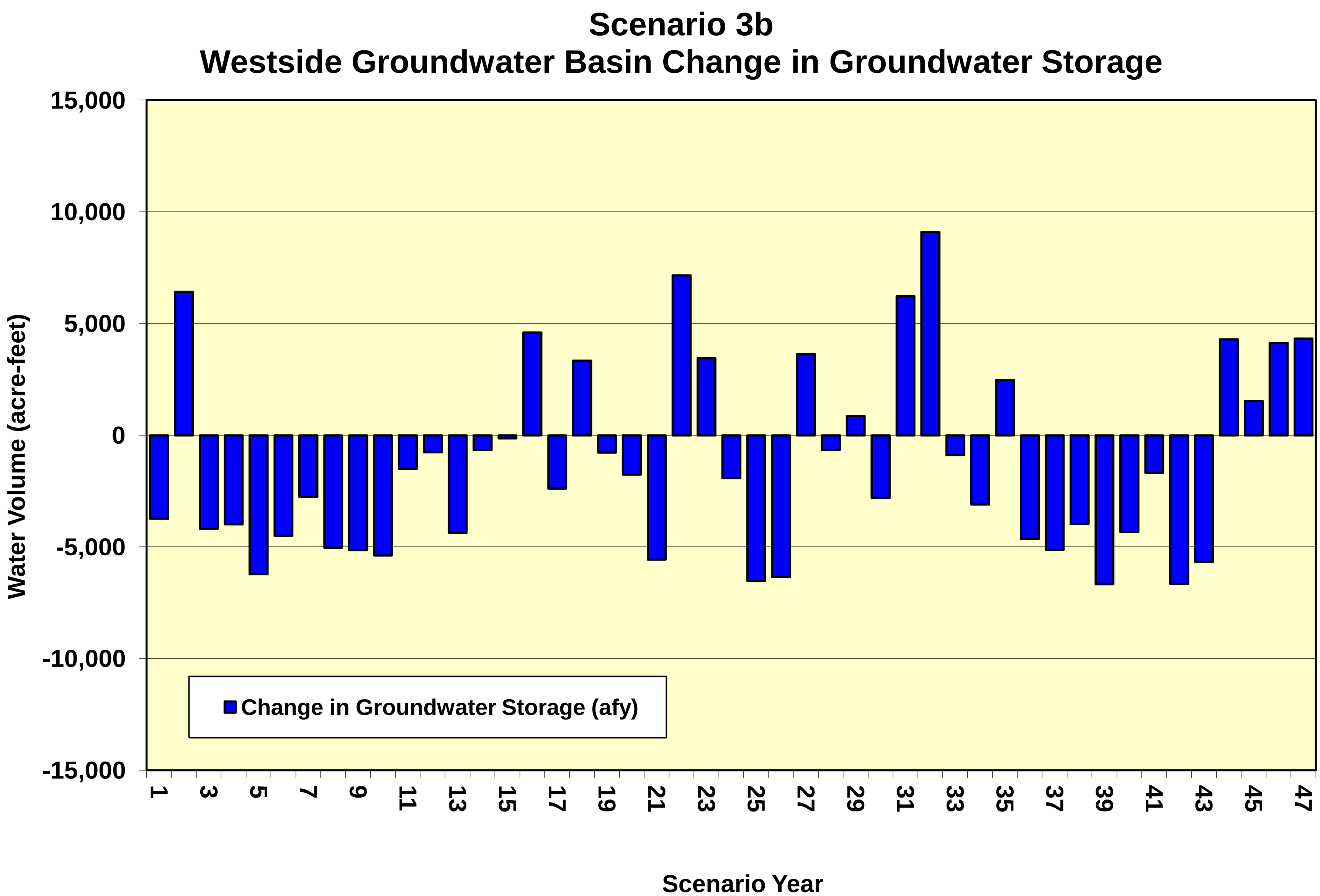
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 626 | 14,845 | 485 | -4,455 | -14,452 | -713 | -71 | -3,730 |
| 2 | 6 | 628 | 24,505 | 532 | -4,703 | -13,711 | -761 | -72 | 6,423 |
| 3 | 9 | 626 | 13,329 | 664 | -4,316 | -13,809 | -609 | -73 | -4,179 |
| 4 | 22 | 626 | 13,169 | 705 | -3,687 | -14,160 | -591 | -74 | -3,990 |
| 5 | 44 | 626 | 10,129 | 747 | -3,082 | -14,074 | -531 | -74 | -6,216 |
| 6 | 74 | 628 | 11,546 | 757 | -2,702 | -14,191 | -541 | -73 | -4,502 |
| 7 | 101 | 626 | 12,988 | 896 | -2,569 | -14,034 | -694 | -72 | -2,758 |
| 8 | 133 | 626 | 10,691 | 890 | -2,312 | -14,298 | -684 | -72 | -5,025 |
| 9 | 175 | 626 | 10,235 | 951 | -2,040 | -14,332 | -681 | -70 | -5,136 |
| 10 | 221 | 628 | 9,386 | 1,116 | -1,817 | -14,032 | -818 | -68 | -5,385 |
| 11 | 255 | 626 | 13,455 | 1,045 | -1,791 | -14,149 | -863 | -68 | -1,491 |
| 12 | 266 | 626 | 13,751 | 1,043 | -1,737 | -13,815 | -827 | -74 | -766 |
| 13 | 314 | 626 | 10,162 | 1,048 | -1,540 | -14,073 | -820 | -76 | -4,359 |
| 14 | 357 | 628 | 13,533 | 1,015 | -1,509 | -13,752 | -846 | -75 | -649 |
| 15 | 342 | 626 | 14,876 | 953 | -1,601 | -14,340 | -906 | -81 | -132 |
| 16 | 309 | 626 | 19,804 | 933 | -1,893 | -14,088 | -1,008 | -84 | 4,600 |
| 17 | 278 | 626 | 12,678 | 964 | -1,756 | -14,143 | -940 | -88 | -2,380 |
| 18 | 278 | 628 | 18,568 | 939 | -1,940 | -13,957 | -1,082 | -92 | 3,342 |
| 19 | 253 | 626 | 14,531 | 955 | -1,937 | -14,078 | -1,022 | -96 | -767 |
| 20 | 261 | 626 | 13,363 | 992 | -1,840 | -14,048 | -1,017 | -99 | -1,763 |
| 21 | 315 | 626 | 9,310 | 1,044 | -1,538 | -14,266 | -968 | -93 | -5,571 |
| 22 | 284 | 628 | 22,751 | 955 | -2,099 | -14,063 | -1,203 | -94 | 7,158 |
| 23 | 217 | 626 | 19,036 | 955 | -2,329 | -13,813 | -1,135 | -101 | 3,456 |
| 24 | 219 | 626 | 13,397 | 1,022 | -2,045 | -13,972 | -1,058 | -105 | -1,915 |
| 25 | 277 | 626 | 8,479 | 1,069 | -1,639 | -14,218 | -1,011 | -107 | -6,524 |
| 26 | 405 | 628 | 8,071 | 1,083 | -1,350 | -14,119 | -966 | -96 | -6,345 |
| 27 | 409 | 626 | 18,354 | 1,008 | -1,560 | -14,032 | -1,071 | -96 | 3,638 |
| 28 | 342 | 626 | 14,398 | 971 | -1,615 | -14,241 | -1,024 | -104 | -647 |
| 29 | 349 | 626 | 15,609 | 975 | -1,590 | -13,978 | -1,024 | -108 | 858 |
| 30 | 384 | 628 | 11,960 | 991 | -1,453 | -14,214 | -990 | -112 | -2,806 |
| 31 | 350 | 626 | 20,974 | 969 | -1,791 | -13,655 | -1,128 | -115 | 6,231 |
| 32 | 252 | 626 | 24,922 | 943 | -2,362 | -13,905 | -1,257 | -117 | 9,102 |
| 33 | 200 | 626 | 15,668 | 949 | -2,462 | -14,544 | -1,194 | -120 | -877 |
| 34 | 224 | 628 | 12,389 | 1,051 | -2,035 | -14,120 | -1,108 | -124 | -3,095 |
| 35 | 238 | 626 | 18,045 | 1,025 | -2,132 | -13,984 | -1,218 | -127 | 2,473 |
| 36 | 240 | 626 | 11,034 | 1,047 | -1,962 | -14,388 | -1,106 | -128 | -4,636 |
| 37 | 292 | 626 | 9,932 | 1,079 | -1,641 | -14,249 | -1,047 | -120 | -5,127 |
| 38 | 347 | 628 | 10,605 | 1,069 | -1,514 | -13,955 | -1,028 | -113 | -3,960 |
| 39 | 446 | 626 | 7,905 | 1,070 | -1,341 | -14,307 | -960 | -105 | -6,666 |
| 40 | 572 | 626 | 9,935 | 1,048 | -1,253 | -14,212 | -947 | -99 | -4,329 |
| 41 | 582 | 626 | 12,714 | 1,011 | -1,298 | -14,251 | -974 | -98 | -1,688 |
| 42 | 723 | 628 | 7,618 | 984 | -1,207 | -14,383 | -926 | -95 | -6,657 |
| 43 | 937 | 626 | 7,975 | 1,000 | -1,114 | -14,119 | -883 | -86 | -5,665 |
| 44 | 803 | 626 | 18,357 | 954 | -1,247 | -14,091 | -1,019 | -86 | 4,297 |
| 45 | 610 | 626 | 16,490 | 901 | -1,391 | -14,525 | -1,080 | -93 | 1,539 |
| 46 | 508 | 626 | 18,714 | 914 | -1,587 | -13,825 | -1,125 | -96 | 4,130 |
| 47 | 416 | 618 | 19,422 | 949 | -1,765 | -14,011 | -1,196 | -99 | 4,333 |
| **Average (afy)** | **312** | **626** | **14,034** | **950** | **-2,012** | **-14,106** | **-949** | **-93** | **-1,237** |
| **Maximum (afy)** | **937** | **628** | **24,922** | **1,116** | **-1,114** | **-13,655** | **-531** | **-68** | **9,102** |
| **Minimum (afy)** | **5** | **618** | **7,618** | **485** | **-4,703** | **-14,544** | **-1,257** | **-128** | **-6,666** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

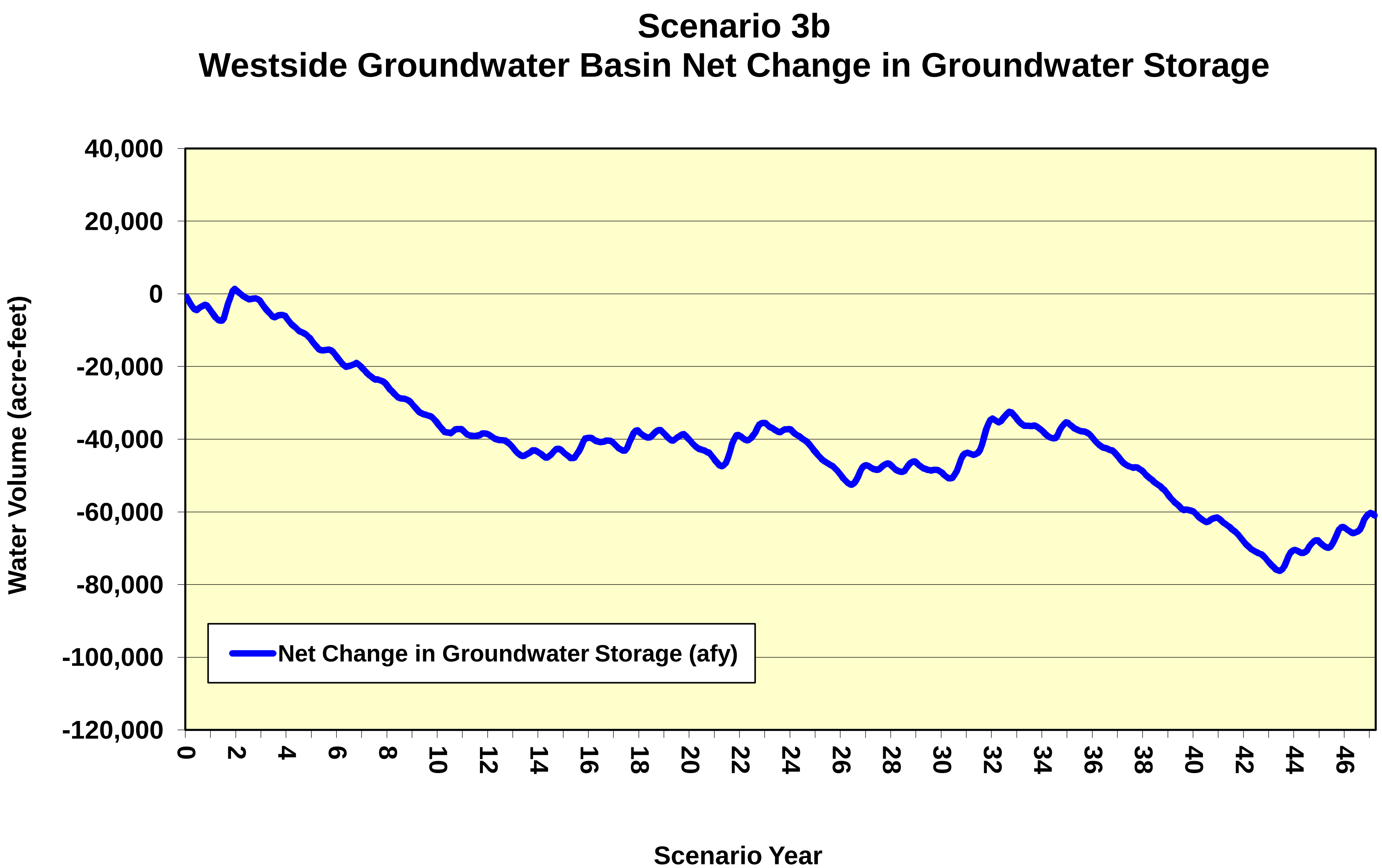
Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.




Note: Volume of some water balance components may be too small to be visible.



Scenario 3b
Westside Groundwater Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
Change in Groundwater Storage (afy)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year



Scenario 3b
Westside Groundwater Basin Net Change in Groundwater Storage
Water Volume (acre-feet)
40,000
20,000
0
-20,000
-40,000
-60,000
-80,000
-100,000
-120,000
Net Change in Groundwater Storage (afy)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
Scenario Year

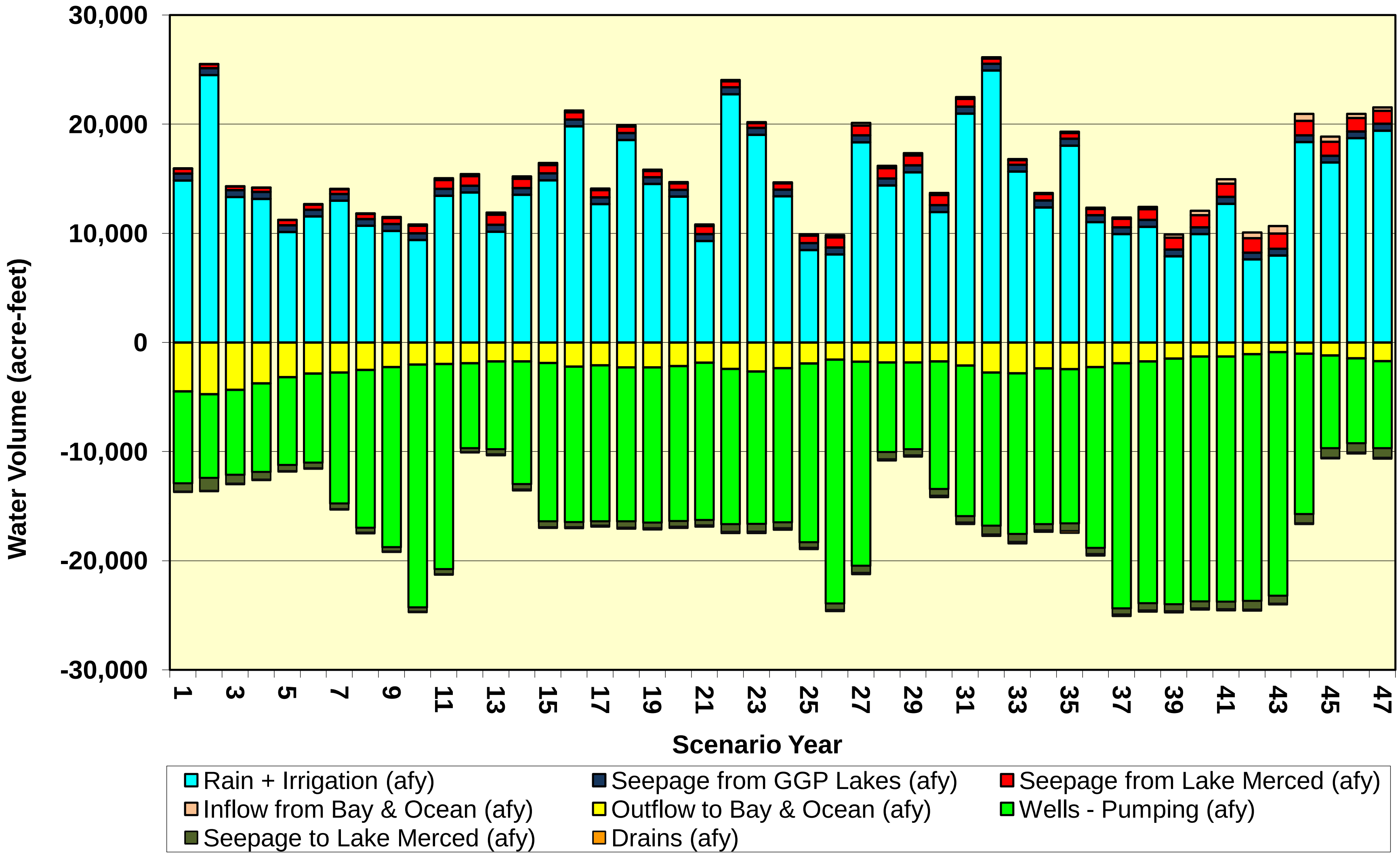
## Scenario 4 Westside Groundwater Basin Water Balance Summary

| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 626 | 14,845 | 460 | -4,466 | -8,435 | -737 | -71 | 2,226 |
| 2 | 5 | 628 | 24,505 | 363 | -4,735 | -7,671 | -1,156 | -72 | 11,867 |
| 3 | 5 | 626 | 13,329 | 336 | -4,339 | -7,771 | -803 | -74 | 1,309 |
| 4 | 9 | 626 | 13,169 | 394 | -3,732 | -8,135 | -676 | -75 | 1,579 |
| 5 | 17 | 626 | 10,129 | 460 | -3,166 | -8,046 | -543 | -77 | -600 |
| 6 | 31 | 628 | 11,546 | 471 | -2,834 | -8,167 | -495 | -77 | 1,103 |
| 7 | 41 | 626 | 12,988 | 422 | -2,750 | -12,007 | -492 | -78 | -1,250 |
| 8 | 57 | 626 | 10,691 | 465 | -2,513 | -14,458 | -440 | -81 | -5,653 |
| 9 | 85 | 626 | 10,235 | 558 | -2,243 | -16,509 | -374 | -84 | -7,707 |
| 10 | 122 | 628 | 9,386 | 687 | -2,009 | -22,245 | -384 | -85 | -13,901 |
| 11 | 170 | 626 | 13,455 | 797 | -1,957 | -18,815 | -433 | -87 | -6,245 |
| 12 | 191 | 626 | 13,751 | 870 | -1,899 | -7,778 | -325 | -94 | 5,341 |
| 13 | 204 | 626 | 10,162 | 921 | -1,728 | -8,045 | -462 | -98 | 1,579 |
| 14 | 213 | 628 | 13,533 | 846 | -1,740 | -11,230 | -485 | -99 | 1,666 |
| 15 | 190 | 626 | 14,876 | 752 | -1,878 | -14,502 | -517 | -110 | -565 |
| 16 | 166 | 626 | 19,804 | 665 | -2,203 | -14,243 | -468 | -117 | 4,230 |
| 17 | 139 | 626 | 12,678 | 666 | -2,085 | -14,299 | -375 | -125 | -2,774 |
| 18 | 138 | 628 | 18,568 | 584 | -2,278 | -14,107 | -559 | -131 | 2,842 |
| 19 | 117 | 626 | 14,531 | 567 | -2,274 | -14,232 | -500 | -137 | -1,303 |
| 20 | 118 | 626 | 13,363 | 594 | -2,166 | -14,202 | -488 | -142 | -2,297 |
| 21 | 151 | 626 | 9,310 | 731 | -1,836 | -14,427 | -477 | -135 | -6,057 |
| 22 | 136 | 628 | 22,751 | 546 | -2,417 | -14,217 | -693 | -136 | 6,597 |
| 23 | 91 | 626 | 19,036 | 444 | -2,653 | -13,958 | -703 | -145 | 2,738 |
| 24 | 90 | 626 | 13,397 | 555 | -2,345 | -14,123 | -537 | -150 | -2,486 |
| 25 | 124 | 626 | 8,479 | 686 | -1,907 | -16,392 | -491 | -152 | -9,029 |
| 26 | 213 | 628 | 8,071 | 936 | -1,563 | -22,336 | -584 | -140 | -14,778 |
| 27 | 247 | 626 | 18,354 | 900 | -1,758 | -18,694 | -647 | -138 | -1,110 |
| 28 | 216 | 626 | 14,398 | 955 | -1,819 | -8,218 | -646 | -146 | 5,366 |
| 29 | 200 | 626 | 15,609 | 914 | -1,823 | -7,947 | -543 | -150 | 6,886 |
| 30 | 195 | 628 | 11,960 | 919 | -1,719 | -11,707 | -589 | -154 | -467 |
| 31 | 170 | 626 | 20,974 | 721 | -2,117 | -13,794 | -567 | -158 | 5,854 |
| 32 | 111 | 626 | 24,922 | 475 | -2,736 | -14,052 | -783 | -162 | 8,400 |
| 33 | 79 | 626 | 15,668 | 428 | -2,826 | -14,713 | -713 | -167 | -1,618 |
| 34 | 90 | 628 | 12,389 | 591 | -2,365 | -14,276 | -547 | -171 | -3,661 |
| 35 | 99 | 626 | 18,045 | 537 | -2,447 | -14,135 | -685 | -176 | 1,864 |
| 36 | 100 | 626 | 11,034 | 588 | -2,258 | -16,566 | -536 | -177 | -7,188 |
| 37 | 137 | 626 | 9,932 | 773 | -1,898 | -22,469 | -541 | -164 | -13,603 |
| 38 | 197 | 628 | 10,605 | 988 | -1,719 | -22,165 | -641 | -153 | -12,261 |
| 39 | 277 | 626 | 7,905 | 1,082 | -1,457 | -22,529 | -614 | -141 | -14,852 |
| 40 | 386 | 626 | 9,935 | 1,119 | -1,280 | -22,433 | -622 | -131 | -12,399 |
| 41 | 415 | 626 | 12,714 | 1,216 | -1,278 | -22,470 | -669 | -128 | -9,573 |
| 42 | 511 | 628 | 7,618 | 1,320 | -1,075 | -22,607 | -761 | -121 | -14,486 |
| 43 | 681 | 626 | 7,975 | 1,390 | -866 | -22,321 | -718 | -108 | -13,342 |
| 44 | 629 | 626 | 18,357 | 1,334 | -1,018 | -14,704 | -814 | -103 | 4,307 |
| 45 | 479 | 626 | 16,490 | 1,277 | -1,188 | -8,494 | -844 | -107 | 8,239 |
| 46 | 384 | 626 | 18,714 | 1,228 | -1,445 | -7,789 | -831 | -107 | 10,780 |
| 47 | 300 | 618 | 19,422 | 1,190 | -1,706 | -7,982 | -857 | -107 | 10,878 |
| **Average (AFY)** | **186** | **626** | **14,034** | **760** | **-2,181** | **-14,264** | **-603** | **-122** | **-1,565** |
| **Maximum (AFY)** | **681** | **628** | **24,922** | **1,390** | **-866** | **-7,671** | **-325** | **-71** | **11,867** |
| **Minimum (AFY)** | **5** | **618** | **7,618** | **336** | **-4,735** | **-22,607** | **-1,156** | **-177** | **-14,852** |

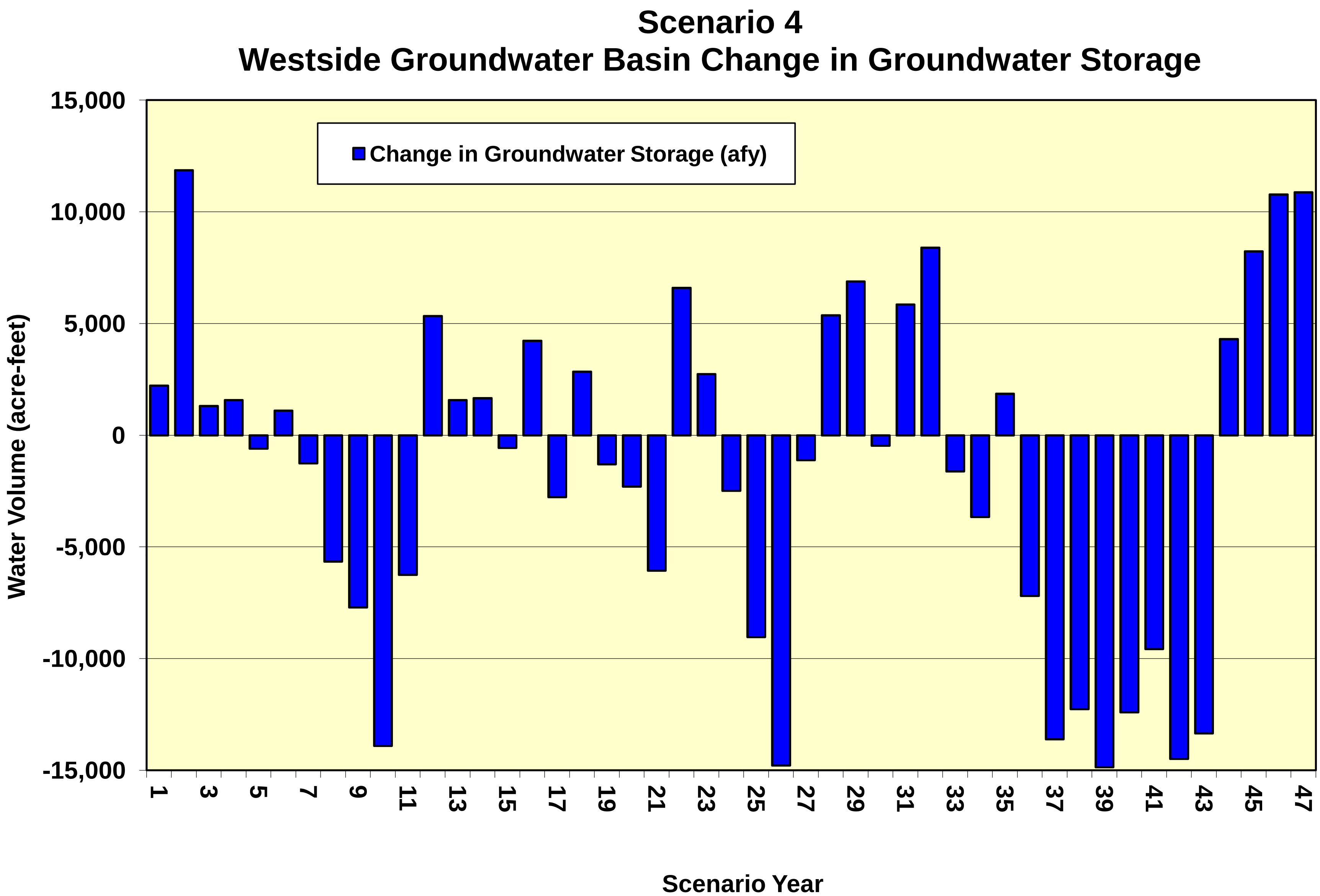
Key:
afy - acre-feet per year
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.

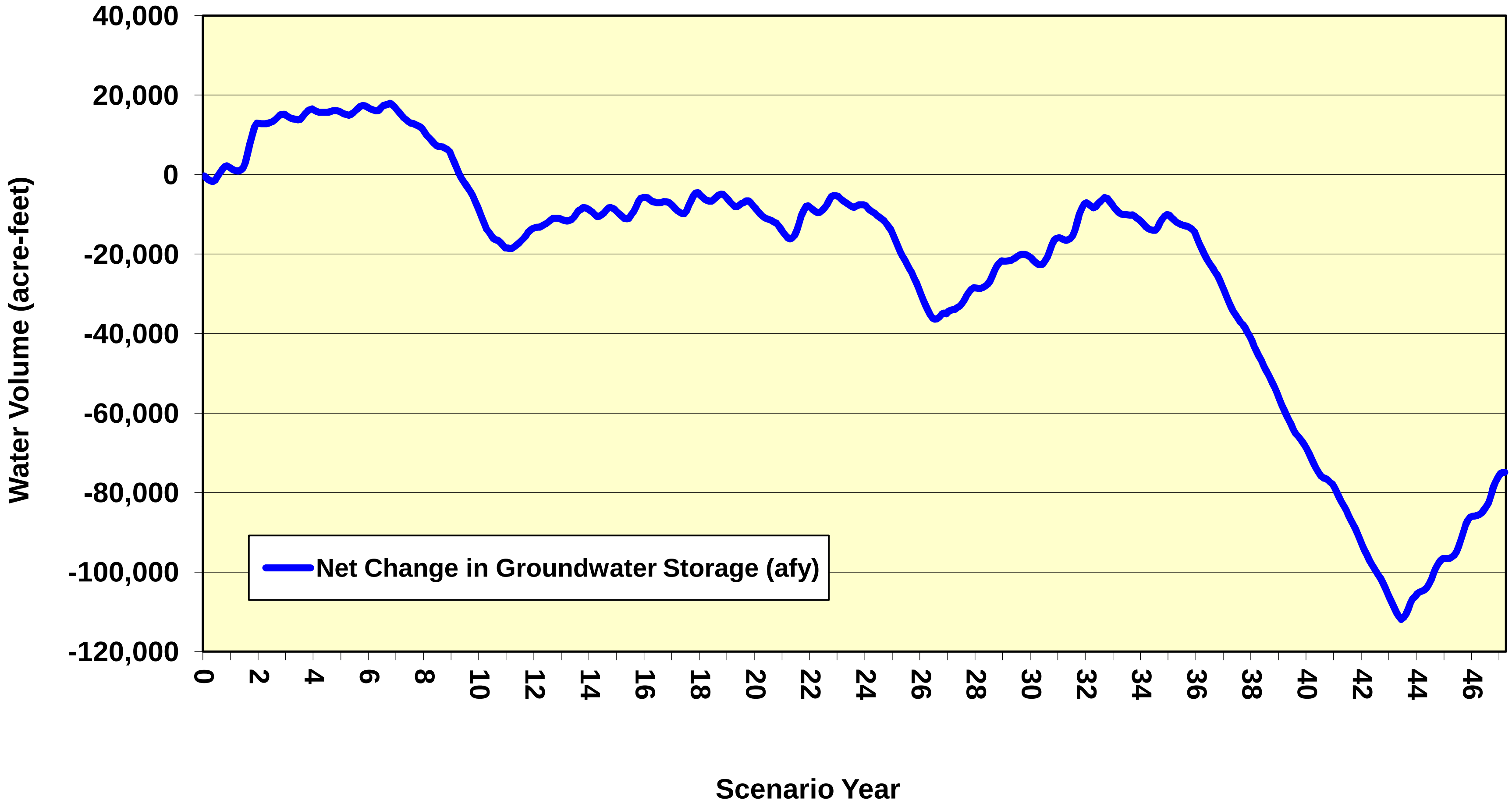
# Scenario 4 Westside Groundwater Basin Water Balance




Note: Volume of some water balance components may be too small to be visible.


Scenario 4
Westside Groundwater Basin Change in Groundwater Storage
Change in Groundwater Storage (afy)
Water Volume (acre-feet)
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year

## Scenario 4
## Westside Groundwater Basin Net Change in Groundwater Storage



# Attachment 10.1-D

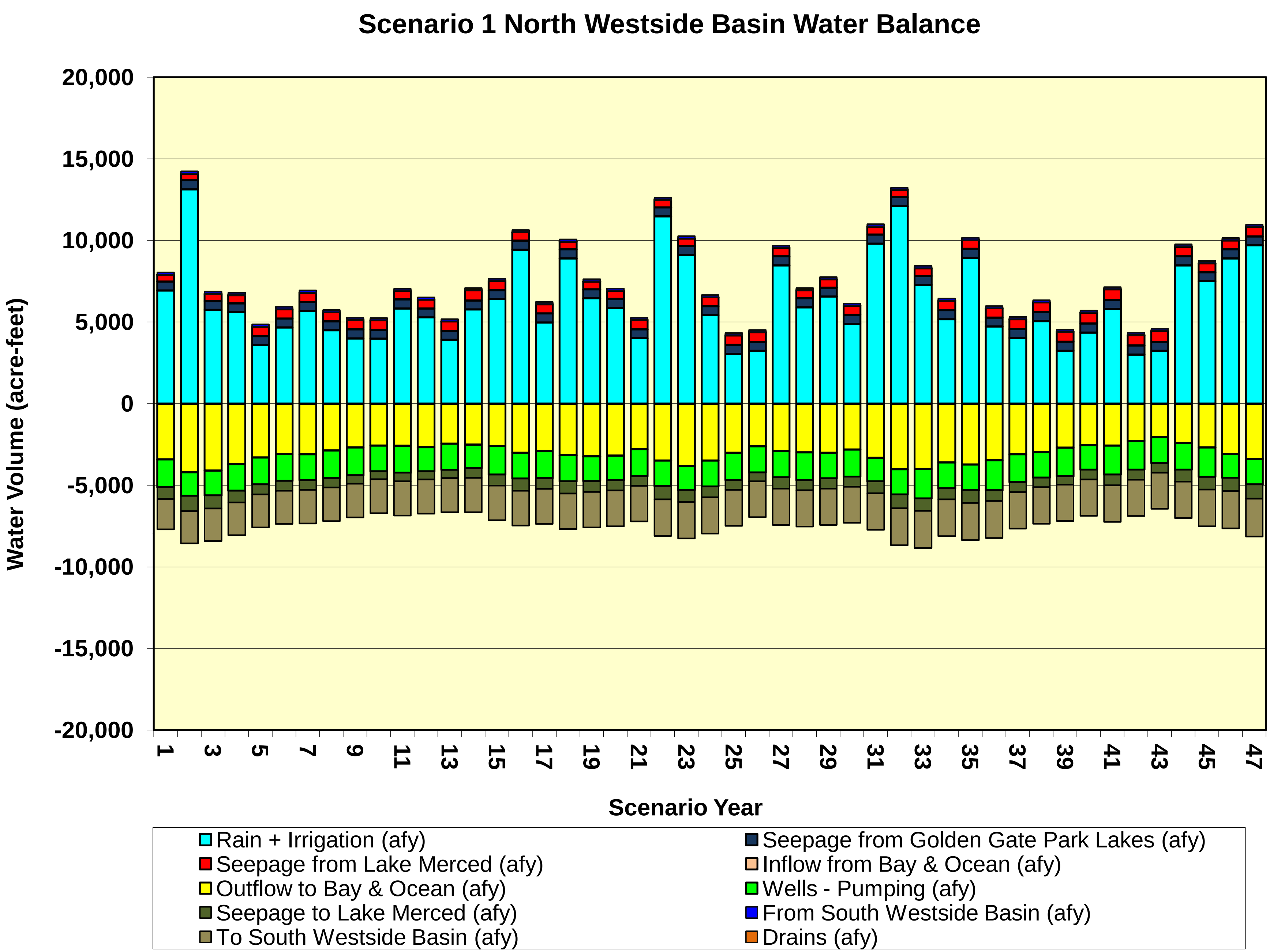
## Model Scenario Water Balance Results – North and South Westside Basins

## Scenario 1 North Westside Basin Water Balance Summary

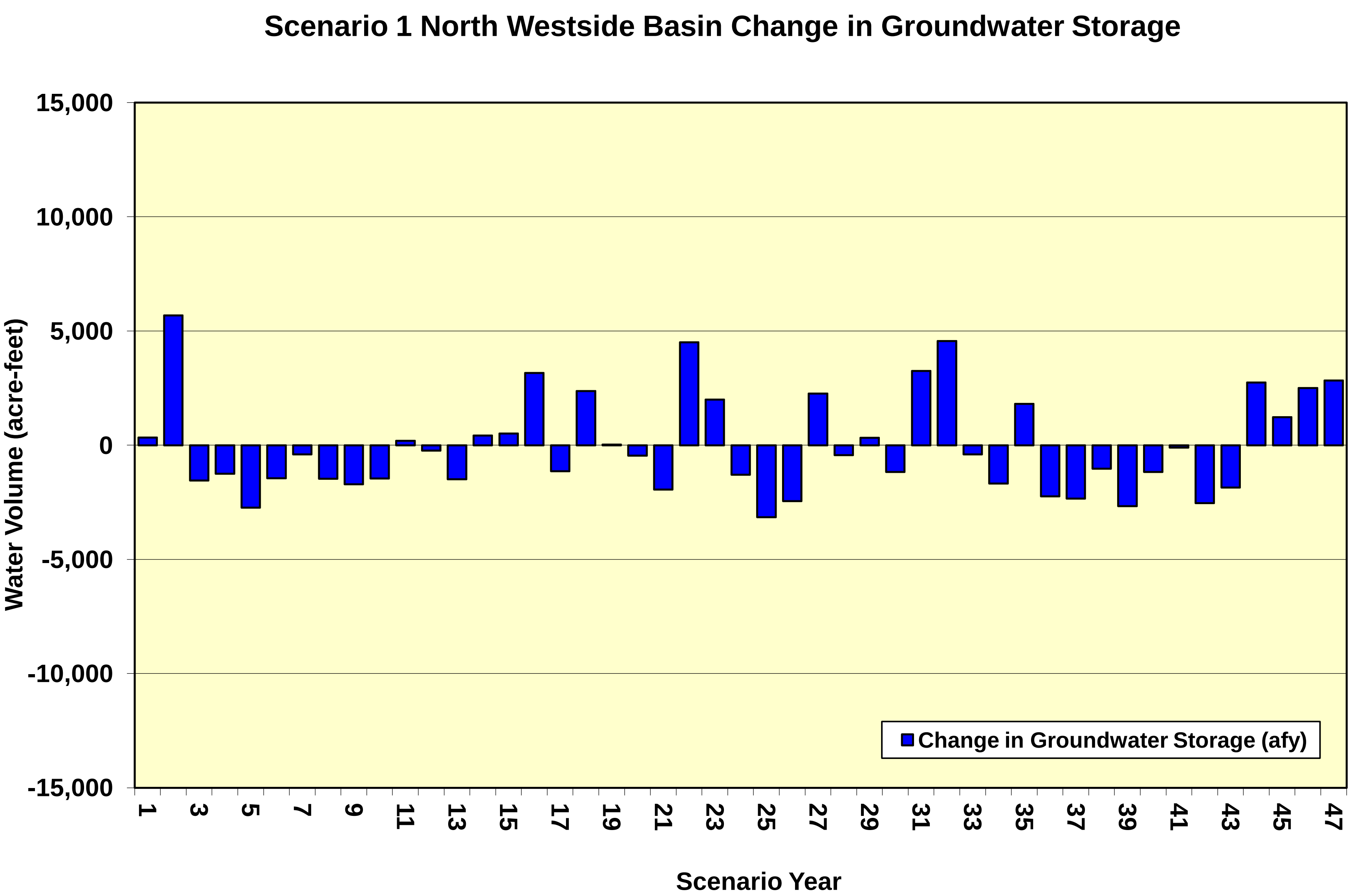
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From South to North Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From North to South Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 546 | 6,941 | 421 | 134 | -3,406 | -1,716 | -711 | -1,870 | 0 | 341 |
| 2 | 2 | 558 | 13,135 | 406 | 138 | -4,193 | -1,457 | -933 | -1,972 | 0 | 5,684 |
| 3 | 2 | 552 | 5,749 | 425 | 146 | -4,100 | -1,523 | -800 | -1,986 | 0 | -1,535 |
| 4 | 2 | 549 | 5,610 | 499 | 142 | -3,703 | -1,635 | -707 | -2,004 | 0 | -1,248 |
| 5 | 2 | 549 | 3,598 | 572 | 138 | -3,291 | -1,648 | -625 | -2,022 | 0 | -2,726 |
| 6 | 2 | 551 | 4,673 | 572 | 134 | -3,079 | -1,649 | -601 | -2,041 | 0 | -1,438 |
| 7 | 2 | 552 | 5,687 | 562 | 132 | -3,103 | -1,586 | -582 | -2,065 | 0 | -401 |
| 8 | 3 | 545 | 4,503 | 557 | 131 | -2,862 | -1,703 | -562 | -2,071 | 0 | -1,459 |
| 9 | 3 | 549 | 4,009 | 573 | 129 | -2,682 | -1,709 | -509 | -2,067 | 0 | -1,703 |
| 10 | 3 | 554 | 3,982 | 587 | 126 | -2,558 | -1,590 | -479 | -2,075 | 0 | -1,450 |
| 11 | 4 | 549 | 5,843 | 524 | 124 | -2,580 | -1,651 | -527 | -2,093 | 0 | 195 |
| 12 | 4 | 556 | 5,286 | 540 | 124 | -2,661 | -1,486 | -492 | -2,099 | 0 | -228 |
| 13 | 5 | 553 | 3,915 | 580 | 124 | -2,457 | -1,597 | -506 | -2,095 | 0 | -1,479 |
| 14 | 7 | 558 | 5,773 | 626 | 123 | -2,505 | -1,431 | -608 | -2,111 | 0 | 432 |
| 15 | 8 | 549 | 6,407 | 574 | 123 | -2,587 | -1,760 | -675 | -2,117 | 0 | 521 |
| 16 | 8 | 556 | 9,441 | 518 | 125 | -3,009 | -1,578 | -739 | -2,149 | 0 | 3,172 |
| 17 | 5 | 549 | 4,984 | 569 | 129 | -2,893 | -1,663 | -666 | -2,144 | 0 | -1,131 |
| 18 | 5 | 554 | 8,904 | 478 | 127 | -3,153 | -1,604 | -754 | -2,178 | 0 | 2,380 |
| 19 | 4 | 553 | 6,466 | 472 | 130 | -3,227 | -1,522 | -648 | -2,190 | 0 | 38 |
| 20 | 4 | 556 | 5,871 | 501 | 130 | -3,178 | -1,513 | -629 | -2,194 | 0 | -453 |
| 21 | 4 | 548 | 4,017 | 570 | 128 | -2,779 | -1,663 | -584 | -2,182 | 0 | -1,940 |
| 22 | 4 | 554 | 11,482 | 454 | 126 | -3,486 | -1,564 | -820 | -2,237 | 0 | 4,513 |
| 23 | 3 | 556 | 9,106 | 464 | 133 | -3,821 | -1,465 | -733 | -2,244 | 0 | 2,000 |
| 24 | 3 | 549 | 5,433 | 540 | 135 | -3,483 | -1,595 | -650 | -2,225 | 0 | -1,291 |
| 25 | 3 | 549 | 3,062 | 582 | 131 | -3,010 | -1,669 | -590 | -2,207 | 0 | -3,149 |
| 26 | 4 | 550 | 3,238 | 600 | 126 | -2,610 | -1,603 | -548 | -2,197 | 0 | -2,440 |
| 27 | 5 | 552 | 8,480 | 526 | 124 | -2,899 | -1,621 | -681 | -2,224 | 0 | 2,263 |
| 28 | 5 | 549 | 5,916 | 493 | 127 | -2,986 | -1,697 | -615 | -2,222 | 0 | -429 |
| 29 | 5 | 553 | 6,566 | 505 | 128 | -3,004 | -1,571 | -625 | -2,227 | 0 | 330 |
| 30 | 5 | 550 | 4,895 | 557 | 128 | -2,805 | -1,671 | -615 | -2,212 | 0 | -1,167 |
| 31 | 5 | 556 | 9,806 | 499 | 127 | -3,311 | -1,443 | -739 | -2,240 | 0 | 3,259 |
| 32 | 3 | 556 | 12,107 | 443 | 133 | -4,011 | -1,556 | -836 | -2,269 | 0 | 4,570 |
| 33 | 3 | 545 | 7,280 | 475 | 139 | -3,996 | -1,811 | -761 | -2,274 | 0 | -400 |
| 34 | 3 | 554 | 5,178 | 572 | 138 | -3,604 | -1,582 | -671 | -2,255 | 0 | -1,667 |
| 35 | 3 | 553 | 8,941 | 532 | 135 | -3,733 | -1,561 | -779 | -2,279 | 0 | 1,811 |
| 36 | 3 | 545 | 4,727 | 575 | 136 | -3,463 | -1,838 | -662 | -2,260 | 0 | -2,236 |
| 37 | 3 | 545 | 4,032 | 604 | 132 | -3,095 | -1,711 | -606 | -2,242 | 0 | -2,337 |
| 38 | 3 | 554 | 5,061 | 591 | 128 | -2,967 | -1,564 | -586 | -2,241 | 0 | -1,022 |
| 39 | 4 | 549 | 3,248 | 605 | 126 | -2,695 | -1,744 | -525 | -2,225 | 0 | -2,656 |
| 40 | 6 | 556 | 4,359 | 666 | 122 | -2,529 | -1,513 | -599 | -2,229 | 0 | -1,160 |
| 41 | 8 | 549 | 5,814 | 652 | 122 | -2,563 | -1,779 | -663 | -2,234 | 0 | -95 |
| 42 | 12 | 550 | 3,017 | 643 | 121 | -2,280 | -1,762 | -615 | -2,217 | 0 | -2,531 |
| 43 | 17 | 549 | 3,238 | 665 | 118 | -2,045 | -1,603 | -580 | -2,210 | 0 | -1,850 |
| 44 | 19 | 552 | 8,481 | 593 | 117 | -2,403 | -1,640 | -726 | -2,243 | 0 | 2,750 |
| 45 | 16 | 545 | 7,522 | 541 | 122 | -2,677 | -1,804 | -774 | -2,261 | 0 | 1,230 |
| 46 | 13 | 556 | 8,902 | 557 | 125 | -3,081 | -1,459 | -812 | -2,290 | 0 | 2,512 |
| 47 | 8 | 545 | 9,712 | 582 | 129 | -3,384 | -1,565 | -875 | -2,313 | 0 | 2,840 |
| **Average (afy)** | **5** | **551** | **6,264** | **546** | **129** | **-3,063** | **-1,619** | **-660** | **-2,170** | **0** | **-17** |
| **Maximum (afy)** | **19** | **558** | **13,135** | **666** | **146** | **-2,045** | **-1,431** | **-479** | **-1,870** | **0** | **5,684** |
| **Minimum (afy)** | **2** | **545** | **3,017** | **406** | **117** | **-4,193** | **-1,838** | **-933** | **-2,313** | **0** | **-3,149** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.



Scenario 1 North Westside Basin Water Balance
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from Golden Gate Park Lakes (afy)
Seepage from Lake Merced (afy)
Inflow from Bay & Ocean (afy)
Outflow to Bay & Ocean (afy)
Wells - Pumping (afy)
Seepage to Lake Merced (afy)
From South Westside Basin (afy)
To South Westside Basin (afy)
Drains (afy)

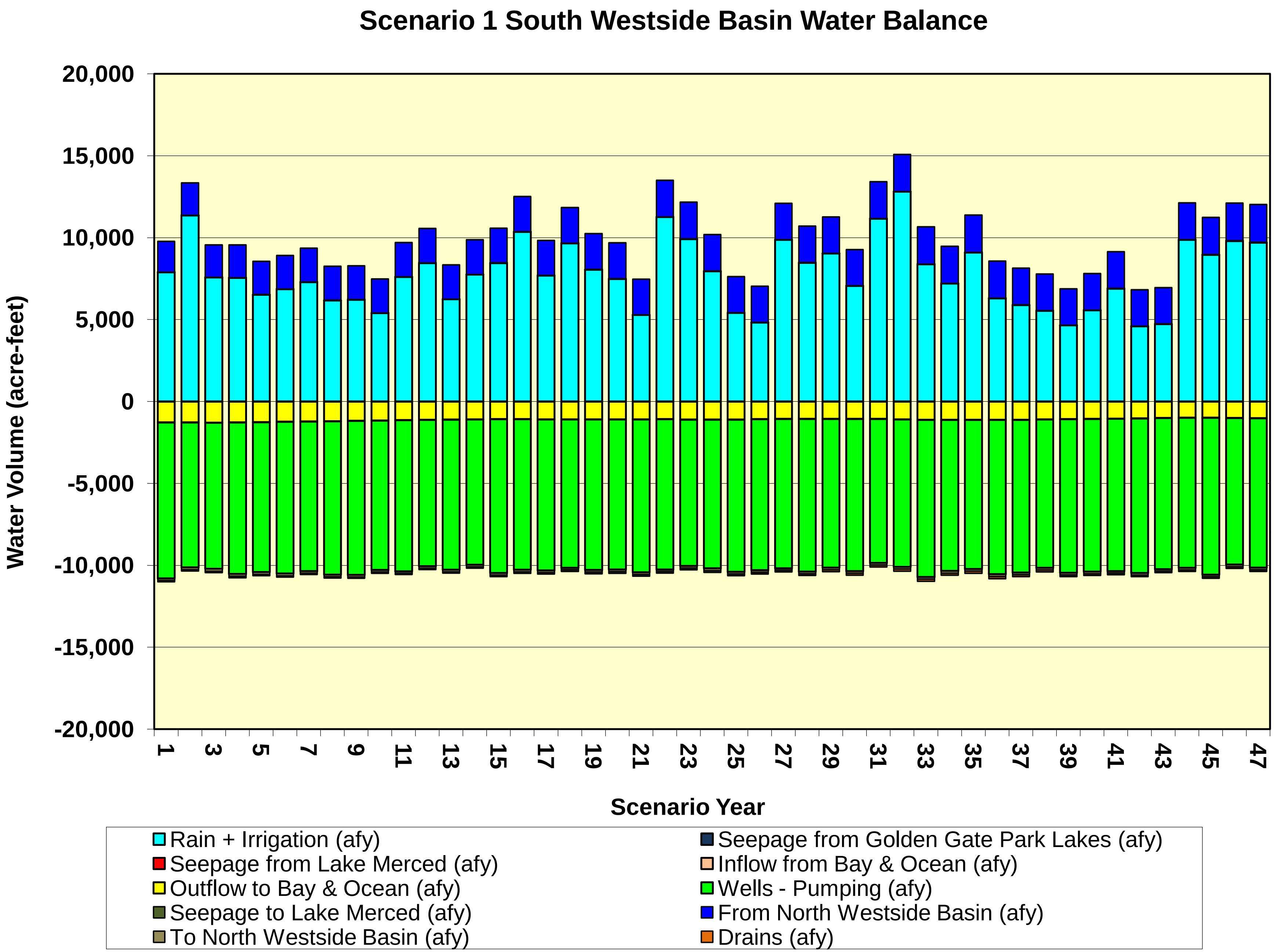

Scenario 1 North Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

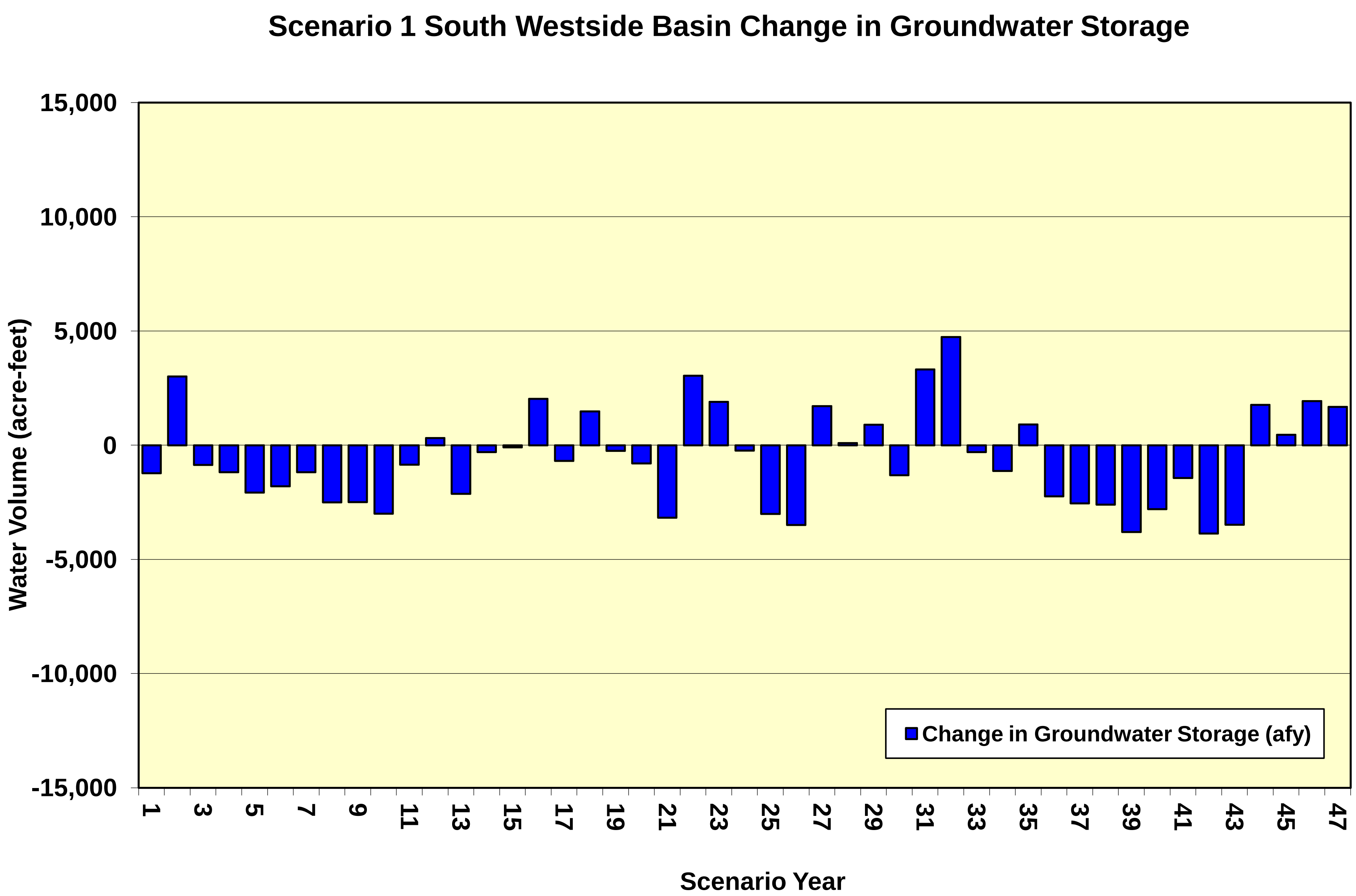
## Scenario 1 South Westside Basin Water Balance Summary

| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From North to South Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From South to North Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0 | 7,904 | 0 | 1,870 | -1,276 | -9,513 | 0 | -134 | -71 | -1,217 |
| 2 | 3 | 0 | 11,370 | 0 | 1,972 | -1,278 | -8,842 | 0 | -138 | -72 | 3,014 |
| 3 | 3 | 0 | 7,580 | 0 | 1,986 | -1,291 | -8,922 | 0 | -146 | -73 | -862 |
| 4 | 3 | 0 | 7,559 | 0 | 2,004 | -1,277 | -9,252 | 0 | -142 | -74 | -1,180 |
| 5 | 3 | 0 | 6,531 | 0 | 2,022 | -1,257 | -9,157 | 0 | -138 | -74 | -2,071 |
| 6 | 3 | 0 | 6,873 | 0 | 2,041 | -1,233 | -9,268 | 0 | -134 | -73 | -1,791 |
| 7 | 3 | 0 | 7,302 | 0 | 2,065 | -1,215 | -9,131 | 0 | -132 | -72 | -1,180 |
| 8 | 3 | 0 | 6,188 | 0 | 2,071 | -1,199 | -9,362 | 0 | -131 | -71 | -2,502 |
| 9 | 3 | 0 | 6,225 | 0 | 2,067 | -1,178 | -9,405 | 0 | -129 | -70 | -2,486 |
| 10 | 3 | 0 | 5,405 | 0 | 2,075 | -1,154 | -9,130 | 0 | -126 | -68 | -2,996 |
| 11 | 3 | 0 | 7,611 | 0 | 2,093 | -1,133 | -9,228 | 0 | -124 | -68 | -847 |
| 12 | 3 | 0 | 8,465 | 0 | 2,099 | -1,118 | -8,934 | 0 | -124 | -74 | 317 |
| 13 | 3 | 0 | 6,247 | 0 | 2,095 | -1,103 | -9,164 | 0 | -124 | -76 | -2,121 |
| 14 | 4 | 0 | 7,760 | 0 | 2,111 | -1,086 | -8,884 | 0 | -123 | -75 | -294 |
| 15 | 4 | 0 | 8,469 | 0 | 2,117 | -1,078 | -9,394 | 0 | -123 | -81 | -86 |
| 16 | 4 | 0 | 10,364 | 0 | 2,149 | -1,079 | -9,188 | 0 | -125 | -84 | 2,041 |
| 17 | 4 | 0 | 7,695 | 0 | 2,144 | -1,085 | -9,220 | 0 | -129 | -88 | -679 |
| 18 | 5 | 0 | 9,663 | 0 | 2,178 | -1,084 | -9,059 | 0 | -127 | -92 | 1,483 |
| 19 | 5 | 0 | 8,066 | 0 | 2,190 | -1,092 | -9,188 | 0 | -130 | -96 | -246 |
| 20 | 5 | 0 | 7,492 | 0 | 2,194 | -1,091 | -9,159 | 0 | -130 | -100 | -789 |
| 21 | 5 | 0 | 5,293 | 0 | 2,182 | -1,081 | -9,348 | 0 | -128 | -93 | -3,169 |
| 22 | 6 | 0 | 11,269 | 0 | 2,237 | -1,080 | -9,165 | 0 | -126 | -94 | 3,047 |
| 23 | 6 | 0 | 9,930 | 0 | 2,244 | -1,100 | -8,937 | 0 | -133 | -101 | 1,908 |
| 24 | 6 | 0 | 7,964 | 0 | 2,225 | -1,107 | -9,075 | 0 | -135 | -106 | -228 |
| 25 | 6 | 0 | 5,416 | 0 | 2,207 | -1,096 | -9,294 | 0 | -131 | -107 | -2,998 |
| 26 | 7 | 0 | 4,834 | 0 | 2,197 | -1,076 | -9,224 | 0 | -126 | -96 | -3,484 |
| 27 | 7 | 0 | 9,875 | 0 | 2,224 | -1,062 | -9,111 | 0 | -124 | -96 | 1,713 |
| 28 | 8 | 0 | 8,482 | 0 | 2,222 | -1,066 | -9,310 | 0 | -127 | -105 | 104 |
| 29 | 8 | 0 | 9,043 | 0 | 2,227 | -1,064 | -9,078 | 0 | -128 | -109 | 898 |
| 30 | 8 | 0 | 7,065 | 0 | 2,212 | -1,060 | -9,290 | 0 | -128 | -112 | -1,306 |
| 31 | 8 | 0 | 11,168 | 0 | 2,240 | -1,060 | -8,786 | 0 | -127 | -115 | 3,327 |
| 32 | 8 | 0 | 12,815 | 0 | 2,269 | -1,086 | -9,008 | 0 | -133 | -118 | 4,747 |
| 33 | 8 | 0 | 8,388 | 0 | 2,274 | -1,119 | -9,587 | 0 | -139 | -121 | -296 |
| 34 | 8 | 0 | 7,212 | 0 | 2,255 | -1,121 | -9,218 | 0 | -138 | -125 | -1,126 |
| 35 | 8 | 0 | 9,104 | 0 | 2,279 | -1,118 | -9,102 | 0 | -135 | -128 | 910 |
| 36 | 8 | 0 | 6,306 | 0 | 2,260 | -1,122 | -9,417 | 0 | -136 | -129 | -2,230 |
| 37 | 8 | 0 | 5,900 | 0 | 2,242 | -1,110 | -9,324 | 0 | -132 | -121 | -2,537 |
| 38 | 8 | 0 | 5,544 | 0 | 2,241 | -1,094 | -9,056 | 0 | -128 | -114 | -2,598 |
| 39 | 8 | 0 | 4,657 | 0 | 2,225 | -1,079 | -9,375 | 0 | -126 | -106 | -3,796 |
| 40 | 9 | 0 | 5,576 | 0 | 2,229 | -1,059 | -9,327 | 0 | -122 | -100 | -2,794 |
| 41 | 9 | 0 | 6,900 | 0 | 2,234 | -1,044 | -9,302 | 0 | -122 | -100 | -1,424 |
| 42 | 10 | 0 | 4,601 | 0 | 2,217 | -1,030 | -9,440 | 0 | -121 | -96 | -3,859 |
| 43 | 11 | 0 | 4,737 | 0 | 2,210 | -1,007 | -9,224 | 0 | -118 | -87 | -3,478 |
| 44 | 12 | 0 | 9,876 | 0 | 2,243 | -990 | -9,166 | 0 | -117 | -87 | 1,772 |
| 45 | 13 | 0 | 8,968 | 0 | 2,261 | -994 | -9,567 | 0 | -122 | -95 | 465 |
| 46 | 14 | 0 | 9,812 | 0 | 2,290 | -1,002 | -8,953 | 0 | -125 | -98 | 1,938 |
| 47 | 15 | 0 | 9,710 | 0 | 2,313 | -1,013 | -9,116 | 0 | -129 | -101 | 1,678 |
| **Average (afy)** | **6** | **0** | **7,770** | **0** | **2,170** | **-1,110** | **-9,196** | **0** | **-129** | **-94** | **-581** |
| **Maximum (afy)** | **15** | **0** | **12,815** | **0** | **2,313** | **-990** | **-8,786** | **0** | **-117** | **-68** | **4,747** |
| **Minimum (afy)** | **3** | **0** | **4,601** | **0** | **1,870** | **-1,291** | **-9,587** | **0** | **-146** | **-129** | **-3,859** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.


Scenario 1 South Westside Basin Water Balance
Water Volume (acre-feet)
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from Golden Gate Park Lakes (afy)
Seepage from Lake Merced (afy)
Inflow from Bay & Ocean (afy)
Outflow to Bay & Ocean (afy)
Wells - Pumping (afy)
Seepage to Lake Merced (afy)
From North Westside Basin (afy)
To North Westside Basin (afy)
Drains (afy)



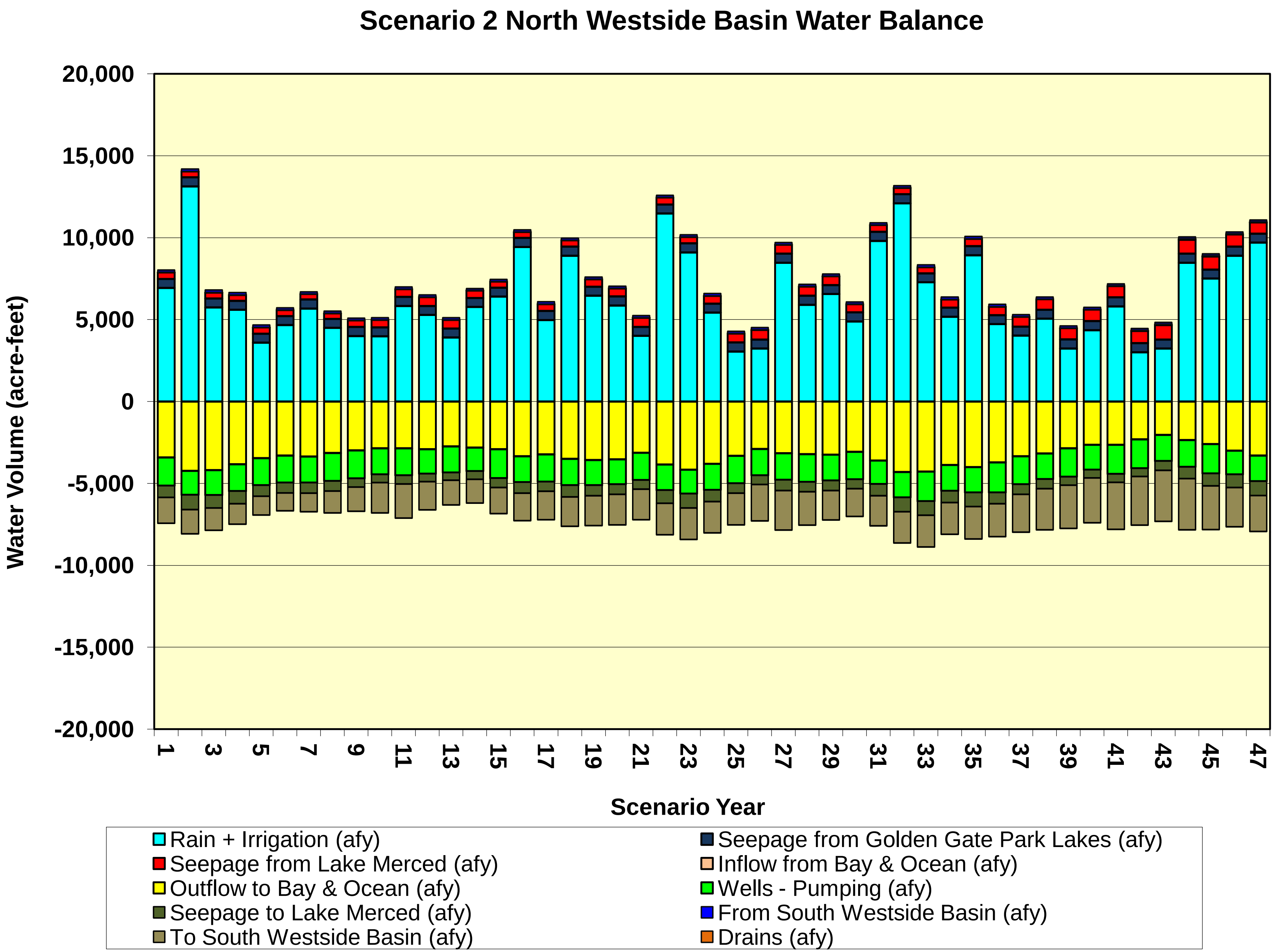
Scenario 1 South Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

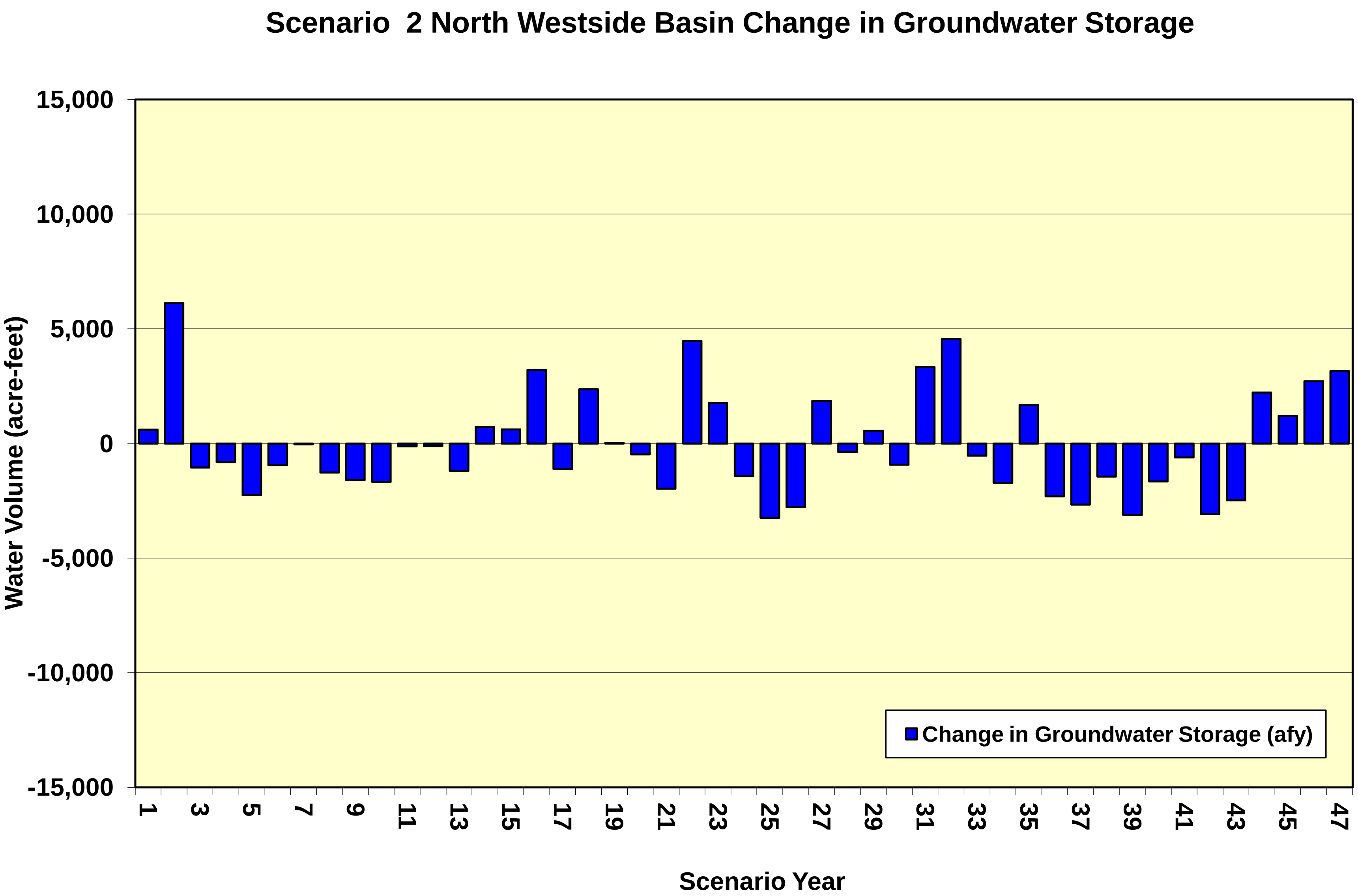
## Scenario 2 North Westside Basin Water Balance Summary

| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From South to North Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From North to South Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 546 | 6,941 | 409 | 134 | -3,414 | -1,716 | -713 | -1,587 | 0 | 601 |
| 2 | 2 | 558 | 13,135 | 363 | 139 | -4,234 | -1,457 | -897 | -1,487 | 0 | 6,122 |
| 3 | 2 | 552 | 5,749 | 360 | 146 | -4,188 | -1,523 | -789 | -1,354 | 0 | -1,044 |
| 4 | 2 | 549 | 5,610 | 358 | 143 | -3,834 | -1,635 | -762 | -1,248 | 0 | -817 |
| 5 | 2 | 549 | 3,598 | 389 | 140 | -3,458 | -1,648 | -666 | -1,160 | 0 | -2,253 |
| 6 | 2 | 551 | 4,673 | 368 | 136 | -3,289 | -1,649 | -641 | -1,093 | 0 | -943 |
| 7 | 2 | 552 | 5,687 | 325 | 134 | -3,356 | -1,586 | -655 | -1,130 | 0 | -28 |
| 8 | 2 | 545 | 4,503 | 344 | 134 | -3,142 | -1,703 | -616 | -1,329 | 0 | -1,261 |
| 9 | 2 | 549 | 4,009 | 399 | 131 | -2,974 | -1,709 | -542 | -1,464 | 0 | -1,598 |
| 10 | 2 | 554 | 3,982 | 461 | 129 | -2,854 | -1,590 | -496 | -1,856 | 0 | -1,668 |
| 11 | 3 | 549 | 5,843 | 474 | 127 | -2,850 | -1,651 | -536 | -2,077 | 0 | -118 |
| 12 | 3 | 556 | 5,286 | 534 | 126 | -2,910 | -1,486 | -491 | -1,723 | 0 | -104 |
| 13 | 2 | 553 | 3,915 | 519 | 126 | -2,730 | -1,597 | -474 | -1,502 | 0 | -1,189 |
| 14 | 2 | 558 | 5,773 | 448 | 124 | -2,811 | -1,431 | -506 | -1,445 | 0 | 713 |
| 15 | 2 | 549 | 6,407 | 371 | 125 | -2,913 | -1,760 | -573 | -1,587 | 0 | 620 |
| 16 | 2 | 556 | 9,441 | 352 | 127 | -3,341 | -1,578 | -665 | -1,683 | 0 | 3,211 |
| 17 | 2 | 549 | 4,984 | 425 | 131 | -3,231 | -1,663 | -584 | -1,725 | 0 | -1,113 |
| 18 | 2 | 554 | 8,904 | 389 | 129 | -3,496 | -1,604 | -717 | -1,793 | 0 | 2,371 |
| 19 | 2 | 553 | 6,466 | 447 | 133 | -3,575 | -1,522 | -649 | -1,828 | 0 | 27 |
| 20 | 2 | 556 | 5,871 | 487 | 132 | -3,527 | -1,513 | -627 | -1,853 | 0 | -472 |
| 21 | 2 | 548 | 4,017 | 549 | 130 | -3,126 | -1,663 | -563 | -1,859 | 0 | -1,964 |
| 22 | 2 | 554 | 11,482 | 427 | 128 | -3,834 | -1,564 | -803 | -1,925 | 0 | 4,468 |
| 23 | 2 | 556 | 9,106 | 388 | 136 | -4,160 | -1,465 | -869 | -1,926 | 0 | 1,769 |
| 24 | 2 | 549 | 5,433 | 471 | 138 | -3,798 | -1,595 | -712 | -1,907 | 0 | -1,419 |
| 25 | 2 | 549 | 3,062 | 547 | 133 | -3,314 | -1,669 | -611 | -1,928 | 0 | -3,229 |
| 26 | 3 | 550 | 3,238 | 594 | 128 | -2,900 | -1,603 | -553 | -2,234 | 0 | -2,776 |
| 27 | 4 | 552 | 8,480 | 544 | 125 | -3,148 | -1,621 | -658 | -2,415 | 0 | 1,864 |
| 28 | 4 | 549 | 5,916 | 564 | 129 | -3,205 | -1,697 | -608 | -2,028 | 0 | -374 |
| 29 | 3 | 553 | 6,566 | 538 | 129 | -3,239 | -1,571 | -618 | -1,796 | 0 | 565 |
| 30 | 2 | 550 | 4,895 | 507 | 129 | -3,067 | -1,671 | -583 | -1,691 | 0 | -928 |
| 31 | 2 | 556 | 9,806 | 426 | 128 | -3,590 | -1,443 | -717 | -1,836 | 0 | 3,331 |
| 32 | 2 | 556 | 12,107 | 383 | 134 | -4,294 | -1,556 | -872 | -1,910 | 0 | 4,550 |
| 33 | 2 | 545 | 7,280 | 380 | 140 | -4,269 | -1,811 | -857 | -1,935 | 0 | -524 |
| 34 | 2 | 554 | 5,178 | 510 | 139 | -3,869 | -1,582 | -706 | -1,946 | 0 | -1,720 |
| 35 | 2 | 553 | 8,941 | 447 | 136 | -3,993 | -1,561 | -854 | -1,982 | 0 | 1,689 |
| 36 | 2 | 545 | 4,727 | 525 | 137 | -3,714 | -1,838 | -684 | -2,002 | 0 | -2,300 |
| 37 | 2 | 545 | 4,032 | 597 | 134 | -3,334 | -1,711 | -617 | -2,306 | 0 | -2,657 |
| 38 | 4 | 554 | 5,061 | 635 | 129 | -3,168 | -1,564 | -588 | -2,501 | 0 | -1,439 |
| 39 | 5 | 549 | 3,248 | 693 | 126 | -2,849 | -1,744 | -517 | -2,626 | 0 | -3,113 |
| 40 | 10 | 556 | 4,359 | 700 | 122 | -2,640 | -1,513 | -502 | -2,744 | 0 | -1,650 |
| 41 | 17 | 549 | 5,814 | 689 | 121 | -2,631 | -1,779 | -526 | -2,863 | 0 | -609 |
| 42 | 29 | 550 | 3,017 | 748 | 120 | -2,306 | -1,762 | -508 | -2,969 | 0 | -3,082 |
| 43 | 44 | 549 | 3,238 | 893 | 116 | -2,030 | -1,603 | -565 | -3,118 | 0 | -2,477 |
| 44 | 53 | 552 | 8,481 | 853 | 114 | -2,345 | -1,640 | -709 | -3,136 | 0 | 2,223 |
| 45 | 46 | 545 | 7,522 | 794 | 118 | -2,587 | -1,804 | -757 | -2,663 | 0 | 1,214 |
| 46 | 30 | 556 | 8,902 | 750 | 121 | -2,989 | -1,459 | -803 | -2,390 | 0 | 2,718 |
| 47 | 15 | 545 | 9,712 | 693 | 125 | -3,301 | -1,565 | -872 | -2,191 | 0 | 3,161 |
| **Average (afy)** | **7** | **551** | **6,264** | **512** | **130** | **-3,273** | **-1,619** | **-656** | **-1,952** | **0** | **-35** |
| **Maximum (afy)** | **53** | **558** | **13,135** | **893** | **146** | **-2,030** | **-1,431** | **-474** | **-1,093** | **0** | **6,122** |
| **Minimum (afy)** | **2** | **545** | **3,017** | **325** | **114** | **-4,294** | **-1,838** | **-897** | **-3,136** | **0** | **-3,229** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.


Scenario 2 North Westside Basin Water Balance
Water Volume (acre-feet)
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from Golden Gate Park Lakes (afy)
Seepage from Lake Merced (afy)
Inflow from Bay & Ocean (afy)
Outflow to Bay & Ocean (afy)
Wells - Pumping (afy)
Seepage to Lake Merced (afy)
From South Westside Basin (afy)
To South Westside Basin (afy)
Drains (afy)

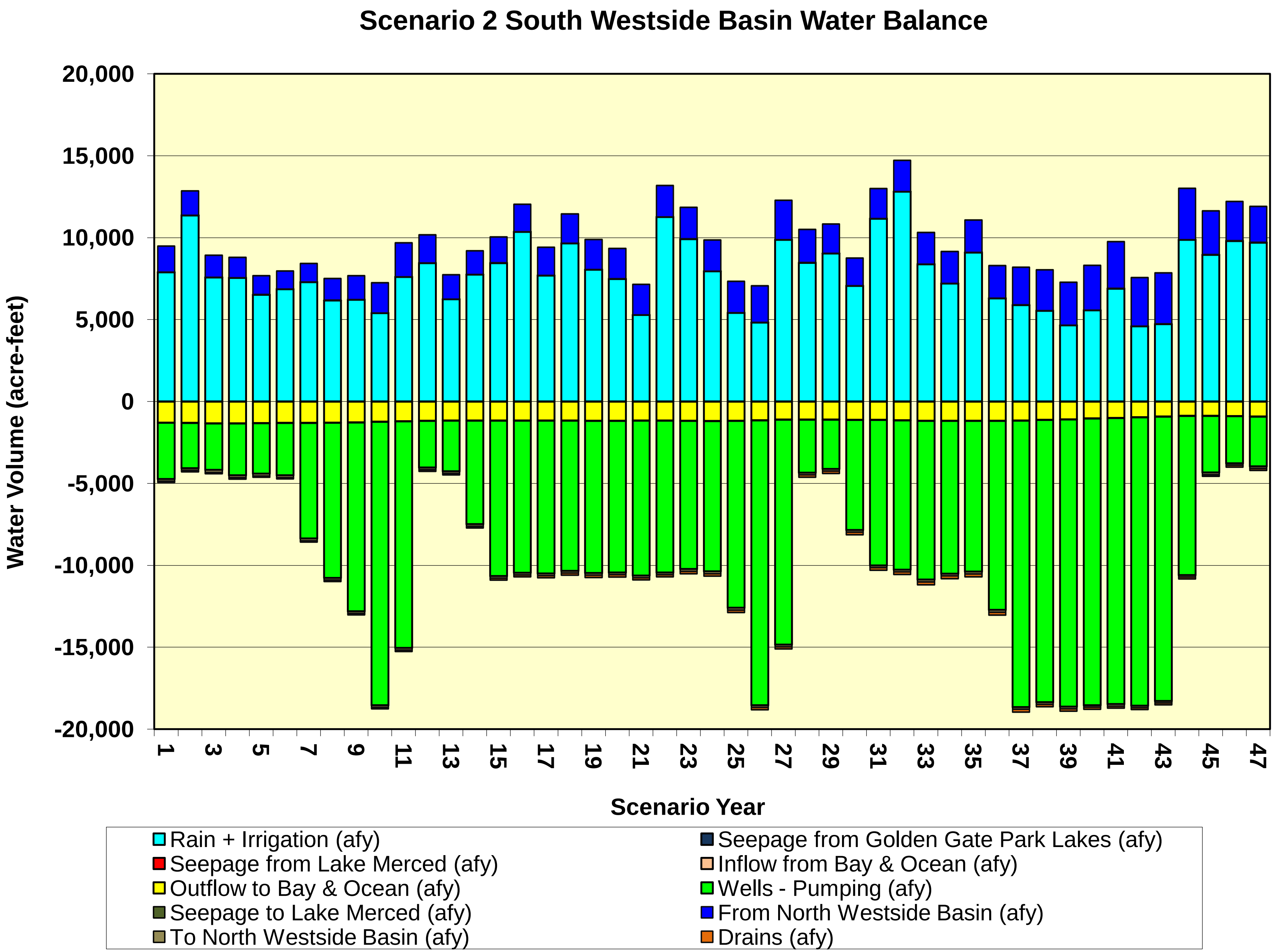

Scenario 2 North Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

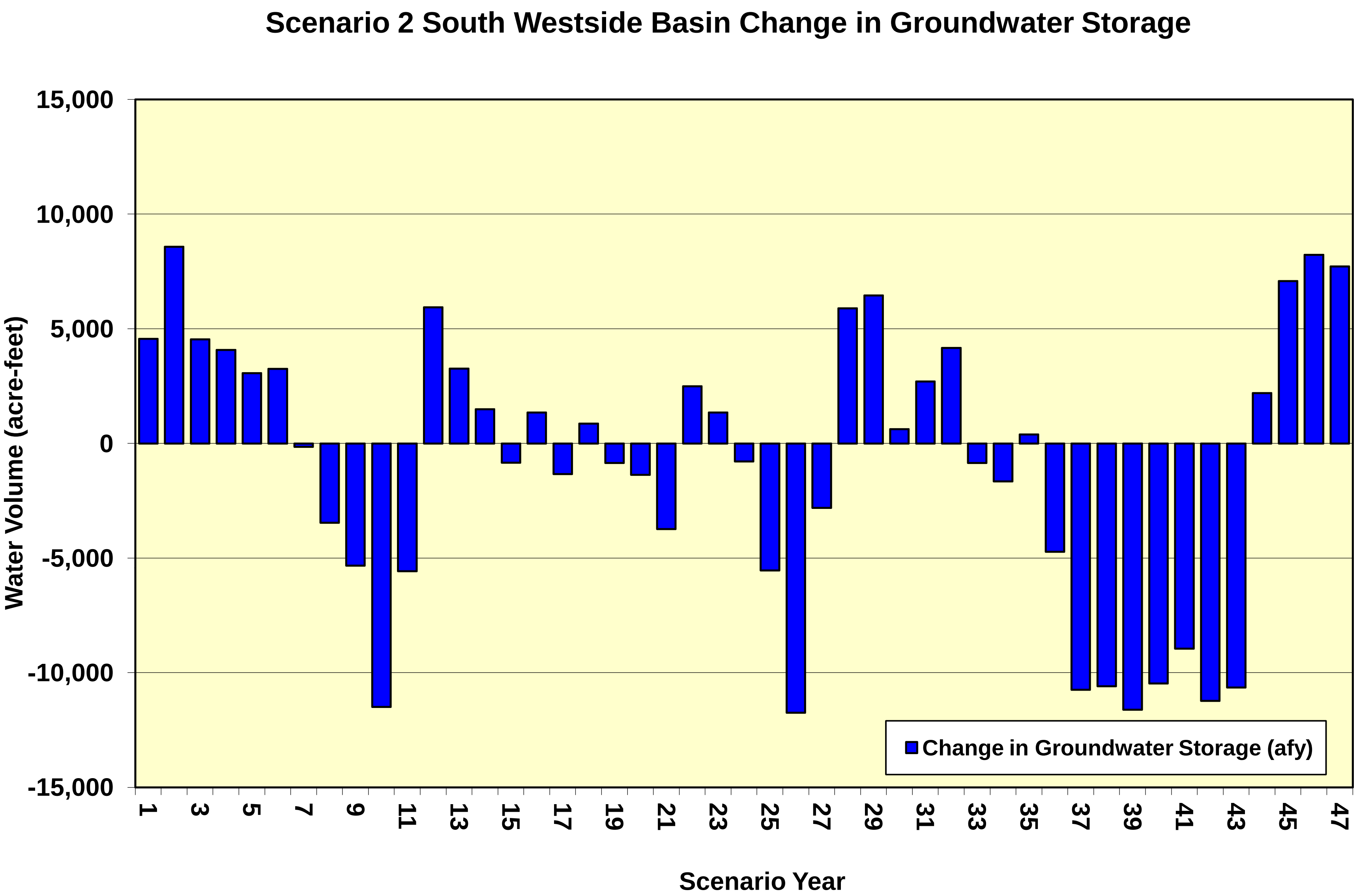
## Scenario 2 South Westside Basin Water Balance Summary

| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From North to South Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From South to North Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0 | 7,904 | 0 | 1,587 | -1,283 | -3,441 | 0 | -134 | -71 | 4,566 |
| 2 | 3 | 0 | 11,370 | 0 | 1,487 | -1,298 | -2,770 | 0 | -139 | -72 | 8,581 |
| 3 | 3 | 0 | 7,580 | 0 | 1,354 | -1,325 | -2,850 | 0 | -146 | -74 | 4,542 |
| 4 | 3 | 0 | 7,559 | 0 | 1,248 | -1,326 | -3,180 | 0 | -143 | -75 | 4,085 |
| 5 | 3 | 0 | 6,531 | 0 | 1,160 | -1,319 | -3,085 | 0 | -140 | -77 | 3,073 |
| 6 | 3 | 0 | 6,873 | 0 | 1,093 | -1,309 | -3,196 | 0 | -136 | -77 | 3,251 |
| 7 | 3 | 0 | 7,302 | 0 | 1,130 | -1,303 | -7,061 | 0 | -134 | -78 | -142 |
| 8 | 2 | 0 | 6,188 | 0 | 1,329 | -1,291 | -9,470 | 0 | -134 | -81 | -3,456 |
| 9 | 2 | 0 | 6,225 | 0 | 1,464 | -1,269 | -11,528 | 0 | -131 | -84 | -5,321 |
| 10 | 2 | 0 | 5,405 | 0 | 1,856 | -1,237 | -17,299 | 0 | -129 | -85 | -11,488 |
| 11 | 2 | 0 | 7,611 | 0 | 2,077 | -1,196 | -13,847 | 0 | -127 | -87 | -5,567 |
| 12 | 2 | 0 | 8,465 | 0 | 1,723 | -1,170 | -2,862 | 0 | -126 | -94 | 5,937 |
| 13 | 2 | 0 | 6,247 | 0 | 1,502 | -1,163 | -3,092 | 0 | -126 | -98 | 3,273 |
| 14 | 2 | 0 | 7,760 | 0 | 1,445 | -1,159 | -6,328 | 0 | -124 | -99 | 1,497 |
| 15 | 2 | 0 | 8,469 | 0 | 1,587 | -1,157 | -9,502 | 0 | -125 | -109 | -836 |
| 16 | 2 | 0 | 10,364 | 0 | 1,683 | -1,159 | -9,296 | 0 | -127 | -117 | 1,350 |
| 17 | 2 | 0 | 7,695 | 0 | 1,725 | -1,165 | -9,328 | 0 | -131 | -124 | -1,326 |
| 18 | 2 | 0 | 9,663 | 0 | 1,793 | -1,164 | -9,167 | 0 | -129 | -130 | 867 |
| 19 | 2 | 0 | 8,066 | 0 | 1,828 | -1,172 | -9,296 | 0 | -133 | -136 | -842 |
| 20 | 2 | 0 | 7,492 | 0 | 1,853 | -1,171 | -9,267 | 0 | -132 | -141 | -1,365 |
| 21 | 2 | 0 | 5,293 | 0 | 1,859 | -1,161 | -9,456 | 0 | -130 | -134 | -3,727 |
| 22 | 2 | 0 | 11,269 | 0 | 1,925 | -1,159 | -9,273 | 0 | -128 | -135 | 2,500 |
| 23 | 2 | 0 | 9,930 | 0 | 1,926 | -1,179 | -9,045 | 0 | -136 | -144 | 1,354 |
| 24 | 2 | 0 | 7,964 | 0 | 1,907 | -1,185 | -9,183 | 0 | -138 | -149 | -781 |
| 25 | 2 | 0 | 5,416 | 0 | 1,928 | -1,173 | -11,417 | 0 | -133 | -151 | -5,528 |
| 26 | 2 | 0 | 4,834 | 0 | 2,234 | -1,144 | -17,393 | 0 | -128 | -139 | -11,734 |
| 27 | 3 | 0 | 9,875 | 0 | 2,415 | -1,109 | -13,730 | 0 | -125 | -137 | -2,809 |
| 28 | 3 | 0 | 8,482 | 0 | 2,028 | -1,100 | -3,238 | 0 | -129 | -145 | 5,901 |
| 29 | 3 | 0 | 9,043 | 0 | 1,796 | -1,104 | -3,006 | 0 | -129 | -149 | 6,453 |
| 30 | 3 | 0 | 7,065 | 0 | 1,691 | -1,112 | -6,733 | 0 | -129 | -153 | 632 |
| 31 | 3 | 0 | 11,168 | 0 | 1,836 | -1,117 | -8,895 | 0 | -128 | -157 | 2,711 |
| 32 | 4 | 0 | 12,815 | 0 | 1,910 | -1,142 | -9,116 | 0 | -134 | -162 | 4,174 |
| 33 | 3 | 0 | 8,388 | 0 | 1,935 | -1,174 | -9,695 | 0 | -140 | -166 | -850 |
| 34 | 3 | 0 | 7,212 | 0 | 1,946 | -1,176 | -9,326 | 0 | -139 | -171 | -1,651 |
| 35 | 3 | 0 | 9,104 | 0 | 1,982 | -1,173 | -9,210 | 0 | -136 | -176 | 395 |
| 36 | 3 | 0 | 6,306 | 0 | 2,002 | -1,178 | -11,540 | 0 | -137 | -176 | -4,720 |
| 37 | 3 | 0 | 5,900 | 0 | 2,306 | -1,158 | -17,493 | 0 | -134 | -163 | -10,738 |
| 38 | 4 | 0 | 5,544 | 0 | 2,501 | -1,121 | -17,225 | 0 | -129 | -152 | -10,578 |
| 39 | 4 | 0 | 4,657 | 0 | 2,626 | -1,082 | -17,544 | 0 | -126 | -140 | -11,607 |
| 40 | 5 | 0 | 5,576 | 0 | 2,744 | -1,037 | -17,496 | 0 | -122 | -130 | -10,461 |
| 41 | 6 | 0 | 6,900 | 0 | 2,863 | -997 | -17,471 | 0 | -121 | -128 | -8,948 |
| 42 | 8 | 0 | 4,601 | 0 | 2,969 | -959 | -17,601 | 0 | -120 | -120 | -11,223 |
| 43 | 10 | 0 | 4,737 | 0 | 3,118 | -911 | -17,373 | 0 | -116 | -107 | -10,642 |
| 44 | 12 | 0 | 9,876 | 0 | 3,136 | -868 | -9,733 | 0 | -114 | -103 | 2,205 |
| 45 | 14 | 0 | 8,968 | 0 | 2,663 | -867 | -3,467 | 0 | -118 | -107 | 7,086 |
| 46 | 17 | 0 | 9,812 | 0 | 2,390 | -888 | -2,875 | 0 | -121 | -107 | 8,227 |
| 47 | 19 | 0 | 9,710 | 0 | 2,191 | -919 | -3,043 | 0 | -125 | -107 | 7,725 |
| **Average (afy)** | **4** | **0** | **7,770** | **0** | **1,952** | **-1,145** | **-9,307** | **0** | **-130** | **-122** | **-978** |
| **Maximum (afy)** | **19** | **0** | **12,815** | **0** | **3,136** | **-867** | **-2,770** | **0** | **-114** | **-71** | **8,581** |
| **Minimum (afy)** | **2** | **0** | **4,601** | **0** | **1,093** | **-1,326** | **-17,601** | **0** | **-146** | **-176** | **-11,734** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.


Scenario 2 South Westside Basin Water Balance
Water Volume (acre-feet)
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from Lake Merced (afy)
Outflow to Bay & Ocean (afy)
Seepage to Lake Merced (afy)
To North Westside Basin (afy)
Seepage from Golden Gate Park Lakes (afy)
Inflow from Bay & Ocean (afy)
Wells - Pumping (afy)
From North Westside Basin (afy)
Drains (afy)



Scenario 2 South Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

## Scenario 3a North Westside Basin Water Balance Summary

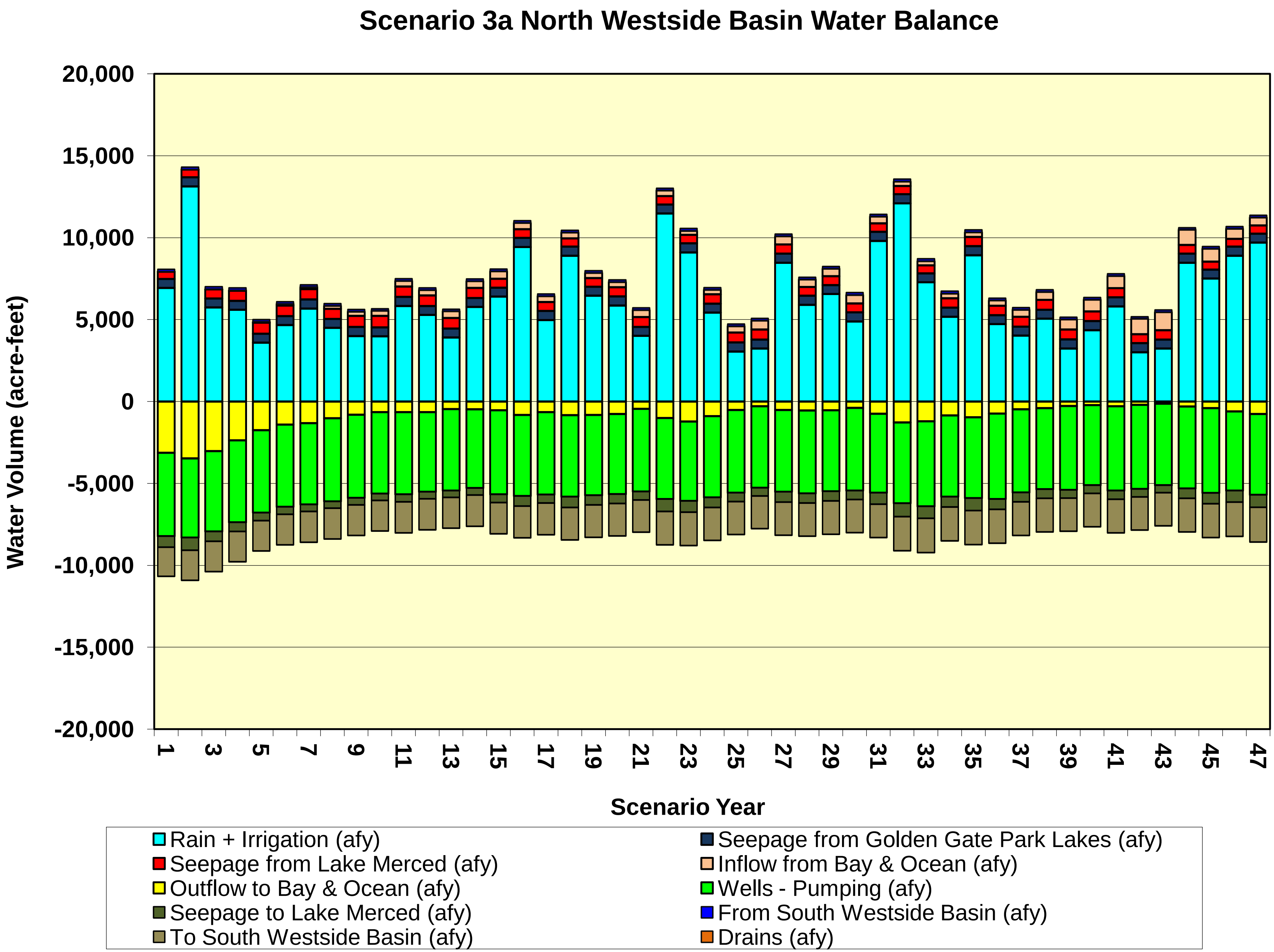
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From South to North Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From North to South Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 546 | 6,941 | 445 | 134 | -3,124 | -5,090 | -670 | -1,777 | 0 | -2,594 |
| 2 | 3 | 558 | 13,135 | 478 | 139 | -3,474 | -4,832 | -772 | -1,836 | 0 | 3,400 |
| 3 | 8 | 552 | 5,749 | 560 | 147 | -3,026 | -4,898 | -612 | -1,840 | 0 | -3,360 |
| 4 | 23 | 549 | 5,610 | 617 | 143 | -2,360 | -5,010 | -560 | -1,847 | 0 | -2,834 |
| 5 | 51 | 549 | 3,598 | 674 | 140 | -1,752 | -5,022 | -487 | -1,852 | 0 | -4,101 |
| 6 | 91 | 551 | 4,673 | 650 | 135 | -1,401 | -5,024 | -461 | -1,858 | 0 | -2,644 |
| 7 | 126 | 552 | 5,687 | 628 | 133 | -1,313 | -4,960 | -440 | -1,871 | 0 | -1,458 |
| 8 | 182 | 545 | 4,503 | 616 | 133 | -1,014 | -5,078 | -418 | -1,874 | 0 | -2,405 |
| 9 | 245 | 549 | 4,009 | 684 | 130 | -799 | -5,083 | -422 | -1,872 | 0 | -2,559 |
| 10 | 302 | 554 | 3,982 | 707 | 128 | -650 | -4,965 | -417 | -1,875 | 0 | -2,234 |
| 11 | 346 | 549 | 5,843 | 635 | 126 | -640 | -5,025 | -461 | -1,890 | 0 | -517 |
| 12 | 334 | 556 | 5,286 | 640 | 126 | -640 | -4,861 | -429 | -1,894 | 0 | -881 |
| 13 | 410 | 553 | 3,915 | 638 | 126 | -458 | -4,972 | -412 | -1,888 | 0 | -2,089 |
| 14 | 426 | 558 | 5,773 | 605 | 124 | -464 | -4,806 | -440 | -1,903 | 0 | -127 |
| 15 | 461 | 549 | 6,407 | 542 | 125 | -526 | -5,134 | -500 | -1,908 | 0 | 15 |
| 16 | 390 | 556 | 9,441 | 525 | 127 | -814 | -4,953 | -606 | -1,938 | 0 | 2,727 |
| 17 | 369 | 549 | 4,984 | 543 | 131 | -637 | -5,038 | -519 | -1,932 | 0 | -1,551 |
| 18 | 354 | 554 | 8,904 | 515 | 129 | -831 | -4,978 | -663 | -1,966 | 0 | 2,019 |
| 19 | 310 | 553 | 6,466 | 529 | 132 | -822 | -4,896 | -595 | -1,977 | 0 | -300 |
| 20 | 324 | 556 | 5,871 | 553 | 132 | -754 | -4,888 | -579 | -1,981 | 0 | -766 |
| 21 | 431 | 548 | 4,017 | 595 | 130 | -447 | -5,037 | -520 | -1,968 | 0 | -2,251 |
| 22 | 335 | 554 | 11,482 | 517 | 128 | -1,006 | -4,938 | -771 | -2,026 | 0 | 4,273 |
| 23 | 246 | 556 | 9,106 | 519 | 135 | -1,217 | -4,840 | -699 | -2,037 | 0 | 1,770 |
| 24 | 270 | 549 | 5,433 | 572 | 137 | -885 | -4,969 | -606 | -2,019 | 0 | -1,518 |
| 25 | 380 | 549 | 3,062 | 607 | 133 | -517 | -5,044 | -548 | -2,001 | 0 | -3,379 |
| 26 | 542 | 550 | 3,238 | 621 | 128 | -279 | -4,977 | -503 | -1,991 | 0 | -2,672 |
| 27 | 511 | 552 | 8,480 | 559 | 125 | -513 | -4,995 | -629 | -2,021 | 0 | 2,069 |
| 28 | 465 | 549 | 5,916 | 531 | 129 | -537 | -5,071 | -583 | -2,025 | 0 | -626 |
| 29 | 455 | 553 | 6,566 | 538 | 130 | -528 | -4,946 | -588 | -2,032 | 0 | 147 |
| 30 | 524 | 550 | 4,895 | 549 | 130 | -389 | -5,045 | -548 | -2,019 | 0 | -1,352 |
| 31 | 411 | 556 | 9,806 | 529 | 129 | -748 | -4,818 | -692 | -2,048 | 0 | 3,126 |
| 32 | 279 | 556 | 12,107 | 502 | 134 | -1,274 | -4,931 | -820 | -2,078 | 0 | 4,475 |
| 33 | 251 | 545 | 7,280 | 497 | 141 | -1,207 | -5,186 | -737 | -2,082 | 0 | -497 |
| 34 | 287 | 554 | 5,178 | 582 | 140 | -843 | -4,957 | -638 | -2,065 | 0 | -1,762 |
| 35 | 292 | 553 | 8,941 | 556 | 137 | -959 | -4,935 | -753 | -2,085 | 0 | 1,746 |
| 36 | 334 | 545 | 4,727 | 574 | 138 | -734 | -5,212 | -630 | -2,067 | 0 | -2,325 |
| 37 | 422 | 545 | 4,032 | 607 | 134 | -464 | -5,086 | -573 | -2,053 | 0 | -2,435 |
| 38 | 485 | 554 | 5,061 | 603 | 130 | -404 | -4,938 | -560 | -2,051 | 0 | -1,120 |
| 39 | 615 | 549 | 3,248 | 605 | 128 | -272 | -5,118 | -495 | -2,034 | 0 | -2,775 |
| 40 | 720 | 556 | 4,359 | 594 | 124 | -220 | -4,887 | -493 | -2,037 | 0 | -1,283 |
| 41 | 750 | 549 | 5,814 | 565 | 123 | -278 | -5,154 | -531 | -2,045 | 0 | -206 |
| 42 | 946 | 550 | 3,017 | 546 | 123 | -195 | -5,137 | -485 | -2,031 | 0 | -2,665 |
| 43 | 1115 | 549 | 3,238 | 567 | 120 | -132 | -4,977 | -450 | -2,024 | 0 | -1,995 |
| 44 | 937 | 552 | 8,481 | 527 | 119 | -292 | -5,014 | -597 | -2,053 | 0 | 2,659 |
| 45 | 792 | 545 | 7,522 | 477 | 124 | -402 | -5,179 | -656 | -2,069 | 0 | 1,155 |
| 46 | 616 | 556 | 8,902 | 487 | 127 | -604 | -4,833 | -697 | -2,098 | 0 | 2,457 |
| 47 | 489 | 545 | 9,712 | 502 | 131 | -755 | -4,939 | -752 | -2,121 | 0 | 2,811 |
| **Average (afy)** | **397** | **551** | **6,264** | **568** | **131** | **-885** | **-4,993** | **-575** | **-1,978** | **0** | **-520** |
| **Maximum (afy)** | **1115** | **558** | **13,135** | **707** | **147** | **-132** | **-4,806** | **-412** | **-1,777** | **0** | **4,475** |
| **Minimum (afy)** | **2** | **545** | **3,017** | **445** | **119** | **-3,474** | **-5,212** | **-820** | **-2,121** | **0** | **-4,101** |

Key:

afy - acre-feet per year

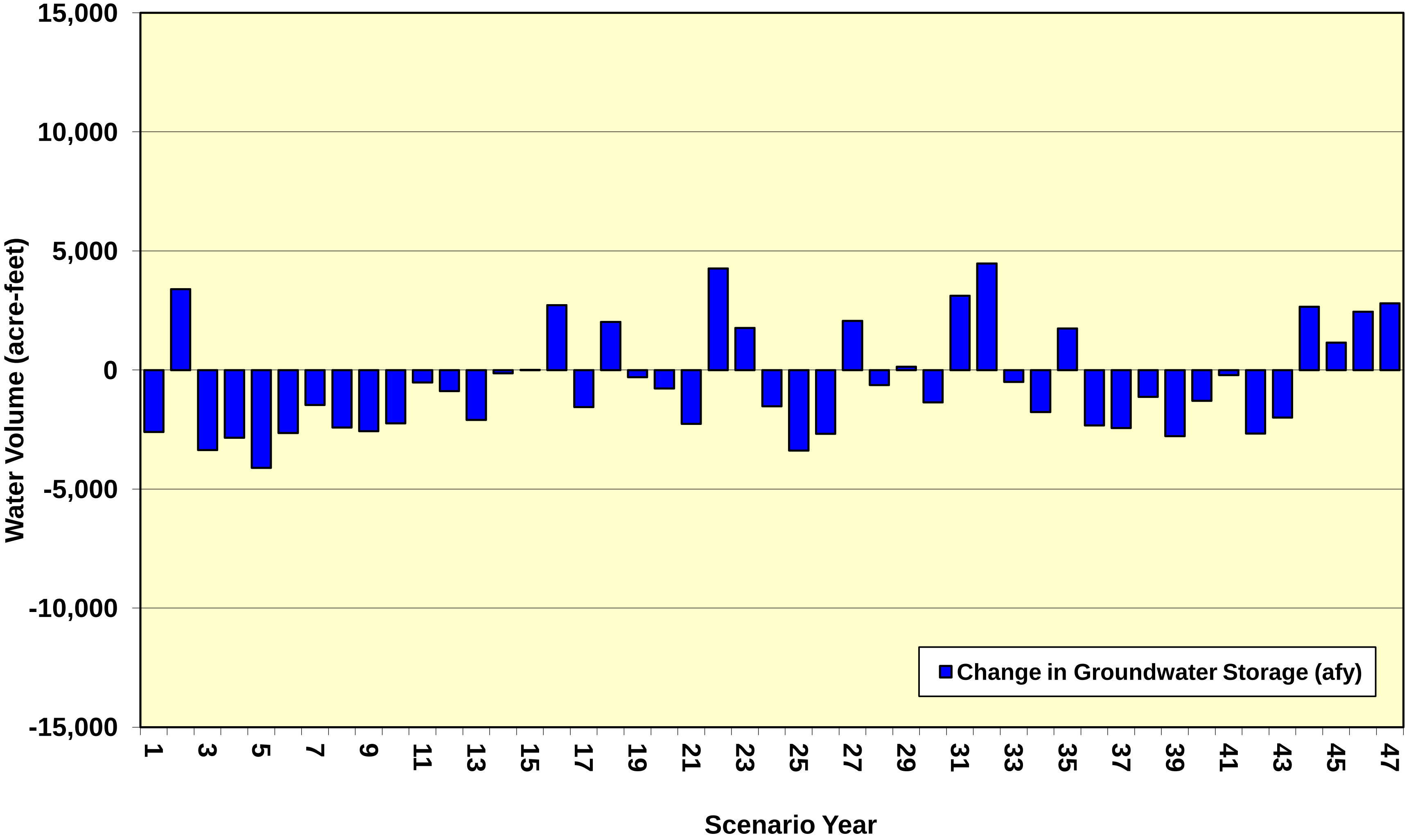
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.



Scenario 3a North Westside Basin Water Balance
Water Volume (acre-feet)
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
Scenario Year
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Rain + Irrigation (afy)
Seepage from Golden Gate Park Lakes (afy)
Seepage from Lake Merced (afy)
Inflow from Bay & Ocean (afy)
Outflow to Bay & Ocean (afy)
Wells - Pumping (afy)
Seepage to Lake Merced (afy)
From South Westside Basin (afy)
To South Westside Basin (afy)
Drains (afy)

Scenario 3a North Westside Basin Change in Groundwater Storage



## Scenario 3a South Westside Basin Water Balance Summary

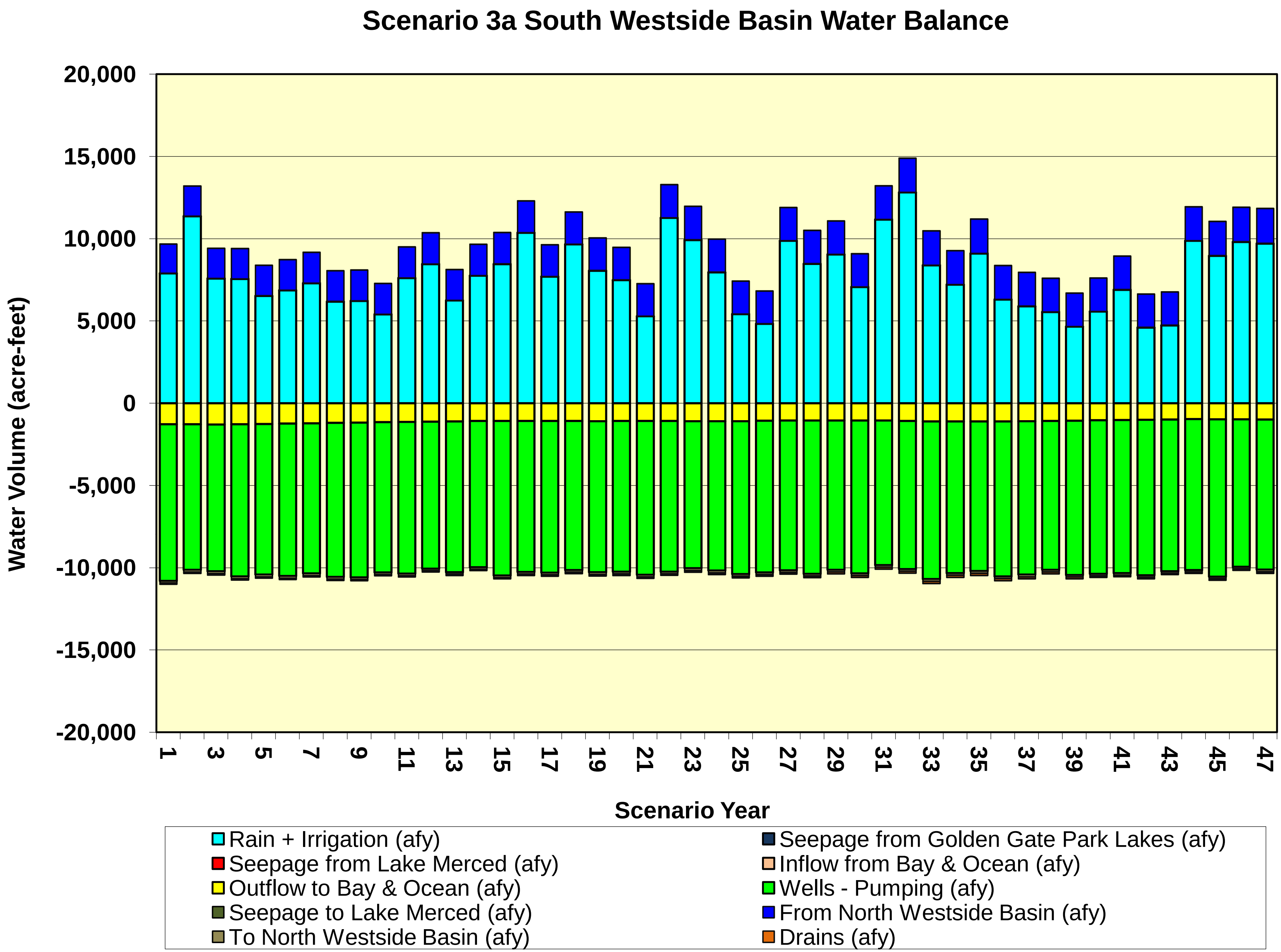
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From North to South Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From South to North Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0 | 7,904 | 0 | 1,777 | -1,276 | -9,513 | 0 | -134 | -71 | -1,310 |
| 2 | 3 | 0 | 11,370 | 0 | 1,836 | -1,277 | -8,842 | 0 | -139 | -72 | 2,879 |
| 3 | 3 | 0 | 7,580 | 0 | 1,840 | -1,289 | -8,922 | 0 | -147 | -73 | -1,008 |
| 4 | 3 | 0 | 7,559 | 0 | 1,847 | -1,275 | -9,252 | 0 | -143 | -74 | -1,336 |
| 5 | 3 | 0 | 6,531 | 0 | 1,852 | -1,255 | -9,157 | 0 | -140 | -74 | -2,240 |
| 6 | 3 | 0 | 6,873 | 0 | 1,858 | -1,230 | -9,268 | 0 | -135 | -73 | -1,972 |
| 7 | 3 | 0 | 7,302 | 0 | 1,871 | -1,211 | -9,131 | 0 | -133 | -72 | -1,372 |
| 8 | 3 | 0 | 6,188 | 0 | 1,874 | -1,195 | -9,362 | 0 | -133 | -71 | -2,696 |
| 9 | 3 | 0 | 6,225 | 0 | 1,872 | -1,172 | -9,405 | 0 | -130 | -70 | -2,678 |
| 10 | 3 | 0 | 5,405 | 0 | 1,875 | -1,148 | -9,130 | 0 | -128 | -68 | -3,191 |
| 11 | 3 | 0 | 7,611 | 0 | 1,890 | -1,126 | -9,228 | 0 | -126 | -68 | -1,045 |
| 12 | 3 | 0 | 8,465 | 0 | 1,894 | -1,111 | -8,934 | 0 | -126 | -74 | 117 |
| 13 | 3 | 0 | 6,247 | 0 | 1,888 | -1,096 | -9,164 | 0 | -126 | -76 | -2,322 |
| 14 | 4 | 0 | 7,760 | 0 | 1,903 | -1,078 | -8,884 | 0 | -124 | -75 | -495 |
| 15 | 4 | 0 | 8,469 | 0 | 1,908 | -1,069 | -9,394 | 0 | -125 | -81 | -288 |
| 16 | 4 | 0 | 10,364 | 0 | 1,938 | -1,070 | -9,188 | 0 | -127 | -84 | 1,838 |
| 17 | 4 | 0 | 7,695 | 0 | 1,932 | -1,076 | -9,220 | 0 | -131 | -88 | -882 |
| 18 | 5 | 0 | 9,663 | 0 | 1,966 | -1,074 | -9,059 | 0 | -129 | -92 | 1,280 |
| 19 | 5 | 0 | 8,066 | 0 | 1,977 | -1,081 | -9,188 | 0 | -132 | -96 | -450 |
| 20 | 5 | 0 | 7,492 | 0 | 1,981 | -1,080 | -9,159 | 0 | -132 | -100 | -993 |
| 21 | 5 | 0 | 5,293 | 0 | 1,968 | -1,069 | -9,348 | 0 | -130 | -92 | -3,372 |
| 22 | 6 | 0 | 11,269 | 0 | 2,026 | -1,067 | -9,165 | 0 | -128 | -94 | 2,847 |
| 23 | 6 | 0 | 9,930 | 0 | 2,037 | -1,087 | -8,937 | 0 | -135 | -101 | 1,713 |
| 24 | 6 | 0 | 7,964 | 0 | 2,019 | -1,093 | -9,075 | 0 | -137 | -105 | -422 |
| 25 | 6 | 0 | 5,416 | 0 | 2,001 | -1,082 | -9,294 | 0 | -133 | -106 | -3,191 |
| 26 | 7 | 0 | 4,834 | 0 | 1,991 | -1,061 | -9,224 | 0 | -128 | -96 | -3,677 |
| 27 | 7 | 0 | 9,875 | 0 | 2,021 | -1,046 | -9,111 | 0 | -125 | -96 | 1,524 |
| 28 | 8 | 0 | 8,482 | 0 | 2,025 | -1,049 | -9,310 | 0 | -129 | -104 | -78 |
| 29 | 8 | 0 | 9,043 | 0 | 2,032 | -1,047 | -9,078 | 0 | -130 | -108 | 719 |
| 30 | 8 | 0 | 7,065 | 0 | 2,019 | -1,043 | -9,290 | 0 | -130 | -112 | -1,482 |
| 31 | 8 | 0 | 11,168 | 0 | 2,048 | -1,042 | -8,786 | 0 | -129 | -115 | 3,153 |
| 32 | 8 | 0 | 12,815 | 0 | 2,078 | -1,067 | -9,008 | 0 | -134 | -117 | 4,574 |
| 33 | 8 | 0 | 8,388 | 0 | 2,082 | -1,099 | -9,587 | 0 | -141 | -121 | -469 |
| 34 | 8 | 0 | 7,212 | 0 | 2,065 | -1,100 | -9,218 | 0 | -140 | -124 | -1,297 |
| 35 | 8 | 0 | 9,104 | 0 | 2,085 | -1,097 | -9,102 | 0 | -137 | -127 | 736 |
| 36 | 8 | 0 | 6,306 | 0 | 2,067 | -1,101 | -9,417 | 0 | -138 | -128 | -2,402 |
| 37 | 8 | 0 | 5,900 | 0 | 2,053 | -1,088 | -9,324 | 0 | -134 | -120 | -2,705 |
| 38 | 8 | 0 | 5,544 | 0 | 2,051 | -1,071 | -9,056 | 0 | -130 | -112 | -2,766 |
| 39 | 8 | 0 | 4,657 | 0 | 2,034 | -1,056 | -9,375 | 0 | -128 | -104 | -3,965 |
| 40 | 9 | 0 | 5,576 | 0 | 2,037 | -1,036 | -9,327 | 0 | -124 | -99 | -2,963 |
| 41 | 10 | 0 | 6,900 | 0 | 2,045 | -1,020 | -9,302 | 0 | -123 | -99 | -1,590 |
| 42 | 10 | 0 | 4,601 | 0 | 2,031 | -1,006 | -9,440 | 0 | -123 | -94 | -4,020 |
| 43 | 11 | 0 | 4,737 | 0 | 2,024 | -982 | -9,224 | 0 | -120 | -86 | -3,640 |
| 44 | 13 | 0 | 9,876 | 0 | 2,053 | -964 | -9,166 | 0 | -119 | -86 | 1,607 |
| 45 | 14 | 0 | 8,968 | 0 | 2,069 | -968 | -9,567 | 0 | -124 | -93 | 299 |
| 46 | 15 | 0 | 9,812 | 0 | 2,098 | -975 | -8,953 | 0 | -127 | -97 | 1,773 |
| 47 | 16 | 0 | 9,710 | 0 | 2,121 | -986 | -9,116 | 0 | -131 | -99 | 1,514 |
| **Average (afy)** | **7** | **0** | **7,770** | **0** | **1,978** | **-1,096** | **-9,196** | **0** | **-131** | **-93** | **-761** |
| **Maximum (afy)** | **16** | **0** | **12,815** | **0** | **2,121** | **-964** | **-8,786** | **0** | **-119** | **-68** | **4,574** |
| **Minimum (afy)** | **3** | **0** | **4,601** | **0** | **1,777** | **-1,289** | **-9,587** | **0** | **-147** | **-128** | **-4,020** |

Key:

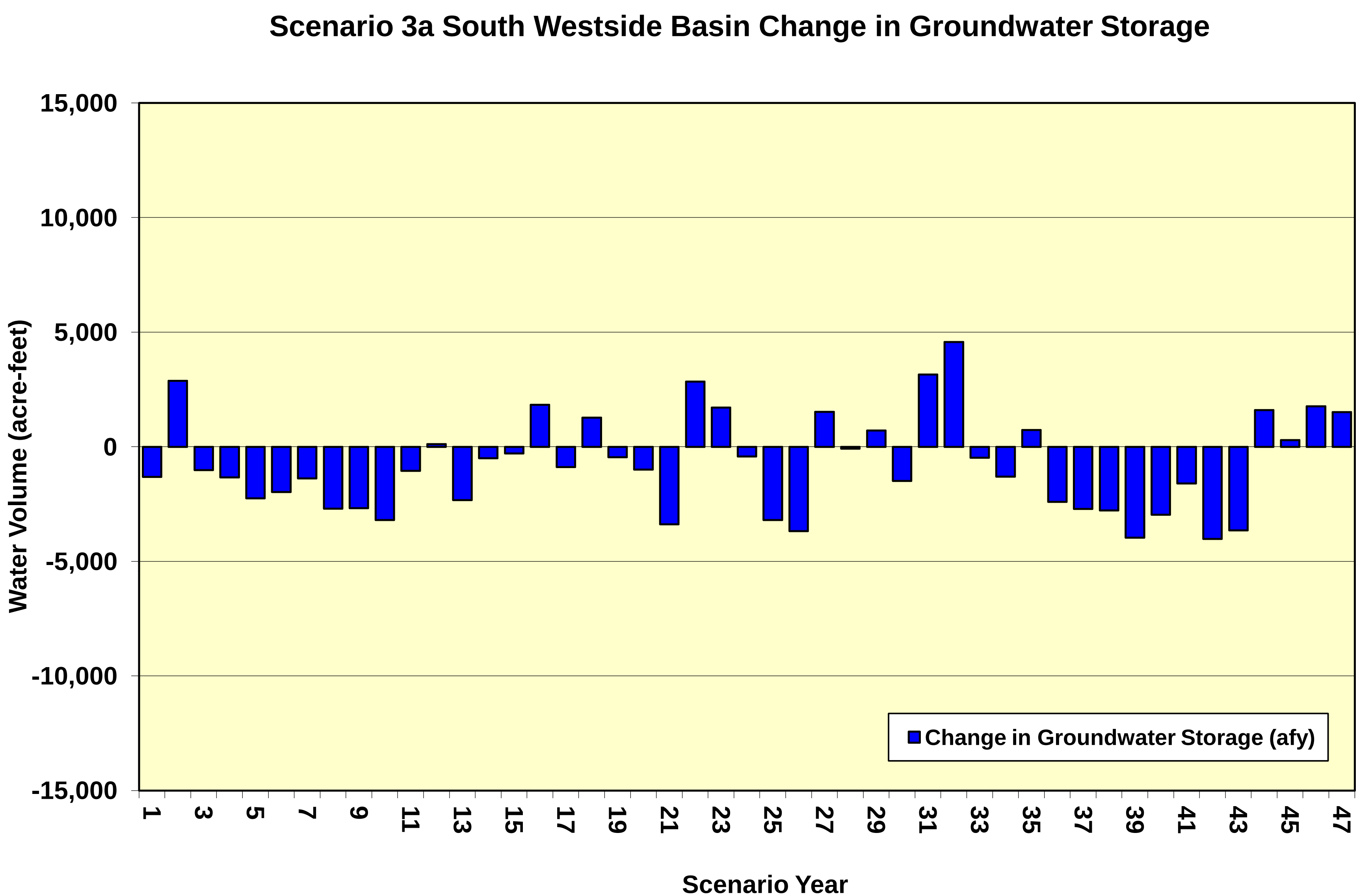
afy - acre-feet per year

GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.



Scenario 3a South Westside Basin Water Balance
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from Golden Gate Park Lakes (afy)
Seepage from Lake Merced (afy)
Inflow from Bay & Ocean (afy)
Outflow to Bay & Ocean (afy)
Wells - Pumping (afy)
Seepage to Lake Merced (afy)
From North Westside Basin (afy)
To North Westside Basin (afy)
Drains (afy)

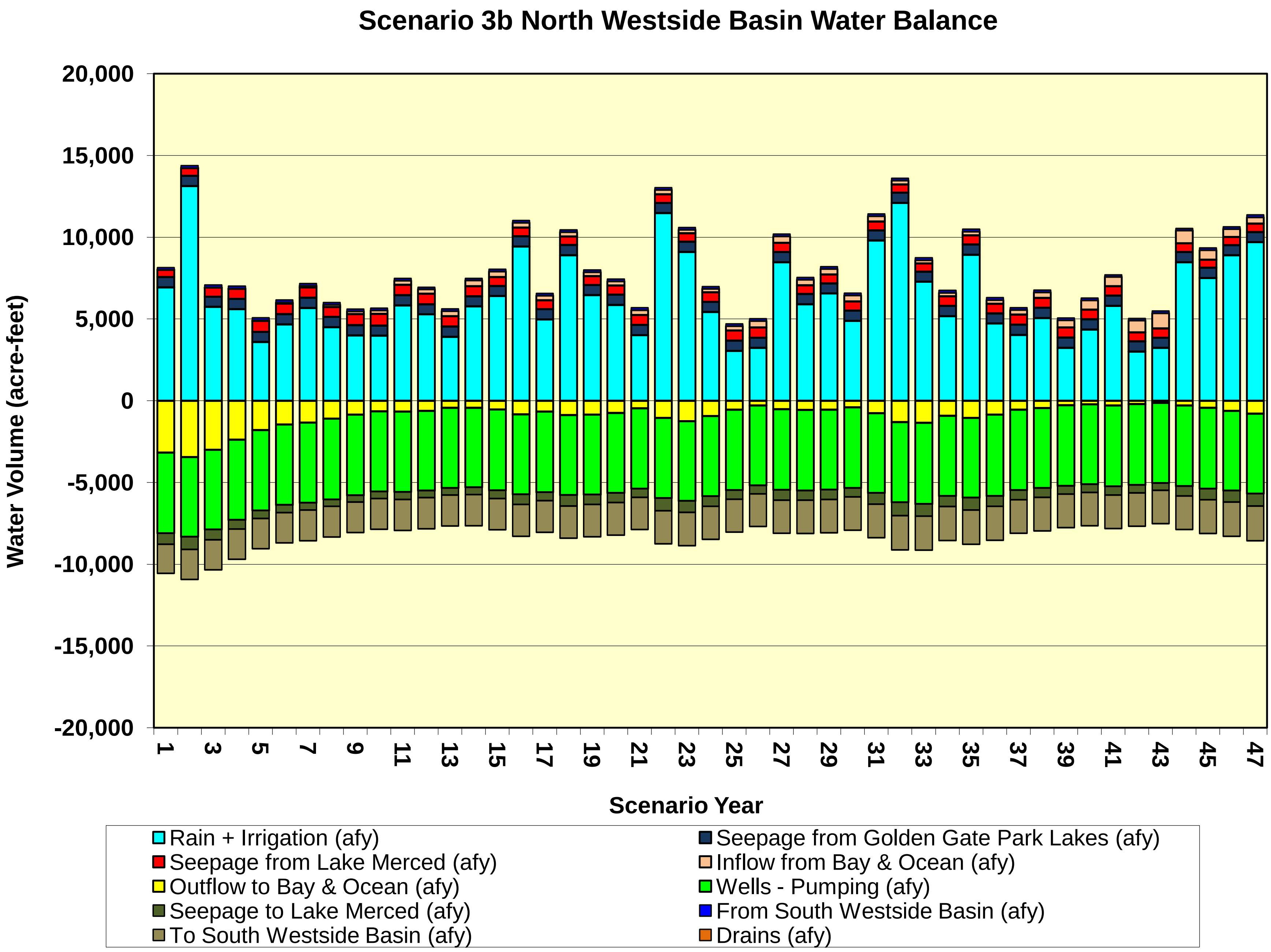

Scenario 3a South Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

## Scenario 3b North Westside Basin Water Balance Summary

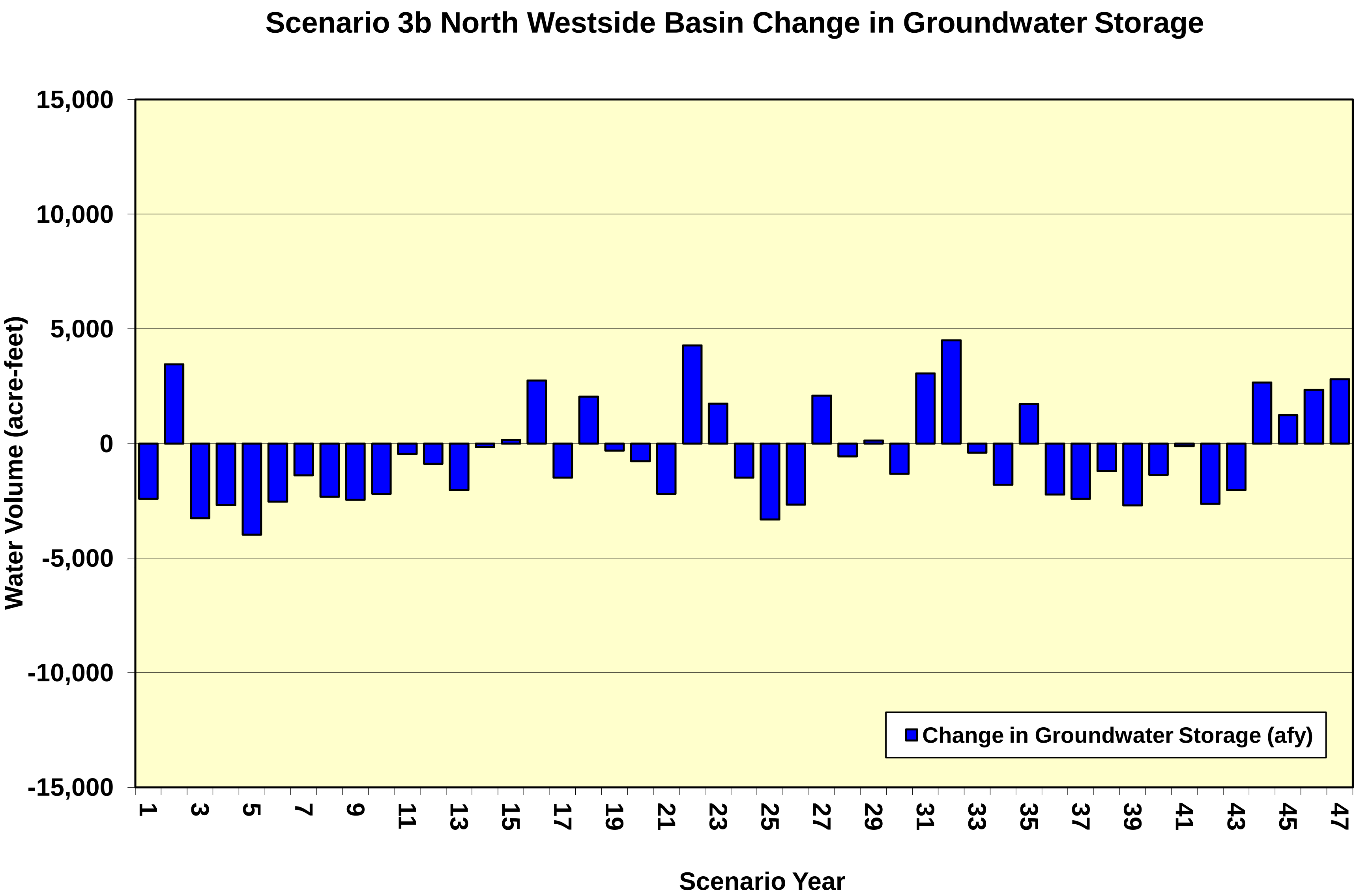
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From South to North Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From North to South Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 626 | 6,941 | 444 | 134 | -3,164 | -4,939 | -672 | -1,777 | 0 | -2,404 |
| 2 | 3 | 628 | 13,135 | 476 | 139 | -3,443 | -4,869 | -777 | -1,837 | 0 | 3,454 |
| 3 | 7 | 626 | 5,749 | 556 | 147 | -2,990 | -4,887 | -618 | -1,841 | 0 | -3,252 |
| 4 | 20 | 626 | 5,610 | 614 | 143 | -2,377 | -4,905 | -565 | -1,848 | 0 | -2,683 |
| 5 | 42 | 626 | 3,598 | 672 | 140 | -1,788 | -4,918 | -492 | -1,853 | 0 | -3,973 |
| 6 | 74 | 628 | 4,673 | 651 | 135 | -1,444 | -4,924 | -466 | -1,860 | 0 | -2,533 |
| 7 | 101 | 626 | 5,687 | 626 | 133 | -1,337 | -4,903 | -444 | -1,874 | 0 | -1,385 |
| 8 | 134 | 626 | 4,503 | 615 | 133 | -1,093 | -4,936 | -423 | -1,877 | 0 | -2,318 |
| 9 | 177 | 626 | 4,009 | 671 | 130 | -845 | -4,927 | -415 | -1,875 | 0 | -2,448 |
| 10 | 223 | 628 | 3,982 | 707 | 128 | -649 | -4,902 | -422 | -1,878 | 0 | -2,184 |
| 11 | 256 | 626 | 5,843 | 637 | 126 | -653 | -4,921 | -468 | -1,893 | 0 | -447 |
| 12 | 267 | 626 | 5,286 | 641 | 126 | -611 | -4,881 | -435 | -1,898 | 0 | -878 |
| 13 | 318 | 626 | 3,915 | 640 | 126 | -428 | -4,909 | -419 | -1,892 | 0 | -2,025 |
| 14 | 357 | 628 | 5,773 | 607 | 124 | -424 | -4,867 | -447 | -1,907 | 0 | -155 |
| 15 | 342 | 626 | 6,407 | 545 | 125 | -523 | -4,946 | -507 | -1,912 | 0 | 156 |
| 16 | 305 | 626 | 9,441 | 528 | 127 | -827 | -4,900 | -613 | -1,942 | 0 | 2,745 |
| 17 | 278 | 626 | 4,984 | 547 | 131 | -662 | -4,924 | -526 | -1,936 | 0 | -1,484 |
| 18 | 275 | 628 | 8,904 | 519 | 129 | -867 | -4,898 | -670 | -1,970 | 0 | 2,050 |
| 19 | 251 | 626 | 6,466 | 533 | 132 | -844 | -4,890 | -603 | -1,981 | 0 | -310 |
| 20 | 258 | 626 | 5,871 | 557 | 132 | -749 | -4,889 | -587 | -1,985 | 0 | -765 |
| 21 | 315 | 626 | 4,017 | 600 | 130 | -457 | -4,918 | -527 | -1,972 | 0 | -2,187 |
| 22 | 276 | 628 | 11,482 | 521 | 128 | -1,044 | -4,898 | -778 | -2,030 | 0 | 4,283 |
| 23 | 211 | 626 | 9,106 | 524 | 135 | -1,240 | -4,876 | -706 | -2,041 | 0 | 1,739 |
| 24 | 216 | 626 | 5,433 | 577 | 137 | -937 | -4,897 | -613 | -2,023 | 0 | -1,481 |
| 25 | 276 | 626 | 3,062 | 613 | 133 | -540 | -4,924 | -555 | -2,005 | 0 | -3,315 |
| 26 | 405 | 628 | 3,238 | 626 | 128 | -280 | -4,895 | -511 | -1,995 | 0 | -2,657 |
| 27 | 400 | 626 | 8,480 | 563 | 125 | -520 | -4,921 | -636 | -2,025 | 0 | 2,092 |
| 28 | 338 | 626 | 5,916 | 535 | 129 | -559 | -4,931 | -589 | -2,029 | 0 | -563 |
| 29 | 343 | 626 | 6,566 | 543 | 130 | -540 | -4,900 | -595 | -2,037 | 0 | 138 |
| 30 | 381 | 628 | 4,895 | 554 | 130 | -404 | -4,925 | -555 | -2,023 | 0 | -1,319 |
| 31 | 340 | 626 | 9,806 | 534 | 129 | -758 | -4,868 | -699 | -2,052 | 0 | 3,057 |
| 32 | 242 | 626 | 12,107 | 506 | 134 | -1,308 | -4,896 | -827 | -2,082 | 0 | 4,503 |
| 33 | 192 | 626 | 7,280 | 502 | 141 | -1,350 | -4,957 | -743 | -2,086 | 0 | -395 |
| 34 | 218 | 628 | 5,178 | 588 | 140 | -923 | -4,902 | -645 | -2,069 | 0 | -1,788 |
| 35 | 230 | 626 | 8,941 | 562 | 137 | -1,041 | -4,882 | -760 | -2,090 | 0 | 1,722 |
| 36 | 235 | 626 | 4,727 | 580 | 137 | -848 | -4,971 | -637 | -2,071 | 0 | -2,221 |
| 37 | 288 | 626 | 4,032 | 613 | 134 | -542 | -4,925 | -581 | -2,057 | 0 | -2,412 |
| 38 | 342 | 628 | 5,061 | 608 | 130 | -440 | -4,899 | -567 | -2,055 | 0 | -1,193 |
| 39 | 445 | 626 | 3,248 | 611 | 128 | -277 | -4,932 | -502 | -2,038 | 0 | -2,692 |
| 40 | 568 | 626 | 4,359 | 600 | 124 | -216 | -4,885 | -500 | -2,041 | 0 | -1,365 |
| 41 | 575 | 626 | 5,814 | 570 | 123 | -278 | -4,949 | -538 | -2,049 | 0 | -105 |
| 42 | 723 | 628 | 3,017 | 551 | 123 | -196 | -4,943 | -492 | -2,035 | 0 | -2,625 |
| 43 | 933 | 626 | 3,238 | 573 | 120 | -129 | -4,895 | -457 | -2,028 | 0 | -2,019 |
| 44 | 783 | 626 | 8,481 | 532 | 119 | -288 | -4,926 | -605 | -2,057 | 0 | 2,666 |
| 45 | 598 | 626 | 7,522 | 482 | 124 | -423 | -4,958 | -663 | -2,073 | 0 | 1,234 |
| 46 | 490 | 626 | 8,902 | 492 | 127 | -616 | -4,871 | -704 | -2,102 | 0 | 2,345 |
| 47 | 399 | 618 | 9,712 | 507 | 131 | -786 | -4,896 | -759 | -2,125 | 0 | 2,801 |
| **Average (afy)** | **307** | **626** | **6,264** | **571** | **131** | **-908** | **-4,910** | **-581** | **-1,981** | **0** | **-481** |
| **Maximum (afy)** | **933** | **628** | **13,135** | **707** | **147** | **-129** | **-4,867** | **-415** | **-1,777** | **0** | **4,503** |
| **Minimum (afy)** | **2** | **618** | **3,017** | **444** | **119** | **-3,443** | **-4,971** | **-827** | **-2,125** | **0** | **-3,973** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.



Scenario 3b North Westside Basin Water Balance
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from Golden Gate Park Lakes (afy)
Seepage from Lake Merced (afy)
Inflow from Bay & Ocean (afy)
Outflow to Bay & Ocean (afy)
Wells - Pumping (afy)
Seepage to Lake Merced (afy)
From South Westside Basin (afy)
To South Westside Basin (afy)
Drains (afy)



Scenario 3b North Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

## Scenario 3b South Westside Basin Water Balance Summary

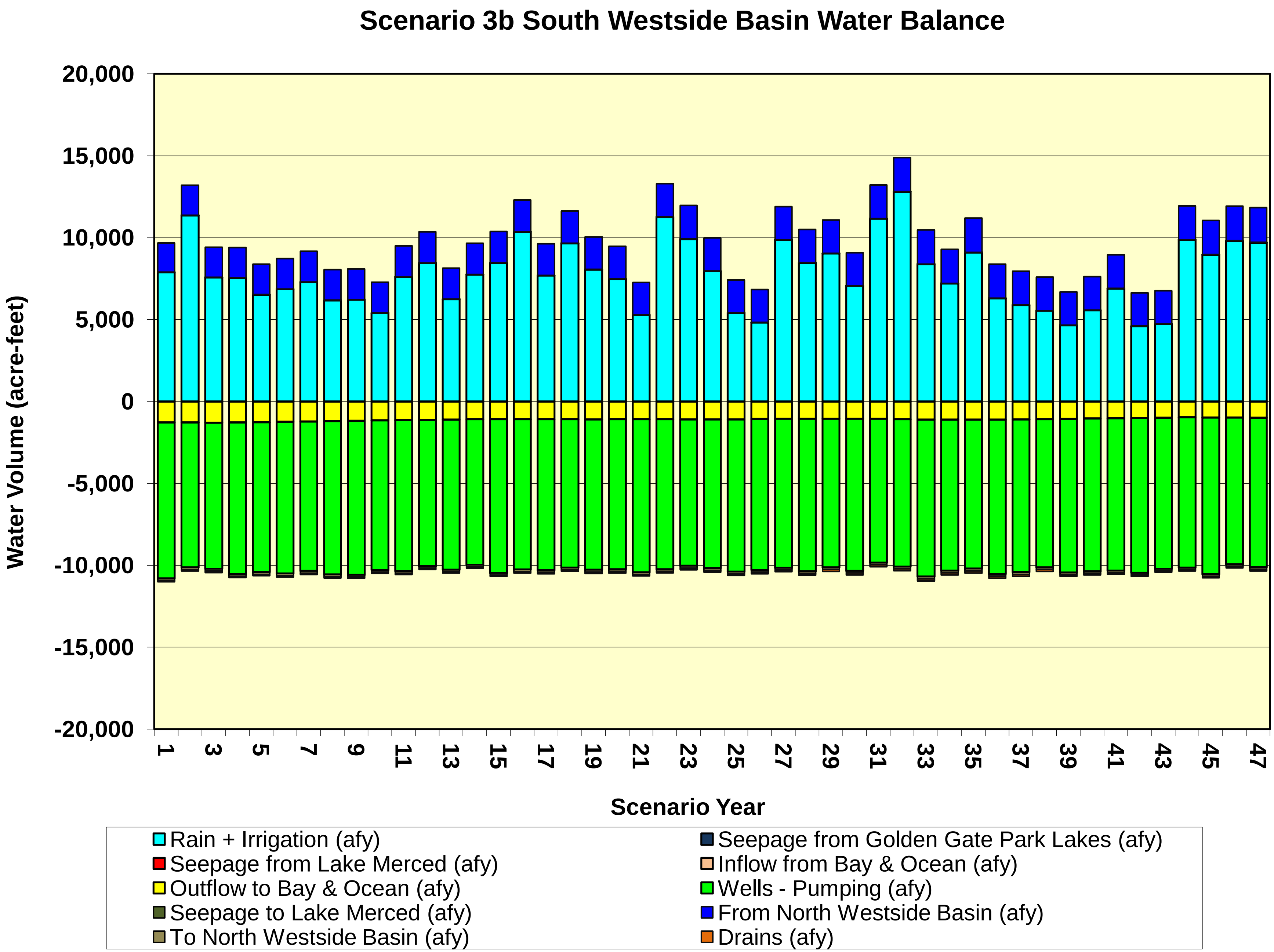
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From North to South Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From South to North Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0 | 7,904 | 0 | 1,777 | -1,276 | -9,513 | 0 | -134 | -71 | -1,310 |
| 2 | 3 | 0 | 11,370 | 0 | 1,837 | -1,277 | -8,842 | 0 | -139 | -72 | 2,879 |
| 3 | 3 | 0 | 7,580 | 0 | 1,841 | -1,289 | -8,922 | 0 | -147 | -73 | -1,007 |
| 4 | 3 | 0 | 7,559 | 0 | 1,848 | -1,275 | -9,252 | 0 | -143 | -74 | -1,335 |
| 5 | 3 | 0 | 6,531 | 0 | 1,853 | -1,255 | -9,157 | 0 | -140 | -74 | -2,238 |
| 6 | 3 | 0 | 6,873 | 0 | 1,860 | -1,230 | -9,268 | 0 | -135 | -73 | -1,969 |
| 7 | 3 | 0 | 7,302 | 0 | 1,874 | -1,211 | -9,131 | 0 | -133 | -72 | -1,369 |
| 8 | 3 | 0 | 6,188 | 0 | 1,877 | -1,195 | -9,362 | 0 | -133 | -71 | -2,693 |
| 9 | 3 | 0 | 6,225 | 0 | 1,875 | -1,172 | -9,405 | 0 | -130 | -70 | -2,675 |
| 10 | 3 | 0 | 5,405 | 0 | 1,878 | -1,148 | -9,130 | 0 | -128 | -68 | -3,188 |
| 11 | 3 | 0 | 7,611 | 0 | 1,893 | -1,126 | -9,228 | 0 | -126 | -68 | -1,042 |
| 12 | 3 | 0 | 8,465 | 0 | 1,898 | -1,112 | -8,934 | 0 | -126 | -74 | 120 |
| 13 | 3 | 0 | 6,247 | 0 | 1,892 | -1,096 | -9,164 | 0 | -126 | -76 | -2,318 |
| 14 | 4 | 0 | 7,760 | 0 | 1,907 | -1,078 | -8,884 | 0 | -124 | -75 | -491 |
| 15 | 4 | 0 | 8,469 | 0 | 1,912 | -1,070 | -9,394 | 0 | -125 | -81 | -284 |
| 16 | 4 | 0 | 10,364 | 0 | 1,942 | -1,070 | -9,188 | 0 | -127 | -84 | 1,842 |
| 17 | 4 | 0 | 7,695 | 0 | 1,936 | -1,076 | -9,220 | 0 | -131 | -88 | -878 |
| 18 | 5 | 0 | 9,663 | 0 | 1,970 | -1,074 | -9,059 | 0 | -129 | -92 | 1,284 |
| 19 | 5 | 0 | 8,066 | 0 | 1,981 | -1,081 | -9,188 | 0 | -132 | -96 | -446 |
| 20 | 5 | 0 | 7,492 | 0 | 1,985 | -1,080 | -9,159 | 0 | -132 | -100 | -989 |
| 21 | 5 | 0 | 5,293 | 0 | 1,972 | -1,069 | -9,348 | 0 | -130 | -92 | -3,368 |
| 22 | 6 | 0 | 11,269 | 0 | 2,030 | -1,067 | -9,165 | 0 | -128 | -94 | 2,851 |
| 23 | 6 | 0 | 9,930 | 0 | 2,041 | -1,087 | -8,937 | 0 | -135 | -101 | 1,717 |
| 24 | 6 | 0 | 7,964 | 0 | 2,023 | -1,093 | -9,075 | 0 | -137 | -105 | -418 |
| 25 | 6 | 0 | 5,416 | 0 | 2,005 | -1,082 | -9,294 | 0 | -133 | -106 | -3,187 |
| 26 | 7 | 0 | 4,834 | 0 | 1,995 | -1,061 | -9,224 | 0 | -128 | -96 | -3,673 |
| 27 | 7 | 0 | 9,875 | 0 | 2,025 | -1,046 | -9,111 | 0 | -125 | -96 | 1,528 |
| 28 | 8 | 0 | 8,482 | 0 | 2,029 | -1,050 | -9,310 | 0 | -129 | -104 | -75 |
| 29 | 8 | 0 | 9,043 | 0 | 2,037 | -1,047 | -9,078 | 0 | -130 | -108 | 723 |
| 30 | 8 | 0 | 7,065 | 0 | 2,023 | -1,043 | -9,290 | 0 | -130 | -112 | -1,478 |
| 31 | 8 | 0 | 11,168 | 0 | 2,052 | -1,042 | -8,786 | 0 | -129 | -115 | 3,157 |
| 32 | 8 | 0 | 12,815 | 0 | 2,082 | -1,067 | -9,008 | 0 | -134 | -117 | 4,578 |
| 33 | 8 | 0 | 8,388 | 0 | 2,086 | -1,099 | -9,587 | 0 | -141 | -121 | -465 |
| 34 | 8 | 0 | 7,212 | 0 | 2,069 | -1,101 | -9,218 | 0 | -140 | -124 | -1,293 |
| 35 | 8 | 0 | 9,104 | 0 | 2,090 | -1,097 | -9,102 | 0 | -137 | -127 | 740 |
| 36 | 8 | 0 | 6,306 | 0 | 2,071 | -1,101 | -9,417 | 0 | -137 | -128 | -2,398 |
| 37 | 8 | 0 | 5,900 | 0 | 2,057 | -1,089 | -9,324 | 0 | -134 | -120 | -2,701 |
| 38 | 8 | 0 | 5,544 | 0 | 2,055 | -1,072 | -9,056 | 0 | -130 | -112 | -2,762 |
| 39 | 8 | 0 | 4,657 | 0 | 2,038 | -1,057 | -9,375 | 0 | -128 | -104 | -3,961 |
| 40 | 9 | 0 | 5,576 | 0 | 2,041 | -1,036 | -9,327 | 0 | -124 | -99 | -2,959 |
| 41 | 10 | 0 | 6,900 | 0 | 2,049 | -1,020 | -9,302 | 0 | -123 | -99 | -1,586 |
| 42 | 10 | 0 | 4,601 | 0 | 2,035 | -1,006 | -9,440 | 0 | -123 | -94 | -4,016 |
| 43 | 11 | 0 | 4,737 | 0 | 2,028 | -982 | -9,224 | 0 | -120 | -86 | -3,636 |
| 44 | 13 | 0 | 9,876 | 0 | 2,057 | -965 | -9,166 | 0 | -119 | -86 | 1,610 |
| 45 | 14 | 0 | 8,968 | 0 | 2,073 | -969 | -9,567 | 0 | -124 | -93 | 303 |
| 46 | 15 | 0 | 9,812 | 0 | 2,102 | -976 | -8,953 | 0 | -127 | -97 | 1,776 |
| 47 | 16 | 0 | 9,710 | 0 | 2,125 | -987 | -9,116 | 0 | -131 | -99 | 1,518 |
| **Average (afy)** | **7** | **0** | **7,770** | **0** | **1,981** | **-1,096** | **-9,196** | **0** | **-131** | **-93** | **-757** |
| **Maximum (afy)** | **16** | **0** | **12,815** | **0** | **2,125** | **-965** | **-8,786** | **0** | **-119** | **-68** | **4,578** |
| **Minimum (afy)** | **3** | **0** | **4,601** | **0** | **1,777** | **-1,289** | **-9,587** | **0** | **-147** | **-128** | **-4,016** |

Key:

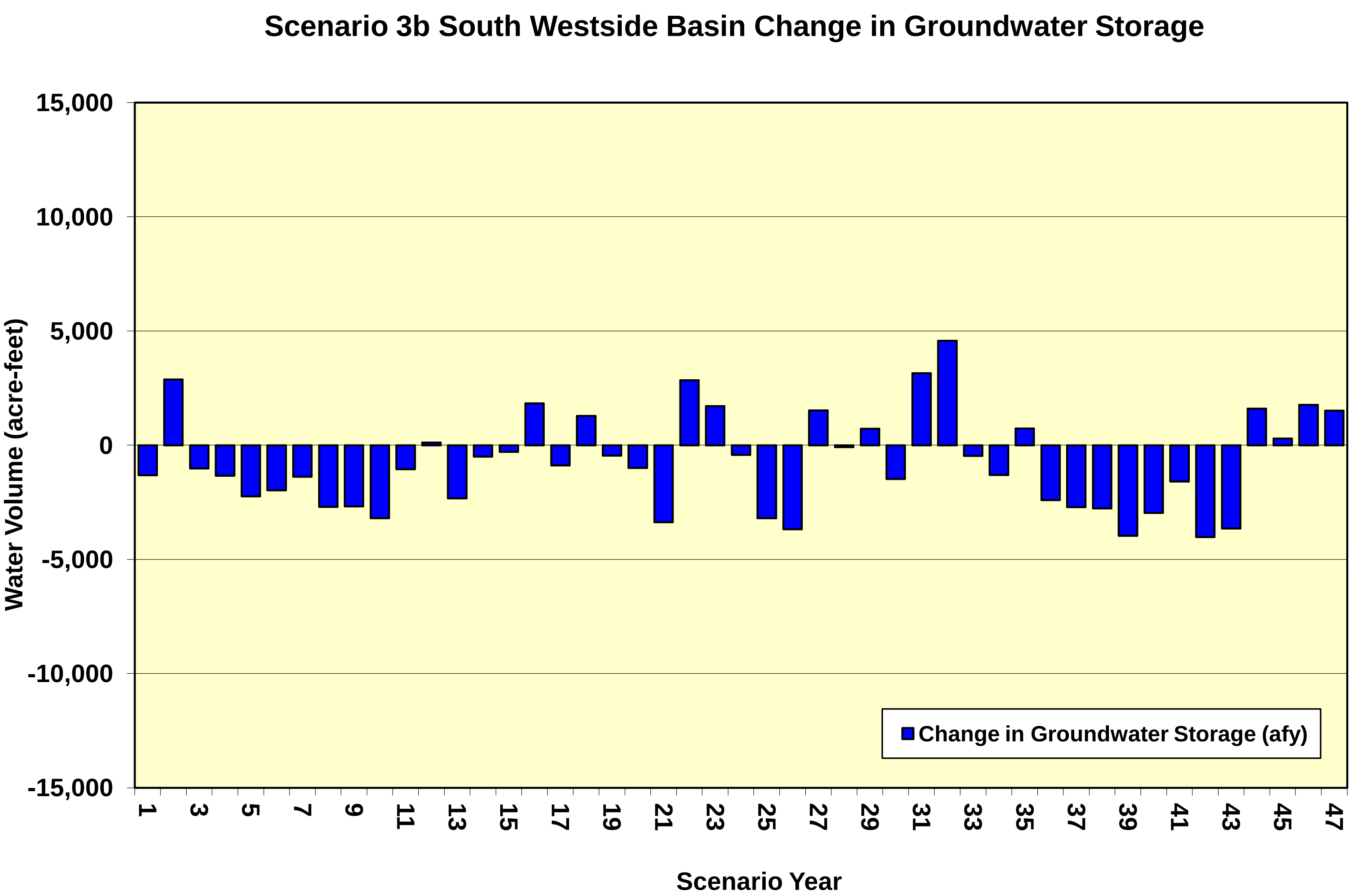
afy - acre-feet per year

GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.



Scenario 3b South Westside Basin Water Balance
Water Volume (acre-feet)
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from Lake Merced (afy)
Outflow to Bay & Ocean (afy)
Seepage to Lake Merced (afy)
To North Westside Basin (afy)
Seepage from Golden Gate Park Lakes (afy)
Inflow from Bay & Ocean (afy)
Wells - Pumping (afy)
From North Westside Basin (afy)
Drains (afy)



Scenario 3b South Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

## Scenario 4 North Westside Basin Water Balance Summary

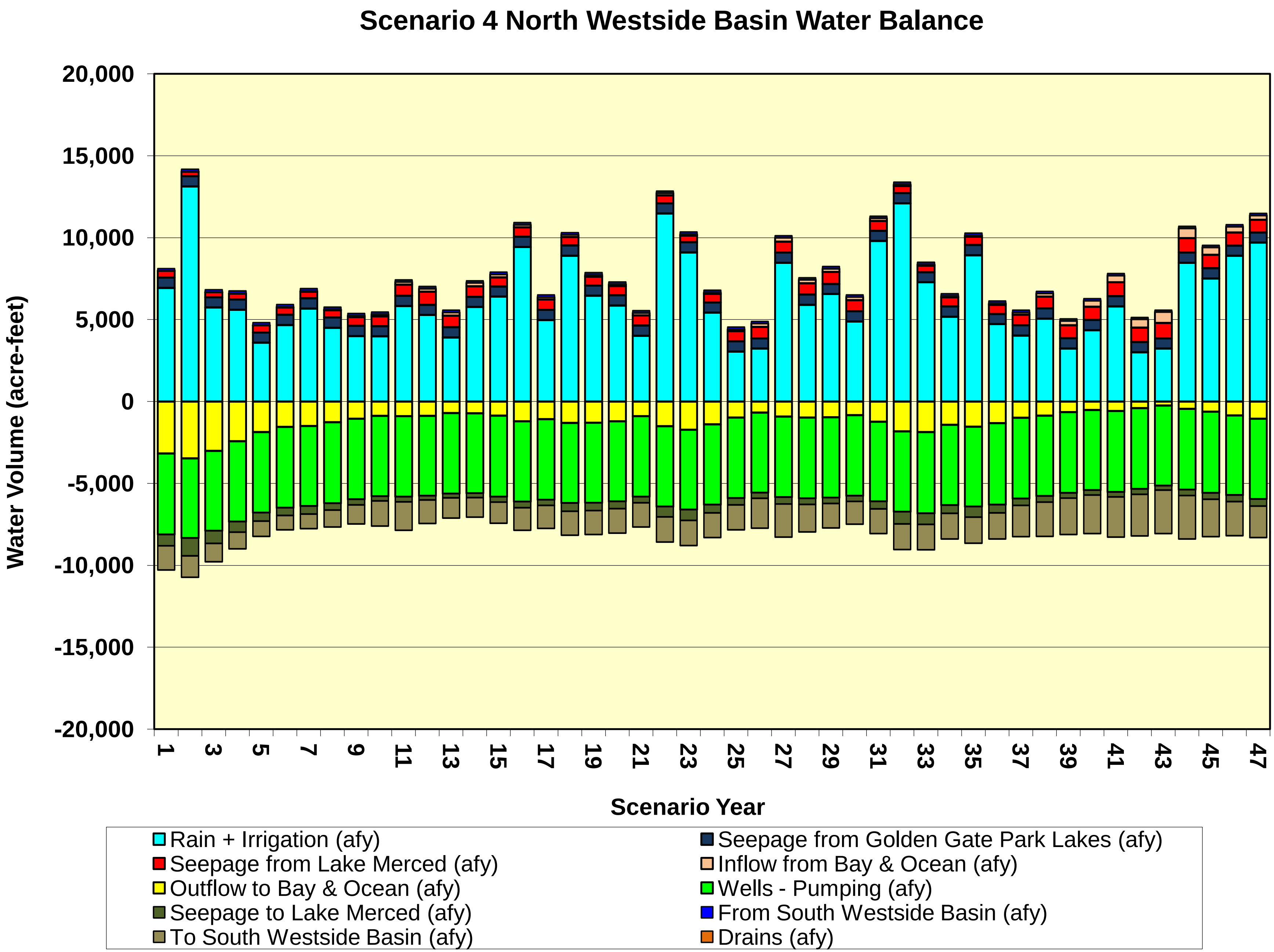
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From South to North Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From North to South Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 626 | 6,941 | 416 | 134 | -3,172 | -4,939 | -694 | -1,480 | 0 | -2,165 |
| 2 | 2 | 628 | 13,135 | 282 | 139 | -3,462 | -4,869 | -1,089 | -1,306 | 0 | 3,460 |
| 3 | 2 | 626 | 5,749 | 305 | 147 | -3,004 | -4,887 | -762 | -1,130 | 0 | -2,954 |
| 4 | 6 | 626 | 5,610 | 365 | 146 | -2,415 | -4,905 | -645 | -1,022 | 0 | -2,235 |
| 5 | 15 | 626 | 3,598 | 439 | 146 | -1,858 | -4,918 | -519 | -939 | 0 | -3,409 |
| 6 | 29 | 628 | 4,673 | 450 | 147 | -1,551 | -4,924 | -473 | -880 | 0 | -1,901 |
| 7 | 39 | 626 | 5,687 | 404 | 138 | -1,483 | -4,903 | -475 | -895 | 0 | -862 |
| 8 | 56 | 626 | 4,503 | 449 | 134 | -1,266 | -4,936 | -417 | -1,041 | 0 | -1,892 |
| 9 | 84 | 626 | 4,009 | 526 | 131 | -1,042 | -4,927 | -343 | -1,152 | 0 | -2,089 |
| 10 | 122 | 628 | 3,982 | 604 | 128 | -868 | -4,902 | -298 | -1,527 | 0 | -2,133 |
| 11 | 169 | 626 | 5,843 | 670 | 125 | -891 | -4,921 | -305 | -1,744 | 0 | -427 |
| 12 | 189 | 626 | 5,286 | 800 | 123 | -873 | -4,881 | -252 | -1,441 | 0 | -423 |
| 13 | 204 | 626 | 3,915 | 712 | 122 | -705 | -4,909 | -256 | -1,242 | 0 | -1,534 |
| 14 | 211 | 628 | 5,773 | 641 | 120 | -722 | -4,867 | -281 | -1,187 | 0 | 316 |
| 15 | 188 | 626 | 6,407 | 559 | 121 | -857 | -4,946 | -328 | -1,293 | 0 | 477 |
| 16 | 162 | 626 | 9,441 | 576 | 123 | -1,204 | -4,900 | -382 | -1,376 | 0 | 3,065 |
| 17 | 138 | 626 | 4,984 | 630 | 127 | -1,073 | -4,924 | -337 | -1,408 | 0 | -1,236 |
| 18 | 135 | 628 | 8,904 | 524 | 125 | -1,302 | -4,898 | -502 | -1,457 | 0 | 2,157 |
| 19 | 115 | 626 | 6,466 | 534 | 127 | -1,292 | -4,890 | -465 | -1,474 | 0 | -253 |
| 20 | 117 | 626 | 5,871 | 559 | 126 | -1,197 | -4,889 | -453 | -1,484 | 0 | -723 |
| 21 | 151 | 626 | 4,017 | 627 | 123 | -885 | -4,918 | -371 | -1,479 | 0 | -2,108 |
| 22 | 132 | 628 | 11,482 | 487 | 121 | -1,503 | -4,898 | -640 | -1,537 | 0 | 4,271 |
| 23 | 89 | 626 | 9,106 | 406 | 128 | -1,712 | -4,876 | -668 | -1,527 | 0 | 1,572 |
| 24 | 89 | 626 | 5,433 | 524 | 130 | -1,391 | -4,897 | -503 | -1,507 | 0 | -1,496 |
| 25 | 124 | 626 | 3,062 | 610 | 126 | -967 | -4,924 | -411 | -1,526 | 0 | -3,281 |
| 26 | 214 | 628 | 3,238 | 694 | 120 | -665 | -4,895 | -339 | -1,830 | 0 | -2,836 |
| 27 | 242 | 626 | 8,480 | 660 | 117 | -916 | -4,921 | -413 | -2,020 | 0 | 1,855 |
| 28 | 213 | 626 | 5,916 | 688 | 120 | -972 | -4,931 | -377 | -1,678 | 0 | -395 |
| 29 | 197 | 626 | 6,566 | 732 | 121 | -963 | -4,900 | -360 | -1,487 | 0 | 532 |
| 30 | 193 | 628 | 4,895 | 677 | 121 | -826 | -4,925 | -347 | -1,392 | 0 | -976 |
| 31 | 164 | 626 | 9,806 | 600 | 121 | -1,225 | -4,868 | -451 | -1,511 | 0 | 3,262 |
| 32 | 106 | 626 | 12,107 | 429 | 127 | -1,825 | -4,896 | -749 | -1,558 | 0 | 4,367 |
| 33 | 76 | 626 | 7,280 | 393 | 134 | -1,866 | -4,957 | -672 | -1,554 | 0 | -540 |
| 34 | 87 | 628 | 5,178 | 557 | 132 | -1,415 | -4,902 | -510 | -1,556 | 0 | -1,802 |
| 35 | 95 | 626 | 8,941 | 496 | 128 | -1,529 | -4,882 | -648 | -1,587 | 0 | 1,640 |
| 36 | 97 | 626 | 4,727 | 553 | 129 | -1,323 | -4,971 | -498 | -1,599 | 0 | -2,258 |
| 37 | 135 | 626 | 4,032 | 656 | 125 | -993 | -4,925 | -418 | -1,901 | 0 | -2,663 |
| 38 | 195 | 628 | 5,061 | 723 | 120 | -866 | -4,899 | -372 | -2,095 | 0 | -1,505 |
| 39 | 276 | 626 | 3,248 | 783 | 117 | -642 | -4,932 | -315 | -2,221 | 0 | -3,059 |
| 40 | 383 | 626 | 4,359 | 803 | 113 | -522 | -4,885 | -305 | -2,343 | 0 | -1,770 |
| 41 | 409 | 626 | 5,814 | 850 | 111 | -566 | -4,949 | -304 | -2,456 | 0 | -464 |
| 42 | 508 | 628 | 3,017 | 878 | 110 | -396 | -4,943 | -317 | -2,541 | 0 | -3,056 |
| 43 | 675 | 626 | 3,238 | 938 | 106 | -242 | -4,895 | -264 | -2,655 | 0 | -2,474 |
| 44 | 611 | 626 | 8,481 | 872 | 104 | -450 | -4,926 | -359 | -2,656 | 0 | 2,304 |
| 45 | 463 | 626 | 7,522 | 818 | 108 | -612 | -4,958 | -387 | -2,290 | 0 | 1,291 |
| 46 | 364 | 626 | 8,902 | 793 | 111 | -839 | -4,871 | -397 | -2,077 | 0 | 2,613 |
| 47 | 279 | 618 | 9,712 | 767 | 116 | -1,051 | -4,896 | -439 | -1,920 | 0 | 3,185 |
| **Average (afy)** | **182** | **626** | **6,264** | **606** | **125** | **-1,221** | **-4,910** | **-449** | **-1,617** | **0** | **-395** |
| **Maximum (afy)** | **675** | **628** | **13,135** | **938** | **147** | **-242** | **-4,867** | **-252** | **-880** | **0** | **4,367** |
| **Minimum (afy)** | **2** | **618** | **3,017** | **282** | **104** | **-3,462** | **-4,971** | **-1,089** | **-2,656** | **0** | **-3,409** |

Key:

afy - acre-feet per year

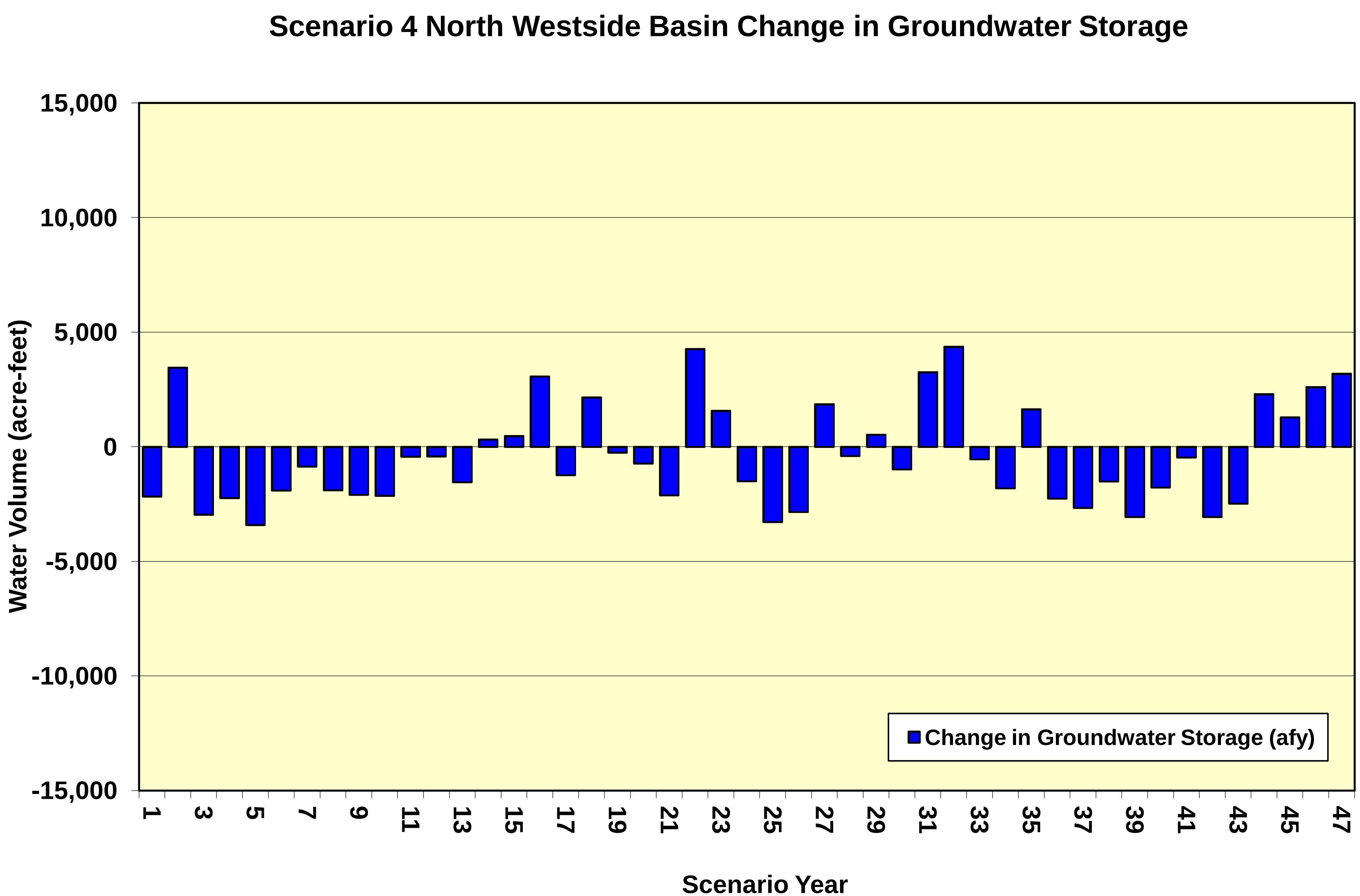
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.



Scenario 4 North Westside Basin Water Balance
Water Volume (acre-feet)
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Rain + Irrigation (afy)
Seepage from Golden Gate Park Lakes (afy)
Seepage from Lake Merced (afy)
Inflow from Bay & Ocean (afy)
Outflow to Bay & Ocean (afy)
Wells - Pumping (afy)
Seepage to Lake Merced (afy)
From South Westside Basin (afy)
To South Westside Basin (afy)
Drains (afy)

D.5-226



Scenario 4 North Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

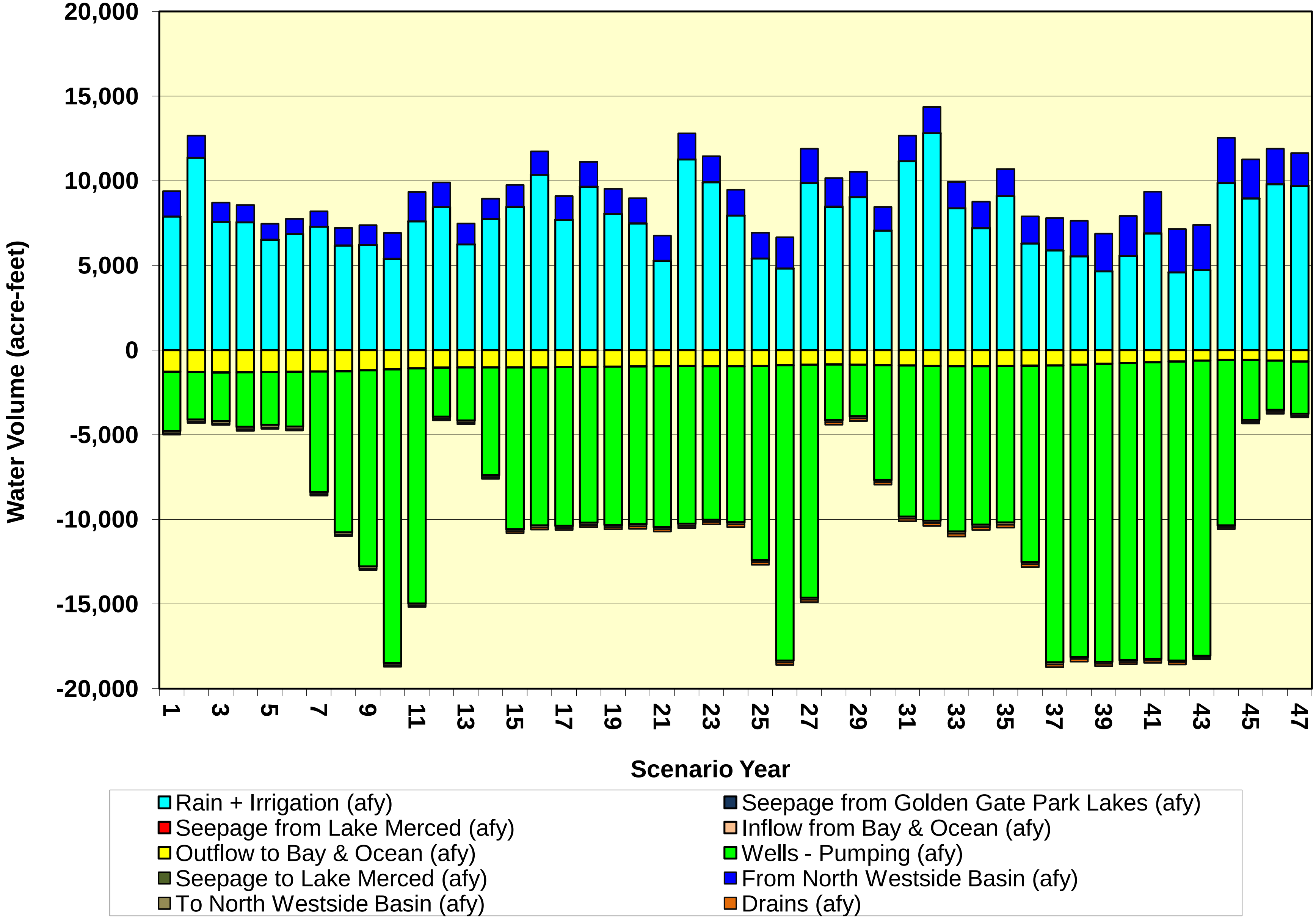
## Scenario 4 South Westside Basin Water Balance Summary

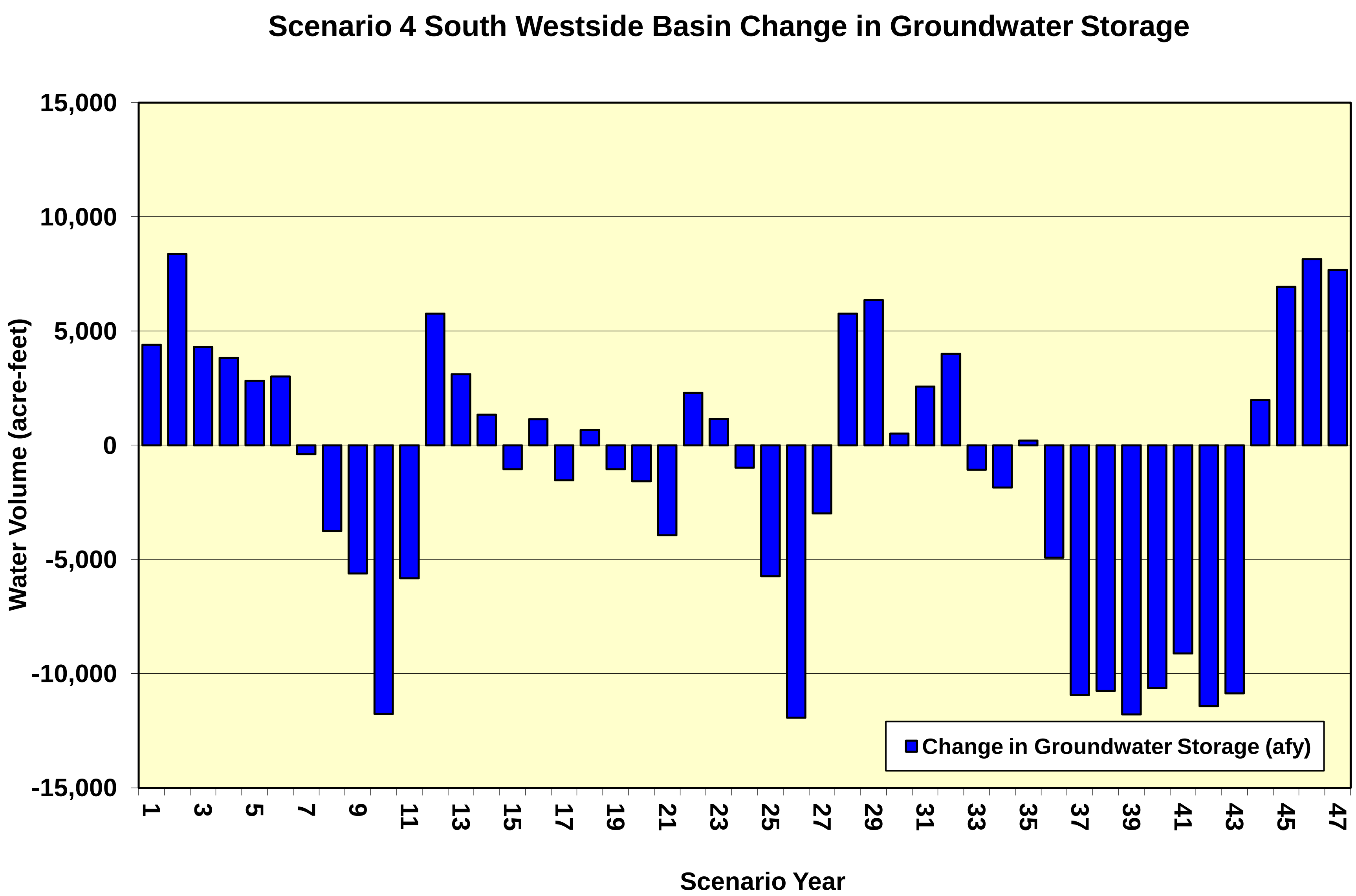
| Scenario Year | Inflow from Bay & Ocean (afy) | Seepage from GGP Lakes (afy) | Rain + Irrigation (afy) | Seepage from Lake Merced (afy) | From North to South Westside Basin (afy) | Outflow to Bay & Ocean (afy) | Wells - Pumping (afy) | Seepage to Lake Merced (afy) | From South to North Westside Basin (afy) | Drains (afy) | Change in Groundwater Storage (afy) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0 | 7,904 | 0 | 1,480 | -1,281 | -3,496 | 0 | -134 | -71 | 4,405 |
| 2 | 3 | 0 | 11,370 | 0 | 1,306 | -1,291 | -2,802 | 0 | -139 | -72 | 8,374 |
| 3 | 3 | 0 | 7,580 | 0 | 1,130 | -1,312 | -2,884 | 0 | -147 | -74 | 4,297 |
| 4 | 3 | 0 | 7,559 | 0 | 1,022 | -1,305 | -3,228 | 0 | -146 | -75 | 3,830 |
| 5 | 3 | 0 | 6,531 | 0 | 939 | -1,293 | -3,128 | 0 | -146 | -77 | 2,829 |
| 6 | 3 | 0 | 6,873 | 0 | 880 | -1,276 | -3,243 | 0 | -147 | -77 | 3,012 |
| 7 | 3 | 0 | 7,302 | 0 | 895 | -1,266 | -7,105 | 0 | -138 | -78 | -388 |
| 8 | 2 | 0 | 6,188 | 0 | 1,041 | -1,240 | -9,522 | 0 | -134 | -81 | -3,746 |
| 9 | 2 | 0 | 6,225 | 0 | 1,152 | -1,193 | -11,582 | 0 | -131 | -84 | -5,611 |
| 10 | 2 | 0 | 5,405 | 0 | 1,527 | -1,134 | -17,343 | 0 | -128 | -85 | -11,756 |
| 11 | 2 | 0 | 7,611 | 0 | 1,744 | -1,067 | -13,894 | 0 | -125 | -87 | -5,817 |
| 12 | 2 | 0 | 8,465 | 0 | 1,441 | -1,025 | -2,898 | 0 | -123 | -95 | 5,768 |
| 13 | 2 | 0 | 6,247 | 0 | 1,242 | -1,017 | -3,136 | 0 | -122 | -98 | 3,118 |
| 14 | 2 | 0 | 7,760 | 0 | 1,187 | -1,022 | -6,362 | 0 | -120 | -100 | 1,345 |
| 15 | 2 | 0 | 8,469 | 0 | 1,293 | -1,022 | -9,556 | 0 | -121 | -110 | -1,046 |
| 16 | 2 | 0 | 10,364 | 0 | 1,376 | -1,013 | -9,343 | 0 | -123 | -118 | 1,145 |
| 17 | 2 | 0 | 7,695 | 0 | 1,408 | -1,002 | -9,375 | 0 | -127 | -125 | -1,525 |
| 18 | 2 | 0 | 9,663 | 0 | 1,457 | -985 | -9,209 | 0 | -125 | -131 | 672 |
| 19 | 2 | 0 | 8,066 | 0 | 1,474 | -979 | -9,342 | 0 | -127 | -137 | -1,044 |
| 20 | 2 | 0 | 7,492 | 0 | 1,484 | -965 | -9,313 | 0 | -126 | -142 | -1,569 |
| 21 | 2 | 0 | 5,293 | 0 | 1,479 | -944 | -9,509 | 0 | -123 | -135 | -3,938 |
| 22 | 2 | 0 | 11,269 | 0 | 1,537 | -933 | -9,319 | 0 | -121 | -136 | 2,299 |
| 23 | 2 | 0 | 9,930 | 0 | 1,527 | -945 | -9,082 | 0 | -128 | -145 | 1,159 |
| 24 | 2 | 0 | 7,964 | 0 | 1,507 | -944 | -9,226 | 0 | -130 | -150 | -976 |
| 25 | 2 | 0 | 5,416 | 0 | 1,526 | -927 | -11,468 | 0 | -126 | -152 | -5,728 |
| 26 | 2 | 0 | 4,834 | 0 | 1,830 | -892 | -17,441 | 0 | -120 | -140 | -11,927 |
| 27 | 3 | 0 | 9,875 | 0 | 2,020 | -852 | -13,773 | 0 | -117 | -138 | -2,983 |
| 28 | 3 | 0 | 8,482 | 0 | 1,678 | -843 | -3,287 | 0 | -120 | -146 | 5,766 |
| 29 | 3 | 0 | 9,043 | 0 | 1,487 | -862 | -3,048 | 0 | -121 | -150 | 6,353 |
| 30 | 3 | 0 | 7,065 | 0 | 1,392 | -890 | -6,783 | 0 | -121 | -154 | 513 |
| 31 | 4 | 0 | 11,168 | 0 | 1,511 | -907 | -8,926 | 0 | -121 | -158 | 2,571 |
| 32 | 4 | 0 | 12,815 | 0 | 1,558 | -928 | -9,156 | 0 | -127 | -162 | 4,002 |
| 33 | 4 | 0 | 8,388 | 0 | 1,554 | -950 | -9,757 | 0 | -134 | -167 | -1,062 |
| 34 | 3 | 0 | 7,212 | 0 | 1,556 | -941 | -9,373 | 0 | -132 | -172 | -1,846 |
| 35 | 3 | 0 | 9,104 | 0 | 1,587 | -927 | -9,253 | 0 | -128 | -176 | 210 |
| 36 | 3 | 0 | 6,306 | 0 | 1,599 | -923 | -11,595 | 0 | -129 | -176 | -4,914 |
| 37 | 3 | 0 | 5,900 | 0 | 1,901 | -895 | -17,544 | 0 | -125 | -163 | -10,924 |
| 38 | 4 | 0 | 5,544 | 0 | 2,095 | -852 | -17,266 | 0 | -120 | -153 | -10,748 |
| 39 | 4 | 0 | 4,657 | 0 | 2,221 | -807 | -17,598 | 0 | -117 | -140 | -11,780 |
| 40 | 5 | 0 | 5,576 | 0 | 2,343 | -757 | -17,547 | 0 | -113 | -130 | -10,623 |
| 41 | 7 | 0 | 6,900 | 0 | 2,456 | -713 | -17,521 | 0 | -111 | -128 | -9,110 |
| 42 | 8 | 0 | 4,601 | 0 | 2,541 | -671 | -17,664 | 0 | -110 | -120 | -11,414 |
| 43 | 10 | 0 | 4,737 | 0 | 2,655 | -620 | -17,426 | 0 | -106 | -107 | -10,857 |
| 44 | 12 | 0 | 9,876 | 0 | 2,656 | -576 | -9,778 | 0 | -104 | -103 | 1,983 |
| 45 | 15 | 0 | 8,968 | 0 | 2,290 | -578 | -3,536 | 0 | -108 | -107 | 6,944 |
| 46 | 17 | 0 | 9,812 | 0 | 2,077 | -614 | -2,917 | 0 | -111 | -107 | 8,156 |
| 47 | 19 | 0 | 9,710 | 0 | 1,920 | -666 | -3,086 | 0 | -116 | -107 | 7,674 |
| **Average (afy)** | **4** | **0** | **7,770** | **0** | **1,617** | **-958** | **-9,354** | **0** | **-125** | **-122** | **-1,168** |
| **Maximum (afy)** | **19** | **0** | **12,815** | **0** | **2,656** | **-576** | **-2,802** | **0** | **-104** | **-71** | **8,374** |
| **Minimum (afy)** | **2** | **0** | **4,601** | **0** | **880** | **-1,312** | **-17,664** | **0** | **-147** | **-176** | **-11,927** |

Key:
afy - acre-feet per year
GGP - Golden Gate Park

Note: Water balance components represent annual average values on a water year basis. The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flowing out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced.

# Scenario 4 South Westside Basin Water Balance





Scenario 4 South Westside Basin Change in Groundwater Storage
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
Water Volume (acre-feet)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Scenario Year
Change in Groundwater Storage (afy)

# Attachment 10.1-E

## Model Scenario Water Balance Results – San Francisco, Daly City, Colma, South San Francisco, and San Bruno Water Budget Zones

Scenario 1 - Summary of Zone Budget Analyses in Subareas

**Daly City — Zone 1**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 538 | Storage | 308 | Storage | -230 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 4253 | Pumpage | -4253 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 1155 | Recharge | 0 | Recharge | 1155 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 2 | 660 | To Zone 2 | 82 | Zone 2 | 578 |
| From Zone 8 | 2183 | To Zone 8 | 71 | Zone 8 | 2112 |
| From Zone 11 | 199 | To Zone 11 | 0 | Zone 11 | 199 |

**Colma — Zone 2**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 436 | Storage | 334 | Storage | -103 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 716 | Pumpage | -716 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 917 | Recharge | 0 | Recharge | 917 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 1 | 82 | To Zone 1 | 659 | Zone 1 | -577 |
| From Zone 3 | 479 | To Zone 3 | 468 | Zone 3 | 11 |
| From Zone 11 | 269 | To Zone 11 | 0 | Zone 11 | 269 |

**Cal Water — Zone 3**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 393 | Storage | 253 | Storage | -140 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 1535 | Pumpage | -1535 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 1453 | Recharge | 0 | Recharge | 1453 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 2 | 467 | To Zone 2 | 478 | Zone 2 | -12 |
| From Zone 4 | 376 | To Zone 4 | 1023 | Zone 4 | -647 |
| From Zone 5 | 180 | To Zone 5 | 139 | Zone 5 | 41 |
| From Zone 11 | 562 | To Zone 11 | 0 | Zone 11 | 562 |

**San Bruno — Zone 4**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 213 | Storage | 229 | Storage | 15 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 2104 | Pumpage | -2104 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 796 | Recharge | 0 | Recharge | 796 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 3 | 1023 | To Zone 3 | 373 | Zone 3 | 650 |
| From Zone 5 | 498 | To Zone 5 | 308 | Zone 5 | 190 |
| From Zone 6 | 870 | To Zone 6 | 387 | Zone 6 | 484 |
| From Zone 11 | 3 | To Zone 11 | 0 | Zone 11 | 3 |

**Bay Plain/Bay — Zone 5**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 59 | Storage | 68 | Storage | 9 |
| Constant Head | 6 | Constant Head | 110 | Constant Head | -103 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 93 | Drains | -93 |
| Recharge | 332 | Recharge | 0 | Recharge | 332 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 3 | 139 | To Zone 3 | 179 | Zone 3 | -40 |
| From Zone 4 | 308 | To Zone 4 | 498 | Zone 4 | -190 |
| From Zone 6 | 283 | To Zone 6 | 265 | Zone 6 | 18 |
| From Zone 7 | 112 | To Zone 7 | 26 | Zone 7 | 86 |

**Millbrae — Zone 6**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 168 | Storage | 153 | Storage | -15 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 110 | Pumpage | -110 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 557 | Recharge | 0 | Recharge | 557 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 4 | 387 | To Zone 4 | 870 | Zone 4 | -484 |
| From Zone 5 | 265 | To Zone 5 | 283 | Zone 5 | -18 |
| From Zone 7 | 65 | To Zone 7 | 25 | Zone 7 | 40 |

**Burlingame — Zone 7**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 361 | Storage | 290 | Storage | -70 |
| Constant Head | 0 | Constant Head | 12 | Constant Head | -12 |
| Pumpage | 0 | Pumpage | 468 | Pumpage | -468 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 537 | Recharge | 0 | Recharge | 537 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 5 | 26 | To Zone 5 | 112 | Zone 5 | -86 |
| From Zone 6 | 25 | To Zone 6 | 65 | Zone 6 | -40 |

**Lake Merced/GGP — Zone 8**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 1652 | Storage | 1497 | Storage | -155 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 551 | Pumpage | 1618 | Pumpage | -1067 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 5979 | Recharge | 0 | Recharge | 5979 |
| Lake Seepage | 544 | Lake Seepage | 649 | Lake Seepage | -105 |
| From Zone 1 | 71 | To Zone 1 | 2175 | Zone 1 | -2104 |
| From Zone 10 | 257 | To Zone 10 | 3139 | Zone 10 | -2882 |
| From Zone 11 | 24 | To Zone 11 | 1 | Zone 11 | 23 |

**Ocean — Zone 10**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 50 | Storage | 44 | Storage | -7 |
| Constant Head | 5 | Constant Head | 4055 | Constant Head | -4050 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 0 | Recharge | 0 | Recharge | 0 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 8 | 3139 | To Zone 8 | 257 | Zone 8 | 2882 |
| From Zone 11 | 1182 | To Zone 11 | 21 | Zone 11 | 1161 |

**Thornton Beach — Zone 11**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 594 | Storage | 480 | Storage | -114 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 2101 | Recharge | 0 | Recharge | 2101 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 1 | 0 | To Zone 1 | 199 | Zone 1 | -199 |
| From Zone 2 | 0 | To Zone 2 | 269 | Zone 2 | -269 |
| From Zone 3 | 0 | To Zone 3 | 562 | Zone 3 | -562 |
| From Zone 4 | 0 | To Zone 4 | 3 | Zone 4 | -3 |
| From Zone 8 | 1 | To Zone 8 | 24 | Zone 8 | -23 |
| From Zone 10 | 21 | To Zone 10 | 1180 | Zone 10 | -1159 |

**Subareas 1, 2, 3, 4, and 8**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 3233 | Storage | 2620 | Storage | -613 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 551 | Pumpage | 10227 | Pumpage | -9676 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 10301 | Recharge | 0 | Recharge | 10301 |
| Lake Seepage | 544 | Lake Seepage | 649 | Lake Seepage | -105 |
| Ocean | 257 | Ocean | 3139 | Ocean | -2882 |
| Bay Plain/Bay | 678 | Bay Plain/Bay | 447 | Bay Plain/Bay | 231 |
| Millbrae | 870 | Millbrae | 387 | Millbrae | 484 |
| Thornton Beach | 1057 | Thornton Beach | 1 | Thornton Beach | 1056 |

**Notes:** (1) The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flow out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced. Negative storage values represent losses of storage from the aquifer, while positive storage values represent gains in storage in the aquifer.

(2) Water balance components represent annual average values on a water year basis, from October to September. The first three months of the simulation period, which represent July through September conditions, are omitted from the annual averages because they represent only a partial water year. The volumes presented represent the 47 complete water years for the simulation period.

(3) Volumes are calculated using the USGS program ZONEBUDGET (Harbaugh, 1990). As noted in Harbaugh (1990), ZONEBUDGET tabulates boundary conditions differently from how they are reported in the MODFLOW output file. Also, ZONEBUDGET calculates volumes using the volumetric flow rate rather than the cumulative volume. Therefore, the water balance presented in Attachment 10.1-C, calculated using the cumulative volume as reported in the MODFLOW output file, may differ from the results reported on this table. However, the volumes calculated by the two methods are correct with respect to each method.

(4) [green] The five water budget areas that are collectively referred to as "Developed Subbasin" as defined by HydroFocus (2011): San Francisco (Lake Merced and Golden Gate Park), Daly City, Colma, South San Francisco, and San Bruno.

[pink] The five water budget areas that are adjacent to the Developed Subbasin as defined by HydroFocus (2011): San Francisco Bay Plain, Millbrae, Burlingame, Pacific Ocean, and Thornton Beach (across the Serra Fault).

**Scenario 2 - Summary of Zone Budget Analyses in Subareas**

**Daly City — Zone 1**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 1116 | Storage | 705 | Storage | -411 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 3921 | Pumpage | -3921 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 1155 | Recharge | 0 | Recharge | 1155 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 2 | 461 | To Zone 2 | 207 | Zone 2 | 254 |
| From Zone 8 | 1958 | To Zone 8 | 63 | Zone 8 | 1895 |
| From Zone 11 | 184 | To Zone 11 | 0 | Zone 11 | 184 |

**Colma — Zone 2**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 737 | Storage | 457 | Storage | -280 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 1198 | Pumpage | -1198 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 917 | Recharge | 0 | Recharge | 917 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 1 | 216 | To Zone 1 | 482 | Zone 1 | -266 |
| From Zone 3 | 560 | To Zone 3 | 566 | Zone 3 | -7 |
| From Zone 11 | 268 | To Zone 11 | 0 | Zone 11 | 268 |

**Cal Water — Zone 3**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 926 | Storage | 552 | Storage | -374 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 2120 | Pumpage | -2120 |
| Drains | 0 | Drains | 1 | Drains | -1 |
| Recharge | 1453 | Recharge | 0 | Recharge | 1453 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 2 | 565 | To Zone 2 | 558 | Zone 2 | 8 |
| From Zone 4 | 404 | To Zone 4 | 725 | Zone 4 | -322 |
| From Zone 5 | 168 | To Zone 5 | 130 | Zone 5 | 38 |
| From Zone 11 | 576 | To Zone 11 | 0 | Zone 11 | 576 |

**San Bruno — Zone 4**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 496 | Storage | 412 | Storage | -84 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 1836 | Pumpage | -1836 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 796 | Recharge | 0 | Recharge | 796 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 3 | 725 | To Zone 3 | 398 | Zone 3 | 328 |
| From Zone 5 | 449 | To Zone 5 | 282 | Zone 5 | 167 |
| From Zone 6 | 787 | To Zone 6 | 350 | Zone 6 | 437 |
| From Zone 11 | 3 | To Zone 11 | 0 | Zone 11 | 3 |

**Bay Plain/Bay — Zone 5**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 131 | Storage | 121 | Storage | -10 |
| Constant Head | 4 | Constant Head | 122 | Constant Head | -118 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 122 | Drains | -122 |
| Recharge | 332 | Recharge | 0 | Recharge | 332 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 3 | 130 | To Zone 3 | 166 | Zone 3 | -35 |
| From Zone 4 | 282 | To Zone 4 | 449 | Zone 4 | -167 |
| From Zone 6 | 254 | To Zone 6 | 243 | Zone 6 | 11 |
| From Zone 7 | 110 | To Zone 7 | 20 | Zone 7 | 90 |

**Millbrae — Zone 6**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 225 | Storage | 188 | Storage | -37 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 179 | Pumpage | -179 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 557 | Recharge | 0 | Recharge | 557 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 4 | 350 | To Zone 4 | 787 | Zone 4 | -437 |
| From Zone 5 | 243 | To Zone 5 | 254 | Zone 5 | -11 |
| From Zone 7 | 60 | To Zone 7 | 28 | Zone 7 | 32 |

**Burlingame — Zone 7**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 360 | Storage | 293 | Storage | -67 |
| Constant Head | 0 | Constant Head | 13 | Constant Head | -13 |
| Pumpage | 0 | Pumpage | 468 | Pumpage | -468 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 537 | Recharge | 0 | Recharge | 537 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 5 | 20 | To Zone 5 | 110 | Zone 5 | -90 |
| From Zone 6 | 28 | To Zone 6 | 60 | Zone 6 | -32 |

**Lake Merced/GGP — Zone 8**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 1704 | Storage | 1523 | Storage | -181 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 551 | Pumpage | 1618 | Pumpage | -1067 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 5979 | Recharge | 0 | Recharge | 5979 |
| Lake Seepage | 496 | Lake Seepage | 645 | Lake Seepage | -149 |
| From Zone 1 | 63 | To Zone 1 | 1923 | Zone 1 | -1859 |
| From Zone 10 | 228 | To Zone 10 | 3333 | Zone 10 | -3104 |
| From Zone 11 | 21 | To Zone 11 | 2 | Zone 11 | 20 |

**Ocean — Zone 10**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 54 | Storage | 44 | Storage | -10 |
| Constant Head | 6 | Constant Head | 4319 | Constant Head | -4313 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 0 | Recharge | 0 | Recharge | 0 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 8 | 3333 | To Zone 8 | 228 | Zone 8 | 3104 |
| From Zone 11 | 1220 | To Zone 11 | 21 | Zone 11 | 1199 |

**Thornton Beach — Zone 11**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 634 | Storage | 497 | Storage | -136 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 2101 | Recharge | 0 | Recharge | 2101 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 1 | 0 | To Zone 1 | 184 | Zone 1 | -184 |
| From Zone 2 | 0 | To Zone 2 | 267 | Zone 2 | -267 |
| From Zone 3 | 0 | To Zone 3 | 574 | Zone 3 | -574 |
| From Zone 4 | 0 | To Zone 4 | 3 | Zone 4 | -3 |
| From Zone 8 | 1 | To Zone 8 | 22 | Zone 8 | -20 |
| From Zone 10 | 21 | To Zone 10 | 1211 | Zone 10 | -1190 |

**Subareas 1, 2, 3, 4, and 8**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 4979 | Storage | 3649 | Storage | -1330 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 551 | Pumpage | 10692 | Pumpage | -10141 |
| Drains | 0 | Drains | 1 | Drains | -1 |
| Recharge | 10301 | Recharge | 0 | Recharge | 10301 |
| Lake Seepage | 496 | Lake Seepage | 645 | Lake Seepage | -149 |
| Ocean | 228 | Ocean | 3333 | Ocean | -3104 |
| Bay Plain/Bay | 617 | Bay Plain/Bay | 412 | Bay Plain/Bay | 205 |
| Millbrae | 787 | Millbrae | 350 | Millbrae | 437 |
| Thornton Beach | 1052 | Thornton Beach | 2 | Thornton Beach | 1051 |

**Notes:** (1) The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flow out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced. Negative storage values represent losses of storage from the aquifer, while positive storage values represent gains in storage in the aquifer.

(2) Water balance components represent annual average values on a water year basis, from October to September. The first three months of the simulation period, which represent July through September conditions, are omitted from the annual averages because they represent only a partial water year. The volumes presented represent the 47 complete water years for the simulation period.

(3) Volumes are calculated using the USGS program ZONEBUDGET (Harbaugh, 1990). As noted in Harbaugh (1990), ZONEBUDGET tabulates boundary conditions differently from how they are reported in the MODFLOW output file. Also, ZONEBUDGET calculates volumes using the volumetric flow rate rather than the cumulative volume. Therefore, the water balance presented in Attachment 10.1-C, calculated using the cumulative volume as reported in the MODFLOW output file, may differ from the results reported on this table. However, the volumes calculated by the two methods are correct with respect to each method.

(4) [green] The five water budget areas that are collectively referred to as "Developed Subbasin" as defined by HydroFocus (2011): San Francisco (Lake Merced and Golden Gate Park), Daly City, Colma, South San Francisco, and San Bruno.

[pink] The five water budget areas that are adjacent to the Developed Subbasin as defined by HydroFocus (2011): San Francisco Bay Plain, Millbrae, Burlingame, Pacific Ocean, and Thornton Beach (across the Serra Fault).

Scenario 3a - Summary of Zone Budget Analyses in Subareas

| | Daly City | Zone 1 | Colma | Zone 2 | Cal Water | Zone 3 | San Bruno | Zone 4 | Bay Plain/Bay | Zone 5 | Millbrae | Zone 6 | Burlingame | Zone 7 | Lake Merced/GGP | Zone 8 | Ocean | Zone 10 | Thornton Beach | Zone 11 | Subareas 1, 2, 3, 4, and 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IN (acre-feet/year) | Storage | 613 | Storage | 458 | Storage | 413 | Storage | 216 | Storage | 60 | Storage | 168 | Storage | 361 | Storage | 2079 | Storage | 58 | Storage | 599 | Storage | 3779 |
| | Constant Head | 0 | Constant Head | 0 | Constant Head | 0 | Constant Head | 0 | Constant Head | 7 | Constant Head | 0 | Constant Head | 0 | Constant Head | 0 | Constant Head | 381 | Constant Head | 0 | Constant Head | 0 |
| | Pumpage | 0 | Pumpage | 0 | Pumpage | 0 | Pumpage | 0 | Pumpage | 0 | Pumpage | 0 | Pumpage | 0 | Pumpage | 551 | Pumpage | 0 | Pumpage | 0 | Pumpage | 551 |
| | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 |
| | Recharge | 1155 | Recharge | 917 | Recharge | 1453 | Recharge | 796 | Recharge | 332 | Recharge | 557 | Recharge | 537 | Recharge | 5979 | Recharge | 0 | Recharge | 2101 | Recharge | 10301 |
| | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 573 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 573 |
| | From Zone 2 | 754 | From Zone 1 | 86 | From Zone 2 | 443 | From Zone 3 | 1016 | From Zone 3 | 137 | From Zone 4 | 388 | From Zone 5 | 26 | From Zone 1 | 67 | From Zone 8 | 904 | From Zone 1 | 0 | Ocean | 560 |
| | From Zone 8 | 1983 | From Zone 3 | 501 | From Zone 4 | 378 | From Zone 5 | 499 | From Zone 4 | 308 | From Zone 5 | 266 | From Zone 6 | 25 | From Zone 10 | 560 | From Zone 11 | 1166 | From Zone 2 | 0 | Bay Plain/Bay | 679 |
| | From Zone 11 | 209 | From Zone 11 | 275 | From Zone 5 | 180 | From Zone 6 | 872 | From Zone 6 | 284 | From Zone 7 | 65 | | | From Zone 11 | 30 | | | From Zone 3 | 0 | Millbrae | 872 |
| | | | | | From Zone 11 | 566 | From Zone 11 | 3 | From Zone 7 | 112 | | | | | | | | | From Zone 4 | 0 | Thornton Beach | 1084 |
| | | | | | | | | | | | | | | | | | | | From Zone 8 | 0 | | |
| | | | | | | | | | | | | | | | | | | | From Zone 10 | 23 | | |
| OUT (acre-feet/year) | Storage | 285 | Storage | 318 | Storage | 242 | Storage | 225 | Storage | 67 | Storage | 152 | Storage | 290 | Storage | 1407 | Storage | 40 | Storage | 477 | Storage | 2478 |
| | Constant Head | 0 | Constant Head | 0 | Constant Head | 0 | Constant Head | 0 | Constant Head | 110 | Constant Head | 0 | Constant Head | 12 | Constant Head | 0 | Constant Head | 1885 | Constant Head | 0 | Constant Head | 0 |
| | Pumpage | 4253 | Pumpage | 716 | Pumpage | 1535 | Pumpage | 2104 | Pumpage | 0 | Pumpage | 110 | Pumpage | 468 | Pumpage | 4990 | Pumpage | 0 | Pumpage | 0 | Pumpage | 13599 |
| | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 93 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 |
| | Recharge | 0 | Recharge | 0 | Recharge | 0 | Recharge | 0 | Recharge | 0 | Recharge | 0 | Recharge | 0 | Recharge | 0 | Recharge | 0 | Recharge | 0 | Recharge | 0 |
| | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 566 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 566 |
| | To Zone 2 | 86 | To Zone 1 | 749 | To Zone 2 | 499 | To Zone 3 | 375 | To Zone 3 | 179 | To Zone 4 | 872 | To Zone 5 | 112 | To Zone 1 | 1974 | To Zone 8 | 560 | To Zone 1 | 209 | Ocean | 904 |
| | To Zone 8 | 67 | To Zone 3 | 446 | To Zone 4 | 1016 | To Zone 5 | 308 | To Zone 4 | 499 | To Zone 5 | 284 | To Zone 6 | 65 | To Zone 10 | 904 | To Zone 11 | 23 | To Zone 2 | 275 | Bay Plain/Bay | 446 |
| | To Zone 11 | 0 | To Zone 11 | 0 | To Zone 5 | 137 | To Zone 6 | 388 | To Zone 6 | 266 | To Zone 7 | 25 | | | To Zone 11 | 0 | | | To Zone 3 | 566 | Millbrae | 388 |
| | | | | | To Zone 11 | 0 | To Zone 11 | 0 | To Zone 7 | 26 | | | | | | | | | To Zone 4 | 3 | Thornton Beach | 0 |
| | | | | | | | | | | | | | | | | | | | To Zone 8 | 31 | | |
| | | | | | | | | | | | | | | | | | | | To Zone 10 | 1163 | | |
| NET (acre-feet/year) | Storage | -328 | Storage | -140 | Storage | -170 | Storage | 9 | Storage | 6 | Storage | -16 | Storage | -71 | Storage | -672 | Storage | -18 | Storage | -122 | Storage | -1301 |
| | Constant Head | 0 | Constant Head | 0 | Constant Head | 0 | Constant Head | 0 | Constant Head | -103 | Constant Head | 0 | Constant Head | -12 | Constant Head | 0 | Constant Head | -1505 | Constant Head | 0 | Constant Head | 0 |
| | Pumpage | -4253 | Pumpage | -716 | Pumpage | -1535 | Pumpage | -2104 | Pumpage | 0 | Pumpage | -110 | Pumpage | -468 | Pumpage | -4439 | Pumpage | 0 | Pumpage | 0 | Pumpage | -13048 |
| | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | -93 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 | Drains | 0 |
| | Recharge | 1155 | Recharge | 917 | Recharge | 1453 | Recharge | 796 | Recharge | 332 | Recharge | 557 | Recharge | 537 | Recharge | 5979 | Recharge | 0 | Recharge | 2101 | Recharge | 10301 |
| | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 8 | Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 8 |
| | Zone 2 | 668 | Zone 1 | -663 | Zone 2 | -57 | Zone 3 | 641 | Zone 3 | -42 | Zone 4 | -485 | Zone 5 | -86 | Zone 1 | -1907 | Zone 8 | 344 | Zone 1 | -209 | Ocean | -344 |
| | Zone 8 | 1915 | Zone 3 | 56 | Zone 4 | -638 | Zone 5 | 191 | Zone 4 | -191 | Zone 5 | -18 | Zone 6 | -40 | Zone 10 | -344 | Zone 11 | 1143 | Zone 2 | -275 | Bay Plain/Bay | 234 |
| | Zone 11 | 209 | Zone 11 | 275 | Zone 5 | 43 | Zone 6 | 485 | Zone 6 | 18 | Zone 7 | 40 | | | Zone 11 | 30 | | | Zone 3 | -566 | Millbrae | 485 |
| | | | | | Zone 11 | 566 | Zone 11 | 3 | Zone 7 | 86 | | | | | | | | | Zone 4 | -3 | Thornton Beach | 1083 |
| | | | | | | | | | | | | | | | | | | | Zone 8 | -30 | | |
| | | | | | | | | | | | | | | | | | | | Zone 10 | -1140 | | |

**Notes: (1) The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flow out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced. Negative storage values represent losses of storage from the aquifer, while positive storage values represent gains in storage in the aquifer.**

**(2) Water balance components represent annual average values on a water year basis, from October to September. The first three months of the simulation period, which represent July through September conditions, are omitted from the annual averages because they represent only a partial water year. The volumes presented represent the 47 complete water years for the simulation period.**

**(3) Volumes are calculated using the USGS program ZONEBUDGET (Harbaugh, 1990). As noted in Harbaugh (1990), ZONEBUDGET tabulates boundary conditions differently from how they are reported in the MODFLOW output file. Also, ZONEBUDGET calculates volumes using the volumetric flow rate rather than the cumulative volume. Therefore, the water balance presented in Attachment 10.1-C, calculated using the cumulative volume as reported in the MODFLOW output file, may differ from the results reported on this table. However, the volumes calculated by the two methods are correct with respect to each method.**

**(4) [green] The five water budget areas that are collectively referred to as "Developed Subbasin" as defined by HydroFocus (2011): San Francisco (Lake Merced and Golden Gate Park), Daly City, Colma, South San Francisco, and San Bruno.**

**[pink] The five water budget areas that are adjacent to the Developed Subbasin as defined by HydroFocus (2011): San Francisco Bay Plain, Millbrae, Burlingame, Pacific Ocean, and Thornton Beach (across the Serra Fault).**

**Scenario 3b - Summary of Zone Budget Analyses in Subareas**

**Daly City — Zone 1**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 611 | Storage | 286 | Storage | -326 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 4253 | Pumpage | -4253 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 1155 | Recharge | 0 | Recharge | 1155 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 2 | 752 | To Zone 2 | 86 | Zone 2 | 667 |
| From Zone 8 | 1987 | To Zone 8 | 67 | Zone 8 | 1919 |
| From Zone 11 | 209 | To Zone 11 | 0 | Zone 11 | 209 |

**Colma — Zone 2**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 457 | Storage | 318 | Storage | -139 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 716 | Pumpage | -716 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 917 | Recharge | 0 | Recharge | 917 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 1 | 86 | To Zone 1 | 748 | Zone 1 | -661 |
| From Zone 3 | 501 | To Zone 3 | 446 | Zone 3 | 55 |
| From Zone 11 | 275 | To Zone 11 | 0 | Zone 11 | 275 |

**Cal Water — Zone 3**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 412 | Storage | 243 | Storage | -170 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 1535 | Pumpage | -1535 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 1453 | Recharge | 0 | Recharge | 1453 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 2 | 443 | To Zone 2 | 499 | Zone 2 | -56 |
| From Zone 4 | 378 | To Zone 4 | 1016 | Zone 4 | -638 |
| From Zone 5 | 180 | To Zone 5 | 137 | Zone 5 | 43 |
| From Zone 11 | 566 | To Zone 11 | 0 | Zone 11 | 566 |

**San Bruno — Zone 4**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 216 | Storage | 226 | Storage | 9 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 2104 | Pumpage | -2104 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 796 | Recharge | 0 | Recharge | 796 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 3 | 1016 | To Zone 3 | 375 | Zone 3 | 642 |
| From Zone 5 | 499 | To Zone 5 | 308 | Zone 5 | 191 |
| From Zone 6 | 872 | To Zone 6 | 388 | Zone 6 | 485 |
| From Zone 11 | 3 | To Zone 11 | 0 | Zone 11 | 3 |

**Bay Plain/Bay — Zone 5**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 60 | Storage | 67 | Storage | 6 |
| Constant Head | 7 | Constant Head | 110 | Constant Head | -103 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 93 | Drains | -93 |
| Recharge | 332 | Recharge | 0 | Recharge | 332 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 3 | 137 | To Zone 3 | 179 | Zone 3 | -42 |
| From Zone 4 | 308 | To Zone 4 | 499 | Zone 4 | -191 |
| From Zone 6 | 284 | To Zone 6 | 266 | Zone 6 | 18 |
| From Zone 7 | 112 | To Zone 7 | 26 | Zone 7 | 86 |

**Millbrae — Zone 6**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 168 | Storage | 152 | Storage | -16 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 110 | Pumpage | -110 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 557 | Recharge | 0 | Recharge | 557 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 4 | 388 | To Zone 4 | 872 | Zone 4 | -485 |
| From Zone 5 | 266 | To Zone 5 | 284 | Zone 5 | -18 |
| From Zone 7 | 65 | To Zone 7 | 25 | Zone 7 | 40 |

**Burlingame — Zone 7**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 361 | Storage | 290 | Storage | -70 |
| Constant Head | 0 | Constant Head | 12 | Constant Head | -12 |
| Pumpage | 0 | Pumpage | 468 | Pumpage | -468 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 537 | Recharge | 0 | Recharge | 537 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 5 | 26 | To Zone 5 | 112 | Zone 5 | -86 |
| From Zone 6 | 25 | To Zone 6 | 65 | Zone 6 | -40 |

**Lake Merced/GGP — Zone 8**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 1922 | Storage | 1292 | Storage | -630 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 626 | Pumpage | 4906 | Pumpage | -4281 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 5979 | Recharge | 0 | Recharge | 5979 |
| Lake Seepage | 576 | Lake Seepage | 572 | Lake Seepage | 4 |
| From Zone 1 | 67 | To Zone 1 | 1978 | Zone 1 | -1910 |
| From Zone 10 | 466 | To Zone 10 | 919 | Zone 10 | -453 |
| From Zone 11 | 30 | To Zone 11 | 0 | Zone 11 | 30 |

**Ocean — Zone 10**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 44 | Storage | 26 | Storage | -17 |
| Constant Head | 294 | Constant Head | 1908 | Constant Head | -1614 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 0 | Recharge | 0 | Recharge | 0 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 8 | 919 | To Zone 8 | 466 | Zone 8 | 453 |
| From Zone 11 | 1166 | To Zone 11 | 22 | Zone 11 | 1143 |

**Thornton Beach — Zone 11**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 599 | Storage | 477 | Storage | -122 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 2101 | Recharge | 0 | Recharge | 2101 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 1 | 0 | To Zone 1 | 209 | Zone 1 | -209 |
| From Zone 2 | 0 | To Zone 2 | 275 | Zone 2 | -275 |
| From Zone 3 | 0 | To Zone 3 | 566 | Zone 3 | -566 |
| From Zone 4 | 0 | To Zone 4 | 3 | Zone 4 | -3 |
| From Zone 8 | 0 | To Zone 8 | 30 | Zone 8 | -30 |
| From Zone 10 | 23 | To Zone 10 | 1163 | Zone 10 | -1141 |

**Subareas 1, 2, 3, 4, and 8**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 3619 | Storage | 2363 | Storage | -1256 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 626 | Pumpage | 13515 | Pumpage | -12890 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 10301 | Recharge | 0 | Recharge | 10301 |
| Lake Seepage | 576 | Lake Seepage | 572 | Lake Seepage | 4 |
| Ocean | 466 | Ocean | 919 | Ocean | -453 |
| Bay Plain/Bay | 679 | Bay Plain/Bay | 446 | Bay Plain/Bay | 234 |
| Millbrae | 872 | Millbrae | 388 | Millbrae | 485 |
| Thornton Beach | 1083 | Thornton Beach | 0 | Thornton Beach | 1083 |

**Notes:** (1) The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flow out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced. Negative storage values represent losses of storage from the aquifer, while positive storage values represent gains in storage in the aquifer.

(2) Water balance components represent annual average values on a water year basis, from October to September. The first three months of the simulation period, which represent July through September conditions, are omitted from the annual averages because they represent only a partial water year. The volumes presented represent the 47 complete water years for the simulation period.

(3) Volumes are calculated using the USGS program ZONEBUDGET (Harbaugh, 1990). As noted in Harbaugh (1990), ZONEBUDGET tabulates boundary conditions differently from how they are reported in the MODFLOW output file. Also, ZONEBUDGET calculates volumes using the volumetric flow rate rather than the cumulative volume. Therefore, the water balance presented in Attachment 10.1-C, calculated using the cumulative volume as reported in the MODFLOW output file, may differ from the results reported on this table. However, the volumes calculated by the two methods are correct with respect to each method.

(4) [green] The five water budget areas that are collectively referred to as "Developed Subbasin" as defined by HydroFocus (2011): San Francisco (Lake Merced and Golden Gate Park), Daly City, Colma, South San Francisco, and San Bruno.

[pink] The five water budget areas that are adjacent to the Developed Subbasin as defined by HydroFocus (2011): San Francisco Bay Plain, Millbrae, Burlingame, Pacific Ocean, and Thornton Beach (across the Serra Fault).

**Scenario 4 - Summary of Zone Budget Analyses in Subareas**

**Daly City — Zone 1**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 1050 | Storage | 659 | Storage | -391 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 3421 | Pumpage | -3421 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 1155 | Recharge | 0 | Recharge | 1155 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 2 | 367 | To Zone 2 | 237 | Zone 2 | 130 |
| From Zone 8 | 1614 | To Zone 8 | 55 | Zone 8 | 1559 |
| From Zone 11 | 175 | To Zone 11 | 0 | Zone 11 | 175 |

**Colma — Zone 2**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 736 | Storage | 468 | Storage | -267 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 1243 | Pumpage | -1243 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 917 | Recharge | 0 | Recharge | 917 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 1 | 248 | To Zone 1 | 382 | Zone 1 | -135 |
| From Zone 3 | 539 | To Zone 3 | 593 | Zone 3 | -54 |
| From Zone 11 | 245 | To Zone 11 | 0 | Zone 11 | 245 |

**Cal Water — Zone 3**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 931 | Storage | 558 | Storage | -372 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 2120 | Pumpage | -2120 |
| Drains | 0 | Drains | 1 | Drains | -1 |
| Recharge | 1453 | Recharge | 0 | Recharge | 1453 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 2 | 593 | To Zone 2 | 536 | Zone 2 | 57 |
| From Zone 4 | 401 | To Zone 4 | 717 | Zone 4 | -317 |
| From Zone 5 | 169 | To Zone 5 | 132 | Zone 5 | 37 |
| From Zone 11 | 524 | To Zone 11 | 0 | Zone 11 | 524 |

**San Bruno — Zone 4**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 497 | Storage | 410 | Storage | -87 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 1836 | Pumpage | -1836 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 796 | Recharge | 0 | Recharge | 796 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 3 | 717 | To Zone 3 | 395 | Zone 3 | 323 |
| From Zone 5 | 450 | To Zone 5 | 282 | Zone 5 | 168 |
| From Zone 6 | 789 | To Zone 6 | 351 | Zone 6 | 438 |
| From Zone 11 | 3 | To Zone 11 | 0 | Zone 11 | 3 |

**Bay Plain/Bay — Zone 5**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 131 | Storage | 121 | Storage | -10 |
| Constant Head | 4 | Constant Head | 121 | Constant Head | -117 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 122 | Drains | -122 |
| Recharge | 332 | Recharge | 0 | Recharge | 332 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 3 | 132 | To Zone 3 | 166 | Zone 3 | -35 |
| From Zone 4 | 282 | To Zone 4 | 450 | Zone 4 | -168 |
| From Zone 6 | 254 | To Zone 6 | 244 | Zone 6 | 10 |
| From Zone 7 | 110 | To Zone 7 | 20 | Zone 7 | 90 |

**Millbrae — Zone 6**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 226 | Storage | 188 | Storage | -38 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 179 | Pumpage | -179 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 557 | Recharge | 0 | Recharge | 557 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 4 | 351 | To Zone 4 | 789 | Zone 4 | -438 |
| From Zone 5 | 244 | To Zone 5 | 254 | Zone 5 | -10 |
| From Zone 7 | 60 | To Zone 7 | 28 | Zone 7 | 32 |

**Burlingame — Zone 7**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 360 | Storage | 293 | Storage | -67 |
| Constant Head | 0 | Constant Head | 13 | Constant Head | -13 |
| Pumpage | 0 | Pumpage | 468 | Pumpage | -468 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 537 | Recharge | 0 | Recharge | 537 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 5 | 20 | To Zone 5 | 110 | Zone 5 | -90 |
| From Zone 6 | 28 | To Zone 6 | 60 | Zone 6 | -32 |

**Lake Merced/GGP — Zone 8**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 1881 | Storage | 1325 | Storage | -556 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 626 | Pumpage | 4906 | Pumpage | -4281 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 5979 | Recharge | 0 | Recharge | 5979 |
| Lake Seepage | 592 | Lake Seepage | 452 | Lake Seepage | 141 |
| From Zone 1 | 55 | To Zone 1 | 1578 | Zone 1 | -1523 |
| From Zone 10 | 346 | To Zone 10 | 1241 | Zone 10 | -895 |
| From Zone 11 | 24 | To Zone 11 | 1 | Zone 11 | 23 |

**Ocean — Zone 10**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 46 | Storage | 28 | Storage | -19 |
| Constant Head | 169 | Constant Head | 2093 | Constant Head | -1924 |
| Pumpage | 0 | Pumpage | 0 | Pumpage | 0 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 0 | Recharge | 0 | Recharge | 0 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 8 | 1241 | To Zone 8 | 346 | Zone 8 | 895 |
| From Zone 11 | 1031 | To Zone 11 | 21 | Zone 11 | 1010 |

**Thornton Beach — Zone 11**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 833 | Storage | 486 | Storage | -346 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 0 | Pumpage | 484 | Pumpage | -484 |
| Drains | 0 | Drains | 0 | Drains | 0 |
| Recharge | 2101 | Recharge | 0 | Recharge | 2101 |
| Lake Seepage | 0 | Lake Seepage | 0 | Lake Seepage | 0 |
| From Zone 1 | 0 | To Zone 1 | 175 | Zone 1 | -175 |
| From Zone 2 | 0 | To Zone 2 | 244 | Zone 2 | -244 |
| From Zone 3 | 0 | To Zone 3 | 522 | Zone 3 | -522 |
| From Zone 4 | 0 | To Zone 4 | 3 | Zone 4 | -3 |
| From Zone 8 | 1 | To Zone 8 | 24 | Zone 8 | -23 |
| From Zone 10 | 21 | To Zone 10 | 1017 | Zone 10 | -996 |

**Subareas 1, 2, 3, 4, and 8**

| IN (acre-feet/year) | | OUT (acre-feet/year) | | NET (acre-feet/year) | |
|---|---|---|---|---|---|
| Storage | 5095 | Storage | 3422 | Storage | -1674 |
| Constant Head | 0 | Constant Head | 0 | Constant Head | 0 |
| Pumpage | 626 | Pumpage | 13526 | Pumpage | -12901 |
| Drains | 0 | Drains | 1 | Drains | -1 |
| Recharge | 10301 | Recharge | 0 | Recharge | 10301 |
| Lake Seepage | 592 | Lake Seepage | 452 | Lake Seepage | 141 |
| Ocean | 346 | Ocean | 1241 | Ocean | -895 |
| Bay Plain/Bay | 619 | Bay Plain/Bay | 413 | Bay Plain/Bay | 205 |
| Millbrae | 789 | Millbrae | 351 | Millbrae | 438 |
| Thornton Beach | 970 | Thornton Beach | 1 | Thornton Beach | 969 |

**Notes:** (1) The sign convention is positive for groundwater flowing into the groundwater basin (inflows). The sign convention is negative for groundwater flow out of the groundwater basin (outflows). This is consistent with the sign convention used by MODFLOW. For example, positive values for "Seepage from Lake Merced" represent flows from Lake Merced to the groundwater basin (aquifer). Negative values for "Seepage to Lake Merced" represent groundwater flow from the aquifer into Lake Merced. Negative storage values represent losses of storage from the aquifer, while positive storage values represent gains in storage in the aquifer.

(2) Water balance components represent annual average values on a water year basis, from October to September. The first three months of the simulation period, which represent July through September conditions, are omitted from the annual averages because they represent only a partial water year. The volumes presented represent the 47 complete water years for the simulation period.

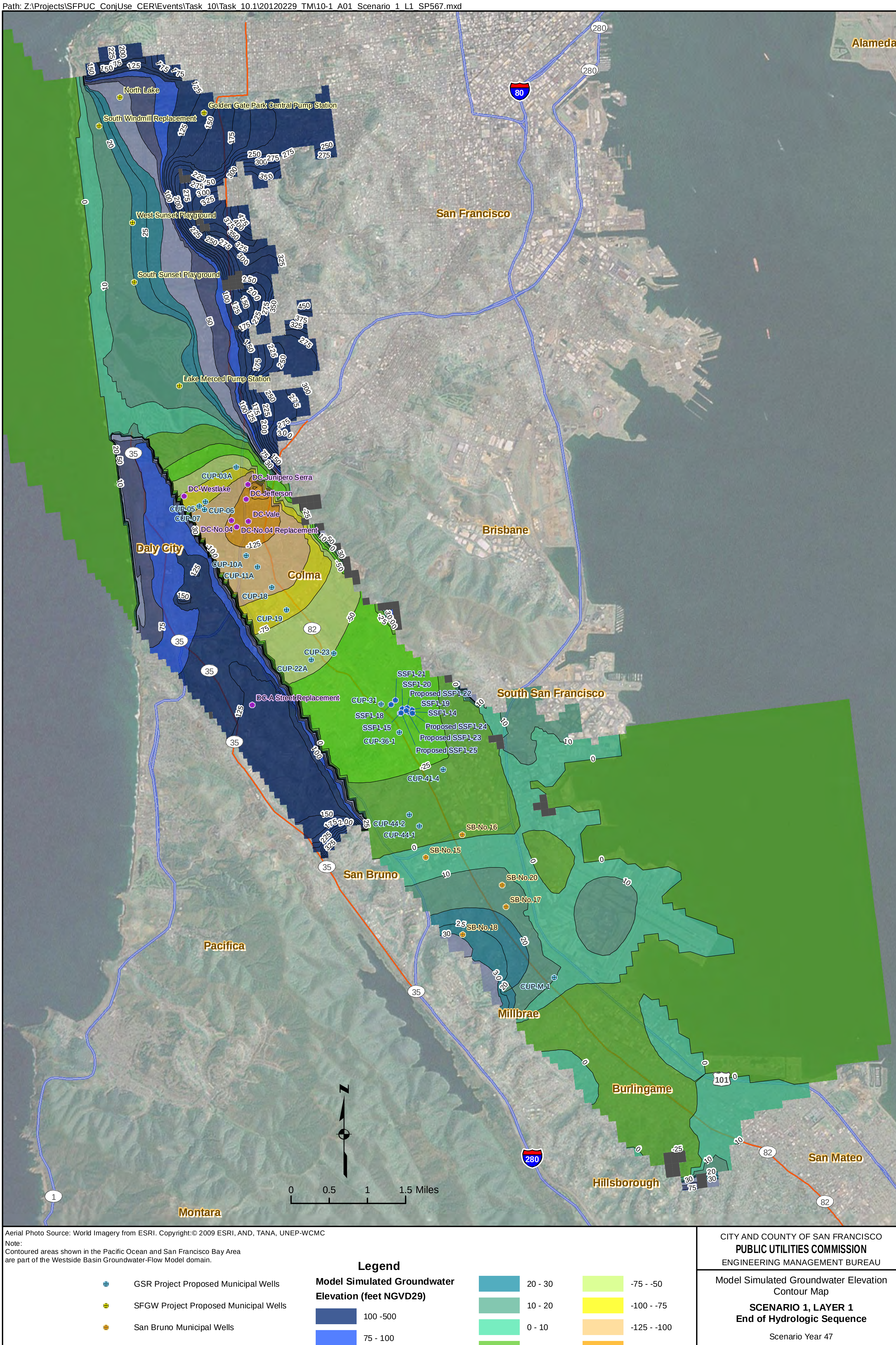
(3) Volumes are calculated using the USGS program ZONEBUDGET (Harbaugh, 1990). As noted in Harbaugh (1990), ZONEBUDGET tabulates boundary conditions differently from how they are reported in the MODFLOW output file. Also, ZONEBUDGET calculates volumes using the volumetric flow rate rather than the cumulative volume. Therefore, the water balance presented in Attachment 10.1-C, calculated using the cumulative volume as reported in the MODFLOW output file, may differ from the results reported on this table. However, the volumes calculated by the two methods are correct with respect to each method.

(4) [green] The five water budget areas that are collectively referred to as "Developed Subbasin" as defined by HydroFocus (2011): San Francisco (Lake Merced and Golden Gate Park), Daly City, Colma, South San Francisco, and San Bruno.

[pink] The five water budget areas that are adjacent to the Developed Subbasin as defined by HydroFocus (2011): San Francisco Bay Plain, Millbrae, Burlingame, Pacific Ocean, and Thornton Beach (across the Serra Fault).

# Attachment 10.1-F

## Model Scenario Groundwater Elevation Contour Maps for Selected Time Periods




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

| | | |
|---|---|---|
| 100 -500 | 20 - 30 | -75 - -50 |
| 75 - 100 | 10 - 20 | -100 - -75 |
| 50 - 75 | 0 - 10 | -125 - -100 |
| 30 - 50 | -25 - 0 | -200 - -125 |
| | -50 - -25 | Dry Cell |

D.5-237

CITY AND COUNTY OF SAN FRANCISCO
PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 1, LAYER 1**
**End of Hydrologic Sequence**

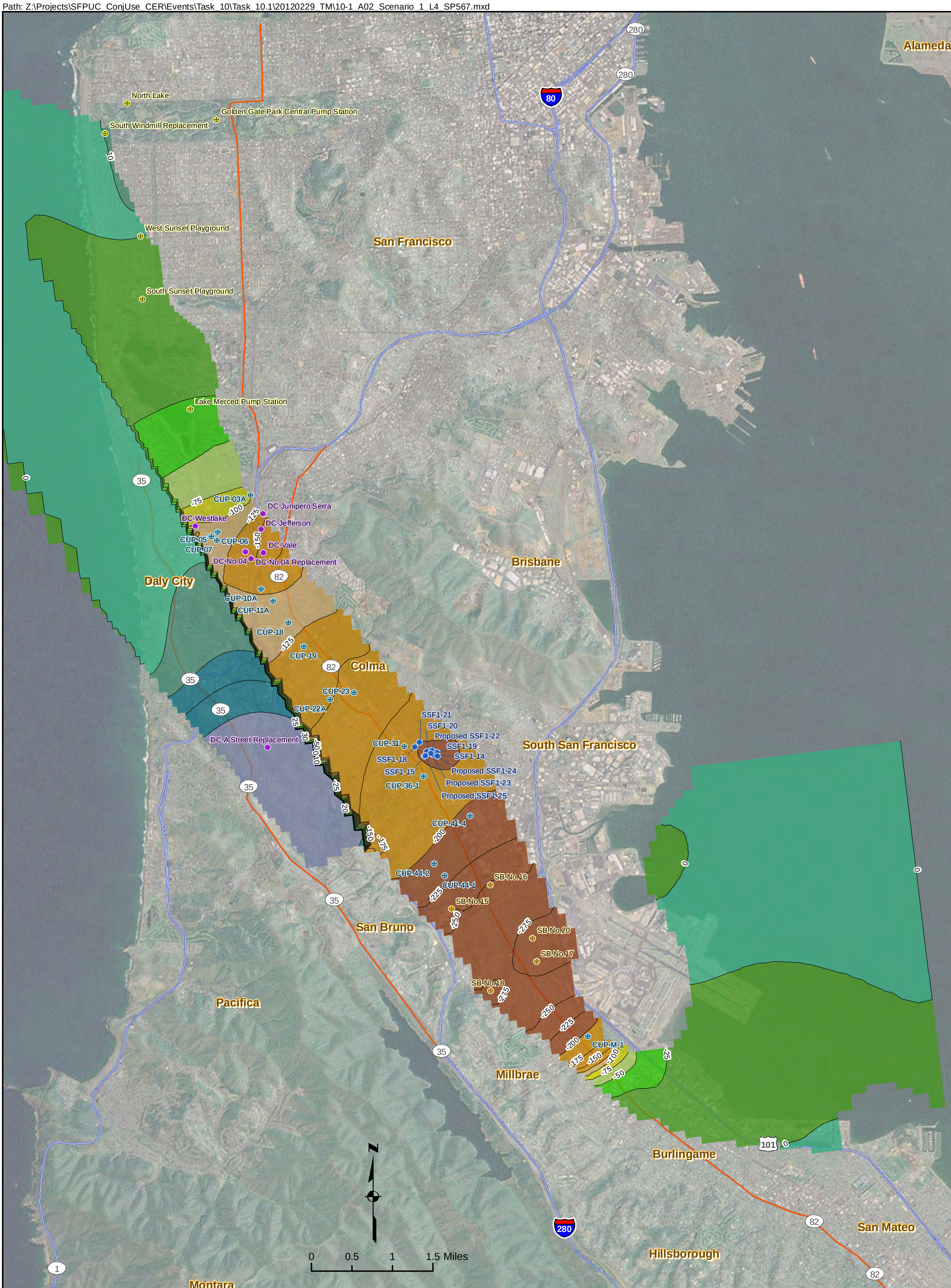
Scenario Year 47

**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.1\20120229_TM\10-1_A02_Scenario_1_L4_SP567.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

- 100 - 150
- 75 - 100
- 50 - 75
- 30 - 50
- 20 - 30
- 10 - 20
- 0 - 10
- -25 - 0
- -50 - -25
- -75 - -50
- -100 - -75
- -125 - -100
- -200 - -125
- -300 - -200

D.5-238

CITY AND COUNTY OF SAN FRANCISCO
PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 1, LAYER 4**
**End of Hydrologic Sequence**

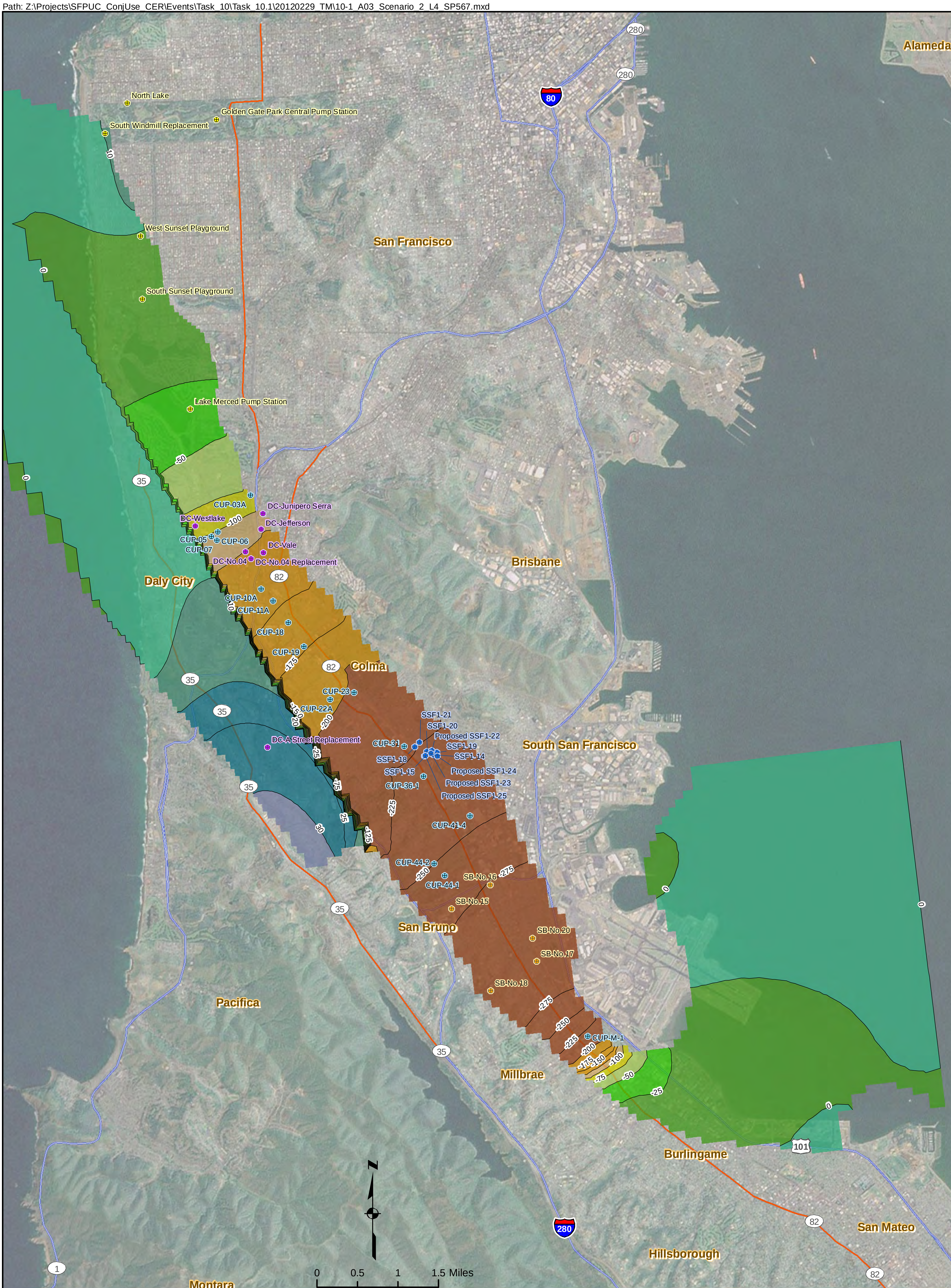
Scenario Year 47

**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.1\20120229_TM\10-1_A03_Scenario_2_L4_SP567.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

- 100 - 150
- 75 - 100
- 50 - 75
- 30 - 50
- 20 - 30
- 10 - 20
- 0 - 10
- -25 - 0
- -50 - -25
- -75 - -50
- -100 - -75
- -125 - -100
- -200 - -125
- -300 - -200

D.5-239

CITY AND COUNTY OF SAN FRANCISCO
**PUBLIC UTILITIES COMMISSION**
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 2, LAYER 4**
**End of Hydrologic Sequence**

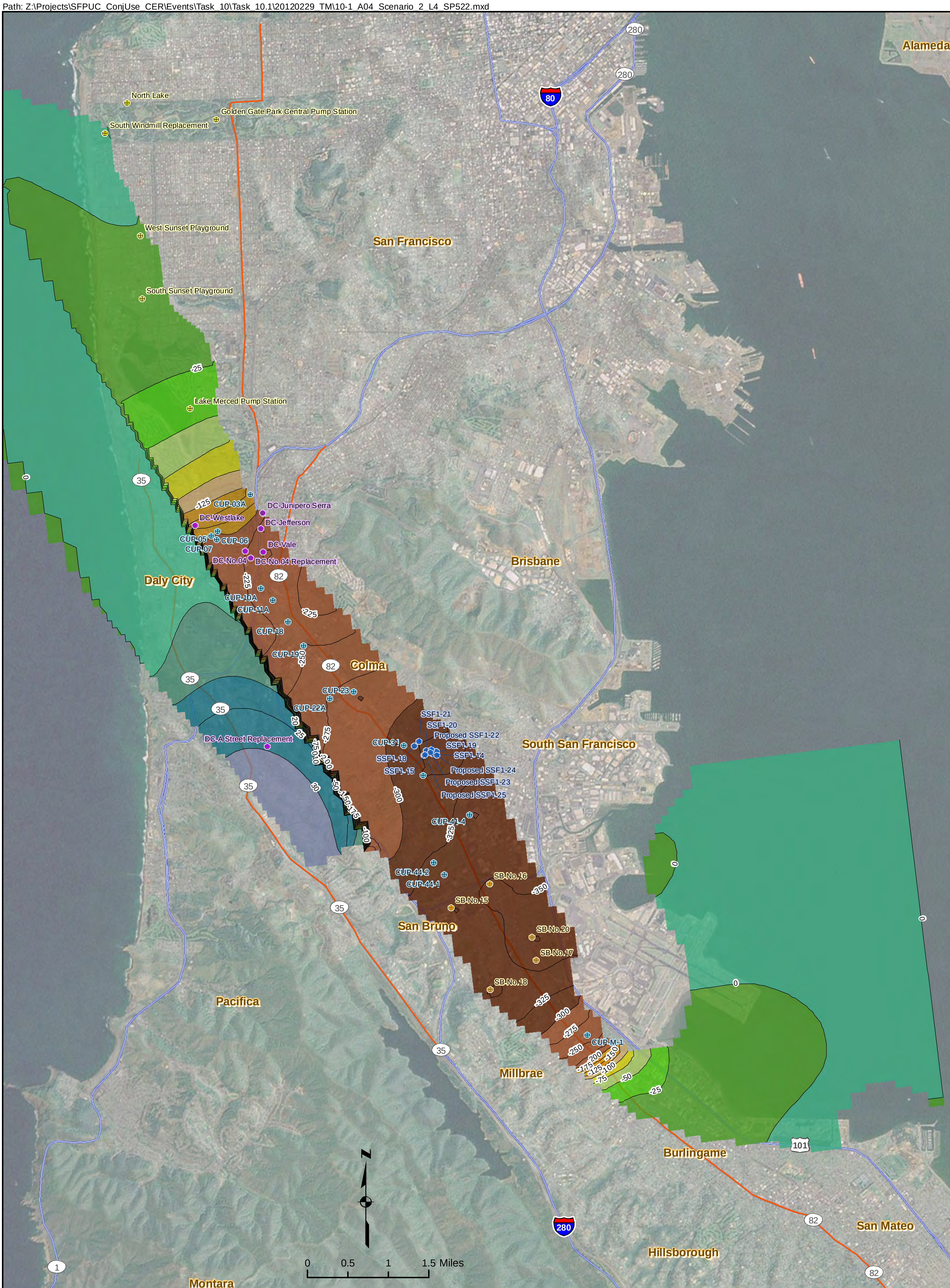
Scenario Year 47

**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.1\20120229_TM\10-1_A04_Scenario_2_L4_SP522.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

- 75 - 100
- 50 - 75
- 30 - 50
- 20 - 30
- 10 - 20
- 0 - 10
- -25 - 0
- -50 - -25
- -75 - -50
- -100 - -75
- -125 - -100
- -200 - -125
- -300 - -200
- -400 - -300

CITY AND COUNTY OF SAN FRANCISCO
PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 2, LAYER 4**
**End of Design Drought**

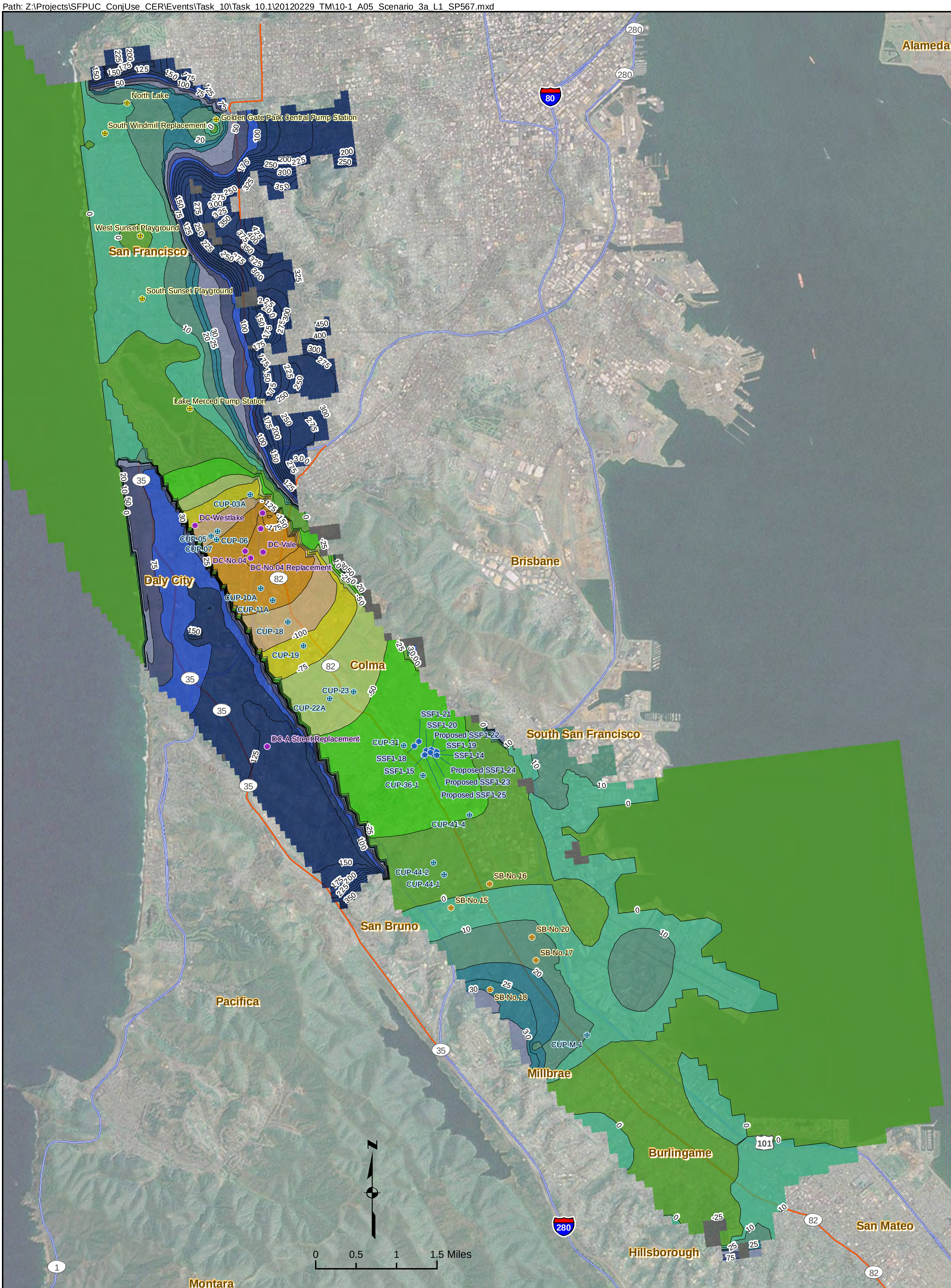
Scenario Year 44

Kennedy/Jenks Consultants
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.1\20120229_TM\10-1_A05_Scenario_3a_L1_SP567.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

- 100 - 500
- 75 - 100
- 50 - 75
- 30 - 50
- 20 - 30
- 10 - 20
- 0 - 10
- -25 - 0
- -50 - -25
- -75 - -50
- -100 - -75
- -125 - -100
- -200 - -125
- Dry Cells

CITY AND COUNTY OF SAN FRANCISCO
PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 3A, LAYER 1**
**End of Hydrologic Sequence**

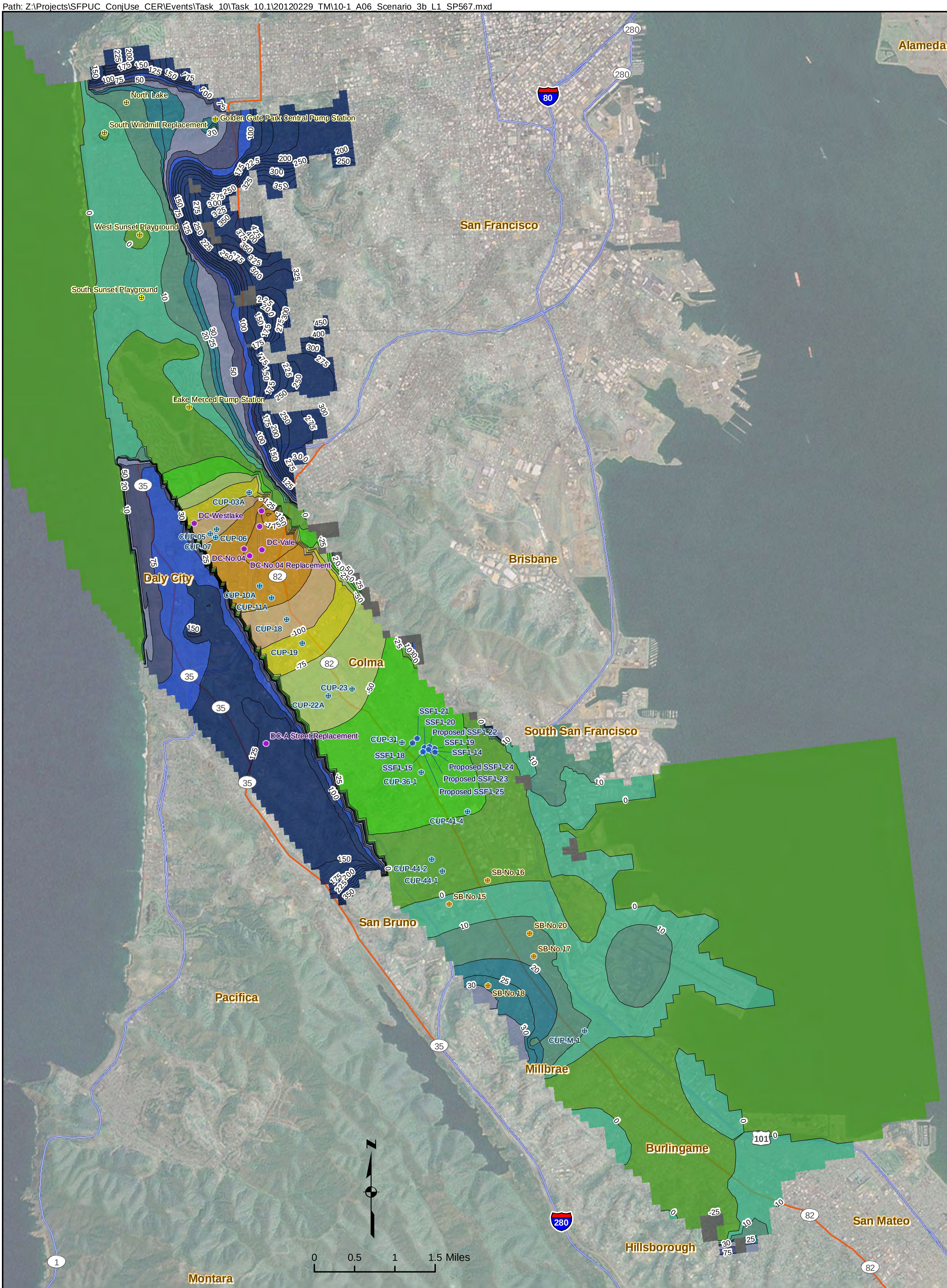
Scenario Year 47

**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.1\20120229_TM\10-1_A06_Scenario_3b_L1_SP567.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

| | | |
|---|---|---|
| 100 - 500 | 20 - 30 | -75 - -50 |
| 75 - 100 | 10 - 20 | -100 - -75 |
| 50 - 75 | 0 - 10 | -125 - -100 |
| 30 - 50 | -25 - 0 | -200 - -125 |
| | -50 - -25 | Dry Cells |

D.5-242

CITY AND COUNTY OF SAN FRANCISCO
**PUBLIC UTILITIES COMMISSION**
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 3B, LAYER 1**
**End of Hydrologic Sequence**

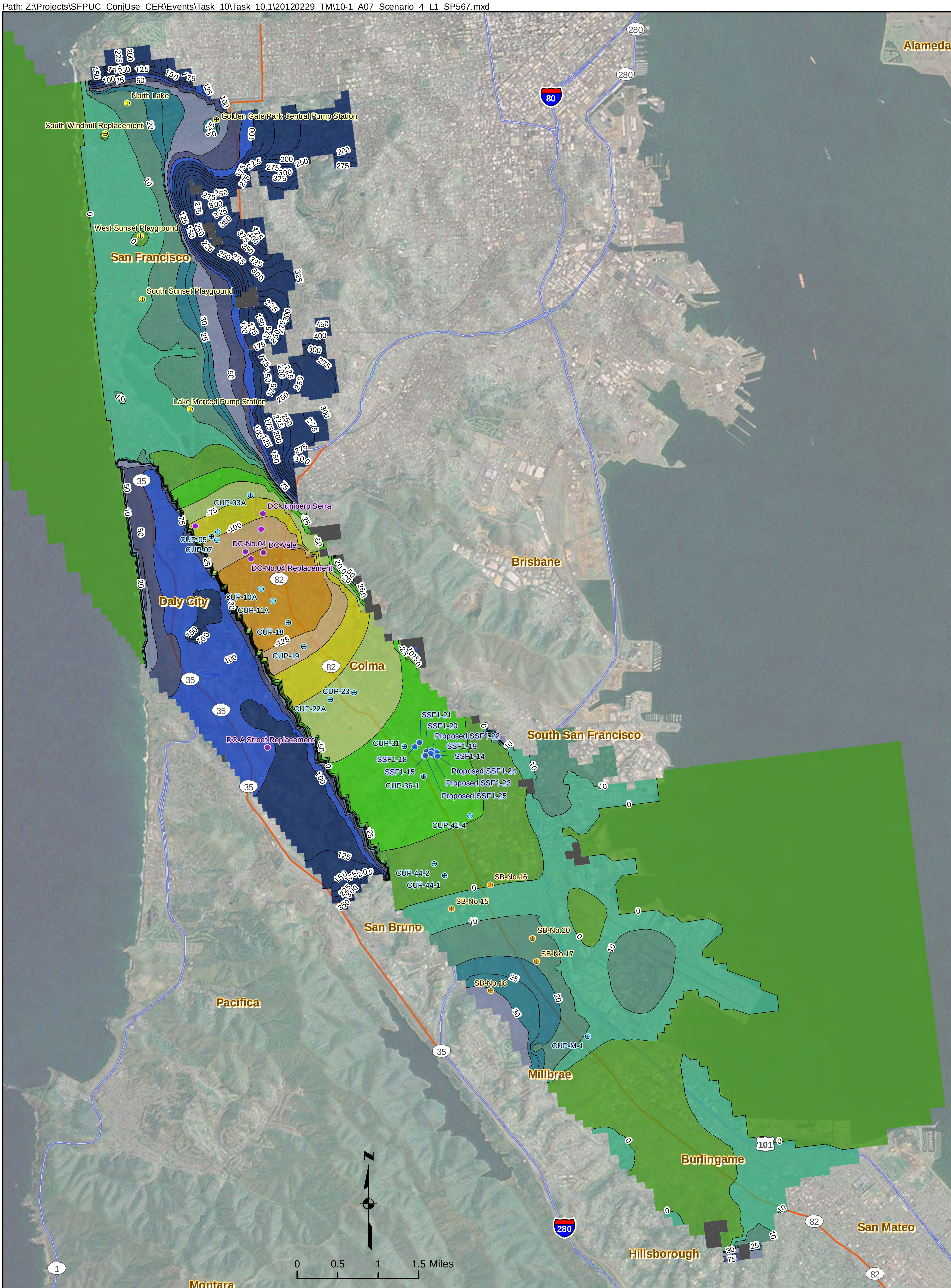
Scenario Year 47

**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.1\20120229_TM\10-1_A07_Scenario_4_L1_SP567.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

- 100 - 500
- 75 - 100
- 50 - 75
- 30 - 50
- 20 - 30
- 10 - 20
- 0 - 10
- -25 - 0
- -50 - -25
- -75 - -50
- -100 - -75
- -125 - -100
- -200 - -125
- Dry Cells

D.5-243

CITY AND COUNTY OF SAN FRANCISCO
PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 4, LAYER 1**
**End of Hydrologic Sequence**

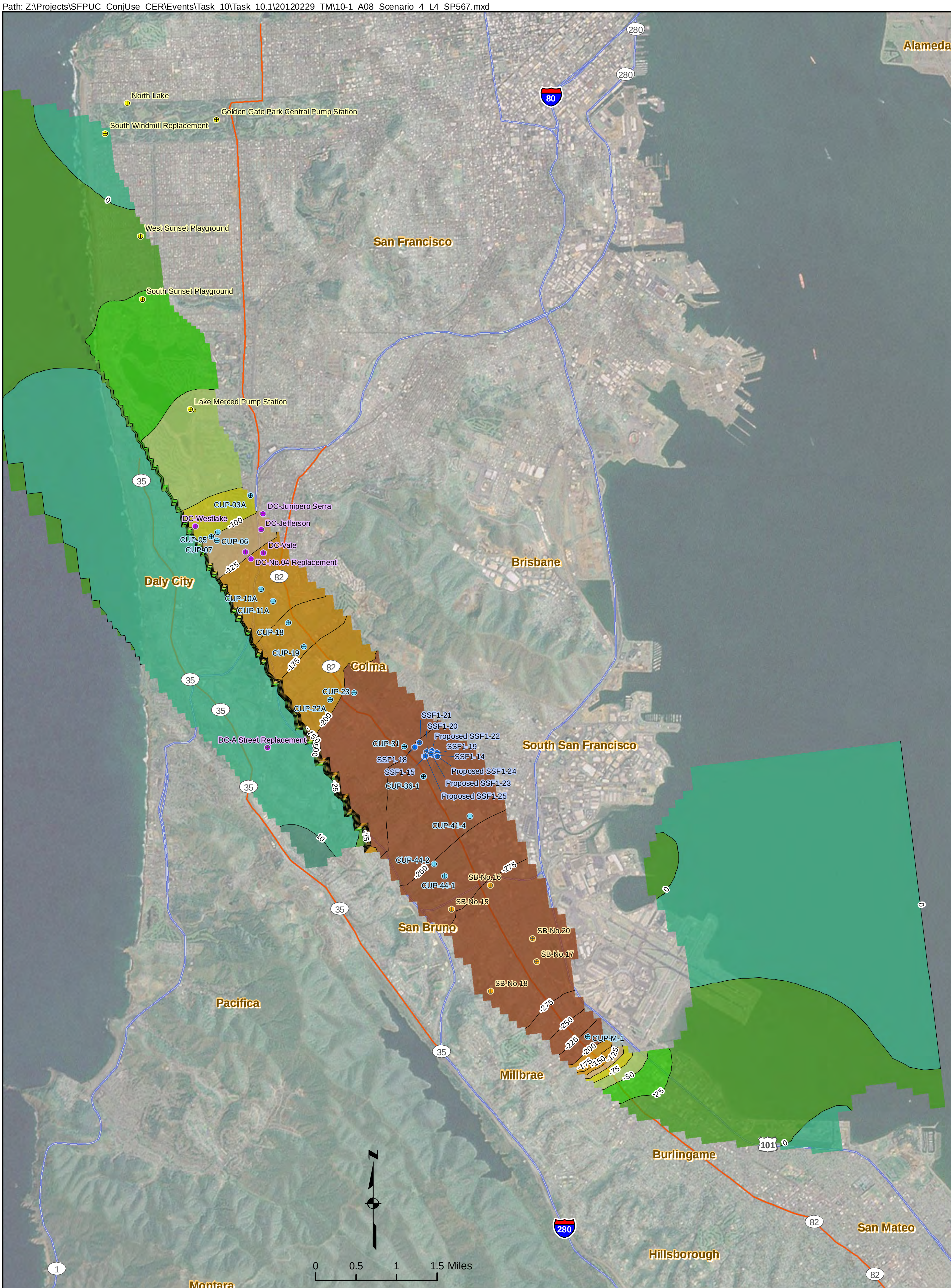
Scenario Year 47

**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.1\20120229_TM\10-1_A08_Scenario_4_L4_SP567.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

| | | |
|---|---|---|
| 100 - 150 | 20 - 30 | -100 - -75 |
| 75 - 100 | 10 - 20 | -125 - -100 |
| 50 - 75 | 0 - 10 | -200 - -125 |
| 30 - 50 | -25 - 0 | -300 - -200 |
| | -50 - -25 | |
| | -75 - -50 | |

CITY AND COUNTY OF SAN FRANCISCO
**PUBLIC UTILITIES COMMISSION**
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 4, LAYER 4**
**End of Hydrologic Sequence**

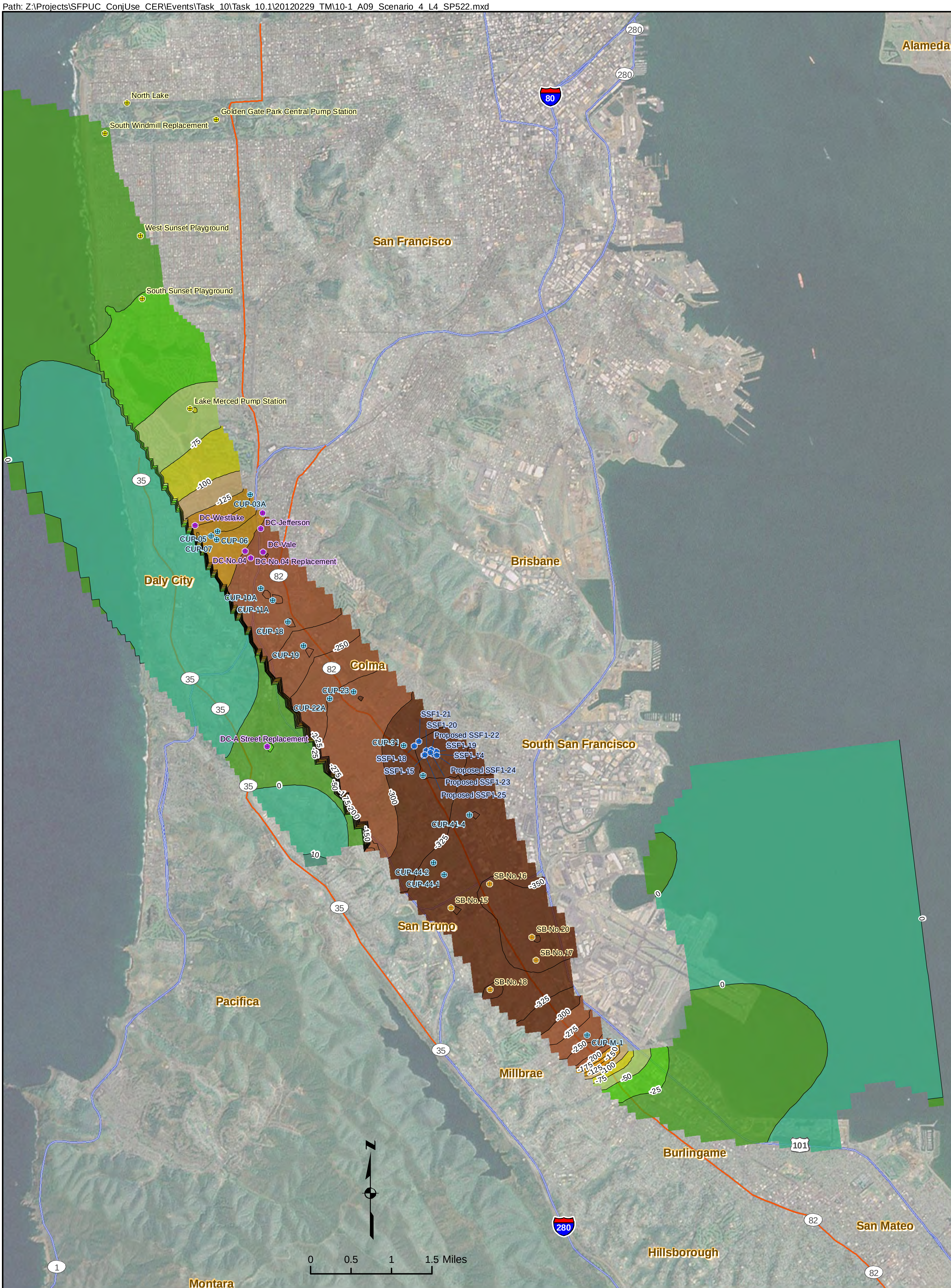
Scenario Year 47

**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.1\20120229_TM\10-1_A09_Scenario_4_L4_SP522.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
Contoured areas shown in the Pacific Ocean and San Francisco Bay Area are part of the Westside Basin Groundwater-Flow Model domain.

## Legend

- GSR Project Proposed Municipal Wells
- SFGW Project Proposed Municipal Wells
- San Bruno Municipal Wells
- Daly City Municipal Wells
- Cal Water Municipal Wells
- Simulated Groundwater Elevation (feet NGVD29)

**Model Simulated Groundwater Elevation (feet NGVD29)**

- 75 - 100
- 50 - 75
- 30 - 50
- 20 - 30
- 10 - 20
- 0 - 10
- -25 - 0
- -50 - -25
- -75 - -50
- -100 - -75
- -125 - -100
- -200 - -125
- -300 - -200
- -400 - -300

CITY AND COUNTY OF SAN FRANCISCO
**PUBLIC UTILITIES COMMISSION**
ENGINEERING MANAGEMENT BUREAU

Model Simulated Groundwater Elevation Contour Map

**SCENARIO 4, LAYER 4**
**End of Design Drought**

Scenario Year 44

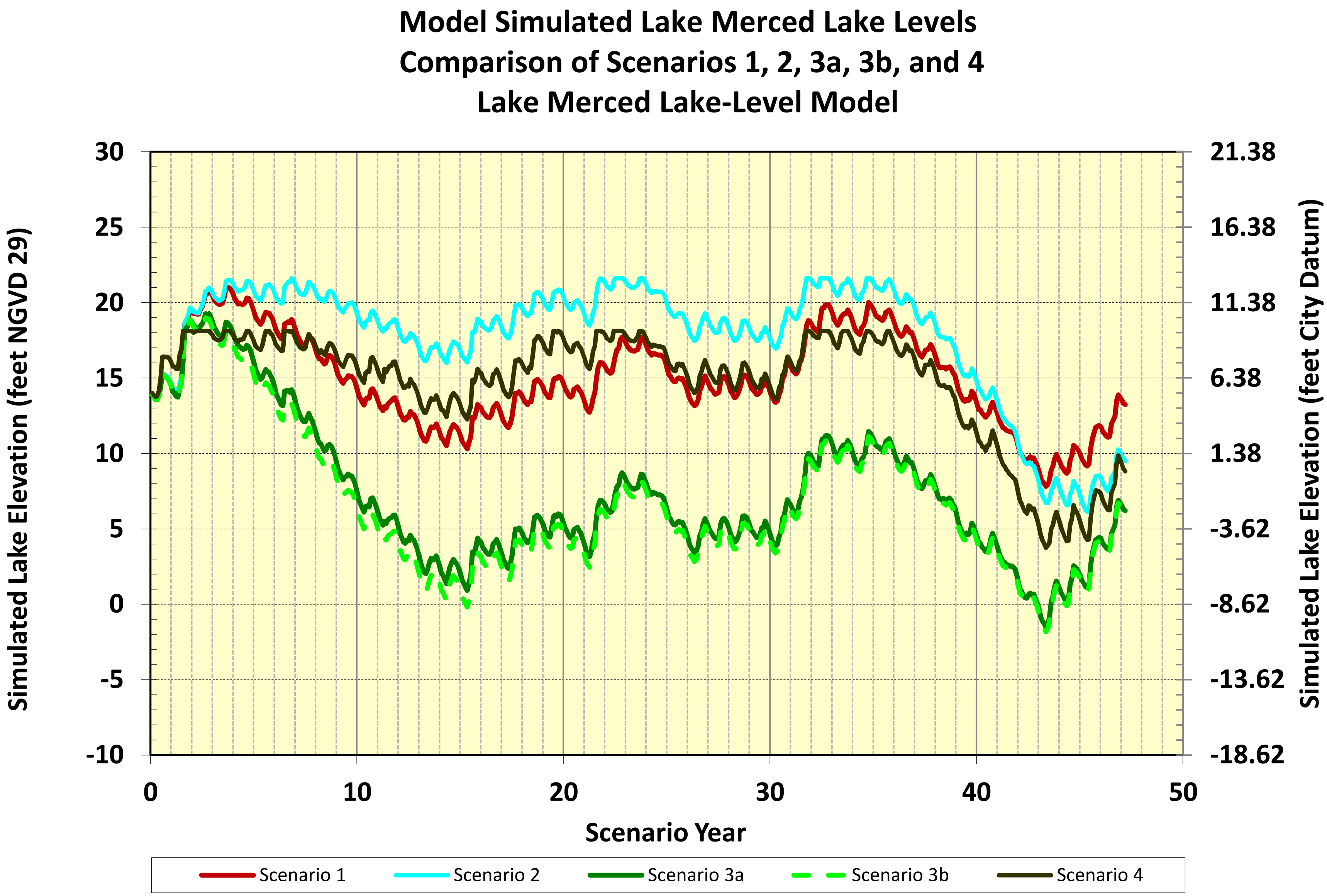
**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
April 2012

# Attachment 10.1-G

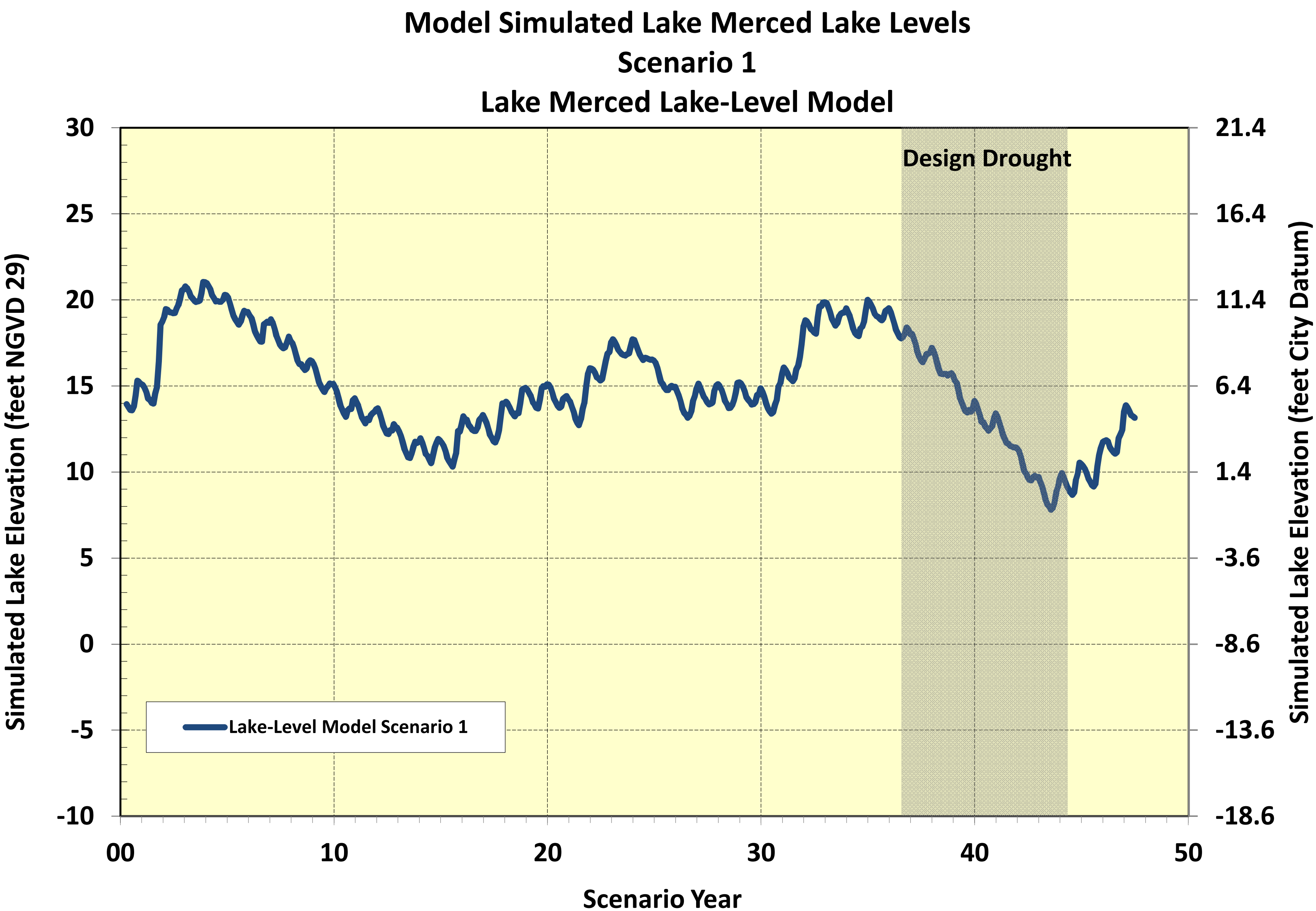
## Model Scenario Lake Hydrographs from Lake Merced Lake-Level Model


Model Simulated Lake Merced Lake Levels
Comparison of Scenarios 1, 2, 3a, 3b, and 4
Lake Merced Lake-Level Model
Simulated Lake Elevation (feet NGVD 29)
Simulated Lake Elevation (feet City Datum)
30
25
20
15
10
5
0
-5
-10
21.38
16.38
11.38
6.38
1.38
-3.62
-8.62
-13.62
-18.62
0
10
20
30
40
50
Scenario Year
Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4

**Lake Merced Lake-Level Model Water Balance**
**Scenario 1**
**SFPUC GSR and SFGW Projects Technical Analysis**

| **Assumptions:** | | **Initial Lake Level** | | **Wetland Source** | | **VG Stormwater** | | **Number of Wells** | | **Diversion Elevation** | | **Spillway Elevation** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(in feet City Datum)** | | **5.7** | | **None** | | **No** | | **No Wells** | | **13.0** | | **13.0** | |
| | | **Lake Merced Natural Hydrology** | | | | | | **Lake Merced Lake Level Management** | | | | **Summary** | |
| **Historical Water Year** | **Scenario Year** | **Precipitation (af)** | **Stormwater Runoff (af)** | **Evaporation (af)** | **Transpiration (af)** | **Groundwater Inflow-Outflow (af)** | **Natural Hydrology Subtotal (af)** | **Lake Additions from Engineered Wetland (af)** | **Lake Additions from Vista Grande Canal Stormflow (af)** | **Lake Additions from Wells (af)** | **Flow over the Spillway (af)** | **Annual (Sept to Sept) Change in Lake Level (feet)** | **Lake Merced Change in Storage (af)** |
| 1996 | 0 | 1 | 0 | -241 | -49 | 78 | -211 | 0 | 0 | 0 | 0 | - | - |
| 1997 | 1 | 499 | 189 | -718 | -144 | 289 | 116 | 0 | 0 | 0 | 0 | 0.41 | 116 |
| 1998 | 2 | 1,186 | 668 | -680 | -134 | 518 | 1,559 | 0 | 0 | 0 | 0 | 5.22 | 1,559 |
| 1999 | 3 | 484 | 134 | -648 | -129 | 382 | 224 | 0 | 0 | 0 | 0 | 0.72 | 224 |
| 2000 | 4 | 481 | 132 | -702 | -135 | 211 | -13 | 0 | 0 | 0 | 0 | -0.04 | -13 |
| 2001 | 5 | 300 | 70 | -673 | -133 | 57 | -378 | 0 | 0 | 0 | 0 | -1.22 | -378 |
| 2002 | 6 | 382 | 104 | -671 | -132 | 29 | -288 | 0 | 0 | 0 | 0 | -0.94 | -288 |
| 2003 | 7 | 514 | 198 | -702 | -136 | 20 | -106 | 0 | 0 | 0 | 0 | -0.33 | -106 |
| 1959 | 8 | 360 | 103 | -688 | -136 | 10 | -352 | 0 | 0 | 0 | 0 | -1.16 | -352 |
| 1960 | 9 | 320 | 96 | -658 | -134 | -65 | -441 | 0 | 0 | 0 | 0 | -1.47 | -441 |
| 1961 | 10 | 369 | 108 | -648 | -134 | -108 | -412 | 0 | 0 | 0 | 0 | -1.41 | -412 |
| 1962 | 11 | 418 | 146 | -599 | -128 | 0 | -163 | 0 | 0 | 0 | 0 | -0.56 | -163 |
| 1963 | 12 | 492 | 170 | -651 | -136 | -48 | -173 | 0 | 0 | 0 | 0 | -0.60 | -173 |
| 1964 | 13 | 316 | 101 | -604 | -131 | -73 | -391 | 0 | 0 | 0 | 0 | -1.38 | -391 |
| 1965 | 14 | 501 | 189 | -584 | -128 | -19 | -41 | 0 | 0 | 0 | 0 | -0.14 | -41 |
| 1966 | 15 | 416 | 157 | -612 | -133 | 99 | -73 | 0 | 0 | 0 | 0 | -0.25 | -73 |
| 1967 | 16 | 717 | 354 | -601 | -130 | 217 | 557 | 0 | 0 | 0 | 0 | 2.00 | 557 |
| 1968 | 17 | 369 | 125 | -649 | -136 | 100 | -191 | 0 | 0 | 0 | 0 | -0.67 | -191 |
| 1969 | 18 | 616 | 257 | -608 | -131 | 273 | 408 | 0 | 0 | 0 | 0 | 1.44 | 408 |
| 1970 | 19 | 536 | 203 | -644 | -133 | 178 | 141 | 0 | 0 | 0 | 0 | 0.50 | 141 |
| 1971 | 20 | 481 | 160 | -610 | -128 | 129 | 32 | 0 | 0 | 0 | 0 | 0.11 | 32 |
| 1972 | 21 | 310 | 95 | -614 | -130 | 16 | -324 | 0 | 0 | 0 | 0 | -1.12 | -324 |
| 1973 | 22 | 810 | 338 | -625 | -131 | 360 | 752 | 0 | 0 | 0 | 0 | 2.59 | 752 |
| 1974 | 23 | 721 | 239 | -642 | -131 | 270 | 457 | 0 | 0 | 0 | 0 | 1.53 | 457 |
| 1975 | 24 | 433 | 125 | -642 | -130 | 112 | -103 | 0 | 0 | 0 | 0 | -0.34 | -103 |
| 1976 | 25 | 236 | 55 | -651 | -134 | 10 | -483 | 0 | 0 | 0 | 0 | -1.61 | -483 |
| 1977 | 26 | 289 | 79 | -647 | -132 | -50 | -462 | 0 | 0 | 0 | 0 | -1.58 | -462 |
| 1978 | 27 | 646 | 239 | -683 | -138 | 148 | 211 | 0 | 0 | 0 | 0 | 0.74 | 211 |
| 1979 | 28 | 418 | 145 | -652 | -135 | 123 | -101 | 0 | 0 | 0 | 0 | -0.34 | -101 |
| 1980 | 29 | 556 | 192 | -641 | -132 | 120 | 94 | 0 | 0 | 0 | 0 | 0.33 | 94 |
| 1981 | 30 | 382 | 125 | -630 | -133 | 59 | -197 | 0 | 0 | 0 | 0 | -0.67 | -197 |
| 1982 | 31 | 778 | 290 | -622 | -130 | 236 | 551 | 0 | 0 | 0 | 0 | 1.89 | 551 |
| 1983 | 32 | 939 | 381 | -719 | -141 | 388 | 848 | 0 | 0 | 0 | 0 | 2.83 | 848 |
| 1984 | 33 | 523 | 184 | -736 | -141 | 290 | 121 | 0 | 0 | 0 | 0 | 0.40 | 121 |
| 1985 | 34 | 469 | 126 | -723 | -140 | 100 | -169 | 0 | 0 | 0 | 0 | -0.55 | -169 |
| 1986 | 35 | 723 | 244 | -741 | -142 | 243 | 327 | 0 | 0 | 0 | 0 | 1.07 | 327 |
| 1987 | 36 | 326 | 91 | -731 | -140 | 91 | -363 | 0 | 0 | 0 | 0 | -1.18 | -363 |
| 1988 | 37 | 360 | 96 | -731 | -141 | 4 | -412 | 0 | 0 | 0 | 0 | -1.35 | -412 |
| 1989 | 38 | 460 | 137 | -699 | -140 | -3 | -246 | 0 | 0 | 0 | 0 | -0.81 | -246 |
| 1990 | 39 | 276 | 75 | -703 | -141 | -80 | -573 | 0 | 0 | 0 | 0 | -1.94 | -573 |
| 1991 | 40 | 410 | 140 | -663 | -137 | -67 | -317 | 0 | 0 | 0 | 0 | -1.09 | -317 |
| 1992 | 41 | 431 | 151 | -716 | -146 | 7 | -273 | 0 | 0 | 0 | 0 | -0.96 | -273 |
| 1976 | 42 | 182 | 47 | -624 | -136 | -26 | -557 | 0 | 0 | 0 | 0 | -2.01 | -557 |
| 1977 | 43 | 264 | 90 | -589 | -132 | -84 | -452 | 0 | 0 | 0 | 0 | -1.69 | -452 |
| 1978 | 44 | 583 | 274 | -632 | -140 | 126 | 210 | 0 | 0 | 0 | 0 | 0.81 | 210 |
| 2004 | 45 | 437 | 198 | -616 | -137 | 233 | 115 | 0 | 0 | 0 | 0 | 0.44 | 115 |
| 2005 | 46 | 681 | 317 | -599 | -132 | 255 | 522 | 0 | 0 | 0 | 0 | 1.94 | 522 |
| 2006 | 47 | 693 | 331 | -624 | -133 | 288 | 556 | 0 | 0 | 0 | 0 | 1.98 | 556 |
| **Average (af)** | | **481** | **176** | **-648** | **-133** | **110** | **-22** | **0** | **0** | **0** | **0** | **-0.05** | **-18** |
| **Maximum (af)** | | **1,186** | **668** | **-241** | **-49** | **518** | **1,559** | **0** | **0** | **0** | **0** | **5.22** | **1,559** |
| **Minimum (af)** | | **1** | **0** | **-741** | **-146** | **-108** | **-573** | **0** | **0** | **0** | **0** | **-2.01** | **-573** |

Key:
af - acre-feet
VG - Vista Grande

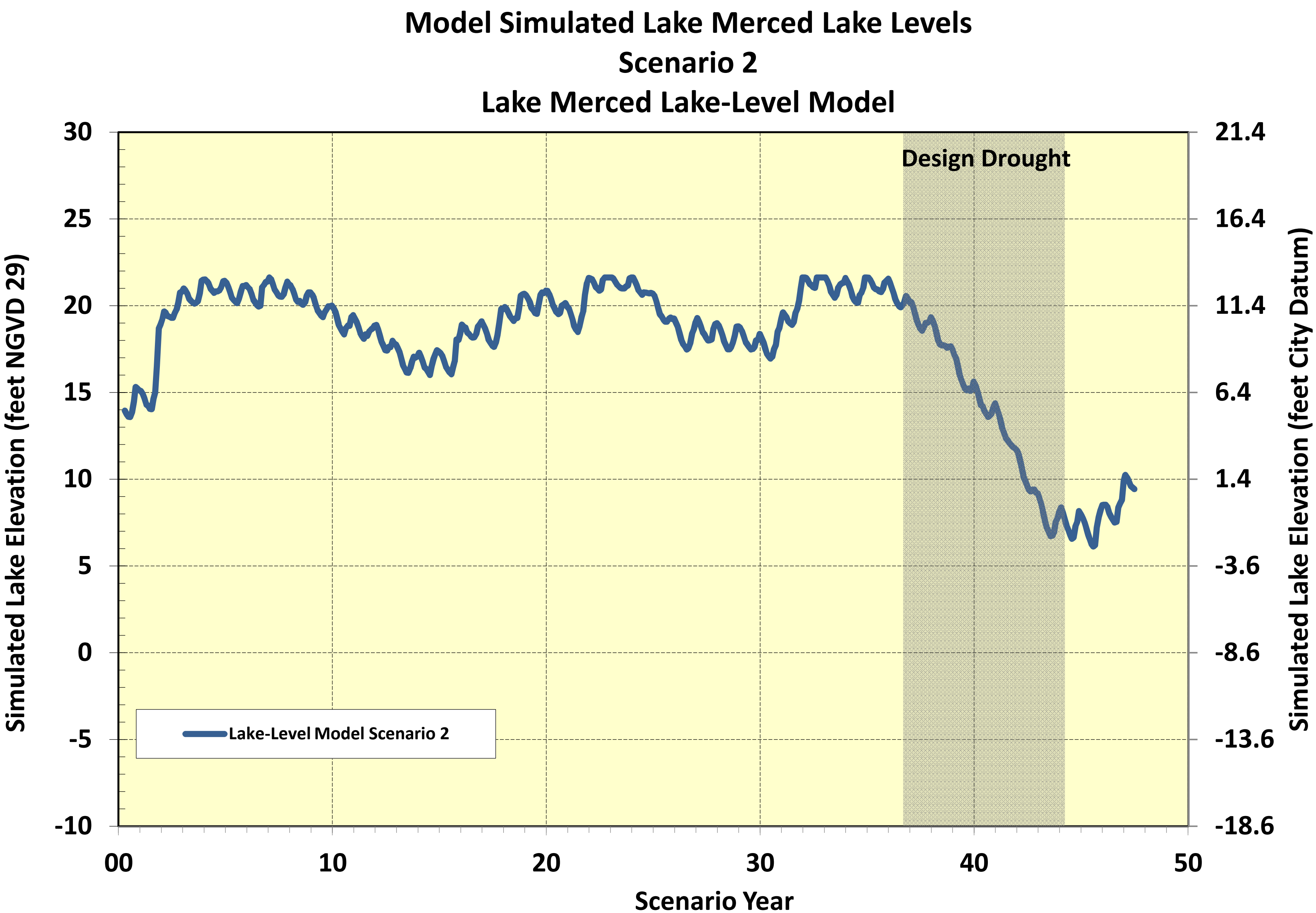


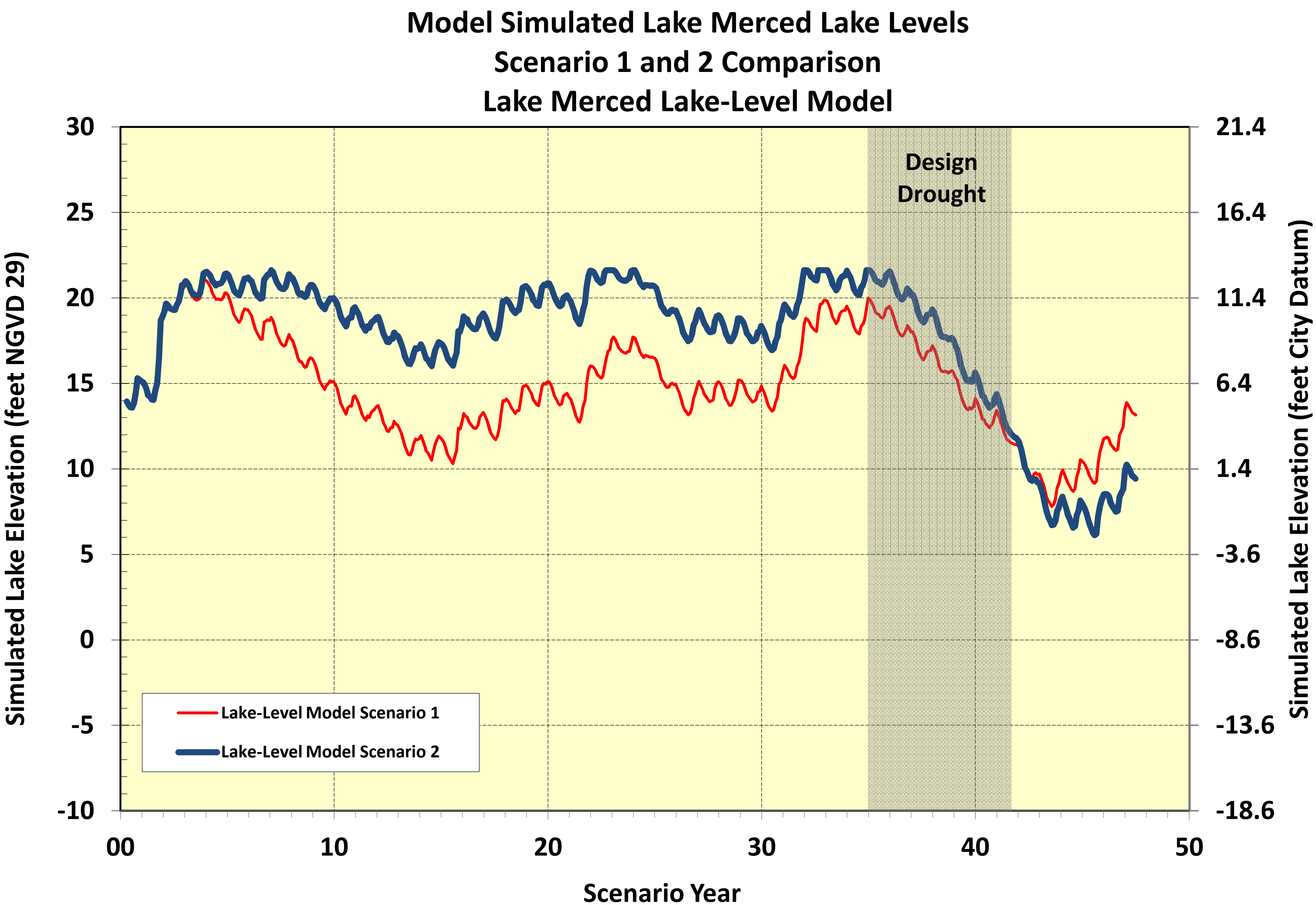
Model Simulated Lake Merced Lake Levels
Scenario 1
Lake Merced Lake-Level Model
Design Drought
Lake-Level Model Scenario 1
Simulated Lake Elevation (feet NGVD 29)
Simulated Lake Elevation (feet City Datum)
Scenario Year
30
25
20
15
10
5
0
-5
-10
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
00
10
20
30
40
50

**Lake Merced Lake-Level Model Water Balance**
**Scenario 2**
**SFPUC GSR and SFGW Projects Technical Analysis**

| **Assumptions:** | | **Initial Lake Level** | | **Wetland Source** | | **VG Stormwater** | | **Number of Wells** | | **Diversion Elevation** | | **Spillway Elevation** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(in feet City Datum)** | | **5.7** | | **None** | | **No** | | **No Wells** | | **13.0** | | **13.0** | |
| | | **Lake Merced Natural Hydrology** | | | | | | **Lake Merced Lake Level Management** | | | | **Summary** | |
| **Historical Water Year** | **Scenario Year** | **Precipitation (af)** | **Stormwater Runoff (af)** | **Evaporation (af)** | **Transpiration (af)** | **Groundwater Inflow-Outflow (af)** | **Natural Hydrology Subtotal (af)** | **Lake Additions from Engineered Wetland (af)** | **Lake Additions from Vista Grande Canal Stormflow (af)** | **Lake Additions from Wells (af)** | **Flow over the Spillway (af)** | **Annual (Sept to Sept) Change in Lake Level (feet)** | **Lake Merced Change in Storage (af)** |
| 1996 | 0 | 1 | 0 | -241 | -49 | 78 | -211 | 0 | 0 | 0 | 0 | - | - |
| 1997 | 1 | 499 | 189 | -718 | -144 | 303 | 129 | 0 | 0 | 0 | 0 | 0.46 | 129 |
| 1998 | 2 | 1,188 | 667 | -681 | -134 | 526 | 1,565 | 0 | 0 | 0 | 0 | 5.24 | 1,565 |
| 1999 | 3 | 485 | 133 | -650 | -129 | 433 | 273 | 0 | 0 | 0 | 0 | 0.88 | 273 |
| 2000 | 4 | 482 | 131 | -705 | -135 | 403 | 176 | 0 | 0 | 0 | 0 | 0.56 | 176 |
| 2001 | 5 | 303 | 69 | -680 | -133 | 279 | -162 | 0 | 0 | 0 | 0 | -0.51 | -162 |
| 2002 | 6 | 389 | 100 | -685 | -132 | 273 | -55 | 0 | 0 | 0 | 0 | -0.17 | -55 |
| 2003 | 7 | 528 | 190 | -720 | -136 | 329 | 191 | 0 | 0 | 0 | -19 | 0.55 | 210 |
| 1959 | 8 | 374 | 95 | -714 | -136 | 275 | -106 | 0 | 0 | 0 | 0 | -0.34 | -106 |
| 1960 | 9 | 335 | 88 | -690 | -134 | 144 | -257 | 0 | 0 | 0 | 0 | -0.82 | -257 |
| 1961 | 10 | 389 | 99 | -686 | -134 | 38 | -295 | 0 | 0 | 0 | 0 | -0.95 | -295 |
| 1962 | 11 | 445 | 131 | -638 | -128 | 62 | -129 | 0 | 0 | 0 | 0 | -0.42 | -129 |
| 1963 | 12 | 526 | 151 | -696 | -136 | -43 | -198 | 0 | 0 | 0 | 0 | -0.64 | -198 |
| 1964 | 13 | 338 | 90 | -647 | -131 | -45 | -394 | 0 | 0 | 0 | 0 | -1.30 | -394 |
| 1965 | 14 | 539 | 168 | -628 | -128 | 57 | 7 | 0 | 0 | 0 | 0 | 0.03 | 7 |
| 1966 | 15 | 451 | 137 | -660 | -133 | 200 | -5 | 0 | 0 | 0 | 0 | -0.01 | -5 |
| 1967 | 16 | 776 | 318 | -649 | -130 | 309 | 624 | 0 | 0 | 0 | 0 | 2.07 | 624 |
| 1968 | 17 | 398 | 110 | -701 | -136 | 163 | -166 | 0 | 0 | 0 | 0 | -0.54 | -166 |
| 1969 | 18 | 665 | 228 | -653 | -131 | 325 | 435 | 0 | 0 | 0 | 0 | 1.42 | 435 |
| 1970 | 19 | 575 | 181 | -688 | -133 | 204 | 139 | 0 | 0 | 0 | 0 | 0.45 | 139 |
| 1971 | 20 | 513 | 142 | -652 | -128 | 141 | 16 | 0 | 0 | 0 | 0 | 0.06 | 16 |
| 1972 | 21 | 330 | 85 | -657 | -130 | 16 | -357 | 0 | 0 | 0 | 0 | -1.15 | -357 |
| 1973 | 22 | 864 | 304 | -662 | -131 | 369 | 745 | 0 | 0 | 0 | 0 | 2.39 | 745 |
| 1974 | 23 | 763 | 214 | -672 | -131 | 478 | 652 | 0 | 0 | 0 | -604 | 0.15 | 1,255 |
| 1975 | 24 | 450 | 115 | -669 | -130 | 245 | 12 | 0 | 0 | 0 | -137 | -0.39 | 149 |
| 1976 | 25 | 249 | 50 | -682 | -134 | 68 | -450 | 0 | 0 | 0 | 0 | -1.44 | -450 |
| 1977 | 26 | 303 | 72 | -680 | -132 | -39 | -476 | 0 | 0 | 0 | 0 | -1.54 | -476 |
| 1978 | 27 | 682 | 217 | -718 | -138 | 108 | 151 | 0 | 0 | 0 | 0 | 0.50 | 151 |
| 1979 | 28 | 439 | 133 | -684 | -135 | 45 | -201 | 0 | 0 | 0 | 0 | -0.65 | -201 |
| 1980 | 29 | 583 | 176 | -669 | -132 | 79 | 36 | 0 | 0 | 0 | 0 | 0.12 | 36 |
| 1981 | 30 | 400 | 115 | -658 | -133 | 74 | -201 | 0 | 0 | 0 | 0 | -0.66 | -201 |
| 1982 | 31 | 813 | 268 | -647 | -130 | 288 | 592 | 0 | 0 | 0 | 0 | 1.94 | 592 |
| 1983 | 32 | 976 | 358 | -743 | -141 | 483 | 934 | 0 | 0 | 0 | -257 | 2.17 | 1,190 |
| 1984 | 33 | 537 | 176 | -752 | -141 | 482 | 302 | 0 | 0 | 0 | -496 | -0.61 | 798 |
| 1985 | 34 | 477 | 122 | -737 | -140 | 199 | -80 | 0 | 0 | 0 | 0 | -0.25 | -80 |
| 1986 | 35 | 740 | 234 | -755 | -142 | 403 | 480 | 0 | 0 | 0 | -248 | 0.74 | 728 |
| 1987 | 36 | 332 | 88 | -746 | -140 | 163 | -302 | 0 | 0 | 0 | 0 | -0.96 | -302 |
| 1988 | 37 | 367 | 93 | -746 | -141 | 22 | -404 | 0 | 0 | 0 | 0 | -1.30 | -404 |
| 1989 | 38 | 471 | 130 | -715 | -140 | -44 | -297 | 0 | 0 | 0 | 0 | -0.96 | -297 |
| 1990 | 39 | 283 | 72 | -719 | -141 | -176 | -682 | 0 | 0 | 0 | 0 | -2.26 | -682 |
| 1991 | 40 | 420 | 135 | -677 | -137 | -196 | -455 | 0 | 0 | 0 | 0 | -1.54 | -455 |
| 1992 | 41 | 439 | 147 | -727 | -146 | -166 | -454 | 0 | 0 | 0 | 0 | -1.57 | -454 |
| 1976 | 42 | 184 | 46 | -627 | -136 | -236 | -770 | 0 | 0 | 0 | 0 | -2.77 | -770 |
| 1977 | 43 | 260 | 92 | -579 | -132 | -326 | -686 | 0 | 0 | 0 | 0 | -2.61 | -686 |
| 1978 | 44 | 566 | 284 | -611 | -140 | -151 | -51 | 0 | 0 | 0 | 0 | -0.19 | -51 |
| 2004 | 45 | 414 | 212 | -584 | -137 | -38 | -132 | 0 | 0 | 0 | 0 | -0.51 | -132 |
| 2005 | 46 | 635 | 344 | -556 | -132 | 52 | 343 | 0 | 0 | 0 | 0 | 1.37 | 343 |
| 2006 | 47 | 645 | 361 | -582 | -133 | 172 | 463 | 0 | 0 | 0 | 0 | 1.78 | 463 |
| | **Average (af)** | **496** | **168** | **-667** | **-133** | **142** | **-4** | **0** | **0** | **0** | **-37** | **-0.13** | **39** |
| | **Maximum (af)** | **1,188** | **667** | **-241** | **-49** | **526** | **1,565** | **0** | **0** | **0** | **0** | **5.24** | **1,565** |
| | **Minimum (af)** | **1** | **0** | **-755** | **-146** | **-326** | **-770** | **0** | **0** | **0** | **-604** | **-2.77** | **-770** |

Key:
af - acre-feet
VG - Vista Grande


Model Simulated Lake Merced Lake Levels
Scenario 2
Lake Merced Lake-Level Model
Design Drought
Lake-Level Model Scenario 2
Simulated Lake Elevation (feet NGVD 29)
Simulated Lake Elevation (feet City Datum)
Scenario Year
30
25
20
15
10
5
0
-5
-10
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
00
10
20
30
40
50

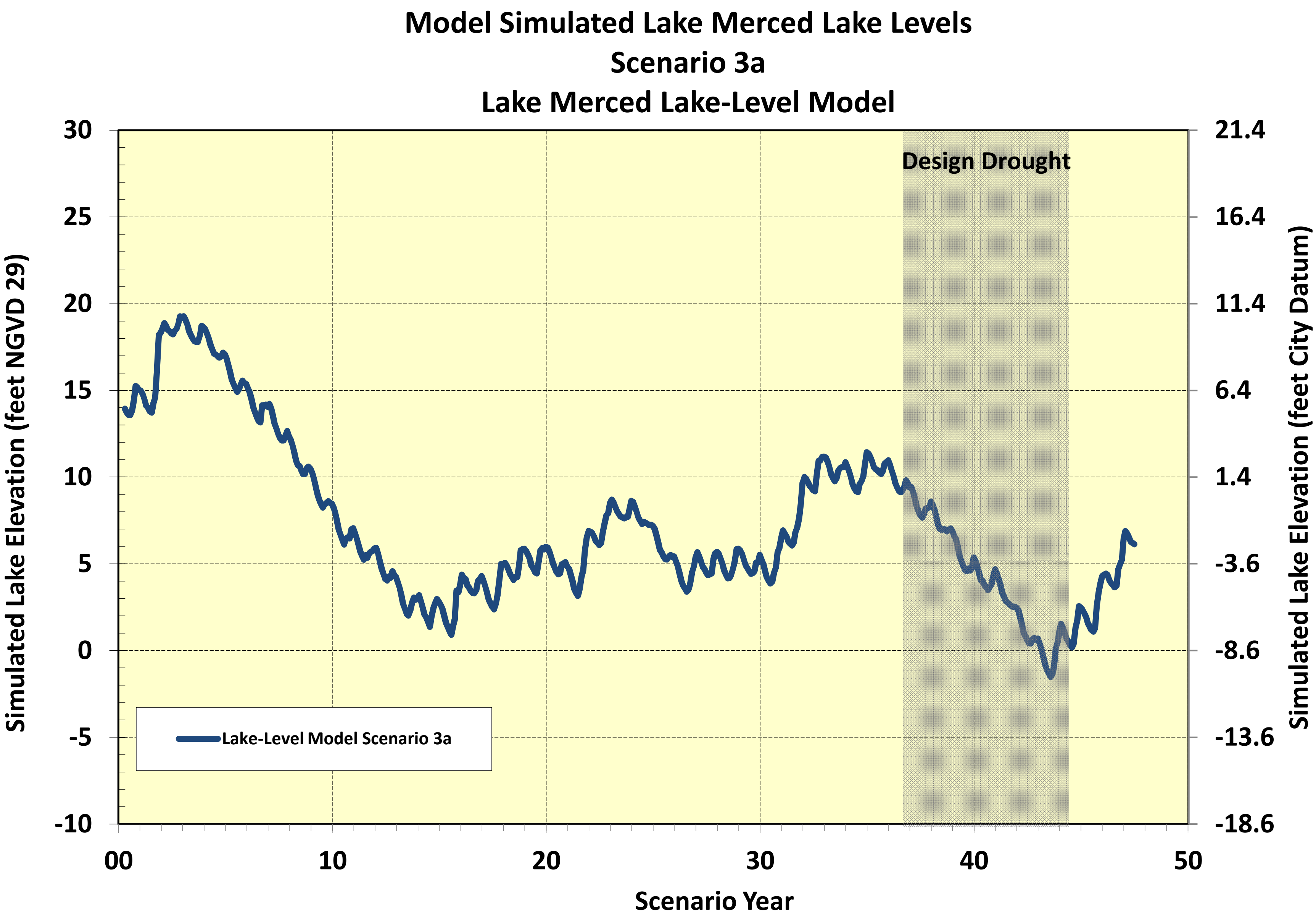


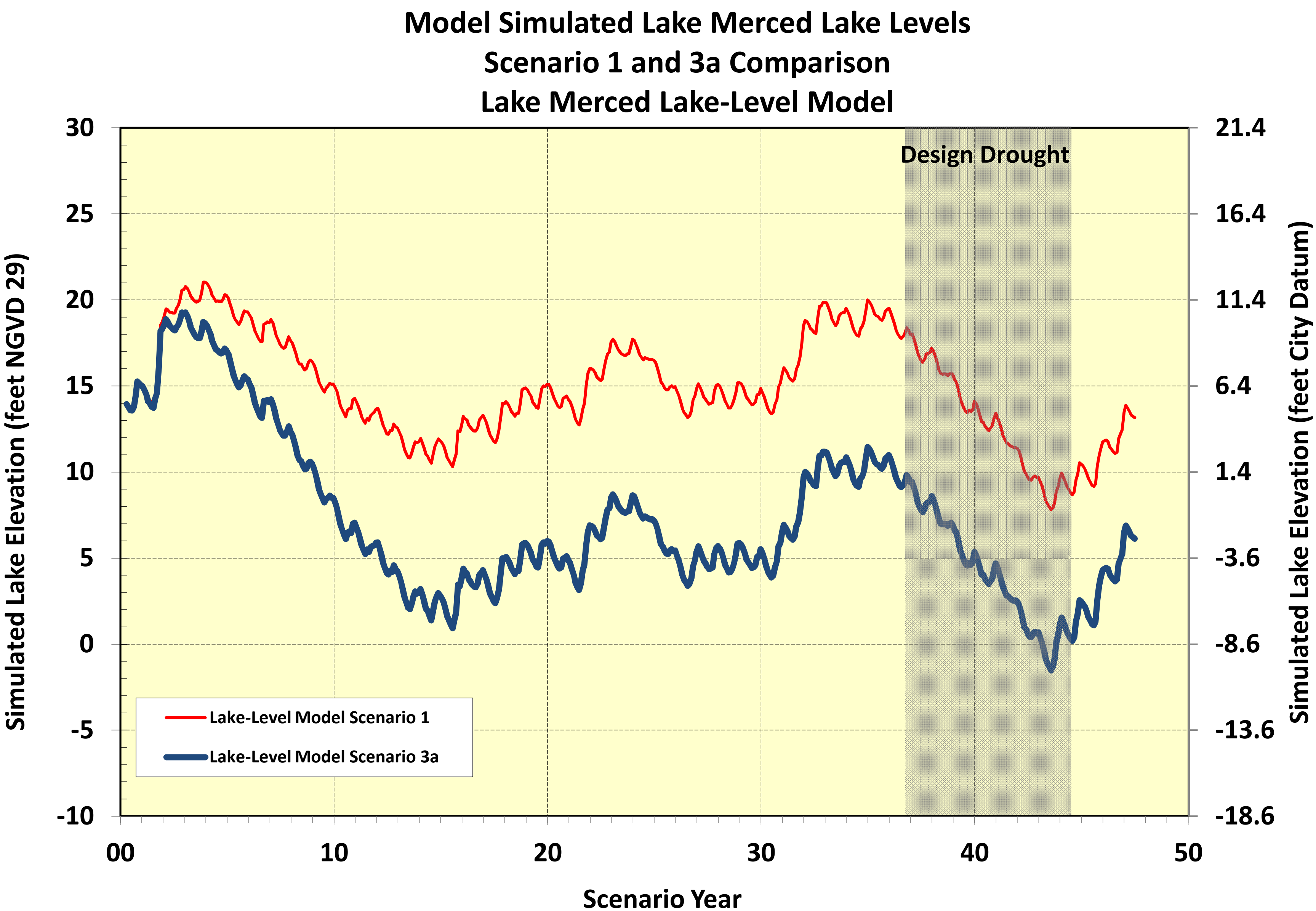
Model Simulated Lake Merced Lake Levels
Scenario 1 and 2 Comparison
Lake Merced Lake-Level Model
Simulated Lake Elevation (feet NGVD 29)
Simulated Lake Elevation (feet City Datum)
Scenario Year
Design Drought
Lake-Level Model Scenario 1
Lake-Level Model Scenario 2
30
25
20
15
10
5
0
-5
-10
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
00
10
20
30
40
50

**Lake Merced Lake-Level Model Water Balance**
**Scenario 3a**
**SFPUC GSR and SFGW Projects Technical Analysis**

| Assumptions: | | Initial Lake Level | | Wetland Source | | VG Stormwater | | Number of Wells | | Diversion Elevation | | Spillway Elevation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (in feet City Datum) | | 5.7 | | None | | No | | No Wells | | 13.0 | | 13.0 | |
| | | Lake Merced Natural Hydrology | | | | | | Lake Merced Lake Level Management | | | | Summary | |
| Historical Water Year | Scenario Year | Precipitation (af) | Stormwater Runoff (af) | Evaporation (af) | Transpiration (af) | Groundwater Inflow-Outflow (af) | Natural Hydrology Subtotal (af) | Lake Additions from Engineered Wetland (af) | Lake Additions from Vista Grande Canal Stormflow (af) | Lake Additions from Wells (af) | Flow over the Spillway (af) | Annual (Sept to Sept) Change in Lake Level (feet) | Lake Merced Change in Storage (af) |
| 1996 | 0 | 1 | 0 | -241 | -49 | 76 | -213 | 0 | 0 | 0 | 0 | - | - |
| 1997 | 1 | 499 | 189 | -717 | -144 | 226 | 54 | 0 | 0 | 0 | 0 | 0.20 | 54 |
| 1998 | 2 | 1,180 | 672 | -677 | -134 | 289 | 1,331 | 0 | 0 | 0 | 0 | 4.50 | 1,331 |
| 1999 | 3 | 478 | 137 | -639 | -129 | 60 | -93 | 0 | 0 | 0 | 0 | -0.30 | -93 |
| 2000 | 4 | 471 | 137 | -686 | -135 | -56 | -268 | 0 | 0 | 0 | 0 | -0.88 | -268 |
| 2001 | 5 | 291 | 75 | -649 | -133 | -184 | -601 | 0 | 0 | 0 | 0 | -2.00 | -601 |
| 2002 | 6 | 366 | 112 | -640 | -132 | -190 | -485 | 0 | 0 | 0 | 0 | -1.65 | -485 |
| 2003 | 7 | 487 | 214 | -661 | -136 | -189 | -286 | 0 | 0 | 0 | 0 | -0.98 | -286 |
| 1959 | 8 | 336 | 115 | -640 | -136 | -196 | -521 | 0 | 0 | 0 | 0 | -1.84 | -521 |
| 1960 | 9 | 291 | 111 | -597 | -134 | -262 | -591 | 0 | 0 | 0 | 0 | -2.18 | -591 |
| 1961 | 10 | 326 | 130 | -571 | -134 | -291 | -540 | 0 | 0 | 0 | 0 | -2.09 | -540 |
| 1962 | 11 | 361 | 179 | -517 | -128 | -177 | -282 | 0 | 0 | 0 | 0 | -1.13 | -282 |
| 1963 | 12 | 419 | 210 | -549 | -136 | -211 | -267 | 0 | 0 | 0 | 0 | -1.12 | -267 |
| 1964 | 13 | 260 | 129 | -487 | -131 | -225 | -455 | 0 | 0 | 0 | 0 | -2.01 | -455 |
| 1965 | 14 | 386 | 255 | -448 | -128 | -166 | -103 | 0 | 0 | 0 | 0 | -0.47 | -103 |
| 1966 | 15 | 314 | 214 | -462 | -133 | -45 | -112 | 0 | 0 | 0 | 0 | -0.51 | -112 |
| 1967 | 16 | 548 | 458 | -479 | -130 | 76 | 474 | 0 | 0 | 0 | 0 | 2.32 | 474 |
| 1968 | 17 | 294 | 165 | -518 | -136 | -22 | -217 | 0 | 0 | 0 | 0 | -0.94 | -217 |
| 1969 | 18 | 487 | 334 | -491 | -131 | 144 | 343 | 0 | 0 | 0 | 0 | 1.57 | 343 |
| 1970 | 19 | 441 | 258 | -533 | -133 | 68 | 102 | 0 | 0 | 0 | 0 | 0.46 | 102 |
| 1971 | 20 | 395 | 208 | -507 | -128 | 27 | -4 | 0 | 0 | 0 | 0 | 0.01 | -4 |
| 1972 | 21 | 250 | 125 | -495 | -130 | -74 | -324 | 0 | 0 | 0 | 0 | -1.39 | -324 |
| 1973 | 22 | 656 | 434 | -521 | -131 | 248 | 685 | 0 | 0 | 0 | 0 | 2.94 | 685 |
| 1974 | 23 | 615 | 303 | -551 | -131 | 180 | 416 | 0 | 0 | 0 | 0 | 1.65 | 416 |
| 1975 | 24 | 372 | 156 | -551 | -130 | 36 | -116 | 0 | 0 | 0 | 0 | -0.45 | -116 |
| 1976 | 25 | 201 | 69 | -551 | -134 | -57 | -472 | 0 | 0 | 0 | 0 | -1.87 | -472 |
| 1977 | 26 | 235 | 103 | -524 | -132 | -116 | -435 | 0 | 0 | 0 | 0 | -1.83 | -435 |
| 1978 | 27 | 519 | 315 | -555 | -138 | 63 | 205 | 0 | 0 | 0 | 0 | 0.91 | 205 |
| 1979 | 28 | 338 | 191 | -530 | -135 | 53 | -83 | 0 | 0 | 0 | 0 | -0.33 | -83 |
| 1980 | 29 | 455 | 250 | -527 | -132 | 50 | 95 | 0 | 0 | 0 | 0 | 0.42 | 95 |
| 1981 | 30 | 310 | 164 | -511 | -133 | -1 | -171 | 0 | 0 | 0 | 0 | -0.71 | -171 |
| 1982 | 31 | 642 | 372 | -521 | -130 | 158 | 522 | 0 | 0 | 0 | 0 | 2.19 | 522 |
| 1983 | 32 | 806 | 464 | -627 | -141 | 314 | 815 | 0 | 0 | 0 | 0 | 3.18 | 815 |
| 1984 | 33 | 459 | 220 | -652 | -141 | 245 | 132 | 0 | 0 | 0 | 0 | 0.51 | 132 |
| 1985 | 34 | 413 | 155 | -638 | -140 | 58 | -152 | 0 | 0 | 0 | 0 | -0.55 | -152 |
| 1986 | 35 | 640 | 294 | -659 | -142 | 193 | 326 | 0 | 0 | 0 | 0 | 1.21 | 326 |
| 1987 | 36 | 290 | 111 | -648 | -140 | 59 | -328 | 0 | 0 | 0 | 0 | -1.20 | -328 |
| 1988 | 37 | 313 | 120 | -637 | -141 | -32 | -377 | 0 | 0 | 0 | 0 | -1.41 | -377 |
| 1989 | 38 | 397 | 170 | -602 | -140 | -41 | -216 | 0 | 0 | 0 | 0 | -0.83 | -216 |
| 1990 | 39 | 235 | 94 | -593 | -141 | -110 | -514 | 0 | 0 | 0 | 0 | -2.07 | -514 |
| 1991 | 40 | 337 | 178 | -544 | -137 | -101 | -267 | 0 | 0 | 0 | 0 | -1.12 | -267 |
| 1992 | 41 | 350 | 196 | -581 | -146 | -38 | -219 | 0 | 0 | 0 | 0 | -0.94 | -219 |
| 1976 | 42 | 138 | 63 | -469 | -136 | -58 | -463 | 0 | 0 | 0 | 0 | -2.23 | -463 |
| 1977 | 43 | 188 | 124 | -415 | -132 | -116 | -351 | 0 | 0 | 0 | 0 | -1.88 | -351 |
| 1978 | 44 | 390 | 392 | -451 | -140 | 63 | 254 | 0 | 0 | 0 | 0 | 1.60 | 254 |
| 2004 | 45 | 326 | 265 | -467 | -137 | 178 | 165 | 0 | 0 | 0 | 0 | 0.87 | 165 |
| 2005 | 46 | 535 | 405 | -488 | -132 | 210 | 530 | 0 | 0 | 0 | 0 | 2.57 | 530 |
| 2006 | 47 | 588 | 396 | -537 | -133 | 246 | 560 | 0 | 0 | 0 | 0 | 2.37 | 560 |
| **Average (af)** | | **409** | **217** | **-553** | **-133** | **2** | **-65** | **0** | **0** | **0** | **0** | **-0.21** | **-62** |
| **Maximum (af)** | | **1,180** | **672** | **-241** | **-49** | **314** | **1,331** | **0** | **0** | **0** | **0** | **4.50** | **1,331** |
| **Minimum (af)** | | **1** | **0** | **-717** | **-146** | **-291** | **-601** | **0** | **0** | **0** | **0** | **-2.23** | **-601** |

Key:
af - acre-feet
VG - Vista Grande


Model Simulated Lake Merced Lake Levels
Scenario 3a
Lake Merced Lake-Level Model
Design Drought
Lake-Level Model Scenario 3a
Simulated Lake Elevation (feet NGVD 29)
Simulated Lake Elevation (feet City Datum)
Scenario Year
30
25
20
15
10
5
0
-5
-10
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
00
10
20
30
40
50



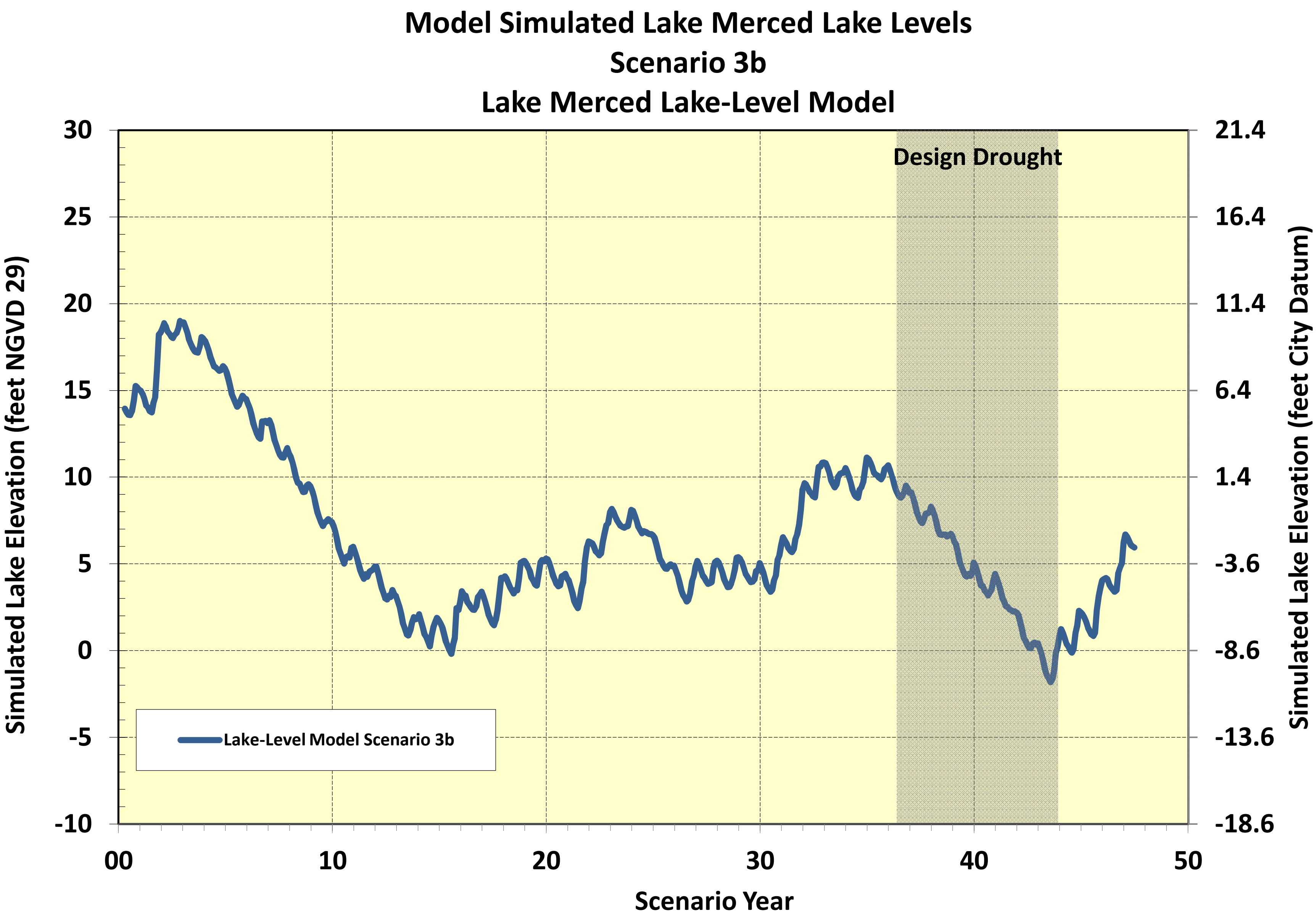
Model Simulated Lake Merced Lake Levels
Scenario 1 and 3a Comparison
Lake Merced Lake-Level Model
Design Drought
Simulated Lake Elevation (feet NGVD 29)
Simulated Lake Elevation (feet City Datum)
Scenario Year
Lake-Level Model Scenario 1
Lake-Level Model Scenario 3a
30
25
20
15
10
5
0
-5
-10
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
00
10
20
30
40
50


D.5-255

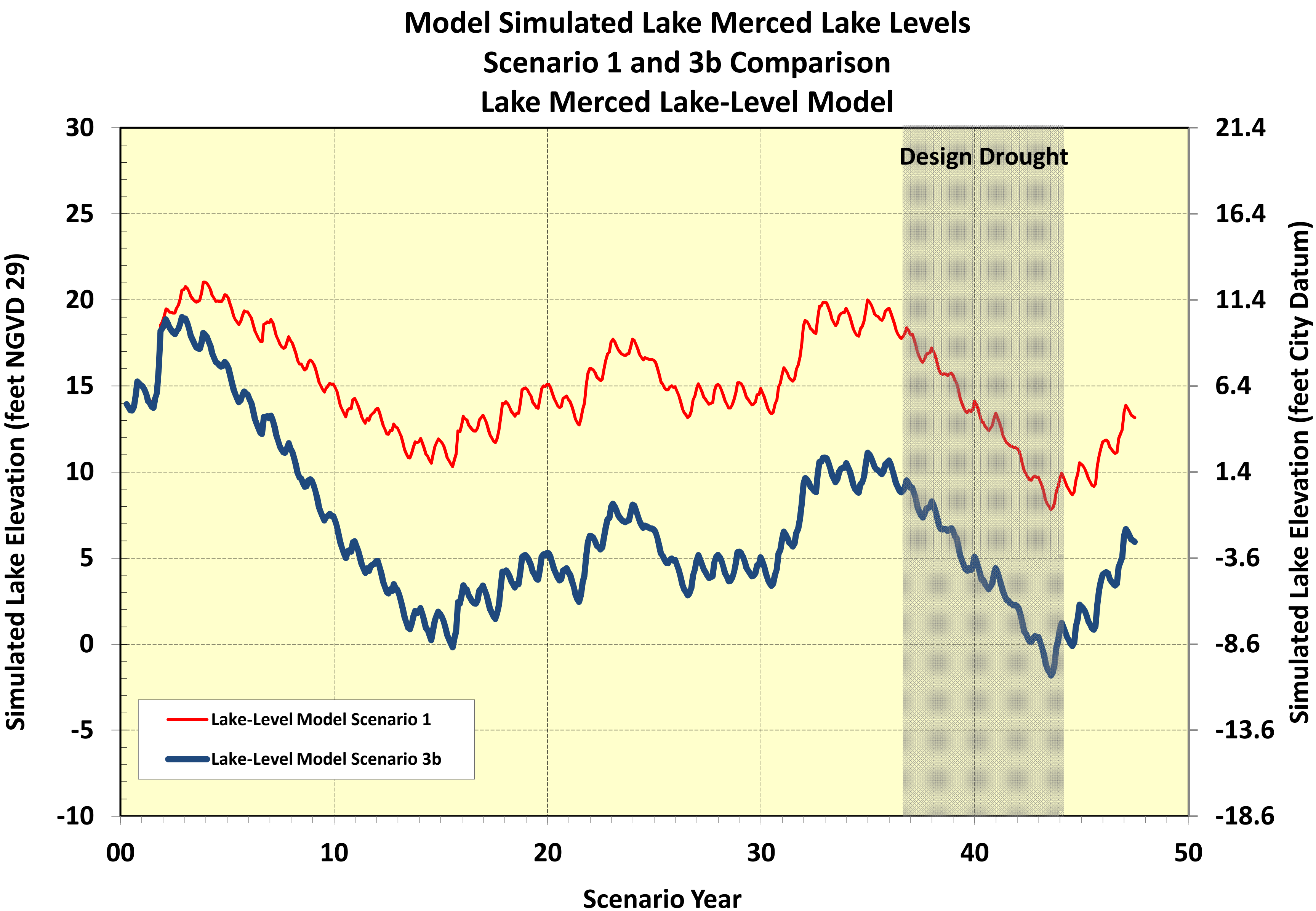
## Lake Merced Lake-Level Model Water Balance
## Scenario 3b
## SFPUC GSR and SFGW Projects Technical Analysis

| **Assumptions:** | | **Initial Lake Level** | | **Wetland Source** | | **VG Stormwater** | | **Number of Wells** | | **Diversion Elevation** | | **Spillway Elevation** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (in feet City Datum) | | 5.7 | | None | | No | | No Wells | | 13.0 | | 13.0 | |
| | | **Lake Merced Natural Hydrology** | | | | | | **Lake Merced Lake Level Management** | | | | **Summary** | |
| **Historical Water Year** | **Scenario Year** | **Precipitation (af)** | **Stormwater Runoff (af)** | **Evaporation (af)** | **Transpiration (af)** | **Groundwater Inflow-Outflow (af)** | **Natural Hydrology Subtotal (af)** | **Lake Additions from Engineered Wetland (af)** | **Lake Additions from Vista Grande Canal Stormflow (af)** | **Lake Additions from Wells (af)** | **Flow over the Spillway (af)** | **Annual (Sept to Sept) Change in Lake Level (feet)** | **Lake Merced Change in Storage (af)** |
| 1996 | 0 | 1 | 0 | -241 | -49 | 76 | -213 | 0 | 0 | 0 | 0 | - | - |
| 1997 | 1 | 499 | 189 | -717 | -144 | 229 | 57 | 0 | 0 | 0 | 0 | 0.21 | 57 |
| 1998 | 2 | 1,180 | 672 | -677 | -134 | 229 | 1,270 | 0 | 0 | 0 | 0 | 4.30 | 1,270 |
| 1999 | 3 | 477 | 138 | -637 | -129 | -54 | -206 | 0 | 0 | 0 | 0 | -0.66 | -206 |
| 2000 | 4 | 466 | 140 | -680 | -135 | -113 | -323 | 0 | 0 | 0 | 0 | -1.06 | -323 |
| 2001 | 5 | 287 | 76 | -643 | -133 | -216 | -629 | 0 | 0 | 0 | 0 | -2.11 | -629 |
| 2002 | 6 | 361 | 115 | -632 | -132 | -216 | -505 | 0 | 0 | 0 | 0 | -1.74 | -505 |
| 2003 | 7 | 480 | 218 | -651 | -136 | -202 | -292 | 0 | 0 | 0 | 0 | -1.02 | -292 |
| 1959 | 8 | 330 | 118 | -629 | -136 | -206 | -523 | 0 | 0 | 0 | 0 | -1.89 | -523 |
| 1960 | 9 | 285 | 114 | -584 | -134 | -270 | -589 | 0 | 0 | 0 | 0 | -2.22 | -589 |
| 1961 | 10 | 318 | 134 | -556 | -134 | -297 | -535 | 0 | 0 | 0 | 0 | -2.13 | -535 |
| 1962 | 11 | 348 | 186 | -500 | -128 | -182 | -276 | 0 | 0 | 0 | 0 | -1.13 | -276 |
| 1963 | 12 | 403 | 220 | -528 | -136 | -216 | -257 | 0 | 0 | 0 | 0 | -1.12 | -257 |
| 1964 | 13 | 247 | 135 | -457 | -131 | -229 | -434 | 0 | 0 | 0 | 0 | -2.07 | -434 |
| 1965 | 14 | 366 | 266 | -426 | -128 | -169 | -91 | 0 | 0 | 0 | 0 | -0.44 | -91 |
| 1966 | 15 | 300 | 221 | -438 | -133 | -47 | -96 | 0 | 0 | 0 | 0 | -0.48 | -96 |
| 1967 | 16 | 524 | 473 | -456 | -130 | 75 | 486 | 0 | 0 | 0 | 0 | 2.46 | 486 |
| 1968 | 17 | 278 | 174 | -490 | -136 | -24 | -198 | 0 | 0 | 0 | 0 | -0.90 | -198 |
| 1969 | 18 | 462 | 349 | -477 | -131 | 143 | 348 | 0 | 0 | 0 | 0 | 1.71 | 348 |
| 1970 | 19 | 425 | 268 | -517 | -133 | 67 | 110 | 0 | 0 | 0 | 0 | 0.52 | 110 |
| 1971 | 20 | 387 | 213 | -494 | -128 | 25 | 3 | 0 | 0 | 0 | 0 | 0.03 | 3 |
| 1972 | 21 | 247 | 126 | -483 | -130 | -75 | -316 | 0 | 0 | 0 | 0 | -1.40 | -316 |
| 1973 | 22 | 637 | 446 | -513 | -131 | 248 | 687 | 0 | 0 | 0 | 0 | 3.05 | 687 |
| 1974 | 23 | 603 | 310 | -543 | -131 | 180 | 418 | 0 | 0 | 0 | 0 | 1.71 | 418 |
| 1975 | 24 | 367 | 159 | -544 | -130 | 35 | -113 | 0 | 0 | 0 | 0 | -0.44 | -113 |
| 1976 | 25 | 200 | 69 | -544 | -134 | -59 | -467 | 0 | 0 | 0 | 0 | -1.88 | -467 |
| 1977 | 26 | 233 | 104 | -517 | -132 | -117 | -429 | 0 | 0 | 0 | 0 | -1.84 | -429 |
| 1978 | 27 | 510 | 321 | -547 | -138 | 63 | 209 | 0 | 0 | 0 | 0 | 0.95 | 209 |
| 1979 | 28 | 337 | 191 | -526 | -135 | 53 | -80 | 0 | 0 | 0 | 0 | -0.33 | -80 |
| 1980 | 29 | 450 | 252 | -519 | -132 | 49 | 101 | 0 | 0 | 0 | 0 | 0.44 | 101 |
| 1981 | 30 | 306 | 166 | -505 | -133 | -1 | -167 | 0 | 0 | 0 | 0 | -0.70 | -167 |
| 1982 | 31 | 625 | 383 | -513 | -130 | 159 | 524 | 0 | 0 | 0 | 0 | 2.28 | 524 |
| 1983 | 32 | 799 | 468 | -621 | -141 | 314 | 819 | 0 | 0 | 0 | 0 | 3.22 | 819 |
| 1984 | 33 | 458 | 221 | -649 | -141 | 245 | 134 | 0 | 0 | 0 | 0 | 0.52 | 134 |
| 1985 | 34 | 409 | 157 | -634 | -140 | 58 | -150 | 0 | 0 | 0 | 0 | -0.55 | -150 |
| 1986 | 35 | 633 | 298 | -654 | -142 | 193 | 328 | 0 | 0 | 0 | 0 | 1.23 | 328 |
| 1987 | 36 | 287 | 113 | -643 | -140 | 58 | -325 | 0 | 0 | 0 | 0 | -1.20 | -325 |
| 1988 | 37 | 313 | 120 | -633 | -141 | -32 | -374 | 0 | 0 | 0 | 0 | -1.42 | -374 |
| 1989 | 38 | 394 | 172 | -598 | -140 | -41 | -213 | 0 | 0 | 0 | 0 | -0.82 | -213 |
| 1990 | 39 | 234 | 95 | -591 | -141 | -110 | -514 | 0 | 0 | 0 | 0 | -2.07 | -514 |
| 1991 | 40 | 333 | 180 | -538 | -137 | -101 | -263 | 0 | 0 | 0 | 0 | -1.11 | -263 |
| 1992 | 41 | 341 | 201 | -569 | -146 | -37 | -211 | 0 | 0 | 0 | 0 | -0.92 | -211 |
| 1976 | 42 | 135 | 64 | -462 | -136 | -58 | -457 | 0 | 0 | 0 | 0 | -2.23 | -457 |
| 1977 | 43 | 186 | 125 | -399 | -132 | -116 | -336 | 0 | 0 | 0 | 0 | -1.92 | -336 |
| 1978 | 44 | 390 | 392 | -450 | -140 | 65 | 257 | 0 | 0 | 0 | 0 | 1.62 | 257 |
| 2004 | 45 | 322 | 268 | -466 | -137 | 179 | 166 | 0 | 0 | 0 | 0 | 0.90 | 166 |
| 2005 | 46 | 535 | 405 | -488 | -132 | 211 | 531 | 0 | 0 | 0 | 0 | 2.58 | 531 |
| 2006 | 47 | 578 | 402 | -531 | -133 | 247 | 563 | 0 | 0 | 0 | 0 | 2.44 | 563 |
| **Average (af)** | | **402** | **221** | **-544** | **-133** | **-5** | **-67** | **0** | **0** | **0** | **0** | **-0.22** | **-63** |
| **Maximum (af)** | | **1,180** | **672** | **-241** | **-49** | **314** | **1,270** | **0** | **0** | **0** | **0** | **4.30** | **1,270** |
| **Minimum (af)** | | **1** | **0** | **-717** | **-146** | **-297** | **-629** | **0** | **0** | **0** | **0** | **-2.23** | **-629** |

Key:
af - acre-feet
VG - Vista Grande



Model Simulated Lake Merced Lake Levels
Scenario 3b
Lake Merced Lake-Level Model
Design Drought
Lake-Level Model Scenario 3b
Simulated Lake Elevation (feet NGVD 29)
Simulated Lake Elevation (feet City Datum)
Scenario Year
30
25
20
15
10
5
0
-5
-10
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
00
10
20
30
40
50

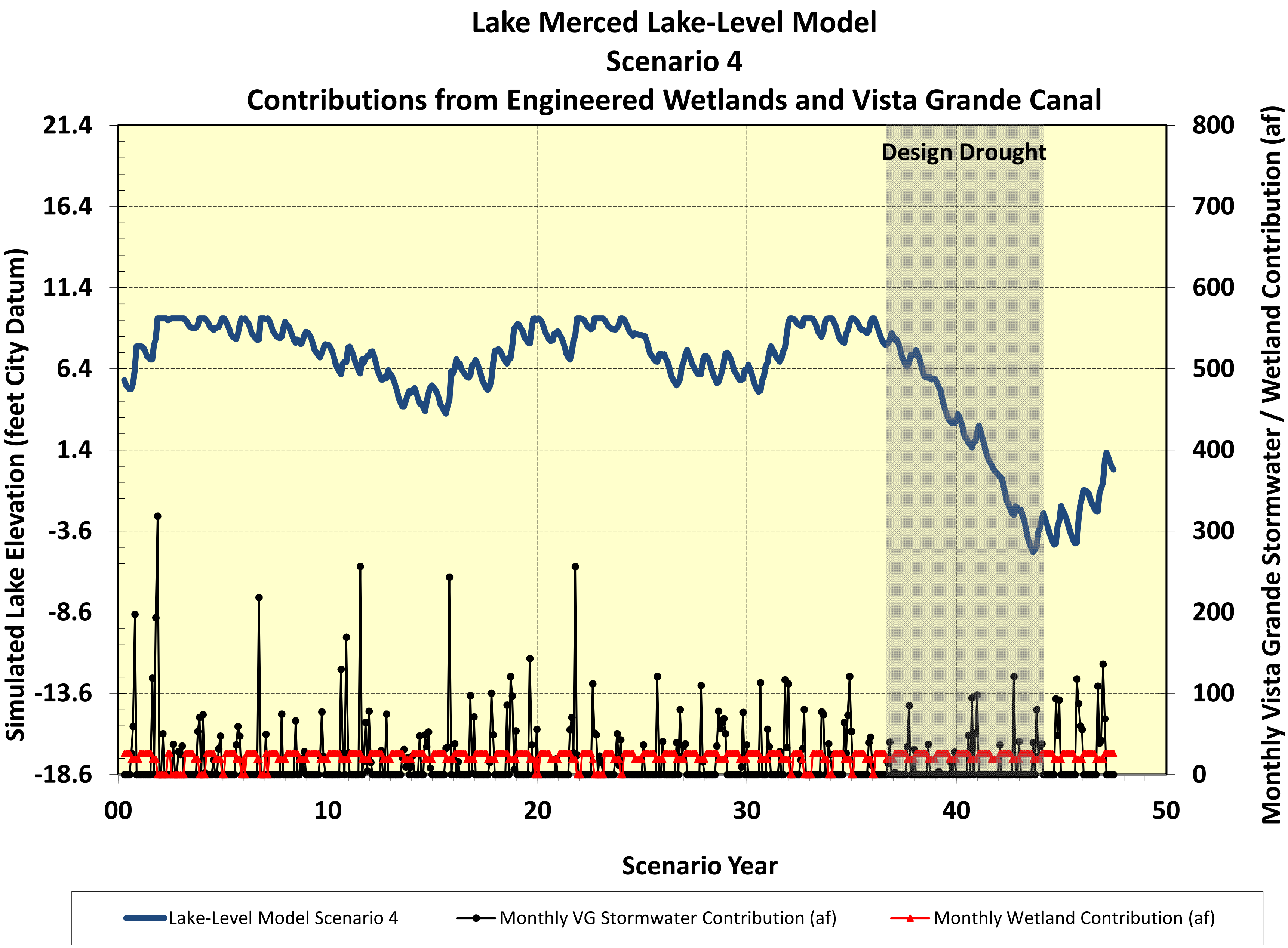


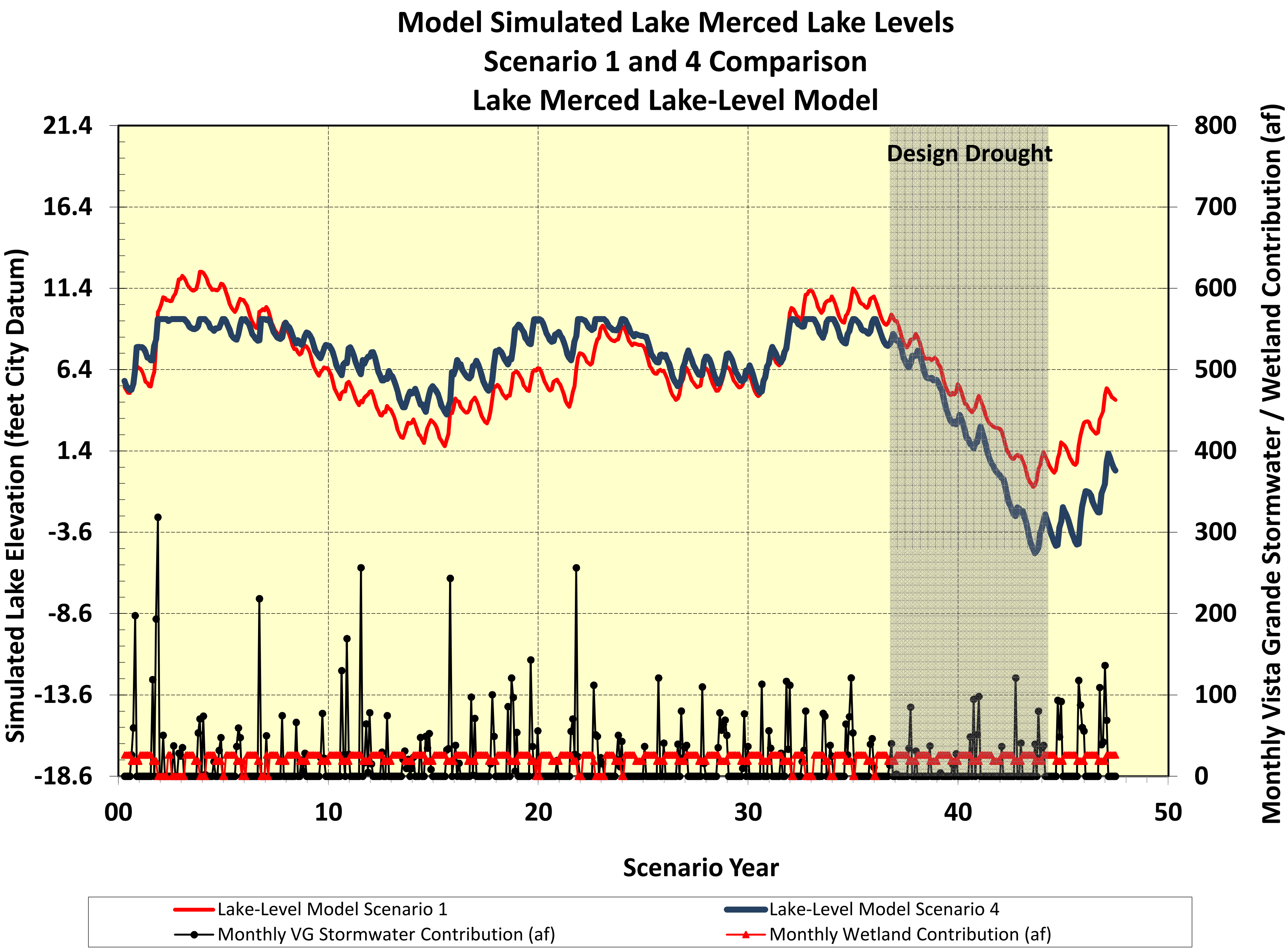
Model Simulated Lake Merced Lake Levels
Scenario 1 and 3b Comparison
Lake Merced Lake-Level Model
Design Drought
Simulated Lake Elevation (feet NGVD 29)
Simulated Lake Elevation (feet City Datum)
Scenario Year
Lake-Level Model Scenario 1
Lake-Level Model Scenario 3b
30
25
20
15
10
5
0
-5
-10
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
00
10
20
30
40
50

## Lake Merced Lake-Level Model Water Balance
## Scenario 4
## SFPUC GSR and SFGW Projects Technical Analysis

| **Assumptions:** | | **Initial Lake Level** | | **Wetland Source** | | **VG Stormwater** | | **Number of Wells** | | **Diversion Elevation** | | **Spillway Elevation** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(in feet City Datum)** | | **5.7** | | **Baseflow** | | **Yes** | | **No Wells** | | **9.5** | | **9.5** | |
| | | **Lake Merced Natural Hydrology** | | | | | | **Lake Merced Lake Level Management** | | | | **Summary** | |
| **Historical Water Year** | **Scenario Year** | **Precipitation (AF)** | **Stormwater Runoff (af)** | **Evaporation (af)** | **Transpiration (af)** | **Groundwater Inflow-Outflow (af)** | **Natural Hydrology Subtotal (af)** | **Lake Additions from Engineered Wetland (af)** | **Lake Additions from Vista Grande Canal Stormflow (af)** | **Lake Additions from Wells (af)** | **Flow over the Spillway (af)** | **Annual (Sept to Sept) Change in Lake Level (feet)** | **Lake Merced Change in Storage (af)** |
| 1996 | 0 | 1 | 0 | -241 | -49 | 49 | -239 | 78 | 0 | 0 | 0 | - | - |
| 1997 | 1 | 504 | 176 | -729 | -144 | 165 | -28 | 277 | 283 | 0 | 0 | 1.82 | 532 |
| 1998 | 2 | 1,205 | 489 | -678 | -134 | 608 | 1,490 | 135 | 681 | 0 | -1,547 | 2.53 | 3,852 |
| 1999 | 3 | 476 | 138 | -634 | -129 | 411 | 262 | 105 | 126 | 0 | -678 | -0.60 | 1,171 |
| 2000 | 4 | 469 | 134 | -683 | -135 | 191 | -24 | 187 | 200 | 0 | -397 | -0.11 | 760 |
| 2001 | 5 | 293 | 74 | -658 | -133 | 12 | -413 | 232 | 97 | 0 | -64 | -0.48 | -20 |
| 2002 | 6 | 377 | 106 | -663 | -132 | -58 | -370 | 232 | 144 | 0 | -10 | -0.01 | 15 |
| 2003 | 7 | 512 | 172 | -697 | -136 | -29 | -178 | 194 | 268 | 0 | -252 | 0.12 | 537 |
| 1959 | 8 | 360 | 102 | -690 | -136 | -113 | -476 | 277 | 141 | 0 | 0 | -0.19 | -59 |
| 1960 | 9 | 323 | 94 | -665 | -134 | -250 | -631 | 277 | 55 | 0 | 0 | -0.99 | -300 |
| 1961 | 10 | 374 | 106 | -659 | -134 | -382 | -695 | 277 | 122 | 0 | 0 | -0.99 | -296 |
| 1962 | 11 | 427 | 141 | -614 | -128 | -490 | -664 | 277 | 353 | 0 | 0 | -0.11 | -35 |
| 1963 | 12 | 508 | 161 | -673 | -136 | -687 | -827 | 277 | 436 | 0 | 0 | -0.38 | -114 |
| 1964 | 13 | 325 | 97 | -622 | -131 | -532 | -863 | 277 | 104 | 0 | 0 | -1.65 | -482 |
| 1965 | 14 | 515 | 182 | -600 | -128 | -429 | -461 | 277 | 163 | 0 | 0 | -0.07 | -21 |
| 1966 | 15 | 430 | 149 | -632 | -133 | -302 | -488 | 277 | 145 | 0 | 0 | -0.22 | -67 |
| 1967 | 16 | 741 | 297 | -621 | -130 | -310 | -23 | 277 | 384 | 0 | 0 | 2.22 | 638 |
| 1968 | 17 | 380 | 120 | -670 | -136 | -381 | -687 | 277 | 170 | 0 | 0 | -0.81 | -241 |
| 1969 | 18 | 634 | 233 | -626 | -131 | -113 | -2 | 277 | 165 | 0 | 0 | 1.51 | 439 |
| 1970 | 19 | 553 | 184 | -666 | -133 | -198 | -260 | 277 | 364 | 0 | 0 | 1.29 | 380 |
| 1971 | 20 | 497 | 151 | -633 | -128 | -206 | -319 | 232 | 236 | 0 | -92 | 0.20 | 240 |
| 1972 | 21 | 322 | 89 | -638 | -130 | -313 | -671 | 277 | 19 | 0 | 0 | -1.25 | -375 |
| 1973 | 22 | 838 | 296 | -642 | -131 | 12 | 374 | 213 | 433 | 0 | -464 | 1.86 | 1,484 |
| 1974 | 23 | 735 | 231 | -649 | -131 | 168 | 354 | 149 | 251 | 0 | -750 | 0.02 | 1,504 |
| 1975 | 24 | 436 | 123 | -644 | -130 | -95 | -311 | 232 | 126 | 0 | -169 | -0.40 | 215 |
| 1976 | 25 | 239 | 54 | -658 | -134 | -257 | -756 | 277 | 37 | 0 | 0 | -1.47 | -443 |
| 1977 | 26 | 291 | 78 | -653 | -132 | -439 | -855 | 277 | 162 | 0 | 0 | -1.41 | -417 |
| 1978 | 27 | 655 | 233 | -691 | -138 | -351 | -292 | 277 | 216 | 0 | 0 | 0.69 | 200 |
| 1979 | 28 | 422 | 140 | -659 | -135 | -389 | -620 | 277 | 126 | 0 | 0 | -0.73 | -217 |
| 1980 | 29 | 561 | 189 | -647 | -132 | -496 | -526 | 277 | 353 | 0 | 0 | 0.37 | 104 |
| 1981 | 30 | 385 | 123 | -634 | -133 | -410 | -668 | 277 | 123 | 0 | 0 | -0.91 | -269 |
| 1982 | 31 | 779 | 282 | -624 | -130 | -248 | 60 | 277 | 204 | 0 | 0 | 1.85 | 540 |
| 1983 | 32 | 943 | 338 | -718 | -141 | 193 | 615 | 224 | 291 | 0 | -470 | 2.20 | 1,599 |
| 1984 | 33 | 519 | 166 | -726 | -141 | 211 | 30 | 176 | 130 | 0 | -542 | -0.68 | 878 |
| 1985 | 34 | 463 | 129 | -714 | -140 | -137 | -400 | 213 | 214 | 0 | -126 | -0.32 | 154 |
| 1986 | 35 | 715 | 235 | -730 | -142 | 20 | 98 | 232 | 338 | 0 | -442 | 0.75 | 1,110 |
| 1987 | 36 | 321 | 94 | -720 | -140 | -123 | -568 | 232 | 97 | 0 | -29 | -0.88 | -210 |
| 1988 | 37 | 354 | 99 | -719 | -141 | -299 | -706 | 277 | 57 | 0 | 0 | -1.24 | -373 |
| 1989 | 38 | 453 | 140 | -689 | -140 | -432 | -668 | 277 | 151 | 0 | 0 | -0.81 | -241 |
| 1990 | 39 | 270 | 78 | -688 | -141 | -527 | -1,009 | 277 | 42 | 0 | 0 | -2.38 | -691 |
| 1991 | 40 | 402 | 141 | -646 | -137 | -545 | -784 | 277 | 42 | 0 | 0 | -1.65 | -465 |
| 1992 | 41 | 413 | 161 | -688 | -146 | -633 | -893 | 277 | 292 | 0 | 0 | -1.18 | -324 |
| 1976 | 42 | 171 | 51 | -586 | -136 | -574 | -1,074 | 277 | 37 | 0 | 0 | -2.92 | -761 |
| 1977 | 43 | 243 | 99 | -538 | -132 | -676 | -1,004 | 277 | 162 | 0 | 0 | -2.34 | -565 |
| 1978 | 44 | 525 | 309 | -572 | -140 | -524 | -403 | 277 | 216 | 0 | 0 | 0.41 | 90 |
| 2004 | 45 | 391 | 226 | -556 | -137 | -437 | -513 | 277 | 234 | 0 | 0 | 0.02 | -3 |
| 2005 | 46 | 610 | 340 | -540 | -132 | -403 | -124 | 277 | 321 | 0 | 0 | 1.99 | 474 |
| 2006 | 47 | 632 | 333 | -573 | -133 | -371 | -112 | 277 | 395 | 0 | 0 | 2.21 | 560 |
| **Average (af)** | | **479** | **168** | **-644** | **-133** | **-229** | **-366** | **248** | **198** | **0** | **-128** | **-0.16** | **216** |
| **Maximum (af)** | | **1,205** | **489** | **-241** | **-49** | **608** | **1,490** | **277** | **681** | **0** | **0** | **2.53** | **3,852** |
| **Minimum (af)** | | **1** | **0** | **-730** | **-146** | **-687** | **-1,074** | **78** | **0** | **0** | **-1,547** | **-2.92** | **-1,547** |

Key:
af - acre-feet
VG - Vista Grande


Lake Merced Lake-Level Model
Scenario 4
Contributions from Engineered Wetlands and Vista Grande Canal
Design Drought
Simulated Lake Elevation (feet City Datum)
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
Monthly Vista Grande Stormwater / Wetland Contribution (af)
800
700
600
500
400
300
200
100
0
00
10
20
30
40
50
Scenario Year
Lake-Level Model Scenario 4
Monthly VG Stormwater Contribution (af)
Monthly Wetland Contribution (af)


Model Simulated Lake Merced Lake Levels
Scenario 1 and 4 Comparison
Lake Merced Lake-Level Model
Design Drought
Simulated Lake Elevation (feet City Datum)
Monthly Vista Grande Stormwater / Wetland Contribution (af)
21.4
16.4
11.4
6.4
1.4
-3.6
-8.6
-13.6
-18.6
800
700
600
500
400
300
200
100
0
00
10
20
30
40
50
Scenario Year
Lake-Level Model Scenario 1
Lake-Level Model Scenario 4
Monthly VG Stormwater Contribution (af)
Monthly Wetland Contribution (af)

# Attachment 10.1-H

## Lake Merced Lake-Level Model Development Technical Memorandum

17 April 2012

# Technical Memorandum
# Attachment H to Task 10.1 Technical Memorandum

## San Francisco Public Utilities Commission

## Lake Merced Lake-Level Model Development
## Regional Groundwater Storage and Recovery Project and
## San Francisco Groundwater Supply Project

Prepared for: Greg Bartow and Jeff Gilman, SFPUC

Prepared by: Michael Maley and Sevim Onsoy, Kennedy/Jenks Consultants

---

## 1. Introduction

This Technical Memorandum (TM) was prepared to document work performed by Kennedy/Jenks Consultants (Kennedy/Jenks) for the San Francisco Public Utilities Commission (SFPUC) pursuant to the amended Task Order (TO) authorizations CUW30103-TO-1.12 of the Regional Groundwater Storage and Recovery (GSR) Project and CUW30102-TO-2.7 of the San Francisco Groundwater Supply (SFGW) Project. These projects are funded by the SFPUC's Water System Improvement Program (WSIP).

### 1.1. Objective

SFPUC is currently undertaking engineering and environmental studies for the GSR and SFGW Projects that includes evaluating the potential effects of these projects on Lake Merced. The Lake Merced Lake-Level Model is one the tools used to evaluate these effects.

The Lake Merced Lake-Level Model is a spreadsheet-based water-balance that applies a rule-based approach for the water balance. The model sums up the inflows and outflows from Lake Merced on a monthly time scale. The water balance components are each calculated independently. The sum represents the net change in water volume in the lake for that month. Based on this net change in water volume, a new lake level is calculated. The advantage of a rule-based approach is that once the rules are defined, they enhance the ability to then adapt the model for use in project simulations.

This technical memorandum documents the model calibration to historical lake levels over a 70-year period from 1939 to 2009. Calibrating the model over this long historical range allows for the historical analysis to be tested over a variety of hydrological conditions including wet, normal and dry precipitation years, flood events, and periods of high and low lake levels. The calibration process defines the level of confidence in the capability of the model to subsequently simulate future-case scenarios. A well calibrated model demonstrates a stronger conceptual understanding of the key hydrological factors that control lake levels. An improved historical calibration also increases confidence in the model's ability to forecast future conditions and reduces uncertainty in the model's applications to future conditions.

The setup and modifications to the Lake-Level Model necessary to apply the model for the GSR and SFGW projects is also documented herein, but the results of the modeling are presented in the main body of the Task 10.1 Technical Memorandum.

### 1.2. Previous Studies

Several previous studies have been conducted to evaluate Lake Merced. EDAW and Talavera & Richardson (2004) conducted a study to understand the cause for declining water levels and to develop plans to restore levels. Several detailed studies were conducted by Luhdorff & Scalmanini Consulting Engineers (LSCE) (LSCE 2002, 2004, and 2007) to provide a description of the aquifers underlying the lake to evaluate the lake-aquifer relationships. The Lake Merced Water Level Restoration Alternatives Analysis Report (AAR) (Metcalf & Eddy, Inc., 2008) identified preferred alternatives to meet recommended lake level elevations through a combination of treated stormwater from the Vista Grande Canal (VGC) and groundwater. A draft Conceptual Engineering Report (CER) was prepared to provide the first phase of the conceptual engineering design for an engineered wetland for stormwater treatment (Kennedy/Jenks, 2009a). The City of Daly City prepared the Vista Grande Drainage Basin Alternatives Analysis in 2011 (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012) to evaluate alternatives to reduce flooding and erosion along Lake Merced, and provide lake level augmentation.

Previous Lake Merced lake-level modeling studies have been conducted to characterize the water balance of Lake Merced and to estimate supplemental water necessary to raise and maintain lake levels. As a part of the EDAW study, a numerical groundwater model was developed to provide preliminary estimates of the volumes of water needed for maintaining lake levels within different target lake levels (EDAW and Talavera & Richardson, 2004). LSCE (2008) developed a spreadsheet-based analytical water-balance model to evaluate changes in lake levels in Lake Merced. This model was updated to support the draft Conceptual Engineering Report (CER) for the conceptual engineering design to increase and maintain Lake Merced Levels (Kennedy/Jenks, 2009a). The Kennedy/Jenks (2009b) model was modified for the Vista Grande Drainage Basin Alternatives Analysis in 2011 (Brown and Caldwell, 2010; Jacobs Associates, 2011a, 2011b) to evaluate lake-levels changes from diversions of stormwater from the VGC.

## 2. Physical Setting

This section provides a summary of the climatic, hydrological, and hydrogeological data representative of the physical setting of Lake Merced.

### 2.1. Lake Merced

Lake Merced is a freshwater lake located in the southwest corner of San Francisco, consisting of four inter-connected freshwater lakes - North Lake, South Lake, East Lake and Impound Lake (Figure 1). Until the early 1900s, Lake Merced was one large body of water that was fed by local runoff and springs, with an outflow to the Pacific Ocean via a stream from North Lake. The springs that flowed into the lake were primarily located on the eastern side and in the southern portion of Lake Merced and resulted in flow through the lake from south to north.

Lake Merced does not have a natural outlet; however Lake Merced has an overflow structure, also known as spillway, near the midpoint of the southwest side of South Lake at 13 feet City Datum. All lake elevations in this memorandum reference the City Datum, which is 11.37 feet higher than the North American Vertical Datum 1988 (NAVD) and 8.62 feet higher than the National Geodetic Vertical Datum 1929 (NGVD) (LSCE, 2002). Lake Merced elevations have historically referenced a Lake Merced Gage Board that has a datum 17.50 feet higher than the City Datum, 8.88 feet higher than NGVD, and 6.13 feet higher than NAVD.

North and East lakes are joined through a narrow channel and these lakes are separated from South Lake by natural or man-made barriers. A conduit between North and South lakes allows water to flow between the two lakes when the lake elevation in either lake is approximately 3.35 feet City Datum. When lake levels drop below that elevation, the two lakes are separated and typically exhibit different elevations. South and Impound lakes are separated below an elevation of approximately 4.26 feet City Datum. When the lake elevation in either lake is above 5 feet City Datum, water flows freely, connecting the two lakes.

### 2.2. History of Lake Levels

Lake levels have been measured daily in South Lake since 1926. Figure 2 shows the historical measured Lake Merced water levels as measured at South Lake. Historically, lake water levels have fluctuated. Prior to the beginning of Hetch-Hetchy aqueduct water delivery in 1935, lake levels typically ranged from 0 to -10 feet City Datum. In the late 1930s to early 1940s, lake levels increased to over 13 feet City Datum which is approximately the spillway elevation and represents the maximum potential lake level.

Lake levels started to decline in the 1940s. During the 1940s to late 1950s, lake levels varied between 8 and 13 feet City Datum. Between the late 1950s and early 1980s, the lake experienced an overall long-term declining trend when lake levels ranged between 4 and 10 feet City Datum (Figure 2). Previous reports cite the primary reasons for the overall declining lake levels as drought, groundwater pumping, evaporation, and urbanization diverting stormwater into the City's combined sewer and stormwater system (Pezzetti and Bellows, 1998).

In the late 1980s and early 1990s, a major drought impacted the area. During this time, lake levels dropped significantly due to the drought and groundwater pumping. A lake level of about -3.2 feet City Datum observed in 1993 was the lowest since the 1930s (Figure 2).

Lake levels have been recovering since 1993. As of June 2009, the lake was at approximately 5.7 feet City Datum (Figure 2). Water level increases over the last 15 years are attributed to a combination of factors, including above average precipitation and direct recharge to the lake and the SFPUC water additions to the lake between 2002 and 2005. During the wet winters of 1997 and 1998, the lake level rose sharply.

Expanded lake-level monitoring was conducted from August 2001 to January 2004. This was during a time when the lake levels were near or below the hydraulic connections between the lakes. This condition caused the lakes to act more independently since the lake levels could not readily equilibrate. These measurements showed that the lake levels decrease progressively from north to south. North and East lakes had higher levels than South Lake, and South Lake was continuously higher than Impound Lake (LSCE, 2004). These observations reflected the predominant shallow groundwater gradient to the south and showed that lake levels separate at lower elevations and have distinct elevations.

### 2.3. Lake Merced Hydrological Conceptual Model

The hydrological conceptual model for Lake Merced provides a representation of the various inflow and outflow components for the overall lake system. The conceptual model also provides the basis for a representative water-balance model that can be used to develop future operations scenarios for managing the lake levels. The conceptual water-balance model described below consists of various key components that include inflows into and outflows from the lake systems.

Figure 3 demonstrates a schematic of the conceptual water-balance model with primary inflows and outflows that are pertinent for Lake Merced. The primary water balance components are defined as follows:

- Change in Lake Storage – Change in the volume of water in the lake. An increase in lake storage results in a rise in lake levels as water is added to the lake. Conversely, a decrease in lake storage results in a decline in lake levels as water is lost from the lake
- Direct Precipitation – Inflow to Lake Merced resulting from rainfall that falls directly onto Lake Merced surface.
- Stormwater Runoff – Inflow to Lake Merced resulting from runoff of precipitation that falls on the areas surrounding Lake Merced or from overflow from VGC during storm events. Stormwater runoff depends on the extent of drainage area that contributes to the runoff, the amount of precipitation, topography and surface conditions in the drainage areas.
- Evaporation – Outflow from Lake Merced resulting from evaporation, or the conversion of water at the lake surface into water vapor that is lost to the atmosphere. Evaporation is considered as the single largest water loss from the lake. Evaporation loss depends

on lake surface area that is subject to evaporation and evaporation rates that vary as a function of climate conditions (temperature, fog, wind).

- Transpiration – Outflow from Lake Merced resulting from transpiration, or the uptake of water from the lake by plants. The primary plant for consideration of transpiration is the California bulrush (*Scirpus californicus*), or tule. Transpiration loss from the lake is dependent upon the area covered by tules and on transpiration rates.
- Groundwater Inflow and Outflow – The net inflow or outflow of groundwater from the lake. Lake Merced is hydraulically connected to the Shallow Aquifer of the groundwater system (LSCE, 2002; LSCE, 2004); thus, groundwater inflow into and outflow from the lake system is an important water balance component. The direction and magnitude of the groundwater flux into or out of the lake is controlled by the relative difference of lake and groundwater levels.
- Singular Events – The net inflow or outflow to the lake resulting from man-made lake water additions or extractions. These are termed singular events because they are determined by arbitrary operating decisions; therefore, they cannot be estimated independently.

This conceptual water-balance model can be formulated mathematically as follows to track the inflow and outflow of water from the lake over time:

*Change in Lake Storage = Direct Precipitation + Stormwater Runoff – Evaporation – Transpiration + Groundwater Inflow – Groundwater Outflow ± Singular Events*

In this form, positive components represent inflows into the lake and negative components are outflows from the lake. When inflow exceeds outflow over a month period, the model outcome is a positive change in lake storage, indicating an increase in lake levels. Conversely, when outflow exceeds inflow, the model outcome is a negative change in lake storage, which indicates a decrease in lake levels.

### 2.4. Physical Lake Condition

As part of the modeling analysis presented here, the lake surface area was calculated as a function of lake level elevation derived from both bathymetric and surface contour data. Table 1 presents the estimated lake surface areas. The estimated lake surface area contours (feet, City Datum) along with the bathymetric contours (feet, City Datum) are shown in Figure 4. For the current lake level as of June 2009 at 5.7 feet City Datum, the total surface area of the lake, including the four lakes, was calculated to be approximately 296 acres. These values are incorporated into the model for converting lake storage into lake levels. This was a model improvement in an effort to refine the lake surface area estimates, which, in turn, improves water balance calculations.

Table 1 – Estimated Lake Merced Surface Area by Lake Levels

| Lake Elevation (feet City Datum) | Estimated Lake Surface Area (Acres) |
|---|---|
| -13 | 106 |
| -12 | 122 |
| -11 | 157 |
| -10 | 157 |
| -9 | 193 |
| -8 | 201 |
| -7 | 209 |
| -6 | 223 |
| -5 | 234 |
| -4 | 240 |
| -3 | 250 |
| -2 | 255 |
| -1 | 261 |
| 0 | 267 |
| 1 | 273 |
| 2 | 279 |
| 3 | 284 |
| 4 | 288 |
| 5 | 292 |
| 6 | 296 |
| 7 | 300 |
| 8 | 304 |
| 9 | 307 |
| 10 | 310 |
| 11 | 313 |
| 12 | 316 |
| 13 | 319 |

Based on previous reports, estimates of the total lake surface area range from approximately 245 acres of open water (EIP Associates, 2000) to 276 acres (Yates et al., 1990) to 300 acres (EDAW and Talavera & Richardson, 2004). The variations are likely due to differences in lake levels and surrounding topography. Estimates of the capacity of the lake also vary greatly from a low of 768 million gallons to high of 1.93 billion gallons (Ecology and Environment, 1993). According to Camp Dresser and McKee (CDM) (1999), the volume of North and East lakes is approximately 280 million gallons, South Lake is approximately 700 million gallons and Impound Lake is approximately 26 million gallons, for a total of approximately 1 billion gallons of water in Lake Merced. Yates et al. (1990) estimates the lake's capacity at 1.2 billion gallons.

Based on the available lake bathymetry data discussed in previous reports, the maximum depth of North Lake is 24 feet with an average depth of 13 feet (Yates et al., 1990). South Lake has a maximum and average depth of 23 and 16 feet, respectively. The maximum and average depth of Impound Lake is 12 and 8 feet, respectively. The maximum water level at Lake Merced is controlled by an overflow structure near the midpoint of the southwest end of South Lake at approximately 13 feet City Datum. The bottom topography of the lake is reported to be generally flat and smooth. Only one reference was found to indicate modifications to the bottom of South Lake when dredging was conducted to remove lead shot in the proximity of the Pacific Rod and Gun Club (Ecology and Environment, 1993).

## 2.5. History of Lake Additions

SFPUC has added water to Lake Merced periodically to help maintain lake levels. These primarily have been diversions of Regional Water System water into South Lake at the Lake Merced Pump Station. Table 2 presents a summary of the known lake water additions based on information provided by the SFPUC (personal comm., Betsey Eagon) and gathered from previous documents (LSCE, 2002; LSCE, 2004). Additional lake water additions are known to have occurred, but records are not available at the time of this study to quantify the volume of water added (personal comm., Greg Bartow, 2009).

Table 2 – Records of Water Additions to Lake Merced

| Calendar Year | Volume (AF) | Data Source |
|---|---|---|
| 1965 -1969 | 740 | LSCE |
| 1978 | 1,200 | LSCE |
| 1992 | 840 | LSCE |
| 1994 | 920 | LSCE |
| 1997 | 129 | SFPUC |
| 2000 | 71 | SFPUC |
| 2002 | 345 | SFPUC & LSCE |
| 2003 | 816 | SFPUC & LSCE |
| 2004 | 2 | SFPUC |
| 2005 | 96 | SFPUC |

In the summer of 2003, decreasing lake levels from north to south changed as North and South lakes reached equilibrium in response to the SFPUC's intentional water additions to the lake (LSCE, 2004). Three water additions to the lake were made using the SFPUC Regional Water System water to evaluate the feasibility of direct water addition to the lake as a practical way to manage lake levels. The additions occurred between October 2002 and October 2003. During the first addition in October 2002, the total volume of water added to the lake was 345 af (Table 2). The impact from the first addition was notable in South Lake, with a measurable 1-1/2 foot rise to an elevation of 1.28 feet City Datum. No definitive response was seen in either North Lake or Impound Lake. The second water addition occurred in April 2003, by adding approximately 111 af to the lake. Similar to the first addition, the impact of the second addition was evident in South Lake and no measurable response was seen in North Lake and Impound Lake. During the third addition between July 25 and October 17, 2003, South Lake rose to a level of 3.35 feet City Datum where it began to spill to North Lake and East Lake, and the lakes reached equilibrium. Approximately 705 af was added during the third addition.

Groundwater monitoring during the 2002 and 2003 water additions also demonstrated that the Shallow Aquifer is in full hydraulic connection with Lake Merced (LSCE, 2004). Groundwater level response after October 2002 event was evident in shallow groundwater monitoring wells in the lake vicinity, located immediately adjacent to South Lake. The third addition provided a significant response in all the shallow monitoring wells around the lake.

## 2.6. Climate

Two weather stations with long-term climatological records were evaluated for this study. These include the Lake Merced Pump Station precipitation gauge operated by SFPUC adjacent to Lake Merced, and the Mission Dolores station located about 5 miles northeast of Lake Merced. The Lake Merced Pump Station gauge is considered to provide representative precipitation data for Lake Merced. Records go back to 1948 but continuous data begins in 1958 (WRCC, 2012a). The Mission Dolores station has a long-term record with continuous climate data records going back to 1914 for both precipitation and temperature (WRCC, 2012b).

### 2.6.1. Rainfall

The close proximity of Lake Merced to the Pacific Ocean results in distinct maritime Mediterranean climate primarily influenced by wind, fog, and precipitation. Based on the historical precipitation data from Lake Merced Pump Station, the majority of annual rainfall occurs from late October through March (Table 3). Precipitation typically declines during the late season and becomes minimal during the summer. Average annual rainfall (based on a water year of October through September) at the Lake Merced Pump Station gauge is approximately 20.7 inches with a record high of 47.6 inches in 1998 and a record low of 9.5 inches in 1976 (Figure 5). The long term historical record uses a combination of data from the Mission Dolores Station (1914 to 1958) combined with the Lake Merced Pump Station data. The long-term average for Mission Dolores is approximately 21.1 inches which is only slightly higher than Lake Merced Pump Station and, therefore, it is considered reasonable to include this data. The combined precipitation data set is provided in Appendix A.

### 2.6.2. Temperature

The maritime Mediterranean climate is characterized by cool, foggy summers and mild, rainy winters. In summer and fall, locations adjacent to the ocean, such as Lake Merced, are often enclosed in fog with cool temperature in the 50s and 60s $^{o}$F. Lake Merced area often experiences its warmest weather in late September and early October as a result of less fog and occasional off-shore breezes (Table 4). Average monthly temperature from the Mission Dolores station ranges from 51 $^{o}$F in January to nearly 63 $^{o}$F in September, based on data from January 1914 to April 2009 (Table 4). The highest average monthly temperature was 69.4 $^{o}$F in September 1984 and the lowest was 43.6 $^{o}$F in January 1937 (see Appendix A).

Table 3 – Summary of Rainfall Data (inches) from Lake Merced Pump Station Precipitation Gauge Based on Records from October 1958 to September 2009

| | Monthly Rainfall Data Statistics (October 1958 – September 2009) | | |
|---|---|---|---|
| **Month** | **Average** | **Minimum** | **Maximum** |
| Jan | 4.22 | 0.42 | 11.67 |
| Feb | 3.56 | 0.24 | 15.64 |
| Mar | 3.02 | 0.12 | 9.29 |
| Apr | 1.45 | 0.06 | 5.56 |
| May | 0.48 | 0.00 | 4.20 |
| Jun | 0.19 | 0.00 | 1.69 |
| July | 0.04 | 0.00 | 0.49 |
| Aug | 0.13 | 0.00 | 2.26 |
| Sep | 0.25 | 0.00 | 2.06 |
| Oct | 1.01 | 0.00 | 4.65 |
| Nov | 2.61 | 0.00 | 8.20 |
| Dec | 3.48 | 0.00 | 8.81 |

Table 4 – Summary of Temperature Data (°F) from the Mission Dolores, San Francisco, Weather Station Based on Records from January 1914 to April 2009

| | Average Monthly Temperature Statistics (January 1914 – April 2009) | | |
|---|---|---|---|
| **Month** | **Average** | **Minimum** | **Maximum** |
| Jan | 51.0 | 43.6 | 56.6 |
| Feb | 53.9 | 48.3 | 58.9 |
| Mar | 55.2 | 50.9 | 60.7 |
| Apr | 56.3 | 50.7 | 62.6 |
| May | 57.5 | 53.3 | 62.7 |
| Jun | 59.5 | 56.2 | 65.9 |
| July | 59.8 | 56.0 | 66.0 |
| Aug | 60.6 | 56.4 | 66.6 |
| Sep | 62.7 | 58.3 | 69.4 |
| Oct | 61.8 | 56.9 | 66.7 |
| Nov | 57.4 | 51.9 | 61.0 |
| Dec | 52.1 | 47.2 | 57.5 |

#### 2.6.3. Evapotranspiration

Fog is prevalent throughout the Lake Merced area and significantly affects sunshine and temperature conditions. This also affects evaporation, transpiration, and evapotranspiration rates. A United State Geological Survey (USGS) study was conducted at Lake Merced during 1987 and 1988 that collected pan evaporation measurements. These pan evaporation measurements were converted to equivalent lake evaporation and tule transpiration rates (Yates et al., 1990). A summary of the results of this study is provided in Table 5.

Evaporation rates for Lake Merced were assumed to be affected by temporal variations based on temperature conditions; however, these data are not available from Lake Merced. Reference evapotranspiration (ETo) data measured at the closest California Irrigation Management Information System (CIMIS) station at Castroville (http://wwwcimis.water.ca.gov/cimis/) were used as the basis to relate ETo to lake evaporation, similar to the approach taken by Yates (2003). Castroville was used because it represents a location with a similar climate near the ocean that is influenced by fog in the summertime. In this analysis, ETo data available from November 1982 to March 2009 at Castroville CIMIS station were used to estimate long-term lake evaporation.

A literature review indicated that evaporation is not directly measured by weather stations, but can be estimated based on ETo of cropped surfaces, using a procedure published by the Food and Agricultural Organization (FAO) Irrigation and Drainage Papers (FAO, 1977; FAO, 1998; Pruitt and Snyder, 1985). This approach is commonly applied in the literature, and it was used in this study to develop a time series of monthly lake evaporation from monthly ETo. Monthly ETo records at Castroville Station were multiplied by a coefficient of 0.735 to estimate monthly lake evaporation. This coefficient is within the typical range of 0.6 to 0.9 as reported by Yates (2003). The standard deviation was calculated for the estimated lake evaporation for each month to evaluate the seasonal variation in lake evaporation. The results of this analysis are provided in Table 6.

Table 5 – Monthly Evaporation Rates for Lake Merced (Yates et al., 1990)

| Month | Pan Evaporation [(a)] (inches) | Lake Evaporation [(b)] (inches) | Tule Transpiration[(c)] (inches) |
|---|---|---|---|
| Jan | 1.18 | 0.89 | 1.01 |
| Feb | 1.77 | 1.33 | 1.52 |
| Mar | 2.80 | 2.11 | 2.41 |
| Apr | 3.11 | 2.33 | 2.67 |
| May | 4.05 | 3.04 | 3.48 |
| Jun | 5.06 | 3.80 | 4.35 |
| Jul | 5.58 | 4.19 | 4.80 |
| Aug | 3.17 | 2.38 | 2.73 |
| Sep | 3.17 | 2.38 | 2.73 |
| Oct | 2.59 | 1.94 | 2.23 |
| Nov | 1.67 | 1.25 | 1.44 |
| Dec | 1.08 | 0.81 | 0.93 |
| **Total** | **35.2** | **26.4** | **30.3** |

**Notes:**

(a) Measurements at Lake Merced during Oct 1987 to Sept 1998 (Yates et al., 1990).
(b) Lake evaporation calculated as 75% of pan evaporation (Yates et al., 1990).
(c) Tule transpiration calculated as 86% of pan evaporation (Yates et al., 1990).

Table 6 – Summary of Evapotranspiration and Estimated Lake Evaporation Data from Castroville CIMIS Station Based on Records from November 1982 to March 2009

| Month | Average Evapotranspiration | Average Estimated Lake Evaporation | Standard Deviation of Estimated Lake Evaporation |
|---|---|---|---|
| | (inches) | (inches) | (inches) |
| Jan | 1.62 | 1.19 | 0.22 |
| Feb | 2.00 | 1.47 | 0.28 |
| Mar | 3.13 | 2.30 | 0.37 |
| May | 4.12 | 3.03 | 0.34 |
| Apr | 4.76 | 3.50 | 0.35 |
| Jun | 4.85 | 3.56 | 0.36 |
| July | 4.34 | 3.19 | 0.55 |
| Aug | 3.88 | 2.85 | 0.40 |
| Sep | 3.25 | 2.39 | 0.39 |
| Oct | 2.72 | 2.00 | 0.32 |
| Nov | 1.79 | 1.31 | 0.25 |
| Dec | 1.50 | 1.10 | 0.18 |

## 2.7. Hydrology

The original watershed that drained into Lake Merced has been estimated at approximately 6,320 acres; however, the current watershed is now estimated to be approximately 650 acres (SFSU, 2005; Pezzetti and Bellows, 1998). The current watershed is defined by the adjacent roadways that include Lake Merced Boulevard, Skyline Boulevard, and John Muir Boulevard.

A significant portion of stormwater that falls on the areas immediately surrounding the lake drains directly into the lake based on information provided by the SFPUC staff (personal comm., Greg Braswell). Overflow from VGC during storm events also has been discharged into the lake; thus, the lake has received additional stormwater runoff from the VGC overflows. Several catch basins draining into the lake are located primarily along the southern portion near the Impound Lake, and the majority of the stormwater drains located along the western shore of Lake Merced empty directly to the lake (Figure 6).

Much of the runoff from the original watershed is now diverted into the City's combined wastewater system, which had an effect on the surface runoff into the lake. The urbanization of the lake watershed diverts stormwater runoff away from the lake into the City's combined sewer and stormwater system and results in reduced recharge to the lake (SFSU, 2005). Runoff from the eastern and northern portions surrounding the lake is directed into the City's combined wastewater system. However, the development of the lake's watershed with impervious surfaces has tended to increase the runoff from these surfaces (SFSU, 2005).

Due to changes in the lake watershed hydrology, the flow through the lake has reversed over time, now flowing from north to south. The development of the urbanized watershed has also affected groundwater recharge to the Shallow Aquifer from precipitation, and in turn, reduced the amount of subsurface inflow to Lake Merced (SFPUC, 2008).

## 2.8. Groundwater

Lake Merced overlies the North Westside Basin, which is the northern portion of the greater Westside Groundwater Basin (Westside Basin). From north to south, the North Westside Basin underlies a portion of the Sunset District in San Francisco from Golden Gate Park to the San Francisco/San Mateo County line. From west to east, the North Westside Basin extends from the Pacific Ocean to inland bedrock exposures generally associated with Mount Sutro and Mount Davidson (LSCE, 2002; LSCE, 2004).

The groundwater aquifer system in the Lake Merced area is stratified consisting of three aquifer units: a shallow unconfined aquifer (Shallow Aquifer), an intermediate semi-confined aquifer (Primary Production Aquifer), and a deep confined aquifer (Deep Aquifer) (LSCE, 2002; LSCE, 2004; LSCE, 2005) (Figure 7). The Shallow Aquifer extends from the top of the zone of saturation (i.e., water table) to the top of the -100 foot clay in the Lake Merced area (LSCE, 2010). The thickness of the Shallow Aquifer varies from 100 to 150 feet. Beneath the unconfined aquifer lies a fairly extensive clay layer known locally as the -100 foot clay. This clay layer forms the top of the semi-confined Primary Production Aquifer that consists of a 250 to 300 foot thick sandy sequence. Beneath the Primary Production Aquifer is the confined Deep Aquifer consisting of a fine sand or loosely-consolidated sandstone.

Lake Merced is hydraulically connected to the unconfined Shallow Aquifer (LSCE, 2002; LSCE, 2004). Previous hydrogeological investigation also provided some evidence that the surface of the lake is essentially an exposed part of the water table that defines the upper boundary of the Shallow Aquifer (Yates et al., 1990). Groundwater monitoring during the SFPUC's 2002 and 2003 water additions to Lake Merced further demonstrated that the Shallow Aquifer is in full hydraulic connection with Lake Merced (LSCE, 2004).Groundwater level response after the October 2002 water addition was evident in shallow groundwater monitoring wells in the lake vicinity, located immediately adjacent to South Lake. The third addition between July 25 and October 17, 2003 provided a significant response in the shallow monitoring wells around the lake, suggesting increased seepage from the lake in response to water additions. Analysis by LSCE (2004) indicated that 70 to 80 percent of the volume of water added contributed to lake storage and the remaining 20 to 30 percent attributed to net outflow and evaporative losses during the addition period.

Interpretation of water level data and some anecdotal groundwater observations (e.g., spring discharge into Lake Merced) show that shallow groundwater previously flowed toward the ocean to the northwest of Lake Merced (LSCE, 2002). Interpretation of recent shallow water level data shows that shallow groundwater has a gradient potentially turned toward the pumping depression that expanded toward Daly City by 1970. At present (based on fall 2007 data), the direction of groundwater flow in the unconfined Shallow Aquifer is predominantly to the southwest, however, north of Lake Merced groundwater flow appears to be more westward toward the ocean (Figure 8). Groundwater elevations ranged from about 13.5 feet (NAVD 88) north of Lake Merced to 15.8 feet (NAVD 88) south of Lake Merced (SFPUC, 2008).

Groundwater levels in the Primary Production Aquifer ranged from 3.4 feet north of Lake Merced to -5.2 feet south of the lake (SFPUC, 2008). These are notably lower elevations than levels in the overlying Shallow Aquifer, suggesting semi-confined to confined conditions in the Primary Production Aquifer. As reported in the draft North Westside Groundwater Management Plan (LSCE, 2005), significant historical groundwater pumping south of Lake Merced toward Daly City has resulted in substantial pumping depression and decline in groundwater levels in the deeper portion of the aquifer. Over the period from the late 1940's to the 1970's, a significant reduction in water levels was seen in the Primary Production Aquifer near the southern end of Lake Merced. It appears that the decrease in groundwater levels in Daly City and South San Francisco resulted in a change in groundwater flow direction from northwesterly to southerly in the Lake Merced-northern San Mateo County area of the Westside Basin. As also reported in the previous studies (LSCE, 2002), general groundwater flow direction in the deeper portion of the aquifer exhibits a more pronounced north to south flow direction than in the Shallow Aquifer, likely due to greater pumping stresses in the deeper aquifer to the south. In addition, interpretation of deeper groundwater levels shows that the groundwater has a steeper gradient toward the pumping depression than the Shallow Aquifer (LSCE, 2002).

### 2.9. Groundwater Pumping

In the Westside Basin, municipal pumping mostly occurs south of Lake Merced, in Daly City and San Bruno, by the California Water Service Company (SFPUC, 2008). Historically, a significant amount of groundwater pumping (for municipal water supply and irrigation) has occurred from the Primary Production Aquifer and Deep Aquifer. Significant municipal pumping commenced in 1949, increased considerably through 1965, and for the most part has continued to the present day (SFPUC, 2008). Total municipal pumping in the Westside Basin was about 7,500 acre feet per year (AFY) from the mid-1970s to the mid-1980s, and then ranged generally between about 6,000 AFY and 8,000 AFY until 2001 (Figure 9). Between 2002 and 2005, municipal pumping was significantly reduced, as part of the conjunctive use pilot project which replaced the majority of groundwater pumping during normal and wet years with the SFPUC's system water.

In addition to municipal pumping in the Westside Basin, groundwater has been pumped for irrigation supply and other non-potable uses, mostly for golf courses around Lake Merced, the cemeteries in Colma, Golden Gate Park, and the San Francisco Zoo. Much of the groundwater pumping for irrigation is unmetered, and historical pumping records are scarce. Total pumping in the Westside Basin, including municipal pumping (metered) combined with irrigation (unmetered) pumping, was estimated to be nearly 15,000 AFY in the late 1960s and was reduced to about 7,500 AFY in 2007 (Figure 9). In 2005, groundwater use for golf course irrigation around Lake Merced reduced significantly as a result of initial deliveries of recycled water. The combination of the conjunctive use pilot project and recycled water deliveries for golf course irrigation resulted in reduced pumping of about 5,600 acre feet (af) in 2005 and 7,500 af in 2006. When the conjunctive use project ended in 2006, approximately 7,500 af of water was pumped based on metered municipal and estimated irrigation pumping.

Pumping in the Primary Production Aquifer and Deep Aquifer has a direct effect on the Shallow (unconfined) Aquifer in the Lake Merced vicinity and on the Lake itself, because the Shallow Aquifer is hydraulically connected to the Primary Production Aquifer and Deep Aquifer; the -100-foot clay is absent to the south of Lake Merced and the Primary Production Aquifer is semi-confined (LSCE, 2002; SFPUC, 2008). Qualitatively, it is generally agreed upon that pumping from the Primary Production Aquifer has led to an overall decline in the water level of Lake Merced. Additionally, pumping from the Shallow Aquifer is known to have occurred, but historical records are scarce. The water-level decline has not been quantified unequivocally due to the many uncertainties associated with incomplete groundwater withdrawal records, subsurface complexities, and urbanization. As reported in the previous studies (LSCE, 2002), greater pumping stresses to the south of Lake Merced have lowered groundwater levels and resulted in depressed aquifer conditions in the Primary Production and Deep Aquifers where most of the current municipal pumping is occurring. As also shown in the 2008 Annual Groundwater Monitoring Report of the Westside Basin (SFPUC, 2009), in the Primary Aquifer groundwater elevations decrease significantly from north of Lake Merced to south of Lake Merced and experience a prominent north to south flow direction, likely due to greater pumping to the south. Previous reports indicate water was pumped from the lake to irrigate Harding Park Golf Course (Yates et al., 1990), but pumping volumes are unknown.

## 3. Lake Merced Lake-Level Model

This section describes how the various water balance components from the hydrological conceptual model were incorporated into the spreadsheet based Lake Merced Lake-Level Model by characterizing each of the conceptual water balance components including data sources, assumptions, and parameters used for the historical analysis.

### 3.1. Model Setup

The Lake Merced Lake-Level Model includes monthly water balance calculations based on the conceptual model described above and is maintained as a spreadsheet-based water-balance model, similar to the original model setup by LSCE (LSCE, 2008). The model includes each component of the water balance needed to simulate lake hydrology, and tracks monthly flows into and out of Lake Merced. The water balance components are inputs to the conceptual model; change in lake storage (in acre-feet) and lake levels (in feet) are the model outputs.

The historical analysis was extended over a 70-year period from October 1939 through June 2009. Prior to 1935, Lake Merced was used as a water supply source for the City of San Francisco. Pumping from the lake and nearby groundwater pumping either directly or indirectly contributed to the substantial decline of lake levels through about 1932, but records are unavailable to quantify these activities. After Regional Water System delivery began around 1935, it took a period of several years for the lake levels to recover. Therefore, 1939 was considered an appropriate starting point for the model.

In addition, the spreadsheet model was made more user-friendly. This was done by setting up each water balance component as a separate spreadsheet tab so that the development of the water balance can be traced. Supporting data are also included in separate data tabs. The calculation of the lake level is done in a summary table that is linked to the individual water balance components so that the contribution of each water balance component in calculating the lake level is clearly shown.

A more detailed discussion of how each of the water balance components was incorporated into the Lake Merced Lake-Level Model is provided below.

### 3.2. Direct Precipitation

In the Lake Merced Lake-Level Model, precipitation includes only the water that falls directly onto the lake surface as rainfall. To calculate the volume for the water balance, the monthly rainfall was multiplied by the lake surface area in acres to estimate the total volume of rainfall entering the lake. The calculation is as follows:

*Direct Precipitation = Precipitation Rate * Lake Surface Area*

The data used in calculating the precipitation component of the water balance are shown below:

- Precipitation Rate is the monthly precipitation data. Precipitation data from the Mission Dolores weather station were used from 1939 to 1958, and from the Lake Merced Pump Station gauge from 1958 to 2009. Data were incorporated directly into the model.
- Lake Surface Area is the lake surface area in acres. The area of the lake surface varies with the lake level, as described above (Table 1). The calculation was based on the starting lake level for the month.

The precipitation contribution was calculated for each month. The total volume of precipitation is listed in the water balance components in acre-feet and is added to the water balance. Potential water losses due to evaporation and other mechanisms are handled separately by the model.

### 3.3. Stormwater Runoff

Historically, stormwater runoff was a major inflow into Lake Merced. However, much of the original watershed is now diverted away from Lake Merced and into the City's combined stormwater system (SFSU, 2005). Currently, stormwater runoff into Lake Merced is generally limited to only those areas immediately adjacent to the lake. Several catch basins draining into the lake are located primarily along the southern portion near the Impound Lake and the majority of the stormwater drains located along the western shore of Lake Merced empty directly to the lake (Figure 10).

Specific runoff measurements into Lake Merced were not available; therefore, the stormwater runoff contribution was calculated using a variation of the Rational Method (Chow, Maidment and Mays 1988). The stormwater runoff contribution was calculated for each month and total volume was listed in the water balance components in acre-feet. The formula for calculating stormwater runoff is as follows:

*Stormwater Runoff = (Precipitation Rate - Rainfall Threshold) * Runoff Coefficient * Drainage Area*

The data used in calculating the stormwater component of the water balance is discussed below:

- Precipitation Rate is the monthly precipitation data. Precipitation data from the Mission Dolores weather station from 1939 to 1958, and from the Lake Merced Pump Station gauge from 1958 to 2009.
- Rainfall Threshold is the minimum amount of monthly rainfall required to generate runoff and was defined for each category. The rainfall threshold was subtracted from the monthly precipitation data. If the threshold was greater than the monthly rainfall, then no stormwater runoff was generated.
- Runoff Coefficient is the percentage of the precipitation, minus the rainfall threshold, that reaches Lake Merced as stormwater runoff.

- Drainage Area is the surface area that is receiving precipitation and contributing stormwater runoff to Lake Merced.

The calculation of stormwater runoff contributions to the lake was based on four drainage (or catch basin) areas surrounding the lake that could potentially contribute stormwater runoff to the lake during the historical period. The surface area for each of these four drainage areas was estimated based on the locations of storm drains and site topography (Figure 10). The stormwater runoff was calculated separately for each of the following drainage (or catch basin) areas:

- Adjacent to Lake – Approximately 123 acres of unpaved, relatively pervious areas adjacent to Lake Merced within the boundary defined by John Muir Drive, Skyline Boulevard and Lake Merced Boulevard.
- Impervious Area – Approximately 31 acres of paved, hardpacked or relatively impervious areas (e.g., roads and parking lots) within the boundary defined by John Muir Drive, Skyline Boulevard and Lake Merced Boulevard.
- Harding Park – Approximately 183 acres that includes Harding Park Municipal Golf Course. This area generally allows precipitation to percolate into the soil, but stormwater runoff does occur during periods of high rainfall.
- Pre-1955 Catch Basin – Pre-1955 total catch basin areas were assumed to be 650 acres during model calibration, which is consistent with the size of the lake watershed. This assumes approximately 313 acres east of Lake Merced Boulevard that drained into Lake Merced before this area was connected to the City's combined sewer and stormwater system. It was assumed that pre-1955 runoff into Lake Merced was only for the period prior to 1955.
- Lake Bed – The surface area of Lake Merced changes with changing lake levels. When the lake level falls below 7.0 feet (City Datum), direct precipitation falling on the dry portion of the lake bed is treated as stormwater using the same assumptions as those for the areas adjacent to the lake. When the lake level rises above 7.0 feet (City Datum), the area available to contribute stormwater from the areas adjacent to the lake is reduced for the stormwater calculation. Because the calculation is dependent upon the calculation of the lake level, it is calculated separately from the other stormwater contributions, but is included in the stormwater for the water balance.

Prior to the mid-1950s, the total drainage area into Lake Merced was assumed to be larger, thus resulting in higher runoff before the combined sewer and stormwater system was established around the mid-1950s. For the purpose of this analysis, the combined system was assumed to be developed in 1955, based on inputs from the SFPUC.

For each of the drainage areas defined above, a runoff coefficient and rainfall threshold were developed that were reflective of average conditions of the topography and surface conditions. A potential range of runoff coefficients was developed for each area based on standard references (CalTrans, 1987; Chow, Maidment, and Mays, 1988). Table 7 summarizes the stormwater runoff parameters, including the estimated drainage areas, runoff coefficients, and thresholds associated with each drainage area.

The rainfall threshold was developed empirically based on model calibration. The rainfall threshold is an adaptation added to the Rational Method that was intended to account for the fact that light rainfall amounts do not generally generate stormwater runoff. The use of the rainfall threshold reduced the stormwater runoff in the lower precipitation months. Also, by using the rainfall threshold, the runoff coefficients were increased to the upper parts of their range. These were adjusted during model calibration. By using the combination of runoff coefficient and rainfall threshold, the Lake Merced Lake-Level Model was better able to capture the seasonal variations in lake levels.

Table 7 – Summary of Stormwater Runoff Components, Coefficients, and Thresholds

| | Area (Acres)[(a)] | Runoff Coefficient [(b)] | Threshold (inches) [(c)] |
|---|---|---|---|
| **Pre-1955 Catch Basin** | 313 | 0.42 | 1 |
| **Adjacent to Lake** | 123 | 0.7 | 0.5 |
| **Impervious Area** | 31 | 0.9 | 0.25 |
| **Harding Park** | 183 | 0.35 | 6 |
| **Total** | **650** | **-** | **-** |

**Notes:**

(a) Estimated based on locations of catch basin drains using the data provided by the SFPUC.
(b) Assumed based on average topography and surface conditions using reference values from Cal Trans Highway Design Manual (1987) and Chow, Maidment, and Mays (1988).
(c) Empirically developed as part of the model calibration.

An adjustment to the stormwater runoff was made based on the surface area of Lake Merced. As noted in Table 1, the surface area of the lake varies with lake level. The drainage area adjacent to the lake was based on an assumption of a lake surface area of 300 acres. If the lake surface area was greater than 300 acres, then there was the potential to double account for areas that received direct precipitation to the lake. If the lake surface area was less than 300 acres, then there was an area that would generate stormwater runoff that was not accounted for. This would potentially be an issue during periods of high precipitation at low lake levels. Therefore, the difference between the estimated lake level and the assumed 300-acre lake surface area for the drainage areas was calculated using the Adjacent to Lake conditions and was added or subtracted from the stormwater runoff water balance component as appropriate.

Flooding from the VGC was calculated separately as part of the stormwater runoff. VGC overflow occurs during storm events when surface water flow in the VGC exceeds its discharge capacity. The water tends to backup where the VGC goes from a surface water canal to a subsurface pipeline. During these periods, water in the VGC overflows from the canal and over John Muir Drive into Impound and South Lakes for a period of hours to days.

To estimate these flooding events, an empirical formula was developed based on model calibration. This formula is as follows:

*VGC Flood = (Precipitation Rate - Rainfall Threshold) * Flood Factor*

The data used in calculating the VGC flood component of the water balance is discussed below:

- Precipitation Rate is the monthly precipitation data. Precipitation data from the Mission Dolores weather station from 1939 to 1958, and from the Lake Merced Pump Station gauge from 1958 to 2009.
- Rainfall Threshold is the minimum amount of monthly rainfall required to generate runoff and was defined for each category. A rainfall threshold of 6.5 inches per month was developed for VGC flooding based on model calibration. The rainfall threshold was subtracted from the monthly precipitation data. If the threshold was greater than the monthly rainfall, then no stormwater runoff was generated.
- Flood Factor is an empirically-derived number based on the model calibration that is used to estimate the flood volume. A flood factor of 140 was developed for VGC flooding based on model calibration.

The VGC is assumed to have been developed in the mid-1950s. For the Lake Merced Lake-Level Model, estimates of VGC flooding are calculated for the period from 1955 to 2009. No flooding is assumed to have occurred prior to 1955. By using a relatively high rainfall threshold of 6.5 inches per month, VGC flooding occurs during 42 months during the period from 1955 through 2009. The primary objective in developing the flood factor was determining a consistent value that was representative for all time periods so that VGC flooding could be incorporated into future case simulations.

### 3.4. Evaporation

Evaporation accounts for water at the lake surface that is converted into water vapor and lost to the atmosphere. Previous studies conducted for Lake Merced consider evaporation as the single largest outflow from the lake (Yates et al., 1990; Yates, 2003). To estimate the total evaporation loss from the lake, the monthly evaporation rate was multiplied by the lake surface area. The calculation is as follows:

*Evaporation = Lake Evaporation Rate * Lake Surface Area*

The evaporation loss was calculated for each month. The total evaporation loss is listed in the water balance components in acre-feet and is subtracted from the water balance. The data used in calculating the evaporation component of the water balance are shown below:

- Lake Evaporation Rate is the estimated monthly evaporation rate for Lake Merced. The monthly evaporation rate varies as a function of the average temperature, based on the Mission Dolores weather station (Appendix A).
- Lake Surface Area is the lake surface area in acres. The lake surface area varies with changes in the lake level, as described above (Table 1). The calculation was based on the starting lake level for the month.

Variations in temperature conditions result in temporal variations in the lake evaporation rate. Table 8 presents estimated monthly lake evaporation data as a function of temperature conditions. An estimation of the lake evaporation rate was developed for three different relative temperature conditions that are defined as cool, normal, and warm, which are defined as follows:

- Normal temperature conditions were defined when the average monthly temperature was within one standard deviation of the long-term average temperature for the month (Table 4 and Appendix A). The normal lake evaporation rate (Table 8) is based on the estimated monthly average lake evaporation rate (Table 5).
- Cool temperature conditions were defined when the average monthly temperature was below one standard deviation of the long-term average temperature for the month (Table 4 and Appendix A). The cool lake evaporation rate (Table 8) is estimated to be the monthly average lake evaporation rate minus one standard deviation based on the monthly measured ET data from Castroville (Table 6).
- Warm temperature conditions were defined when the average monthly temperature was above one standard deviation of the long-term average temperature for the month (Table 4 and Appendix A). The warm lake evaporation rate (Table 8) is estimated to be the normal lake evaporation rate plus one standard deviation based on the monthly measured ET data from Castroville (Table 6).

Table 8 – Monthly Lake Evaporation based on Temperature Conditions

| Lake Evaporation Rate (1982-2007) | | | |
|---|---|---|---|
| | (inches) | (inches) | (inches) |
| **Month** | **Warm** | **Normal** | **Cool** |
| Jan | 1.11 | 0.89 | 0.66 |
| Feb | 1.61 | 1.33 | 1.05 |
| Mar | 2.47 | 2.10 | 1.73 |
| Apr | 2.67 | 2.33 | 1.99 |
| May | 3.39 | 3.04 | 2.68 |
| Jun | 4.16 | 3.80 | 3.43 |
| Jul | 4.73 | 4.19 | 3.64 |
| Aug | 2.78 | 2.38 | 1.98 |
| Sep | 2.77 | 2.38 | 1.99 |
| Oct | 2.26 | 1.94 | 1.62 |
| Nov | 1.50 | 1.25 | 1.01 |
| Dec | 0.99 | 0.81 | 0.63 |
| **Total** | **30.4** | **26.4** | **22.4** |

## 3.5. Transpiration

According to the natural resources inventory of Lake Merced prepared by the SFPUC in 1998, tules border almost the entire lake. In the Lake Merced Lake-Level Model, transpiration water loss from the lake represents water uptake by tules in the immediate areas surrounding the lake. To estimate the total transpiration loss from the lake, the monthly transpiration rate was multiplied by the area covered by the vegetation. The calculation is as follows:

*Transpiration = Transpiration Rate * Tule Area*

The transpiration loss was calculated for each month. The total transpiration loss is listed in the water balance components in acre-feet and is subtracted from the water balance. The data used in calculating the transpiration component of the water balance are shown below:

- Transpiration Rate is the estimated monthly transpiration rate for Lake Merced based on Yates et al. (1990). The monthly evaporation rate is varied based on the average temperature from the Mission Dolores weather station (Appendix A).
- Tule Area is the area of the lake containing tules. Tules extend out up to 150 feet from the lake shore (SFSU, 2005). Thus, for the purpose of this analysis, the area covered by tules around the lake, reported to be 53 acres (Yates et al., 1990), was taken into account.

Monthly transpiration rates reported by Yates et al. (1990) for the Lake Merced area were assumed to reflect normal or average temperature conditions. Similar to the approach taken for lake evaporation, temporal distribution of transpiration data was identified based on monthly temperature conditions for three different relative temperature conditions that are defined as cool, normal, and warm, and which are defined as follows:

- Normal temperature conditions were defined when the average monthly temperature was within one standard deviation of the long-term average temperature for the month. The normal transpiration rate was based on the estimated monthly average lake evaporation rate (Tables 4 and 9).
- Cool temperature conditions were defined when the average monthly temperature was below one standard deviation of the long-term average temperature for the month. The cool lake transpiration rate was assumed to be ten percent less than the estimated monthly average lake evaporation rate for the month (Table 9).
- Warm temperature conditions were defined when the average monthly temperature was above one standard deviation of the long-term average temperature for the month. The warm lake transpiration rate was assumed to be ten percent greater than the estimated monthly average lake evaporation rate for the month (Table 9).

Table 9 – Monthly Transpiration Based on Temperature Conditions

| | Transpiration | | |
|---|---|---|---|
| | (inches) | (inches) | (inches) |
| **Month** | **warm** | **normal** | **cool** |
| Jan | 1.11 | 1.01 | 0.92 |
| Feb | 1.67 | 1.52 | 1.38 |
| Mar | 2.65 | 2.41 | 2.19 |
| Apr | 2.94 | 2.67 | 2.43 |
| May | 3.83 | 3.48 | 3.16 |
| Jun | 4.79 | 4.35 | 3.95 |
| Jul | 5.28 | 4.80 | 4.36 |
| Aug | 3.00 | 2.73 | 2.48 |
| Sep | 3.00 | 2.73 | 2.48 |
| Oct | 2.45 | 2.23 | 2.03 |
| Nov | 1.58 | 1.44 | 1.31 |
| Dec | 1.02 | 0.93 | 0.85 |
| **Total** | **33.33** | **30.30** | **27.55** |

### 3.6. Groundwater Inflow/Outflow

Of the various water balance components, groundwater inflow and outflow from Lake Merced had the highest degree of uncertainty. Conceptually, the direction and magnitude of the groundwater flux into and out of the lake is controlled by the relative difference in lake and groundwater levels. However, consistent groundwater elevation data for the Shallow Aquifer do not exist prior to the late 1990s. Therefore, an empirical approach was applied for defining the water balance calculation for groundwater inflow and outflow.

This approach was initially applied for the previous lake level model (LSCE, 2008) to define a set monthly groundwater inflow or outflow depending upon climatic conditions. Climatic conditions were defined in terms of the total rainfall during the preceding 12-months starting with the month being calculated. The basic assumption for this approach is that during periods of below-average precipitation, there is typically less groundwater recharge to the aquifer which causes groundwater levels to decrease relative to lake levels. The lower groundwater levels cause either reduced groundwater discharge into the lake or increased lake water recharge to the groundwater aquifer depending on aquifer conditions. Alternatively, during periods of above-average precipitation, there is typically higher groundwater recharge to the aquifer which causes groundwater levels to increase relative to lake levels. These higher groundwater levels cause either increased groundwater discharge into the lake or decreased lake water recharge to the groundwater aquifer depending on aquifer conditions.

For the Lake Merced Lake-Level Model, climatic conditions were grouped into three categories based on the combined precipitation data from the Lake Merced Pump Station and Mission Dolores weather stations (Appendix A). By defining the climatic conditions based on the preceding 12-month period, the climatic conditions were allowed to vary on a month-to-month basis. The climatic conditions were defined as follows.

- <u>Normal</u> rainfall conditions were defined when the total precipitation for the preceding 12-months was between 16.5 and 25.5 inches.
- <u>Dry</u> rainfall conditions were defined when the total precipitation for the preceding 12-months was less than 16.5 inches.
- <u>Wet</u> rainfall conditions were defined when the total precipitation for the preceding 12-months was greater than 25.5 inches.

This approach was expanded for this version of the Lake Merced Lake-Level Model to represent a range of aquifer conditions. The Lake Merced Lake-Level Model is a spreadsheet-based water-balance model; therefore, it does not have a mechanism to predict reactions of groundwater and lake levels to pumping. To account for groundwater-lake interactions, assumptions were developed empirically during model calibration. The aquifer conditions were grouped into five categories that provided a qualitative representation of the regional groundwater conditions and the relative groundwater lake conditions. The aquifer conditions were defined in the Lake Merced Lake-Level Model per water year for the period from October through the following September. The aquifer condition category definitions include the following.

- <u>Recovering</u> aquifer conditions were defined as periods of high rainfall along with reduced groundwater pumping when lake levels rose significantly.
- <u>Rising</u> aquifer conditions were defined as periods of reduced groundwater pumping or when groundwater levels were generally higher than lake levels.
- <u>Stable</u> aquifer conditions were defined as periods of reduced groundwater pumping or when groundwater levels were generally similar to lake levels.
- <u>Low</u> aquifer conditions were defined as periods of moderate groundwater pumping or when groundwater levels were generally similar to or lower than lake levels.

- Stressed aquifer conditions were defined as periods of high groundwater pumping or when groundwater levels were generally lower than lake levels.
- Declining aquifer conditions were defined as periods of maximum groundwater pumping or when groundwater levels were generally lower than lake levels.

In the spreadsheet-based Lake Merced Lake-Level Model, a lookup table was set up to approximate the net groundwater flux. Table 10 summarizes the monthly groundwater inflow and outflow volumes relative to Lake Merced based on the assumptions discussed above. Positive numbers represent a net gain of water to the lake signifying an overall net discharge of groundwater into the lake. Conversely, negative numbers represent a net loss of water from the lake signifying an overall net discharge of lake water to the Shallow Aquifer.

Table 10 – Summary of GW Inflow/Outflow Assumptions

| Aquifer Condition | Groundwater Inflow/Outflow (af per month) | | |
|---|---|---|---|
| | Dry | Normal | Wet |
| Recovering | 10 | 15 | 25 |
| Rising | 1 | 5 | 15 |
| Stable | -5 | 1 | 10 |
| Low | -10 | -2 | 5 |
| Stressed | -15 | -10 | 1 |
| Declining | -35 | -30 | -10 |

## 3.7. Singular Events

Man-made water additions to the lake and pumping from the lake have occurred in the past; however, records of these events are limited. These are characterized as singular events in the Lake Merced Lake-Level Model because they represent independent operational decisions.

Lake additions are the results of water additions by the SFPUC at the Lake Merced Pump Station. These were done periodically in the past to help maintain lake levels. The occurrence of recorded additions as identified based on SFPUC records and previously reported data is presented in Table 2 (LSCE, 2002). Other lake additions were known to have occurred in the past; however, the records for these events were not available. Similarly, pumping of water from the lake for golf course irrigation and other uses was known to occur; however, no records are available of the duration and extent of this pumping.

During calibration, singular events were kept within the range of recorded lake additions. Table 11 presents a summary of the estimated annual lake additions and extractions (singular events) by water year (defined as October through September).

For the Lake Merced Lake-Level Model, the available data were used in developing a history of lake additions and extractions. Additional lake additions and extractions were added to the model history during model calibration. During calibration, significant increases or decreases in lake levels that could not be ascribed to natural phenomenon were considered to represent these singular events. In the model, a volume of water was added for those months when the unexplained change in lake levels occurred until a sufficient lake level was achieved. Some modifications were made to known lake additions as shown in Table 2.

Although singular events are interpreted as representing lake additions or extractions, it is also possible that these may also represent, at least in part, necessary adjustments to compensate for natural variations in the lake hydrology. These potential natural variations may reflect unusual hydrological conditions that are not well represented by the rule-based approach.

Table 11 – Estimated Annual Man-Made Additions and Extractions (Singular Events) from Lake Merced

| Water Year | Estimated Lake Addition/Extraction (acre-feet) | Water Year | Estimated Lake Addition/Extraction (acre-feet) | Water Year | Estimated Lake Addition/Extraction (acre-feet) |
|---|---|---|---|---|---|
| 1940 | 0 | 1964 | 150 | 1988 | -300 |
| 1941 | 0 | 1965 | 1,340 | 1989 | 0 |
| 1942 | 0 | 1966 | 250 | 1990 | 0 |
| 1943 | 0 | 1967 | 400 | 1991 | 0 |
| 1944 | 0 | 1968 | -100 | 1992 | 840 |
| 1945 | 0 | 1969 | 400 | 1993 | -600 |
| 1946 | 0 | 1970 | -250 | 1994 | 920 |
| 1947 | 250 | 1971 | 250 | 1995 | -75 |
| 1948 | 250 | 1972 | 650 | 1996 | 0 |
| 1949 | -600 | 1973 | 0 | 1997 | 0 |
| 1950 | 0 | 1974 | 0 | 1998 | 0 |
| 1951 | 0 | 1975 | 250 | 1999 | 0 |
| 1952 | -650 | 1976 | 50 | 2000 | 0 |
| 1953 | 0 | 1977 | 250 | 2001 | 0 |
| 1954 | 750 | 1978 | 1,450 | 2002 | 0 |
| 1955 | 600 | 1979 | -400 | 2003 | 1,161 |
| 1956 | 500 | 1980 | 500 | 2004 | 2 |
| 1957 | 250 | 1981 | 0 | 2005 | 0 |
| 1958 | 0 | 1982 | 100 | 2006 | 0 |
| 1959 | -150 | 1983 | 0 | 2007 | 0 |
| 1960 | 250 | 1984 | 0 | 2008 | 0 |
| 1961 | 250 | 1985 | 0 | 2009 | 0 |
| 1962 | 250 | 1986 | 0 | | |
| 1963 | 250 | 1987 | 0 | | |

# 4. Model Calibration Results

Model calibration provides an evaluation of the long-term performance of the Lake Merced Lake-Level Model to match the observed lake levels. The overall objective of the historical analysis was to develop a rule-based approach for the water balance and to calibrate the model results to measured lake levels. The following discussion characterizes the match of simulated to historical Lake Merced lake levels.

## 4.1. Comparison of Simulated and Historical Lake Levels

The Lake Merced Lake-Level Model was calibrated to historical lake levels over a 70 year period from October 1939 to June 2009. This period includes a variety of hydrological conditions including wet, normal and dry precipitation years, flood events, and periods of high and low lake levels, thus representing a variety of conditions that may be representative of future conditions.

The comparison of simulated and historical lake levels between October 1939 and June 2009 is presented on Figure 11. Model calibration was conducted primarily as a visual comparison of simulated and historical lake levels. This visual comparison was considered as an appropriate level of calibration to meet the objectives of the historical analysis. Additional statistical analysis could be conducted in the future if necessary.

Overall, the Lake Merced Lake-Level Model closely follows both the long-term and short-term trends, demonstrating a very strong correlation of both the magnitude of annual and seasonal fluctuations. Below is a summary of some of the observations:

- The model results follow the long-term trends in lake levels. The model simulates high and low lake levels as appropriate.
- The model results demonstrate the capability to capture the seasonal variations in lake levels during the year under a wide range of climatic and aquifer conditions. The model results provide approximately the same amplitude of lake level variation per year for each year from 1939 to 2009.
- The model was able to simulate the period of high lake levels near the level of the spillway in the 1940s. This demonstrates that the model provides a realistic evaluation of lake levels and is not overly conservative.
- The model results demonstrate a strong capability of reproducing the period of drought during 1976-77 and the late 1980s and early 1990s. The model produces a similar minimum lake level of approximately -3.3 feet City Datum in 1993.
- The model results show the capability to simulate the recovery of lake levels during the period of above-average precipitation from 1995 to 2006.

Overall, with the improved historical match, the Lake Merced Lake-Level Model builds enough confidence to develop future lake filling scenarios to help evaluate the volumes of water necessary to manage Lake Merced water levels.

#### 4.1.1. Comparison to MODFLOW Model

The Westside Basin Groundwater Model, (HydroFocus, 2007, 2009, and 2011) is a numerical groundwater model that has the capacity to evaluate the effect of changes in groundwater pumping and other stresses on groundwater levels in the Lake Merced area. Understanding the changes in groundwater levels is one key aspect to understanding groundwater-surface water interactions. This model also has the capacity to calculate the flux between Lake Merced and the groundwater aquifer.

The comparison of the calibrated 1958 to 2009 historical simulation using the Westside Basin Groundwater-Flow Model to the measured Lake Merced lake levels and the simulated results from the Lake Merced Lake Level Model is presented in Figure 11. The MODFLOW model shows a divergence from the measured data from 1958 to 1971 with MODFLOW simulated lake levels about 3 to 6 feet higher and have significantly different trends. From 1971 to 1996, the MODFLOW model shows a closer correlation with simulated lake levels within about 1 to 2 feet of the measured data. From 1996 to 2009, the MODFLOW simulated lake levels show similar trends to the measured data but are about 2 to 5 feet higher than the measured data.

Comparing the performance of the MODFLOW model to the Lake-Level model shows that the Lake-Level model has a significantly stronger correlation to the measured Lake Merced lake levels over the same period. Since the general approach between the MODFLOW Lake Package and the Lake-Level Model are similar, and the models use similar data sets, the improved performance by the Lake-Level model is attributed to more site-specific and detailed handling of the hydrologic conditions.

The Lake-Level Model is a spreadsheet-based mass balance model that is used to evaluate changes in water levels of Lake Merced. MODFLOW treats Lake Merced as a boundary condition using the LAK3 package, which relies on a mass balance approach to calculate the lake level. The Lake-Level Model uses a site-specific characterization of Lake Merced that is more complex than that used by the MODFLOW model. Some of the key advantages of the Lake-Level Model include the following:

- Allows changes in the surface area of Lake Merced as a function of lake level, based on measured bathymetry data. This is essential because key water balance components (such as precipitation and evaporation) are dependent upon the lake surface area, as briefly described below.
    - Precipitation accounts for rainfall falling directly onto the lake. As lake levels decline, rain that would have fallen directly onto a fuller lake falls instead on the dry lakebed. In the Lake-Level Model, this is treated as stormwater runoff, only a fraction of which actually reaches the lake.
    - Evaporation is dependent on the surface area of the lake open to the atmosphere; as the surface area declines with lowering lake levels, the overall evaporation losses also decline.

- At lower lake levels, the volume of the lake is smaller; therefore, the volume of water required to change the lake level by a certain amount is less than at higher lake levels.
- The Lake-Level Model includes a more complete evaluation of stormwater runoff that incorporates varied land surface types within the limited lake watershed area, including high runoff coefficients the for paved areas surrounding the lake.
- The Lake-Level Model accounts for flooding events resulting from overflows from the Vista Grande Canal. These are short-tem, high-volume events that can significantly affect lake levels.
- The Lake-Level Model has been more closely calibrated to historical lake levels than was the MODFLOW model, showing that this more site-specific characterization of Lake Merced applies appropriate assumptions that provide the capability to properly evaluate lake conditions.

The primary limitation of the Lake-Level Model is that the GW/SW interactions are based on assumptions of annual average groundwater flux into or out of Lake Merced. To address this limitation, the MODFLOW-calculated groundwater flux for Lake Merced was used, which is calculated on a monthly basis and dynamically incorporates the effects of changing groundwater levels. In this manner, the combined approach provides the best available analysis of the changes in Lake Merced.

A more detailed discussion of the Westside Basin Groundwater-Flow Model and the Lake-Level Model is provided in the TM-10.1.

### 4.2. Water Balance

The Lake Merced Lake-Level Model tracked the contribution of each of the water balance components from the conceptual model. Reviewing these water balance results is another measure of calibration. The water balance results are provided in Appendix B as an annual summary for each of the water balance components. Figure 12 presents a summary of all water balance components on an annual basis. The Lake Merced water balance over the 70-year historical period is summarized in Table 12.

Table 12 – Water Balance Summary of 70-year Historical Analysis for Lake Merced (in acre-feet)

| Statistics | Precipi-tation | Stormwater Runoff | Evapo-ration | Transpi-ration | Ground-water | Singular Events | Lake Storage |
|---|---|---|---|---|---|---|---|
| Average Inflow | 514 | 221 | 0 | 0 | 69 | 179 | 188 |
| Average Outflow | 0 | 0 | -647 | -133 | -171 | -45 | -193 |
| Overall Average | 514 | 221 | -647 | -133 | -99 | 135 | -5 |
| Maximum | 1,069 | 666 | -263 | -54 | 231 | 1,450 | 1,257 |
| Minimum | 238 | 55 | -725 | -146 | -418 | -650 | -956 |
| Total Volume | 35,959 | 15,436 | -45,314 | -9,320 | -6,948 | 9,438 | -380 |

A summary of the average annual inflow for each of the relevant water balance components is provided in Table 12. A brief summary of the inflow components to Lake Merced is provided below.

- Direct precipitation was the largest inflow source. Year to year variations in precipitation are significant as a function of hydraulic conditions, ranging from 238 AFY (in 1976) to 1,069 AFY (in 1998), with a long-term average of 514 AFY. Direct precipitation accounted for approximately 55 percent of the average inflow to Lake Merced.
- Stormwater runoff, including estimated flooding events from the VGC, contributed an annual average inflow of 221 AFY. Stormwater runoff recharge to the lake ranged from 55 to 666 AFY, accounting for approximately 25 percent of the average inflow to Lake Merced.
- Groundwater inflow was an overall minor source of inflow to Lake Merced over the historical period. The average annual inflow was approximately 69 AFY with a maximum inflow of 231 AFY. Groundwater inflow accounted for approximately 1 percent of average inflow to Lake Merced.
- Singular events accounted for an annual average annual inflow of approximately 179 AFY over the 70-year history with a maximum inflow of 1,450 AFY. Inflow from singular events accounted for approximately 19 percent of average inflow to Lake Merced.

In addition, a summary of the average annual outflow for each of the relevant water balance components is provided in Table 12. A brief summary of the outflow components from Lake Merced is provided below.

- Evaporation was the largest outflow source with an annual average of approximately 650 AFY. The year to year variations in outflow ranged from about 263 to 725 AFY. Evaporation accounted for approximately 67 percent of the average outflow.
- Transpiration had an annual average outflow of approximately 133 AFY. The year to year variations ranged from about 54 to 146 AFY. Transpiration accounted for approximately 14 percent of the average outflow.
- Groundwater outflow accounted for an average annual outflow of approximately 171 AFY with a maximum outflow of 418 AFY. Groundwater outflow accounted for approximately 14 percent of average outflow from Lake Merced.
- Singular events were an overall minor source of outflow to Lake Merced accounting for an annual average annual outflow of approximately 45 AFY over the 70-year history with a maximum outflow of 650 AFY. Outflow from singular events accounted for approximately 5 percent of average outflow from Lake Merced.

The annual change in lake storage varied significantly over years from an increase of 1,257 af to a decrease of 956 af. Total decrease in lake storage over the entire 70 years was estimated to be 380 af, which is equivalent to about 5 AFY of loss on an annual basis (Table 12). This relatively small long-term loss represents the fact that while the lake levels experienced significant declines in the past, lake level increases during the last 15 years have reversed the declining trend.

The annual contribution from each of the water balance components is presented in graphical form in Figure 12, which demonstrates year-to-year variations. The primary recharge components of direct precipitation and stormwater runoff are significantly affected by variations in rainfall. However, the primary outflow components of evaporation and transpiration are much less variable. This shows why the lake is subject to variations in lake levels over time. The change in lake storage is the difference between the total inflow and the total outflow. Figure 13 provides a graphical summary of the annual change in lake storage. For nearly 50 percent of the years analyzed (32 years out of 70 years), the model results showed increasing lake storage (positive change in storage).

# 5. GSR and SFGW Project Model Setup

For the Project Analysis, the Lake Merced Lake-Level Model was modified to account for the hydrology and incorporate the changes resulting from the Daly City Vista Grande Drainage Area Improvements Project. Otherwise, the GSR and SFGW project scenarios rely on the conceptual hydrology used for the historical calibration analysis (Section 4). Below is a discussion of the setup for the Project Model.

## 5.1. GSR and SFGW Project Scenarios

Five different scenarios were developed for analysis. The initial model scenario simulated groundwater conditions within the Westside Basin influenced by recent (as of June 2009) municipal and irrigation pumping within the Basin; this is referred to as the "Existing Conditions" scenario. Additional modeled scenarios included the simulated operation of the GSR Project and the SFGW Project separately, and a cumulative scenario that includes the operation of the two Projects together with other reasonably foreseeable future water resources projects within the Basin. The following is a summary of the five scenarios used for the groundwater model analysis:

- Scenario 1 - Existing Conditions: The existing conditions scenario uses recent (as of June 2009) pumping conditions and provides a basis for comparison for the other project scenarios.
- Scenario 2 - GSR Project: Includes the GSR Project operations (i.e., in-lieu recharge in the South Westside Basin). Other conditions are the same as Scenario 1.
- Scenario 3a - SFGW Project (3 mgd): This scenario assumes that groundwater pumping for irrigation is still conducted in Golden Gate Park. The SFGW project includes pumping from 4 wells at an annual average rate of 3 million gallons per day (mgd). Other conditions are the same as Scenario 1.
- Scenario 3b - SFGW Project (4 mgd): This scenario assumes that irrigation pumping in Golden Gate Park is replaced with recycled water, so that the equivalent groundwater production may be used for the project. The SFGW project includes pumping from 6 wells at an annual average rate of 4 mgd. Other conditions are the same as Scenario 1.
- Scenario 4 - Cumulative Scenario: This scenario combines the conditions of the GSR Project (Scenario 2) and the SFGW Project (Scenario 3b). Other reasonably foreseeable future projects that are included primarily consist of the Vista Grande Drainage Area Improvements Project Lake Merced Alternative. Other conditions are the same as Scenario 1.

## 5.2. Modifications to the Lake Hydrology

For the Project Analysis, the Lake Merced Lake-Level Model was developed for a 47.25-year period based on the background hydrology developed in the historical calibration analysis. The lake-level model for the Project Analysis uses the same rearranged hydrologic sequence as was used for the MODFLOW scenarios. This sequence is based on historical hydrological conditions and includes an 8.5-year Design Drought period used in the PEIR (SFPUC, 2007; SFPUC, 2009a). The rationale for the rearranged hydrology is presented in the main body of the Task 10.1 Technical Memorandum.

The rearranged hydrologic sequence used for the five model scenarios presented in this analysis consists of the following:

- July 1996 to September 2003.
- October 1958 to November 1992.
- December 1975 to June 1978.
- July 2003 to September 2006.

For the Project Analysis, the following modifications were made to the Lake Merced Lake-Level Model used for the historical calibration analysis to represent anticipated future conditions. These modifications include:

- Initial Lake Level was set at 5.7 feet City Datum based on measured lake levels in South Lake during June 2009.
- Groundwater Inflow and Outflow in the historical calibration analysis was based on an empirical analysis developed during the model calibration. For the GSR and SFGW Project scenarios, the groundwater inflow to and outflow from Lake Merced were based on the equivalent MODFLOW scenario. The MODFLOW calculated groundwater-surface water exchange between Lake Merced and the groundwater was input directly into the Lake Merced Lake-Level Model. By so doing, the groundwater inflows and outflows were based on the groundwater model rather than an assumption relative change in groundwater levels in the Lake Merced area. The MODFLOW results are discussed in the main body of the Task 10.1 Technical Memorandum.
- Stormwater Runoff in the Historical Analysis included an area called the pre-1955 drainage area that represented expansion of the City's combined sewer and stormwater system in the Lake Merced watershed. This represents a historical event that is no longer relevant for future project operations. Therefore, this component was not included in the Project Analysis.
- Singular Events from the historical analysis were defined as historical lake additions and extractions; therefore, these are no longer relevant for future project operations. Since these represent historical events, the singular events from the Historical Analysis were not included in the Project Analysis.

All five of the model scenarios performed for the Project Analysis that are reported in this Technical Memorandum use identical lake hydrology to insure consistency in reviewing the results. The precipitation, lake evaporation, transpiration, and stormwater runoff components use the same data, apply the same assumptions, and incorporate the modifications listed above.

## 5.3. Modifications for the Vista Grande Drainage Area Improvements Project

For the cumulative scenario (Scenario 4), the use of Lake Merced as part of the Vista Grande Drainage Basin Alternatives Analysis project for Daly City is considered one of the other reasonably foreseeable future projects. Daly City's Vista Grande Drainage Basin Alternatives Analysis recommended the Lake Merced Alternative, in which stormwater flow from the Vista Grande Canal would be diverted to Lake Merced (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012).

### 5.3.1. Changes in Lake Merced Spillway

The Lake Merced Lake-Level Model has a provision for the spillway or overflow from Lake Merced. The existing spillway elevation is approximately 13 feet City Datum; therefore, the maximum lake level is set to 13 feet City Datum in the Project Analysis for Scenarios 1, 2, 3a and 3b. Lake levels in excess of 13 feet City Datum are removed from the lake via a spillway near the VGC, and not accounted for in the water balance.

For the Vista Grande Drainage Area Improvements Project, the assumption is that the spillway will be lowered to 9.5 feet City Datum. This lower spillway elevation is used for Scenario 4.

### 5.3.2. Engineered Wetland

The Lake Merced Alternative scenarios of Daly City's Vista Grande Drainage Basin Alternatives Analysis also include provisions for an engineered wetland and modification of the Lake Merced spillway (Brown and Caldwell, 2010). In the 75-cfs scenario, the average base flow in the Vista Grande Canal is assumed to be diverted into an engineered wetland for treatment and then discharged to Lake Merced on an ongoing basis. Typical flows in the Vista Grande Canal, or baseflow, would be continuously diverted through an engineered wetland for treatment prior to discharge into Lake Merced. Baseflows have been estimated to range from 18 to 26 af per month (Kennedy/Jenks, 2009).

For the Project Analysis, two different operating scenarios listed below were evaluated for the engineered wetland:

- <u>Baseflow Option</u> is based on the consistent monthly flow rate in the VGC or the minimum anticipated flow without significant input from storms.
- <u>Stormwater Option</u> has a variable monthly flow that includes stormwater flow from the VGC. The maximum stormwater option for the Project Analysis is constrained by the design flow rates for the engineered wetland rather than the maximum stormwater flow rates in the VGC.

An option was included in the Project Analysis to account for the engineering design that includes a diversion of water from the engineered wetland back to the VGC rather than to Lake Merced. For the GSR and SFGW project scenarios, this option was set to the spillway level. When lake levels reached the level of the spillway, the wetland contribution was not included in the annual total. The input for the engineered wetland component is listed in Table 13.

Table 13 – Calculated Stormwater Inflows from the Vista Grande Drainage Area Improvements Project

| Scenario Year | Wetland Contribution | VGC Stormwater Diversions (acre-feet) | Scenario Year | Wetland Contribution | VGC Stormwater Diversions (acre-feet) |
|---|---|---|---|---|---|
| 0 | 78 | 0 | 24 | 232 | 126 |
| 1 | 277 | 283 | 25 | 277 | 37 |
| 2 | 135 | 681 | 26 | 277 | 162 |
| 3 | 105 | 126 | 27 | 277 | 216 |
| 4 | 187 | 200 | 28 | 277 | 126 |
| 5 | 232 | 97 | 29 | 277 | 353 |
| 6 | 232 | 144 | 30 | 277 | 123 |
| 7 | 194 | 268 | 31 | 277 | 204 |
| 8 | 277 | 141 | 32 | 224 | 291 |
| 9 | 277 | 55 | 33 | 176 | 130 |
| 10 | 277 | 122 | 34 | 213 | 214 |
| 11 | 277 | 353 | 35 | 232 | 338 |
| 12 | 277 | 436 | 36 | 232 | 97 |
| 13 | 277 | 104 | 37 | 277 | 57 |
| 14 | 277 | 163 | 38 | 277 | 151 |
| 15 | 277 | 145 | 39 | 277 | 42 |
| 16 | 277 | 384 | 40 | 277 | 42 |
| 17 | 277 | 170 | 41 | 277 | 292 |
| 18 | 277 | 165 | 42 | 277 | 37 |
| 19 | 277 | 364 | 43 | 277 | 162 |
| 20 | 232 | 236 | 44 | 277 | 216 |
| 21 | 277 | 19 | 45 | 277 | 234 |
| 22 | 213 | 433 | 46 | 277 | 321 |
| 23 | 149 | 251 | 47 | 277 | 395 |

**Note:** Scenario Year represents a water year from October until the following September
Scenario Year 0 represents a 3-month period for July, August and September at the beginning of the model

### 5.3.3. VGC Stormwater Diversions

Scenario 4 incorporates the 75-cubic-feet-per-second (cfs) scenario of the Lake Merced Alternative of the Vista Grande Drainage Basin Alternatives Analysis (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012). The 75-cfs scenario assumes that stormwater discharge rates in the Vista Grande Canal exceeding 75 cfs would be diverted to Lake Merced (Brown and Caldwell, 2010). These flows would occur periodically in response to large storms, and have been calculated as part of the Vista Grande Drainage Basin Alternatives Analysis based on historical precipitation data. Stormwater diversions are calculated to occur in every year and range from 19 to 681 AFY, with an average of 207 AFY (Brown and Caldwell, 2010). The calculated stormwater diversion values are listed in Table 13. These calculated values are input into the Lake-Level model to account for the VGC stormwater diversion component.

### 5.4. Project Model Scenario Results

The results of the Project Analysis for the Lake Merced Lake-Level Model are documented in the main body and Attachment G of the Task 10.1 Technical Memorandum.

## 6. Summary and Conclusions

The Lake Merced Lake-Level Model has been developed as a spreadsheet-based model that simulates the hydrological conceptual model of Lake Merced. The conceptual model is composed of hydrologic and hydraulic components with inflows and outflows that simulate the Lake Merced water storage and water levels.

The Lake Merced Lake-Level Model is calibrated to historically measured lake levels over the past 70 years from October 1939 to June 2009. This historical calibration period includes a variety of hydrological conditions including wet, normal and dry precipitation years, flood events, and periods of high and low lake levels, thus representing a variety of conditions that are considered representative of future conditions.

In this study, the historical calibration analysis has been used to develop a rule-based approach that provides a mechanism to estimate the water balance for Lake Merced. The historical calibration analysis using the Lake Merced Lake-Level Model shows a very strong correlation to the historical (observed) lake levels over the entire 70-year period. This model calibration demonstrates a strong conceptual understanding of the key hydrological factors that control lake levels, and increases confidence in the model's ability to forecast future conditions.

The Lake Merced Lake-Level Model has been adapted from the historical calibration analysis to include potential future project conditions, such as the use of an engineered wetland to treat water from the VGC before discharge in Lake Merced, the diversion of stormwater directly from the VGC into Lake Merced, changes in the spillway elevation, and other operational variations. Based on the ability of the Lake-Level Model to simulate historical Lake Merced conditions and the ability to incorporate future project conditions, it is appropriate to use this model as a tool to evaluate the effects of the GSR, SFGW and Cumulative project scenarios on water levels in Lake Merced.

## References

B. Eagon, personal communication, e-mail message to Mike Maley, May 14, 2009.

Brown and Caldwell, 2010, Historical Rain Data and Flow Evaluation, Technical Memorandum No. 1, April 13, 2010 (revised), prepared for City of Daly City.

California Department of Transportation (CalTrans). 1987. Highway Design Manual, Sacramento, January. California Irrigation Management Information System Department of Water Resources Office of Water Use Efficiency, Castroville #19. Last visited August 24, 2009, from http://wwwcimis.water.ca.gov/cimis/frontStationDetailInfo.do?stationId=19.

Camp Dresser & McKee (CDM). 1999. Lake Merced Water Sanitary Survey November 1999 Report. San Francisco Public Utilities Commission.

Chow , V.T., D.R. Maidment, and L.W. Mays. 1988. Applied Hydrology. pp. 572. McGraw-Hill Book Co. New York.

City of Daly City, 2012, Web site for Vista Grande Drainage Basin Alternatives Analysis (2011) http://www.dalycity.org/City_Hall/Departments/public_works/Reports_1119/vistagrande_alts.htm

Ecology and Environment. 1993. Environmental Lead characterization. Pacific Rod and Gun Club. Lake Merced, San Francisco, California. Final Report

EDAW, Inc. and Talavera & Richardson. 2004. Initiative to Raise and Maintain Lake Level and Improve Water Quality, Task 3 Technical Memorandum.

EIP Associates 2000. Significant Natural Resource Areas Management Plan. Prepared for Natural Areas Program, San Francisco Recreation and Parks Department.

Food and Agriculture Organization of the United States (FAO) Irrigation and Drainage Paper 24. 1977. Guidelines for Predicting Crop Water Requirements by J. Doorenbos and W.O. Pruitt.

FAO Irrigation and Drainage Paper 56. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements by Richard G. Allen, Luis S. Pereira, Dirk Raes, and Mark Smith.

G. Bartow, personal communication, April 16, 2009.

G. Braswell, personal communication, April 10, 2009.

Jacobs Associates, 2011a, Vista Grande Drainage Basin Alternatives Analysis Report, Alternatives Evaluation Report Executive Summary, prepared for City of Daly City, February 7, 2011 (Final Draft), Jacobs Associates, 2011b, Vista Grande Drainage Basin Alternatives Analysis Report, Volume 3 Lake Merced Alternative, prepared for City of Daly City, February 7, 2011 (Final Draft),

Kennedy/Jenks Consultants. 2009a. San Francisco Water System Improvement Program (WSIP) Lake Merced Water Levels Restoration (CUW30101) Draft 100% Conceptual Engineering Report. Prepared for San Francisco Public Utilities Commission. January 2009.

Kennedy/Jenks Consultants, 2009b, *Restoration Project Draft Lake Merced Lake Level Model – Historical Analysis,* technical memorandum prepared by Kennedy/Jenks Consultants for the SFPUC, August 25, 2009.

Luhdorff & Scalmanini Consulting Engineers (LSCE), 2002. Conceptualization of the Lake-Aquifer System, Westside Ground-Water Basin, San Francisco and San Mateo Counties. Dated March 2002, Re-released July 2002.

Luhdorff & Scalmanini Consulting Engineers (LSCE). 2004. Update on the Conceptualization of the Lake-Aquifer System Westside Groundwater basin San Francisco and San Mateo Counties. April 2004.

Luhdorff & Scalmanini Consulting Engineers (LSCE). 2005. North Westside Groundwater Basin Management Plan City and County of San Francisco. Final Draft. April 2005.

Luhdorff & Scalmanini Consulting Engineers (LSCE). 2007. Assessment of Groundwater Recharge and Potential Groundwater Development for Maintenance of Lake Merced North Westside Groundwater Basin. Technical Memorandum. August 2007.

Luhdorff & Scalmanini Consulting Engineers (LSCE), 2008. Simulation of Lake Level Response to SFPUC Lake Addition Preferred Operating Criteria, Lake Merced, North Westside Groundwater Basin. Technical Memorandum. October 2008.

Metcalf & Eddy, Inc. 2008. Lake Merced Water Level Restoration Alternative Analysis Report (AAR). Prepared for San Francisco Public Utilities Commission. January 2008.

Pezzetti, Toni and Bellows, Michele. 1998. Feasibility Evaluation of Alternatives to Raise Lake Merced. San Francisco Public Utilities Commission by CH2M Hill and the Duffey Co., San Francisco, CA.

Pruitt, W.O. and R.L. Snyder, 1985. Crop Water Use. *In* Irrigation with Reclaimed Municipal Wastewater – A Guidance Manual. Edited by G. Stuart Pettygrove and Takashi Asano.

San Fran Mission Dolores, California. Last visited August 24, 2009. from http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?casfod+sfo.

San Francisco Public Utilities Commission (SFPUC) 2008. 2007 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California. Dated April 2008.

SFPUC. 2009. 2008 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California. Dated April 2009.

San Francisco State University (SFSU). 2005. The Climatology of Lake Merced.

Western Regional Climate Center (WRCC), 2012a, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca7772, San Francisco Richmond, California (047767) Period of Record Monthly Climate Summary 7/ 1/1948 to 11/30/2011, web site maintained by Desert Research Institute wrcc@dri.edu, Reno, NV.

Western Regional Climate Center (WRCC), 2012b, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca7772, San Francisco Mission Dolores, California (047772) Period of Record Monthly Climate Summary 1/ 1/1914 to 1/31/2012, web site maintained by Desert Research Institute wrcc@dri.edu, Reno, NV.

Yates, E.B, S.N. Hamlin, and L.H. McCann, 1990. Geohydrology, Water Quality, and Water Budgets of Golden Gate Park, and the Lake Merced Area in the Western Part of San Francisco, California. U.S.G.S. Water Resources Investigations Report 90-4080. Prepared in Cooperation with the S.F. Water Department. Sacramento, CA 1990.

Yates, G. 2003. Estimating and Measuring Evaporation from Lake Merced. September 2003.


Filename: Z:\Projects\SFPUC_ConjUseEvents\20090804_LakeMercedFigures\Figure1.mxd

Source: ESRI Online Aerial Imagery, 2007 (2ft resolution)

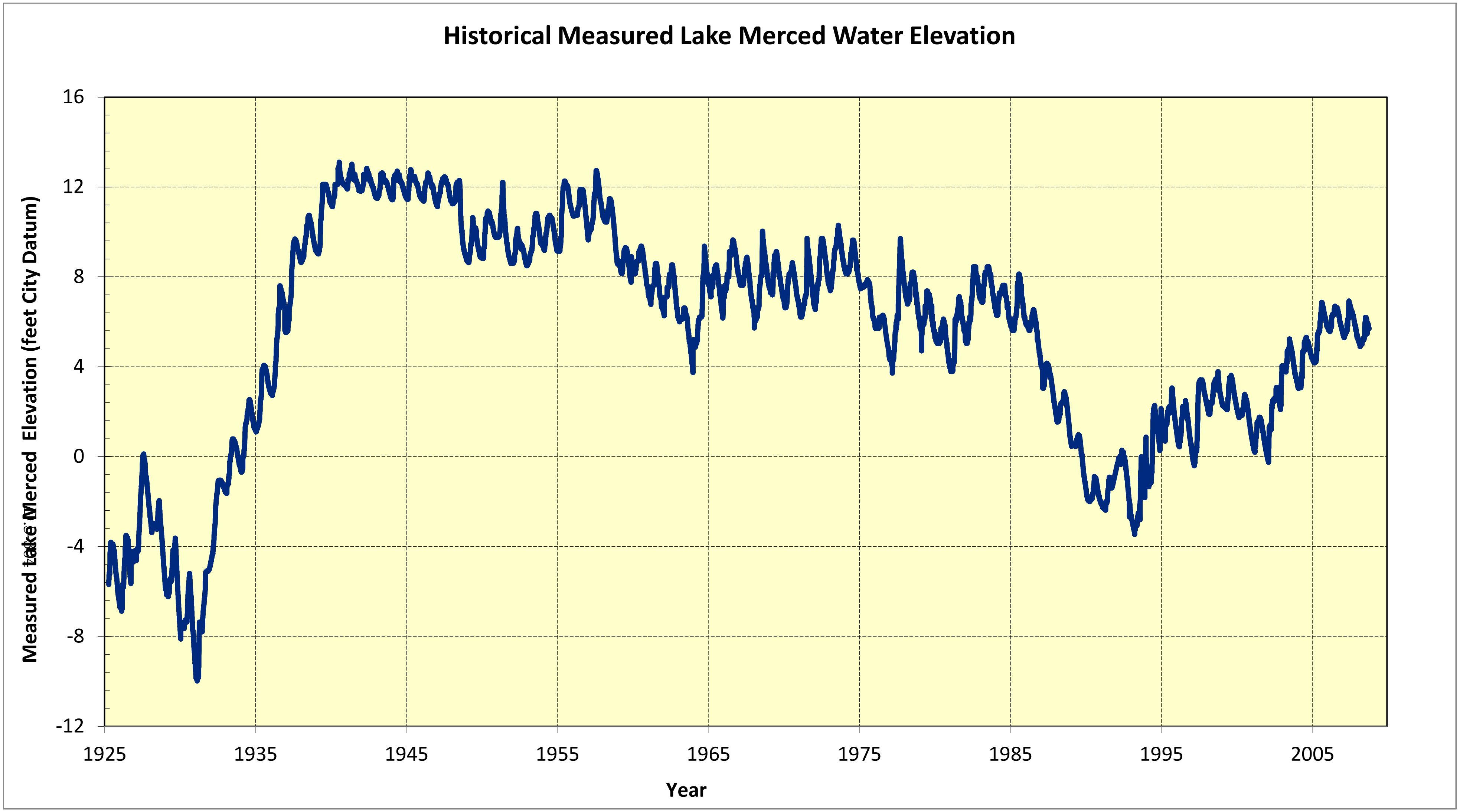
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Lake Merced Project Area**

K/J 0864001
April 2012

**Figure 1**




Source: Historical Lake Merced water elevation data from the San Francisco Public Utilities Commission
City Datum = NAVD - 11.37 feet

**Legend**

Historical Measured Lake Merced Water Elevation (feet City Datum)

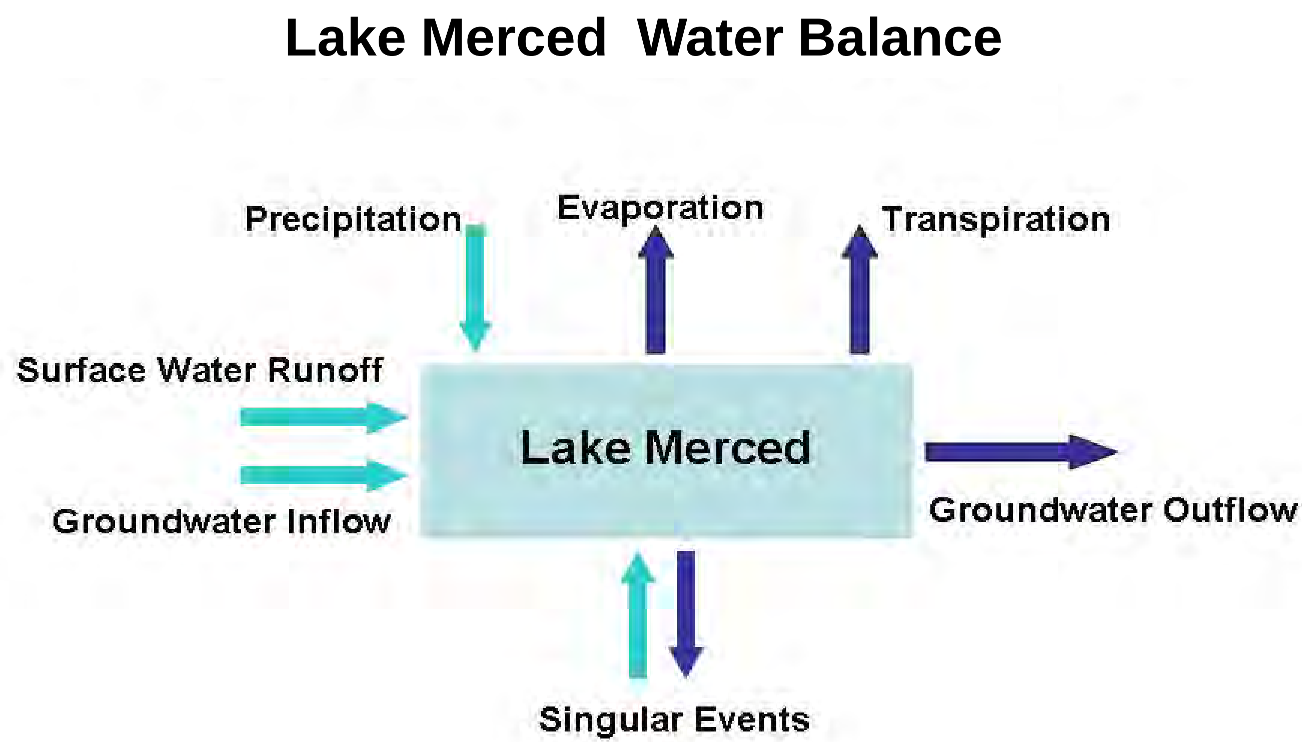
Kennedy/Jenks Consultants

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Historical Lake Merced Water Elevation**

K/J 0864001
April 2012

**Figure 2**




D.5-305

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Schematic of Conceptual Lake Merced Water Balance Model**

K/J 0864001
April 2012

**Figure 3**


Source: ESRI Online Aerial Imagery, 2007 (2ft resolution)
Bathymetic, Elevation Contours, and Vista Grande Canal Location from SFPUC, 2008

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Lake Merced Elevation Contours**

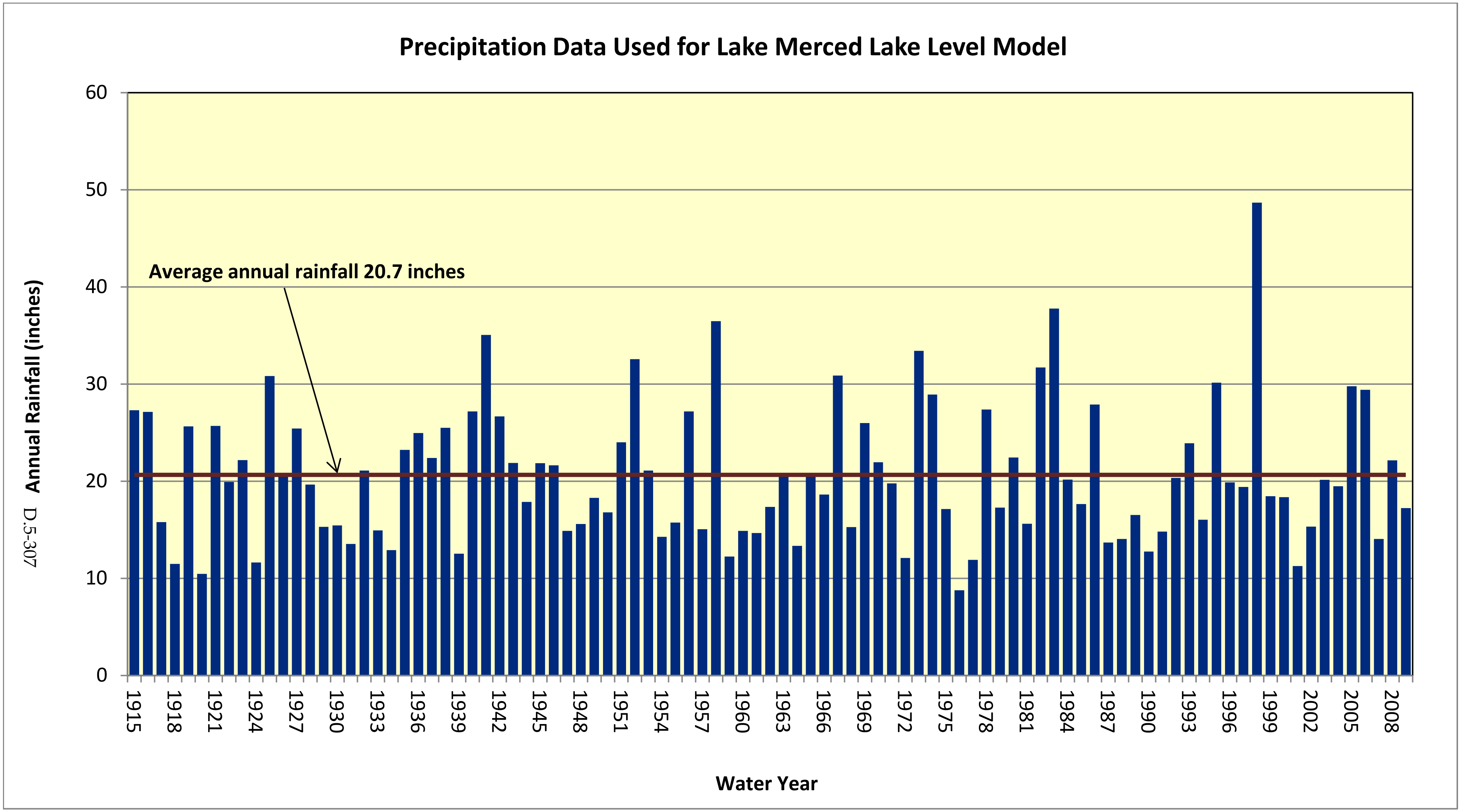
K/J 0864001
April 2012

**Figure 4**

## Legend

Vista Grande Canal

Bathymetric Contour (City Datum, 2 foot contour intervals)




D.5-307

Source: San Francisco Mission Dolores Weather Station, Western Regional Climate Center website (http://www.wrcc.dri.edu/)

Note: Mission Dolores Weather Station Used 1915 to 1958; San Francisco Richmond Sunset station used 1958 to 2009.

**Legend**

Annual Rainfall (inches)    Average Rainfall (inches)

Kennedy/Jenks Consultants

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Lake Merced Annual Rainfall (inches)**

K/J 0864001
April 2012

**Figure 5**


Source: ESRI Online Aerial Imagery, 2007 (2ft resolution)
Stormdrain Data from SFPUC, 2008

## Legend

- Stormdrain Catch Basin
- Stormdrain Manhole
- Stormdrain Junction
- Vista Grande Canal
- Stormdrain Line

**Kennedy/Jenks Consultants**

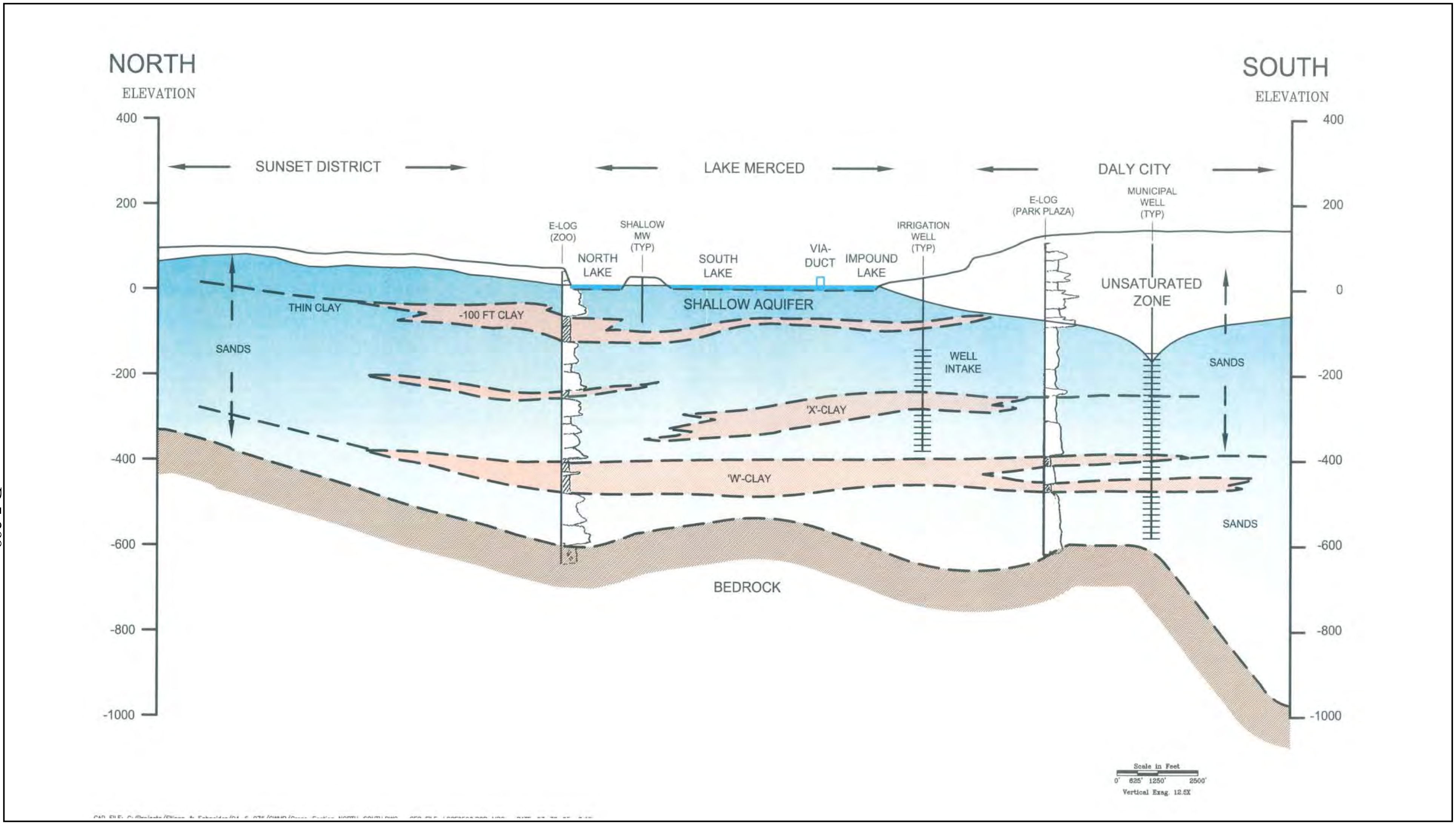
Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Locations of Stormdrain Catch Basins**

K/J 0864001
April 2012

**Figure 6**

D.5-309




Source: North Westside Groundwater Management Plan (LSCE, 2005)

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Schematic North – South Cross-Section**
**North Westside Groundwater Basin**

K/J 0864001
April 2012

**Figure 7**


Path: Z:\Projects\SFPUC_ConjUse\Events\20090804_LakeMercedFigures\Figure8.mxd

Source: ESRI Online Aerial Imagery, 2007 (2ft resolution)
Contours from "2007 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California (SFPUC)

**Legend**

- Groundwater Elevation Measurement Location
- Approximate Groundwater Elevation Contour (ft NAVD 88)
- Contour dashed where inferred
- General Groundwater Flow Direction

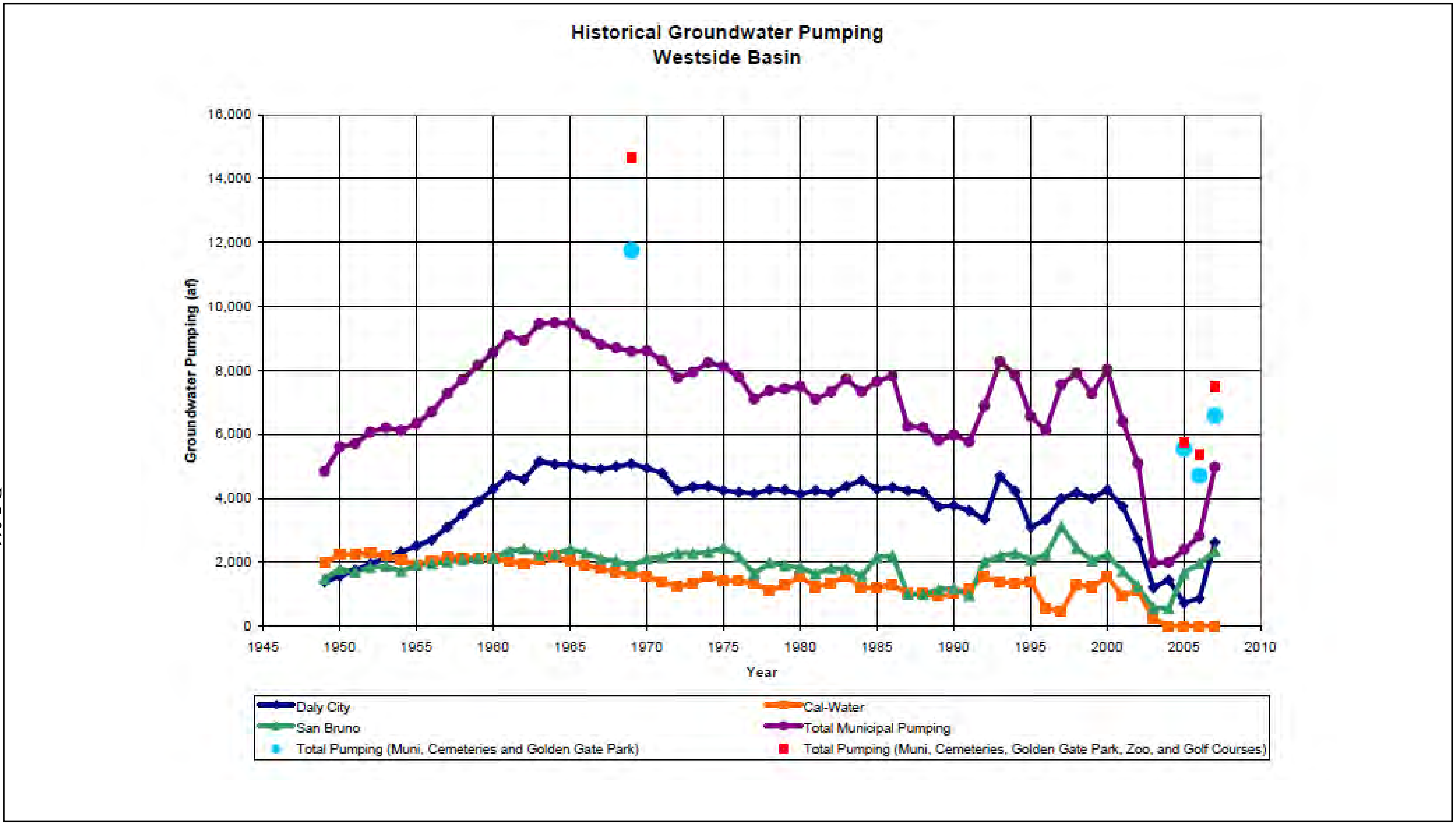
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Approximate Groundwater Elevation Contours, Shallow Aquifer, Fall 2007**

K/J 0864001
April 2012

**Figure 8**




Source: 2007 Annual Groundwater Monitoring Report Westside Basin San Francisco and San Mateo Counties, California, Prepared by San Francisco Public Utilities Commission

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Historical Groundwater Pumping**
**Westside Basin**

K/J 0864001
April 2012

**Figure 9**


Filename: Z:\Projects\SFPUC_ConjUse\Events\20090804_LakeMerced\Figures\Figure10.mxd

Source: ESRI Online Aerial Imagery, 2007 (2ft resolution)
Stormdrain Data from SFPUC, 2008

**Legend**

- Stormdrain Catch Basin
- Stormdrain Manhole
- Stormdrain Junction
- Vista Grande Canal
- Stormdrain Line
- Adjacent to Lake (123 Acres)
- Impervious Areas (31 Acres)
- Harding Park Golf Course (183 Acres)

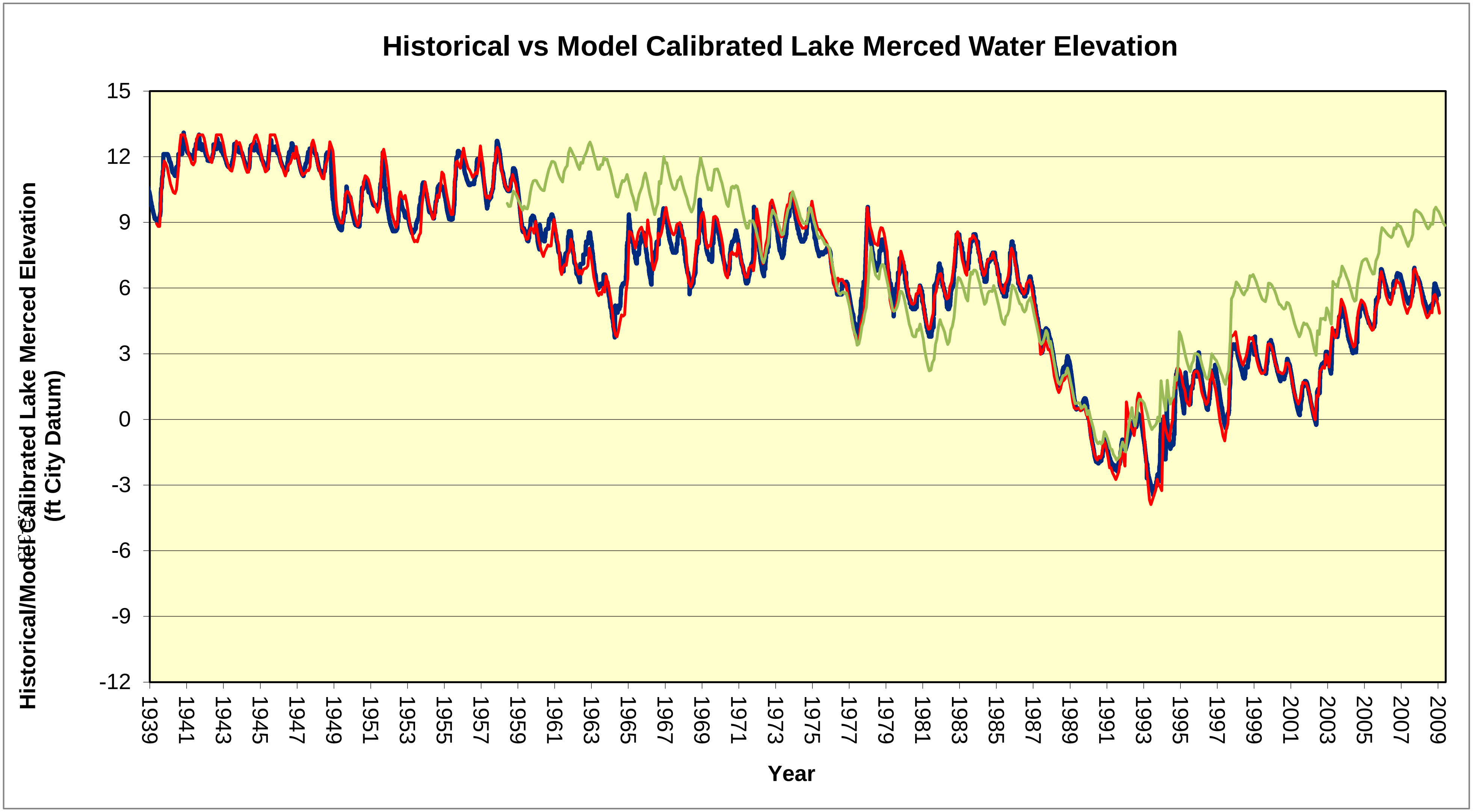
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Locations of Stormdrain Catch Basins and Approximate Areas of Stormwater Runoff**

K/J 0864001
April 2012

**Figure 10**




Source: Historical Lake Merced water elevation data from the San Francisco Public Utilities Commission
City Datum = NAVD - 11.37 feet

**Legend**

- Historical Measured Lake Elevation (feet City Datum)
- Lake-Level Model Simulated Lake Elevation (feet City Datum)
- MODFLOW Simulated Lake Elevations (feet City Datum)

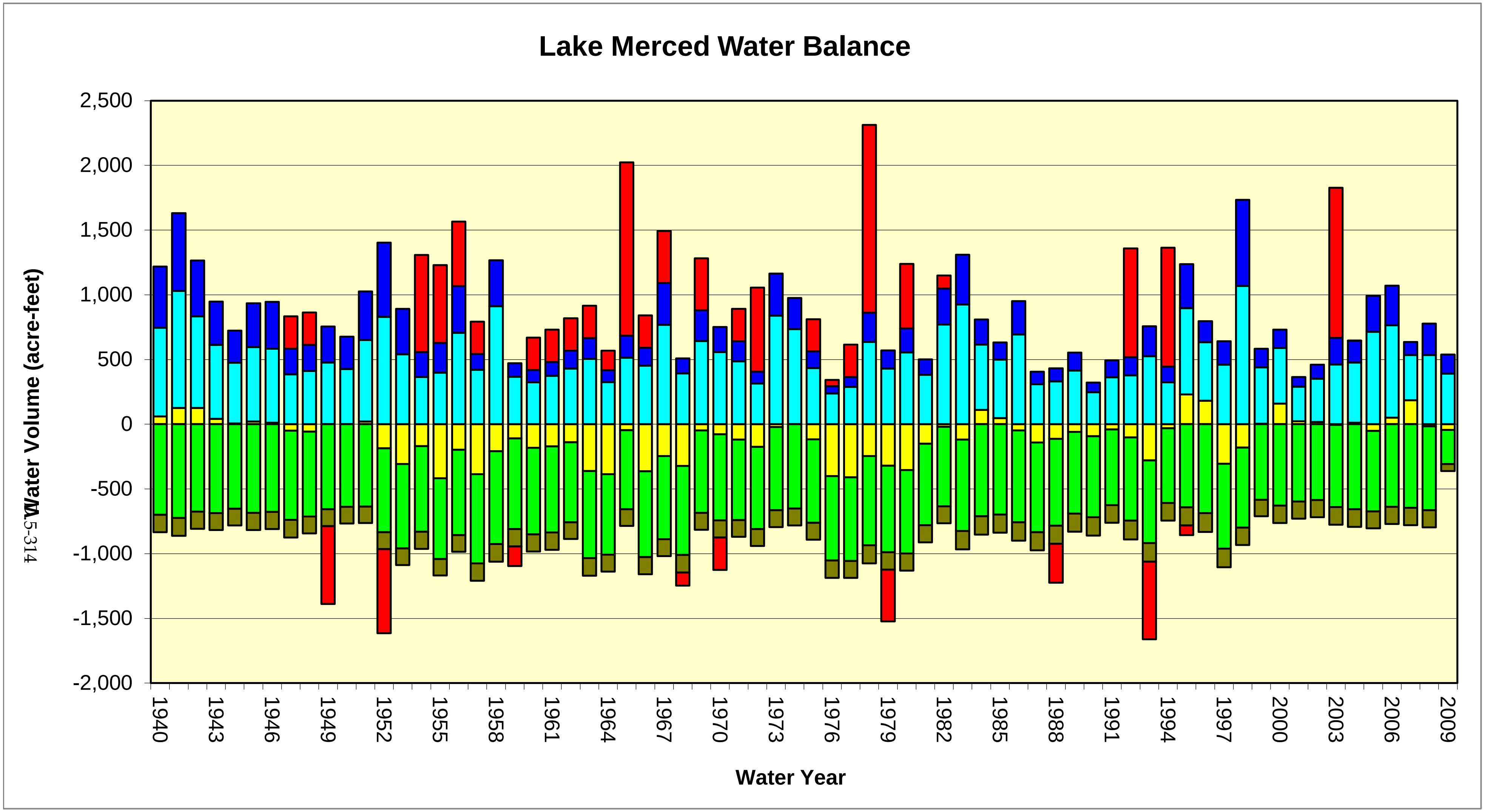
Kennedy/Jenks Consultants

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Historical vs Simulated Lake Merced Levels**

K/J 0864001
April 2012

**Figure 11**




4-5-314

**Legend**

- Groundwater In/Out (acre-feet)
- Precipitation (acre-feet)
- Stormwater Runoff (acre-feet)
- Evaporation (acre-feet)
- Transpiration (acre-feet)
- Singular Events (acre-feet)

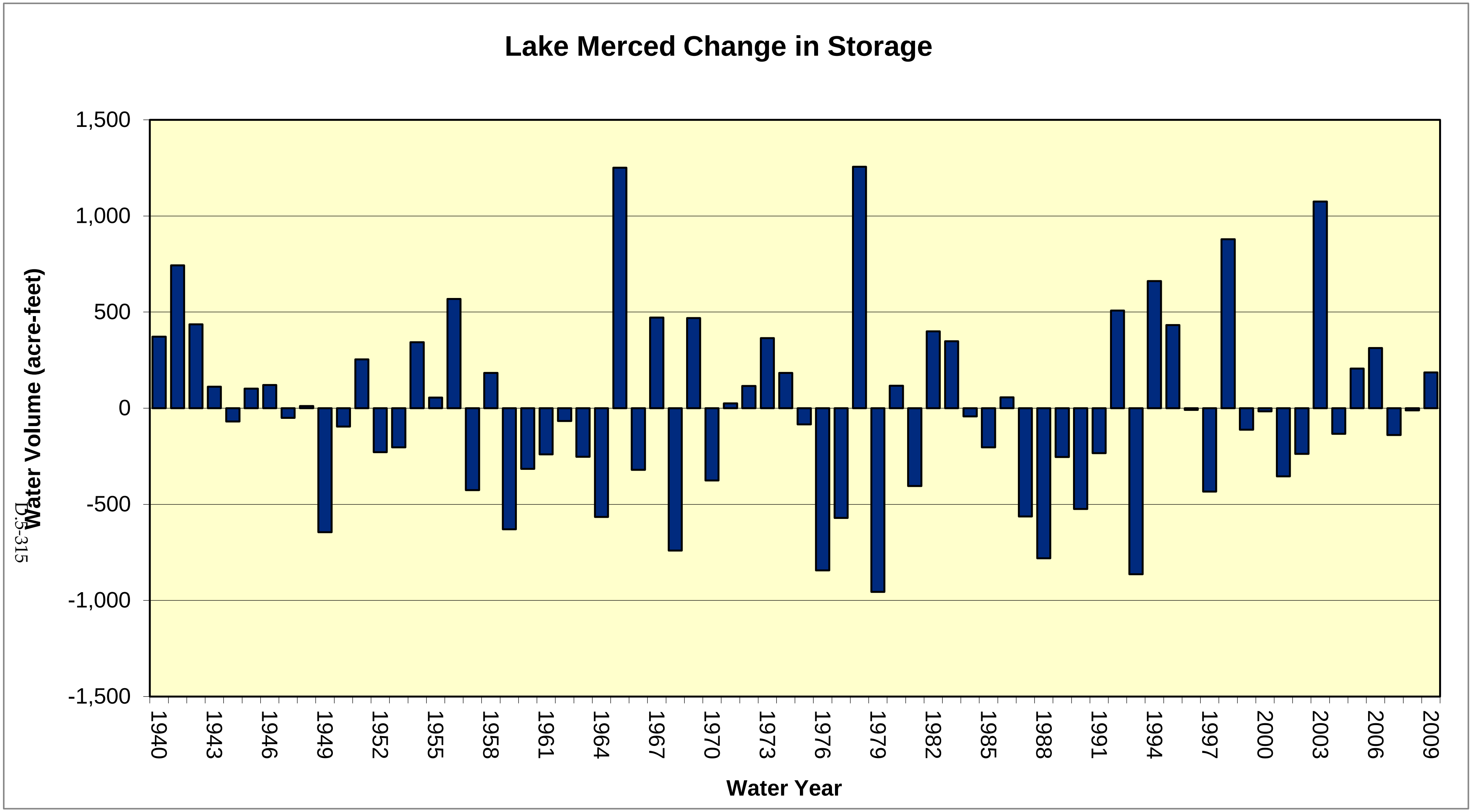
Kennedy/Jenks Consultants

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Lake Merced Annual Water Balance**

K/J 0864001
April 2012

**Figure 12**






**Legend**

■ Annual Change in Lake Storage (acre-feet)

Kennedy/Jenks Consultants

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Lake Merced Change in Storage**

K/J 0864001

April 2012

**Figure 13**

# Attachment 10.1-H

# Appendix A

San Francisco Lake Merced Pump Station and Mission Dolores
Weather Station Data Summary

**Monthly Rainfall Total at Used in Historical Lake Merced Lake-Level Model**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1914** | 9.76 | 5.04 | 1.09 | 0.99 | 0.37 | 0.29 | 0.02 | 0.00 | 0.00 | 0.29 | 0.70 | 5.49 | 24.04 |
| **1915** | 6.64 | 7.36 | 3.02 | 0.62 | 3.17 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.92 | 6.42 | 28.17 |
| **1916** | 14.59 | 3.77 | 1.33 | 0.00 | 0.07 | 0.00 | 0.03 | 0.29 | 1.20 | 0.52 | 1.50 | 4.79 | 28.09 |
| **1917** | 1.83 | 3.81 | 1.42 | 0.33 | 0.06 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.81 | 0.72 | 9.00 |
| **1918** | 0.81 | 5.79 | 2.73 | 0.60 | 0.00 | 0.00 | 0.00 | 0.00 | 2.53 | 0.17 | 5.60 | 2.62 | 20.85 |
| **1919** | 2.57 | 9.31 | 2.74 | 0.10 | 0.00 | 0.00 | 0.01 | 0.00 | 0.39 | 0.27 | 0.44 | 3.21 | 19.04 |
| **1920** | 0.26 | 1.23 | 3.25 | 1.36 | 0.00 | 0.04 | 0.00 | 0.00 | 0.13 | 1.83 | 2.70 | 7.98 | 18.78 |
| **1921** | 6.30 | 1.38 | 2.28 | 0.54 | 2.54 | 0.00 | 0.00 | 0.00 | 0.35 | 0.52 | 1.43 | 6.39 | 21.73 |
| **1922** | 2.41 | 5.15 | 2.38 | 0.47 | 0.55 | 0.26 | 0.00 | 0.00 | 0.00 | 2.95 | 3.77 | 7.77 | 25.71 |
| **1923** | 2.84 | 0.77 | 0.03 | 3.92 | 0.06 | 0.06 | 0.00 | 0.01 | 0.44 | 0.46 | 0.49 | 1.91 | 10.99 |
| **1924** | 2.75 | 3.30 | 1.96 | 0.30 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 2.98 | 1.50 | 7.37 | 20.17 |
| **1925** | 1.62 | 7.90 | 2.63 | 2.73 | 4.02 | 0.05 | 0.06 | 0.00 | 0.45 | 0.31 | 2.32 | 1.01 | 23.10 |
| **1926** | 5.48 | 5.40 | 0.25 | 5.26 | 0.15 | 0.00 | 0.00 | 0.04 | 0.00 | 1.90 | 7.21 | 1.04 | 26.73 |
| **1927** | 3.77 | 6.85 | 2.19 | 1.95 | 0.10 | 0.38 | 0.00 | 0.00 | 0.00 | 1.93 | 3.18 | 3.94 | 24.29 |
| **1928** | 2.40 | 1.97 | 4.65 | 1.31 | 0.26 | 0.00 | 0.00 | 0.00 | 0.03 | 0.13 | 3.35 | 4.89 | 18.99 |
| **1929** | 1.32 | 2.14 | 1.56 | 1.01 | 0.01 | 0.86 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 3.09 | 10.00 |
| **1930** | 4.99 | 2.09 | 3.53 | 1.56 | 0.16 | 0.00 | 0.00 | 0.00 | 0.10 | 0.89 | 1.56 | 0.98 | 15.86 |
| **1931** | 5.50 | 1.10 | 1.68 | 0.31 | 1.10 | 0.32 | 0.00 | 0.00 | 0.00 | 0.68 | 2.93 | 9.24 | 22.86 |
| **1932** | 3.23 | 3.00 | 0.86 | 0.47 | 0.65 | 0.03 | 0.00 | 0.00 | 0.00 | 0.01 | 1.00 | 2.75 | 12.00 |
| **1933** | 5.68 | 1.13 | 2.93 | 0.06 | 1.36 | 0.01 | 0.00 | 0.00 | 0.14 | 1.49 | 0.00 | 4.19 | 16.99 |
| **1934** | 1.03 | 4.68 | 0.07 | 0.51 | 0.12 | 0.68 | 0.01 | 0.00 | 0.13 | 0.88 | 3.76 | 4.06 | 15.93 |
| **1935** | 6.23 | 2.38 | 2.31 | 3.45 | 0.01 | 0.00 | 0.00 | 0.25 | 0.08 | 1.44 | 1.24 | 3.25 | 20.64 |
| **1936** | 5.77 | 10.06 | 1.01 | 1.09 | 0.49 | 0.28 | 0.03 | 0.02 | 0.00 | 0.69 | 0.01 | 2.94 | 22.39 |
| **1937** | 5.26 | 4.88 | 7.05 | 0.86 | 0.06 | 0.59 | 0.00 | 0.00 | 0.00 | 0.90 | 2.46 | 3.73 | 25.79 |
| **1938** | 2.65 | 8.49 | 5.73 | 1.52 | 0.00 | 0.00 | 0.01 | 0.00 | 0.15 | 1.33 | 0.88 | 1.48 | 22.24 |
| **1939** | 3.07 | 1.94 | 2.62 | 0.42 | 0.63 | 0.00 | 0.00 | 0.00 | 1.06 | 0.17 | 0.20 | 1.05 | 11.16 |
| **1940** | 9.98 | 7.81 | 5.32 | 0.94 | 0.63 | 0.01 | 0.00 | 0.00 | 0.59 | 1.05 | 2.22 | 6.25 | 34.80 |
| **1941** | 8.24 | 6.71 | 4.75 | 4.05 | 1.18 | 0.01 | 0.01 | 0.03 | 0.00 | 0.93 | 1.99 | 7.30 | 35.20 |
| **1942** | 4.76 | 4.27 | 2.62 | 3.65 | 1.11 | 0.00 | 0.01 | 0.00 | 0.18 | 0.95 | 4.45 | 2.87 | 24.87 |
| **1943** | 6.15 | 1.95 | 3.18 | 1.88 | 0.13 | 0.13 | 0.00 | 0.00 | 0.02 | 0.74 | 0.80 | 2.69 | 17.67 |
| **1944** | 4.31 | 5.34 | 0.83 | 2.07 | 0.94 | 0.12 | 0.01 | 0.02 | 0.00 | 1.73 | 6.24 | 3.97 | 25.58 |
| **1945** | 1.33 | 3.43 | 4.15 | 0.32 | 0.64 | 0.01 | 0.00 | 0.00 | 0.04 | 1.95 | 3.24 | 9.84 | 24.95 |
| **1946** | 1.76 | 2.03 | 2.34 | 0.05 | 0.37 | 0.02 | 0.06 | 0.00 | 0.06 | 0.15 | 2.73 | 2.77 | 12.34 |
| **1947** | 1.35 | 2.65 | 3.64 | 0.17 | 0.67 | 0.64 | 0.00 | 0.00 | 0.00 | 2.09 | 1.39 | 1.84 | 14.44 |
| **1948** | 1.00 | 2.32 | 3.36 | 3.04 | 0.54 | 0.01 | 0.02 | 0.02 | 0.09 | 0.20 | 1.18 | 4.76 | 16.54 |
| **1949** | 2.20 | 3.04 | 5.85 | 0.00 | 0.93 | 0.00 | 0.06 | 0.04 | 0.00 | 0.08 | 1.18 | 2.77 | 16.15 |
| **1950** | 7.40 | 2.33 | 1.65 | 0.87 | 0.37 | 0.03 | 0.00 | 0.00 | 0.00 | 2.72 | 4.96 | 6.01 | 26.34 |
| **1951** | 4.41 | 3.00 | 1.32 | 0.89 | 0.65 | 0.04 | 0.01 | 0.43 | 0.08 | 0.81 | 3.33 | 7.92 | 22.89 |
| **1952** | 10.69 | 2.62 | 4.90 | 1.08 | 0.30 | 0.39 | 0.00 | 0.01 | 0.00 | 0.07 | 2.42 | 9.06 | 31.54 |
| **1953** | 3.26 | 0.04 | 1.83 | 3.42 | 0.38 | 0.61 | 0.00 | 0.07 | 0.00 | 0.34 | 1.88 | 0.82 | 12.65 |
| **1954** | 3.11 | 2.42 | 4.56 | 0.82 | 0.11 | 0.14 | 0.03 | 0.20 | 0.00 | 0.24 | 2.55 | 5.67 | 19.85 |
| **1955** | 4.05 | 1.18 | 0.29 | 1.49 | 0.04 | 0.00 | 0.02 | 0.00 | 0.02 | 0.03 | 2.38 | 11.47 | 20.97 |
| **1956** | 8.72 | 2.03 | 0.12 | 1.68 | 0.68 | 0.02 | 0.00 | 0.01 | 0.33 | 1.14 | 0.04 | 0.37 | 15.14 |
| **1957** | 2.84 | 3.58 | 2.39 | 1.09 | 3.19 | 0.06 | 0.01 | 0.00 | 1.46 | 3.46 | 1.13 | 3.60 | 22.81 |
| **1958** | 4.38 | 7.78 | 8.22 | 5.47 | 0.88 | 0.09 | 0.05 | 0.00 | 0.04 | 0.21 | 0.28 | 1.50 | 28.90 |
| **1959** | 4.17 | 4.50 | 0.49 | 0.91 | 0.08 | 0.00 | 0.00 | 0.02 | 2.06 | 0.09 | 0.00 | 1.75 | 14.07 |
| **1960** | 4.45 | 2.92 | 1.91 | 0.96 | 0.72 | 0.00 | 0.00 | 0.00 | 0.00 | 0.48 | 3.40 | 2.33 | 17.17 |
| **1961** | 2.78 | 1.30 | 2.47 | 0.96 | 0.91 | 0.03 | 0.01 | 0.04 | 0.27 | 0.08 | 4.72 | 2.10 | 15.67 |
| **1962** | 1.05 | 6.11 | 2.69 | 0.23 | 0.05 | 0.00 | 0.00 | 0.10 | 0.15 | 4.11 | 0.58 | 3.48 | 18.55 |
| **1963** | 2.25 | 2.55 | 3.71 | 2.92 | 0.66 | 0.03 | 0.00 | 0.00 | 0.16 | 1.46 | 3.26 | 0.82 | 17.82 |
| **1964** | 4.50 | 0.24 | 1.82 | 0.24 | 0.38 | 0.46 | 0.10 | 0.04 | 0.02 | 1.46 | 3.46 | 4.50 | 17.22 |
| **1965** | 3.68 | 0.90 | 2.48 | 3.92 | 0.00 | 0.05 | 0.00 | 0.97 | 0.00 | 0.02 | 5.34 | 4.58 | 21.94 |
| **1966** | 3.18 | 2.86 | 0.75 | 0.45 | 0.29 | 0.17 | 0.00 | 0.18 | 0.12 | 0.04 | 4.52 | 3.72 | 16.28 |
| **1967** | 10.14 | 0.64 | 4.14 | 5.56 | 0.13 | 1.69 | 0.00 | 0.00 | 0.02 | 0.73 | 1.00 | 2.15 | 26.20 |
| **1968** | 4.88 | 2.71 | 3.32 | 0.28 | 0.19 | 0.00 | 0.04 | 0.13 | 0.08 | 0.74 | 3.18 | 4.73 | 20.28 |
| **1969** | 7.14 | 6.98 | 1.00 | 1.84 | 0.05 | 0.08 | 0.00 | 0.00 | 0.13 | 2.77 | 0.93 | 5.79 | 26.71 |
| **1970** | 7.35 | 2.02 | 1.99 | 0.12 | 0.05 | 0.80 | 0.00 | 0.28 | 0.00 | 0.81 | 5.82 | 6.24 | 25.48 |
| **1971** | 1.98 | 0.41 | 2.64 | 1.14 | 0.46 | 0.00 | 0.00 | 0.00 | 0.15 | 0.15 | 1.68 | 4.74 | 13.35 |
| **1972** | 1.68 | 2.17 | 0.28 | 1.10 | 0.00 | 0.13 | 0.00 | 0.00 | 0.80 | 4.65 | 6.22 | 3.67 | 20.70 |
| **1973** | 8.38 | 6.64 | 2.93 | 0.06 | 0.06 | 0.00 | 0.21 | 0.00 | 0.40 | 2.01 | 5.90 | 5.19 | 31.78 |
| **1974** | 4.25 | 1.74 | 6.23 | 2.76 | 0.00 | 0.22 | 0.49 | 0.03 | 0.00 | 0.78 | 0.57 | 1.31 | 18.38 |
| **1975** | 1.18 | 5.07 | 5.99 | 1.57 | 0.05 | 0.10 | 0.33 | 0.11 | 0.02 | 2.40 | 0.81 | 0.35 | 17.98 |
| **1976** | 0.53 | 1.49 | 1.38 | 1.26 | 0.05 | 0.03 | 0.00 | 0.98 | 0.18 | 0.53 | 1.31 | 2.60 | 10.34 |
| **1977** | 1.84 | 1.02 | 2.63 | 0.13 | 0.66 | 0.02 | 0.00 | 0.00 | 1.00 | 0.24 | 2.13 | 3.67 | 13.34 |
| **1978** | 6.54 | 3.80 | 5.89 | 4.10 | 0.01 | 0.00 | 0.00 | 0.00 | 0.26 | 0.00 | 1.25 | 1.09 | 22.94 |
| **1979** | 6.70 | 4.14 | 2.63 | 0.94 | 0.23 | 0.03 | 0.06 | 0.00 | 0.00 | 1.55 | 2.63 | 3.50 | 22.41 |
| **1980** | 4.83 | 6.47 | 2.10 | 1.04 | 0.26 | 0.00 | 0.05 | 0.00 | 0.36 | 0.10 | 1.26 | 1.72 | 18.19 |

**Monthly Rainfall Total at Used in Historical Lake Merced Lake-Level Model**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | 4.72 | 1.69 | 5.30 | 0.23 | 0.19 | 0.00 | 0.00 | 0.09 | 0.41 | 2.13 | 5.07 | 3.38 | 23.21 |
| **1982** | 7.10 | 3.00 | 5.81 | 4.53 | 0.00 | 0.18 | 0.04 | 0.00 | 0.55 | 2.62 | 5.56 | 2.89 | 32.28 |
| **1983** | 5.17 | 7.18 | 9.29 | 3.85 | 0.62 | 0.00 | 0.00 | 0.06 | 0.11 | 0.60 | 8.20 | 6.35 | 41.43 |
| **1984** | 0.42 | 2.31 | 1.04 | 0.86 | 0.07 | 0.13 | 0.00 | 0.23 | 0.08 | 2.69 | 4.82 | 2.29 | 14.94 |
| **1985** | 1.32 | 1.22 | 4.09 | 0.34 | 0.26 | 0.31 | 0.21 | 0.02 | 0.62 | 1.00 | 4.95 | 2.04 | 16.38 |
| **1986** | 3.74 | 7.01 | 7.18 | 0.84 | 0.14 | 0.13 | 0.00 | 0.00 | 1.07 | 0.21 | 0.18 | 1.94 | 22.44 |
| **1987** | 4.56 | 2.52 | 2.96 | 0.20 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 1.10 | 2.07 | 2.60 | 16.06 |
| **1988** | 4.24 | 0.42 | 0.20 | 2.67 | 0.40 | 0.36 | 0.00 | 0.00 | 0.00 | 0.64 | 2.90 | 3.68 | 15.51 |
| **1989** | 1.54 | 1.93 | 4.75 | 0.90 | 0.18 | 0.00 | 0.06 | 0.00 | 1.70 | 2.06 | 1.25 | 0.00 | 14.37 |
| **1990** | 1.90 | 2.25 | 1.20 | 0.45 | 1.78 | 0.10 | 0.00 | 0.00 | 0.12 | 0.06 | 0.61 | 2.10 | 10.57 |
| **1991** | 0.51 | 2.88 | 6.71 | 1.13 | 0.43 | 0.26 | 0.04 | 2.26 | 0.05 | 1.11 | 0.31 | 2.30 | 17.99 |
| **1992** | 2.52 | 5.78 | 5.09 | 0.41 | 0.00 | 0.46 | 0.04 | 0.03 | 0.00 | 1.39 | 0.19 | 5.77 | 21.68 |
| **1993** | 8.67 | 3.67 | 1.77 | 1.10 | 0.90 | 0.36 | 0.01 | 0.04 | 0.01 | 0.31 | 2.79 | 2.32 | 21.95 |
| **1994** | 2.75 | 4.70 | 0.35 | 1.23 | 1.47 | 0.05 | 0.00 | 0.00 | 0.14 | 0.12 | 5.16 | 3.22 | 19.19 |
| **1995** | 10.11 | 0.66 | 7.85 | 1.28 | 0.98 | 0.62 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 5.40 | 27.00 |
| **1996** | 3.29 | 5.28 | 2.43 | 1.87 | 1.49 | 0.00 | 0.00 | 0.02 | 0.01 | 1.14 | 2.95 | 6.37 | 24.85 |
| **1997** | 7.45 | 0.25 | 0.27 | 0.29 | 0.20 | 0.45 | 0.00 | 1.10 | 0.08 | 0.86 | 5.94 | 3.63 | 20.52 |
| **1998** | 11.67 | 15.64 | 2.77 | 2.73 | 4.20 | 0.05 | 0.02 | 0.00 | 0.05 | 0.69 | 2.69 | 2.04 | 42.55 |
| **1999** | 3.90 | 5.27 | 1.01 | 2.68 | 0.09 | 0.02 | 0.00 | 0.03 | 0.18 | 0.42 | 0.86 | 1.03 | 15.49 |
| **2000** | 4.74 | 6.79 | 1.75 | 1.20 | 0.54 | 0.80 | 0.00 | 0.00 | 0.25 | 1.40 | 0.30 | 0.57 | 18.34 |
| **2001** | 1.92 | 4.10 | 1.96 | 0.63 | 0.00 | 0.12 | 0.00 | 0.00 | 0.50 | 0.38 | 2.73 | 4.28 | 16.62 |
| **2002** | 3.50 | 0.84 | 1.94 | 0.29 | 0.86 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.18 | 8.81 | 17.42 |
| **2003** | 1.96 | 2.16 | 1.27 | 3.65 | 1.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.88 | 6.52 | 18.54 |
| **2004** | 3.56 | 6.42 | 0.94 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 2.01 | 8.13 | 21.46 |
| **2005** | 6.13 | 4.32 | 4.03 | 1.55 | 1.78 | 1.58 | 0.00 | 0.00 | 0.00 | 0.35 | 1.64 | 7.23 | 28.61 |
| **2006** | 3.03 | 3.14 | 8.85 | 4.82 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.51 | 2.45 | 4.33 | 27.46 |
| **2007** | 0.63 | 3.72 | 0.66 | 1.36 | 0.39 | 0.00 | 0.10 | 0.00 | 0.15 | 3.79 | 1.96 | 4.01 | 16.77 |
| **2008** | 9.75 | 2.14 | 0.12 | 0.12 | 0.00 | 0.00 | 0.03 | 0.04 | 0.00 | 0.29 | 2.08 | 2.58 | 17.15 |
| **2009** | 0.74 | 7.44 | 2.84 | 0.30 | 0.89 | 0.00 | 0.08 | 0.00 | 0.36 | | | | 12.65 |

**Period of Record Statistics**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MEAN** | **4.31** | **3.72** | **2.88** | **1.45** | **0.57** | **0.17** | **0.02** | **0.09** | **0.24** | **0.98** | **2.39** | **3.89** | **20.62** |
| **S.D.** | **2.91** | **2.63** | **2.12** | **1.40** | **0.81** | **0.30** | **0.07** | **0.29** | **0.45** | **1.02** | **1.88** | **2.43** | **6.47** |
| **MAX** | **14.59** | **15.64** | **9.29** | **5.56** | **4.20** | **1.69** | **0.49** | **2.26** | **2.53** | **4.65** | **8.20** | **11.47** | **42.55** |
| **MIN** | **0.26** | **0.04** | **0.03** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** | **9.00** |
| **NO YRS** | **96** | **96** | **96** | **96** | **96** | **96** | **96** | **96** | **96** | **95** | **95** | **95** | **96** |

5.85 Precipitation Data from Mission Dolores Station

0.09 Precipitation Data from Lake Merced Pump Station Gauge

# SAN FRAN MISSION DOLORE, CALIFORNIA

## Monthly Average Temperature (Degrees Fahrenheit)

### (047772)

File last updated on Jul 29, 2009
*** Note *** Provisional Data *** After Year/Month 200903
a = 1 day missing, b = 2 days missing, c = 3 days, ..etc..,
z = 26 or more days missing, A = Accumulations present
Long-term means based on columns; thus, the monthly row may not
sum (or average) to the long-term annual value.
MAXIMUM ALLOWABLE NUMBER OF MISSING DAYS : 5
Individual Months not used for annual or monthly statistics if more than 5 days are missing.
Individual Years not used for annual statistics if any month in that year has more than 5 days missing.

| YEAR (S) | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1914 | 51.50 | 53.93 | 58.40 | 58.30 | 56.19 | 56.60 | 57.03 | 58.19 | 60.77 | 62.05 | 58.98 | 48.69 | 56.72 |
| 1915 | 50.69 | 52.82 | 57.89 | 57.07 | 57.60 | 58.90 | 60.26 | 61.16 | 62.40 | 61.26 | 56.13 | 52.11 | 57.36 |
| 1916 | 46.98 | 55.86 | 56.56 | 57.58 | 55.79 | 57.42 | 60.00 | 58.58 | 62.18 | 56.94 | 54.43 | 48.87 | 55.93 |
| 1917 | 47.58 | 52.20 | 51.68 | 55.10 | 53.98 | 58.60 | 59.82 | 57.48 | 63.98 | 62.29 | 58.67 | 54.58 | 56.33 |
| 1918 | 52.65 | 51.88 | 54.87 | 57.25 | 54.68 | 59.25 | 58.82 | 60.82 | 62.27 | 64.03 | 55.60 | 50.15 | 56.85 |
| 1919 | 51.21 | 51.59 | 52.61 | 55.98 | 57.15 | 57.78 | 57.06 | 58.32 | 61.98 | 60.71 | 56.02 | 48.82 | 55.77 |
| 1920 | 52.21 | 52.83 | 52.48 | 54.97 | 55.76 | 60.20 | 57.85 | 60.11 | 60.42 | 60.03 | 55.35 | 50.98 | 56.10 |
| 1921 | 49.61 | 52.91 | 54.55 | 54.88 | 54.31 | 61.42 | 59.79 | 59.55 | 63.28 | 61.48 | 57.78 | 52.92 | 56.87 |
| 1922 | 46.74 | 50.21 | 52.34 | 53.55 | 58.02 | 60.03 | 60.16 | 60.40 | 63.32 | 61.31 | 54.30 | 50.60 | 55.91 |
| 1923 | 48.10 | 52.18 | 56.74 | 56.07 | 57.21 | 57.18 | 60.81 | 61.69 | 63.95 | 62.50 | 60.80 | 51.06 | 57.36 |
| 1924 | 50.21 | 57.05 | 54.50 | 57.47 | 59.11 | 59.82 | 59.05 | 59.13 | 62.45 | 59.48 | 56.70 | 47.85 | 56.90 |
| 1925 | 51.42 | 55.18 | 55.39 | 56.95 | 58.98 | 60.72 | 61.21 | 61.15 | 62.72 | 62.19 | 56.62 | 52.71 | 57.94 |
| 1926 | 47.90 | 56.02 | 60.65 | 61.62 | 61.06 | 59.15 | 61.10 | 60.84 | 61.28 | 63.45 | 60.87 | 51.50 | 58.79 |
| 1927 | 51.31 | 54.02 | 54.23 | 55.50 | 58.19 | 59.83 | 58.66 | 59.79 | 62.38 | 62.48 | 58.12 | 51.82 | 57.19 |
| 1928 | 50.44 | 55.10 | 58.24 | 57.73 | 58.92 | 60.52 | 58.68 | 58.45 | 61.20 | 59.52 | 56.35 | 49.63 | 57.06 |
| 1929 | 47.56 | 51.77 | 54.24 | 53.35 | 56.50 | 63.00 | 61.55 | 61.11 | 61.42 | 63.48 | 59.70 | 54.24 | 57.33 |
| 1930 | 49.68 | 56.64 | 57.61 | 59.23 | 56.08 | 59.93 | 58.65 | 61.52 | 62.40 | 63.19 | 58.08 | 52.10 | 57.93 |
| 1931 | 52.27 | 56.70 | 59.02 | 59.02 | 61.85 | 62.02 | 62.31 | 60.45 | 62.67 | 59.73 | 54.45 | 49.24 | 58.31 |
| 1932 | 49.32 | 51.36 | 57.10 | 55.95 | 58.40 | 59.17 | 59.73 | 60.97 | 62.97 | 62.15 | 60.67 | 47.45 | 57.10 |
| 1933 | 47.02 | 51.21 | 55.42 | 55.47 | 55.15 | 57.62 | 59.50 | 59.77 | 61.13 | 62.34 | 60.03 | 50.47 | 56.26 |
| 1934 | 51.84 | 55.62 | 60.65 | 58.97 | 60.61 | 60.93 | 59.94 | 60.90 | 63.65 | 61.76 | 58.50 | 52.92 | 58.86 |
| 1935 | 50.77 | 54.12 | 52.63 | 58.52 | 58.68 | 61.32 | 60.16 | 59.97 | 60.53 | 60.97 | 54.87 | 52.85 | 57.12 |
| 1936 | 53.85 | 53.41 | 57.47 | 58.92 | 61.53 | 61.68 | 59.48 | 59.31 | 63.02 | 62.21 | 58.03 | 51.53 | 58.37 |
| 1937 | 43.58 | 49.89 | 54.81 | 54.52 | 57.15 | 61.37 | 59.29 | 58.90 | 61.43 | 63.37 | 58.28 | 54.71 | 56.44 |
| 1938 | 51.45 | 53.07 | 52.82 | 54.92 | 56.60 | 57.45 | 58.85 | 60.08 | 61.18 | 61.56 | 56.78 | 53.61 | 56.53 |
| 1939 | 51.97 | 51.23 | 52.74 | 55.75 | 56.97 | 57.88 | 58.98 | 60.69 | 66.17 | 62.97 | 59.15 | 55.32 | 57.49 |
| 1940 | 52.61 | 55.41 | 57.40 | 57.77 | 58.02 | 59.00 | 60.16 | 60.00 | 65.08 | 62.29 | 57.03 | 55.45 | 58.35 |
| 1941 | 53.97 | 55.36 | 58.39 | 55.82 | 61.18 | 60.03 | 60.16 | 61.21 | 63.48 | 60.82 | 58.40 | 53.45 | 58.52 |
| 1942 | 51.11 | 53.36 | 55.26 | 55.58 | 56.85 | 58.58 | 59.73 | 58.47 | 60.27 | 60.90 | 56.02 | 52.08 | 56.52 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1943 | 51.89 | 54.75 | 55.61 | 55.58 | 58.61 | 57.35 | 59.05 | 59.84 | 63.45 | 61.32 | 59.23 | 53.58 | 57.52 |
| 1944 | 51.79 | 51.62 | 55.77 | 53.20 | 56.79 | 57.77 | 57.32 | 58.87 | 60.65 | 61.45 | 55.75 | 54.19 | 56.27 |
| 1945 | 50.19 | 54.34 | 51.82 | 55.90 | 55.39 | 61.30 | 59.55 | 58.65 | 62.52 | 61.56 | 56.38 | 52.74 | 56.70 |
| 1946 | 51.37 | 50.68 | 53.19 | 55.22 | 55.61 | 58.80 | 60.48 | 58.10 | 62.77 | 60.31 | 54.67 | 51.32 | 56.04 |
| 1947 | 47.18 | 53.61 | 55.98 | 58.47 | 57.76 | 61.82 | 60.11 | 61.76 | 61.40 | 62.03 | 55.33 | 50.97 | 57.20 |
| 1948 | 54.71 | 50.78 | 51.73 | 53.58 | 55.55 | 59.38 | 59.29 | 59.66 | 59.95 | 60.34 | 56.58 | 47.79 | 55.78 |
| 1949 | 44.68 | 48.30 | 53.21 | 55.55 | 56.71 | 58.78 | 57.53 | 59.39 | 62.48 | 58.50 | 59.82 | 50.60 | 55.46 |
| 1950 | 46.84 | 51.82 | 53.19 | 56.07 | 54.69 | 56.78 | 57.74 | 59.55 | 61.90 | 61.68 | 61.00 | 53.63 | 56.24 |
| 1951 | 50.26 | 52.18 | 54.05 | 52.32 | 57.29 | 56.28 | 56.24 | 57.29 | 59.75 | 61.52 | 56.22 | 49.95 | 55.28 |
| 1952 | 48.03 | 52.14 | 51.68 | 55.33 | 57.34 | 56.55 | 58.68 | 57.89 | 61.48 | 58.76 | 55.88 | 51.60 | 55.45 |
| 1953 | 54.34 | 54.00 | 53.18 | 52.67 | 56.58 | 57.78 | 57.23 | 59.50 | 62.52 | 61.56 | 56.67 | 54.98 | 56.75 |
| 1954 | 51.50 | 53.93 | 52.06 | 57.02 | 56.15 | 58.50 | 59.05 | 57.85 | 61.80 | 61.47 | 56.63 | 49.92 | 56.32 |
| 1955 | 48.11 | 52.21 | 54.81 | 52.25 | 56.60 | 57.00 | 56.85 | 56.37 | 59.03 | 59.63 | 56.22 | 53.05 | 55.18 |
| 1956 | 51.66 | 51.36 | 53.65 | 54.35 | 57.52 | 58.87 | 57.08 | 58.89 | 62.53 | 59.40 | 59.42 | 52.71 | 56.45 |
| 1957 | 48.82 | 53.96 | 54.11 | 57.65 | 57.89 | 61.38 | 59.55 | 59.52 | 63.57 | 62.31 | 56.80 | 51.45 | 57.25 |
| 1958 | 52.76 | 56.16 | 53.10 | 57.13 | 59.48 | 62.43 | 58.94 | 61.03 | 66.82 | 61.76 | 58.03 | 57.53 | 58.76 |
| 1959 | 54.00 | 53.43 | 58.16 | 57.85 | 56.76 | 59.37 | 59.98 | 61.82 | 62.92 | 65.18 | 60.17 | 54.84 | 58.71 |
| 1960 | 51.03 | 54.24 | 55.79 | 56.00 | 56.90 | 59.55 | 58.10 | 57.71 | 59.82 | 60.94 | 55.48 | 51.35 | 56.41 |
| 1961 | 49.05 | 55.43 | 54.24 | 56.90 | 55.71 | 60.12 | 59.98 | 60.92 | 63.37 | 61.19 | 56.47 | 50.02 | 56.95 |
| 1962 | 51.87 | 51.82 | 52.63 | 56.98 | 55.18 | 57.52 | 55.95 | 59.95 | 58.30 | 60.79 | 58.82 | 52.85 | 56.06 |
| 1963 | 50.39 | 58.38 | 54.10 | 54.37 | 57.19 | 58.07 | 59.69 | 59.76 | 64.73 | 62.89 | 56.62 | 48.23 | 57.03 |
| 1964 | 50.94 | 54.98 | 53.11 | 53.78 | 53.34 | 57.78 | 58.84 | 60.00 | 62.42 | 63.03 | 55.30 | 53.66 | 56.43 |
| 1965 | 51.39 | 53.98 | 54.39 | 55.65 | 54.84 | 56.17 | 57.42 | 61.19 | 61.18 | 64.95 | 58.10 | 48.32 | 56.47 |
| 1966 | 52.08 | 51.79 | 53.81 | 57.90 | 55.08 | 59.40 | 58.13 | 58.81 | 63.53 | 62.60 | 57.22 | 51.31 | 56.80 |
| 1967 | 52.61 | 53.16 | 52.69 | 50.73 | 57.85 | 57.07 | 58.85 | 59.15 | 63.48 | 65.48 | 59.95 | 51.85 | 56.91 |
| 1968 | 49.74 | 56.66 | 56.66 | 56.17 | 55.66 | 58.98 | 57.97 | 62.24 | 63.08 | 60.50 | 56.20 | 49.81 | 56.97 |
| 1969 | 48.55 | 50.04 | 54.21 | 54.17 | 56.98 | 58.65 | 57.61 | 59.32 | 60.85 | 61.87 | 59.32 | 55.76 | 56.44 |
| 1970 | 54.00 | 57.34 | 57.77 | 53.28 | 57.69 | 56.73 | 57.82 | 57.19 | 64.38 | 58.58 | 57.83 | 50.55 | 56.93 |
| 1971 | 50.82 | 51.91 | 53.29 | 53.10 | 54.55 | 57.30 | 57.44 | 61.05 | 64.68 | 57.79 | 55.58 | 49.00 | 55.54 |
| 1972 | 48.50 | 53.97 | 55.82 | 55.48 | 55.52 | 57.43 | 60.82 | 60.19 | 61.48 | 61.71 | 54.90 | 47.19 | 56.09 |
| 1973 | 50.15 | 54.86 | 52.53 | 57.20 | 56.27 | 60.67 | 58.56 | 57.08 | 61.30 | 60.95 | 55.32 | 51.98 | 56.41 |
| 1974 | 51.08 | 52.11 | 53.31 | 55.42 | 54.87 | 58.15 | 59.53 | 59.90 | 60.28 | 62.24 | 56.63 | 51.10 | 56.22 |
| 1975 | 51.02 | 53.30 | 53.08 | 51.90 | 57.16 | 56.88 | 58.84 | 59.45 | 59.43 | 59.65 | 55.55 | 53.39 | 55.80 |
| 1976 | 53.34 | 52.83 | 52.55 | 54.10 | 56.77 | 61.47 | 59.18 | 62.50 | 62.15 | 62.73 | 60.33 | 54.55 | 57.71 |
| 1977 | 49.87 | 56.09 | 53.18 | 56.07 | 55.31 | 57.05 | 59.02 | 61.52 | 61.93 | 60.53 | 58.55 | 54.92 | 57.00 |
| 1978 | 54.97 | 55.18 | 58.95 | 56.30 | 60.73 | 58.85 | 58.40 | 60.56 | 65.48 | 61.89 | 55.92 | 49.58 | 58.07 |
| 1979 | 50.94 | 52.89 | 55.68 | 56.42 | 59.15 | 58.58 | 60.21 | 60.79 | 66.32 | 63.16 | 57.65 | 55.34 | 58.09 |
| 1980 | 52.95 | 57.17 | 55.92 | 56.92 | 55.37 | 57.93 | 59.48 | 57.95 | 61.30 | 61.97 | 58.22 | 53.42 | 57.38 |
| 1981 | 52.39 | 56.02 | 54.94 | 55.77 | 56.76 | 62.18 | 57.79 | 59.21 | 60.37 | 59.29 | 58.32 | 53.97 | 57.25 |
| 1982 | 48.44 | 55.00 | 52.77 | 55.60 | 55.76 | 56.28 | 57.92 | 60.13 | 62.58 | 62.77 | 54.40 | 52.19 | 56.15 |
| 1983 | 49.37 | 54.62 | 55.29 | 56.80 | 59.66 | 61.78 | 63.42 | 65.90 | 67.07 | 63.97 | 56.12 | 52.82 | 58.90 |
| 1984 | 51.58 | 52.57 | 56.66 | 54.20 | 59.90 | 59.65 | 63.89 | 62.73 | 69.35 | 61.48 | 55.93 | 50.84 | 58.23 |
| 1985 | 49.95 | 55.98 | 53.16 | 59.80 | 58.05 | 63.83 | 64.05 | 64.08 | 64.08 | 63.15 | 54.95 | 51.24 | 58.53 |
| 1986 | 56.56 | 58.91 | 60.44 | 58.55 | 60.00 | 63.22 | 62.76 | 61.87 | 62.75 | 63.58 | 60.18 | 52.47 | 60.11 |
| 1987 | 51.79 | 56.41 | 57.11 | 60.43 | 61.06 | 60.47 | 61.48 | 63.45 | 63.78 | 65.03 | 58.73 | 52.24 | 59.33 |
| 1988 | 52.82 | 57.66 | 59.06 | 58.73 | 59.11 | 61.02 | 64.19 | 64.00 | 63.03 | 61.44 | 57.25 | 53.23 | 59.30 |
| 1989 | 51.26 | 49.98 | 55.35 | 60.87 | 59.26 | 61.55 | 62.42 | 63.00 | 61.80 | 62.00 | 58.80 | 52.60 | 58.24 |
| 1990 | 52.74 | 51.95 | 54.84 | 59.22 | 59.00 | 62.33 | 62.89 | 65.24 | 65.95 | 64.21 | 57.98 | 49.10 | 58.79 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 | 53.37 | 57.88 | 53.19 | 57.03 | 56.77 | 58.58 | 61.29 | 63.00 | 63.12 | 64.35 | 60.05 | 53.39 | 58.50 |
| 1992 | 51.42 | 58.38 | 59.23 | 62.62 | 62.73 | 62.53 | 65.10 | 63.76 | 65.78 | 66.73 | 59.72 | 51.69 | 60.81 |
| 1993 | 51.08 | 53.77 | 59.00 | 59.42 | 62.45 | 65.92 | 63.39 | 66.56 | 63.38 | 64.27 | 58.17 | 51.52 | 59.91 |
| 1994 | 53.66 | 52.68 | 58.10 | 57.58 | 58.71 | 61.03 | 59.61 | 63.42 | 63.67 | 62.19 | 51.93 | 49.52 | 57.68 |
| 1995 | 54.03 | 56.91 | 56.15 | 56.92 | 57.39 | 61.67 | 65.98 | 64.05 | 64.68 | 64.58 | 60.85 | 55.50 | 59.89 |
| 1996 | 54.02 | 57.09 | 58.74 | 61.40 | 61.71 | 62.83 | 63.65 | 63.73 | 63.55 | 62.84 | 58.02 | 55.82 | 60.28 |
| 1997 | 52.65 | 56.09 | 58.21 | 58.10 | 62.60 | 61.62 | 62.27 | 65.74 | 67.75 | 62.45 | 59.30 | 53.82 | 60.05 |
| 1998 | 53.63 | 52.66 | 55.66 | 55.43 | 56.55 | 59.30 | 60.10 | 61.08 | 61.72 | 60.55 | 55.18 | 49.95 | 56.82 |
| 1999 | 50.50 | 51.45 | 51.18 | 54.88 | 53.74 | 56.37 | 58.66 | 60.87 | 61.48 | 62.42 | 57.78 | 54.23 | 56.13 |
| 2000 | 52.63 | 53.83 | 54.94 | 57.10 | 58.24 | 59.50 | 58.32 | 60.66 | 64.70 | 59.52 | 53.80 | 53.95 | 57.27 |
| 2001 | 51.37 | 52.05 | 55.85 | 52.50 | 61.52 | 61.30 | 60.47 | 61.50 | 61.00 | 62.65 | 58.63 | 52.76 | 57.63 |
| 2002 | 50.68 | 55.45 | 53.85 | 54.83 | 55.02 | 58.02 | 59.16 | 60.39 | 61.52 | 60.77 | 59.38 | 54.23 | 56.94 |
| 2003 | 56.27 | 54.59 | 56.45 | 53.92 | 58.03 | 60.50 | 59.32 | 63.48 | 64.83 | 62.97 | 55.33 | 52.85 | 58.21 |
| 2004 | 51.77 | 53.69 | 60.24 | 58.48 | 58.13 | 58.93 | 60.68 | 62.81 | 64.88 | 60.03 | 56.50 | 53.48 | 58.30 |
| 2005 | 50.32 | 55.84 | 57.52 | 55.92 | 59.10 | 59.33 | 60.92a | 59.77 | 59.67 | 60.52 | 60.25 | 55.48 | 57.89 |
| 2006 | 52.61 | 54.70 | 50.89 | 54.87 | 57.35 | 60.20 | 61.73 | 59.52 | 59.57 | 60.69 | 56.25 | 52.35 | 56.73 |
| 2007 | 49.97 | 53.02 | 57.17a | 55.40 | 57.29 | 59.12 | 61.44 | 61.95 | 63.40 | 60.35 | 57.28 | 50.77 | 57.26 |
| 2008 | 49.85a | 53.14 | 54.48 | 54.88 | 57.60 | 59.53 | 60.47 | 61.94 | 63.33 | 63.40 | 59.08 | 50.42 | 57.34 |
| 2009 | 54.11 | 52.78a | 54.11 | 55.85 | 58.02 | 60.39b | 59.48h | -----z | -----z | -----z | -----z | -----z | 55.88 |

Period of Record Statistics

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | 51.04 | 53.87 | 55.21 | 56.25 | 57.53 | 59.49 | 59.78 | 60.59 | 62.67 | 61.79 | 57.39 | 52.05 | 57.30 |
| S.D. | 2.32 | 2.19 | 2.40 | 2.23 | 2.12 | 1.98 | 1.98 | 2.06 | 1.98 | 1.72 | 1.93 | 2.19 | 1.22 |
| SKEW | -0.46 | 0.11 | 0.42 | 0.29 | 0.54 | 0.47 | 0.79 | 0.62 | 0.60 | 0.01 | -0.07 | -0.10 | 0.72 |
| MAX | 56.56 | 58.91 | 60.65 | 62.62 | 62.73 | 65.92 | 65.98 | 66.56 | 69.35 | 66.73 | 61.00 | 57.53 | 60.81 |
| MIN | 43.58 | 48.30 | 50.89 | 50.73 | 53.34 | 56.17 | 55.95 | 56.37 | 58.30 | 56.94 | 51.93 | 47.19 | 55.18 |
| NO YRS | 96 | 96 | 96 | 96 | 96 | 96 | 95 | 95 | 95 | 95 | 95 | 95 | 95 |

# Attachment 10.1-H

# Appendix B

Lake Merced Lake-Level Model – Historical Analysis Annual Water Balance Data Summary

**Lake Merced Lake-Level Model - Historical Analysis Annual Water Balance Data Summary**

| Water Year | Precipitation (AF) | Stormwater Runoff (AF) | Evaporation (AF) | Transpiration (AF) | Groundwater In/Out (AF) | Singular Events (AF) | Change in Lake Storage (AF) |
|---|---|---|---|---|---|---|---|
| 1940 | 686 | 473 | -699 | -135 | 60 | 0 | 373 |
| 1941 | 905 | 601 | -725 | -137 | 126 | 0 | 743 |
| 1942 | 707 | 431 | -676 | -132 | 126 | 0 | 436 |
| 1943 | 572 | 334 | -686 | -132 | 41 | 0 | 112 |
| 1944 | 469 | 249 | -653 | -129 | 6 | 0 | -70 |
| 1945 | 574 | 339 | -685 | -133 | 22 | 0 | 102 |
| 1946 | 570 | 363 | -678 | -132 | 13 | 0 | 120 |
| 1947 | 386 | 197 | -689 | -135 | -50 | 250 | -50 |
| 1948 | 411 | 203 | -656 | -130 | -57 | 250 | 12 |
| 1949 | 477 | 277 | -658 | -131 | 0 | -600 | -645 |
| 1950 | 427 | 250 | -638 | -128 | 0 | 0 | -95 |
| 1951 | 630 | 375 | -635 | -128 | 22 | 0 | 254 |
| 1952 | 829 | 573 | -649 | -130 | -186 | -650 | -229 |
| 1953 | 540 | 352 | -651 | -130 | -307 | 0 | -203 |
| 1954 | 366 | 192 | -662 | -132 | -168 | 750 | 343 |
| 1955 | 399 | 230 | -624 | -126 | -418 | 600 | 55 |
| 1956 | 707 | 359 | -659 | -130 | -196 | 500 | 568 |
| 1957 | 422 | 120 | -689 | -134 | -387 | 250 | -426 |
| 1958 | 912 | 355 | -717 | -138 | -208 | 0 | 183 |
| 1959 | 366 | 105 | -700 | -136 | -109 | -150 | -630 |
| 1960 | 324 | 96 | -668 | -134 | -182 | 250 | -316 |
| 1961 | 375 | 106 | -666 | -134 | -171 | 250 | -240 |
| 1962 | 430 | 138 | -618 | -128 | -139 | 250 | -67 |
| 1963 | 506 | 159 | -673 | -136 | -362 | 250 | -252 |
| 1964 | 325 | 93 | -622 | -131 | -385 | 150 | -566 |
| 1965 | 514 | 170 | -611 | -128 | -46 | 1,340 | 1,251 |
| 1966 | 452 | 138 | -663 | -133 | -364 | 250 | -321 |
| 1967 | 768 | 324 | -642 | -130 | -246 | 400 | 472 |
| 1968 | 392 | 116 | -688 | -136 | -323 | -100 | -741 |
| 1969 | 642 | 239 | -637 | -131 | -47 | 400 | 469 |
| 1970 | 557 | 194 | -666 | -133 | -77 | -250 | -377 |
| 1971 | 487 | 154 | -621 | -128 | -120 | 250 | 25 |
| 1972 | 315 | 91 | -636 | -130 | -175 | 650 | 116 |
| 1973 | 839 | 325 | -642 | -131 | -21 | 0 | 365 |
| 1974 | 734 | 239 | -652 | -131 | 1 | 0 | 184 |
| 1975 | 434 | 127 | -646 | -130 | -116 | 250 | -84 |
| 1976 | 238 | 55 | -652 | -134 | -401 | 50 | -844 |
| 1977 | 289 | 77 | -645 | -132 | -411 | 250 | -570 |
| 1978 | 635 | 227 | -690 | -138 | -245 | 1,450 | 1,257 |
| 1979 | 430 | 140 | -668 | -135 | -321 | -400 | -956 |
| 1980 | 556 | 184 | -644 | -132 | -354 | 500 | 117 |
| 1981 | 382 | 119 | -629 | -133 | -151 | 0 | -405 |
| 1982 | 770 | 279 | -615 | -130 | -20 | 100 | 399 |
| 1983 | 925 | 384 | -706 | -141 | -119 | 0 | 348 |
| 1984 | 506 | 193 | -712 | -141 | 110 | 0 | -43 |
| 1985 | 452 | 133 | -697 | -140 | 48 | 0 | -203 |
| 1986 | 694 | 257 | -710 | -142 | -47 | 0 | 57 |
| 1987 | 309 | 97 | -693 | -140 | -141 | 0 | -563 |
| 1988 | 332 | 101 | -670 | -141 | -112 | -300 | -781 |
| 1989 | 415 | 138 | -632 | -140 | -58 | 0 | -254 |
| 1990 | 247 | 75 | -627 | -141 | -92 | 0 | -524 |

**Lake Merced Lake-Level Model - Historical Analysis Annual Water Balance Data Summary**

| Water Year | Precipitation (AF) | Stormwater Runoff (AF) | Evaporation (AF) | Transpiration (AF) | Groundwater In/Out (AF) | Singular Events (AF) | Change in Lake Storage (AF) |
|---|---|---|---|---|---|---|---|
| 1991 | 362 | 131 | -583 | -137 | -41 | 0 | -234 |
| 1992 | 378 | 140 | -642 | -146 | -102 | 840 | 508 |
| 1993 | 525 | 232 | -639 | -144 | -279 | -600 | -863 |
| 1994 | 324 | 120 | -577 | -138 | -30 | 920 | 662 |
| 1995 | 665 | 340 | -641 | -140 | 231 | -75 | 432 |
| 1996 | 452 | 163 | -687 | -146 | 182 | 0 | -9 |
| 1997 | 461 | 181 | -656 | -144 | -305 | 0 | -434 |
| 1998 | 1,069 | 666 | -620 | -134 | -180 | 0 | 878 |
| 1999 | 436 | 144 | -583 | -129 | 4 | 0 | -112 |
| 2000 | 429 | 143 | -628 | -135 | 159 | 0 | -16 |
| 2001 | 267 | 76 | -597 | -133 | 22 | 0 | -355 |
| 2002 | 333 | 110 | -586 | -132 | 18 | 0 | -238 |
| 2003 | 463 | 204 | -635 | -136 | -5 | 1,161 | 1,075 |
| 2004 | 465 | 168 | -656 | -137 | 12 | 2 | -134 |
| 2005 | 714 | 278 | -621 | -132 | -52 | 0 | 206 |
| 2006 | 713 | 306 | -638 | -133 | 52 | 0 | 313 |
| 2007 | 349 | 101 | -646 | -134 | 185 | 0 | -140 |
| 2008 | 534 | 243 | -647 | -134 | -17 | 0 | -11 |
| 2009 | 392 | 147 | -263 | -54 | -44 | 0 | 186 |
| **Total** | **35,959** | **15,436** | **-45,314** | **-9,320** | **-6,948** | **9,438** | **-380** |
| **Average** | **514** | **221** | **-647** | **-133** | **-99** | **135** | **-5** |
| **Max** | **1,069** | **666** | **-263** | **-54** | **231** | **1,450** | **1,257** |
| **Min** | **238** | **55** | **-725** | **-146** | **-418** | **-650** | **-956** |
| **Std Dev** | **182** | **129** | **57** | **11** | **159** | **379** | **476** |
| **Years** | **68** | **68** | **68** | **68** | **68** | **27** | **68** |

# APPENDIX D-6

## Task 10.3 Technical Memorandum, Assessment of Potential Seawater Intrusion for the Regional Groundwater Storage and Recovery Project and the San Francisco Groundwater Supply Project

The hydrographs referenced in Section 5.16, Hydrology and Water Quality, are Figures 10.3-4 through 10.3-12c.

*This page intentionally left blank*

Kennedy/Jenks Consultants

303 Second Street, Suite 300 South
San Francisco, California 94107
415-243-2150
FAX: 415-896-0999

# Technical Memorandum 10.3

# Assessment of Potential Seawater Intrusion

for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

24 April 2012

Prepared for

San Francisco Public Utilities Commission
525 Golden Gate Avenue, 10th Floor
San Francisco, CA 94102

K/J Project No. 0864001

# Supplemental Explanation for Hydrographs - TM10.3

This supplemental explanation is prepared to address discrepancies on several graphs presented in TM 10.3.

First, the x-axis on several graphs showing model results was shifted. The x-axis is named Scenario Year which should correspond to a water year[1]. However, the graph template was plotted using a calendar year, so the intervals on the x-axis represent the period from January to December. The result is that the graph is shifted 3-months later relative to Scenario Year.

Second, the shaded area representing the Design Drought was added manually and because of this process, it was not presented consistently on the graphs. By definition per the PEIR, the 8.5-year Design Drought includes one Hold year before the 7.5-year Take period. In addition, the Design Drought needs to be shifted 3-months later for the x-axis issue to be consistent with the model output. The Design Drought should be shown as Scenario Years 35.5 to 44.0 on the shifted x-axis.

The following is a list of figures in TM 10.3 where the Design Drought shaded area is shown slightly different and does not match the correct display of the Design Drought. The figures should be viewed based on the correct representation of the Design Drought as explained above.

- Figures 10.3-4 through 10.3-17 (a total of 30 figures) have the shifted x-axis. The Design Drought should be shown as Scenario Years 35.5 to 44.0 on the shifted x-axis.

[1] A water year is October 1 of the previous year to September 30 of the current (named) year.

24 April 2012

# Task 10.3 Technical Memorandum

## San Francisco Public Utilities Commission

## Assessment of Potential Seawater Intrusion for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Prepared For: Greg Bartow and Jeff Gilman, SFPUC

Prepared by: Matthew Baillie, Michael Maley and Sevim Onsoy, Kennedy/Jenks Consultants

---

## 1. Introduction

This Technical Memorandum (TM) was prepared to document work performed by Kennedy/Jenks Consultants (Kennedy/Jenks) for the San Francisco Public Utilities Commission (SFPUC) pursuant to the amended Task Order (TO) authorizations CUW30103-TO-1.12 of the Regional Groundwater Storage and Recovery (GSR) Project and CUW30102-TO-2.7 of the San Francisco Groundwater Supply (SFGW) Project. These projects are funded by the SFPUC's Water System Improvement Program (WSIP).

### 1.1. GSR and SFGW Project Description

The GSR Project is a conjunctive use project that would allow for increased groundwater supplies in the southern portion of the Westside Groundwater Basin (South Westside Basin) during periods of drought when SFPUC surface water supplies might become limited (MWH, 2008). The project would be designed to provide up to 60,500 acre-feet (af) of stored water to meet SFPUC system demands during the last 7.5 years of SFPUC's Design Drought. The SFPUC plans to install 16 new production wells for the GSR Project to recover the stored groundwater. Under the Draft GSR Operating Agreement, the SFPUC would "store" water in the South Westside Basin through the mechanism of in-lieu recharge by providing supplemental surface water as a substitute for groundwater pumping by the Partner Agencies (PAs). As a result of the in-lieu deliveries, up to 60,500 af of groundwater storage or put credits could accrue to the SFPUC Storage Account. During shortages of SFPUC Regional Water System water due to drought, emergencies, or scheduled maintenance, the PAs would return to pumping from their existing wells, and SFPUC would extract groundwater from GSR Project wells as long as a positive balance exists in the SFPUC Storage Account.

The SFGW Project would provide a reliable, local source of high-quality groundwater in the northern portion of the Westside Groundwater Basin (North Westside Basin) to supplement the

San Francisco municipal water system. The SFGW Project would construct up to four wells (and convert two existing irrigation wells in Golden Gate Park for municipal supply) and associated facilities in the western part of San Francisco and extract an annual average of up to 4.0 million gallons per day (mgd) of water from the North Westside Basin (SFPUC, 2009a). The extracted groundwater, which would be used both for regular and emergency water supply purposes, would be blended in small quantities with imported surface water before entering the municipal drinking water system for distribution. The SFGW Project includes two phases. In phase one, SFPUC would build four new groundwater wells at the Lake Merced Pump Station, West Sunset Playground, South Sunset Playground, and the Golden Gate Park Central Pump Station. In phase two, SFPUC would modify two existing irrigation wells (South Windmill Replacement and North Lake) in Golden Gate Park, converting them into municipal water supply wells.

The locations of existing and proposed GSR and SFGW wells, existing PA wells, and monitoring wells are shown on Figure 10.3-1. Additional detailed discussion of the GSR and SFGW Projects is provided in Task 10.1 Technical Memorandum - Groundwater Modeling Analysis for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project (TM-10.1).

### 1.2. Objective

Implementation of the proposed GSR and SFGW Projects would influence groundwater heads in the Westside Groundwater Basin (Westside Basin, or Basin). Because the Westside Basin underlies both the Pacific Ocean west of San Francisco and San Francisco Bay near San Bruno, there is the potential for seawater intrusion to occur as a result of implementation of the GSR and SFGW Projects.

The purpose of this TM is to present the results of an evaluation of potential changes in groundwater head resulting from operation of each of the GSR and SFGW Projects, as well as the cumulative effects of both the GSR and SFGW Projects (along with other reasonably foreseeable future groundwater projects in the Basin), in order to assess the potential for seawater intrusion in areas that may be susceptible. The potential changes in groundwater head resulting from implementation of the GSR and SFGW Projects and other reasonably foreseeable future projects were evaluated based on groundwater model scenarios developed using the existing Westside Basin Groundwater-Flow Model (HydroFocus, 2007, 2009, and 2011). These model results were evaluated with respect to the potential to induce seawater intrusion. This TM presents information on the past, current, and future subsurface conditions that are relevant to the issue of seawater intrusion along with a conceptual discussion of the mechanisms that control seawater intrusion.

## 2. Approach and Conceptual Understanding of Seawater Intrusion

Before analyzing seawater intrusion in the context of the Westside Basin, a conceptual understanding of the process of seawater intrusion is presented. This section includes a description of the process, including the variables involved, the time-frame over which intrusion typically occurs, and hydrogeological factors that control intrusion.

### 2.1. General Approach

The general approach used to evaluate potential seawater intrusion for this TM is based on an analysis of the changes in groundwater conditions in the Basin, including groundwater heads[1] and flux, resulting from the operation of the GSR and SFGW Projects. This TM is part of a series of technical memoranda that address various aspects of the GSR and SFGW Projects. Two of these include significant data and analysis that are used for this TM. These include the following:

- Task 8B Technical Memorandum No.1 Hydrologic Setting of the Westside Basin (referred to in the text as TM#1; LSCE, 2010)
- Task 10.1 Groundwater Modeling Analysis for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project (referred to in the text as TM-10.1; Kennedy/Jenks, 2012)

The primary quantitative tools for evaluating potential future conditions are model scenarios generated using the existing Westside Basin Groundwater-Flow Model developed by HydroFocus (2007, 2009, and 2011). For this analysis, the potential for seawater intrusion is evaluated using scenarios that evaluate the proposed GSR and SFGW Projects in isolation. A Cumulative Scenario is evaluated that includes both the GSR and SFGW Projects along with other reasonably foreseeable future groundwater projects in the Basin. The development of the model scenarios is documented in TM-10.1.

This TM includes a brief conceptual understanding of the hydrogeologic processes and factors that influence seawater intrusion and a hydrogeological evaluation summarizing the current conditions with respect to seawater intrusion in the Westside Basin. Much of the information used for this analysis is discussed in detail in TM#1.

[1] As used in this TM, head is the elevation at which groundwater would rest in a piezometer completed in the referenced aquifer. In an unconfined aquifer, this is equivalent to the water table elevation; in a confined aquifer, this is equivalent to the piezometric head.

## 2.2. Westside Groundwater Basin

This section provides a brief overview of the physical setting and Basin hydrogeology. More detailed evaluations of the hydrogeology of the Westside Basin are presented in TM#1 and TM10.1.

Figure 10.3-2 provides a representative cross-section from north to south across the Westside Basin. There are three aquifer systems that are commonly referred to within the Westside Basin. These include:

- Shallow Aquifer: this aquifer is present in the northern part of the Basin, in the vicinity of Lake Merced and the southern portion of the Sunset district of San Francisco. The base of the Shallow Aquifer is defined as the top of the “-100 foot clay.”
- Primary Production Aquifer: this aquifer is present throughout the Basin, overlying the “W-clay” where present. Where the W-clay is not present in locations to the south (in the South San Francisco area), the Primary Production Aquifer is divided into shallow and deep units separated by a clay unit at an elevation of approximately -300 feet mean sea level (msl).
- Deep Aquifer: this aquifer underlies the W-clay, and thus its extent is limited to the generally-known extent of that clay unit (TM#1).

The three aquifer systems are separated by thick, extensive clay units (e.g., the -100 ft clay and W-clay). Because of the discontinuous nature of these clay layers, the basin is considered to be a semi-confined aquifer system with limited flow between the different aquifer systems where local geologic conditions permit (TM#1).

### 2.2.1. Areas Susceptible to Seawater Intrusion

The Westside Basin is bounded by bedrock highs in Golden Gate Park to the north and at Coyote Point to the south (Rogge, 2003; San Bruno, 2007; DWR, 2003). San Bruno Mountain and the San Francisco Bay form the eastern boundary of the Basin (Cal Water, 2006). The San Andreas Fault and Pacific Ocean form the Basin’s western boundary, and its southern limit is defined by a bedrock high that separates it from the San Mateo Plain Groundwater Basin (Rogge, 2003, DWR, 2003, and San Bruno, 2007). The Westside Basin opens to the Pacific Ocean on the northwest and San Francisco Bay on the southeast. Major structural features include the San Andreas Fault system and the Serra Fault.

Areas that are considered potentially susceptible must be investigated for the occurrence of seawater intrusion. Two areas of the Basin are likely to be susceptible to seawater intrusion given certain conditions (Figure 10.3-1). The first is along the Pacific Ocean, between Lincoln Park in the north and Lake Merced in the South. The second is along San Francisco Bay, from the Basin border with the Visitacion Valley Basin in the north to the border with the San Mateo

Plain Basin to the south. The susceptibility of the Westside Basin to seawater intrusion is discussed in more detail in Section 7.

### 2.2.2. Current Seawater-Intrusion Monitoring System

The two areas monitored for seawater intrusion (the Pacific Coast and the Bay Coast) contain a number of monitoring wells completed in the various aquifers present in the Westside Basin. The two sets of wells are known as the coastal and Bay side monitoring networks. Groundwater head in the Westside Basin is monitored in a network of production and monitoring wells as part of the semi-annual monitoring program that was initiated throughout the Basin in 2000. Results of the most recent groundwater level monitoring were reported in the 2010 Westside Basin Annual Groundwater Monitoring Report (SFPUC, 2011), prepared by SFPUC in coordination with the City of Daly City (Daly City), the City of San Bruno (San Bruno), and the California Water Service Company (Cal Water). Annual monitoring reports have been published by the SFPUC since 2006 (LSCE, 2006 and SFPUC, 2007, 2008a, 2009b, 2010, and 2011); these reports are summarized in TM#1 and TM10.1.

The coastal monitoring network consists of a series of wells stretching along the Pacific Coast from the west end of Golden Gate Park south to Thornton Beach in Daly City (SFPUC, 2009b). The three well clusters (nested wells) along the Old Great Highway (near Kirkham, Ortega, and Taraval Streets) and the well cluster at the San Francisco Zoo were installed specifically for the purpose of monitoring seawater intrusion, and were completed by 2004. Head in some of these wells is monitored continuously using pressure transducers, while in others it is measured quarterly by hand. The results of these monitoring activities are presented as hydrographs in Appendix B of TM#1.

Nested wells or well clusters are present at the South Windmill (57 and 140 feet below land surface; ft bls), Kirkham (130, 255, 385, and 435 ft bls), Ortega (125, 265, 400, and 475 ft bls), Taraval (145, 240, 400, and 530 ft bls), Zoo (275, 450, and 565 ft bls), and Thornton Beach (225, 360, and 670 ft bls) locations. Additional monitoring wells in the coastal monitoring network are present at Lake Merced (LMMW-9SS, LMMW-1D, LMMW-1S) and Fort Funston (S and M).

The Bay side monitoring network is less extensive. Head data were provided to SFPUC for two monitoring wells by the San Francisco Airport (UAL MW13C, constructed to a depth of 146 ft bls, and MW13D, constructed to a depth of 41.5 ft bls) from late 2003 to 2006, and since then SFPUC has been collecting data. Two additional clusters of wells were installed in the Bay side area by San Bruno in 2006 (WRIME, 2007) at the San Francisco Airport (SFO-S, 74 ft bls, and SFO-D, 146 ft bls) and in Burlingame (Burlingame-S, 98 ft bls, Burlingame-M, 166 ft bls, and Burlingame-D, 280 ft bls). These wells have been monitored for groundwater elevation and various chemical constituents since November 2006.

The groundwater elevation and water quality data collected to date from these monitoring wells are provided in TM#1, and the monitoring results are discussed in Sections 7.2 and 7.3.

### 2.3. Conceptual Understanding of Seawater Intrusion

Seawater intrusion is the movement of saline water from an ocean or bay into freshwater aquifers. Some degree of seawater intrusion occurs in virtually all coastal aquifers, as long as they are hydraulically connected with seawater. Seawater intrusion usually occurs when coastal freshwater aquifers begin to be developed as sources of water supply. Pumping of freshwater from an aquifer reduces the groundwater head and gradient towards the seawater-freshwater interface, drawing seawater into the freshwater aquifer. The increase in chloride and other constituents that accompanies seawater intrusion can cause the freshwater aquifer to become unfit for beneficial uses such as drinking or irrigation.

The intrusion of seawater into a freshwater aquifer is an effect of the respective heads in the ocean and the freshwater aquifer and the difference in densities of the two fluids (the standard value of density for freshwater is 1.0 grams per cubic centimeter, $g/cm^3$, and a typical value of seawater density is 1.026 $g/cm^3$). Because freshwater is less dense than seawater, it actually floats on top of the saline water when both are present in an aquifer. The depth of the interface between the saline and freshwater depends on the freshwater head in the aquifer, with a higher head leading to a greater depth to the salt water. Under a simplified aquifer system with groundwater flowing toward the ocean, the freshwater head declines closer to the ocean, so the seawater-freshwater interface gets progressively closer to the ground surface moving from inland toward the ocean; this has led to the seawater intrusion into the aquifer being termed a “wedge” (Figure 10.3-3).

As discussed above, due to its high salt content seawater has a density about 2.6% higher than does freshwater. Based on this difference in densities, the Ghyben-Herzberg principle states that, for every foot of freshwater head in an unconfined aquifer above sea level, there will be 38 feet of fresh water in the aquifer below sea level at equilibrium (Badon-Ghyben, 1888; Herzberg, 1901).

When freshwater heads drop, the seawater-freshwater interface can migrate inland, and over time the interface may eventually reach coastal wells. If the groundwater head were to rise again, the seawater-freshwater interface would migrate back seaward. Movement of the seawater-freshwater interface is a slow process. Seawater intrusion may not reach a production well for a number of years, and only when the conditions leading to seawater intrusion are sustained for an extended period of time.

It is important to note that the freshwater head does not need to be lowered below sea level for seawater intrusion to occur, although a groundwater head below sea level certainly increases the potential rate and extent of seawater intrusion. Instead, the groundwater head must simply be dropped to a level lower than 1/38 the depth below sea level of the bottom of the aquifer. If this occurs, the thickness of freshwater is no longer great enough to exclude seawater from intruding along the base of the aquifer. The presence of freshwater head above this level represents what in this TM is termed a hydrologic control.

In addition, seawater intrusion does not necessarily need to follow the typical conceptual route of intruding from the location of freshwater discharge to the seawater body, as shown in Figure 10.3-3; instead, an aquifer can be intruded via another, bounding aquifer. To illustrate this, we can consider an unconfined aquifer in direct contact with the ocean overlying a semi-confined aquifer that is not in direct contact with the ocean, and is separated from the unconfined aquifer by a discontinuous low-permeability confining layer. If head in the unconfined aquifer is lowered far enough to allow it, seawater would intrude along the base of the aquifer. If the intruding wedge encounters a gap in the low-permeability base of the unconfined aquifer, its density, higher than that of freshwater, dictates that it would sink and intrude into the lower semi-confined aquifer.

The seawater-freshwater interface is not actually a sharp interface because of the action of dispersion and diffusion, instead it forms a transition zone where chloride concentrations range from values typical of freshwater to those of seawater (Bear and Cheng, 1999). The movement of the transition zone within the aquifer is due to changing of the groundwater conditions on the freshwater side of the interface. As the seaward flow of freshwater and/or the groundwater elevations near the interface decline, the interface can move landward. If freshwater flow and groundwater head later increase, the interface would move back toward the ocean; however, some of the salt can remain in the freshwater aquifer even after the interface moves away. Once salt water enters a part of the freshwater aquifer, it is very difficult to expunge, demonstrating that it is important to prevent the movement of the interface into the freshwater aquifer to the extent possible (Bear and Cheng, 1999).

Geologic features can limit communication between the freshwater aquifer and ocean water. In order for seawater to intrude into a freshwater aquifer, that aquifer must be in contact with the ocean in some way, usually by being exposed on the ocean floor. Other geologic configurations can limit or prevent seawater intrusion. These can include tilted beds, impermeable bedrock, gradational changes in aquifer permeability (i.e., the freshwater aquifer grading from sand inland into mud offshore), or fault zones. If one or more of these physical controls exists between the freshwater aquifer and the ocean, and is sufficiently low in permeability, it can serve as an effective barrier to the intrusion of seawater into the aquifer. If this is the case, less care would be required to prevent seawater intrusion, as long as the barrier (or barriers) is known to be sound and continuous. Of course, no natural barrier is truly impervious to flow, but its hydraulic conductivity may be so low that the flux of seawater through it would not have a substantial effect on the quality of water in bounding freshwater aquifers. These structural controls, referred to herein as physical controls, are, for all intents and purposes, permanent.

The two types of controls noted above (hydrologic and physical) are discussed further throughout this TM, and can be used to consider the vulnerability of a given freshwater aquifer to seawater intrusion. As is implied by the above discussion, either a hydrologic control or a physical control can prevent seawater intrusion; therefore, both must be absent for seawater intrusion to occur. In locations where physical controls on seawater intrusion (such as a low-permeability clay layer or fault zone) are absent, hydrologic controls are necessary to limit intrusion. For locations where physical controls do exist, freshwater head below the level dictated by the Ghyben-Herzberg relationship may be possible without leading to any intrusion, depending on the nature of the physical control.

# 3. Groundwater Model Analysis

Groundwater models are useful tools that can help quantify the changes in groundwater conditions due to future activities. This section summarizes previous modeling studies of seawater intrusion along the Pacific Coast of the Westside Basin and documents the results of the current modeling conducted for this study using the existing Westside Basin Groundwater-Flow Model (HydroFocus, 2007, 2009 and 2011).

## 3.1. Previous Seawater Intrusion Model

CH2M HILL (1995) performed a numerical modeling exercise to determine the effect that proposed increases in groundwater extraction would have on the intrusion of seawater into the freshwater aquifers of the North Westside Basin. Although focused in the same area, their model does not deal with the same changes in pumping as would be entailed in the SFGW Project.

There are important differences between the CH2M HILL seawater intrusion model (SIM) and the numerical model for the Westside Basin discussed here. The most important difference is that the SIM was constructed as a steady-state model, unlike the transient Westside Basin model; this means that the results of the model indicate the seawater intrusion that would eventually happen if a given pumping rate was maintained indefinitely, and cannot deal with changes in pumping rate or climatic conditions (e.g., an extended drought). The SIM does not simulate the connection between Lake Merced and the North Westside Basin, instead assuming a general head boundary to be present just north of Lake Merced that imposes head values that are constant in time and assumed to be uniform vertically throughout the aquifer. This rigid assumption does not allow head in the aquifer in the Lake Merced area to vary, meaning that the North Westside Basin cannot be dynamically linked to the South Westside Basin using this model, and therefore does not have the capacity to simulate changes to the groundwater system in the North Westside Basin due to changes in hydrologic conditions in the South Westside Basin, a key component of this analysis. In particular, the head in the Deep Aquifer along this boundary is assumed to be the same as the head in the Shallow Aquifer, which does not conform to measurements (see TM#1). Finally, the model assumes that the gradient across the entire model domain is the same as in Golden Gate Park, while the gradient across the southern Sunset District has been shown to be lower than in Golden Gate Park (see, for example, HydroFocus, 2009). Unlike the Westside Basin model, the SIM is explicitly designed to handle the problems of dual-density fluids and the movement of seawater onshore. The SIM used a combination of the finite-element code MicroFem and a seawater migration routine developed by CH2M HILL.

The SIM simulated the intrusion of seawater into the North Westside Basin under various pumping conditions (total of 9 scenarios). These scenarios dealt with the installation of three wells, and increased pumping in one previously-existing well. The new wells, located between Golden Gate Park and Lake Merced: one at the location of the currently proposed West Sunset Playground well, one at the Francis Scott Key Elementary School, and one at Noriega Early

Education School. The previously existing well was the Elk Glen well in Golden Gate Park. All other pumping in the study area was set equal to values estimated for water year 1988. The total pumping under their calibration scenario was 1.02 mgd.

Total additional pumping in the four wells mentioned varied from 0.54 to 0.94 mgd in the nine model scenarios. For all of these scenarios, the greatest pumping occurred at the Elk Glen well, due to the fact that the freshwater flux through Golden Gate Park is assumed to be greater than it is to the south of the Park. The pumping was generally assumed to be equal in the three proposed Sunset wells.

The results of this modeling exercise indicate that the North Westside Basin can handle an additional pumping load of about 0.9 mgd above the rates of water year 1988, as long as the pumping is properly configured. Rates between 0.91 and 0.94 mgd did induce seawater intrusion into the proposed Sunset wells, which are well inland (some 2,000 feet or more) from the coast. This implies that smaller amounts of pumping in the Sunset area would induce substantial seawater intrusion some way inland of the coast. The baseline scenario of the CH2M HILL model (which involved no changes from existing pumping) calculated the top of the freshwater-seawater interface (i.e., the point where the freshwater discharges from the seafloor) as being about 1,400 feet offshore. Figure 10 in CH2M HILL (1995) shows the calculated location of the interface along a cross-section perpendicular to the coast that runs through their proposed well at the Francis Scott Key School; at this location, the toe of the interface wedge stretches inland from the shore by about 2,200 feet, while the well is about 2,600 feet inland. Under one pumping scenario shown, the toe of the wedge stretches inland for more than 4,600 feet, although the interface does not actually intersect the well since it is not screened across the entire model thickness. The results of the CH2M HILL model indicate that, at least in the North Westside Basin, pumping of about 2 mgd may result in the landward shift of the seawater-freshwater interface.

As stated above, the CH2M HILL model has certain limitations that make it less than ideal for analyzing seawater intrusion into the North Westside Basin along the Pacific Coast. The first is that the model is a steady-state model, meaning that it simulates seawater intrusion at equilibrium. Thus, it does not have the capacity to model seawater intrusion in the context of changing conditions, whether these changes are in the amount and location of pumping, or in the climatic conditions that act as inputs to the model (such as wet years and droughts). Second, the SIM does not have the capacity to allow conditions from Lake Merced south to change dynamically, meaning that it cannot simulate how the North Westside Basin would respond to changes in the South Westside Basin. Therefore, the HydroFocus Westside Basin model is considered a better tool to assess the dynamic vulnerability of the North Westside Basin to seawater intrusion.

### 3.2. MODFLOW Model

The existing Westside Basin Groundwater-Flow Model (HydroFocus, 2007, 2009, and 2011) was used as a tool to provide the level of analysis necessary to evaluate the potential for

seawater intrusion as a result of the GSR and SFGW Projects. The setup and results of the model are documented in TM-10.1. A limitation of this model is the handling of the boundary conditions representing the Pacific Ocean and San Francisco Bay. These boundary conditions are set to a constant head of zero elevation. This usage is overly rigid, limiting the ability of the near-Ocean head in the aquifer to behave dynamically. HydroFocus (2007) states that "model results should be interpreted with caution near constant head boundaries like the Pacific Ocean or San Francisco Bay."

The model does not simulate dual-density flow. Therefore, the application of the model results to the problem of seawater intrusion is accomplished in this TM chiefly by analyzing how hydrologic controls are affected by the conditions simulated by the various scenarios, rather than by any direct simulation of seawater flow and transport. The two important hydrologic controls that will be examined here are the flux toward the Ocean or Bay and the groundwater (freshwater) head elevation. The more the oceanward flux is reduced, or the lower the groundwater head drops, the less effective would be the hydrologic controls preventing seawater intrusion (as discussed above, a lack of hydrologic control on seawater intrusion does not automatically imply actual intrusion, as physical controls may still exist that effectively prevent intrusion).

### 3.3. Model Scenario Summary

Five model scenarios were constructed and simulated to evaluate potential groundwater and related hydrological effects from the GSR and SFGW Projects and from the Cumulative Scenario that includes the GSR and SFGW Projects and other reasonably foreseeable future projects. The following is a summary of the five scenarios used for the groundwater model analysis:

- Scenario 1, Existing Conditions: Scenario 1 represents the continuation of the Existing Conditions into the future and does not include the SFPUC Projects (either GSR or SFGW Project). Groundwater pumping by the PAs and irrigation pumping are representative of the existing pumping conditions (as of June 2009). The PA pumping was established based on the historical pumping rates, using the median of the 1959-2009 pumping data for individual agencies.
- Scenario 2, GSR Project Only: Scenario 2 represents implementation of the GSR Project operations including put periods when groundwater pumping by SFPUC and the PAs does not occur and groundwater is placed into storage using in-lieu recharge; hold periods when the PAs are pumping and no in-lieu recharge is occurring because the SFPUC Storage Account is full, and take periods which represent periods when both SFPUC and the PAs are pumping from the South Westside Basin.

- Scenario 3a, SFGW Project Only (3 mgd): For Scenario 3a, the four new wells constructed for the SFGW Project would pump an annual average of 3.0 mgd; however, the two existing irrigation wells in Golden Gate Park would remain irrigation wells, and their pumping rates would be the same as in Scenario 1.
- Scenario 3b, SFGW Project Only (4 mgd): For Scenario 3b, the four news wells constructed for the SFGW Project and the two modified irrigation wells in Golden Gate Park would pump an annual average of 4.0 mgd. Irrigation in Golden Gate Park is assumed to be replaced by the WestsideRecycled Water Project. Total combined pumping in the Westside Basin for Scenario 3b is slightly less than Scenario 3a, because the total SFGW Project pumping in Scenario 3b would increase by 1.0 mgd, whereas the irrigation pumping that is replaced would be slightly more than 1.0 mgd.
- Scenario 4, Cumulative Scenario: Scenario 4 represents implementation of both the GSR and SFGW Projects (Scenarios 2 and 3b) along with other reasonably foreseeable future projects. The other foreseeable projects are discussed in more detail in TM-10.1 but primarily include the Daly City Vista Grande Drainage Area Improvements Project, which increases stormwater diversions into Lake Merced, and a minor increase in irrigation pumping based on the planned build-out of the Holy Cross cemetery.

As discussed in TM-10.1, the strongest predictive capability of the existing model is to forecast relative changes over time, rather than absolute predictions of head. Therefore, analyzing differences in head relative to a base case rather than the actual groundwater elevation output by the model is the more appropriate method to evaluate the results of the groundwater model. However, in the case of seawater intrusion, the important relationship is between groundwater head in the model and sea level, so absolute head must be considered in this analysis as well. Scenario 1 (the Existing Conditions scenario) forms a basis of comparison for evaluating the results of the GSR-only, SFGW-only, and Cumulative Project scenarios.

To allow for the model scenarios to be directly comparable, all five model scenarios are set up using similar sets of assumptions regarding initial conditions and background hydrology. All of the modeled scenarios have the same projected simulation period of 47.25 years and use initial groundwater conditions representing June 2009 conditions.

All five model scenarios use the same hydrologic sequence and include the 8.5-year Design Drought period included in the Water System Improvement Program Environmental Impact Report PEIR (SFPUC, 2008b and 2009c). The 8.5-year Design Drought repeats the December 1975 to March 1978 drought period following the dry hydrologic conditions of July 1987 to November 1992. To incorporate the Design Drought, the historical hydrological sequence was rearranged. A more detailed discussion of the development of the background hydrology is presented in TM-10.1.

Table 10.3-1 presents a summary of the estimated Basin-wide average pumping rates corresponding to each of the model scenarios. Note that, in addition to the anticipated GSR and

SFGW Project wells, average pumping rates are also provided for the PA wells and for irrigation wells in Golden Gate Park.

## 3.4. Use of Model Results

As stated above, HydroFocus (2007) suggests that the strongest predictive capability of the MODFLOW model is to forecast relative changes over time, rather than absolute predictions of head. Therefore, the model analysis for the different scenarios will consider differences in head and flux relative to the Existing Conditions Scenario (Scenario 1). However, because seawater intrusion is dependent on the relationship between elevations of the seawater and the freshwater aquifers, it is necessary to evaluate the simulated groundwater elevations as well as the relative changes, to evaluate the potential for seawater intrusion.

For the evaluation of the model scenarios, the results of the MODFLOW model are applied to seawater intrusion by considering the flux of water across the coastal boundary conditions and the head just landward of the coastal boundaries. These quantities will be analyzed for each of the five model scenarios listed at the beginning of this section.

### 3.4.1. Head Results

The numerical model includes the capability of monitoring head at 87 different monitoring points, included to track head in the aquifer. Of these, this section examines the results for 9 monitoring points along the Pacific Coast and 3 monitoring points along the Bay Coast. Hydrograph representations for each of the monitoring points are presented as Figures 10.3-4 through 10.3-15. In each of these figures, the upper panel includes the absolute simulated head for each of the five scenarios; the lower panel is the difference between the results of each scenario and those of Scenario 1. Each figure presents results for Model Layer 1, 4, or 5 as representative of conditions in the Shallow, Primary Production, or Deep Aquifer, respectively. The exclusion heads plotted on these figures represent a theoretical freshwater head that must be maintained at the well location to prevent seawater intrusion to reach that location; see Section 3.5. Selected statistics (average, maximum and minimum as calculated from the 47.25 years of model simulation) were compiled for the difference between the head results of the four Project scenarios and Scenario 1 (Table 10.3-2).

Along the Pacific coast, 9 monitoring locations were set in the numerical model. All of these except for North Windmill correspond to locations of an actual monitoring well or well cluster, which correspond to the seawater intrusion monitoring network already existing along the Pacific Coast (Figure 10.3-1). The North Windmill location corresponds to a historical well location, but not an active monitoring well. These locations include:

- North Windmill
- South Windmill
- Kirkham
- Ortega
- West Sunset Playground

- Taraval
- Zoo
- Fort Funston
- Thornton Beach

Along the Bay Coast, monitoring locations were set in the numerical model at the locations of actual monitoring well clusters (UAL, SFO, and Burlingame). These locations correspond to the seawater intrusion monitoring network already existing in the South Westside Basin (Figure 10.3-1). The UAL cluster consists of pre-existing monitoring wells, but the SFO and Burlingame clusters were installed as part of work conducted under Assembly Bill 303[2] specifically to track the occurrence of seawater intrusion (WRIME, 2007).

In addition to the absolute and relative heads depicted in the hydrographs (Figures 10.3-4 through 10.3-15), seasonal fluctuations in absolute head were computed for each of the model scenarios. These values were determined by calculating the average annual difference in head values under each scenario for May (generally representing the highest annual heads) and November (generally representing the lowest annual heads). These values were analyzed to determine whether the aquifer experiences annual head declines sufficient to leave it substantially more susceptible to seawater intrusion during the dry parts of the year.

### 3.4.2. Flux Results

The flux of groundwater out to the Ocean or Bay from the coast is a convenient variable for tracking the occurrence of seawater intrusion in the model domain because it tracks the amount of water passing through the boundary conditions placed along the coastlines. The fluxes are presented as total fluxes for the entire North Westside Basin (Pacific Coast) (Figure 10.3-16) and South Westside Basin (Bay Coast) (Figure 10.3-17). This means that these flux values indicate whether or not each of the coasts is, as a whole, experiencing seawater intrusion on average. Seawater intrusion is expected to occur locally during its initial stages, and this would not be captured in this analysis. However, in the context of the strengths and limitations of the numerical model discussed above, this approach is considered a sufficiently comprehensive, conservative, and scientifically-sound evaluation that properly addresses seawater intrusion.

A positive freshwater flux toward the Ocean or Bay does not necessarily preclude seawater intrusion, because the seawater wedge would enter into the lowest part of the freshwater aquifer. Therefore, the use of modeled freshwater flux as a proxy for seawater intrusion is a way to indicate when intrusion is predicted to be a major problem, rather than when it might begin to occur.

As with the head analysis, this analysis of the flux calculated by the numerical model is not able to give accurate quantification of the intrusion of seawater into the freshwater aquifer. This is

[2] Passed by the California Legislature in 2000, Assembly Bill 303 created the Local Groundwater Assistance Grant Program, providing funding to local public agencies for the performance of groundwater studies or to carry out groundwater monitoring and management activities.

due to several factors: the flux numbers are totals of flux along the entire coastline; the boundary condition along the coastline does not accurately reflect the dynamic conditions at the land-Ocean interface; and the real occurrence of seawater intrusion is a complex process involving aquifer heterogeneity, tidal fluctuations, diffusive transport, and dual-density fluid flow, which are not captured in the existing model.

#### 3.4.3. Groundwater Contour Map Analysis

Under Scenario 1, the model-simulated groundwater elevations for the Shallow Aquifer (Model Layer 1) are above sea level throughout the North Westside Basin (Figure 10.3-18). The water table gradient was highest through Golden Gate Park and along the fronts of the elevated bedrock areas, and lowest just north of Lake Merced. Water table elevations were predicted to be between five and ten feet above sea level in the direct vicinity of the Coast, with higher elevations along the northern part of the Coast. This indicates that the existing conditions are not anticipated to induce seawater intrusion along the Pacific Coast.

### 3.5. Application of Analytical Method Along the Pacific Coast

As mentioned, the Westside Basin model does not have the capability to evaluate seawater intrusion using the density differences between freshwater and saline water. Therefore, an analytical evaluation is included with the groundwater model results to incorporate the density driven components of seawater intrusion while evaluating the MODFLOW output.

#### 3.5.1. Methodology

The movement of the seawater-freshwater interface is a dynamic process that is dependent upon the relative difference in the freshwater and seawater groundwater head, flux and density. The analytical method discussed in Attachment A was used to evaluate the freshwater head, based on the Ghyben-Herzberg relationship, necessary to maintain hydrologic control, keeping seawater from intruding into freshwater aquifers (a function of the depth below sea level of the bottom of the aquifer). This value is termed the "exclusion head" and it represents a conservative analysis for maintaining freshwater aquifer conditions (see Section A.5).

The freshwater head results from the numerical model were compared to the exclusion head at the various monitoring points; it is assumed that groundwater head at a location equal to or greater than its exclusion head indicates that the location would not experience seawater intrusion.

For locations where the groundwater head stays above the exclusion head, the pressure of the freshwater aquifer is sufficient that seawater would not intrude to this location based on the Ghyben-Herzberg relationship for the aquifer thickness at a given location.

For locations where groundwater head falls below the exclusion head, there is the potential that seawater could intrude to this location. However, there are other factors that control seawater intrusion, so groundwater head below the exclusion head does not necessarily imply that seawater intrusion may reach this location, but rather that the hydrologic potential exists for the landward migration of the seawater-freshwater interface. Therefore, this is a conservative analysis of the potential for seawater intrusion.

If groundwater head moves back above the exclusion head, the interface could be expected to slow or reverse its movement toward land. It should be noted that sustained, repeated fluctuations in head, even when they remain above the exclusion head, would result in a widening of the transition zone between seawater and freshwater.

Movement of the seawater-freshwater interface is a slow process. Seawater intrusion may not manifest in a production well for a number of years, and only when the conditions leading to seawater intrusion are continuously sustained for an extended period of time, depending on aquifer conditions. Additionally, physical controls, where present, can prevent seawater intrusion even if head conditions are maintained below the exclusion head long-term.

Uncertainty in these results is due mostly to uncertainties in the prediction of the input parameter, *b* (aquifer thickness below sea level). However, uncertainties in the estimate of *b* must be very large to create substantial errors in the estimate of the exclusion head, due to the fact that the exclusion head is only a fraction of the aquifer thickness. Additionally, the analytical method assumes that the individual aquifers are single bodies; if aquifers are divided up into several discrete sections separated by continuous low-permeability layers, seawater intrusion would be less extensive than indicated by this method because the exclusion head is higher in the thicker, composite aquifer than in the thinner, separate aquifers.

It is important to note that the analytical analysis presented here assumes that the aquifer is near horizontal. As the analytical method shows (Attachment A), this has some effect on the length of intrusion. The aquifers present in the North Westside Basin are actually sloped toward the Ocean, and so the intrusion length could be expected to be somewhat smaller than shown by the analytical method, thus making the analysis more conservative with relation to the potential for seawater intrusion.

#### 3.5.2. Definition of Parameters

For this analysis, the elevation of the base of the aquifer is the only variable that must be known. Because the offshore structure of the coastal aquifers (e.g., the continuity of low-permeability layers between aquifers, which is key to the movement of intruding seawater) is not precisely known, two approaches were taken to compute the exclusion head. The thicknesses were then input into the Ghyben-Herzberg equation to determine the exclusion head. These levels are indicated on Figures10.3-4 through 10.3-15, and given in Table 10.3-3.

Along the Pacific Coast, the sediment thickness is considered to include several aquifers (multiple-aquifer case). The thicknesses of the individual aquifers were determined using the cross-sections of LSCE (2010) by estimating (to the nearest 10 feet) the elevations of the bottom of each aquifer below sea level. It should be noted that extensive clay layers present within an aquifer (e.g., the Y clay within the Primary Production Aquifer at the Taraval and Zoo clusters) are not removed from the aquifer thickness, so that these clay layers are counted as part of the aquifer. This is a conservative assumption, as excluding them would reduce the thickness of the aquifer, thereby reducing the exclusion head. Because the Primary Production Aquifer is thicker than the other two aquifers, the values of exclusion head in this aquifer are higher than in the others.

#### 3.5.3. Use of the Analytical Evaluation

As discussed, the results are a conservative estimate of the potential for seawater intrusion along the Coast, but do provide a point of reference for evaluating the MODFLOW results with respect to the density aspects of seawater intrusion. The analysis can identify areas where seawater intrusion would not occur, or where there is the potential that seawater intrusion may occur. Other factors have to be considered. A major limitation to evaluation of seawater intrusion is that the seawater-freshwater interface has not been located along the Pacific Coast.

The results of this analysis for the Pacific Coast are discussed for the SFGW-Only and Cumulative Scenarios. The GSR-Only Scenarios are not presented, because the MODFLOW model analysis showed little variation from Scenario 1.

# 4. GSR Only Scenario Analysis

The GSR-Only Scenario analysis evaluates the potential for seawater intrusion from the operation of the GSR Project. The GSR Project is a conjunctive use project that would allow for increased groundwater supplies in the Westside Basin during periods of drought (MWH, 2008). The GSR Project is sponsored by the SFPUC in coordination with its PAs: Cal Water, Daly City, and San Bruno. The GSR Project is located within San Mateo County in the South Westside Basin. This Project is discussed in more detail in Section 1.1 of this TM, and in TM-10.1. In summary, the PAs would reduce pumping during normal and wetter than normal times (put periods) to naturally replenish groundwater in the South Westside Basin, and both SFPUC and the PAs would extract groundwater during drier than normal times (take periods). The total pumping capacity to be developed by the Project would be about 7.2 mgd, and the maximum amount of groundwater that would be placed in a storage account via this in-lieu recharge would be 60,500 af (MWH, 2008). If surface water is available, but the storage account is full (hold periods), the PAs would pump as during a take period, but SFPUC would not extract groundwater, aside from a small amount to exercise the Project wells[3].

## 4.1. Conceptual Analysis

The GSR Project consists primarily of using excess surface water instead (or “in-lieu”) of pumping groundwater from the Westside Basin. The Project is planned to have up to 60,500 af of in-lieu recharge capacity. During the take cycle, both SFPUC and the PAs would be pumping groundwater; however, SFPUC would not take more than the amount of in-lieu recharge available in the SFPUC Storage Account.

In addition, the GSR Project would be operated in the South Westside Basin, where groundwater head has been substantially below sea level for decades. This portion of the Basin appears to be isolated from sources of saline water from the Pacific Ocean and San Francisco Bay.

Because of this mode of operation, the GSR Project would typically produce groundwater head similar to or higher than Scenario 1 in the South Westside Basin. Higher groundwater head would typically have the effect of reducing the potential for seawater intrusion due to the higher freshwater head and flux towards the Ocean and the Bay. Therefore, in general, the likelihood of seawater intrusion resulting from the GSR Project is considered to be low.

## 4.2. Model Results along the Pacific Coast

The GSR-only Scenario (2) does not include any additional pumping in the North Westside Basin, so large changes in head are not anticipated in this area. Hydrographs (Figures 10.3-4 through 10.3-12) present the model-derived head for this scenario, as well as the differences in

---

[3] Exercising the production wells would entail pumping for a few hours approximately monthly, with an anticipated average monthly total production rate for all of the wells of 0.04 mgd.

head between this scenario and Scenario 1. Table 10.3-2 presents the maximum, average, and minimum differences between the results for this scenario and those of Scenario 1.

#### 4.2.1. Head

In Model Layer 1, head at the various monitoring locations is generally slightly higher than under Scenario 1 throughout most of the simulation duration, dropping slightly below Scenario 1 levels at the end of the simulation. The maximum increase over Scenario 1 (Table 10.3-2a) is less than a foot at all of the monitoring locations except the West Sunset Playground well (1.3 ft; Figure 10.3-8) and the Zoo cluster (2.7 ft; Figure 10.3-10). The maximum decrease compared to Scenario 1 at the end of the simulation reaches a maximum of 0.4 ft at the Zoo cluster, and is 0.2 ft or less at all other locations.

In Model Layer 4, the difference in head from Scenario 1 follows a similar pattern to that of Model Layer 1, but the changes tend to be more pronounced, especially in the southern part of the North Westside Basin. The maximum increase over Scenario 1 (Table 10.3-2b) varies from 0.1 ft at the South Windmill cluster (Figure 10.3-5) to 6.1 ft at the Zoo cluster. In almost all monitoring locations, the head results from Scenario 2 are above those of Scenario 1 except during and after the Design Drought, except at the Thornton Beach cluster (Figure 10.3-12), where head drops below the Scenario 1 results around Scenario Year 28. The maximum decrease compared to Scenario 1 near the end of the simulation varies from 0.1 ft at the South Windmill cluster to 4.3 ft at the Zoo cluster. This Model Layer is not present at the North Windmill location.

In Model Layer 5, the difference in head from Scenario 1 follows a similar pattern to that of the other Model Layers, with still more pronounced changes. The Scenario 2 heads are below those of Scenario 1 during the take periods (as shown by large downward deflections in relative head difference) at many locations. The maximum increase over Scenario 1 (Table 10.3-2c) varies from 0.3 ft at the Kirkham cluster (Figure 10.3-6) to 12.2 ft at the Zoo cluster. The greatest relative decrease at all locations occurs just after the Design Drought, and varies from 0.2 ft at the Kirkham cluster to 14.4 ft at the Zoo cluster. Head values recover to levels similar to or above those of Scenario 1 throughout the North Westside Basin by the end of the simulation period. This Model Layer is not present at the North Windmill location or the South Windmill cluster.

The average differences presented here indicate that the GSR Project would not have a substantial effect on the occurrence of seawater intrusion in the North Westside Basin within the Shallow Aquifer. There would also not be much of an effect north of the Zoo cluster in the Primary Production Aquifer. In the southern part of the North Westside Basin, head dips during take periods, particularly the Design Drought. The effect is smallest in Model Layer 1, greater in Model Layer 4, and largest in Model Layer 5 (Figures 10.3-4 through 10.3-12). The magnitude of the dips in head is indicated by the maximum relative decrease compared to the results of Scenario 1 (“minimum difference” in Table 10.3-2). Although the declines in head during the take periods are locally substantial (greatest during the Design Drought in the southern part of the North Westside Basin in the Deep Aquifer; see results for the Zoo cluster above), the aquifer returns to conditions similar to Scenario 1 by the end of the simulation period, indicating that the situation of lowered head is fairly short-lived.

Simulated seasonal fluctuations in head (defined in Section 3.5.1; Table 10.3-4) varied in Model Layer 1 from 0.5 ft at the Taraval cluster to 1.7 ft at the North Windmill location, from -0.7 ft (South Windmill cluster) to 0.3 ft (Kirkham, Ortega, and Taraval clusters and West Sunset Playground well) in Model Layer 4, and from -0.5 ft (Zoo cluster) to 0.3 ft (Kirkham and Ortega clusters) in Model Layer 5; it should be noted that negative values of seasonal fluctuation indicate that head is generally higher in the summer than in the winter. The greatest fluctuations are in Model Layer 1 at every location, as the Shallow Aquifer (represented by Model Layer 1) directly receives recharge from precipitation, the root cause of the seasonal fluctuations. These results indicate that seasonal changes in head are not very large, and would not substantially affect the occurrence of seawater intrusion in the North Westside Basin.

#### 4.2.2. Groundwater Flux

Freshwater flux leaving the model domain through the Pacific Coast is the result of recharge in the upper reaches of the North Westside Basin that flows through the aquifers in this Basin toward the Ocean. A reduction in this freshwater flux indicates an increasing chance of seawater intrusion occurring along this coast. Figure 10.3-16 shows the fluxes predicted for the North Westside Basin by the numerical model, as well as the difference between the results of each scenario and Scenario 1. Table 10.3-5 gives the maximum, minimum, and average monthly freshwater fluxes and fluxes relative to Scenario 1 for each scenario.

As discussed above, the GSR Project pumping conditions included in Scenario 2 are not expected to have a large effect on head in the North Westside Basin. Therefore, the freshwater flux into the Pacific Ocean is not expected to change very much. Indeed, Figure 10.3-16 indicates very minor differences between Scenario 1 and this scenario. For most of the duration of the model simulation, the freshwater flux out of the Pacific Coast remains above the Scenario 1 conditions, up to 30 acre-feet per month (afm). Toward the end of the simulation, during the Design Drought, the freshwater flux dips slightly below the Scenario 1 conditions, by up to about 10 afm. The minimum freshwater flux for this scenario was about 150 afm, the same as for Scenario 1. Compared to the absolute flux values (an average of about 270 afm for Scenario 2 versus an average of about 260 afm for Scenario 1), the differences in flux values indicate, as do the head results, that the GSR Project pumping conditions are not expected to have a substantial effect on the occurrence of seawater intrusion in this part of the Basin.

#### 4.2.3. Groundwater Contour Map Analysis

Under Scenario 2, the model-simulated groundwater elevation map for the Shallow Aquifer at the end of the simulation period (Figure 10.3-19) is almost identical to that simulated under Scenario 1 (Figure 10.3-18), with slightly lower groundwater elevations (by approximately 5 feet or less) in the southern part of the North Westside Basin; almost no difference is visible north of

Lake Merced. This confirms that the operation of the GSR Project by itself would have little effect on the water table in the North Westside Basin. This indicates that the GSR Project is not anticipated to induce seawater intrusion along the Pacific Coast.

#### 4.2.4. Evaluation

Pumping in the South Westside Basin for the GSR-only Scenario (2) would have only a minor effect on groundwater head in the North Westside Basin. These conditions are anticipated to lead to minimal landward movement of the seawater-freshwater interface due to operation of the GSR Project.

None of the monitoring points in Model Layer 1 show head falling below sea level, although some of the heads do approach sea level. In Model Layer 4, the head drops below sea level at the Zoo and Taraval clusters and the West Sunset Playground well. In Model Layer 5, the head drops below sea level at the Ortega, Taraval, Zoo, and Fort Funston clusters and the West Sunset Playground well. In fact, head is largely below sea level throughout the simulation period in the southern half of the North Westside Basin in Model Layers 4 and 5, indicating that the hydrologic conditions would be conducive to seawater intrusion; however, as noted above, these layers are likely to have physical controls that would prevent intrusion from happening. In addition, at no location does head drop below sea level in the Scenario 2 results without also dropping below sea level in the Scenario 1 results. The differences between this scenario and Scenario 1 are not great, with generally higher head through most of the simulation except the take periods (Section 4.2.1), indicating that the changes in the pumping regime included in the GSR Project would not substantially alter the likelihood of seawater intrusion along the Coast. The drops in head seen during the take periods may lead to conditions more favorable for seawater intrusion along the Pacific Coast, but the drops do not persist for more than a few years after the end of each take period, indicating that any such increase in the possibility of seawater intrusion due to the operation of the GSR Project would be temporary. Similarly, seasonal declines in freshwater head throughout the North Westside Basin are unlikely to substantially alter the likelihood of seawater intrusion along the Pacific Coast, as the declines are temporary and compensated for by seasonal increases. In much of the North Westside Basin, the differences between Scenarios 2 and 1 are not great, indicating that the GSR Project is not responsible for any substantial decreases in head.

### 4.3. Model Results along the San Francisco Bay Coast

The GSR-only scenario (Scenario 2) focuses on changes in the pumping regime in the South Westside Basin, so substantial changes in head may occur in this area. Figures 10.3-13 through 10.3-15 show heads for this scenario, as well as the differences in head versus Scenario 1 (note that the results for this Scenario are nearly identical to those of Scenario 4, so their lines overlap on the hydrograph figures). Table 10.3-2 presents the maximum, average, and minimum differences between the results for this scenario and those of Scenario 1.

### 4.3.1. Head

Under GSR-only conditions, the heads in the Bay monitoring system react similarly to the Scenario 1 conditions. Compared to Scenario 1, the head results of Scenario 2 at the Burlingame cluster are mostly higher than under Scenario 1 (up to maximums of 1.3 ft in Model Layer 1 and 2.3 ft in Model Layer 4), although at the end of the simulation period the head in Model Layer 4 is lower, by up to 0.6 ft (Figure 10.3-13, Table 10.3-2b). At both the SFO (Figure 10.3-14) and UAL (Figure 10.3-15) clusters, the Scenario 2 results are higher (up to 3.1 ft at the SFO cluster and 2.4 ft at the UAL cluster) in Model Layer 1 than in Scenario 1. Model Layer 4 is not present at the SFO and UAL clusters, and Model Layer 5 is not present at any of the three well clusters along the Bay coast.

To understand the implications of the Scenario 2 results, it is helpful to note how groundwater head behaves in this area under Scenario 1. The Burlingame cluster is projected to see a substantial decline in head during Scenario 1, approaching sea level in Model Layer 1 (Figure 10.3-13), while in Model Layer 4, head at the Burlingame cluster begins just above sea level, and declines throughout the scenario. These results indicate that, if there is a route for seawater intrusion, intrusion would become more rapid over the simulation period in both Model Layers. Because Scenario 2 head results are mostly higher than under Scenario 1 throughout the simulation, the potential rate of seawater intrusion over time would actually be lower than in Scenario 1. At the SFO (Figure 10.3-14) and UAL (Figure 10.3-15) clusters, head under Scenario 2 rises throughout most of the simulation period, indicating that, if seawater intrusion were occurring in this area, its pace may decline or even reverse.

Whether heads are higher or lower under Scenario 2, the results are not very different from those of Scenario 1. This indicates that the GSR Project pumping rates would not have a substantial effect on the occurrence of seawater intrusion in this part of the Basin because groundwater head is mostly higher than under Scenario 1.

Seasonal fluctuations along the Bay Coast are very small, and all between +0.1 ft and -0.1 ft for this scenario (Table 10.3-4). These results indicate that seasonal fluctuations in head would not have a substantial effect on seawater intrusion in this area.

### 4.3.2. Groundwater Flux

Freshwater flux into the San Francisco Bay is expected to be substantially lower than flux into the Pacific Ocean. The exposed coastline is somewhat shorter, the Bay Mud presents a low-permeability barrier between the freshwater aquifer and the saline water, the aquifer is thinner, and heads on land are lower. As discussed in Section 7.3, this area may or may not be physically susceptible to seawater intrusion. Table 10.3-5 gives the maximum, minimum, and average monthly freshwater fluxes and fluxes relative to Scenario 1 for these scenarios.

Scenario 2 adds the pumping entailed in the GSR Project. The maximum freshwater flux is about 110 afm, while the minimum is about 70 afm (Figure 10.3-17); these maximum and minimum numbers are similar to those of Scenario 1. The freshwater flux is slightly higher than in Scenario 1 through most of the simulation before dropping below Scenario 1 conditions around Scenario Year 40, during the Design Drought. Because the freshwater flux is generally higher than under Scenario 1 conditions, GSR Project pumping is not anticipated to have a substantial effect on seawater intrusion along the Bay Coast.

### 4.3.3. Evaluation

In general, the changes to groundwater pumping for the GSR-only Scenario (2) would not have a substantial effect on the potential for seawater intrusion compared to Scenario 1 conditions. The freshwater flux out of the aquifer into the San Francisco Bay is quite low, and is not modified to any great degree by the pumping configurations simulated in the numerical model.

The modeling results suggest that the Bay Coast is not especially vulnerable to seawater intrusion, at least under the conditions simulated by the model (Figure 10.3-17). The presence of the Bay Mud is considered to represent a physical barrier that limits the potential for seawater intrusion along the San Francisco Bay Coast, even when groundwater head is lowered.

# 5. SFGW Only Scenario Analysis

The SFGW Project would provide a local source of high-quality groundwater within the North Westside Basin. The SFGW Project is discussed further in Section 1.1 and TM-10.1.

The SFGW Project Scenarios (3a and 3b) simulate increased pumping in the North Westside Basin, and so the model predicts a much greater change in head in this area under these scenarios than under the GSR Project Scenario (2). Scenario 3a assumes that irrigation in Golden Gate Park would continue as in the past. Scenario 3b assumes that irrigation would be provided largely by a recycled water project, so that two of the existing irrigation wells can be converted for use as a municipal supply. These two scenarios begin with June 2009 initial head conditions.

## 5.1. Conceptual Analysis

Because operation of the SFGW Project includes substantial pumping of groundwater, and the wells to be utilized are located relatively close to the Pacific Coast, there is the potential for seawater intrusion in this area. Therefore, additional analysis is necessary to characterize the potential for seawater intrusion in the North Westside Basin. However, because of the distance from the pumping wells to the San Francisco Bay Coast, the potential of seawater intrusion induced by the SFGW Project in the South Westside Basin is low.

## 5.2. Pacific Coast

The SFGW-only Scenarios (3a and 3b) include substantial additional pumping in the North Westside Basin (3.0 mgd and 2.9 mgd, respectively; see Table 10.3-1), so changes in head would be expected to occur in this area. Figures 10.3-4 through 10.3-12 show head results for these scenarios, as well as the differences in head between these scenarios and Scenario 1. Table 10.3-2 presents the maximum, average, and minimum differences between the results for these scenarios and those of Scenario 1.

### 5.2.1. Head

*Scenario 3a*: In general, heads in the North Westside Basin under Scenario 3a decline quickly over the first approximately 10 years of the simulation period, eventually leveling out at a fairly constant offset from Scenario 1 results (Figures 10.3-4 through 10.3-12). This fairly constant offset (as represented by the average difference between the scenario results and those of Scenario 1 from Scenario Years 37 to 47) varies from well to well. In Model Layer 1 (Table 10.3-2a), the average offset varies from 0.1 ft at the Fort Funston cluster to 23.0 ft at the West Sunset Playground well. In Model Layer 4 (Table 10.3-2b), the average offsets varied from 0.3 ft at the Thornton Beach cluster to 18.5 ft at the Zoo cluster. In Model Layer 5 (Table 10.3-2c), the average offsets varied from 0.3 ft at the Thornton Beach cluster to 6.9 ft at the West Sunset well cluster. Note that head decreases more at the West Sunset Playground well because its location is close to a proposed SFGW Project production well. Additionally, it is important to note that this well is about 3,000 feet inland, so results at this location should not be considered typical of head along the coast.

At the North Windmill location and the Fort Funston and Thornton Beach clusters (Figures 10.3-4, 10.3-11, and 10.3-12), the head in all present Model Layers remains at least a bit above sea level at all times during the model simulations. Elsewhere, head drops to sea level and below, up to -11.4 ft msl at the West Sunset Playground well (Figure 10.3-8a) in Model Layer 1, -31.3 ft msl at the Zoo cluster (Figure 10.3-10b) in Model Layer 4, and -32.1 ft msl at the Zoo cluster in Model Layer 5 (Figure 10.3-10c). After head declines slow between Scenario Years 10 and 15, heads are mainly above sea level at all Model Layer 1 locations aside from the West Sunset Playground well, only dropping below sea level at isolated times (particularly during the Design Drought). In Model Layer 4, head hovers around sea level at the South Windmill and Kirkham clusters, and remain below sea level through most of the simulation period at the Ortega, Taraval, and Zoo clusters and the West Sunset Playground well. In Model Layer 5, head is around sea level at the Kirkham cluster, and below sea level at the Ortega, Taraval, and Zoo clusters and the West Sunset Playground well.

*Scenario 3b*: Scenario 3b is similar to Scenario 3a, except that it includes the assumed recycled water delivered to Golden Gate Park; this means that total groundwater extraction in Golden Gate Park is slightly lower in Scenario 3b than in Scenario 3a, and also slightly lower in the South Sunset Playground and West Sunset Playground wells.

The difference between the results of Scenario 3b and Scenario 3a is generally not large. As might be expected by the scenario construction, head in the Golden Gate Park wells resulting from Scenario 3b is slightly lower at the North Windmill location (Figure 10.3-4a) and the South Windmill cluster (Figure 10.3-5) in Model Layer 1. In Model Layer 4, head at the South Windmill cluster is generally higher than in Scenario 3a, and with much larger seasonal fluctuations. At the Kirkham cluster (Figure 10.3-6b), head is generally slightly higher, with larger seasonal fluctuation, than in Scenario 3a. At the Ortega (Figure 10.3-7b), Taraval (Figure 10.3-9b), and Zoo (Figure 10.3-10b) clusters and the West Sunset Playground well (Figure 10.3-8b), head results for Scenario 3b are slightly higher than those for Scenario 3a. Finally, heads at the Fort Funston (Figure 10.3-11) and Thornton Beach (Figure 10.3-12) clusters are almost equal under Scenarios 3b and 3a.

*Seasonal Fluctuations*: Seasonal fluctuations are generally somewhat smaller than under Scenario 1 (Table 10.3-4). For Scenario 3a, values range from about 0.5 ft (West Sunset Playground well and Taraval cluster) to 1.6 ft (North Windmill location) in Model Layer 1, from -0.8 ft (South Windmill cluster) to 0.3 ft (Kirkham, Ortega, and Taraval clusters and West Sunset Playground well) in Model Layer 4, and from -0.6 ft (Zoo cluster) to 0.2 ft (Kirkham and Ortega clusters) in Model Layer 5. For Scenario 3b, seasonal fluctuations vary from 0.5 ft (West Sunset Playground well and Taraval cluster) to 1.3 ft (Fort Funston cluster) in Model Layer 1, from 0.0 ft (Fort Funston and Thornton Beach clusters) to 0.3 ft (South Windmill, Kirkham, and Taraval) in Model Layer 4, and from -0.6 ft (Zoo cluster) to 0.2 ft (Kirkham and Ortega clusters) in Model Layer 5. These results indicate that seasonal fluctuations in head would not have a substantial effect on the occurrence of seawater intrusion in this area.

### 5.2.2. Groundwater Flux

Scenario 3a includes increased pumping in the North Westside Basin envisioned as part of the SFGW Project. As discussed in Section 5.2.1, the general reaction of the aquifers in this part of the Basin is a decline in head, although it is not uniform throughout the area studied. This decline in head indicates that the oceanward freshwater flux could be expected to decrease. Figure 10.3-16 shows the freshwater flux predicted by the numerical model for this scenario. Table 10.3-5 gives the maximum, minimum, and average monthly freshwater fluxes and fluxes relative to Scenario 1 for these scenarios.

Although flux still responds strongly to climatic variation, the fluxes predicted for this scenario are much lower than those of Scenario 1, varying from a maximum of about 370 afm to a minimum of about 10 afm. Additionally, the variance of flux is higher (standard deviation of about 70 afm versus about 50 afm under Scenario 1).

As discussed above, the flux values presented in this analysis represent the total flux for the entire coast, and so can only be used to discuss average conditions along the coast. However, it is probable that, at the extremely low flux totals seen in this scenario, flux is either zero or negative (i.e., inland from the Ocean) at certain locations. Therefore, this analysis indicates that the increased pumping entailed by the SFGW Project would create conditions conducive to the potential inducement of seawater intrusion in localized areas along the coast.

Scenario 3b is identical to Scenario 3a, except as noted above. The results for this scenario are very similar to those of Scenario 3a: a maximum freshwater flux of about 350 afm, and a minimum of about 10 afm. The change in pumping conditions does not have a substantial effect on the flux out of this stretch of coastline compared to Scenario 3a, although the head results (Section 5.2.1) do show some spatial variability in the North Westside Basin. This indicates that the freshwater flux may be decreased in some places and increased in others compared to Scenario 3a, something that this analysis of total flux would not capture. These results indicate that the pumping rates and distribution of pumping under Scenario 3b would not have a substantial effect on seawater intrusion in the North Westside Basin compared to Scenario 3a, although the location and timing of intrusion may be affected.

These results indicate that there is no major difference between Scenarios 3a and 3b in terms of seawater intrusion, except on the coastline directly west of Golden Gate Park, where heads are projected to be slightly higher under Scenario 3b, possibly reducing the rate of intrusion along this part of the coast.

### 5.2.3. Groundwater Contour Map Analysis

Under Scenario 3a, the model-simulated groundwater head elevations for the Shallow Aquifer at the end of the simulation period (Figure 10.3-19) were lower than under Scenario 1

(Figure 10.3-18). This reflects the effect of the SFGW Project operations in the North Westside Basin. The head was just below sea level in the immediate area around West Sunset Playground and in central Golden Gate Park, representing the drawdown cones around production wells. Head was above sea level through most of the rest of the North Westside Basin, other than the southernmost parts (where head was below sea level in Scenario 1 as well).

Scenario 3b was similar to Scenario 3a, except as noted above. The model-simulated water table elevations in the North Westside Basin under this scenario (Figure 10.3-20) were mostly similar to those of Scenario 3a. The water table was very slightly higher at the western end of Golden Gate Park. The area of the North Westside Basin with groundwater heads below sea level under this scenario was slightly smaller than under Scenario 3a, as the cone of depression in central Golden Gate Park does not reach below sea level.

The map distributions for Scenarios 3a and 3b suggest that the area between the West and South Sunset Playgrounds would have an increased potential for landward migration of the seawater-freshwater interface resulting from groundwater pumping (as noted in Section 2, the groundwater elevation does not have to drop below sea level for seawater intrusion to occur). Areas along the northern part of the Coast are predicted to have higher groundwater head even with the pumping, suggesting a lesser potential for the landward migration of the seawater-freshwater interface in this area compared to the southern part of the Coast.

### 5.2.4. Evaluation of Analytical Results

Comparing the exclusion heads calculated by the analytical method (see Section 3.5.1) to the head results from the numerical model suggests that conditions near the Pacific Coast of the North Westside Basin under Scenarios 3a and 3b have the potential for seawater intrusion, particularly during periods of drought. Table 10.3-6 provides the percentage of each scenario duration during which head is below the applicable exclusion heads.

- At the North Windmill location (Figure 10.3-4), head in Model Layer 1 is below the single-aquifer exclusion head[4] for much of the simulation after about Scenario Year 10 (57% of the simulation duration for Scenario 3a, 60% for Scenario 3b), and is below the Shallow Aquifer exclusion head during the Design Drought and Scenario Year 27 (5% of the simulation duration for Scenario 3a, 4% for Scenario 3b).

- At the South Windmill cluster (Figure 10.3-5), head in Model Layer 1 is below the single-aquifer exclusion head for the entire simulation duration after about Scenario Year 4 (95% of the Scenario 3a simulation duration, 98% for Scenario 3b), and varies around the Shallow Aquifer exclusion head throughout most of the simulation duration (below the exclusion head for 73% of the simulation duration under Scenario 3a, 85% for

[4] As discussed in Section 3.5.1, this represents the exclusion head for the entire subsurface taken as a single aquifer, rather than discretized into multiple aquifers.

Scenario 3b). In Model Layer 4, head is below the single-aquifer and Primary Production Aquifer exclusion heads for the entire simulation.

- At the Kirkham cluster (Figure 10.3-6), head in Model Layer 1 is below the single-aquifer exclusion head for the entire simulation duration, and is mostly below the Shallow Aquifer exclusion head for most of the simulation after about Scenario Year 8 (77% of the Scenario 3a simulation duration, 75% for Scenario 3b). In Model Layers 4 and 5, head is below both exclusion heads for the entire simulation, although this is also true of Scenario 1.

- At the Ortega cluster (Figure 10.3-7), head in Model Layer 1 is below the single-aquifer exclusion head for the entire simulation duration (as is true of Scenario 1), and below the Shallow Aquifer exclusion head for the bulk of the simulation duration after about Scenario Year 6 (89% of the total simulation duration for both scenarios). In Model Layers 4 and 5, head is below both exclusion heads for the entire simulation, as is true for Scenario 1.

- At the West Sunset Playground Well (Figure 10.3-8), head in Model Layer 1 is below the single-aquifer exclusion head for the entire simulation duration after about Scenario Year 1 (99% of the simulation duration for both scenarios), and below the Shallow Aquifer exclusion head after about Scenario Year 6 (90% of the simulation duration for both scenarios). In Model Layers 4 and 5, head is below both exclusion heads throughout the simulation duration, as is the case for Scenario 1.

- At the Taraval cluster (Figure 10.3-9), head in Model Layer 1 is below the single-aquifer exclusion head throughout the simulation (as is the case for Scenario 1), and below the Shallow Aquifer exclusion head for the entire simulation duration after about Scenario Year 5 (91% of the simulation duration for both scenarios). Head in Model Layers 4 and 5 is below both exclusion heads for the entire simulation period, as is the case for Scenario 1.

- At the Zoo cluster (Figure 10.3-10), head in Model Layer 1 is below the single-aquifer exclusion head throughout the simulation duration (as is the case for Scenario 1), and varies around the Shallow Aquifer exclusion head for the entire simulation duration after about Scenario Year 14 (below for 35% of the simulation duration for Scenario 3a, 30% for Scenario 3b). Head in Model Layers 4 and 5 is below both exclusion heads for the entire simulation, as is the case for Scenario 1.

- At the Fort Funston cluster (Figure 10.3-11), head in Model Layers 1, 4 and 5 is below the single-aquifer exclusion heads for the model simulation, as is the case for Scenario 1. Note that the units at this cluster and at the Thornton Beach cluster do not correlate to the individual aquifers present east of the Serra Fault, so only the single-aquifer exclusion head is considered and presented on the hydrographs.
- At the Thornton Beach cluster (Figure 10.3-12), head in Model Layer 1 varies around the single-aquifer exclusion head throughout the simulation duration (below the exclusion head for 64% of the simulation duration for both scenarios, compared to 63% of the simulation duration for Scenario 1). Head is below the single-aquifer exclusion head for the entire simulation duration for Model Layers 4 and 5, as is true of Scenario 1.

These results indicate that there is the potential for the landward migration of the seawater-freshwater interface under the pumping conditions proposed for the SFGW Project along some parts of the Pacific Coast, but not others. The exclusion head is a way to evaluate the long-term potential for seawater intrusion. It is important to note that groundwater heads below the exclusion head at a location do not necessarily imply that seawater intrusion will reach that location, because there are other hydrogeologic factors that may influence the location of the seawater-freshwater interface. In particular, physical controls may exist, such as low-permeability layers or offshore fault zones, as discussed earlier. Rather, the analytical model indicates that there is an increased potential for the landward migration of the seawater-freshwater interface. Also, seawater intrusion is typically a slow process that may take years to manifest in a production well, and only if the conditions favorable for seawater intrusion are sustained continuously for an extended period of time.

Varying groundwater heads over the year can have a substantial effect on the movement of the seawater-freshwater interface. If groundwater head rises and falls within a similar range from year to year, then the seawater-freshwater interface would move back and forth in a similar fashion. If this were the case, the interface would not continue to advance landward over time, but would establish a new transition zone and remain at that new location over time. If groundwater head declines over a period but become stable at some lower level, then the seawater-freshwater interface would shift to a new equilibrium location, which may still be offshore.

For the most part, seasonal fluctuations in head in Model Layer 1 are not great enough to lower head below exclusion head values during dry parts of the year (Table 10.3-4). In general, seasonal fluctuations, even when they repeatedly cross the exclusion head, are not likely to substantially affect the occurrence of seawater intrusion, because intrusion occurs on a much greater time scale than these annual fluctuations. Therefore, the small inward interface migration that would occur during the low summer heads would be offset by the outward migration that would occur during the higher winter heads. In this conceptual scenario, the seasonal fluctuations would approximately cancel each other out, indicating that the average annual head is the most important factor that relates to the potential for seawater intrusion.

### 5.2.5. Evaluation

Groundwater head, especially in the southern half of the North Westside Basin, is projected by the model to be below sea level (and the calculated exclusion heads) for some or most of the simulation period. During the operation of the SFGW Project, the model results show lower groundwater heads throughout the northern half of the North Westside Basin. For Scenarios 3a and 3b, the groundwater heads along the Pacific Coast would be depressed and hydrologic conditions may allow for the landward migration of the seawater-freshwater interface in the aquifer in areas where no physical controls exist to prevent intrusion. Based on the groundwater elevation contour maps from the model, these areas would be limited to an area along the Coast. It is unclear how far landward the seawater-freshwater interface may move or at what rate.

Groundwater head responds similarly during drought periods compared to the same drought periods under Scenario 1, except that they are offset by fairly uniform amounts, so the change in head appears to be due almost entirely to the increase in pumping in this area; head also does not rebound to Scenario 1 levels during wet periods, indicating that the extra pumping in the North Westside Basin would have a uniform effect on head in both wet and dry times.

The results of this analysis indicate that the increase in pumping in the North Westside Basin entailed in the SFGW Project would result in the landward migration of the seawater-freshwater interface in the aquifer beyond that which would occur naturally due to climatic fluctuations. Although the flux results quantified by the numerical model are not expected to accurately represent the actual flux everywhere along the coast, the relative changes resulting from the various scenarios are informative for understanding the possible timing of seawater intrusion.

## 5.3. San Francisco Bay Coast

The SFGW-only Scenarios (3a and 3b) do not include any additional pumping in the South Westside Basin, so large changes in head are not anticipated in this area. Figures 10.3-13 through 10.3-15 show the difference in head for these scenarios versus Scenario 1 (note that the results of these scenarios are nearly identical to those of Scenario 1, so the Scenario 1 results are generally not visible on the hydrographs). Table 10.3-2 presents the maximum, average, and minimum differences between the results for these scenarios and those of Scenario 1.

### 5.3.1. Head

*Scenario 3a*: This scenario includes additional pumping in the North Westside Basin, which is far from the Bay monitoring well locations. Therefore, minimal change is expected in these wells. Indeed, the average differences in head in these wells compared to Scenario 1 are all between -0.01 and -0.03 ft (Table 10.3-2 ). This indicates that the SFGW Project pumping conditions would not have a substantial effect on the occurrence of seawater intrusion in this part of the Basin.

Seasonal fluctuations under this scenario are all between +0.1 ft and -0.1 ft (Table 10.3-4), indicating that seasonal head fluctuations would not have a substantial effect on the occurrence of seawater intrusion in this part of the Basin.

*Scenario 3b*: As with Scenario 3a, the situation simulated in this scenario is not expected to affect this area greatly. The average differences in head compared to Scenario 1 are all between -0.01 and -0.03 ft (Table 10.3-2). As such, the Scenario 3b conditions are not expected to have a substantial effect on the occurrence of seawater intrusion in this part of the Basin.

Seasonal fluctuations in head under this scenario are all between +0.1 ft and -0.1 ft (Table 10.3-4), indicating that seasonal head fluctuations would not have a substantial effect on the occurrence of seawater intrusion in this part of the Basin.

### 5.3.2. Groundwater Flux

*Scenario 3a*: This scenario simulates the pumping entailed in the SFGW Project, which increases groundwater extraction in the North Westside Basin. Even though pumping is not modified in the South Westside Basin, the inclusion of the SFGW Project seems to have a slight effect on the freshwater flux along the Bay coast, decreasing it slightly compared to Scenario 1 throughout the simulation period (Figure 10.3-17 and Table 10.3-5). This decrease is not reflected in the heads. The minimum freshwater flux is about 80 afm, a decline of only 2 afm compared to Scenario 1. These results indicate that this configuration of the SFGW Project would not have a substantial effect on the occurrence of seawater intrusion in the South Westside Basin.

*Scenario 3b*: This scenario is identical to Scenario 3a, except as noted above. Because of the distance to the North Westside Basin and the relatively small change in pumping involved from Scenario 3a, conditions along the Bay Coast are expected to show only minimal changes. The minimum freshwater flux is still about 80 afm (Table 10.3-5). These results indicate that the changes between Scenarios 3a and 3b do not have a substantial effect on the occurrence of seawater intrusion along the Bay coast.

### 5.3.3. Evaluation

In general, the modeling results suggest that the Bay Coast would not be vulnerable to seawater intrusion due to the operation of the SFGW Project. The freshwater flux out of the aquifer into San Francisco Bay is quite low, and would not be modified to a great degree by the pumping configurations simulated in the numerical model (Figure 10.3-17). As noted previously, the hydrogeological framework in this part of the Basin is not well-known, so these results are considered to be fairly qualitative.

## 6. Cumulative Scenario Analysis

The Cumulative Scenario (4) includes the assumed operation of both the GSR and SFGW Projects, projected pumping for the PAs and third party pumpers, and other reasonably foreseeable future projects. Reasonably foreseeable projects that are considered under the cumulative scenario include the Daly City Vista Grande Drainage Basin Improvements Project and the Holy Cross cemetery future build-out with its anticipated increase in irrigation pumping.

### 6.1. Scenario Conditions

Scenario 4 assumes the operations of the GSR (as per Scenario 2) and SFGW Projects with total SFGW Project pumping of 4 mgd (as per Scenario 3b). The model assumptions used for Scenario 4 are summarized in TM-10.1.

The Daly City Vista Grande Drainage Basin Improvements Project is assumed to be a reasonably foreseeable future project under the cumulative scenario. It is assumed that supplemental water to the Lake would be supplied by Daly City storm water from the Vista Grande canal with baseflows being maintained via a wetland (see TM-10.1 for details).

Based on the future land use development projections in the Holy Cross cemetery, irrigation pumping in this cemetery is anticipated to increase under the cumulative scenario by 0.04 mgd, and the associated recharge to groundwater has also been adjusted (see TM-10.1).

### 6.2. Conceptual Analysis

The Cumulative Scenario includes both the GSR and SFGW Projects. However, since the GSR Project is located in the South Westside Basin, and the SFGW Project is located in the North Westside Basin, it is not anticipated that there would be much interaction between the two projects with respect to seawater intrusion. Scenario 2 showed that the GSR Project conditions did not have a large effect on conditions in the North Westside Basin, while Scenarios 3a and 3b showed that the SFGW Project conditions did not have a large effect on conditions in the South Westside Basin. Therefore, in terms of the potential for seawater intrusion, it is anticipated that the Cumulative Scenario would produce results in the South Westside Basin similar to those of the GSR-only Scenario (2), and in the North Westside Basin similar to those of the SFGW-only Scenarios (3a and 3b).

As shown in TM-10.1, diversion of water from the Vista Grande Canal into Lake Merced would have the effect of raising groundwater head in the Lake Merced area as a result of leakage from the Lake to the aquifer. This localized increase in head may decrease the potential for seawater intrusion along the coast near Lake Merced, but this effect diminishes with distance from the Lake.

The changes to pumping associated with the Cumulative Scenario (such as the pumping increase at the Holy Cross cemetery) are located in the South Westside Basin and are too far from either coast to have a substantial effect on seawater intrusion.

## 6.3. Pacific Coast

The results of the Cumulative Scenario (4) are shown on Figures 10.3-4 through 10.3-12. These figures show predicted head at the various Pacific Coast monitoring locations as well as the difference in head between this scenario and Scenario 1. Table 10.3-2 presents the maximum, average, and minimum differences between the results for this scenario and those of Scenario 1.

### 6.3.1. Head

Scenario 4 combines the GSR Project pumping of Scenario 2 with the SFGW Project pumping of Scenario 3b. Because the GSR Project pumping is concentrated in the South Westside Basin, the results of this scenario in the Pacific Coast area are very similar to those of Scenario 3b (Figures 10.3-4 through 10.3-12). At the North Windmill location, and the South Windmill and Kirkham clusters, the average difference between the results of Scenario 3b and those of this scenario in Model Layer 1 is minimal (Table 10.3-2a).

Further to the south, head is slightly higher in this scenario versus Scenario 3b. This reflects the operation of the GSR Project, which is shown (under Scenario 2; see Section 4.2.1) to increase head slightly in this area compared to Scenario 1. At the Ortega Cluster, head in Model Layer 1 (Table 10.3-2a) is on average less than a foot higher than under Scenario 3b. This average difference increases to the south to about 0.8 ft at the Taraval cluster and 4 ft at the Zoo cluster. At the West Sunset Playground well (Figure 10.3-8), head is about 2 ft higher than under Scenario 3b. Head is nearly unchanged at the Fort Funston (Figure 10.3-11) and Thornton Beach (Figure 10.3-12) clusters.

In Model Layer 4 (Table 10.3-2b), the results are similar. At the West Sunset Playground well, the average difference from Scenario 1 is about 3 fthigher than under Scenario 3b, about 3 ft higher at the Taraval cluster, and 6 ft higher at the Zoo cluster.

In Model Layer 5 (Table 10.3-2c), results are similar to those of Model Layer 1, except that the average difference is about 2 ft higher at the Taraval cluster than under Scenario 3b.

Seasonal fluctuations in this area are mostly smaller than under Scenario 1 for the Cumulative Scenario, and similar to those of Scenario 3b (Table 10.3-4). Values for Scenario 4 range from about 0.5 ft (West Sunset Playground well and Taraval cluster) to 1.3 ft (Zoo and Fort Funston clusters) in Model Layer 1, from about 0 ft (Fort Funston and Thornton Beach clusters) to 0.3 ft (South Windmill, Kirkham, and Taraval clusters and West Sunset Playground well) in Model Layer 4, and from -0.5 ft (Zoo cluster) to 0.2 ft (Kirkham and Ortega clusters) in Model Layer 5. These results indicate that seasonal fluctuations in head would not have a substantial effect on the occurrence of seawater intrusion in this part of the Basin.

### 6.3.2. Groundwater Flux

Scenario 4 combines the pumping changes of the GSR and SFGW Projects simulated in Scenarios 2 and 3b. The average flux (and head) conditions are higher than under the SFGW Project Scenarios (3a and 3b), although by only a small amount relative to the total flux (Figure 10.3-16 and Table 10.3-5).

The maximum freshwater flux for this simulation is about 350 afm, while the minimum is about 15 afm. The minimum flux is slightly higher than under Scenarios 3a and 3b, but the difference is not large compared to the total range of fluxes from maximum to minimum. Therefore, the results of this scenario indicate that the combination of the SFGW and GSR Project pumping regimes would not have a substantial effect in the North Westside Basin compared to the SFGW Project alone.

### 6.3.3. Groundwater Contour Map Analysis

Under Scenario 4, the model-simulated groundwater elevations for the Shallow Aquifer at the end of the simulation period (Figure 10.3-20) are very similar to those of Scenario 3b. The lack of difference between the results of Scenarios 3b and 4 indicate again that the GSR Project would have only a minor effect on groundwater head in the North Westside Basin. The cone of depression around the West Sunset Playground well is very slightly smaller, and areas north of this well see very slightly higher groundwater elevations. South of the West Sunset Playground well, areas of below-sea-level groundwater elevations around Lake Merced disappear, and groundwater elevations just north of Lake Merced are generally around five feet higher, a likely result of the modeled additions of the Daly City Vista Grande Drainage Basin Improvement Project under the Cumulative Scenario.

Compared to Scenario 1, the map distribution for Scenario 4 suggests that the area of the West Sunset Playground well would have an increased potential for landward migration of the seawater-freshwater interface resulting from groundwater pumping, similar to the results of Scenarios 3a and 3b. Areas to the south would have a much smaller extent of decreased groundwater head, suggesting a lesser potential for the landward migration of the seawater-freshwater interface.

### 6.3.4. Evaluation of Analytical Results

From the Ortega cluster (Figure 10.3-7) south, head is actually higher than predicted for Scenario 3b in Model Layers 1 and 4, likely the result of the Vista Grande additions to Lake Merced. However, the differences are generally quite small, and would only slightly change the degree and rate of seawater intrusion, not its occurrence. Therefore, combined operation of the GSR and SFGW Projects is considered to have the same effect on seawater intrusion as does the SFGW Project alone. The exception to this is in Model Layer 1 at the Zoo cluster (Figure 10.3-10a), where heads are about four feet higher under this simulation and above the Shallow Aquifer exclusion head throughout the simulation duration (compared to Scenario 3b, during which head was below the Shallow Aquifer exclusion head for 30% of the simulation duration).

Seasonal head fluctuations in Model Layer 1 (Table 10.3-4) are similar to those of Scenario 3b, and the same conclusions apply (Section 5.2.4). Even in the southern part of the North Westside Basin, where there is some slight difference between the head values for this scenario and those of Scenario 3b, the seasonal fluctuations are not markedly different.

#### 6.3.5. Evaluation

The Scenario 4 results indicate that some of the groundwater heads in the North Westside Basin for the Cumulative Scenario would be higher than those for the SFGW-only Scenarios (3a and 3b), while other groundwater heads would be similar to Scenarios 3a and 3b. Exceptions are seen in Model Layer 5 in the southern part of the North Westside Basin (from the West Sunset Playground well south). Head values under Scenario 4 drop below the results of Scenarios 3a and 3b during take periods, with the largest declines seen during the Design Drought; these declines follow similar patterns as the Scenario 2 results, indicating that they result from the operation of the GSR Project. As noted in Section 4.2.4, the declines in head seen during the take periods are temporary, and would not have a significant effect on the occurrence of seawater intrusion along this Coast. Taken as a whole, the results of Scenario 4 indicate that the combined effects of the Projects would create conditions less favorable for the landward migration of the seawater-freshwater interface than those seen in Scenarios 3a and 3b.

### 6.4. San Francisco Bay Coast

The results of the Cumulative Scenario (4) for the Bay side monitoring network locations are shown on Figures 10.3-13 through 10.3-15, which depict the head predictions for this scenario as well as the differences in head between this scenario and Scenario 1. Table 10.3-2 presents the maximum, average, and minimum differences between the results for this scenario and those of Scenario 1.

#### 6.4.1. Head

Scenario 4 combines the pumping changes entailed in the GSR and SFGW Projects. Because neither of these projects would have much of an effect on head in this part of the Basin (see Sections 4.3.3 and 5.3.3), the Cumulative Scenario pumping would not have a large effect either. Indeed, the hydrograph results for the three well clusters in the area (Figures 10.3-13 through 10.3-15) show minimal differences compared to the results of Scenario 2. This finding is confirmed by the statistical evaluation of head (Table 10.3-2). This indicates that the operation of the combined Projects would not have a substantial effect on seawater intrusion in this part of the Basin.

Seasonal fluctuations in head under Scenario 4 are between about -0.1 ft and +0.1 ft (Table 10.3-4). This indicates that seasonal fluctuations in head would not have a substantial effect on the occurrence of seawater intrusion in this part of the Basin.

### 6.4.2. Groundwater Flux

Scenario 4 combines the pumping conditions of the GSR and SFGW Projects. The average freshwater flux results of this scenario fall below those of the other scenarios (Figure 10.3-17 and Table 10.3-5), with a maximum flux of about 110 afm and a minimum flux of about 50 afm. This minimum flux is substantially lower than under Scenario 2 (minimum flux of 70 afm), indicating that the combined operation of the Projects may have an increased effect on freshwater flux, but the flux remains well above zero throughout the simulation period, and the fine-grained nature of the aquifer deposits may represent a physical control preventing seawater intruson.

### 6.4.3. Evaluation

In general, the changes to groundwater pumping entailed in the GSR and SFGW Projects would not have a substantial effect on seawater intrusion along the San Francisco Bay Coast compared to what may occur under Scenario 1 conditions. The Burlingame cluster is projected to see a decline in head during Scenario 1, approaching sea level in Model Layer 1 (Figure 10.3-13a). In Model Layer 4 (Figure 10.3-13b), head at the Burlingame cluster begin slightly above sea level, and decline throughout the scenario. At the SFO (Figure 10.3-14) and UAL (Figure 10.3-15) clusters, the head rises throughout the simulation period.

## 7. Assessment of Areas Susceptible to Seawater Intrusion

The occurrence of seawater intrusion into a freshwater aquifer depends greatly on the connection between the ocean and the aquifers. If the aquifer is isolated from seawater, there is no potential for intrusion, while freshwater aquifers in direct communication with seawater may have no physical barrier preventing the intrusion of seawater. To understand the susceptibility of the various aquifers in the study area to seawater intrusion, it is necessary to understand the configuration of the aquifers offshore. In general, studies suggest that the aquifers present in the North Westside Basin do stretch offshore to some distance, but how far, and whether these aquifers are in direct communication with the ocean, are questions that have not to date been fully resolved.

### 7.1. Potential Rate of Intrusion

The rate of seawater intrusion into an aquifer can be widely variable, depending on the values of the various parameters that control it. Because groundwater head in the coastal areas of the Westside Basin is not as far below sea level as in some of the examples presented in Section 8.2, the rate of seawater intrusion that would be seen in this basin may be on the low end of the rates determined by other studies.

The timing of seawater intrusion depends on a number of variables. A large inland gradient or high horizontal hydraulic conductivity would hasten seawater intrusion. Seawater intrusion would also occur more quickly if the seawater front is already close to land due to lower onshore head or freshwater flux. Although the thickness of the aquifer does not analytically have an effect on the rate at which seawater intrudes into a freshwater aquifer, a seawater wedge would form earlier in a thicker aquifer because the thicker aquifer requires a larger freshwater head to keep seawater out. An analytical equation can be developed that gives a first approximation of the potential rate of seawater intrusion under various conditions; this is described in Attachment A.

A simplified aquifer was constructed to apply this analytical solution, and the various parameters were chosen to reflect approximate actual values at the South Windmill cluster in Golden Gate Park. The parameter values, and the sources from which they were derived, are given in Table 10.3-7. These values were used to calculate the change in seawater intrusion length over various periods of time (0.25, 0.5, 1, 2, 5, 10, 20, and 50 years) at pumping rates varying from zero to equal to the freshwater flux rate determined by Yates et al. (1990) for the Golden Gate Park area. It should be noted that the aquifer at this location was assumed to be continuous from the top of the sediments to the bedrock surface, due to the lack of large aquifer-bounding clay layers here (LSCE, 2010).

The results of this analysis indicate that the rate of intrusion would be quite low (Figure 10.3-21; note that the vertical axis is logarithmic). The dotted line on this figure represents the equilibrium change in intrusion length (i.e., the equilibrium intrusion length, $L_{eq}$, minus the pre-pumping intrusion length, $L_0$) based on the new freshwater flux rate (i.e., the original freshwater flux rate,

$Q'_0$, minus the pumping rate, $Q'_w$); this is the intrusion length that would eventually be reached at steady state. The blue dashed line indicates the percentage of the original freshwater flux rate that is left after pumping is increased. The three solid lines indicate the change in intrusion length (i.e., the transient intrusion length, L(t), minus the pre-pumping intrusion length, $L_0$) at three different values of t: 1, 10, and 50 years. The change in intrusion length, read off the left-hand axis, represents how far the toe of the intrusion wedge would have advanced in the period of time corresponding to each line; for example, at a pumping rate of 5,000 cubic feet per year per foot of shoreline (cfy/ft of shoreline), the intruding wedge would have moved 3 feet in 1 year, 13 feet in 10 years, and 39 feet in 50 years. When a solid line intersects with or is above the red dotted curve representing the equilibrium change in intrusion length, the system would be at equilibrium, and the interface would not progress past $L_{eq}$.

These results indicate that the rate of seawater intrusion is lower than has been seen in other settings (see Section 8.2). Even if pumping in the Basin were equal to the pre-pumping freshwater flux (an extreme scenario that is not expected to occur), the change in the intrusion length would be 7 feet after 1 year, 33 feet after 10 years, and 96 feet after 50 years (note that the method assumes that the freshwater pumping is small compared to the initial freshwater flux, so these results should be considered approximate). An equilibrium change in intrusion length of 12,600 feet for this pumping rate indicates that it would take many decades for this system to reach equilibrium.

This method can be applied to the pumping rates from the various modeling scenarios. Scenario 1 utilizes an average pumping rate of about 4,830 cfy/ft of shoreline. The proposed total pumping in the North Westside Basin is about 13,640 cfy/ft of shoreline in Scenario 3a, which represents an increase of about 8,810 cfy/ft of shoreline. The analytical method indicates that the change in intrusion length would be 4 feet over the first year, 19 feet over 10 years, and 57 feet over 50 years. The proposed total pumping of 14,050 cfy/ft of shoreline in Scenario 3b represents an increase of about 9,220 cfy/ft of shoreline. At this rate, the change in intrusion length would be 4 feet over 1 year, 20 feet over 10 years, and 59 feet over 50 years. It should be noted that the increased pumping entailed by the SFGW Project represents about 45% of the initial freshwater flux under Scenario 3a and 47% under Scenario 3b, which indicates that one of the assumptions of the analytical method (that pumping be small compared to the initial freshwater flux) is not completely valid. Because of this, these results should be considered approximate. However, the results are still instructive of the general magnitude of the potential seawater intrusion rate, and are useful in providing an independent line of evidence that pertains to the seawater intrusion analysis.

As with the analysis of flux predicted by the numerical model, it should be noted that this rate analysis assumes that the fluxes can be applied in average across the entire Pacific coast. The actual rate of intrusion at Golden Gate Park may be greater or less than that implied by this analysis, depending on how flux in the area is actually modified.

## 7.2. Physical Conditions Along the Pacific Coast

Previous reports (LSCE, 2002; LSCE, 2010; SFPUC, 2005; SFPUC, 2006) discussed the coastal topography and stratigraphy in relation to the problem of seawater intrusion. These reports considered pre-existing information on the onshore geology (e.g., Clifton and Hunter, 1987) coupled with the results of a study of offshore seismic reflection (Bruns et al., 2002). The information in these reports is summarized in this section. Because no control studies have been performed (i.e., coring offshore to confirm stratigraphy), this discussion of offshore stratigraphy is somewhat speculative.

### 7.2.1. Offshore Geology

The upper surface of sediments continues offshore at a very gentle slope for a large distance. The water depth in the Ocean is only 60 feet about 2 miles offshore, 100 feet 8 miles offshore, and 300 feet 25 miles offshore, at the edge of the continental shelf; the Ocean bottom drops off steeply further offshore. This indicates that the onshore sedimentary units, if they stretch continuously offshore, may not outcrop on the Ocean floor for some distance. The intersection of the top of each aquifer with the Ocean bottom (i.e., its highest outcrop) is important to the problem of seawater intrusion because this is, theoretically, where freshwater exits the aquifer, and is the location where the uppermost part of the seawater wedge exists within the aquifer (Figure 10.3-3).

Because of the structural complications that exist offshore, the slope of the aquifer boundaries that exist onshore and the depth to the Ocean floor cannot be used to predict the depths of the units offshore and where the aquifers are connected to the Ocean. The San Andreas Fault is present offshore from around Mussel Rock north to Bolinas Lagoon. Further to the west, the San Gregorio Fault Zone also sits offshore. Between these faults exists the extensional San Gregorio Basin, a down-dropped area that results from the structure of the two bounding fault zones. This extensional basin has filled with more than 3,000 feet of sediment that is presumed to correlate to the Merced and Colma Formation sediments further inland (Bruns et al., 2002). However, no control points exist to confirm this. The extensional regime that led to the deepening of this basin likely made this a somewhat different depositional environment from the areas east of the San Andreas Fault, so there may be some differences even between units that correlate exactly in time across the San Andreas Fault. West of the San Gregorio Fault Zone, the stratigraphic sequence revealed by the seismic profiling resembles the units seen in the Santa Cruz Mountains to the southeast, indicating that these units have been translated by strike-slip motion along the San Andreas and San Gregorio Fault Zones (Bruns et al., 2002), and the aquifers that exist in the North Westside Basin therefore cannot be correlated to units west of the San Gregorio Basin. As long as the individual onshore aquifer units do not intersect the Ocean floor before reaching the San Andreas Fault, this fault zone may act as a physical barrier preventing seawater intrusion. The Shallow Aquifer, which is not covered by a confining clay layer, is in direct communication with the Ocean all along the coast.

Faults may represent hydrologic barriers in other parts of the Basin. The Serra Fault makes the Daly City area non-susceptible to seawater intrusion from the Ocean (see Section 7.2.3), and the same might be true of the lower aquifers in the North Westside Basin north of Lake Merced due to the presence of the San Andreas Fault, although no direct evidence of this exists.

An additional factor that may aid in reducing the likelihood of seawater intrusion is the presence of freshwater in offshore sediments (LSCE, 2010). During the Pleistocene glaciations, Ocean levels were about 300 to 400 feet lower, exposing the coastal plain to the atmosphere. During that time, the Sacramento-San Joaquin River system flowed across the coastal plain, depositing river sediments. The presence of this river and the exposure to the atmosphere for a relatively long period of time likely allowed fresh water to flush through most or all of the present-day offshore aquifer system. Provided the fine-grained units that exist between the aquifer layers are continuous offshore, these offshore units may still be filled with fresh water. If this is the case, then even head below sea level in the Primary Production and Deep Aquifers may not lead to seawater intrusion on any near-term time frame (SFPUC, 2006); it may take years to decades of continuously below-sea level onshore freshwater head for seawater to intrude through the miles of aquifer potentially occupied by fresh water. Indeed, about 5.5 mgd of groundwater was pumped from the North Westside Basin from 1930 to 1935, immediately prior to the completion of the Hetch Hetchy aqueduct, without inducing any noticeable degradation of water quality in the production wells (Gilman, 2010; SFPUC, 2006). LSCE (2010) also notes that the boreholes at the Fort Funston and Thornton Beach clusters, both located in deformed Merced Formation sediments west of the Serra Fault, did not encounter any saline water to their total depths of 1,500 feet.

### 7.2.2. Pacific Coast Northeast of the Serra Fault

The western boundary of the North Westside Basin is the Pacific Ocean. This stretch of the Pacific Coast is considered potentially susceptible to seawater intrusion due to its direct connection to the Pacific Ocean; however, it does not seem to be currently affected by seawater intrusion. Chloride levels in the monitoring wells along the coast have remained steady and fairly low. The shallow well at the South Windmill monitoring well cluster shows relatively high chloride concentrations, up to 154 milligrams per liter (mg/L) in the most recent (2011) samples (J. Gilman, personal communication, April 22, 2012). The California secondary maximum contaminant level (MCL) for chloride is 250 mg/L recommended and 500 mg/L upper limit.

As noted above, three aquifers exist in this part of the Basin, the Shallow, Primary Production, and Deep Aquifers, although the Deep Aquifer pinches out between the Kirkham and South Windmill well clusters (LSCE, 2010). The boundaries between these units tend to dip slightly toward the Ocean, especially in the deepest sediments as noted in TM#1.

The onshore hydrogeology presented in Appendix A of LSCE (2010) provides insights into the structure of the aquifers. Cross-sections J-J’, Z-Z’, and Y-Y’ stretch through this area. According to these cross-sections, the Shallow Aquifer is in direct contact with the Ocean, and so there are no physical controls to prevent the intrusion of seawater should currently-existing hydrologic controls change.

The cross-sections do not stretch far enough off the coast to show where the Primary Production and Deep Aquifers may be in direct contact with seawater. SFPUC (2006) notes that the structural and depositional features that exist in the offshore sediments preclude the intrusion of seawater into the Primary Production and Deep Aquifers north of Lake Merced, but the physical barriers implied by this are not yet proven to exist. Rather, they are suggested by offshore seismic studies (Bruns et al., 2002) and the presence of offshore fault zones.

Cross-section J-J' is located along an west-east transect from the Ocean through Golden Gate Park to Strawberry Hill. In this area, the Shallow and Primary Production Aquifers are present. At the coast, the Shallow Aquifer is about 100 feet thick, while the Primary Production Aquifer may be about 350 feet thick. There is no fine-grained layer between the two aquifers at this location, meaning that they are hydraulically connected, and they can effectively be considered to be one thick aquifer. According to the cross-section, no physical barrier exists here that would prevent intrusion of seawater into the Primary Production Aquifer via the Shallow Aquifer above. As noted above, these cross-sections do not stretch far offshore; the absence of an intervening fine-grained layer onshore does not necessarily imply that no such layer separates the different aquifers offshore.

Cross-section Z-Z' runs from the Ortega cluster approximately east through the West Sunset Playground to the Sunset Reservoir. Along this cross-section, all three aquifers are present, and they are divided by at least some thickness of fine-grained units, although these lenses are fairly thin and could be discontinuous between the existing wells. At the coast, the Shallow Aquifer is about 120 feet thick, while the Primary Production Aquifer is about 310 feet thick and the Deep Aquifer is about 60 feet thick. If the clay layers between the aquifers are continuous as indicated on the cross-section, and if they continue offshore to some physical barrier (e.g., the San Andreas Fault), the Primary Production and Deep Aquifers at this location may be physically protected from seawater intrusion.

Cross-section Y-Y' runs from the San Francisco Zoo area east to Pine Lake Park and beyond. This cross-section, like Z-Z', indicates that there are continuous clay layers present between (and, in some cases, within) the aquifers here. The Shallow Aquifer is about 40 feet thick at the coast, while the Primary Production Aquifer is about 300 feet thick and the Deep Aquifer is about 130 feet thick. As with cross-section Z-Z', the Primary Production and Deep Aquifers may be isolated from the Ocean. It should be noted that the thick clay present between the Shallow and Primary Production Aquifers at the coast (the "-100 clay") is indicated to be possibly discontinuous about 2,000 feet inland of the coast.

From the information summarized above, a conceptual model of the potential route of seawater intrusion can be constructed for the North Westside Basin. The Shallow Aquifer is connected directly to the Ocean everywhere along the coast, indicating that seawater intrusion would occur in this aquifer anywhere that the on-shore freshwater head is low enough that seawater is not excluded from the aquifer. From the Kirkham cluster north, there are no continuous confining layers present that separate the aquifers, indicating that all three aquifers are open to intrusion along this stretch of the coast should head levels permit it.

South of the Kirkham cluster, clay layers are present between the three aquifers. To the extent that these layers are laterally continuous, they present a barrier to seawater intruding into the lower two aquifers from the Shallow Aquifer above. Cross-section D-D’ in LSCE (2010) indicates that the W clay is continuous from the Kirkham cluster south to the Serra Fault, separating the Primary Production Aquifer from the Deep Aquifer below. This indicates that, should seawater enter the Primary Production Aquifer, it would not intrude into the Deep Aquifer except at the rate allowed by the W clay. The -100 clay, which separates the Shallow from the Primary Production Aquifer, is not fully continuous south of the Ortega cluster, and there is a gap in this layer between the Taraval and Zoo clusters. Should seawater intrusion occur in the Shallow Aquifer along the coast in locations where the -100 clay is not present, the Primary Production Aquifer would also be susceptible to seawater intrusion. The -100 clay is continuous from north of the Zoo cluster to the Serra Fault (to the south).

#### 7.2.3. Pacific Coast Southwest of the Serra Fault

The southwestern boundary of the South Westside Basin is made up of the San Andreas Fault, which juxtaposes Merced Formation sediments against the Franciscan bedrock southwest of the Basin. This barrier likely prevents the part of the Basin bounding it from experiencing any ill effects in terms of seawater intrusion due to groundwater development. As with the bedrock high sections along the eastern edge of the North Westside Basin, it is always somewhat possible that connate water (seawater trapped in a formation when the sediments are deposited) could be mobilized out of marine sediments by changes in the head distribution, but this is considered unlikely. Therefore, the areas of the Basin bounded by the San Andreas Fault, from San Andreas Lake to the Pacific Ocean, are considered non-susceptible to seawater intrusion.

The Serra Fault, which runs sub-parallel to the San Andreas Fault, has unknown hydraulic characteristics. While the San Andreas Fault to the south has placed low-permeability bedrock against the sediments of the Merced Formation, the Serra Fault separates Merced Formation sediments from those of the Colma Formation, implying that, if a physical barrier to groundwater flow exists, it must be the fault zone itself rather than the rocks bounding it. LSCE (2002) suggest that, due to their “presence and configuration,” the deformed Merced Formation sediments present along the Serra Fault could act as a barrier to seawater intrusion as far north as Fort Funston, where the fault heads offshore, but no corroborating evidence for this has been found elsewhere. The well cluster at Thornton Beach shows very different groundwater head trends from the other wells in the coastal monitoring network, indicating that this cluster, which is located between the San Andreas and Serra Faults, may be hydraulically disconnected by the Serra Fault from the rest of the Westside Basin. For the purposes of this TM, the portion of the Basin along the Pacific Ocean southwest of the Serra Fault between the San Andreas Fault and Lake Merced is considered to be non-susceptible to seawater intrusion based on the assumption that the Serra Fault represents an effective physical barrier to intrusion.

### 7.2.4. Pacific Coast Head Monitoring

The coastal monitoring wells are screened in the Shallow, Primary Production, and Deep Aquifers (hydrographs for the wells discussed in this section are presented as Appendix B of TM#1). Within the Shallow Aquifer, head has generally not changed much since monitoring began (2004) at the Ortega (120 ft bls) and Taraval (145 ft bls) well clusters. At the Kirkham cluster, head in the well screened within the Shallow Aquifer (130 ft bls) fluctuates quite a bit on a seasonal basis, and LSCE (2010) suggest that this is due to irrigation cycles in Golden Gate Park. The average head in this well dropped by about 4 feet around the spring of 2006; this drop could be related to a change in the irrigation practices. All available heads in the Shallow Aquifer remain above sea level, currently averaging about +10 ft mean sea level (msl) in the Ortega and Taraval wells and about +8 ft msl in the Kirkham wells.

The recent head trends in the Primary Production Aquifer have shown more spatial variability, although they have generally been fairly steady and above sea level. The South Windmill well (140 ft bls) has seen head dip below sea level repeatedly during the irrigation season, by as much as 20 feet. Of the three wells screened in this aquifer at the Kirkham cluster, head in the upper one (255 ft bls) has fluctuated around an average of about +11 ft msl, that in the middle one (385 ft bls) has fluctuated around an average of +8 ft msl, and has not dropped below sea level, and head in the deeper one (435 ft bls) has generally been about +5 ft msl, and dipped below sea level in September of 2007; at the same time, head in the upper (255 ft bls) and middle (385 ft bls) wells dropped below +3 ft msl for the only time over the period of record. The Ortega cluster also has three wells screened within the Primary Production Aquifer. The upper two (265 and 400 ft bls) show very similar trends in head over time, with little change and values hovering around +12 ft msl for most of the period of record. Head in the lowest well (475 ft bls) has fluctuated quite a bit, with two major excursions below sea level in 2006 and 2007. Two wells screened in the Primary Production Aquifer at the Taraval cluster (240 and 400 ft bls) have had heads averaging around +10 to +13 ft msl, with fairly steady heads and no major trends up or down. At the West Sunset Playground well, head has been fairly steady over the period of record at between +17 and +18 ft msl. At the Zoo cluster, two wells are screened within the Primary Production Aquifer. The upper one (275 ft bls) has shown a generally rising head since 2004, staying consistently above sea level; recent head measurements have ranged between about +6 and +7 ft msl. The lower well (450 ft bls) head has also been highly variable, although it has seen at least three drops slightly below sea level, in 2004, 2006, and 2007. Finally, the Thornton Beach cluster has two wells screened within the Primary Production Aquifer. The upper one (225 ft bls) shows head between +82 and +85 ft msl, with the most recent heads about a foot above the earliest heads. The lower one (360 ft bls) shows head between +13 and +15 feet msl, with no appreciable trend over time.

Head in the Deep Aquifer has generally stayed steady on average, with large seasonal fluctuations. The deepest wells at the Taraval (530 ft bls) and Zoo (565 ft bls) clusters are screened in this aquifer. Head in the Taraval well varies between 4 and -9 ft msl, with the lowest heads recorded during the autumn of 2007. The Zoo well varies between +1 and -14 ft msl, with the timing of the deepest head coincident with that in the Taraval well. Neither of these wells shows an identifiable upward or downward groundwater head elevation trend over the period of record.

### 7.2.5. Pacific Coast Chemical Monitoring

Within the coastal monitoring network, the clusters at South Windmill, Kirkham, Ortega, and Taraval are sampled for chloride, total dissolved solids (TDS), and specific conductance, while the Zoo cluster and the West Sunset Playground well are measured for nitrate and general minerals (which includes chloride and TDS). Chloride concentrations for selected wells are included on the hydrographs of TM#1, and average concentrations for selected chemical constituents are given in Table 10.3-8.

The wells in the monitoring network are sampled for chloride semi-annually. At the Kirkham, Ortega, and Taraval wells, chloride has varied between about 20 and 40 mg/L, and each well has seen fairly steady concentrations since monitoring began in 2004. The three wells in the Zoo cluster have higher chloride, varying from about 70 mg/L (275 ft bls) to 45 mg/L (450 ft bls) to 50 mg/L (565 ft bls). These wells have shown no appreciable upward or downward trend in concentrations over time. Limited data exist for the cluster at South Windmill, with the shallower well (57 ft bls) concentrations varying from 115 to 193 mg/L, and the deeper well (140 ft bls) concentrations varying between 48 and 70 mg/L. The concentrations in this shallower well increased with every measurement from when monitoring began in 2006 through 2009, but have since decreased to 154 mg/L in November 2011.

The highest chloride concentrations measured in the North Westside basin have been at LMMW-1S, screened in the Shallow Aquifer and located between Lake Merced and the Pacific Ocean along the west side of John Muir Drive (data are available for April and November of 2009 and 2010). The highest chloride concentration measured was 393 mg/L in November 2009, with the lowest concentration being 129 mg/L in April 2010 (SFPUC, 2011). The ultimate cause of these high chloride concentrations is unknown. The co-located well LMMW-1D, screened in the Primary Production Aquifer, yielded samples with chloride concentrations of 104 and 106 mg/L in April and November of 2010. The proximity of these wells to the Pacific Ocean (approximately 1,300 feet to the west) indicates that the Ocean is a potential source for elevated chloride; however, LMMW-1S is separated from the Ocean by the Serra Fault, which is interpreted to be a barrier to groundwater flow and seawater intrusion in this area, as discussed further in TM#1. In addition, some other chemical constituents are not typical of Ocean water; in particular, the pH (average of 6.8) is well below the average pH of seawater (about 7.8 to 8.4; see, for example, Krauskopf and Bird, 1995) and below the values seen in the other wells within the North Westside Basin (averages for wells monitored by SFPUC vary from 7.2 to 8.6), perhaps indicating that some other source is affecting the chemistry of groundwater at LMMW-1S. These observations indicate that the elevated chloride concentrations seen in LMMW-1S likely result from a source other than seawater intrusion.

Other previous studies have also presented chloride data in the North Westside Basin that could potentially provide useful information on the occurrence of seawater intrusion along the Pacific coast. AGS (1994) presented results of production well sampling in November and December of 1993 at various wells around the North Westside Basin. Chloride varied from 21 to 68 mg/L, with the highest value at the Oceanside Water Pollution Control Plant (just south of the Zoo cluster and LMMW-4S on Figure 10.3-1); outside of this sample, the highest chloride concentration was 42 mg/L at Sunset Well #7. Samples were obtained from a few locations studied in detail in this TM: North Windmill, South Windmill, and the San Francisco Zoo. At these production wells, chloride concentrations varied from 37 to 39 mg/L. High capacity, deep production wells have been pumping at the west end of Golden Gate Park since the 1920s and at the San Francisco Zoo since the 1930s.

Yates et al. (1990) and Phillips et al. (1993) provided the results of sampling for various constituents (including chloride) at several wells, mostly in the North Westside Basin. Chloride concentrations in all of the wells sampled varied from 21 to 210 mg/L (this highest value was seen at the Elk Glen-S monitoring well in central Golden Gate Park; the highest value along the coast was 130 mg/L at HLA E). Samples from the North Windmill, South Windmill, and Zoo locations (including both production and monitoring wells) had chloride concentrations of 35 to 54 mg/L, except a sample from the shallowest monitoring well at South Windmill, which had a chloride concentration of 100 mg/L. Yates et al. (1990) offered the following explanation for the chloride concentrations in shallow groundwater: “Most of the chloride in shallow ground water is probably derived from near-surface sources. For example, the average concentration of chloride during 1987 in sewage flowing out of the Richmond-Sunset Water Pollution Control Plant was 145 mg/L.” Phillips et al. (1993) offered the following explanation for the elevated chloride concentrations seen at the Elk Glen-S and the South Windmill-S (now known as MW57) monitoring wells: “The apparent saltwater contamination in shallow wells at Golden Gate Park probably is a result of leakage of seawater used at Steinhart Aquarium, either from the supply pipe or exfiltration of saltwater discharge to the sewer system.”

The data presented in the reports discussed above indicate that there have not been appreciable trends over time in the coastal chloride concentrations in the North Westside Basin. Further, the recent sample results have been in line with historical data. The generally stable chloride concentrations along the Pacific Coast indicate that substantial seawater intrusion has not occurred to date, despite long-operating irrigation wells in the areas of Golden Gate Park and the San Francisco Zoo.

Additional groundwater chemistry monitoring has been performed on a short-term basis as part of construction projects in the North Westside Basin. An important and instructive example occurred during dewatering associated with construction at the Oceanside Water Pollution Control Plan (WPCP) from 1989 to 1994 (dewatering started in May of 1990, and continued until April 1991). Oceanside WPCP is located south of the San Francisco Zoo, between the Pacific Ocean and Lake Merced. ESA (1994) presented monitoring data collected in the Oceanside WPCP area during the construction activities. Observation wells were installed surrounding the site, including along the Great Highway along the Pacific Coast (OB-3, OB-6, and OB-7), along the northern end of the site (OB-1, OB-2, and OB-5), and along the eastern boundary of the site where it borders Lake Merced (OB-4). Well OB-3, screened in the Shallow Aquifer, was directly west of the field of dewatering wells, and saw 19 feet of water table decline during dewatering operations, but rebounded to pre-pumping levels within a month of the cessation of dewatering. Water quality was also monitored during construction activities; chloride in OB-3 rose quickly from background concentrations, eventually reaching a maximum of 10,500 mg/L. Monitoring of chloride continued after the cessation of dewatering, and the groundwater in OB-3 remained brackish throughout the period of post-dewatering monitoring, at least to 1994 when ESA reported these results. The monitoring results indicate several important things relevant to this TM:

- Based on the speed with which seawater reached OB-3 after dewatering began, the freshwater-seawater interface in the Shallow Aquifer must be located just offshore in this aquifer, and the Shallow Aquifer is in direct contact with the Ocean here.
- Seawater intrusion can affect coastal monitoring wells within a span of just a few months.
- Once seawater intrusion does occur, it is difficult to reverse the process and return aquifer water quality to its pre-intrusion state, even when head has rebounded to this pre-intrusion state.
- Intrusion, especially when it is caused by highly localized pumping in the vicinity of the coast, can be localized (none of the other monitoring wells saw any decline in water quality during dewatering operations) and temporary (SFPUC, 2005).

The results of the dewatering operations are not expected to exemplify the reaction of the aquifer system to pumping associated with either the GSR or SFGW Projects, which would involve pumping further away from the Coast, and would derive groundwater from deeper, confined aquifers that are not expected to experience seawater intrusion on the short timescales demonstrated for the Shallow Aquifer by ESA (1994).

### 7.3. Physical Conditions Along the San Francisco Bay Coast

The portion of the Westside Basin along the San Francisco Bay is the easternmost part of the South Westside Basin. This is another area potentially susceptible to seawater intrusion, and may in fact currently be affected by seawater intrusion. Chloride concentrations in this area vary from 42 to 13,000 mg/L, with the highest values seen in the shallowest wells. The chloride-bromide ratios for the sampling events in November 2006 and April 2007 (WRIME, 2007) are fairly similar to that of water collected from a nearby location in the San Francisco Bay (Cl:Br = 327), also in April 2007.

As noted in WRIME (2007), both the Bay Mud and the artificial fill were emplaced in the environment of the saline Bay, meaning that these deposits likely contain substantial connate water. While the similarity of chloride concentrations and chloride-bromide ratios to those of Bay water may seem indicative of seawater intrusion into this area, similar concentrations could be due to the presence of connate Bay water in the sediments of the area, which may be expected to be fairly similar chemically to today's Bay water and would therefore have a similar effect on aquifer water quality as would intruding seawater. Because the available reservoir of connate water is determined by the porosity of the Bay Mud, this reservoir can be assumed to be much smaller than the effectively infinitely large reservoir of Bay water nearby; therefore, the flux of connate water into the freshwater aquifer would likely be lower than would be the flux of seawater intrusion from the Bay if the aquifer were in direct communication with the Bay.

### 7.3.1. San Francisco Bay Geology

In the San Bruno area, the deposits closest to the Bay are made up of Bay Mud overlain by artificial fill deposited into the Bay (WRIME, 2007). LSCE (2010) produced two cross-sections that stretch through the South Westside Basin toward the Bay, although neither provides a representation of the sediments at the Bay Coast. These cross-sections (N-N' and O-O' in Appendix A of LSCE, 2010) show Colma Formation deposits on the surface inland, interfingering with Bay deposits closer to the Bay. A subsurface bedrock ridge is also shown that provides some protection to the southern portion of the South Westside Basin from potential seawater intrusion from San Francisco Bay.

Cross-section O-O' runs from San Andreas Lake northeast towards San Francisco Bay. Based on the inferred geologic correlations, the Colma Formation sediments that are present on this cross-section inland are not continuous to the Bay, being separated from it by deposits of low-permeability Bay Mud that likely stretch from the land surface to the bedrock surface below. If true, this would present a physical barrier, likely precluding seawater intrusion in this area. The Bay deposits are very fine-grained, and are considered by some to be a physical control on seawater intrusion into the freshwater aquifers. However, TM#1 notes the presence of some sands within this unit that could be conduits for seawater intrusion. The properties of the artificial fill deposited over the Bay Mud are not noted in WRIME (2007), although it is likely that it contains a wide variety of grain sizes.

### 7.3.2. San Francisco Bay Head Monitoring

Head in the Bay side monitoring well network is available for the Shallow and Primary Production Aquifers (hydrographs for the wells discussed in this section are presented as Appendix B of TM#1). At the UAL site, one well (MW13D) is screened within the Shallow Aquifer (SFPUC, 2010). Head in this well hovered around +2.5 ft msl from late 2003 to early 2006, after which head dropped to around -0.5 ft msl through at least late 2009. At the SFO and Burlingame sites, the shallowest wells (SFO-S and Burlingame-S) are both screened within the Shallow Aquifer; these two wells show very similar head results (with fairly sparse data). Each well shows a seasonal variation, with high values (around +2.3 ft msl at SFO and +3.5 ft msl at Burlingame) in the winter and low values (around +1.9 ft msl at SFO and +1.8 ft msl at Burlingame) in the summer.

At the UAL site, one well (MW13C) is screened within the Primary Production Aquifer. This well shows head varying between -29 and -33 ft msl from 2004 to 2009. At the SFO and

Burlingame sites, the deepest wells (SFO-D and Burlingame-D) are both screened within the Primary Production Aquifer. These wells show a similar seasonal fluctuation to the co-located wells screened within the Shallow Aquifer. SFO-D head varies from about -30 ft msl in the summer to about -29 ft msl in the winter. Burlingame-D head varies from about -5 ft msl in the summer to about -4 ft msl in the winter.

#### 7.3.3. San Francisco Bay Chemical Monitoring

The wells in the Bay side monitoring network are sampled for general minerals, nitrate, bromide, boron, and orthophosphate (see Table 10.3-8 for average concentrations of selected constituents for each well). The Burlingame cluster contains three wells. Samples from the shallowest (Burlingame-S) well have chloride concentrations varying from 110 to 518 mg/L, with the highest values measured in February, 2009. The middle well (Burlingame-M) has shown concentrations ranging from 63 to 140 mg/L, while the deep well (Burlingame-D) has shown concentrations between 41 and 140 mg/L; these two wells have both shown a decreasing trend in chloride concentration over the sampling period. In the SFO cluster, the shallow well (SFO-S) has shown the most elevated values of chloride, between 8,400 and 12,400 mg/L, with increasing chloride over time. The deep well (SFO-D) has shown chloride values between 240 and 2,210 mg/L, with highly variable concentrations that don't seem to have a specific trend. Chloride results from the UAL cluster indicate that concentrations in the deeper well (MW-13C) are slightly over 500 mg/L, while one sample in the shallower well (MW-13D) shows a chloride concentration of 13,000 mg/L (WRIME, 2007). Bay water near the site was reported to have a chloride concentration of 17,000 mg/L. The high chloride concentrations observed in the Bay side monitoring network wells may result from the mobilization of or mixing with connate water with high salt concentrations (see Section 7.3).

Bromide results are also available for the Burlingame and SFO clusters from two sampling events (WRIME, 2007). At Burlingame, bromide concentrations were 0.22 and 0.36 mg/L in Burlingame-D, 0.24 and 0.38 mg/L in Burlingame-M, and 0.26 and 0.66 mg/L in Burlingame-S. At SFO, bromide concentrations were 0.79 and 1.7 mg/L in SFO-D and 27 and 32 mg/L in SFO-S. Bay water near the site was reported to have a bromide concentration of 52 mg/L.

Chloride:bromide ratios represent a better method for detecting seawater intrusion than simple chloride concentrations. In the Burlingame well cluster, this ratio was 389 and 427 in Burlingame-D, 368 and 458 in Burlingame-M, and 333 and 423 in Burlingame-S. At the SFO cluster, the ratio was 259 and 342 in SFO-D and 291 and 311 in SFO-S (WRIME, 2007). The ratio in Bay water near the site was reported to be 327. Salinity in the southern Bay changes on a seasonal basis due to changes in the inflows, reaching a maximum in October and a minimum in February (Figure 10.3-22). Because this salinity change is the result of the mixing of two very different waters, the chloride:bromide ratio may be expected to change seasonally as well, so a single measurement should not be taken as the definitive representation of Bay water.

## 8. Seawater Intrusion Monitoring and Management

In addition to evaluating the conceptual model and the results of the analytical and MODFLOW models, other evaluations were conducted to add insight into potential seawater intrusion issues.

### 8.1. Drinking Water Standards

For the purpose of managing water resources to minimize the occurrence of seawater intrusion, a set of performance measures must be defined. Although this is a complex issue, it is helpful to put the problem in terms that are easily understood. CH2M HILL (1995) defined seawater intrusion as “significant migration (based upon an intermediate composition of fresh water and salt water) of salt water into the potable aquifer and/or extraction of salt water by production wells.” However, this definition is fairly subjective, and represents a definition of seawater intrusion that is reactionary, rather than preventative, in nature.

For effects on the freshwater aquifer, it is useful to define some level of chloride (and other constituents) that represents degradation of the groundwater resource. Although various levels can be defined, management agencies generally use pre-existing maximum contaminant level (MCL) values. The Environmental Protection Agency (EPA) publishes a secondary drinking water standard of 250 milligrams per liter (mg/L) for chloride (EPA, 2009); there is no primary MCL for chloride as high chloride levels are not dangerous to health, but rather cause aesthetic degradation (e.g., taste or odor). This level has been used as a threshold for defining seawater intrusion in other basins, including Soquel Creek in California (Hydrometrics, 2009) and those around the City of Honolulu in Hawaii (Todd, 2004). Performance measures could be defined for other constituents based on EPA MCL values, but chloride is the most commonly utilized one for seawater intrusion.

### 8.2. Summary of Seawater Intrusion Rate Studies

The rate at which the seawater-freshwater interface enters the aquifer depends on a number of parameters, and is difficult to determine except by direct measurement or numerical simulation. This section summarizes the results of previous studies in other parts of the world, where geophysical, chemical, or modeling techniques were used to estimate a rate of seawater intrusion.

Izbicki (1996) summarized the occurrence of seawater intrusion into the Oxnard and Mugu aquifers of southern California. Seawater intrusion into these aquifers occurred as the result of extended groundwater overdraft in the coastal zone, with head levels dropping to below sea level in large parts of the aquifer system. Seawater began intruding into the coastal freshwater aquifers as early as the mid-1950’s. Using a time-series of chloride measurements, Izbicki (1996) was able to estimate the total extent of seawater intrusion from 1955 to 1992 as being 2.7 miles in the Oxnard aquifer and 1.9 miles in the Mugu aquifer, implying rates of 375 and 264 feet per year (ft/yr), respectively.

Yakirevich et al. (1998) used the SUTRA computer model code to predict the rate of seawater intrusion in the coastal aquifer along the Gaza Strip. Seawater intrusion is currently occurring in this aquifer, where groundwater is heavily over-used. Yakirevich et al. (1998) predicted that seawater intrusion over the ten-year period from 1997 to 2006 would occur at a rate of 66 to 148 ft/yr.

Kennedy/Jenks (2004) studied the intrusion of seawater into the Salinas Valley groundwater basin by constructing a three-dimensional hydrogeologic conceptual model to assess the susceptibility of the different aquifers to seawater intrusion. An analysis of the movement of chloride fronts was based on a time-series of chloride concentration from a system of monitoring wells. It was concluded that the rate of intrusion into the coastal aquifer varied between 202 and 673 ft/yr, depending on location in the aquifer.

## 8.3. Typical Monitoring Procedures

To monitor whether seawater intrusion is occurring, an extensive monitoring system is typically employed. A network of groundwater monitoring wells is typically employed that monitors groundwater head and water quality at different depth intervals within the aquifer (or aquifers). Monitoring different depth ranges is necessary because, since seawater intrusion occurs as a wedge, the presence of vertical variations in water quality is important to understanding the extent of intrusion. Also, aquifer heterogeneity may cause seawater intrusion to find preferential pathways through the aquifer that a single well screen might miss.

The primary parameter that is monitored is groundwater head, as this represents the driving mechanism for seawater intrusion. Based on the Ghyben-Herzberg ratio, seawater is kept out of the freshwater aquifer if the groundwater elevation above sea level is at least about 1/38$^{th}$ of the thickness of the aquifer. For example, if the aquifer is 380 feet thick, a freshwater head of 10 feet is required to keep the aquifer at that location free of seawater at the bottom of that aquifer. Therefore, at each location an aquifer thickness must be defined, and then divided by 38 to determine the threshold above which freshwater head should be maintained.

Water quality parameters are also monitored, primarily chloride (Cl) and total dissolved solid (TDS) concentrations. Because of the contrast in marine and typical continental anion matrices, the clearest indication of possible seawater intrusion is an increase in Cl concentration as a proxy for salinity (although other processes may lead to a similar phenomenon; see below). In those coastal aquifers where continuous over-exploitation causes a reduction of groundwater head levels, intrusion of seawater would result in an increase in salinity. Thus, a time-series of chloride concentrations can help provide early indications of seawater intrusion.

In addition to the lateral infiltration of seawater through aquifers that communicate directly with the ocean, there are several possible sources of increased salinity of freshwater aquifers (DWR, 1958). The best way to differentiate intruding seawater from degradation through some other cause is to employ an extensive monitoring network to track the spatial and temporal variability in groundwater chemistry. If saline water can be observed progressing steadily inland and upward in the formerly freshwater aquifer, causes other than seawater intrusion can be discounted. In situations where salinity increases are observed in a monitoring network, more intensive monitoring may be initiated, using other ionic constituent concentrations or stable isotope values to identify seawater intrusion and differentiate it from other potential sources of increased salinity. These approaches exploit the differences in geochemistry and transport processes between seawater intrusion and other sources of salinity. In summary, these include (modified from Jones et al., 1999):

- **Chloride-bromide (Cl/Br) ratios:** These ratios can be used as a reliable tracer as both constituents usually behave conservatively (i.e., they are not particularly subject to retardation through reaction or sorption, and therefore are transported almost entirely by advection alone). Seawater is distinguished from anthropogenic sources like sewage effluents (which have higher Cl/Br ratios) or agriculture-return flows (which have lower Cl/Br ratios). This and the other geochemical methods listed here rely on the fact that seawater chemistry is quite uniform in time and space.
- **Sodium-chloride (Na/Cl) ratios:** Na/Cl ratios of intruding seawater are usually lower than the values in ocean water due to the fact that sodium interacts with aquifer sediments more strongly than does chloride. The low Na/Cl ratio of seawater intrusion is distinguishable from the higher Na/Cl ratios typical of anthropogenic sources like domestic wastewaters.
- **Calcium-anion (Ca/X) ratios:** One of the most conspicuous features of seawater intrusion is the enrichment of Ca over its concentration in seawater. High Calcium-Magnesium (Ca/Mg) and Calcium-Bicarbonate-Sulfate ($Ca/(HCO_3 + SO_4)$) ratios are further indicators of seawater intrusion.
- **Oxygen and hydrogen stable isotopes:** Linear correlations are expected from mixing of seawater with $^{18}O$-depleted groundwater when comparing $\delta^{18}O$[5] to $\delta^{2}H$ or Cl because all three behave conservatively (so a straightforward mixture of seawater and freshwater would fall along a line between the seawater and freshwater end-members). Salinity introduced to an aquifer by sources enriched by evaporative processes (e.g., agriculture-return flows) would result in mixing lines with different slopes from the seawater-freshwater mixing line, which could generally be expected to follow a meteoric water line.
- **Boron isotopes:** The boron isotopic composition of groundwater can be useful in distinguishing seawater intrusion from anthropogenic salinity sources such as domestic wastewater or non-seawater salinity sources such as hydrothermal fluids (Vengosh and Spivack, 1999). The $\delta^{11}B$ value of seawater is about 39‰, distinctly different from the more depleted values in sewage effluents (0-10‰) and non-marine hydrothermal fluids (-10-5‰). Because of the significant differences between seawater and other potential

[5] Stable isotope measurements are expressed in delta (δ) notation, calculated as the difference between the abundance of a specific isotope to that in a reference standard divided by the abundance in the reference standard. This is a much more accurate measure than the actual abundance. See Clark and Fritz, 1997.

salinity sources, boron isotopes may be one of the most useful constituents to include in a monitoring program.

- **Residence time tracers:** The above constituents are measured to monitor for the intrusion of saline water, and to differentiate intruding seawater from domestic effluents and evaporatively enriched groundwater. Radioactive and other residence time tracers can be used to differentiate between recently-intruded seawater and connate water (seawater trapped in a formation when the sediments are deposited) that may have been present in the sediments for thousands of years. The specific tracer chosen would depend on the expected residence time of the connate water.

### 8.4. Potential Control Measures for Seawater Intrusion

Various control methods can be utilized to prevent, slow, or reverse seawater intrusion into coastal aquifers. These methods have been developed in areas that have experienced significant intrusion. Control measures have been summarized elsewhere (e.g., DWR, 1975; van Dam, 1999), and will only be briefly discussed here. Two categories of control methods exist, corresponding to two types of controls on seawater intrusion discussed in Section 2.3: physical and hydrological methods.

Physical controls entail the installation of actual physical barriers in the subsurface to block the flow of ocean water. These barriers are only useful when intrusion occurs on a fairly small scale, where the area of intrusion is limited. Barriers can be constructed of grout, slurry, or some kind of membrane, anything that is low enough in permeability to effectively exclude seawater. In thick or complex aquifer systems, physical barriers would have to be very long and extend very deep into the aquifer to prevent seawater intrusion, making them impractical.

Hydrologic controls are more widely employed, and are better suited to large aquifers. As discussed in Section 2.3, the two important factors for preventing seawater intrusion are freshwater flux into the ocean and the freshwater head just landward of the coast. Hydrologic methods of control consist of enhancing one or both of these. The simplest method is conservation, where extraction of groundwater is reduced. This can be considered a “natural” approach to control, as it seeks to prevent intrusion by returning the hydrologic system closer to its “natural” (or pre-development) state. However, this method may not be practical in systems where the groundwater extraction is necessary. Similarly, active management of groundwater extraction, where pumping is shifted around in the basin so that individual locations are not pumped too heavily, is used to allow the aquifer to recover when not pumped; this requires the installation of extra wells, and could greatly increase the cost required to build a groundwater extraction network.

Seawater intrusion can also be controlled hydrologically through artificial means. Attempts to limit or prevent seawater intrusion through engineering often focus on creating a head barrier near the shoreline through injection of freshwater. Commonly, this involves the injection of freshwater into the aquifer landward of the intrusion wedge, and seaward of production wells.

The injected freshwater can be locally-sourced groundwater, imported surface water, or reclaimed wastewater. The goal of this method is to build up a mound of freshwater with sufficient head to prevent seawater from intruding into the base of the aquifer.

A similar effect can be achieved by pumping groundwater on the seaward side of the seawater intrusion wedge, although this is necessarily temporary (since the goal is to get the wedge to move toward, and eventually past, these extraction wells), and the produced water must be disposed of somehow; as the wedge is moved back toward the pumping wells, much of the extracted water would be made up of useful freshwater that is mixed with the saline water, and this freshwater may have to be wasted by simply discharging it to an appropriate location.

The control method (or methods) used depends on the exact conditions under which seawater intrusion occurs. This would require an analysis to be made before seawater intrudes into the freshwater aquifer, through the investigation of various mitigation alternatives.

## 9. Summary

This section summarizes the results of the conceptual model, empirical data, numerical modeling, and analytical approaches with respect to seawater intrusion.

### 9.1. Assessment of Susceptible Areas

The two areas of the Westside Basin that were determined to be susceptible to seawater intrusion are (1) the Pacific Coast from the south side of Lincoln Park to Lake Merced, and (2) the San Francisco Bay Coast from the Visitacion Valley Basin to the San Mateo Plain Basin (Figure 10.3-1).

Along the Pacific Coast, sediments are more permeable, and reductions in head along the Coast could move the seawater wedge inland. There is no physical barrier to seawater intrusion into the Shallow Aquifer because the sediments here are fairly coarse-grained and in direct communication with the Ocean offshore. The offshore San Andreas Fault may represent a physical control on seawater intrusion into the Primary Production and Deep Aquifers, although discontinuities in the -100-foot clay may serve as locations where seawater could intrude into the Primary Production Aquifer from the Shallow Aquifer above.

In general, the San Francisco Bay Coast is not particularly susceptible to seawater intrusion due to the presence of the Bay Mud and a subsurface bedrock ridge that provides some protection to the southern portion of the South Westside Basin from potential seawater intrusion from San Francisco Bay. Chloride levels in the Shallow Aquifer at the SFO cluster are very high, near those of Bay water. However, this could be due to the presence of connate water in the Bay Mud itself, which may be easier to mobilize locally than it would be for seawater to intrude from the Bay to the freshwater aquifer through the Bay Mud. It should be noted that the chloride concentrations in the Primary Production Aquifer, where head levels are well below sea level and seawater intrusion would occur more quickly, are much lower than in the Shallow Aquifer.

Non-susceptible parts of the basin are areas where some sort of physical control precludes the current and future intrusion of seawater into the Basin. The inland parts of the basin, separated from the coast by the mountain ranges located on the northeastern and southwestern boundaries of the basin, are not susceptible to seawater intrusion. Parts of the North Westside Basin where the bedrock surface is above sea level are also not susceptible. The southern part of the Basin's Pacific Coast, where the Serra Fault represents a barrier between the Ocean and inland areas, seems to not be susceptible to seawater intrusion.

### 9.2. GSR-Only Scenario

The GSR Project is a conjunctive use project that would allow for increased groundwater supplies in the Westside Basin during periods of drought and emergencies (MWH, 2008). The conjunctive use project is based on the concept of providing available surplus surface water from the SFPUC Regional Water System to the Partner Agencies (PAs). This water would be used by the PAs instead (or “in-lieu”) of pumping groundwater from the Westside Basin.

The project is planned to provide up to 60,500 af of in-lieu recharge. During the take cycle, both SFPUC and the PAs would be pumping groundwater; however, SFPUC would not take more than the amount of in-lieu recharge available in the SFPUC Storage Account.

Pumping in the South Westside Basin for the GSR-only Scenario (2) would have a minimal effect on head in the North Westside Basin. South of Lake Merced the Serra Fault likely presents a physical barrier to seawater intrusion. The operation of the GSR Project would not change the potential for seawater intrusion relative to Scenario 1 because groundwater head at wells in the North Westside Basin along the Pacific Coast would not substantially change.

Along the San Francisco Bay Coast, the changes to groundwater pumping do not show a substantial effect on seawater intrusion compared to what may occur under Scenario 1 conditions. The freshwater flux out of the aquifer into the San Francisco Bay is quite low under existing conditions, and is not modified to any great degree by the pumping configurations simulated in the MODFLOW model.

Based on this analysis, the likelihood of seawater intrusion resulting from the GSR Project would be considered low along either the Pacific Coast or the San Francisco Bay Coast.

### 9.3. SFGW-Only Scenarios

The SFGW Project would construct up to four wells (along with conversion of two irrigation wells) and associated facilities in the western part of San Francisco and extract an annual average of up to 4 mgd of water from the North Westside Basin (SFPUC, 2009a). The SFGW wells would pump at this rate on a near-continuous basis over periods of many years.

Two model scenarios incorporate the pumping of the SFGW Project (3a and 3b). The results of these scenarios indicate that there is the potential for the landward migration of the seawater-freshwater interface along the Pacific Coast as a result of increased groundwater pumping from the SFGW Project. Many of the heads, especially in the southern half of the North Westside Basin, are projected by the numerical model to be below sea level for some to most of the simulation period; even in the northern half of the North Westside Basin, head would drop everywhere near and along the Pacific coast, possibly low enough to induce seawater intrusion.

It is important to note that the groundwater head in the Deep Aquifer at the Zoo monitoring well cluster has been almost uniformly below sea level since monitoring began in 2003. Despite this, and despite the fact that the cluster is only about 300 feet from the Ocean, the chloride concentration has remained steady between 50 and 60 mg/L over the same time period, indicating that this location has not yet been affected by seawater intrusion. This indicates one or more of the following: 1) that conditions ideal for seawater intrusion (i.e., groundwater head below sea level) must be present for some time (in this case more than at least 9 years) before the intrusion actually occurs; 2) the assumption of a coastal location for the discharge point is not applicable for these aquifers (i.e., the discharge point is further offshore); and 3) the Deep Aquifer is separated from the Ocean by a physical barrier, such as the W-clay. Without more knowledge of offshore geologic structures and their ability to act as physical controls, and the locations where freshwater discharges from the different aquifers, the exact reason that seawater has not shown itself to be intruding into the freshwater aquifer is unknown.

Similarly, measured head elevations in wells along the west end of Golden Gate Park have repeatedly dipped below the single-aquifer and Shallow Aquifer exclusion heads in the recent past (TM#1), and this area has been subject to relatively continuous groundwater pumping for irrigation since the 1920's. Despite this, there has been no appreciable increase in chloride concentrations in the production wells at the North Windmill and South Windmill locations over many years of monitoring. Unlike the Deep Aquifer at the Zoo monitoring well cluster (see above), the aquifers along the west end of Golden Gate Park seem to be in fairly direct contact with seawater (see Figure 10.3-2), so there does not seem to be a specific physical control that would prevent seawater intrusion. The fact that seawater intrusion does not seem to have had an effect on chloride concentrations in this area may indicate that the seasonal rebound in head that occurs in the winter (when head in the Shallow Aquifer is above the single-aquifer and Shallow Aquifer exclusion heads) effectively compensates for seasonal excursions below the exclusion heads, or that the small fine-grained layers present in the area break the sediments into multiple thin aquifers, which are theoretically less susceptible to seawater intrusion than would be a single thick aquifer.

Along the San Francisco Bay coast, the freshwater aquifer would not be vulnerable to seawater intrusion due to the operation of the SFGW Project primarily because of the distance from the SFGW groundwater pumping to the San Francisco Bay. The freshwater flux out of the aquifer into the San Francisco Bay is quite low, and would not be modified to any great degree by the pumping configurations for the SFGW Project. Therefore, the model results indicate that there is not a substantial change in the potential for seawater intrusion along the San Francisco Bay as a result of the SFGW Project.

### 9.4. Cumulative Scenario

The cumulative scenario (4) assumes the operations of the GSR and SFGW Projects at the same time. The cumulative scenarios also include other reasonably foreseeable future projects, such as the Daly City Vista Grande Drainage Basin Improvements Project and Holy Cross cemetery future build-out.

The Daly City Vista Grande Drainage Basin Improvements Project involves diverting stormwater from the Vista Grande Canal into Lake Merced with baseflow to Lake Merced being maintained via a wetland. The addition of water to Lake Merced to maintain lake levels would have the net effect of recharging the groundwater system locally.

Because the GSR Project pumping is concentrated in the South Westside Basin, the results of cumulative Scenario 4 are very similar to those of Scenario 3b.

Similar to both the GSR and SFGW Projects, the changes to groundwater pumping under the Cumulative Scenario do not show a substantial effect on seawater intrusion along the San Francisco Bay Coast compared to what may occur under Scenario 1 conditions. The freshwater flux out of the aquifer into the San Francisco Bay is quite low, and is not modified to any great degree by the pumping configurations simulated in the MODFLOW model.

These results indicate that there is the potential for the landward migration of the seawater-freshwater interface along the Pacific Coast as a result of increased groundwater pumping from the SFGW Project under the cumulative scenario. In addition,, the results of the Cumulative Scenario generally do not indicate an increased risk of seawater intrusion along the San Francisco Bay Coast.

### 9.5. Analytical Evaluation Along the Pacific Coast

The exclusion head analysis was performed to evaluate the potential for the landward migration of the seawater-freshwater interface under the Westside Basin Groundwater-Flow Model Results for Scenarios 3a, 3b, and 4. The results suggest that the lowering of groundwater head along the coast would increase the potential for the landward migration of the seawater-freshwater interface along several portions of the Pacific Coast. However, the rate analysis suggests that any seawater intrusion would occur at rates on the order of feet per year. It should be noted that the analytical method employed assumes a horizontal aquifer base, and that the actual intrusion into the sloped aquifers of the North Westside Basin would be slightly smaller than shown by the method.

The potential rate of seawater intrusion was estimated for the North Westside Basin using analytical equations. These results indicate that the rate of possible seawater intrusion would be on the order of 4 feet after 1 year, about 20 feet after 10 years, and about 60 feet after 50 years under implementation of the SFGW Project, a very slow rate of intrusion. Therefore, careful groundwater monitoring would be able to indicate the potential for seawater intrusion to occur with sufficient time to take proper actions to correct the situation.

Therefore, seawater intrusion along the Pacific Coast would occur slowly and would be recognizable in the Coastal Groundwater Monitoring Network before it could affect the beneficial use of pumping wells in the North Westside Basin. Historical data have shown that chloride levels along the Pacific Coast have remained low, even when there have been periods of relatively substantial groundwater pumping in the North Westside Basin in the past (5.5 mgd from 1930 to 1935; note that this rate is higher than the 3.0 to 4.0 mgd of municipal pumping proposed for the SFGW Project). This confirms that, although the potential for seawater intrusion exists, there may be other geologic factors that are limiting both the occurrence and rate of seawater intrusion along the Pacific Coast.

## References

Abarca, E., J. Carrera, X. Sánchez-Vila, and C. Voss, 2007, Quasi-horizontal circulation cells in 3D seawater intrusion, *Journal of Hydrology*, 339, p.118-129.

AGS, Inc., 1994, *San Francisco Groundwater Master Plan Technical Memorandum TM-18: Westside Basin Field Investigation, Volume 1*, AGS, Inc., 33p.

Badon-Ghyben, W., 1888, Nota in verband met de voorgenomen putboring nabij Amsterdam (Notes on the probable results of well drilling near Amsterdam), *Tijdschrift vay het Koninklijk Instituut van Ingenieurs*, The Hague, Netherlands, 1888/9, p.8-22.

Baylosis, J.I., B.E. Cole, and J.E. Cloern, 1998, Studies of the San Francisco Bay, California, Estuarine Ecosystem, Regional Monitoring Program Results, 1997, *U.S. Geological Survey Open-File Report 98-168*, U.S. Geological Survey, Menlo Park, CA, 215p.

Bear, J., 1972, *Dynamics of Fluids in Porous Media*, Dover Publications, Inc., New York, NY, 764p.

Bear, J., 1999, Conceptual and mathematical modeling, in: *Seawater Intrusion in Coastal Aquifers – Concepts, Methods, and Practices*, J. Bear, A.H.-D. Cheng, S. Sorek, D. Ouazar, and I. Herrera, eds., Kluwer Academic Publishers, Boston, MA, p.127-161.

Bear, J. and A.H.-D. Cheng, 1999, Introduction, in: *Seawater Intrusion in Coastal Aquifers – Concepts, Methods, and Practices*, J. Bear, A.H.-D. Cheng, S. Sorek, D. Ouazar, and I. Herrera, eds., Kluwer Academic Publishers, Boston, MA, p.1-8.

Bouwer, H., 1978, *Groundwater Hydrology*, McGraw Hill, New York, NY, 480p.

Bruns, T.R., A.K. Cooper, P.R. Carlson, and D.S. McCulloch, 2002, Structure of the submerged San Andreas and San Gregorio Fault Zones in the Gulf of the Farallones, as inferred from high-resolution seismic-reflection data, in: T. Parsons, ed., Crustal structure of the coastal and marine San Francisco Bay Region, California, *U.S. Geological Survey Professional Paper 1658*, U.S. Geological Survey, Denver, CO, p.77-117.

California Department of Water Resources (DWR), 1958, Sea-water intrusion in California, *Bulletin No. 63*, DWR, Sacramento, CA, 123p.

California Department of Water Resources (DWR), 1975, Sea-water intrusion in California: Inventory of coastal ground water basins, *Bulletin No. 63-5*, DWR, Sacramento, CA, 408p.

California Department of Water Resources (DWR), 2003, California's groundwater, *Bulletin No. 118*, DWR, Sacramento, CA, 265p.

California Water Service Company (Cal Water), 2006, *Urban Water Management Plan, South San Francisco District*, 76p.

CH2M HILL, 1995, *San Francisco Groundwater Master Plan Technical Memorandum TM-14: Saltwater Intrusion Model*, CH2M HILL, 27p.

Cheng, A.H.-D. and D. Ouazar, 1999, Analytical Solutions, in: *Seawater Intrusion in Coastal Aquifers – Concepts, Methods, and Practices*, J. Bear, A.H.-D. Cheng, S. Sorek, D. Ouazar, and I. Herrera, eds., Kluwer Academic Publishers, Boston, MA, p.163-191.

Clark, I.D. and P. Fritz, 1997, *Environmental Isotopes in Hydrogeology*, Lewis Publishers, New York, NY, 328p.

Clifton, H.E. and R.E. Hunter, 1987, The Merced Formation and related beds: A mile-thick succession of late Cenozoic coastal and shelf deposits in the seacliffs of San Francisco, California, in: M.L. Hill, ed., Cordilleran Section of the Geological Society of America Centennial Field Guide Volume 1, Geological Society of America, Boulder, CO, p.257-262.

Environmental Science Associates, Inc. (ESA), 1994, *Oceanside WPCP Construction Project Environmental Compliance Summary Report*, prepared for Department of Public Works, City and County of San Francisco, November, 1994.

Freeze, R.A. and J.A. Cherry, 1979, *Groundwater*, Prentice-Hall, Englewood Cliffs, NJ, 604p.

Gilman, J., 2010, *Restoring Groundwater's Place in San Francisco's Water Supply*, Presented at the Groundwater Resources Association of California 2010 Annual Meeting, September 15-16, 2010, Burlingame, CA.

Gilman, J., personal communication, April 22, 2012, phone conversation regarding the most recent, unpublished water quality monitoring data.

Herzberg, A., 1901, Die Wasserversorgung einiger Nordseebder (The water supply of parts of the North Sea coast in Germany), *Zeitschrift fur Gasbeleuchtung und Wasserversorgung*, 44, p.815-819 and 45, p.842-844.

HydroFocus, 2007, *Westside Basin Groundwater-Flow Model (version 2.0), Historical Calibration Run (1959-2005) Results and Sensitivity Analysis*, 76p.

HydroFocus, 2009, *Westside Basin Groundwater-Flow Model: Revised Historical Simulation and No-Project Simulation Results*, 145p.

HydroFocus, 2011, *Westside Basin Groundwater-Flow Model: Updated Model and 2008 No Project Simulation Results*, 143p.

Hydrometrics, LLC, 2009, *Groundwater Levels to Protect against Seawater Intrusion and Store Freshwater Offshore*, prepared for Soquel Creek Water District, Hydrometrics, Oakland, CA, 52p.

Izbicki, J.A., 1996, Seawater intrusion in a coastal California aquifer, *U.S. Geological Survey Fact Sheet 125-96*, U.S. Geological Survey, San Diego, CA, 4p.

Jones, B.F., A. Vengosh, E. Rosenthal, and Y. Yechieli, 1999, Geochemical investigations, in: *Seawater Intrusion in Coastal Aquifers – Concepts, Methods, and Practices*, J. Bear, A.H.-D. Cheng, S. Sorek, D. Ouazar, and I. Herrera, eds., Kluwer Academic Publishers, Boston, MA, p.51-71.

Kennedy/Jenks Consultants, 2004, Hydrostratigraphic Analysis of the Northern Salinas Valley, prepared for Monterey County Water Resources Agency, Kennedy/Jenks, San Francisco, CA, 112p.

Kennedy/Jenks Consultants, 2012, *Task 10.1 Technical Memorandum: Groundwater Modeling Analysis for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project*, Kennedy/Jenks, San Francisco, CA, 320p.

Krauskopf, K.B. and D.K. Bird, 1995, *Introduction to Geochemistry, Third Edition*, McGraw-Hill, Boston, MA, 647p.

Luhdorff & Scalmanini, Consulting Engineers (LSCE), 2002, *Conceptualization of the Lake-Aquifer System, Westside Ground-Water Basin, San Francisco and San Mateo Counties*, 100p.

Luhdorff & Scalmanini, Consulting Engineers (LSCE), 2005, *Groundwater Exploration and Aquifer Testing, South Sunset Area, North Westside Groundwater Basin*, 38p.

Luhdorff and Scalmanini, Consulting Engineers (LSCE), 2006, *Hydrogeologic Conditions in the Westside Basin: 2005*, 147p.

Luhdorff & Scalmanini, Consulting Engineers (LSCE), 2010, *Task 8B Technical Memorandum No. 1: Hydrologic Setting of the Westside Basin*, 40p.

Mantoglou, A., 2003, Pumping management of coastal aquifers using analytical models of saltwater intrusion, *Water Resources Research*, 39(12), 1335, 12p.

Mulligan, A.E., R.L. Evans, and D. Lizarralde, 2007, The role of paleochannels in groundwater/seawater exchange, *Journal of Hydrology*, 335, p.313-329.

MWH, 2008, *San Francisco Public Utilities Commission Water System Improvement Program, Groundwater Conjunctive Use Project, WSIP Project CUW30103, Conceptual Engineering Report*, 299p.

Phillips, S.P., S.N. Hamlin, and E.B. Yates, 1993, Geohydrology, water quality, and estimation of ground-water recharge in San Francisco, California, 1987-92, *U.S. Geological Survey Water-Resources Investigations Report 93-4019*, U.S. Geological Survey, Sacramento, CA, 73p.

Rogge, E.H., 2003, *Dimensions of the Westside Groundwater Basin, San Francisco and San Mateo Counties, California*, Master's Thesis, San Francisco State University, 200p.

San Bruno, 2007, *City of San Bruno Urban Water Management Plan*, 321p.

San Francisco Public Utilities Commission (SFPUC), 2005, North Westside Groundwater Basin Management Plan, Final Draft, City and County of San Francisco, San Francisco Public Utilities Commission, San Francisco, CA, 52p.

San Francisco Public Utilities Commission (SFPUC), 2006, Conceptual Engineering Report, Groundwater Sub-Project B [SFGW Project], North Westside Basin Local Supply, San Francisco Public Utilities Commission, San Francisco, CA, 155p.

San Francisco Public Utilities Commission (SFPUC), 2007, *2006 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California*, SFPUC, San Francisco, CA 210p.

San Francisco Public Utilities Commission (SFPUC), 2008a, *2007 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California*, SFPUC, San Francisco, CA 304p.

San Francisco Public Utilities Commission (SFPUC), 2008b, *Final Program Environmental Impact Report for the SFPUC Water System Improvement Program*, SFPUC, San Francisco, CA, 8 volumes.

San Francisco Public Utilities Commission (SFPUC), 2009a, *Calaveras Dam Replacement Project Draft Environmental Impact Report, Appendix D.2: SFPUC Memorandum Detailing Revised 2018 HHLSM Model Run Performed for the Calaveras Dam Replacement Project*, SFPUC, San Francisco, CA, 38p.

San Francisco Public Utilities Commission (SFPUC), 2009b, *2008 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California*, SFPUC, San Francisco, CA, 285p.

San Francisco Public Utilities Commission (SFPUC), 2009c, *Conceptual Engineering Report Groundwater Sub-Project B North Westside Basin Local Supply,* SFPUC, San Francisco, CA, 155p.

San Francisco Public Utilities Commission (SFPUC), 2010, *2009 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California*, SFPUC, San Francisco, CA, 279p.

San Francisco Public Utilities Commission (SFPUC), 2011, *2010 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California*, SFPUC, San Francisco, CA, 230p.

Strack, O.D.L., 1976, A single-potential solution for regional interface problems in coastal aquifers, *Water Resources Research*, 12(6), p.1,165-1,174.

Todd Engineers (Todd), 2004, *Conceptual Hydrogeologic Model in Support of Honolulu Perennial Yield Study Development of a Groundwater Management Model*, prepared for Honolulu Board of Water Supply, Todd, Emeryville, CA, 49p.

U.S. Environmental Protection Agency (EPA), 2009, National primary drinking water regulations, *U.S. EPA Fact Sheet 816-F-09-004*, EPA, Washington, DC, 6p.

van Dam, J.C., 1999, Exploitation, restoration and management, in: *Seawater Intrusion in Coastal Aquifers – Concepts, Methods, and Practices*, J. Bear, A.H.-D. Cheng, S. Sorek, D. Ouazar, and I. Herrera, eds., Kluwer Academic Publishers, Boston, MA, p.73-125.

Vengosh, A. and A.J. Spivack, 2000, $\delta^{11}B$, rare earth elements, $\delta^{37}Cl$, $^{32}Si$, $^{35}S$, $^{129}I$: Boron isotopes in groundwater, in: *Environmental Tracers in Subsurface Hydrology*, ed. by P. Cook and A.L. Herczeg, Kluwer Academic Publishers, Boston, MA, p.479-485.

Water Resources and Information Management Engineering, Inc. (WRIME), 2007, *San Bruno Groundwater Monitoring Wells: Installation and Monitoring, an AB3030 Project Report*, WRIME, Sacramento, CA, 176p.

Yakirevich, A., A.J. Melloul, S. Sorek, S. Shaath, and V. Borisov, 1998, Simulation of seawater intrusion into Khan Yunis area of the Gaza Strip, *Hydrogeology Journal*, 6(4), p.549-559.

Yates, E.B., S.N. Hamlin, and L.H. McCann, 1990, Geohydrology, water quality, and water budgets of Golden Gate Park and the Lake Merced area in the western part of San Francisco, California, *U.S. Geological Survey Water-Resources Investigations Report 90-4080*, U.S. Geological Survey, Sacramento, CA, 50p.

## Figure List

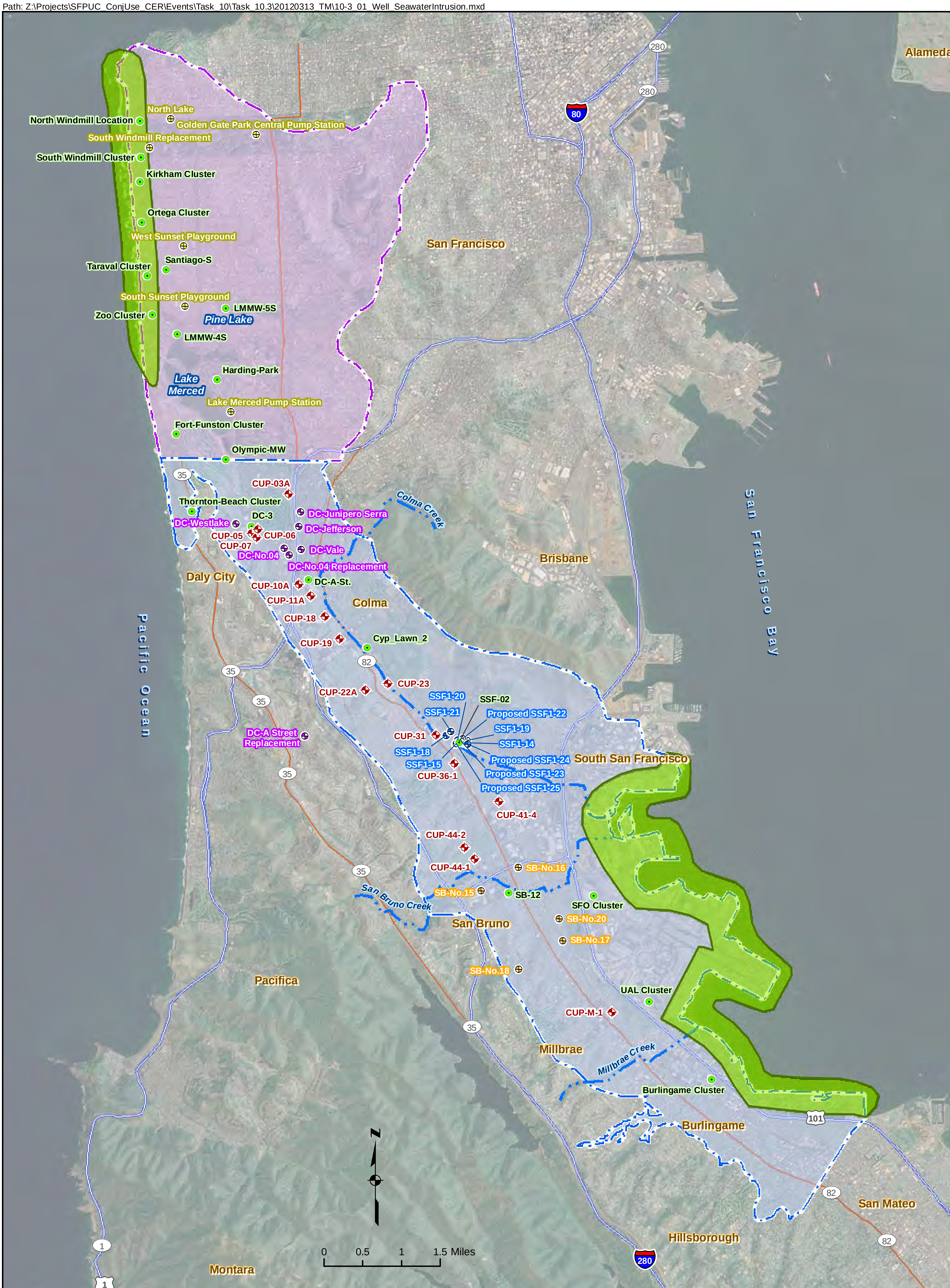
## Table List



## Attachment List

# Figures

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.3\20120313_TM\10-3_01_Well_SeawaterIntrusion.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Note:
The North Windmill Location is a location used by the Westside Basin Groundwater-Flow Model to track the model-simulated groundwater head. It represents a historical well location, but is not the current location of an active monitoring well.

## Legend

- GSR Proposed Municipal Wells
- SFGW Proposed Municipal Wells
- Selected Representative Monitoring Location
- Cal Water Municipal Wells
- Daly City Municipal Wells
- San Bruno Municipal Wells
- North Westside Groundwater Basin
- South Westside Groundwater Basin
- Approximate Areas Susceptible to Seawater Intrusion

CITY AND COUNTY OF SAN FRANCISCO
PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

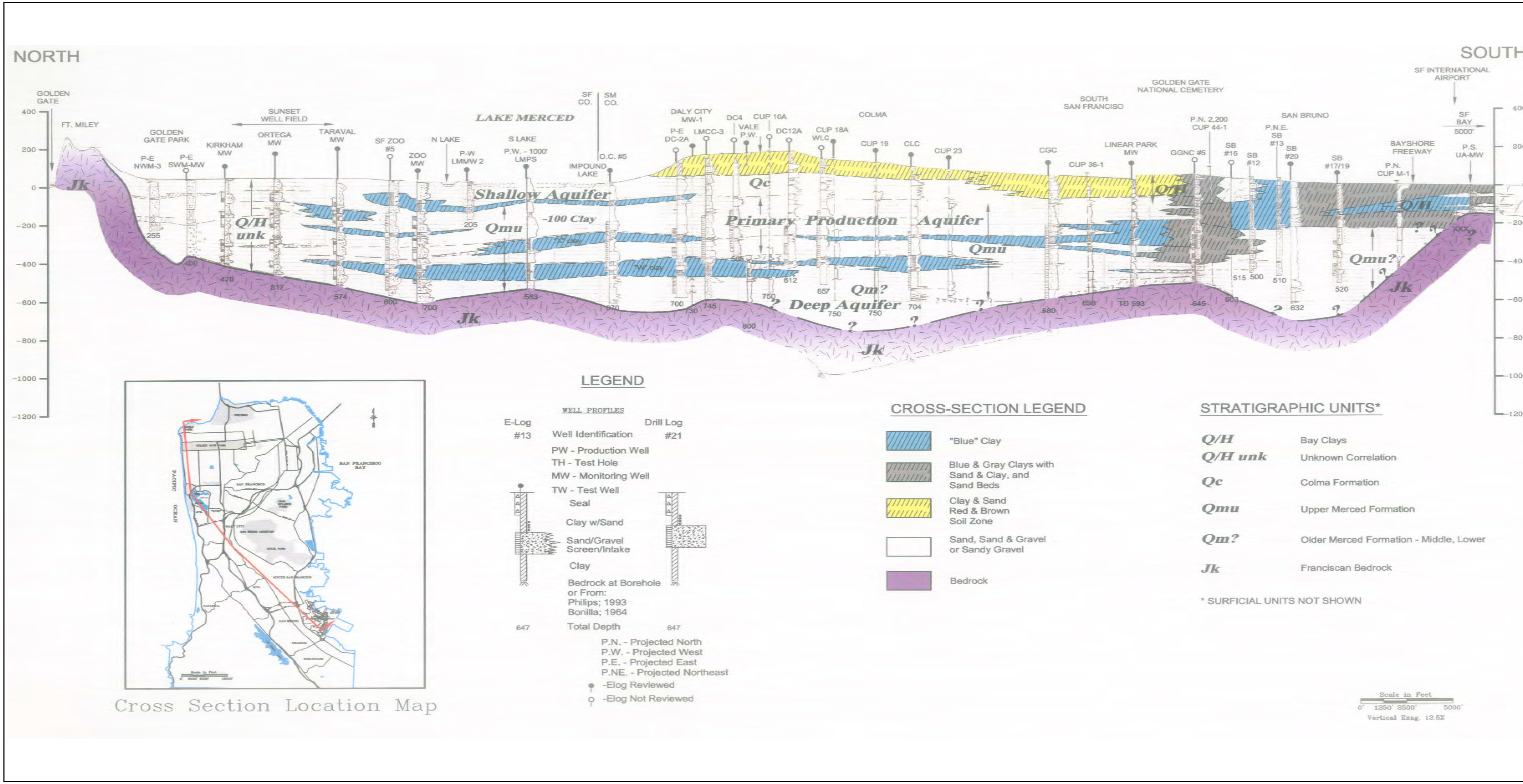
**WELL LOCATIONS AND AREAS POTENTIALLY SUSCEPTIBLE TO SEAWATER INTRUSION**


Kennedy/Jenks Consultants
303 Second Street, Suite 300 South
San Francisco, CA 94107


Figure 10.3-1

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date April 2012




Source: Final Task 8B Technical Memorandum No.1, Hydrologic Setting of the Westside Basin, LSCE, May 2010.

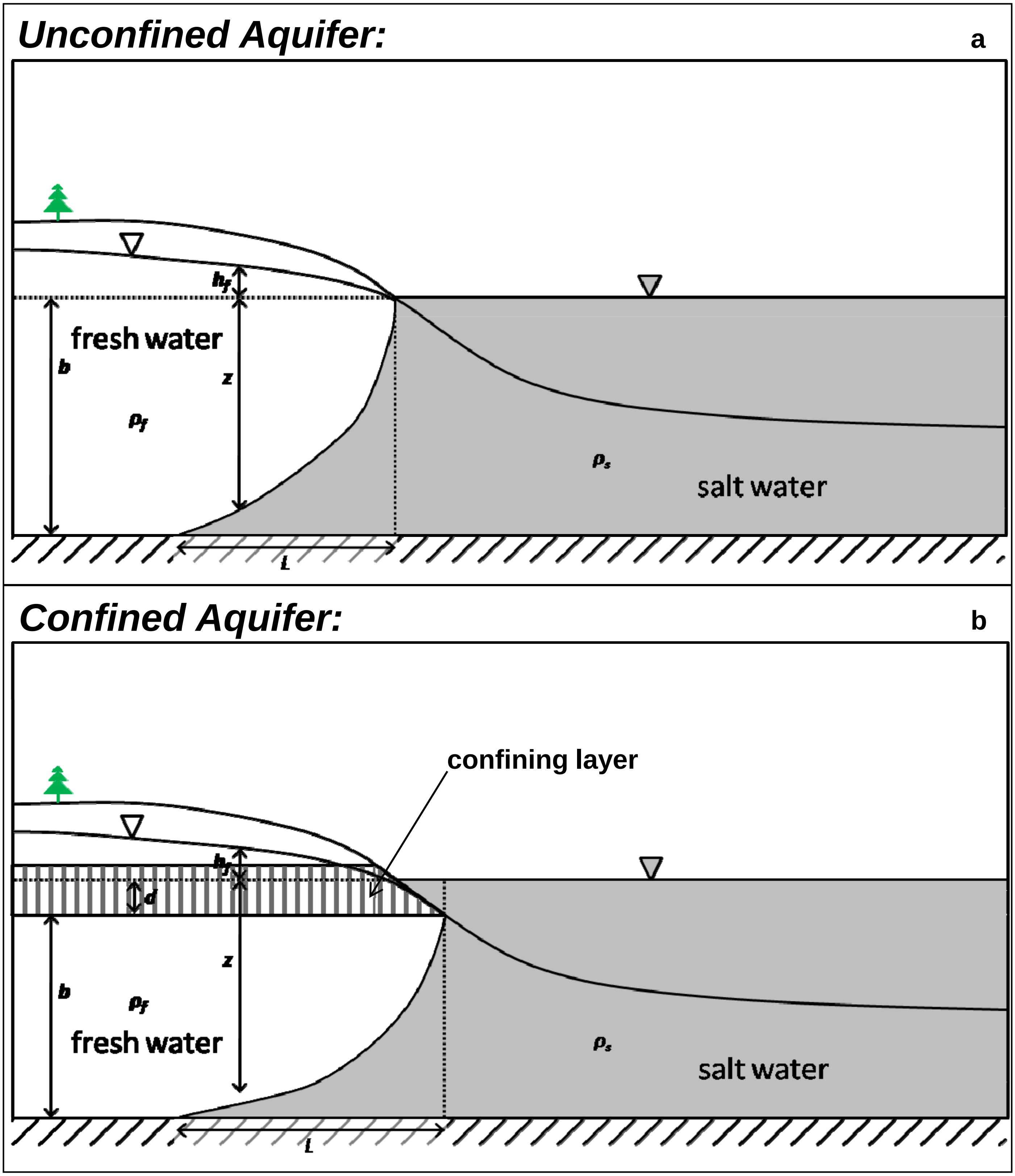
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
And San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Westside Basin Regional Subsurface Hydrogeology**

K/J 0864001
April 2012

**Figure 10.3-2**




**Explanation of Variables:**

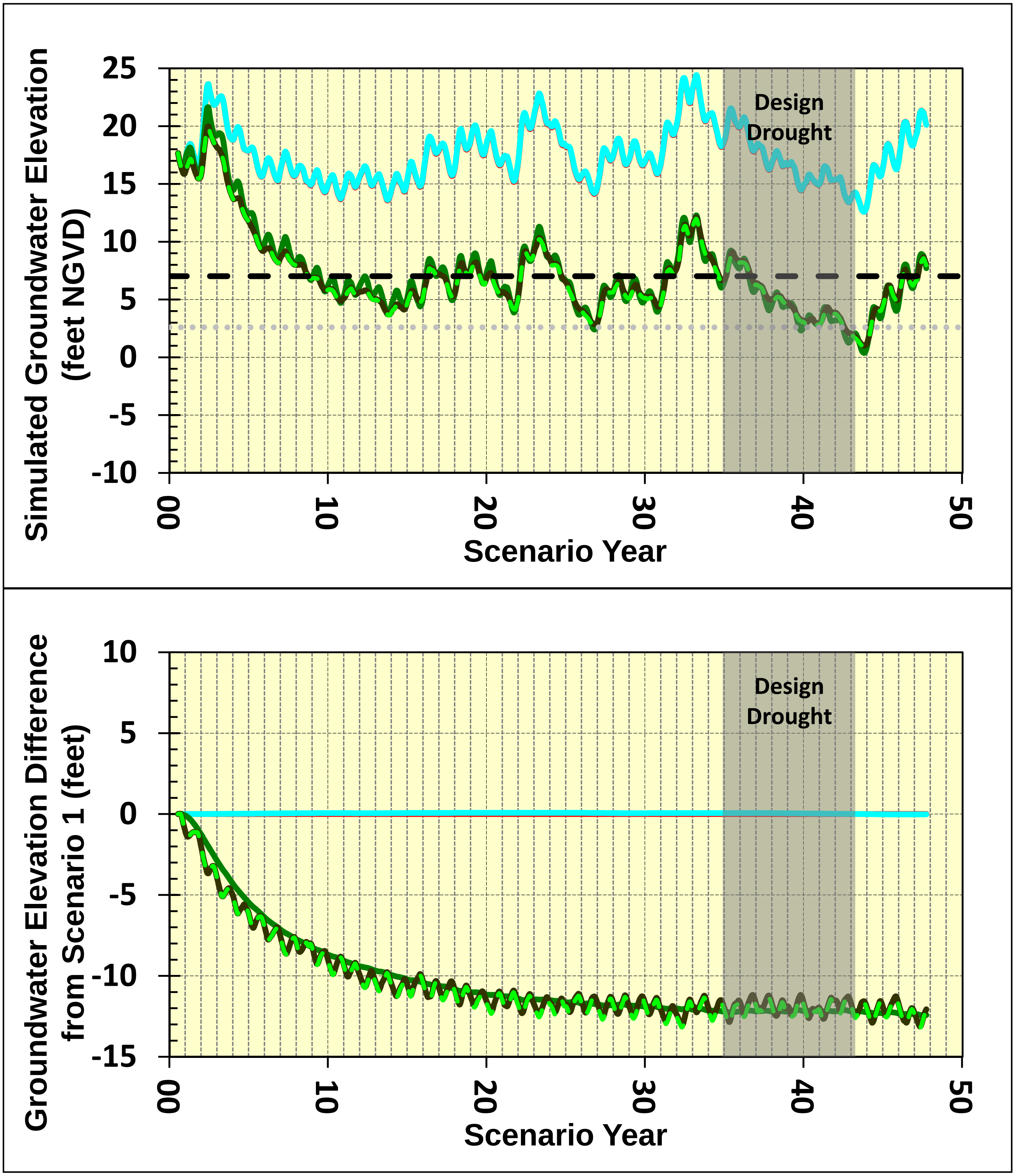
- $\rho_f$ = density of freshwater (mass/volume)
- $\rho_s$ = density of seawater (mass/volume)
- z = depth of freshwater-seawater interface below sea level (length)
- $h_f$ = freshwater head above sea level (length)
- b = depth below sea level to aquifer base (length); unconfined conditions
- b = aquifer thickness (length); confined conditions
- d = depth below sea level of base of confining layer (length)
- L = length of intruding wedge (length)

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Seawater Intrusion Schematics for Unconfined and Confined Aquifers**

K/J 0864001
April 2012
**Figure 10.3-3**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

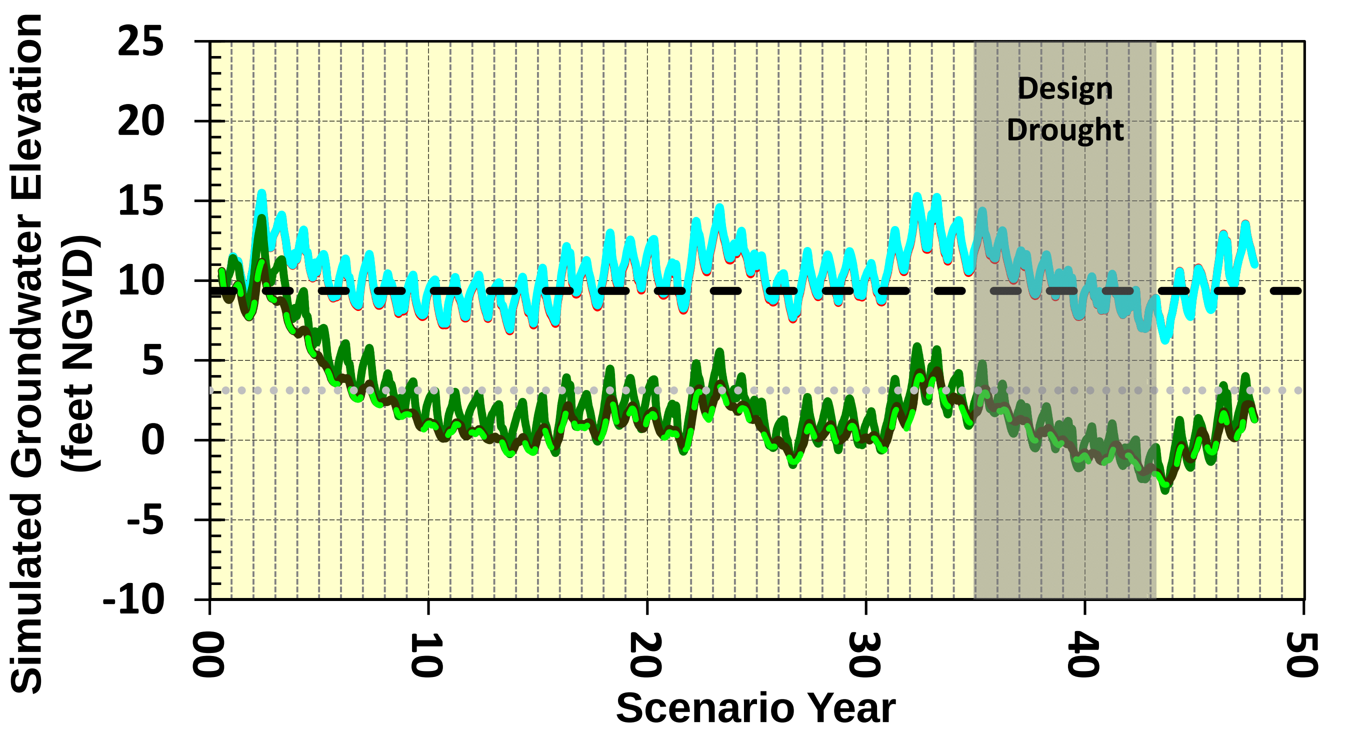
- Single-Aquifer
- Shallow Aquifer

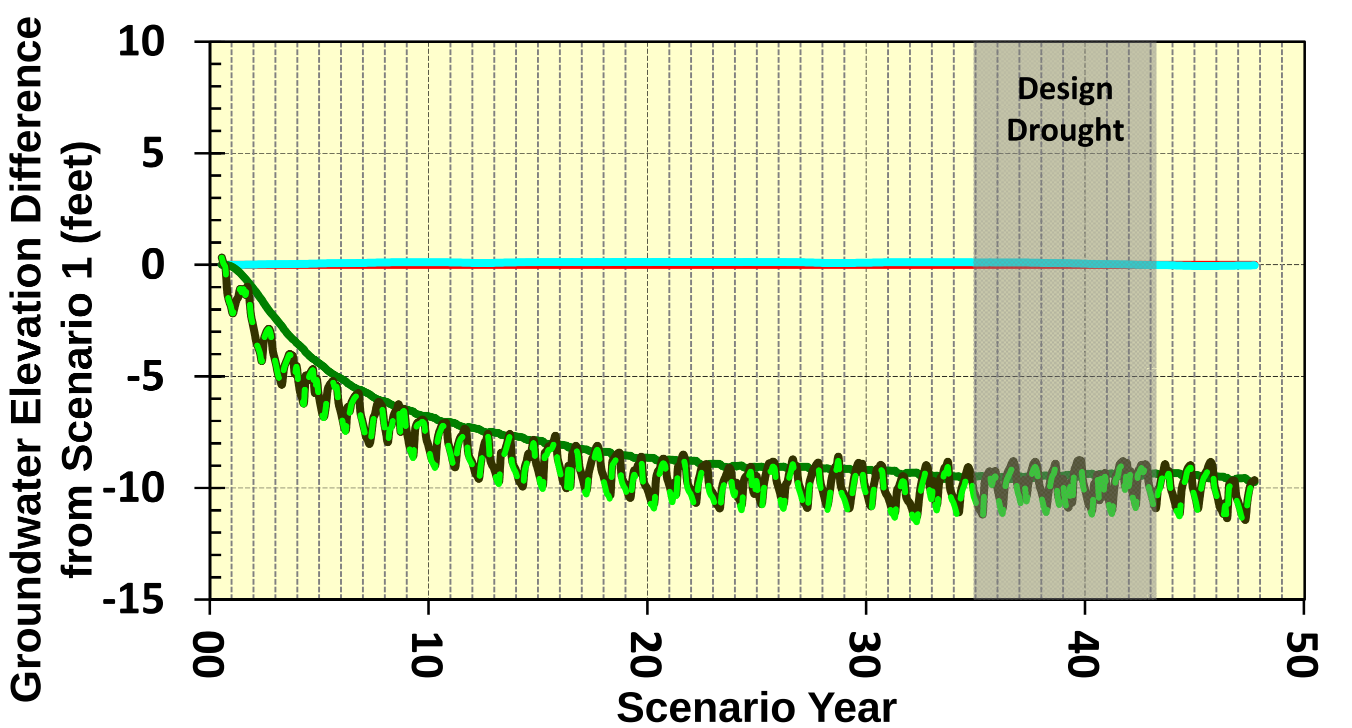
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for North Windmill Location**

K/J 0864001
April 2012
**Figure 10.3-4**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

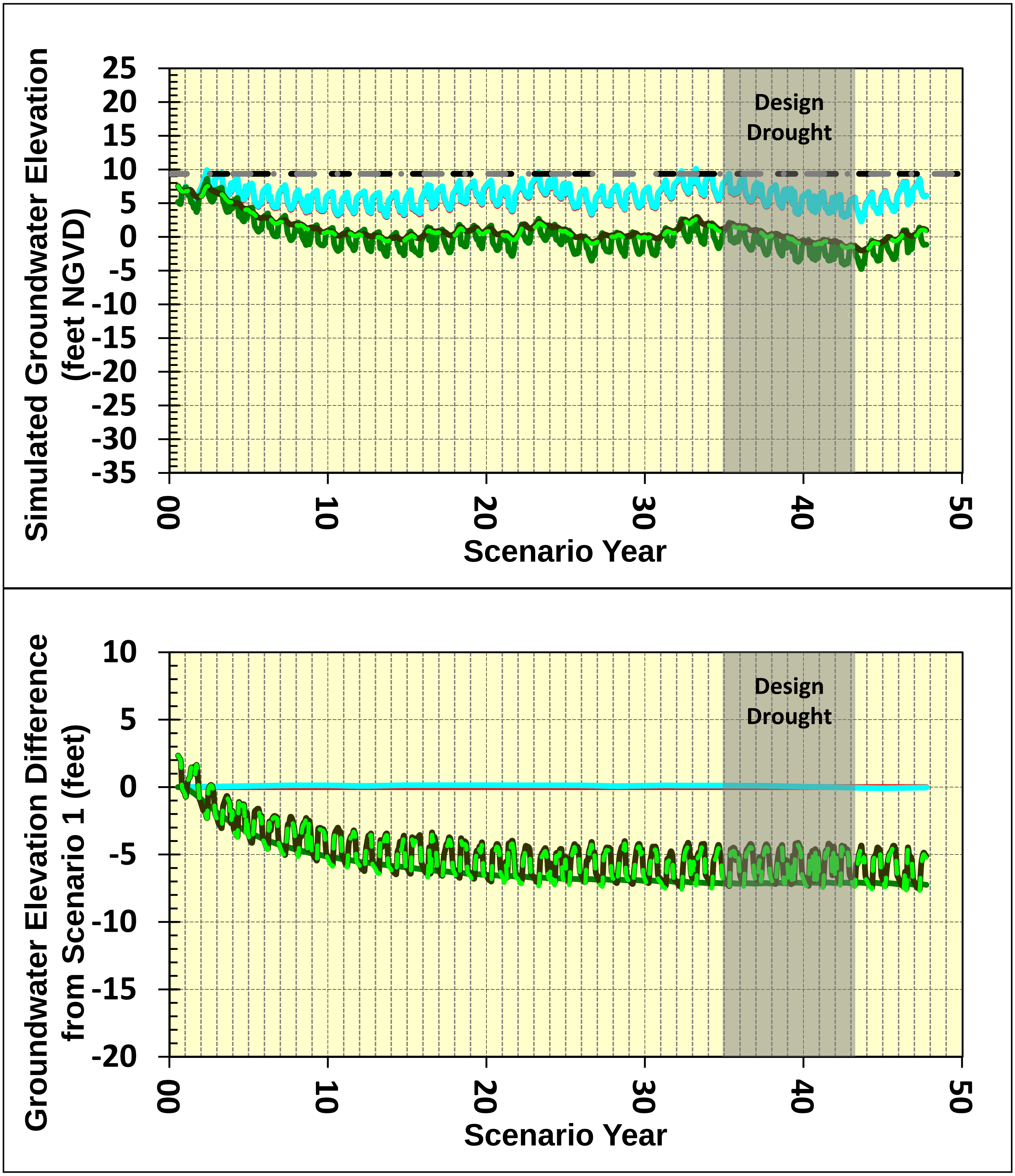
- Single-Aquifer
- Shallow Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for South Windmill Cluster**

K/J 0864001
April 2012
**Figure 10.3-5a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

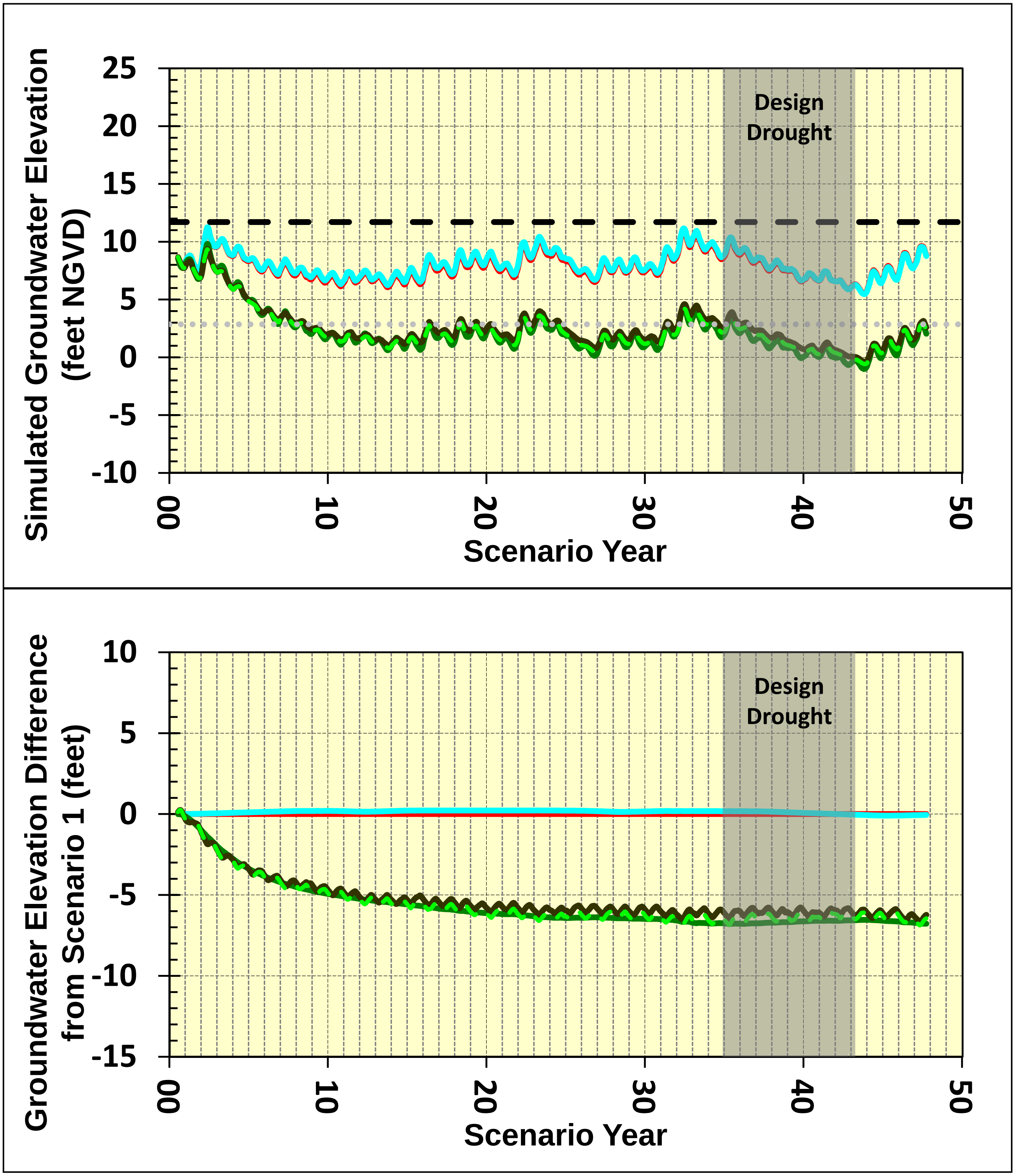
**Exclusion Heads:**
- Single-Aquifer
- Primary Production Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for South Windmill Cluster**

K/J 0864001
April 2012
**Figure 10.3-5b**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

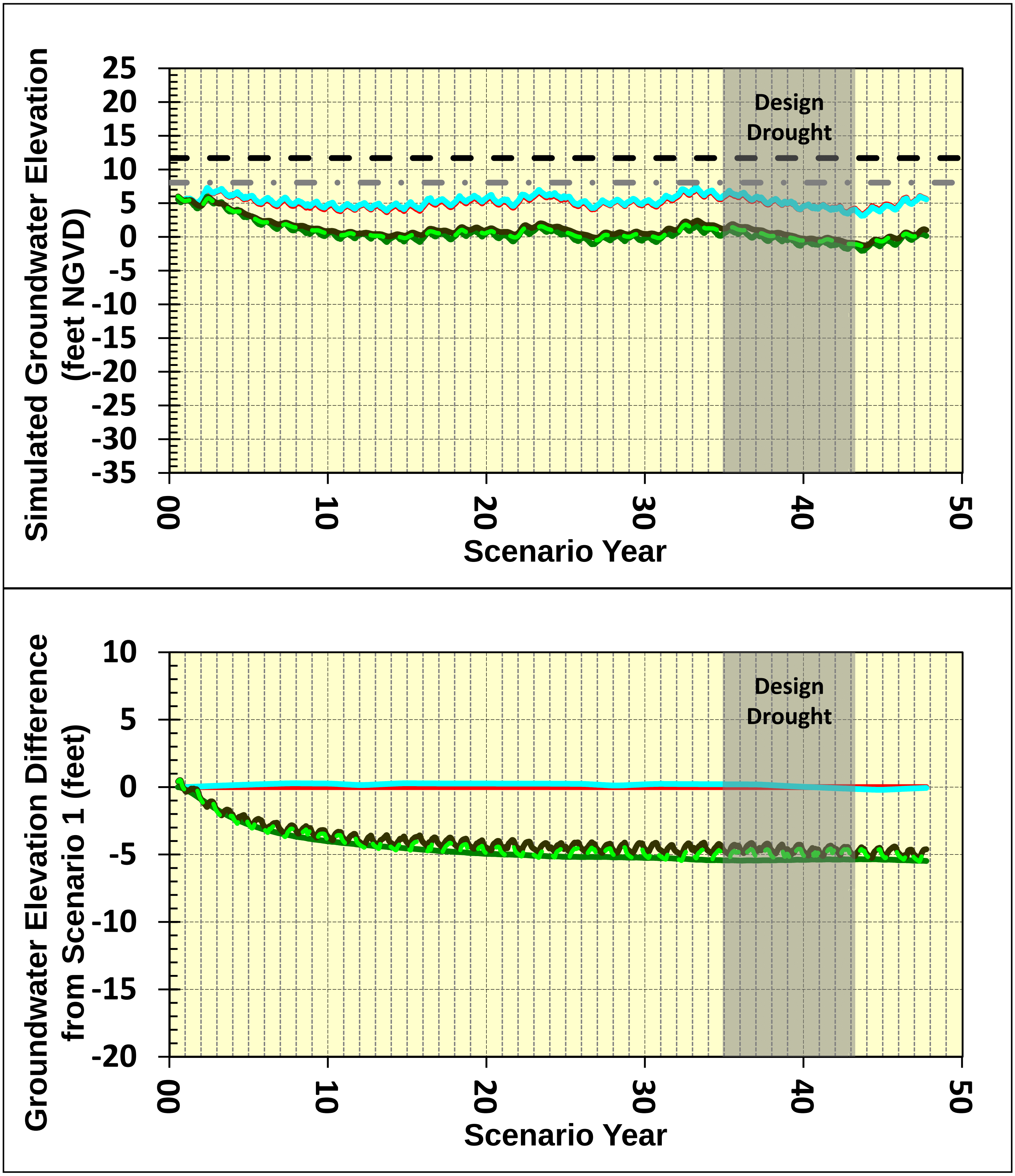
**Exclusion Heads:**
- Single-Aquifer
- Shallow Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for Kirkham Cluster**

K/J 0864001
April 2012
**Figure 10.3-6a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

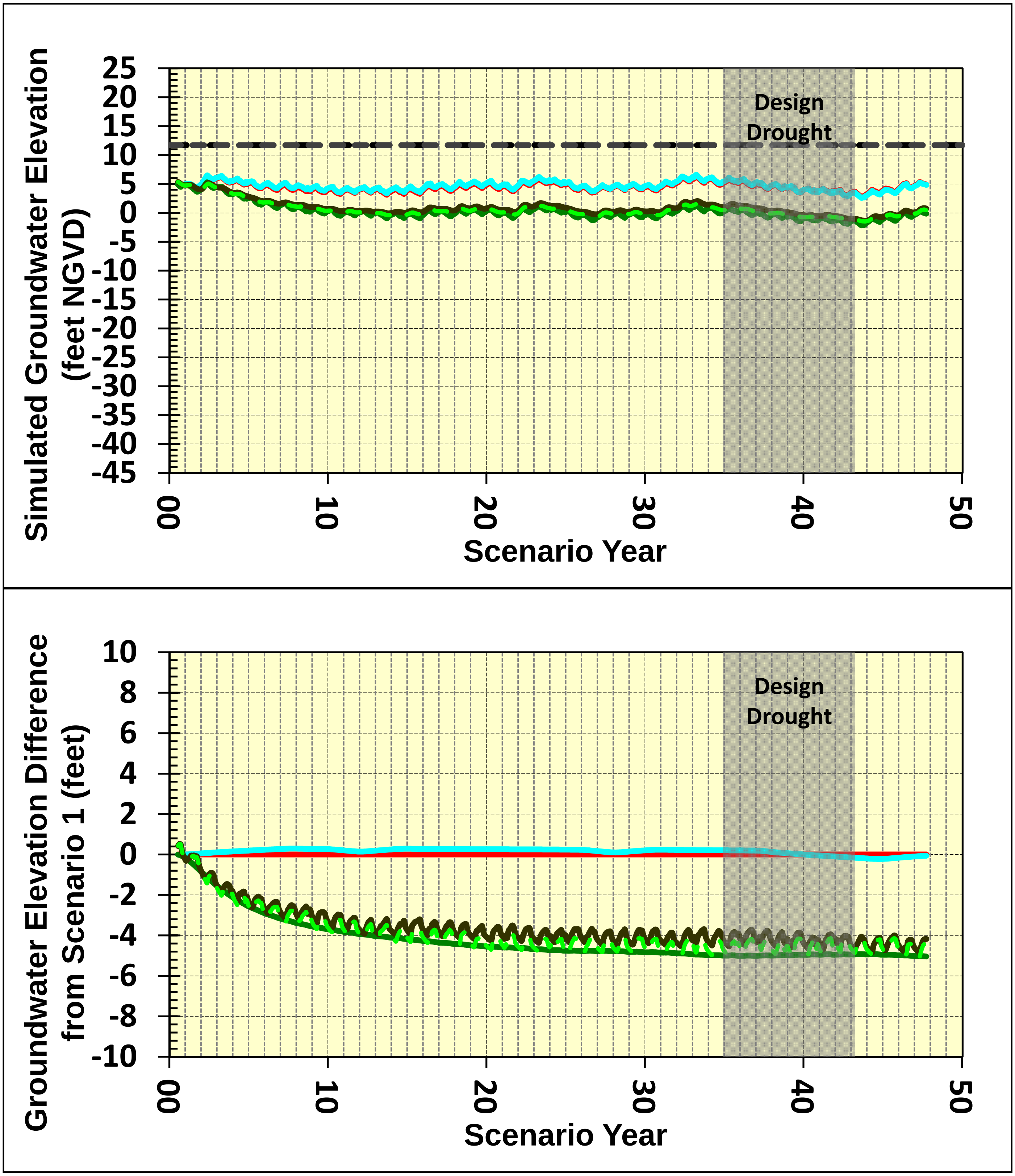
- Single-Aquifer
- Primary Production Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for Kirkham Cluster**

K/J 0864001
April 2012
**Figure 10.3-6b**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

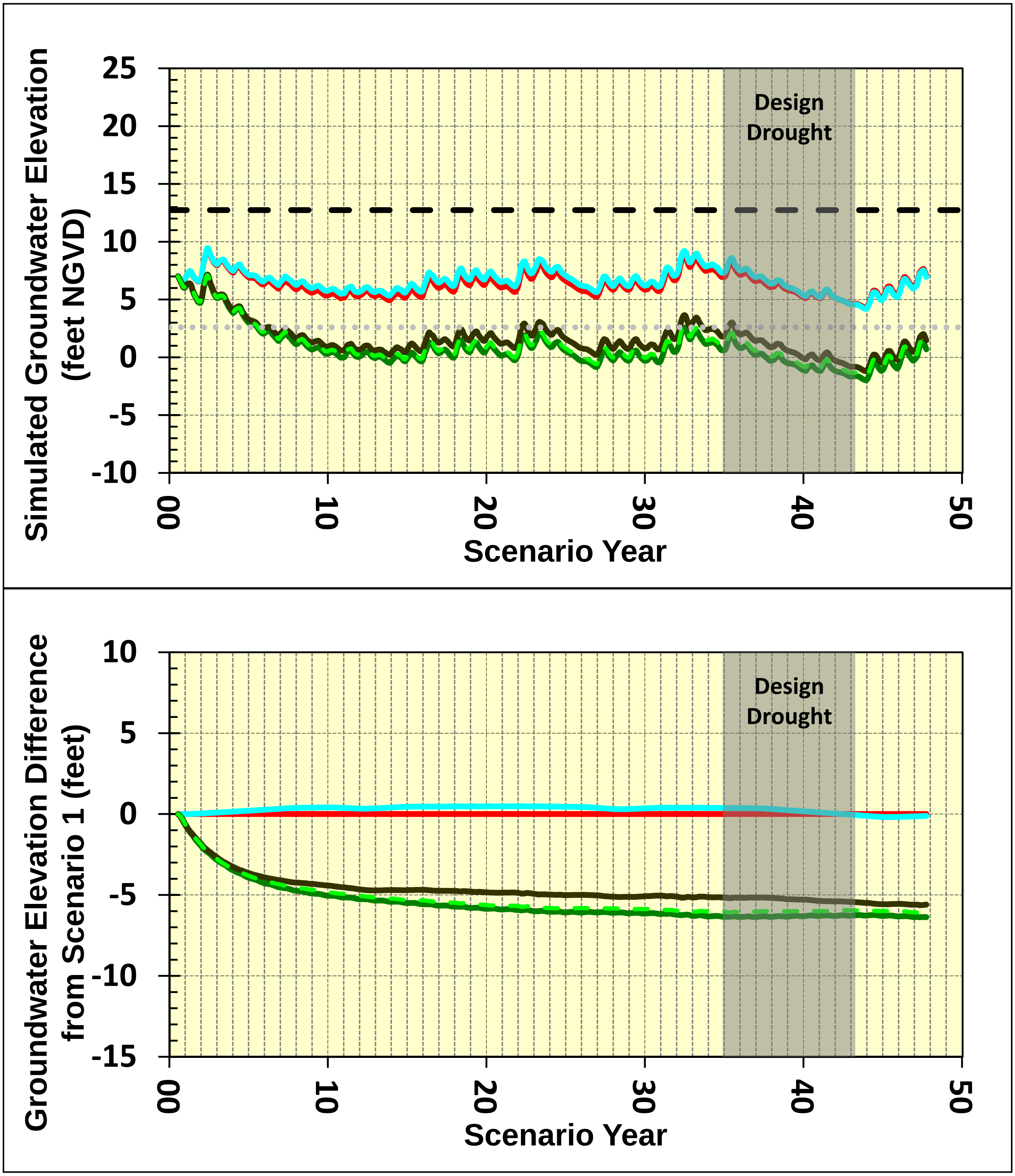
**Model Heads:**
**Scenario 1** **Scenario 2**
**Scenario 3a** **Scenario 3b**
**Scenario 4**
**Exclusion Heads:**
**Single-Aquifer** **Deep Aquifer**

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 5 Hydrographs for Kirkham Cluster**

K/J 0864001
April 2012
**Figure 10.3-6c**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**
- **Scenario 1**
- **Scenario 2**
- **Scenario 3a**
- **Scenario 3b**
- **Scenario 4**

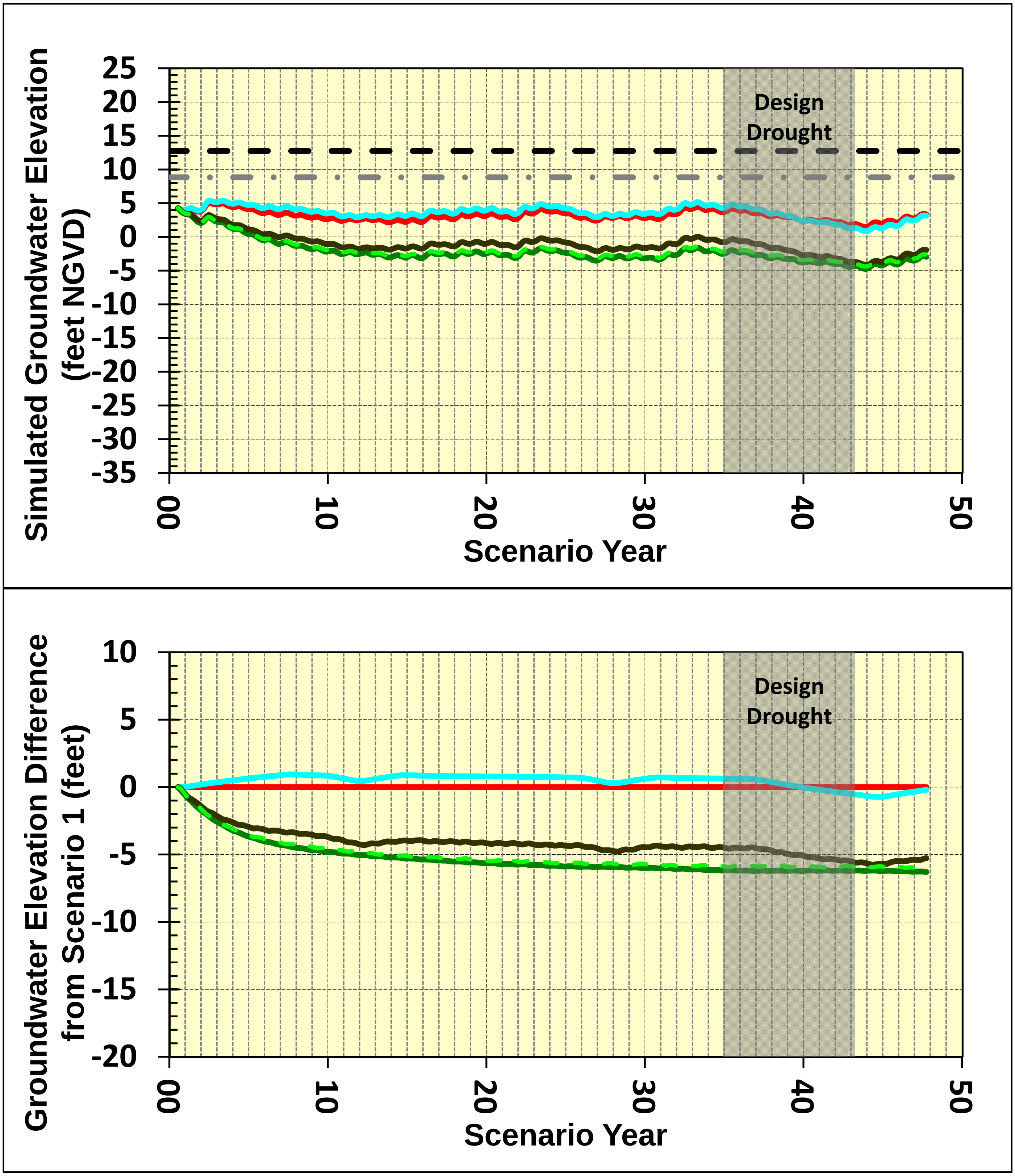
**Exclusion Heads:**
- **Single-Aquifer**
- **Shallow Aquifer**

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for Ortega Cluster**

K/J 0864001
April 2012
**Figure 10.3-7a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

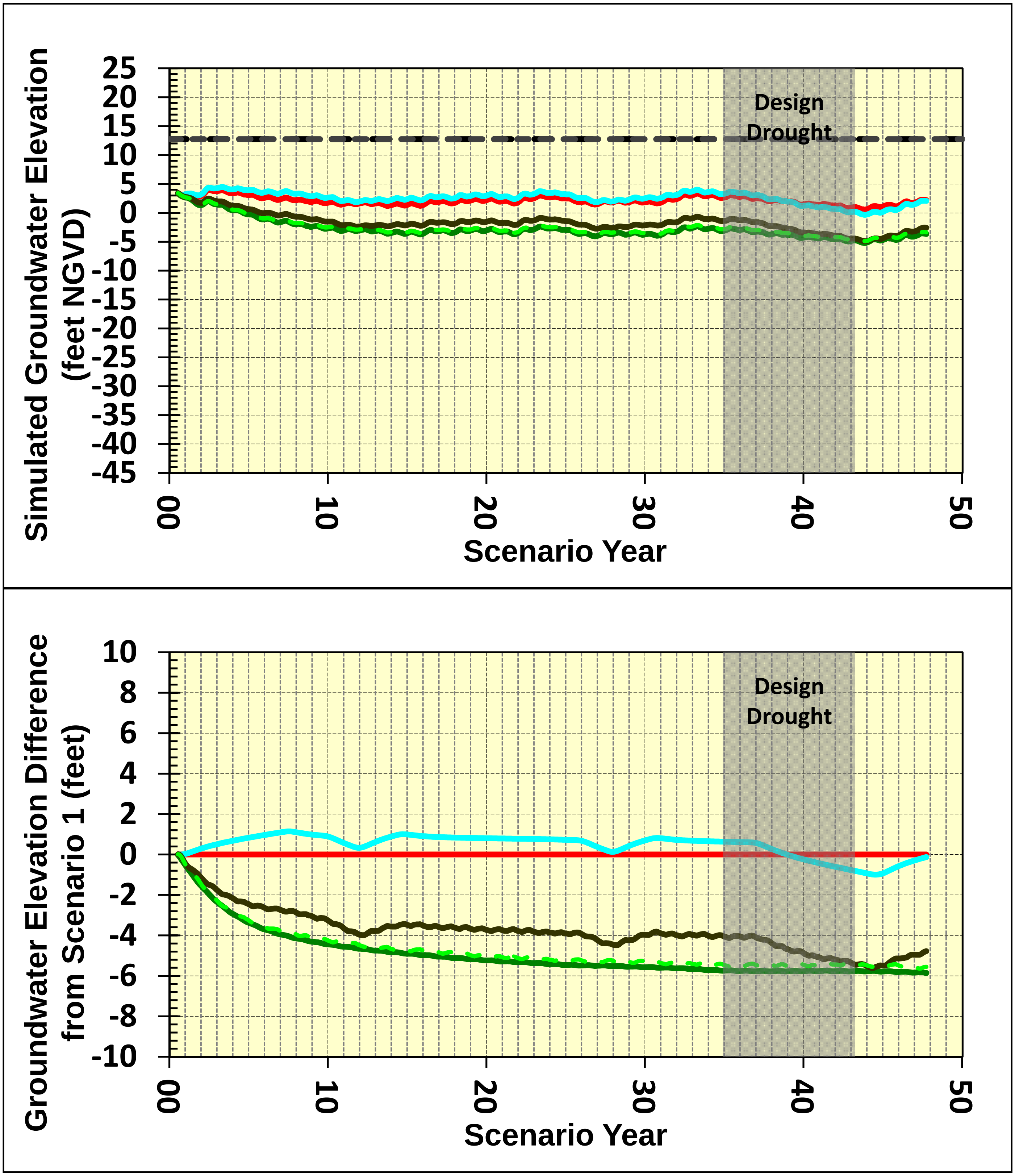
**Exclusion Heads:**
- Single-Aquifer
- Primary Production Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for Ortega Cluster**

K/J 0864001
April 2012
**Figure 10.3-7b**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

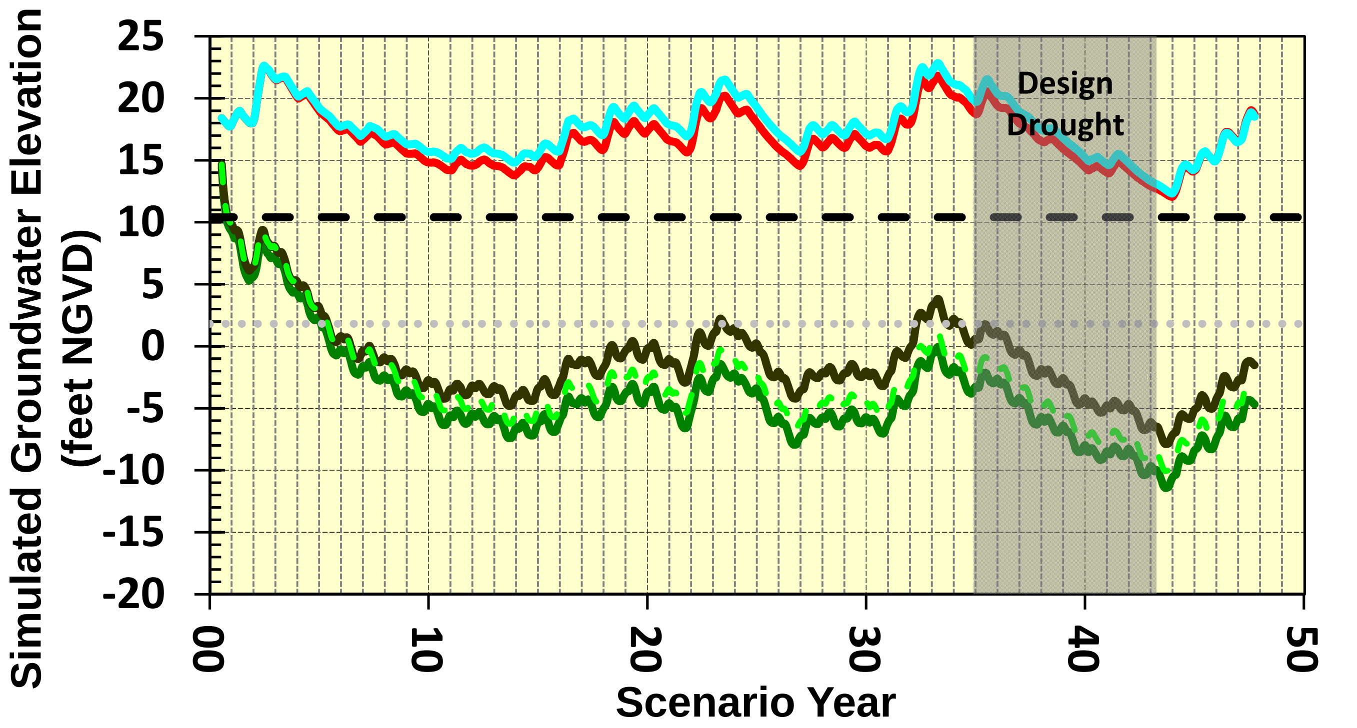
**Exclusion Heads:**
- Single-Aquifer
- Deep Aquifer

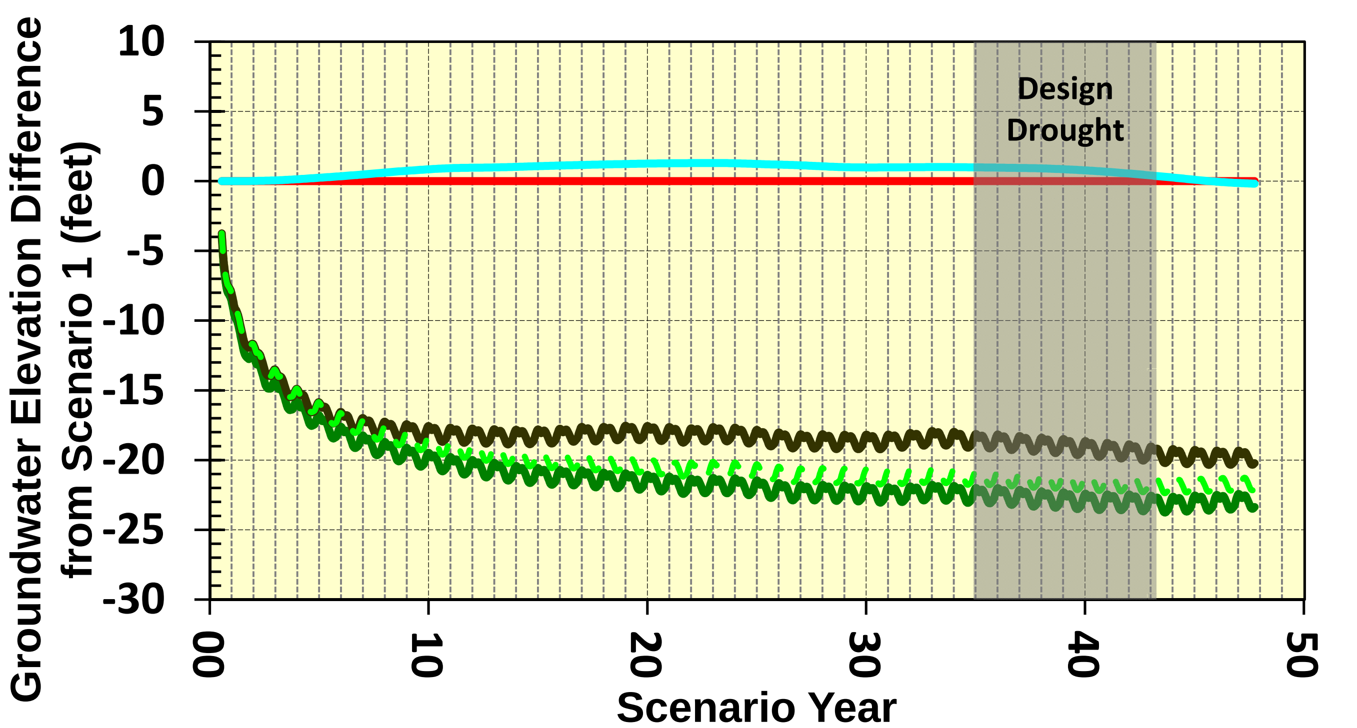
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 5 Hydrographs for Ortega Cluster**

K/J 0864001
April 2012
**Figure 10.3-7c**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

- **Scenario 1**
- **Scenario 2**
- **Scenario 3a**
- **Scenario 3b**
- **Scenario 4**

**Exclusion Heads:**

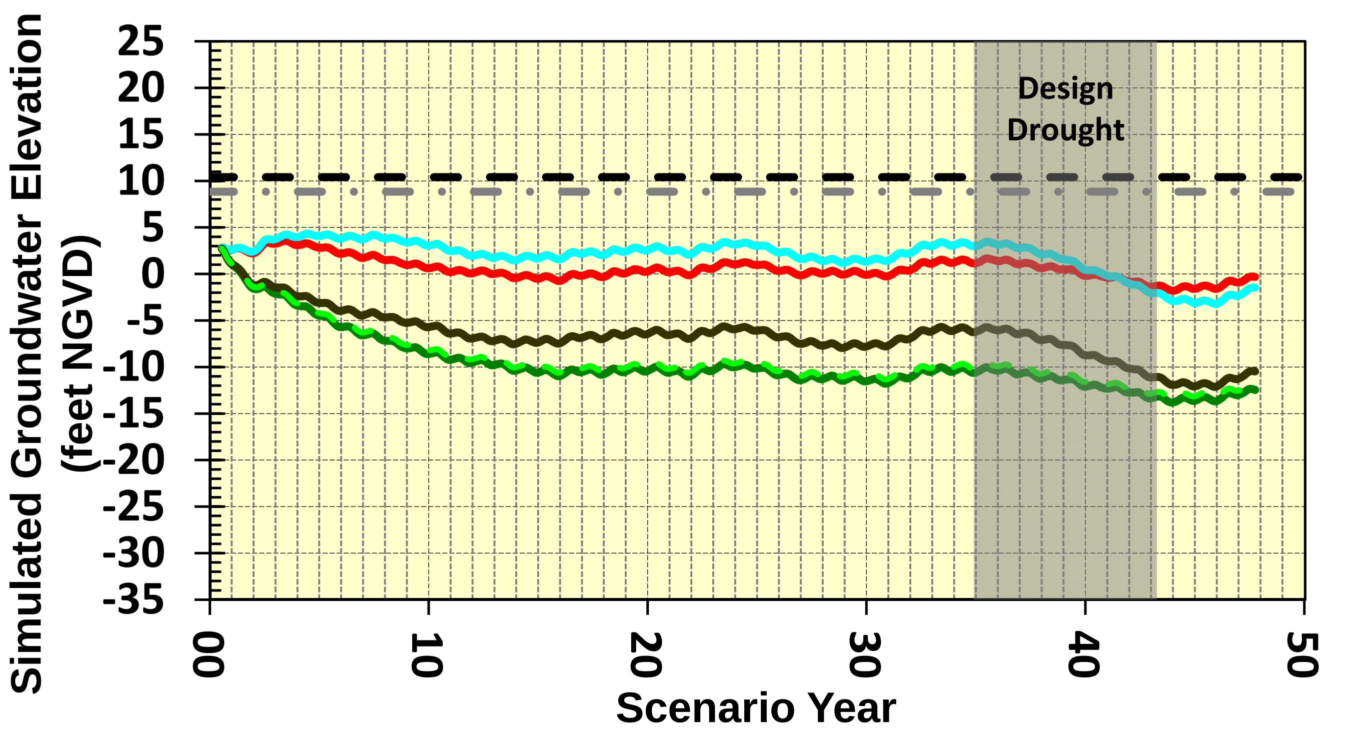
- **Single-Aquifer**
- **Shallow Aquifer**

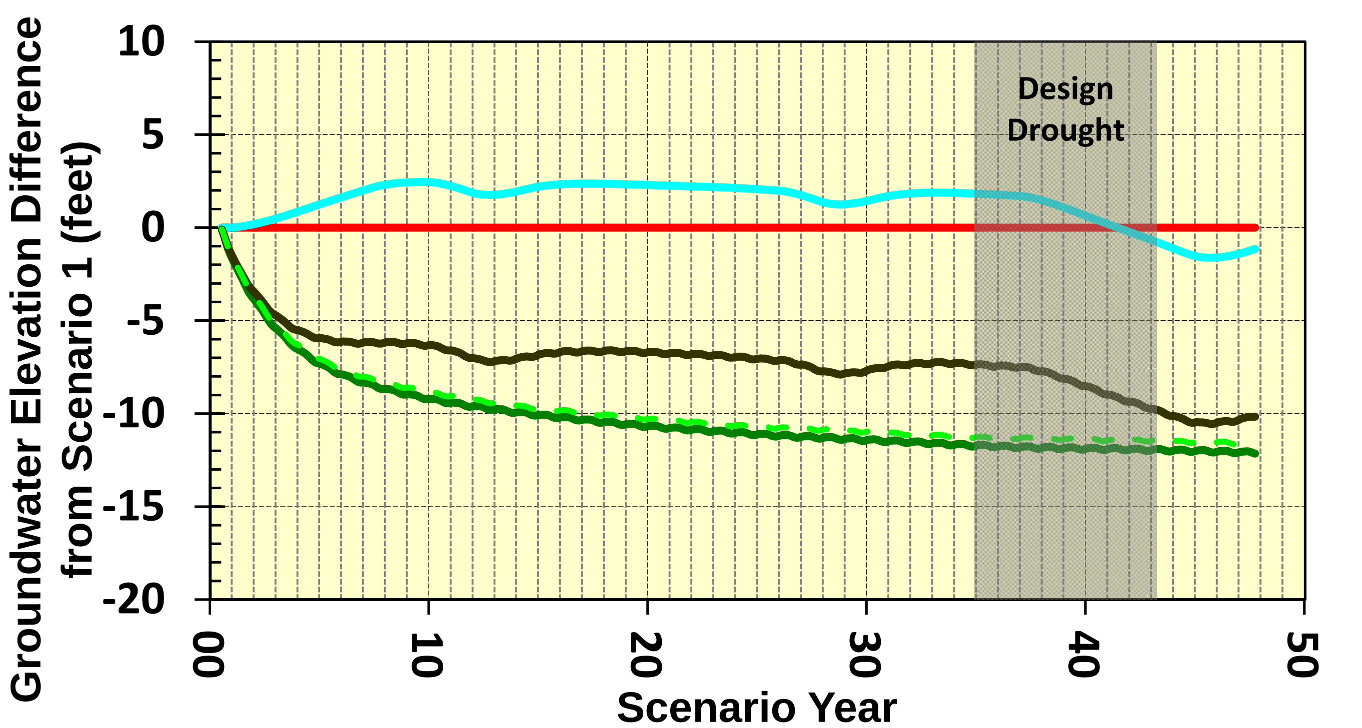
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for West Sunset Playground Well**

K/J 0864001
April 2012
**Figure 10.3-8a**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

**Scenario 1** **Scenario 2**

**Scenario 3a** **Scenario 3b**

**Scenario 4**

**Exclusion Heads:**

**Single-Aquifer** **Primary Production Aquifer**

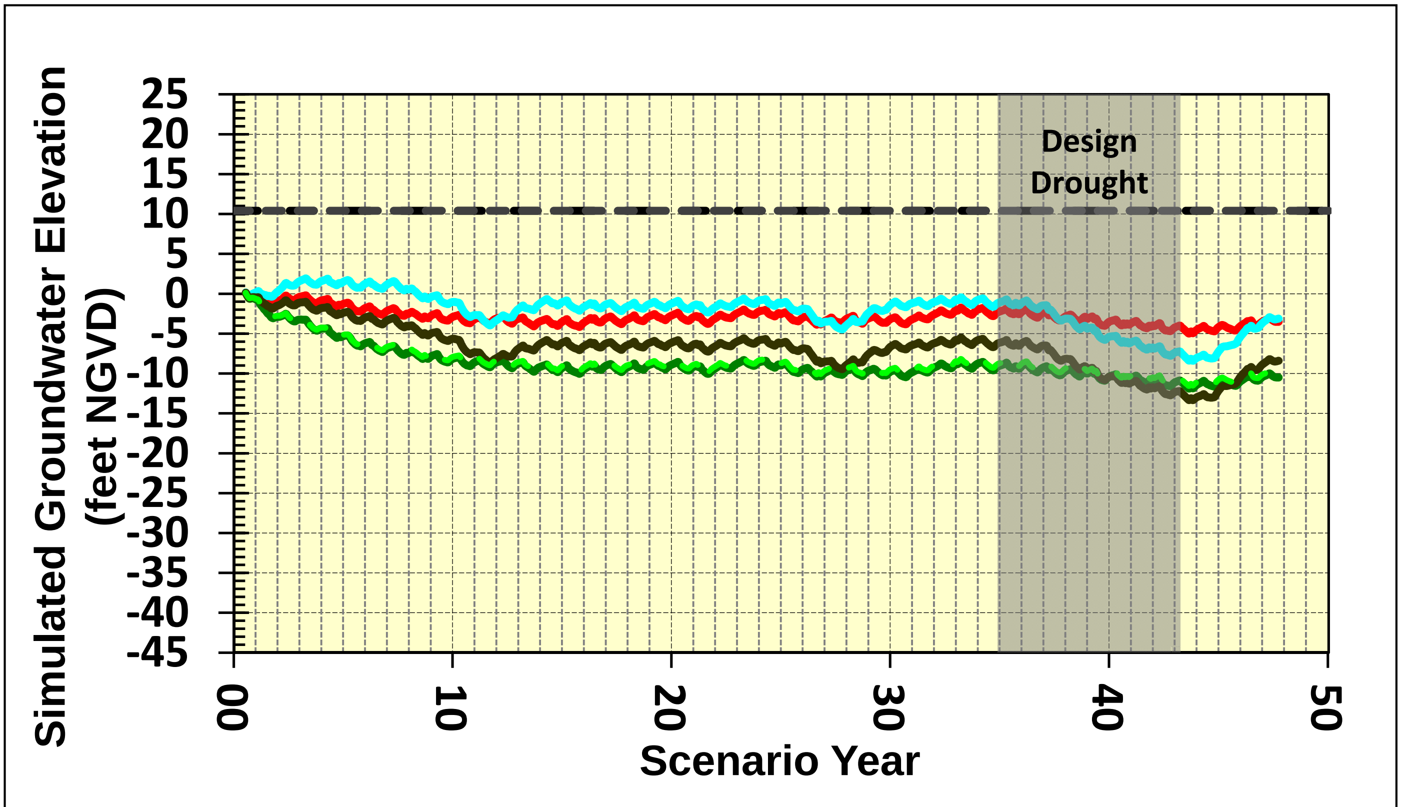
**Kennedy/Jenks Consultants**

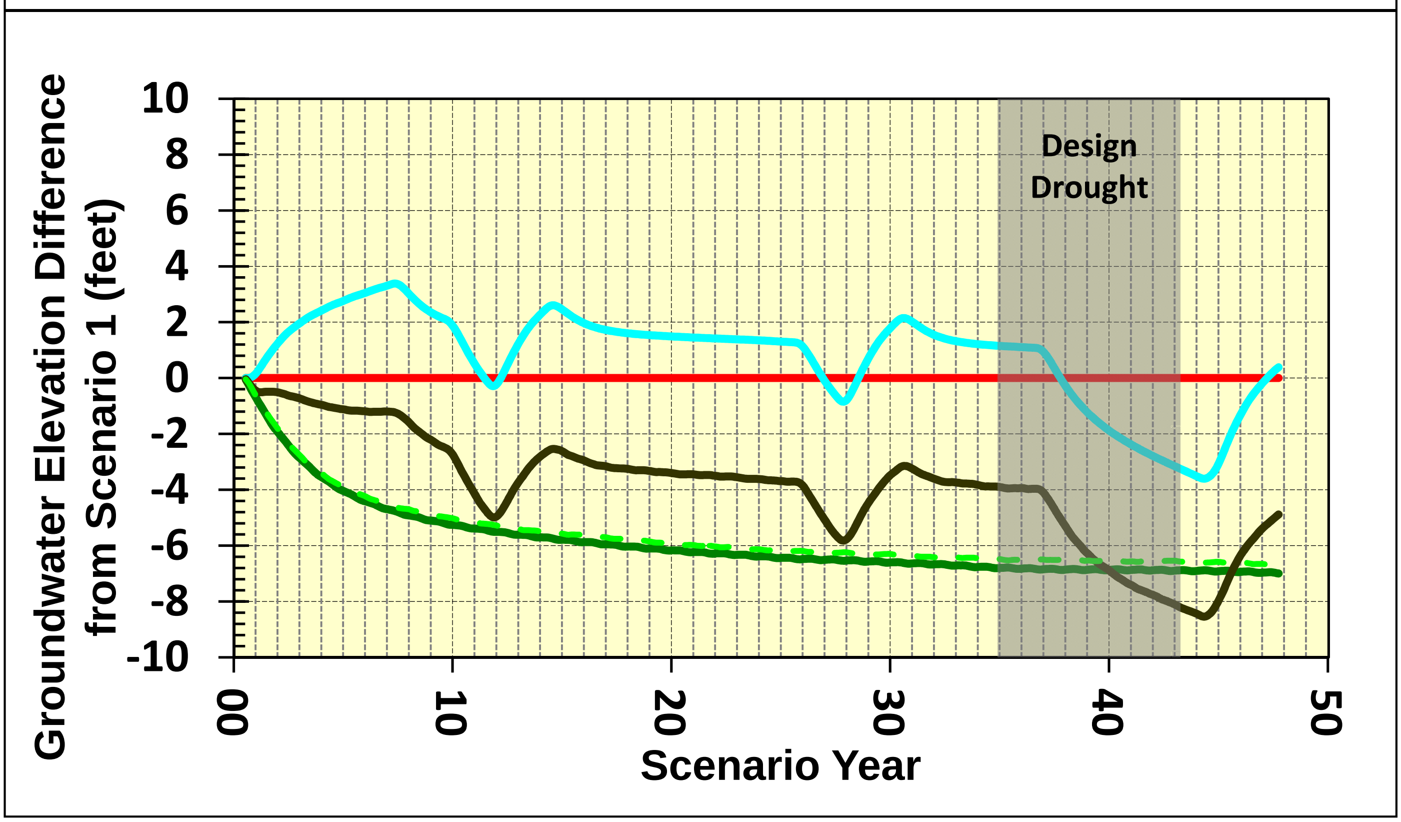
Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for West Sunset Playground Well**

K/J 0864001
April 2012

**Figure 10.3-8b**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

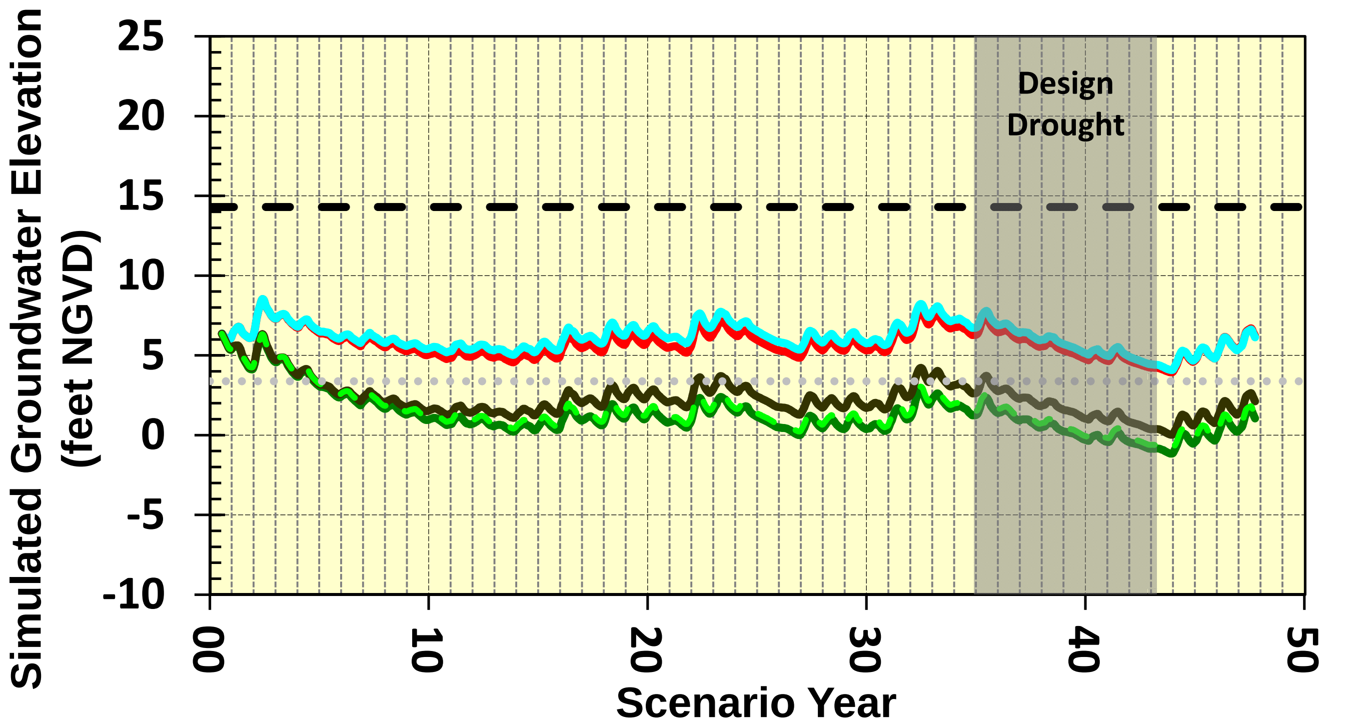
- Single-Aquifer
- Deep Aquifer

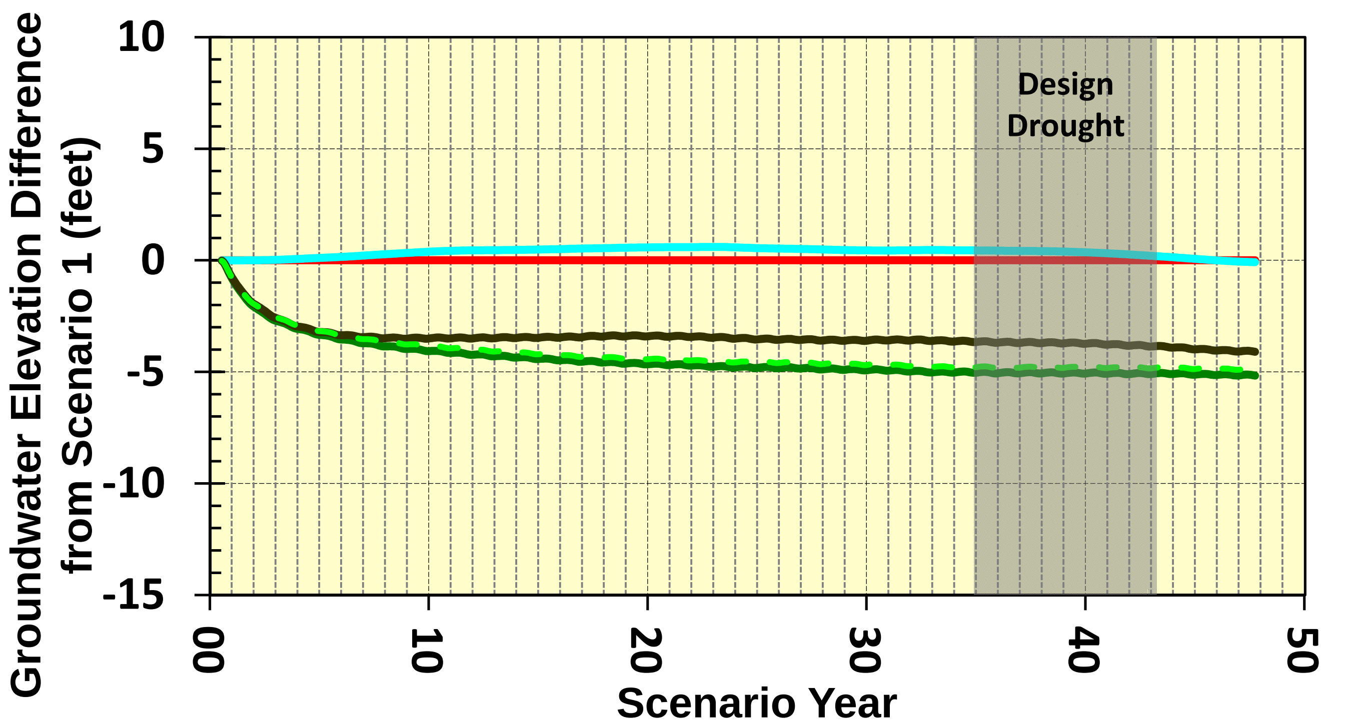
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 5 Hydrographs for West Sunset Playground Well**

K/J 0864001
April 2012
**Figure 10.3-8c**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

- **Scenario 1**
- **Scenario 2**
- **Scenario 3a**
- **Scenario 3b**
- **Scenario 4**

**Exclusion Heads:**

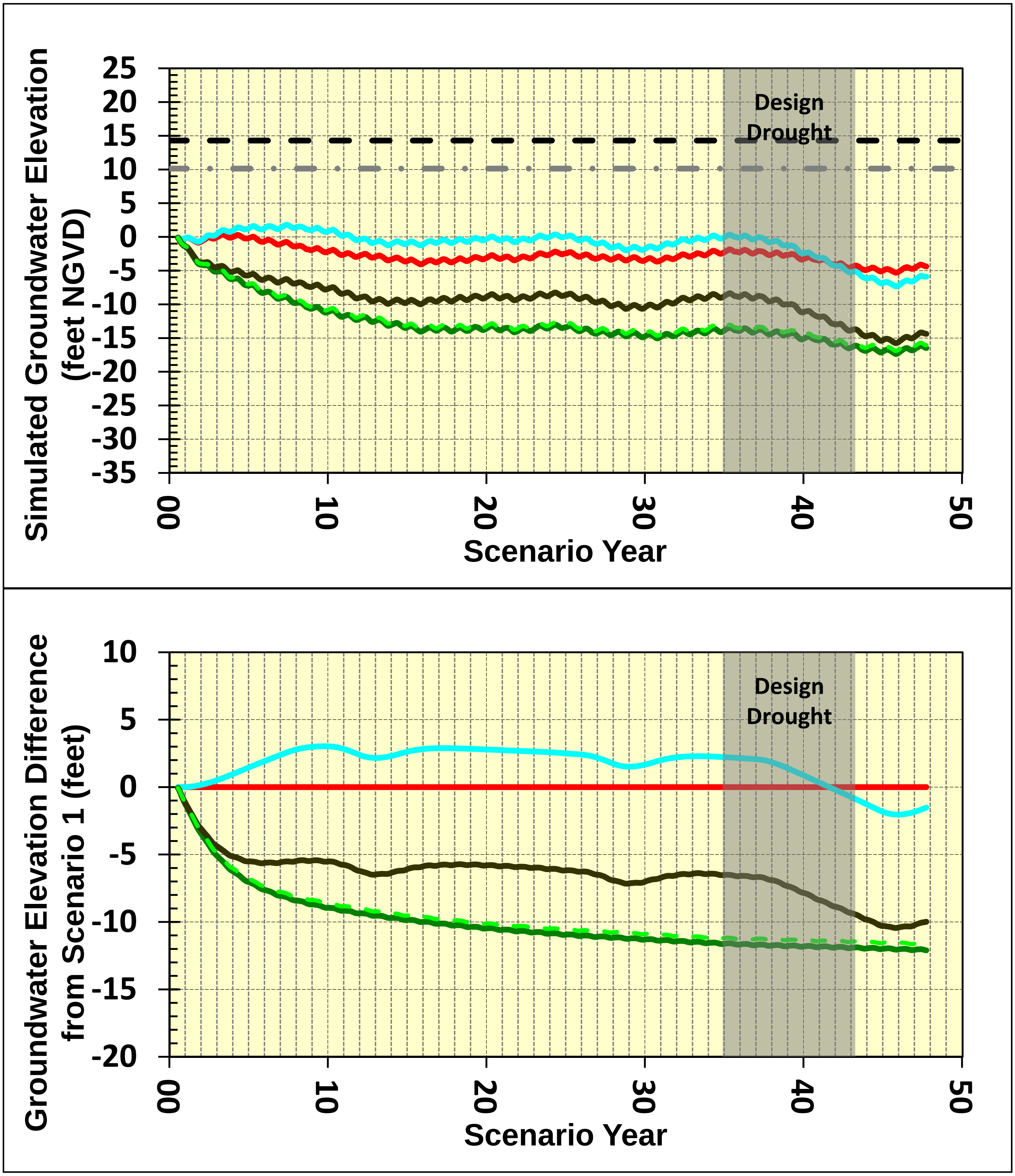
- **Single-Aquifer**
- **Shallow Aquifer**

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for Taraval Cluster**

K/J 0864001
April 2012
**Figure 10.3-9a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

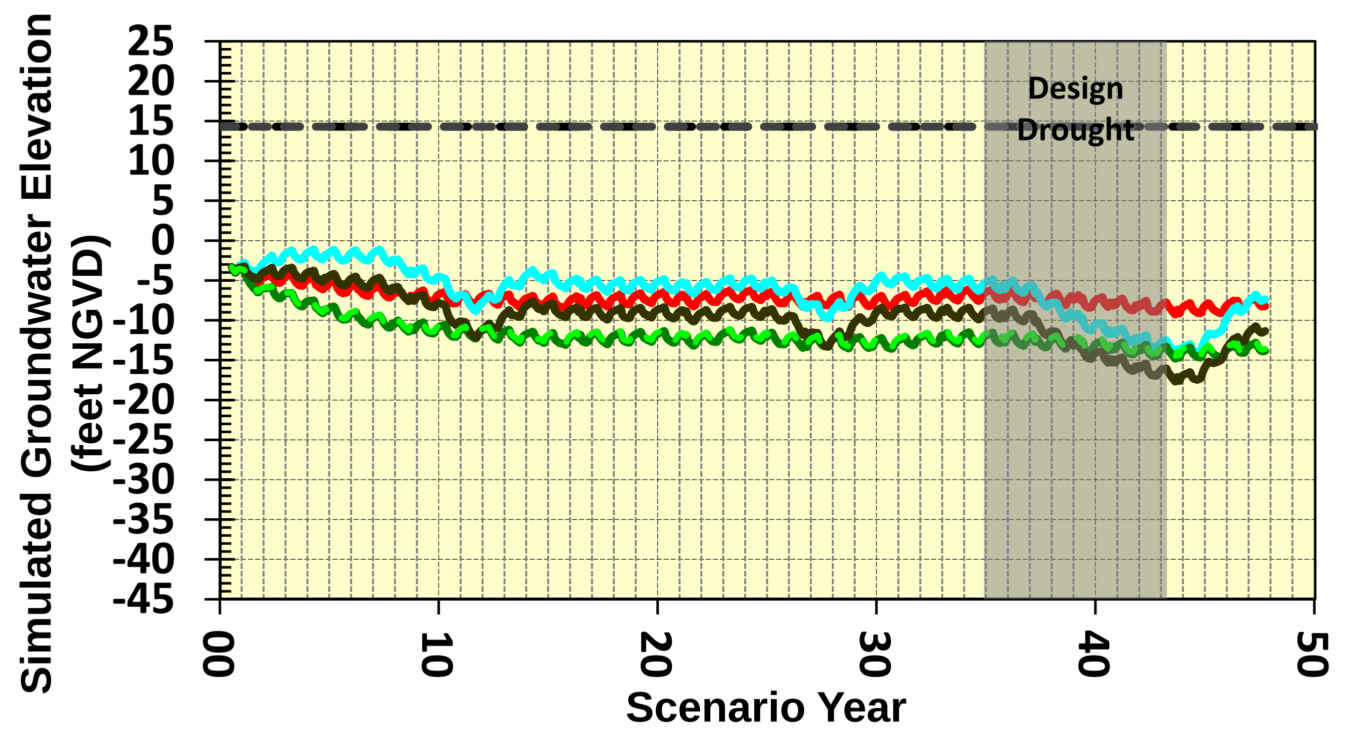
- Single-Aquifer
- Primary Production Aquifer

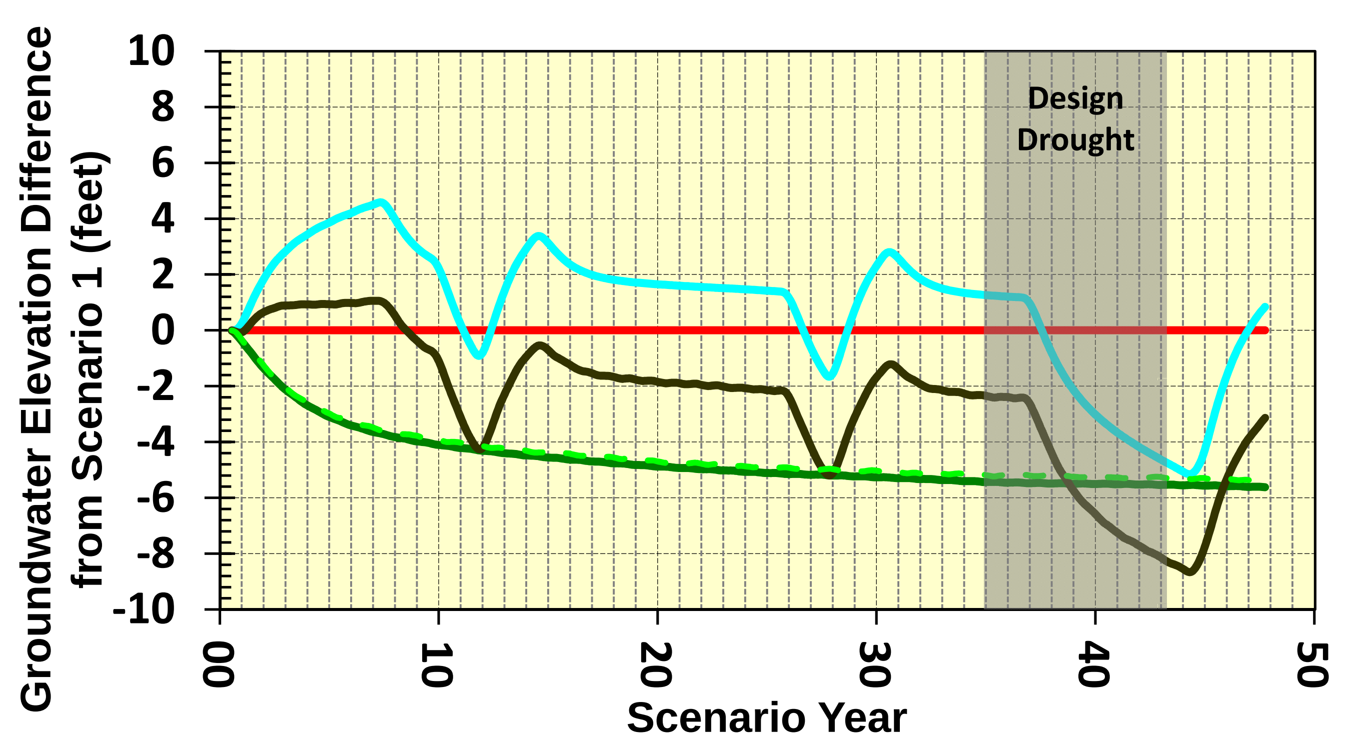
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for Taraval Cluster**

K/J 0864001
April 2012
**Figure 10.3-9b**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

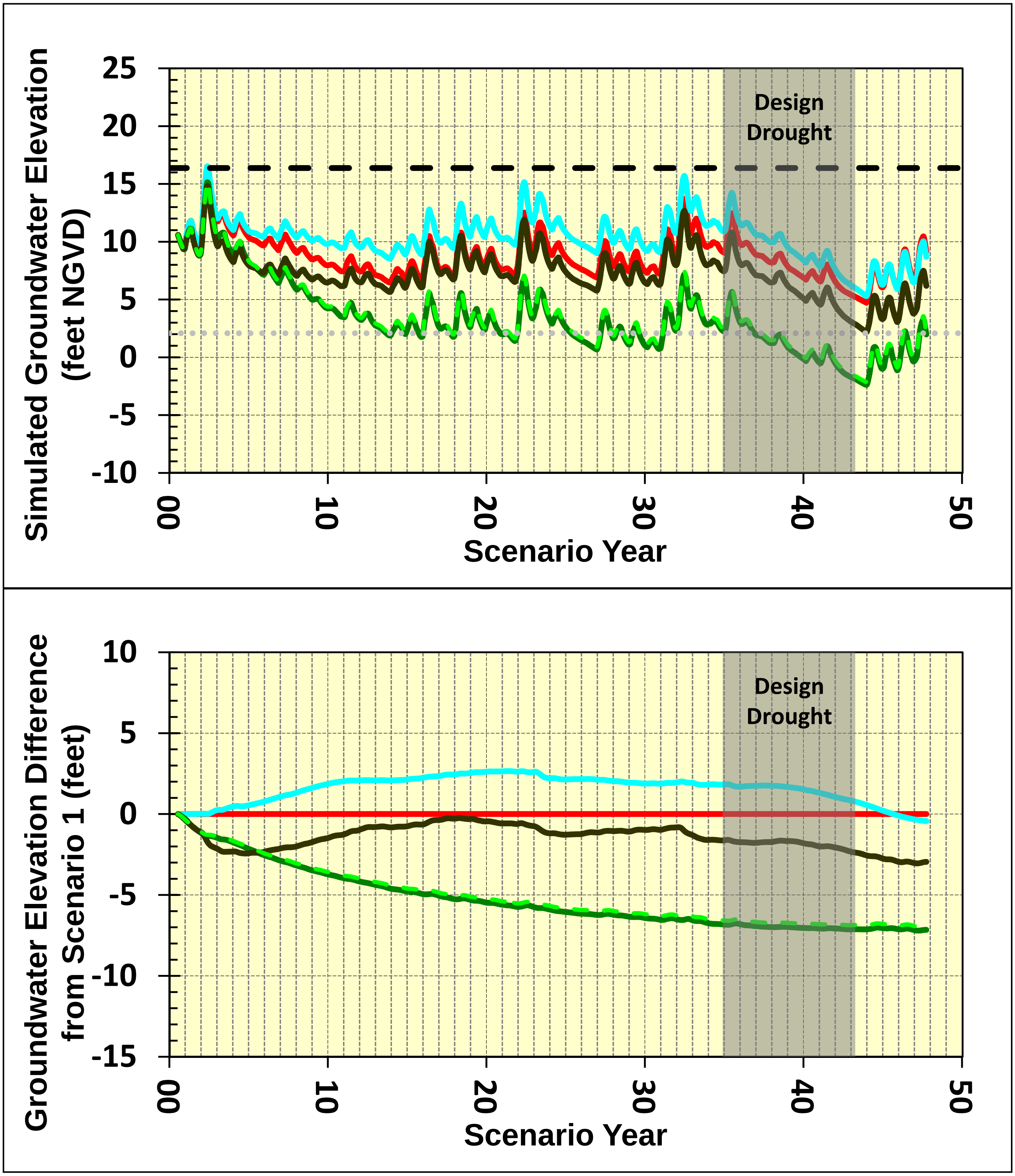
- Single-Aquifer
- Deep Aquifer

**Kennedy/Jenks Consultants**

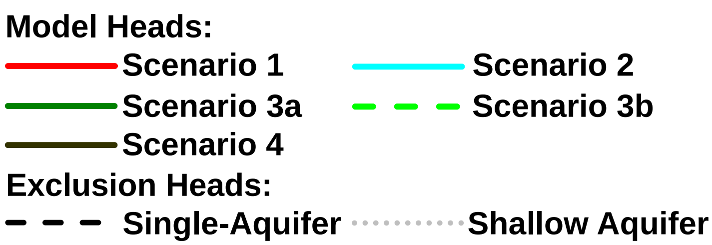
Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 5 Hydrographs for Taraval Cluster**

K/J 0864001
April 2012
**Figure 10.3-9c**




Note: Zero elevation is equivalent to mean sea level NGVD.

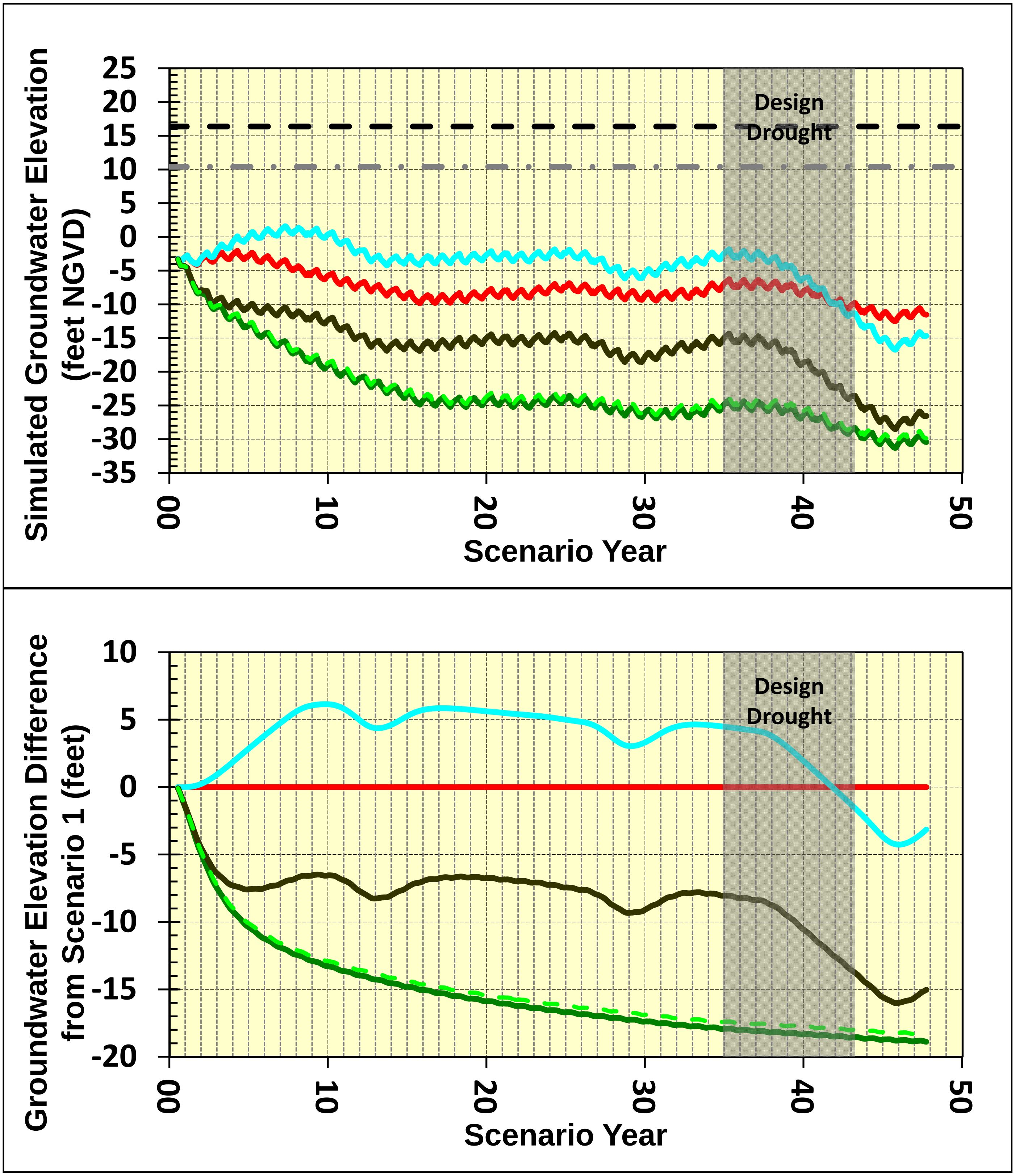



**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for Zoo Cluster**

K/J 0864001
April 2012
**Figure 10.3-10a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

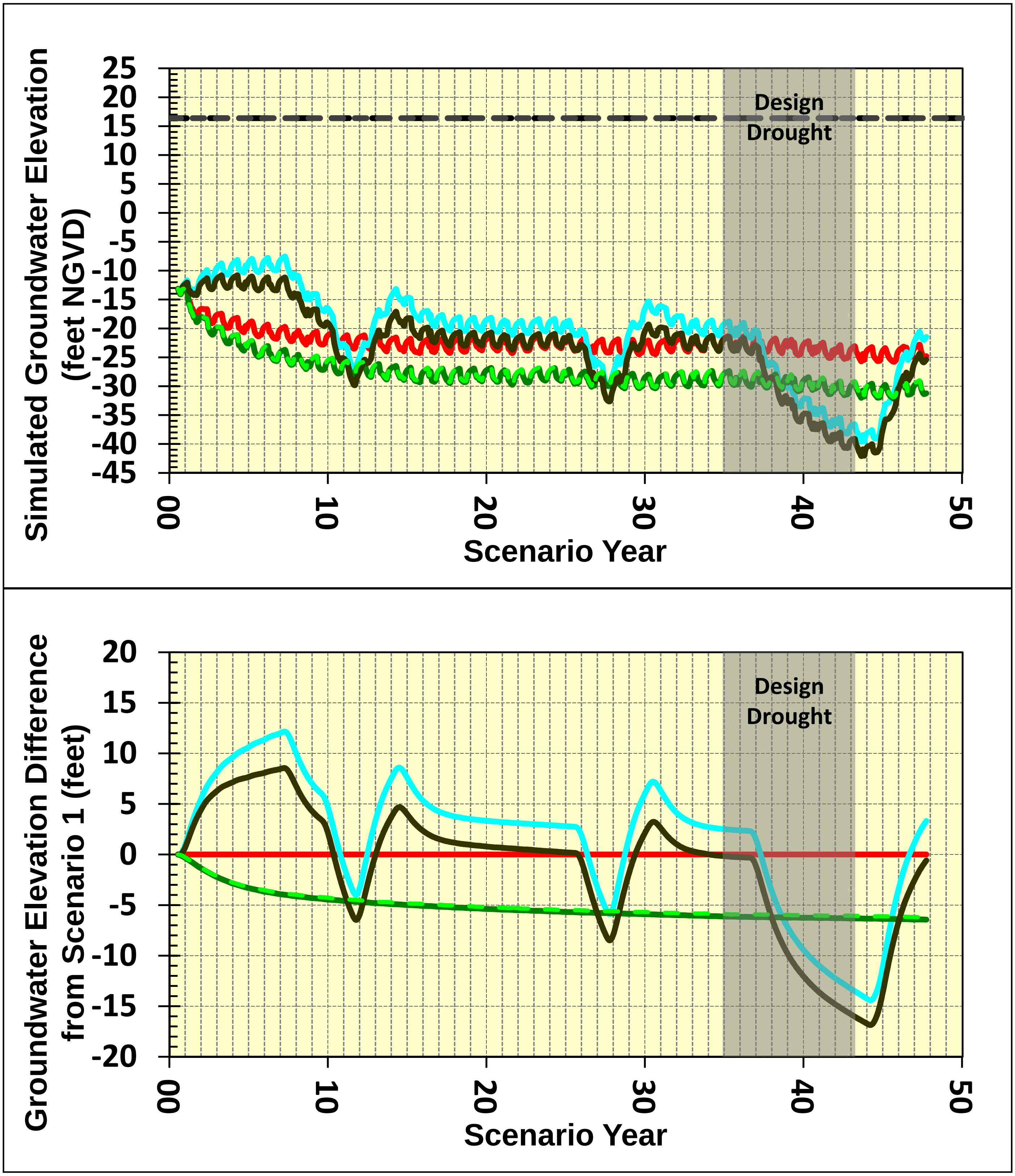
**Exclusion Heads:**
- Single-Aquifer
- Primary Production Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for Zoo Cluster**

K/J 0864001
April 2012
**Figure 10.3-10b**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

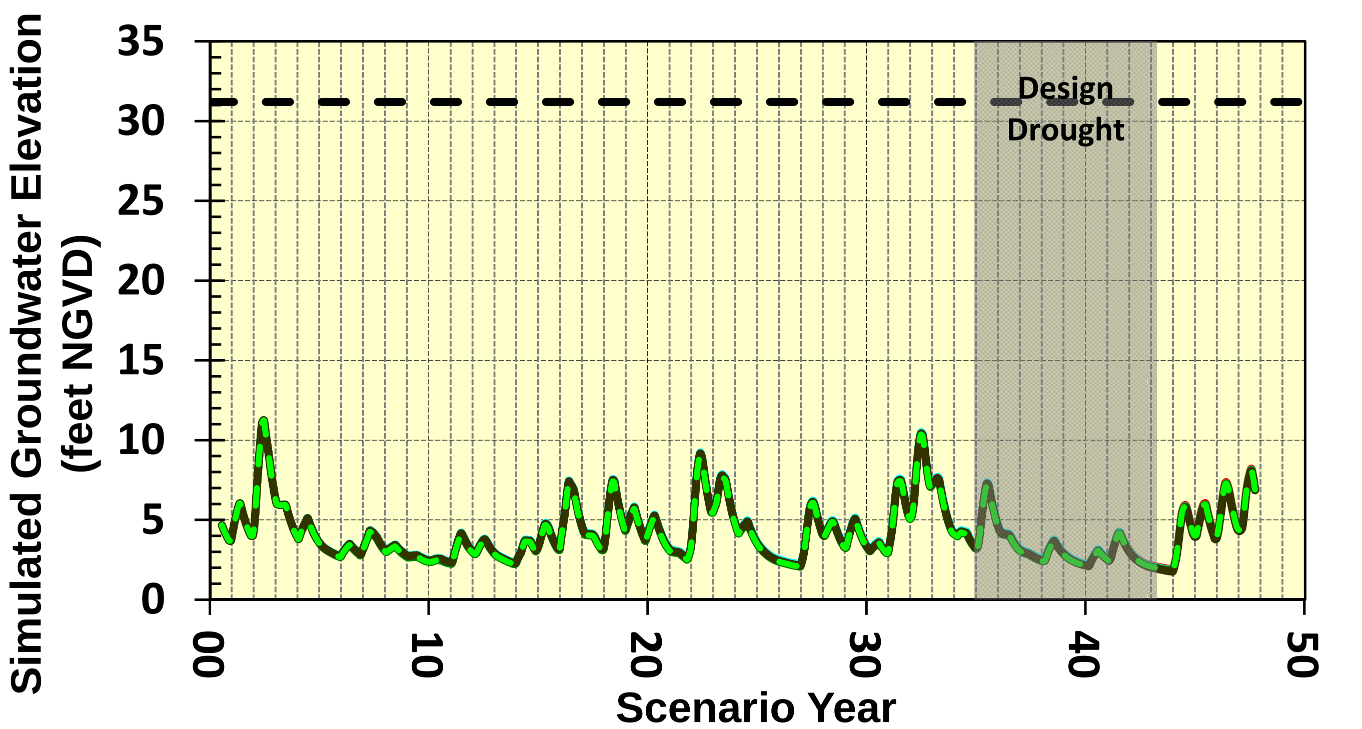
**Exclusion Heads:**
- Single-Aquifer
- Deep Aquifer

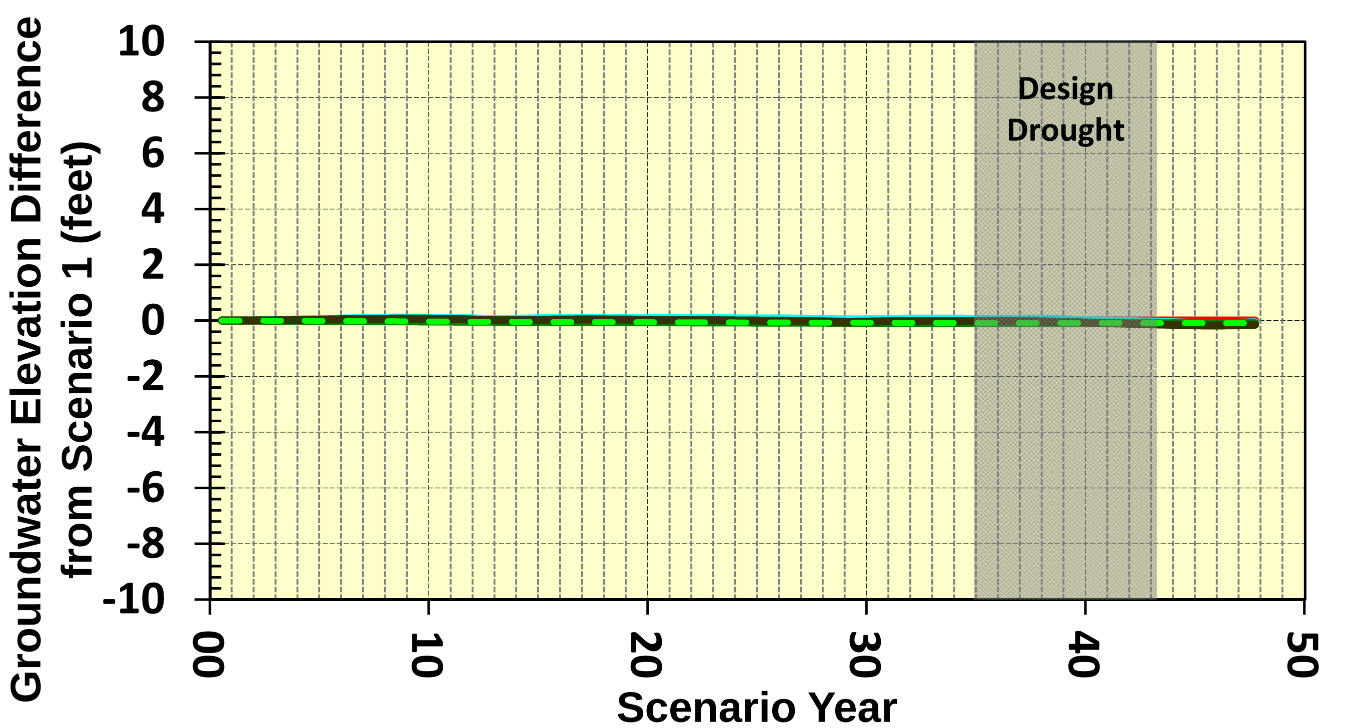
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 5 Hydrographs for Zoo Cluster**

K/J 0864001
April 2012
**Figure 10.3-10c**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

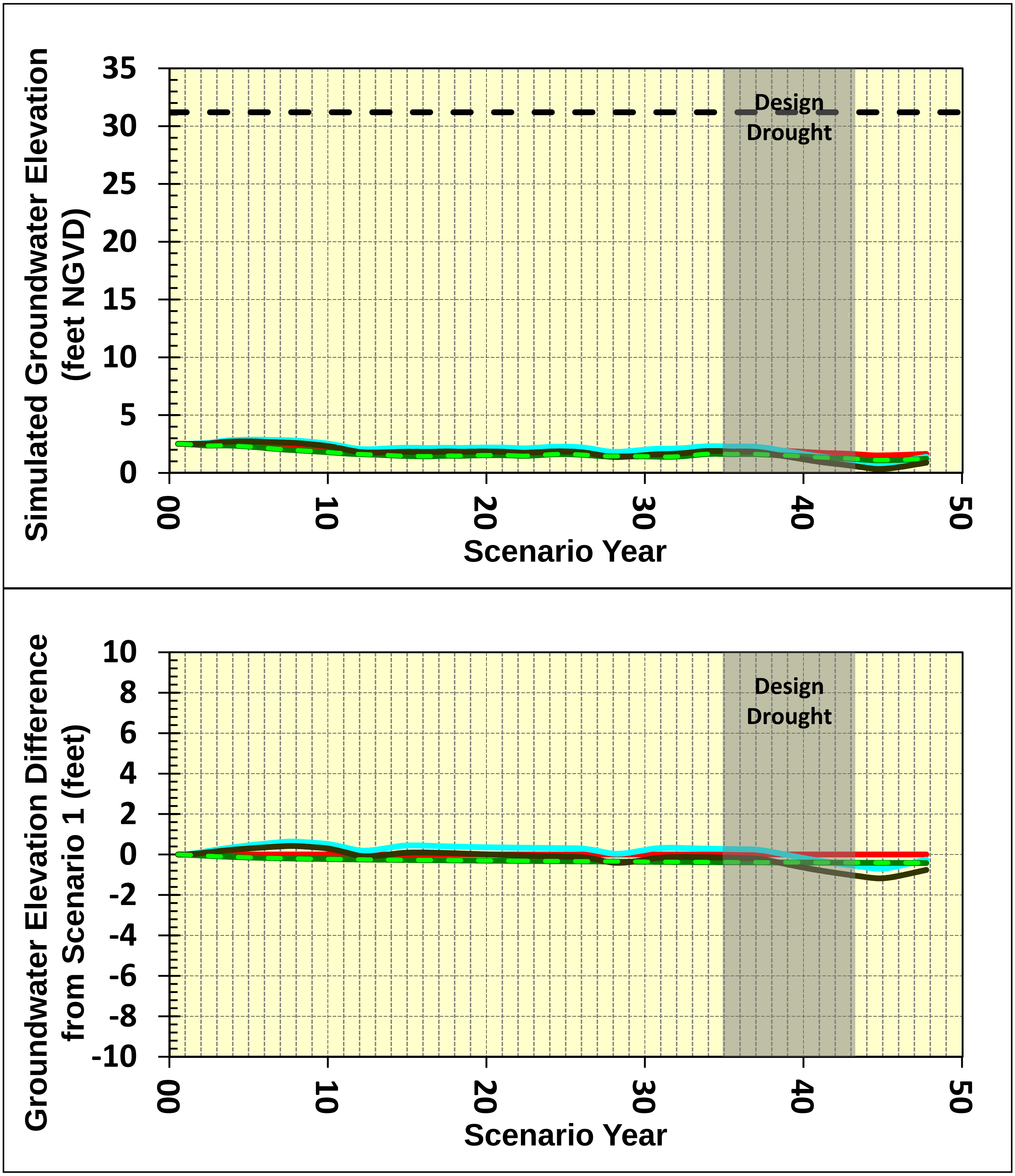
- Single-Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for Fort Funston Cluster**

K/J 0864001
April 2012
**Figure 10.3-11a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

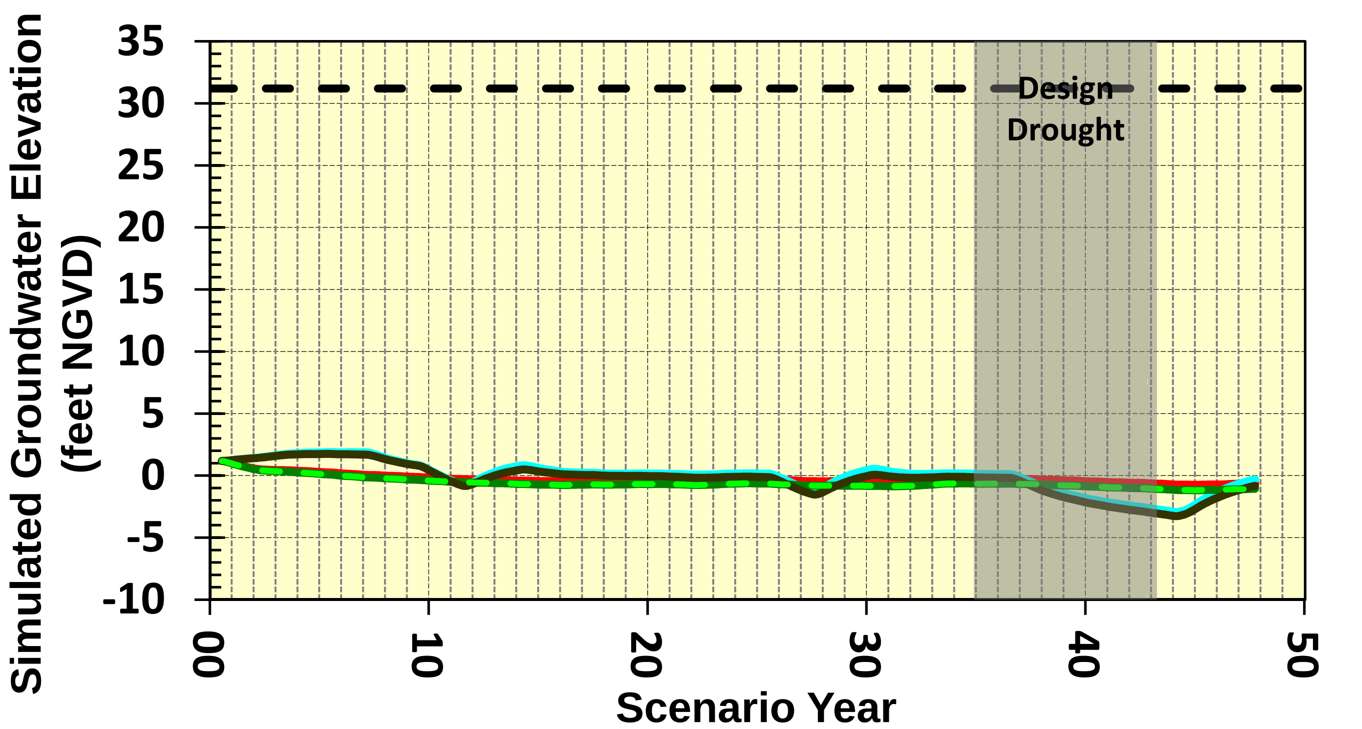
**Exclusion Heads:**
- Single-Aquifer

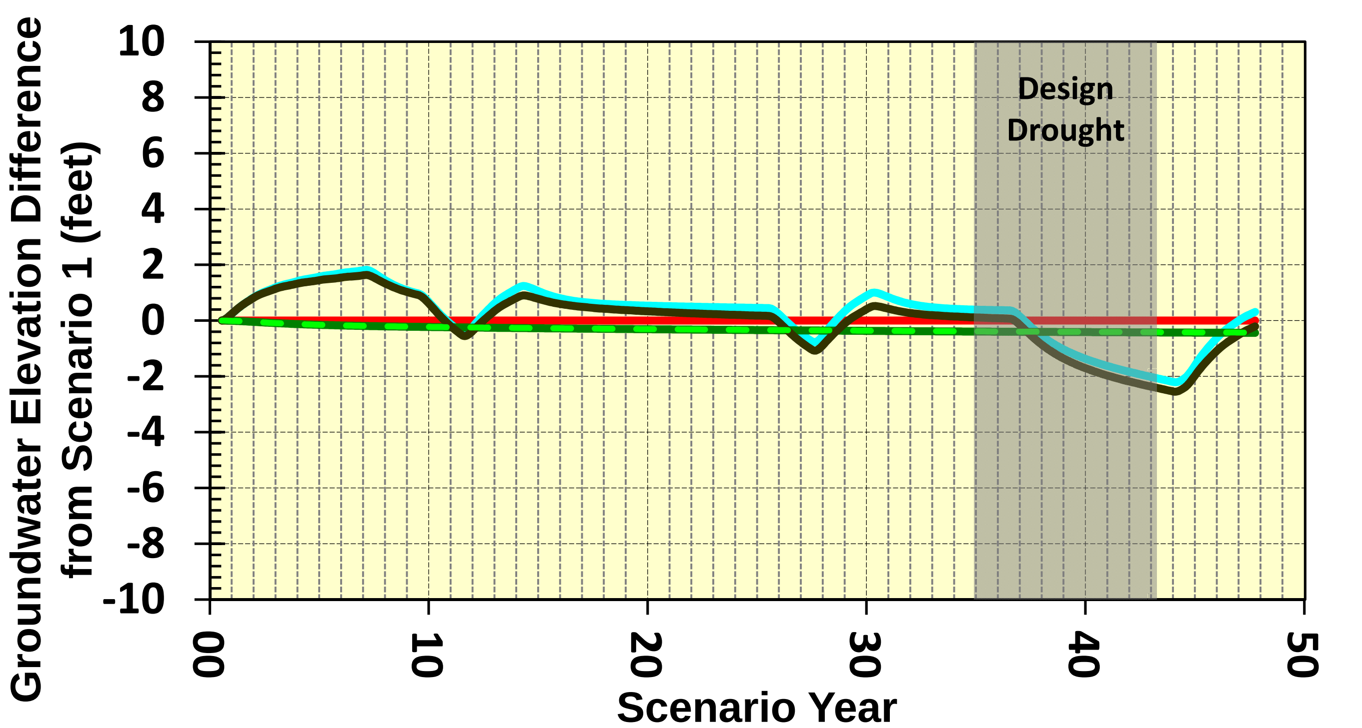
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

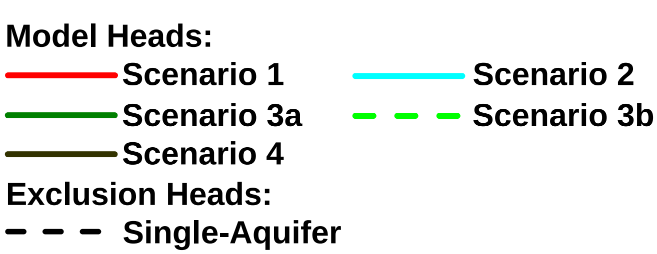
**Model Layer 4 Hydrographs for Fort Funston Cluster**

K/J 0864001
April 2012
**Figure 10.3-11b**




**Note: Zero elevation is equivalent to mean sea level NGVD.**



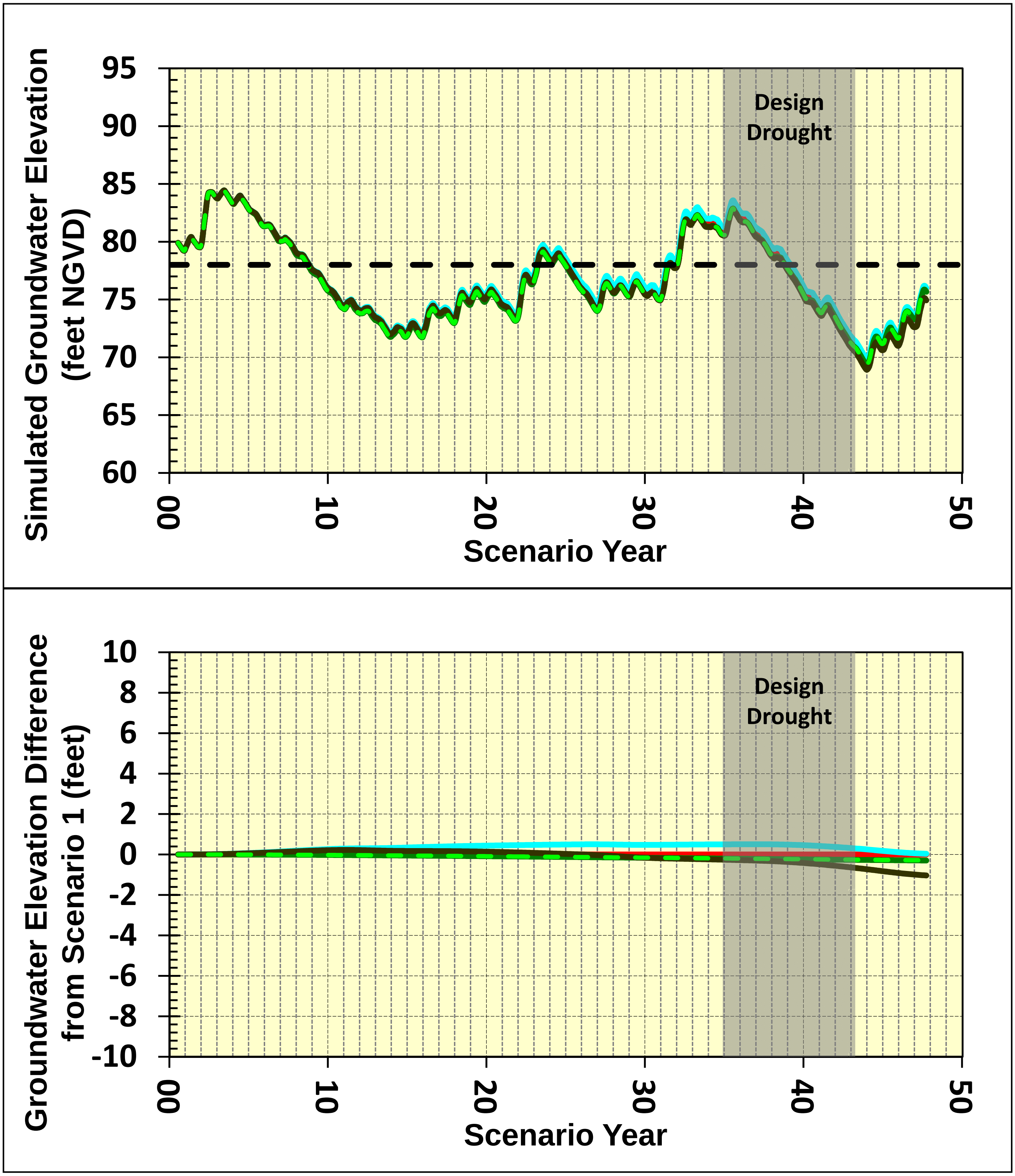

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 5 Hydrographs for Fort Funston Cluster**

K/J 0864001
April 2012

**Figure 10.3-11c**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**
**Scenario 1**
**Scenario 2**
**Scenario 3a**
**Scenario 3b**
**Scenario 4**

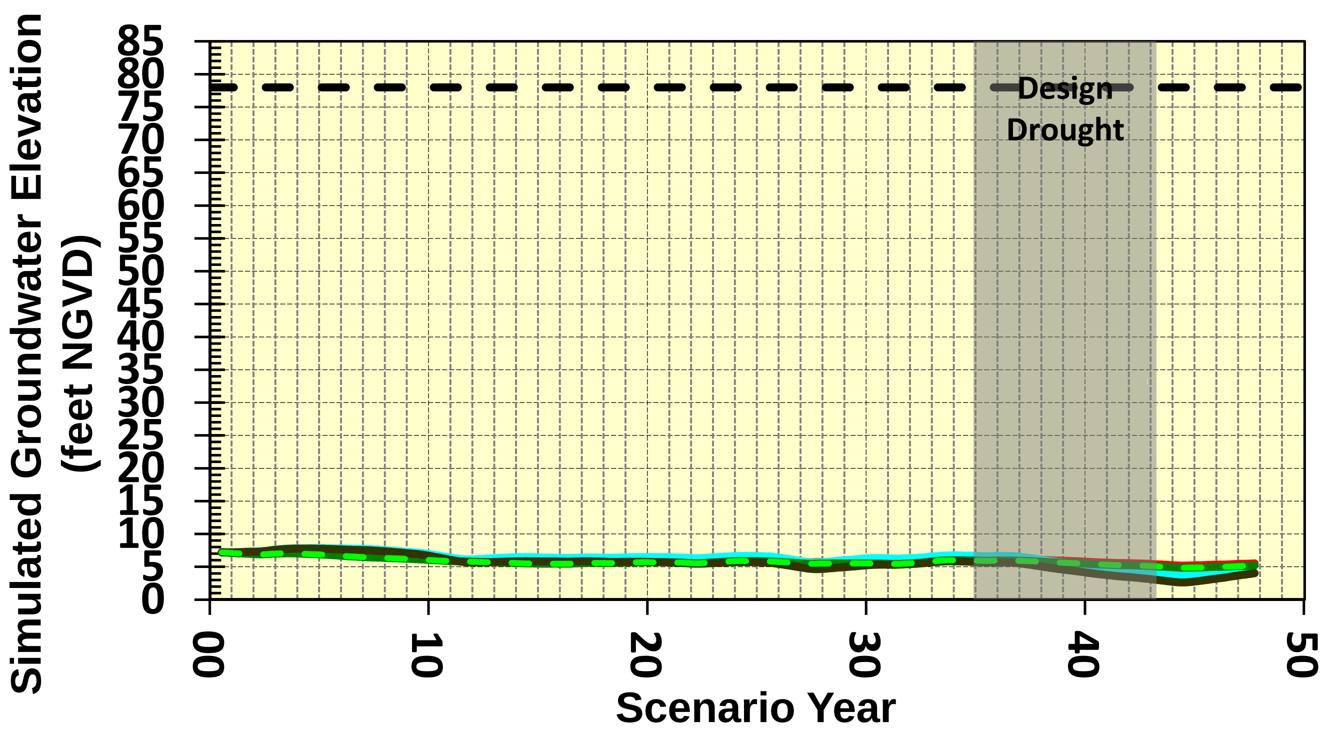
**Exclusion Heads:**
**Single-Aquifer**

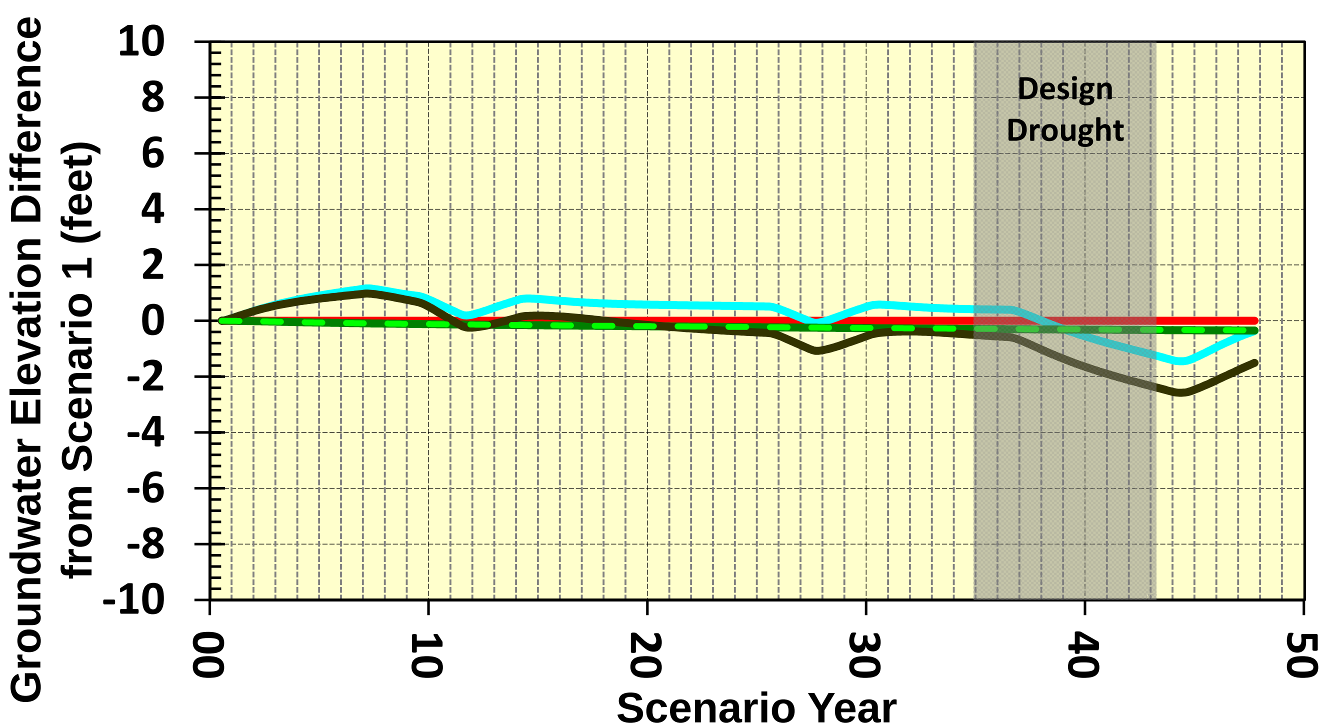
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for Thornton Beach Cluster**

K/J 0864001
April 2012
**Figure 10.3-12a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4

**Exclusion Heads:**

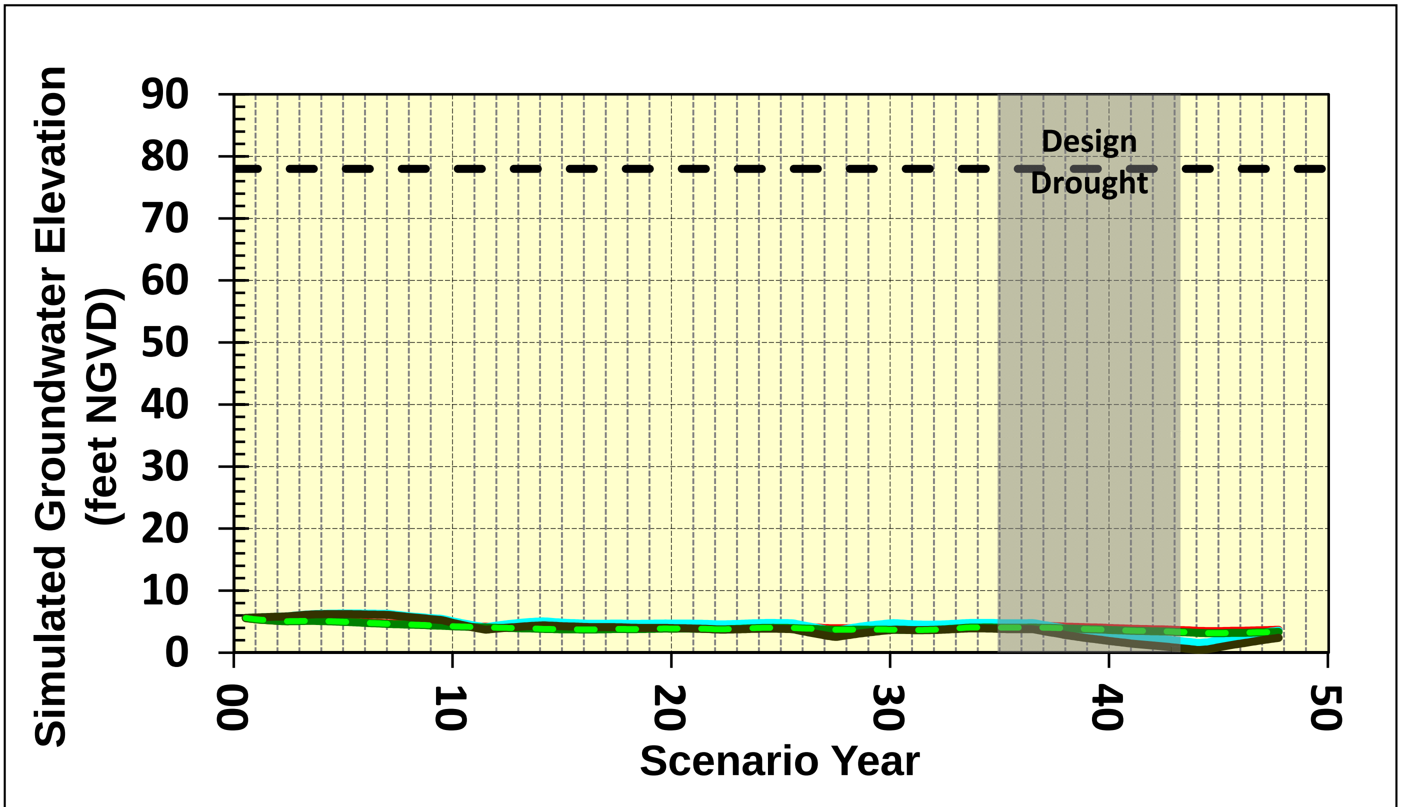
Single-Aquifer

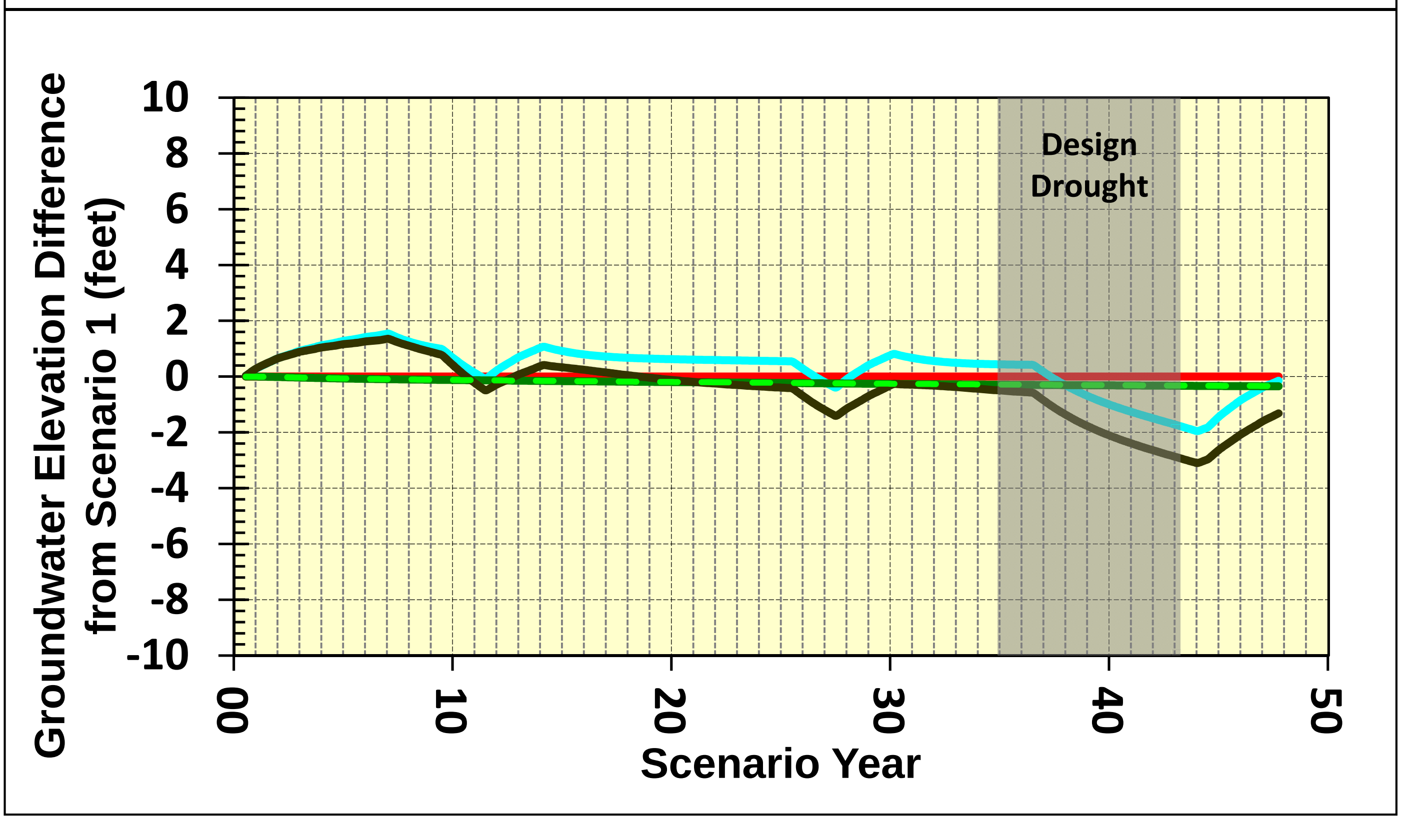
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for Thornton Beach Cluster**

K/J 0864001
April 2012
**Figure 10.3-12b**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

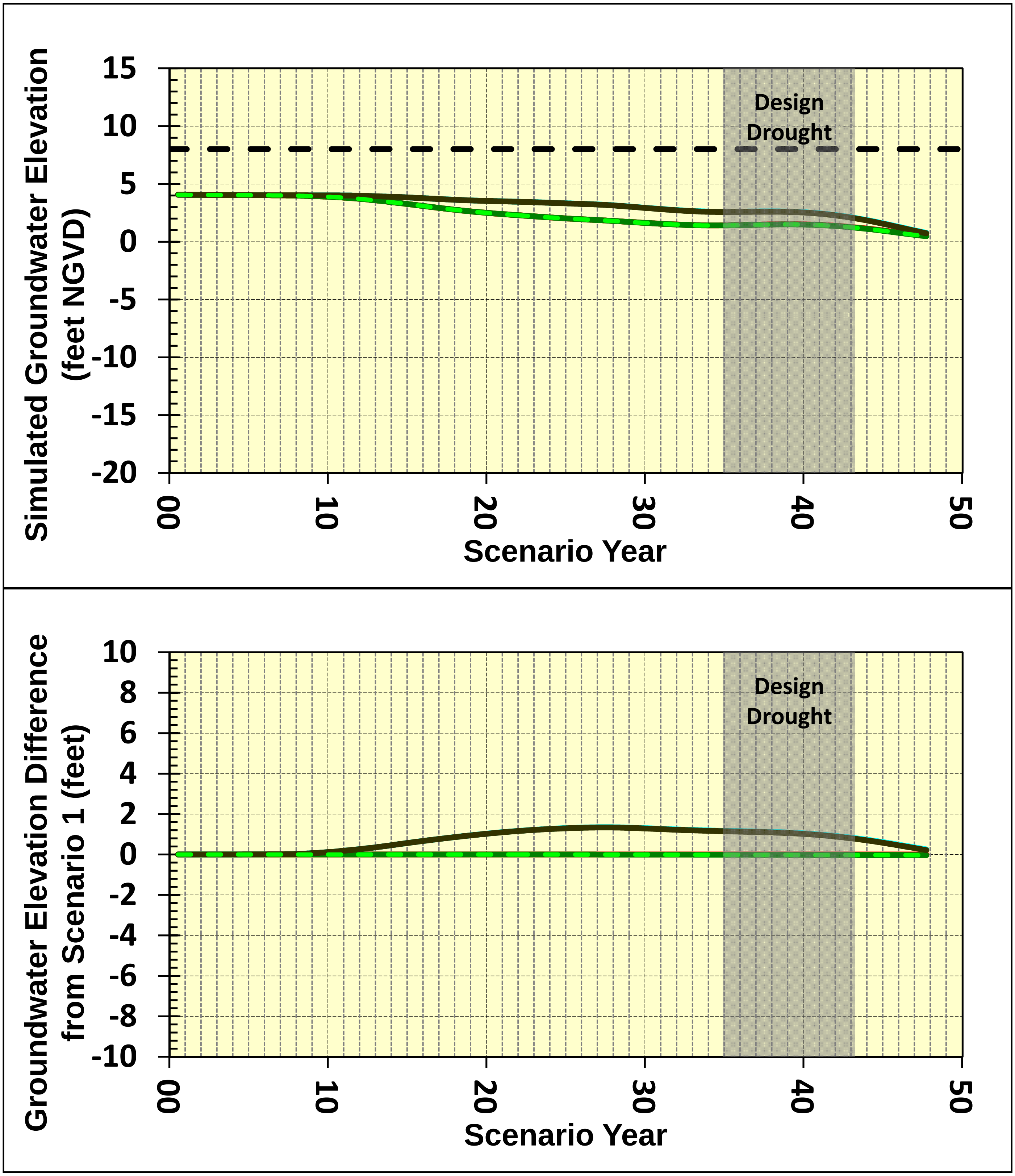
**Exclusion Heads:**
- Single-Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 5 Hydrographs for Thornton Beach Cluster**

K/J 0864001
April 2012
**Figure 10.3-12c**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

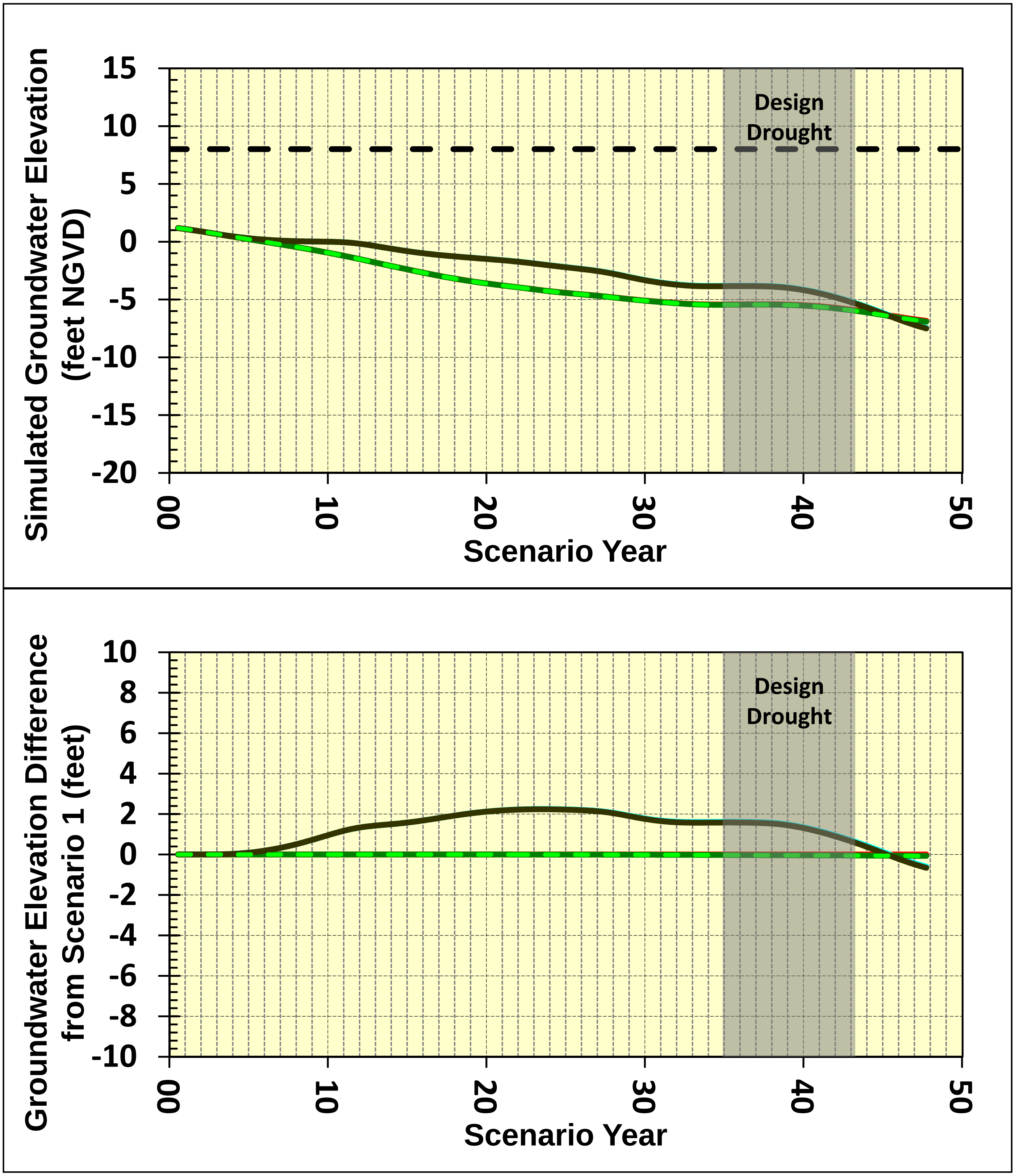
- Single-Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for Burlingame Cluster**

K/J 0864001
April 2012
**Figure 10.3-13a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

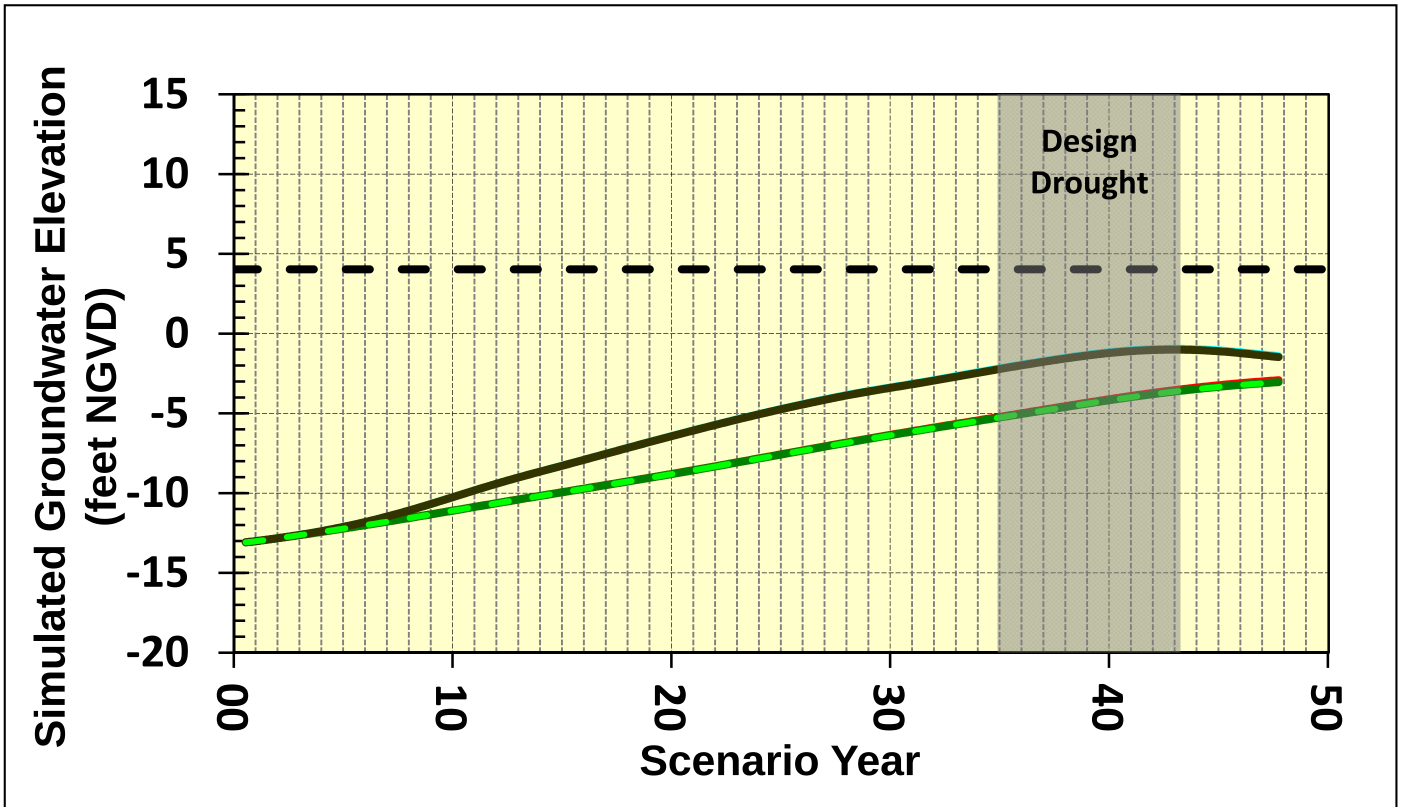
- Single-Aquifer

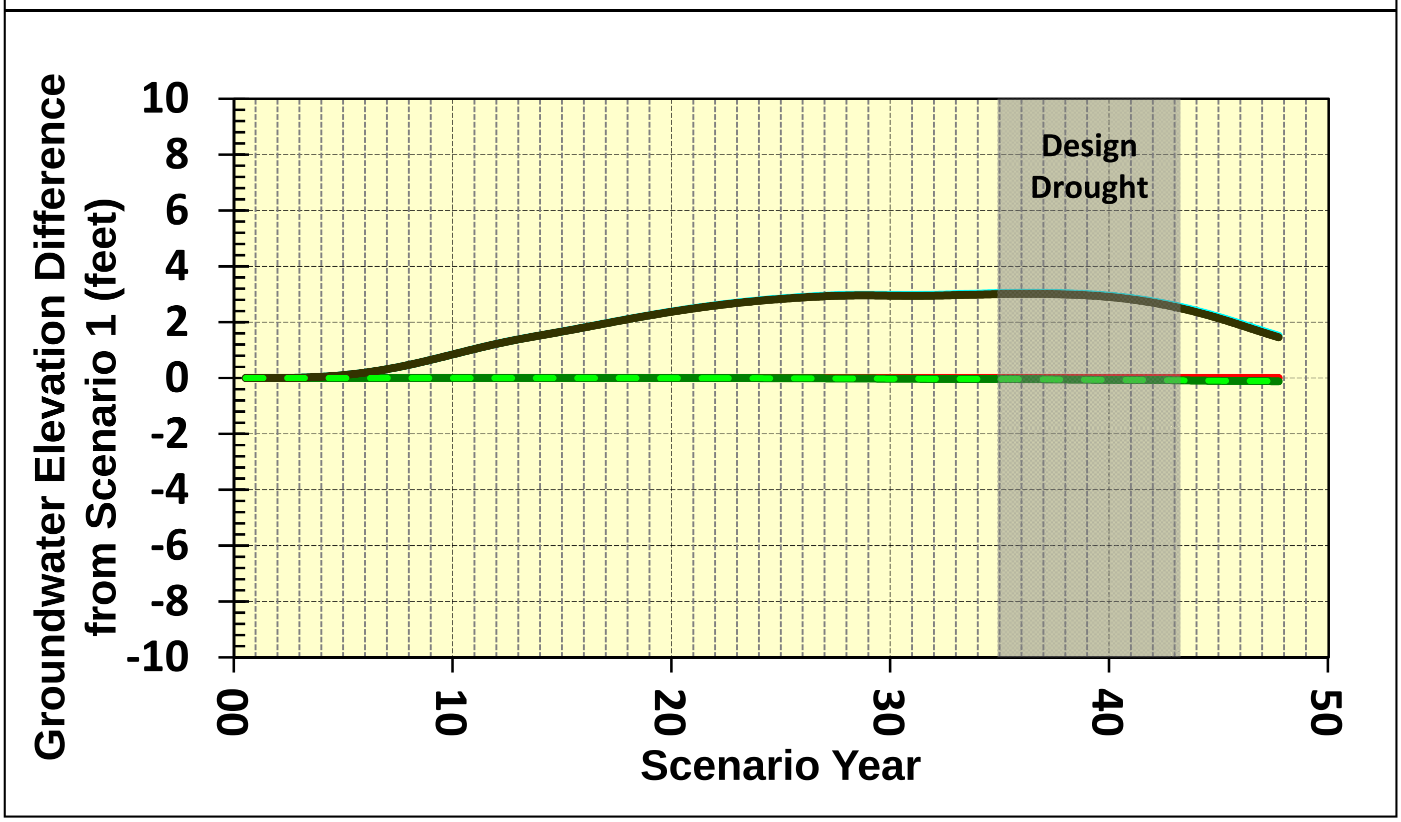
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for Burlingame Cluster**

K/J 0864001
April 2012
**Figure 10.3-13b**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

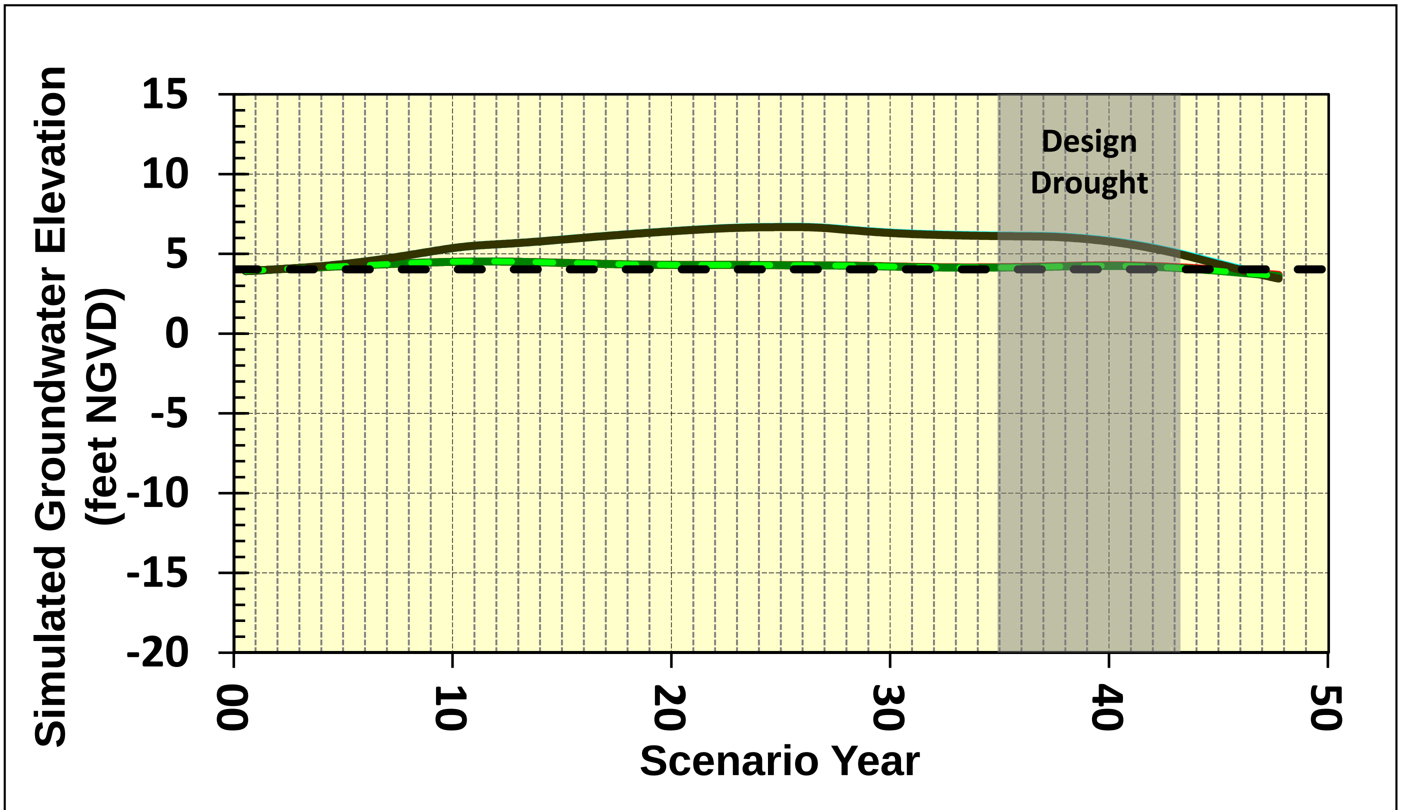
- Single-Aquifer

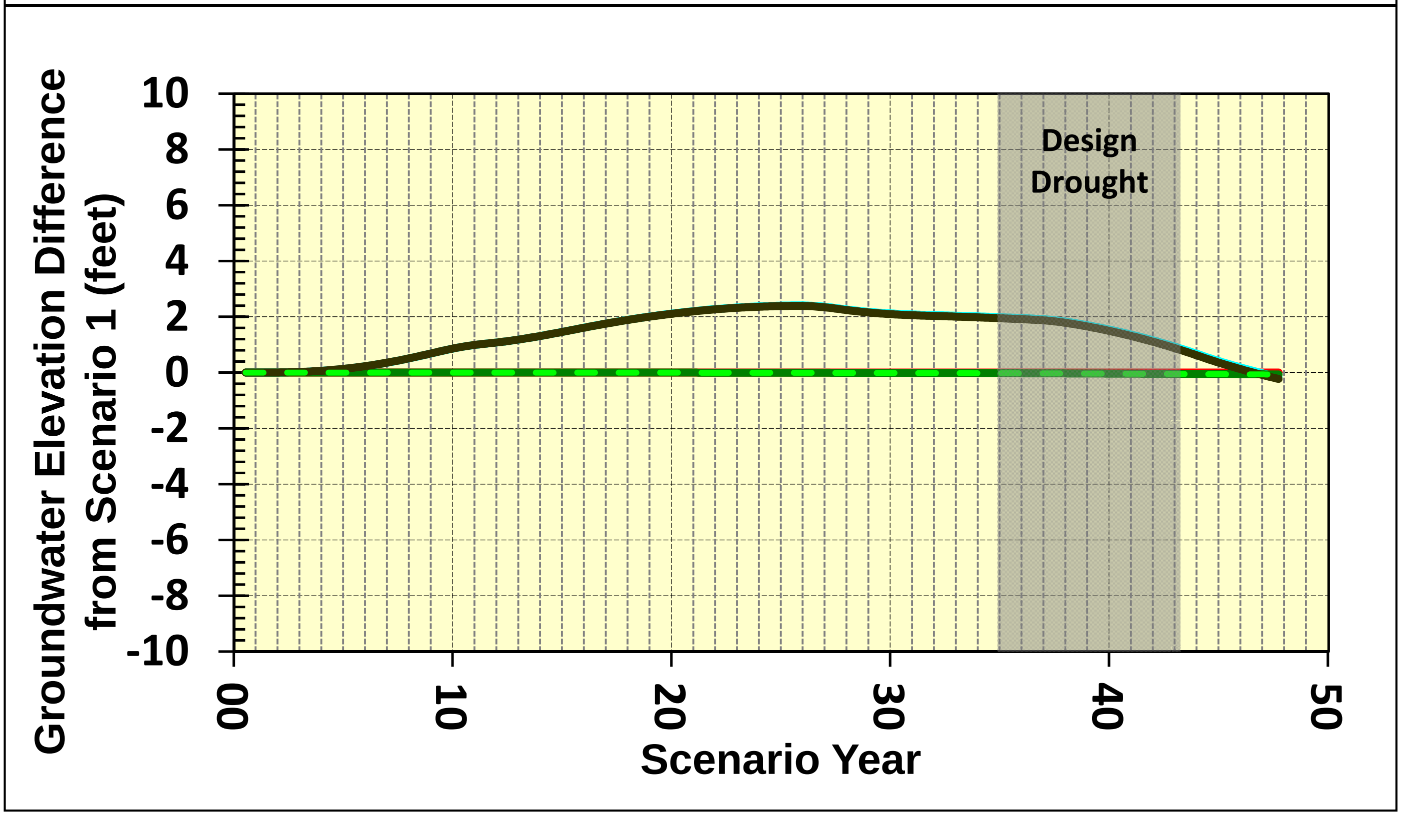
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for SFO Cluster**

K/J 0864001
April 2012
**Figure 10.3-14**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Exclusion Heads:**

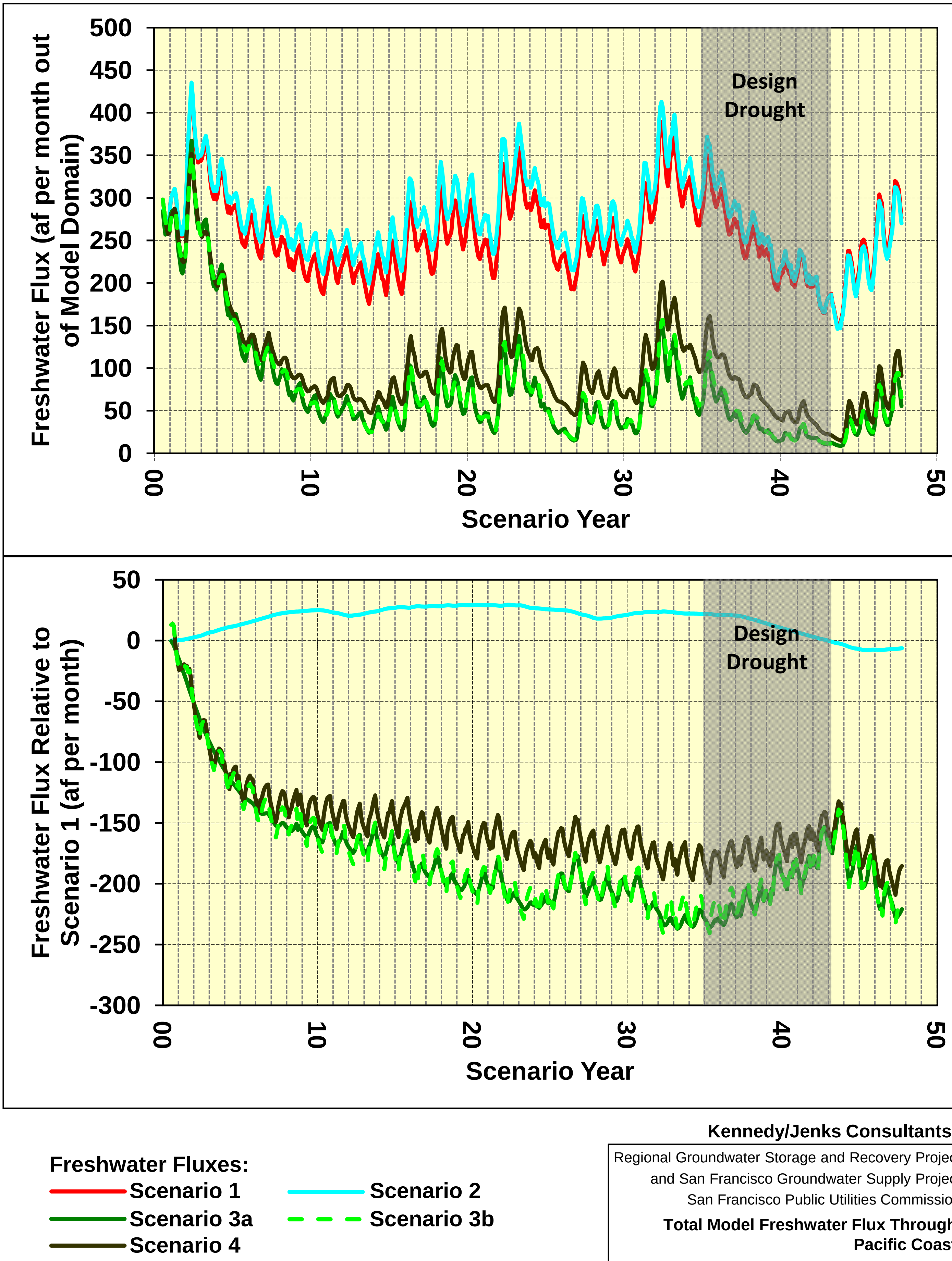
- Single-Aquifer

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for UAL Cluster**

K/J 0864001
April 2012
**Figure 10.3-15**

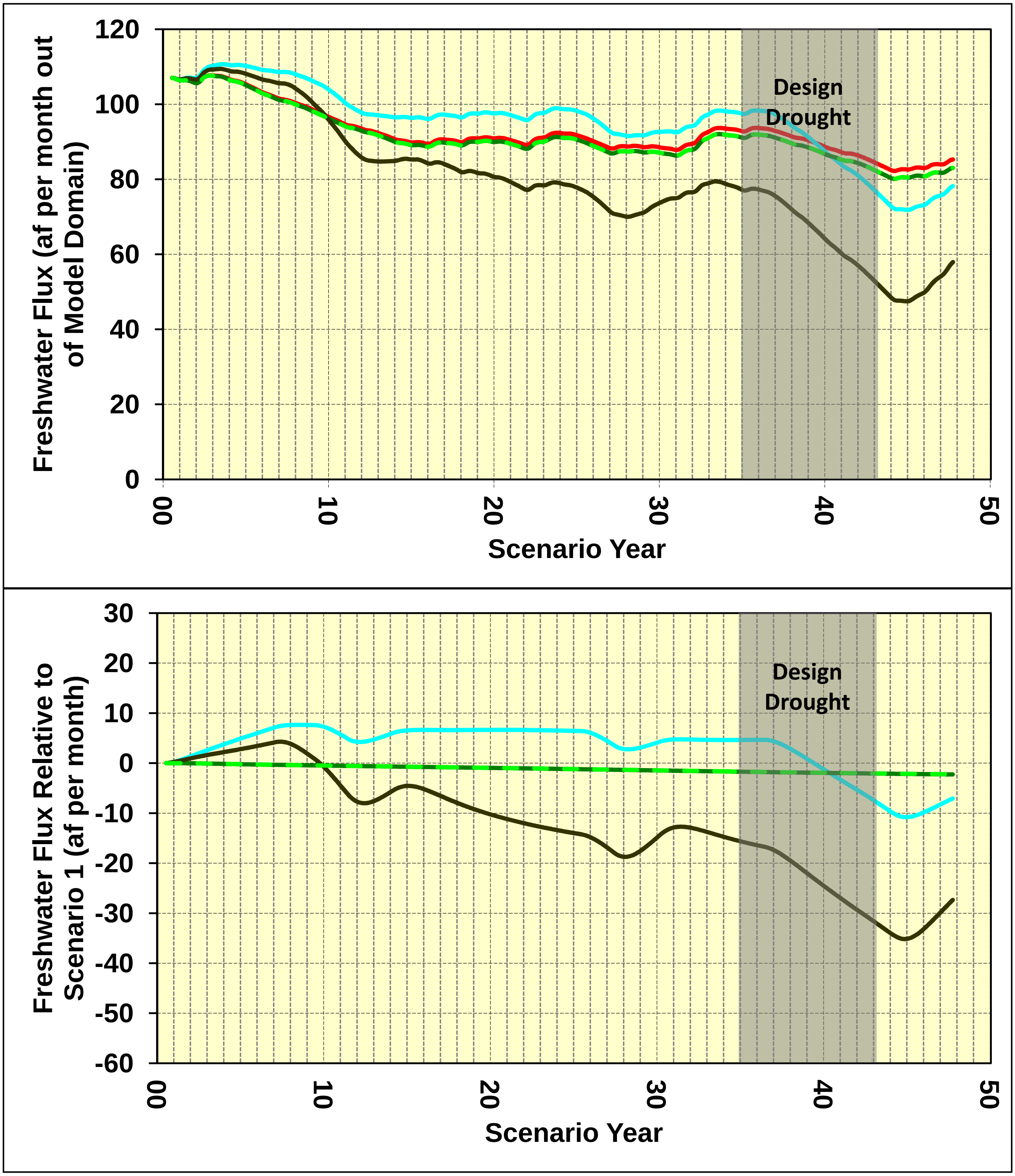



**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Total Model Freshwater Flux Through Pacific Coast**

K/J 0864001
April 2012
**Figure 10.3-16**




**Freshwater Fluxes:**

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

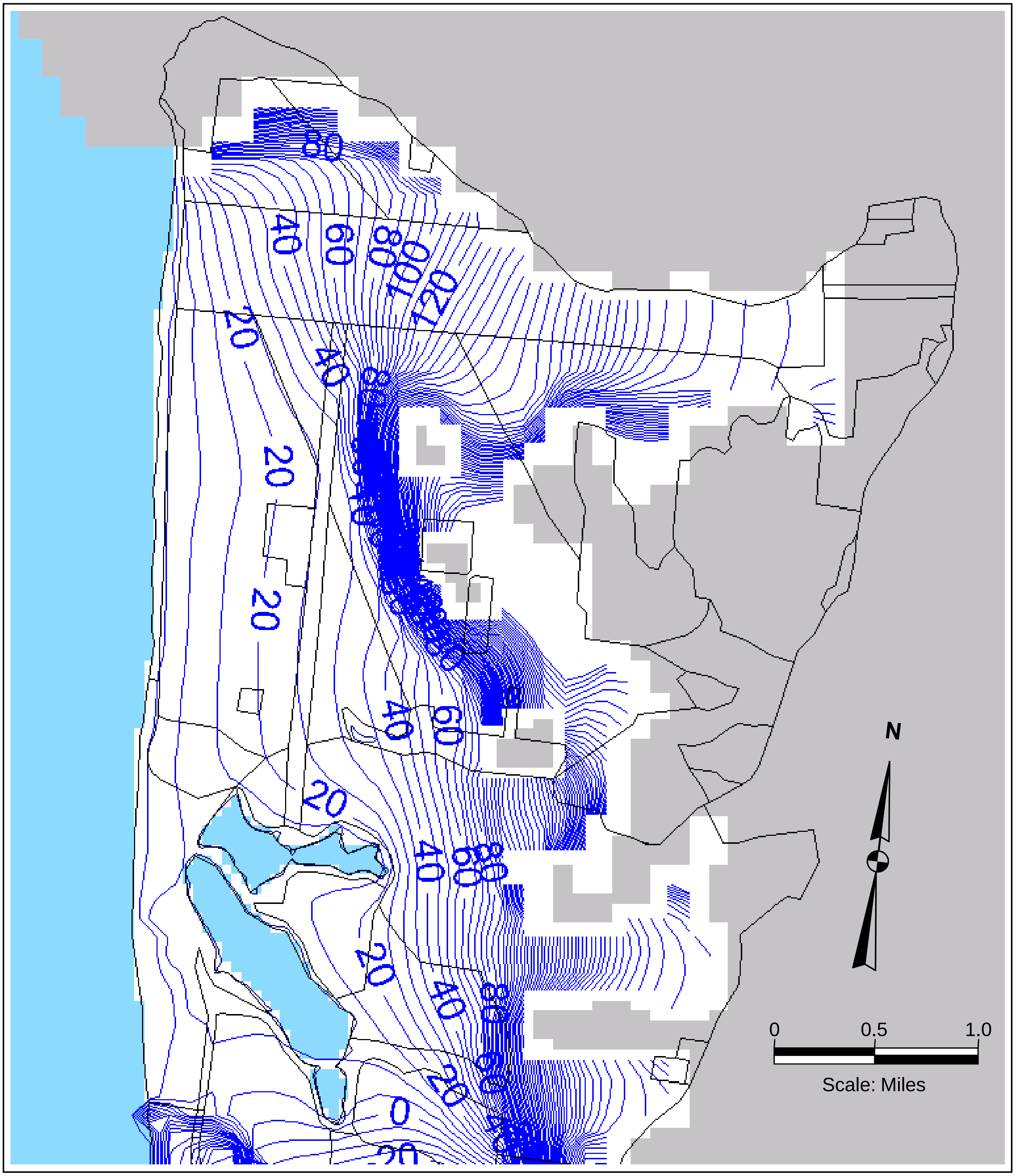
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Total Model Freshwater Flux Through Bay Coast**

K/J 0864001
April 2012

**Figure 10.3-17**



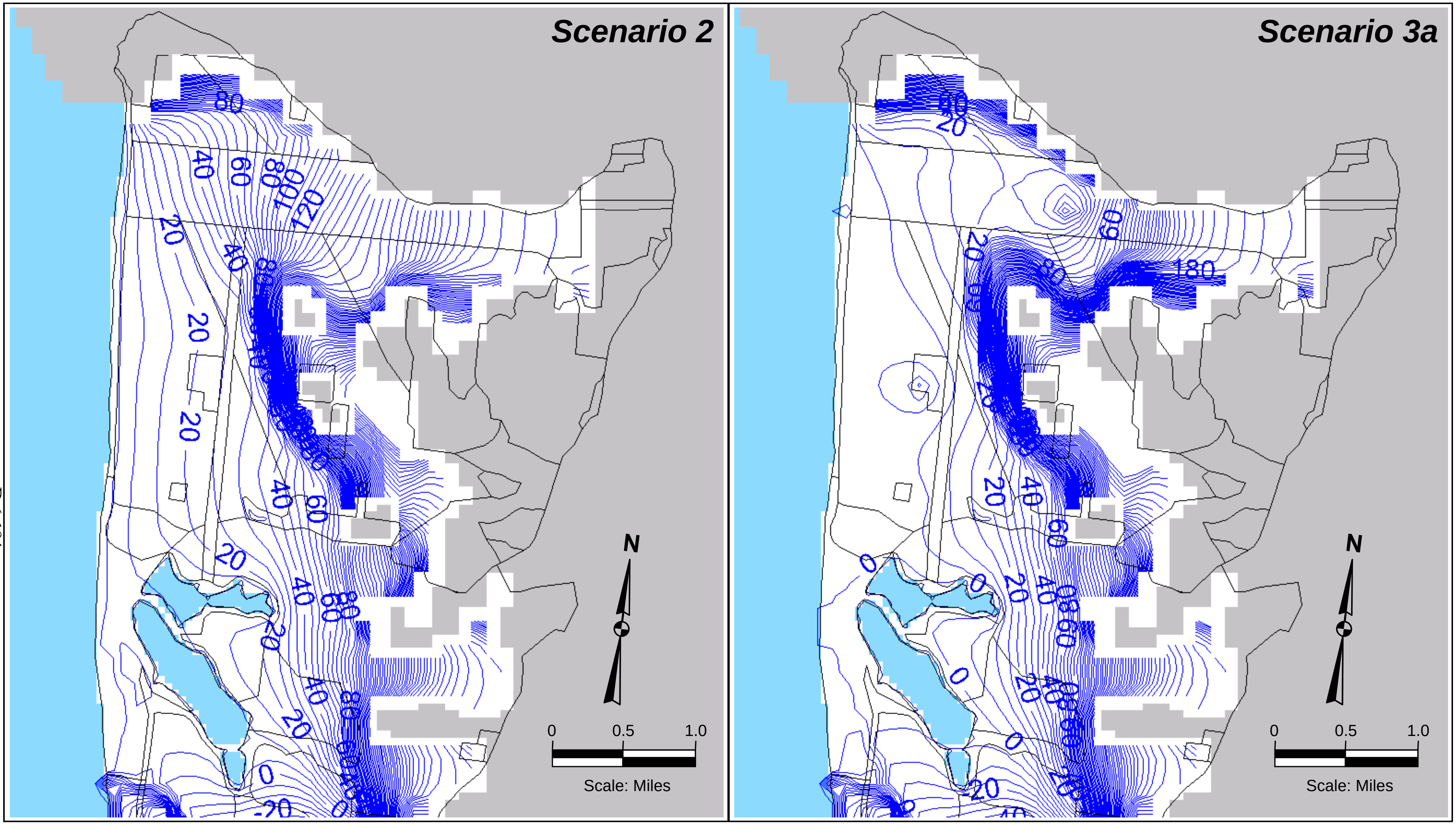

**Note: Elevations are in feet NGVD 29. Contour interval is 5 feet.**

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Water Table Elevation at End of Scenario 1 (Model Layer 1)**

K/J 0864001
April 2012
**Figure 10.3-18**



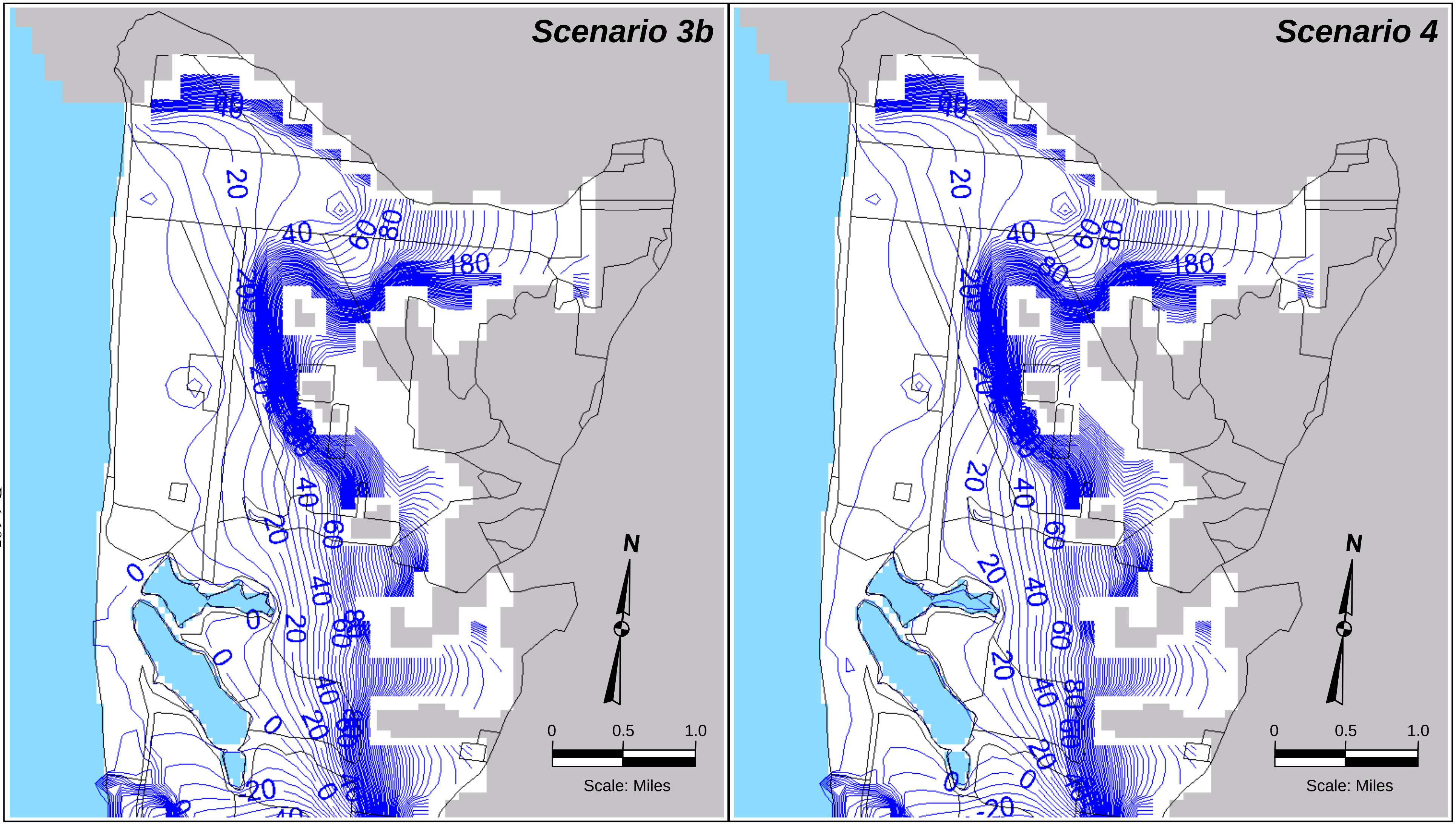

**Note: Elevations are in feet NGVD 29. Contour interval is 5 feet.**

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Water Table Elevation at End of Scenarios 2 and 3a (Model Layer 1)**

K/J 0864001
April 2012
**Figure 10.3-19**




**Note: Elevations are in feet NGVD 29. Contour interval is 5 feet.**

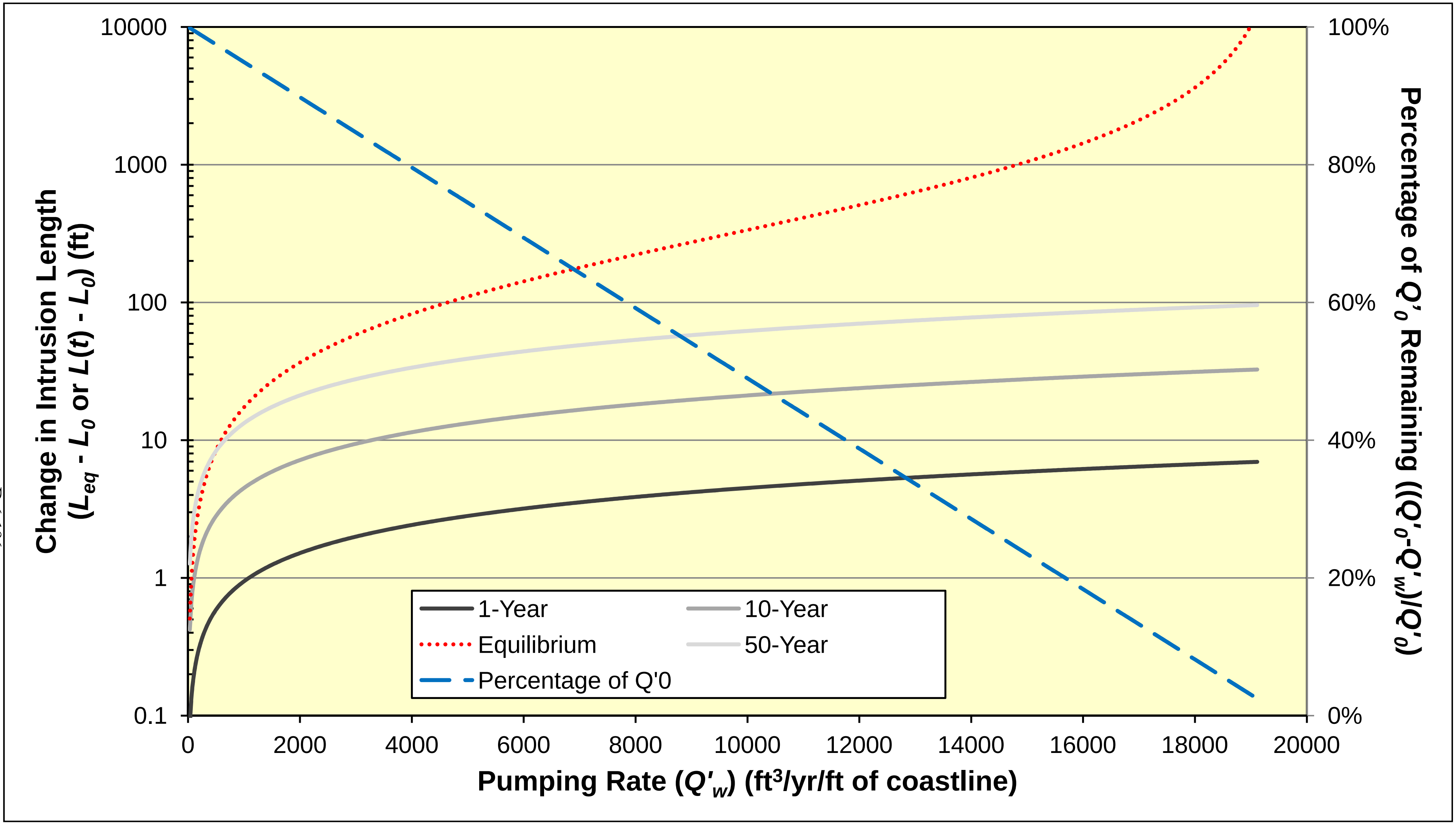
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Water Table Elevation at End of Scenarios 3b and 4 (Model Layer 1)**

K/J 0864001
April 2012

**Figure 10.3-20**



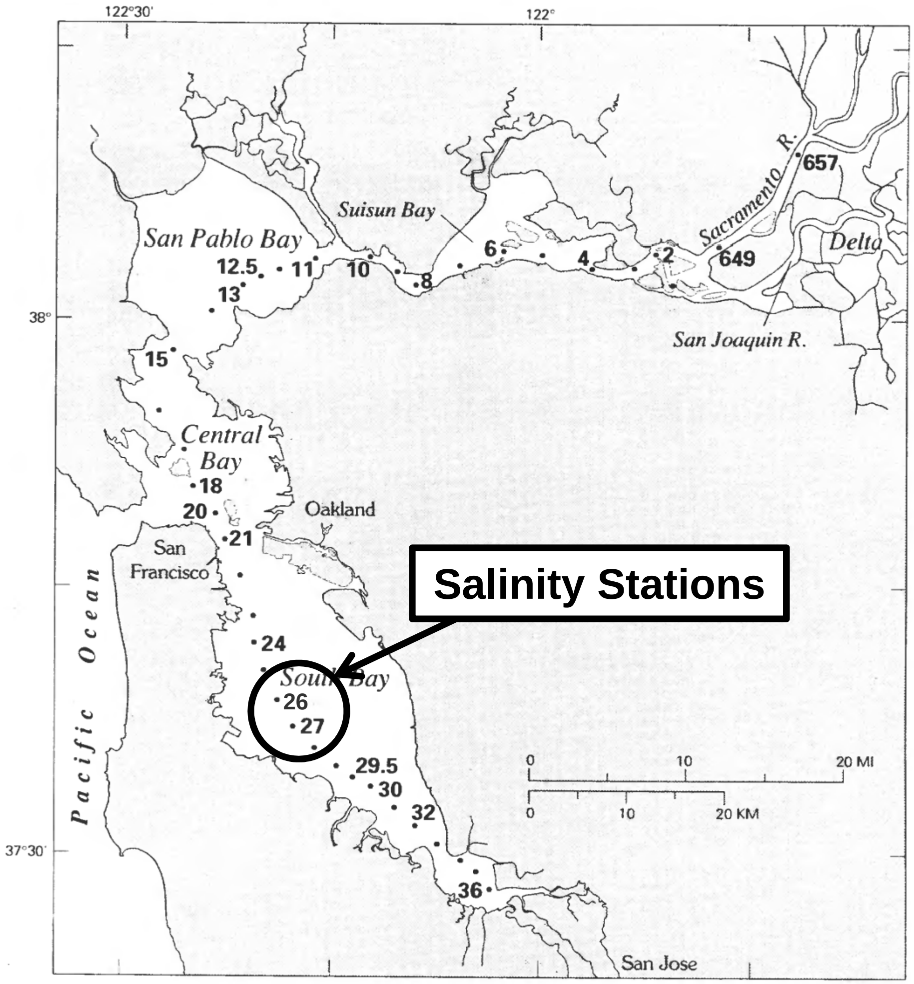

**Kennedy/Jenks Consultants**

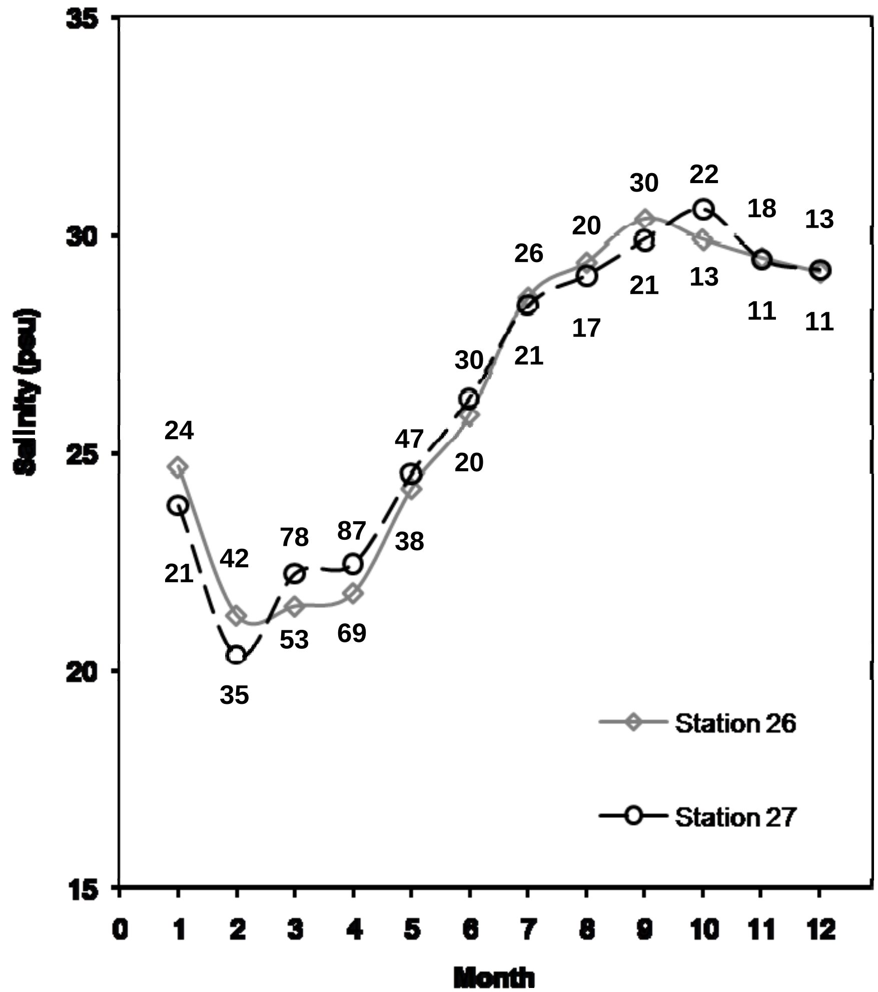
Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Analytical Model of Rate of Change of Intrusion Length versus Pumping**

K/J 0864001
April 2012

**Figure 10.3-21**




**Note: Data from the U.S. Geological Survey; see for example Baylosis et al. (1998). Period of record is 1969 to 1998. Readings are from 1 meter depth. Numbers above the data are the number of records for Station 26, while numbers below the data are the number of records for Station 27. Map is modified from Baylosis et al. (1998).**

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Monthly Salinity in the South San Francisco Bay**

K/J 0864001
April 2012
**Figure 10.3-22**

# Tables

## Table 10.3-1: Summary of Model Scenario Pumping Assumptions

| Model Scenarios | | Scenario 1<br>Existing Conditions | Scenario 2<br>GSR | Scenario 3a<br>SFGW | Scenario 3b<br>SFGW | Scenario 4<br>Cumulative |
|---|---|---|---|---|---|---|
| **Establish Initial Conditions** | | Hydrologic Sequence | Hydrologic Sequence | Hydrologic Sequence | Hydrologic Sequence | Hydrologic Sequence |
| | June 2009 Condition | √ | √ | √ | √ | √ |
| **Model Scenario Simulation Period** | | | | | | |
| | 47.25 years (including Design Drought)<br>Hydrologic Sequence:<br>July 1996 to September 2003 -><br>October 1958 to November 1992 -><br>December 1975 to June 1978 -><br>July 2003 - September 2006 | | √ | √ | √ | √ |
| **Pumping Assumptions for Municipal Use** | | | | | | |
| **PA Municipal Wells (mgd)** | | | | | | |
| | "Take" Periods | 6.84 | 6.90 | 6.84 | 6.84 | 6.90 |
| | "Put" Periods | 6.84 | 1.38 | 6.84 | 6.84 | 1.38 |
| | "Hold" Periods | 6.84 | 6.90 | 6.84 | 6.84 | 6.90 |
| **GSR Project Proposed Municipal Wells (mgd)** | | | | | | |
| | "Take" Periods | 0.0 | 7.23 | 0.0 | 0.0 | 7.23 |
| | "Put" Periods | 0.0 | 0.04 | 0.0 | 0.0 | 0.04 |
| | "Hold" Periods | 0.0 | 0.04 | 0.0 | 0.0 | 0.04 |
| **SFGW Project Proposed Municipal Wells (mgd)** | | | | | | |
| | Year-Round Pumping | 0.0 | 0.0 | 3.0 | 4.0 | 4.0 |
| ***Total Municipal Pumping (PA + GSR + SFGW)*** | | | | | | |
| | ***"Take" Periods*** | ***6.84*** | ***14.13*** | ***9.84*** | ***10.84*** | ***18.13*** |
| | ***"Put" Periods*** | ***6.84*** | ***1.42*** | ***9.84*** | ***10.84*** | ***5.42*** |
| | ***"Hold" Periods*** | ***6.84*** | ***6.94*** | ***9.84*** | ***10.84*** | ***10.94*** |
| **Irrigation and Other Non-Potable Pumping Assumptions (mgd)(1)** | | | | | | |
| Golden Gate Park | Elk Glen (GGP) | 0.081 | 0.081 | 0.081 | 0.000 | 0.000 |
| | South Windmill (GGP) | 0.498 | 0.498 | 0.498 | 0.000 | 0.000 |
| | North Lake (GGP) | 0.563 | 0.563 | 0.563 | 0.000 | 0.000 |
| | ***Sub-Total*** | ***1.142*** | ***1.142*** | ***1.142*** | ***0.000*** | ***0.000*** |
| Golf Courses | Burlingame Golf Club | 0.150 | 0.150 | 0.150 | 0.150 | 0.150 |
| | California Golf No. 02 | 0.192 | 0.192 | 0.192 | 0.192 | 0.192 |
| | Green Hills No. 05 | 0.099 | 0.099 | 0.099 | 0.099 | 0.099 |
| | Lake Merced Golf No. 01 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| | Lake Merced Golf No. 02 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| | Lake Merced Golf No. 03 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 |
| | Olympic Club No. 09(2) | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| | SF Golf West | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |
| | ***Sub-Total*** | ***0.495*** | ***0.495*** | ***0.495*** | ***0.495*** | ***0.495*** |
| Cemeteries | Cypress Lawn No. 02 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| | Cypress Lawn No. 03 | 0.144 | 0.144 | 0.144 | 0.144 | 0.144 |
| | Eternal Home | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 |
| | Hills of Eternity No. 02 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| | Holy Cross No. 03(3) | 0.190 | 0.190 | 0.190 | 0.190 | 0.230 |
| | Home of Peace No. 02 | 0.039 | 0.039 | 0.039 | 0.039 | 0.039 |
| | Italian Cemetery | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 |
| | Olivet | 0.098 | 0.098 | 0.098 | 0.098 | 0.098 |
| | Woodlawn No. 02 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 |
| | ***Sub-Total*** | ***0.641*** | ***0.641*** | ***0.641*** | ***0.641*** | ***0.681*** |
| Other | Hillsborough Residents No. 1-12 | 0.291 | 0.291 | 0.291 | 0.291 | 0.291 |
| | Edgewood Development Ctr. | 0.009 | 0.009 | 0.009 | 0.009 | 0.009 |
| | Zoo No.05 | 0.321 | 0.321 | 0.321 | 0.321 | 0.321 |
| | Stern Grove | 0.004 | 0.004 | 0.012 | 0.013 | 0.013 |
| | ***Sub-Total*** | ***0.626*** | ***0.626*** | ***0.634*** | ***0.635*** | ***0.635*** |
| ***Total Irrigation and Other Non-Potable Pumping*** | | ***2.90*** | ***2.90*** | ***2.91*** | ***1.77*** | ***1.81*** |

Key:
afy - acre-feet per year
mgd - million gallons per day
PA - Partner Agencies
GGP - Golden Gate Park
GSR - Regional Groundwater Storage and Recovery
SFGW - San Francisco Groundwater Supply
SFPUC - San Francisco Public Utilities Commission

Notes:
(1) Pumping wells that are listed identify the wells in the model scenarios whose pumping assumptions were modified compared to the 2008 No-Project Scenario by HydroFocus (May, 2011, ver. 3.1), as a result of revised Soil Moisture Budget (SMB). Pumping rates for the three wells in GGP and the California Golf No. 02, Edgewood Development Center, Zoo No. 05, and Stern Grove wells were further modified compared to the results of revised SMB.
(2) Olympic Club No. 09 values include pumping for both Olympic Golf Club wells.
(3) Holy Cross No. 3 well irrigation pumping for Scenarios 1, 2, 3a, and 3b is based on the results of revised SMB. Based on the projected future build-out at the Holy Cross cemetery, an additional pumping of 0.04 mgd (45 afy) was estimated to occur under Scenario 4 (Cumulative).

# Table 10.3-2a: Statistics for Relative Differences Between Model Scenario Groundwater Head and Scenario 1 Head in Model Layer 1

| | Scenario | 2 | | | | 3a | | | | 3b | | | | 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | Maximum Difference[a] | Minimum Difference[b] | Avgerage Difference[c] | Average Offset[d] | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset |
| Pacific Coast | North Windmill | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | -12.4 | -10.2 | -12.2 | 0.0 | -13.2 | -10.5 | -12.1 | 0.0 | -13.1 | -10.4 | -12.0 |
| | South Windmill | 0.1 | -0.1 | 0.1 | 0.0 | 0.0 | -9.7 | -7.9 | -9.5 | 0.3 | -11.5 | -8.9 | -10.1 | 0.3 | -11.4 | -8.7 | -9.9 |
| | Kirkham | 0.2 | -0.1 | 0.1 | 0.0 | 0.0 | -6.8 | -5.6 | -6.6 | 0.2 | -6.9 | -5.5 | -6.4 | 0.2 | -6.7 | -5.3 | -6.1 |
| | Ortega | 0.5 | -0.2 | 0.3 | 0.0 | 0.0 | -6.4 | -5.5 | -6.3 | 0.0 | -6.1 | -5.3 | -6.0 | 0.0 | -5.6 | -4.7 | -5.4 |
| | West Sunset Playground | 1.3 | -0.2 | 0.8 | 0.5 | -4.0 | -23.8 | -20.9 | -23.0 | -3.7 | -22.4 | -19.8 | -21.6 | -3.7 | -20.3 | -18.0 | -19.4 |
| | Taraval | 0.6 | -0.1 | 0.4 | 0.2 | 0.0 | -5.2 | -4.4 | -5.1 | 0.0 | -4.9 | -4.2 | -4.8 | 0.0 | -4.1 | -3.4 | -3.8 |
| | Zoo | 2.7 | -0.4 | 1.6 | 0.9 | 0.0 | -7.2 | -5.3 | -7.1 | 0.0 | -6.9 | -5.1 | -6.8 | 0.0 | -3.0 | -1.4 | -2.3 |
| | Fort Funston | 0.1 | -0.1 | 0.0 | 0.0 | 0.0 | -0.1 | -0.1 | -0.1 | 0.0 | -0.1 | -0.1 | -0.1 | 0.1 | -0.2 | 0.0 | -0.1 |
| | Thornton Beach | 0.5 | 0.0 | 0.3 | 0.3 | 0.0 | -0.3 | -0.1 | -0.3 | 0.0 | -0.3 | -0.1 | -0.3 | 0.2 | -1.0 | -0.1 | -0.6 |
| Bay Coast | Burlingame | 1.3 | 0.0 | 0.8 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.7 | 0.8 |
| | SFO | 3.1 | 0.0 | 2.0 | 2.5 | 0.0 | -0.1 | 0.0 | -0.1 | 0.0 | -0.1 | 0.0 | -0.1 | 3.0 | 0.0 | 2.0 | 2.5 |
| | UAL | 2.4 | -0.2 | 1.4 | 1.0 | 0.0 | -0.1 | 0.0 | 0.0 | 0.0 | -0.1 | 0.0 | 0.0 | 2.4 | -0.2 | 1.4 | 1.0 |

Notes: (a) Maximum positive difference from Scenario 1. If this value is negative, the head was lower than Scenario 1 at all times.
(b) Maximum negative difference from Scenario 1. If this value is positive, the head was higher than Scenario 1 at all times.
(c) Average difference from Scenario 1.
(d) Average difference from Scenario 1 over Scenario Years 37 to 47.

# Table 10.3-2b: Statistics for Relative Differences Between Model Scenario Groundwater Head and Scenario 1 Head in Model Layer 4

| | Scenario | 2 | | | | 3a | | | | 3b | | | | 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | Maximum Difference[a] | Minimum Difference[b] | Avgerage Difference[c] | Average Offset[d] | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset |
| Pacific Coast | North Windmill | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Pacific Coast | South Windmill | 0.1 | -0.1 | 0.1 | 0.0 | 0.0 | -7.3 | -6.0 | -7.1 | 2.3 | -7.7 | -5.1 | -6.0 | 2.3 | -7.6 | -4.9 | -5.8 |
| Pacific Coast | Kirkham | 0.3 | -0.2 | 0.2 | 0.0 | 0.0 | -5.5 | -4.6 | -5.4 | 0.5 | -5.5 | -4.3 | -5.0 | 0.5 | -5.3 | -4.0 | -4.7 |
| Pacific Coast | Ortega | 0.9 | -0.7 | 0.5 | -0.2 | 0.0 | -6.3 | -5.3 | -6.2 | 0.0 | -6.0 | -5.1 | -5.9 | 0.0 | -5.8 | -4.2 | -5.3 |
| Pacific Coast | West Sunset Playground | 2.5 | -1.6 | 1.3 | -0.2 | -0.1 | -12.2 | -10.2 | -11.9 | -0.1 | -11.7 | -9.8 | -11.5 | -0.1 | -10.6 | -7.2 | -9.3 |
| Pacific Coast | Taraval | 3.0 | -2.0 | 1.6 | -0.2 | -0.1 | -12.1 | -10.1 | -11.9 | -0.1 | -11.7 | -9.7 | -11.4 | -0.1 | -10.4 | -6.5 | -8.8 |
| Pacific Coast | Zoo | 6.1 | -4.3 | 3.3 | -0.4 | -0.1 | -18.9 | -15.4 | -18.5 | -0.1 | -18.3 | -14.9 | -17.9 | -0.1 | -16.0 | -8.5 | -12.6 |
| Pacific Coast | Fort Funston | 0.6 | -0.7 | 0.2 | -0.3 | 0.0 | -0.4 | -0.3 | -0.4 | 0.0 | -0.4 | -0.3 | -0.4 | 0.4 | -1.2 | -0.2 | -0.8 |
| Pacific Coast | Thornton Beach | 1.2 | -1.4 | 0.3 | -0.7 | 0.0 | -0.3 | -0.2 | -0.3 | 0.0 | -0.3 | -0.2 | -0.3 | 1.0 | -2.6 | -0.5 | -1.8 |
| Bay Coast | Burlingame | 2.3 | -0.6 | 1.3 | 0.7 | 0.0 | -0.1 | 0.0 | 0.0 | 0.0 | -0.1 | 0.0 | -0.1 | 2.2 | -0.7 | 1.2 | 0.7 |
| Bay Coast | SFO | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Bay Coast | UAL | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Notes: (a) Maximum positive difference from Scenario 1. If this value is negative, the head was lower than Scenario 1 at all times.
(b) Maximum negative difference from Scenario 1. If this value is positive, the head was higher than Scenario 1 at all times.
(c) Average difference from Scenario 1.
(d) Average difference from Scenario 1 over Scenario Years 37 to 47.

# Table 10.3-2c: Statistics for Relative Differences Between Model Scenario Groundwater Head and Scenario 1 Head in Model Layer 5

D.6-112

| | Scenario | 2 | | | | 3a | | | | 3b | | | | 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | Maximum Difference[a] | Minimum Difference[b] | Avgerage Difference[c] | Average Offset[d] | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset | Maximum Difference | Minimum Difference | Avgerage Difference | Average Offset |
| Pacific Coast | North Windmill | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Pacific Coast | South Windmill | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Pacific Coast | Kirkham | 0.3 | -0.2 | 0.2 | -0.1 | 0.0 | -5.0 | -4.2 | -5.0 | 0.5 | -5.1 | -3.9 | -4.5 | 0.5 | -4.8 | -3.6 | -4.3 |
| Pacific Coast | Ortega | 1.1 | -1.0 | 0.5 | -0.4 | 0.0 | -5.9 | -4.9 | -5.8 | 0.0 | -5.6 | -4.7 | -5.5 | 0.0 | -5.6 | -3.8 | -5.0 |
| Pacific Coast | West Sunset Playground | 3.4 | -3.6 | 0.8 | -1.7 | -0.1 | -7.0 | -5.9 | -6.9 | 0.0 | -6.7 | -5.6 | -6.6 | 0.0 | -8.5 | -3.9 | -6.8 |
| Pacific Coast | Taraval | 4.6 | -5.2 | 0.8 | -2.6 | 0.0 | -5.6 | -4.7 | -5.5 | 0.0 | -5.4 | -4.5 | -5.3 | 1.1 | -8.7 | -2.6 | -6.2 |
| Pacific Coast | Zoo | 12.2 | -14.4 | 1.5 | -7.5 | 0.0 | -6.4 | -5.2 | -6.3 | 0.0 | -6.2 | -5.0 | -6.1 | 8.5 | -16.9 | -1.3 | -10.3 |
| Pacific Coast | Fort Funston | 1.8 | -2.2 | 0.2 | -1.2 | 0.0 | -0.4 | -0.3 | -0.4 | 0.0 | -0.4 | -0.3 | -0.4 | 1.6 | -2.5 | 0.0 | -1.5 |
| Pacific Coast | Thornton Beach | 1.5 | -2.0 | 0.3 | -1.0 | 0.0 | -0.3 | -0.2 | -0.3 | 0.0 | -0.3 | -0.2 | -0.3 | 1.4 | -3.1 | -0.5 | -2.1 |
| Bay Coast | Burlingame | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Bay Coast | SFO | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Bay Coast | UAL | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Notes: (a) Maximum positive difference from Scenario 1. If this value is negative, the head was lower than Scenario 1 at all times.
(b) Maximum negative difference from Scenario 1. If this value is positive, the head was higher than Scenario 1 at all times.
(c) Average difference from Scenario 1.
(d) Average difference from Scenario 1 over Scenario Years 37 to 47.

# Table 10.3-3: Aquifer Thicknesses and Exclusion Head Values at Westside Basin Coastal Monitoring Points

| | Well or Cluster | Single Aquifer | | Multi-Aquifer | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Shallow | | Primary Production | | Deep | |
| | | $b$ [a] | $E_h$ [b] | $b$ | $E_h$ | $b+d$ [c] | $E_h$ | $b+d$ | $E_h$ |
| Pacific Coast | North Windmill | 270 | 7.0 | 100 | 2.6 | 270 | 7.0 | -- | -- |
| Pacific Coast | South Windmill | 360 | 9.4 | 120 | 3.1 | 360 | 9.4 | -- | -- |
| Pacific Coast | Kirkham | 450 | 11.7 | 110 | 2.9 | 310 | 8.1 | 450 | 11.7 |
| Pacific Coast | Ortega | 490 | 12.7 | 100 | 2.6 | 340 | 8.8 | 490 | 12.7 |
| Pacific Coast | West Sunset Playground | 400 | 10.4 | 70 | 1.8 | 340 | 8.8 | 400 | 10.4 |
| Pacific Coast | Taraval | 550 | 14.3 | 130 | 3.4 | 390 | 10.1 | 550 | 14.3 |
| Pacific Coast | Zoo | 630 | 16.4 | 80 | 2.1 | 400 | 10.4 | 630 | 16.4 |
| Pacific Coast | Fort Funston | 1200 | 31.2 | -- | -- | -- | -- | -- | -- |
| Pacific Coast | Thornton Beach | 3000 | 78.0 | -- | -- | -- | -- | -- | -- |
| Bay Coast | Burlingame | 308 | 8.0 | -- | -- | -- | -- | -- | -- |
| Bay Coast | SFO | 155 | 4.0 | -- | -- | -- | -- | -- | -- |
| Bay Coast | UAL | 155 | 4.0 | -- | -- | -- | -- | -- | -- |

Notes:

(a) *b* = Depth (below sea level) of aquifer bottom (for Single-Aquifer and Shallow Aquifer cases), or aquifer thickness (for Primary Production and Deep Aquifer cases) (see Figure 10.3-3).
(b) *Eh* = Exclusion head, defined in Section 3.5.1.
(c) *d* = Depth (below sea level) of bottom of the confining unit (see Figure 10.3-3).

# Table 10.3-4: Seasonal Fluctuation in Head for Model Layers 1, 4, and 5 at the Pacific Ocean and San Francisco Bay Monitoring Network Wells

| Scenario | 1 | | | 2 | | | 3a | | | 3b | | | 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Layer / Location | 1 | 4 | 5 | 1 | 4 | 5 | 1 | 4 | 5 | 1 | 4 | 5 | 1 | 4 | 5 |
| North Windmill | 1.7 | -- | -- | 1.7 | -- | -- | 1.6 | -- | -- | 0.8 | -- | -- | 0.8 | -- | -- |
| South Windmill | 0.7 | -0.7 | -- | 0.7 | -0.7 | -- | 0.6 | -0.8 | -- | 0.7 | 0.3 | -- | 0.7 | 0.3 | -- |
| Kirkham | 0.9 | 0.3 | 0.3 | 0.9 | 0.3 | 0.3 | 0.9 | 0.3 | 0.2 | 0.6 | 0.3 | 0.2 | 0.6 | 0.3 | 0.2 |
| Ortega | 0.6 | 0.3 | 0.3 | 0.6 | 0.3 | 0.3 | 0.6 | 0.3 | 0.2 | 0.6 | 0.2 | 0.2 | 0.6 | 0.2 | 0.2 |
| West Sunset Playground | 0.7 | 0.3 | 0.1 | 0.7 | 0.3 | 0.1 | 0.5 | 0.3 | 0.1 | 0.5 | 0.2 | 0.0 | 0.5 | 0.3 | 0.1 |
| Taraval | 0.5 | 0.4 | -0.1 | 0.5 | 0.3 | -0.1 | 0.5 | 0.3 | -0.1 | 0.5 | 0.3 | -0.2 | 0.5 | 0.3 | -0.2 |
| Zoo | 1.3 | 0.3 | -0.5 | 1.3 | 0.2 | -0.5 | 1.2 | 0.1 | -0.6 | 1.2 | 0.1 | -0.6 | 1.3 | 0.2 | -0.5 |
| Fort Funston | 1.3 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 |
| Thornton Beach | 0.6 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 |
| Burlingame | 0.0 | -0.1 | -- | 0.0 | -0.1 | -- | 0.0 | -0.1 | -- | 0.0 | -0.1 | -- | 0.0 | -0.1 | -- |
| SFO | 0.1 | -- | -- | 0.1 | -- | -- | 0.1 | -- | -- | 0.1 | -- | -- | 0.1 | -- | -- |
| UAL | 0.0 | -- | -- | 0.0 | -- | -- | 0.0 | -- | -- | 0.0 | -- | -- | 0.0 | -- | -- |

Note:
Table cells containing "--" indicate that this Model Layer is not present in this location. Seasonal fluctuation is defined as the average difference between May head (generally representing the highest head annually) and November head (generally representing the lowest head annually).

# Table 10.3-5: Model-Predicted Flux Through the Pacific Ocean and San Francisco Bay Coasts, Both Absolute and Relative to Scenario 1 (in acre-feet per month)

| | Location | Scenario | 1 | 2 | 3a | 3b | 4 |
|---|---|---|---|---|---|---|---|
| Absolute | Pacific | AMax[a] | 432 | 435 | 367 | 351 | 352 |
| | | AMin[b] | 149 | 146 | 9 | 9 | 15 |
| | | AAvg[c] | 255 | 273 | 75 | 77 | 103 |
| | Bay | AMax | 108 | 111 | 108 | 108 | 109 |
| | | AMin | 82 | 72 | 80 | 80 | 47 |
| | | AAvg | 93 | 96 | 91 | 91 | 80 |
| Relative | Pacific | RMax[d] | -- | 29 | -1 | 14 | 14 |
| | | RMin[e] | -- | -8 | -237 | -241 | -209 |
| | | RAvg[f] | -- | 17 | -181 | -179 | -153 |
| | Bay | RMax | -- | 8 | 0 | 0 | 4 |
| | | RMin | -- | -11 | -2 | -2 | -35 |
| | | RAvg | -- | 3 | -1 | -1 | -13 |

Notes:

(a) Maximum absolute freshwater flux.

(b) Minimum absolute freshwater flux.

(c) Average absolute freshwater flux.

(d) Maximum flux difference from Scenario 1; if this value is negative, flux is always lower than in Scenario 1.

(e) Minimum flux difference from Scenario 1; if this value is positive, flux is always higher than in Scenario 1.

(f) Average flux difference from Scenario 1.

# Table 10.3-6a: Percentage of Simulation Duration Below the Freshwater Exclusion Head (Model Layer 1)

| | Single-Aquifer Case | | | | | |
|---|---|---|---|---|---|---|
| | **Location** | **Scenario 1** | **Scenario 2** | **Scenario 3a** | **Scenario 3b** | **Scenario 4** |
| **Pacific Coast** | North Windmill | 0% | 0% | **57%** | **60%** | **59%** |
| | South Windmill | **33%** | **31%** | **95%** | **98%** | **98%** |
| | Kirkham | 100% | 100% | 100% | 100% | 100% |
| | Ortega | 100% | 100% | 100% | 100% | 100% |
| | West Sunset Playground | 0% | 0% | **99%** | **99%** | **99%** |
| | Taraval | 100% | 100% | 100% | 100% | 100% |
| | Zoo | 100% | 100% | 100% | 100% | 100% |
| | Fort Funston | 100% | 100% | 100% | 100% | 100% |
| | Thornton Beach | **63%** | **61%** | **64%** | **64%** | **64%** |
| **Bay Coast** | Burlingame | 100% | 100% | 100% | 100% | 100% |
| | SFO | 100% | 100% | 100% | 100% | 100% |
| | UAL | **10%** | **7%** | **11%** | **11%** | **7%** |

| | Shallow Aquifer | | | | | |
|---|---|---|---|---|---|---|
| | **Location** | **Scenario 1** | **Scenario 2** | **Scenario 3a** | **Scenario 3b** | **Scenario 4** |
| **Pacific Coast** | North Windmill | 0% | 0% | **5%** | **4%** | **4%** |
| | South Windmill | 0% | 0% | **73%** | **85%** | **83%** |
| | Kirkham | 0% | 0% | **77%** | **75%** | **66%** |
| | Ortega | 0% | 0% | **89%** | **89%** | **83%** |
| | West Sunset Playground | 0% | 0% | **90%** | **90%** | **85%** |
| | Taraval | 0% | 0% | **91%** | **91%** | **86%** |
| | Zoo | 0% | 0% | **35%** | **30%** | **0%** |
| | Fort Funston | -- | -- | -- | -- | -- |
| | Thornton Beach | -- | -- | -- | -- | -- |
| **Bay Coast** | Burlingame | -- | -- | -- | -- | -- |
| | SFO | -- | -- | -- | -- | -- |
| | UAL | -- | -- | -- | -- | -- |

Notes:

(1) Percentage represents the percentage of timesteps (i.e. months) with head below the exclusion head (see Section 3.5.1).

(2) -- = Model Layer is not present at this location.

# Table 10.3-6b: Percentage of Simulation Duration Below the Freshwater Exclusion Head (Model Layer 4)

| | Single-Aquifer Case | | | | | |
|---|---|---|---|---|---|---|
| | Location | Scenario 1 | Scenario 2 | Scenario 3a | Scenario 3b | Scenario 4 |
| Pacific Coast | North Windmill | -- | -- | -- | -- | -- |
| | South Windmill | **99%** | **99%** | 100% | 100% | 100% |
| | Kirkham | 100% | 100% | 100% | 100% | 100% |
| | Ortega | 100% | 100% | 100% | 100% | 100% |
| | West Sunset Playground | 100% | 100% | 100% | 100% | 100% |
| | Taraval | 100% | 100% | 100% | 100% | 100% |
| | Zoo | 100% | 100% | 100% | 100% | 100% |
| | Fort Funston | 100% | 100% | 100% | 100% | 100% |
| | Thornton Beach | 100% | 100% | 100% | 100% | 100% |
| Bay Coast | Burlingame | 100% | 100% | 100% | 100% | 100% |
| | SFO | -- | -- | -- | -- | -- |
| | UAL | -- | -- | -- | -- | -- |

| | Primary Production Aquifer | | | | | |
|---|---|---|---|---|---|---|
| | Location | Scenario 1 | Scenario 2 | Scenario 3a | Scenario 3b | Scenario 4 |
| Pacific Coast | North Windmill | -- | -- | -- | -- | -- |
| | South Windmill | **99%** | **99%** | 100% | 100% | 100% |
| | Kirkham | 100% | 100% | 100% | 100% | 100% |
| | Ortega | 100% | 100% | 100% | 100% | 100% |
| | West Sunset Playground | 100% | 100% | 100% | 100% | 100% |
| | Taraval | 100% | 100% | 100% | 100% | 100% |
| | Zoo | 100% | 100% | 100% | 100% | 100% |
| | Fort Funston | -- | -- | -- | -- | -- |
| | Thornton Beach | -- | -- | -- | -- | -- |
| Bay Coast | Burlingame | -- | -- | -- | -- | -- |
| | SFO | -- | -- | -- | -- | -- |
| | UAL | -- | -- | -- | -- | -- |

Notes:

(1) Percentage represents the percentage of timesteps (i.e. months) with head below the exclusion head (see Section 3.5.1).

(2) -- = Model Layer is not present at this location.

# Table 10.3-6c: Percentage of Simulation Duration Below the Freshwater Exclusion Head (Model Layer 5)

**Single-Aquifer Case**

| | Location | Scenario 1 | Scenario 2 | Scenario 3a | Scenario 3b | Scenario 4 |
|---|---|---|---|---|---|---|
| Pacific Coast | North Windmill | -- | -- | -- | -- | -- |
| | South Windmill | -- | -- | -- | -- | -- |
| | Kirkham | 100% | 100% | 100% | 100% | 100% |
| | Ortega | 100% | 100% | 100% | 100% | 100% |
| | West Sunset Playground | 100% | 100% | 100% | 100% | 100% |
| | Taraval | 100% | 100% | 100% | 100% | 100% |
| | Zoo | 100% | 100% | 100% | 100% | 100% |
| | Fort Funston | 100% | 100% | 100% | 100% | 100% |
| | Thornton Beach | 100% | 100% | 100% | 100% | 100% |
| Bay Coast | Burlingame | -- | -- | -- | -- | -- |
| | SFO | -- | -- | -- | -- | -- |
| | UAL | -- | -- | -- | -- | -- |

**Deep Aquifer**

| | Location | Scenario 1 | Scenario 2 | Scenario 3a | Scenario 3b | Scenario 4 |
|---|---|---|---|---|---|---|
| Pacific Coast | North Windmill | -- | -- | -- | -- | -- |
| | South Windmill | -- | -- | -- | -- | -- |
| | Kirkham | 100% | 100% | 100% | 100% | 100% |
| | Ortega | 100% | 100% | 100% | 100% | 100% |
| | West Sunset Playground | 100% | 100% | 100% | 100% | 100% |
| | Taraval | 100% | 100% | 100% | 100% | 100% |
| | Zoo | 100% | 100% | 100% | 100% | 100% |
| | Fort Funston | -- | -- | -- | -- | -- |
| | Thornton Beach | -- | -- | -- | -- | -- |
| Bay Coast | Burlingame | -- | -- | -- | -- | -- |
| | SFO | -- | -- | -- | -- | -- |
| | UAL | -- | -- | -- | -- | -- |

Notes:

(1) Percentage represents the percentage of timesteps (i.e. months) with head below the exclusion head (see Section 3.5.1).

(2) -- = Model Layer is not present at this location.

# Table 10.3-7: Descriptions, Values, and Sources for Parameters Used in Analytical Rate Estimation Model (see Section 7.1)

| Parameter | Type | Description | Value | Units | Source |
|---|---|---|---|---|---|
| $b_u$ | parameter | Thickness of the unconfined aquifer below sea level | 360 | feet | LSCE, 2010 |
| $b_c$ | parameter | Thickness of the confined aquifer | 240 | feet | LSCE, 2010 |
| d | parameter | Depth to the top of the confined aquifer below sea level | 120 | feet | LSCE, 2010 |
| $n_e$ | parameter | Effective (or available) porosity | 0.2 | -- | CH2MHILL, 1995 |
| x | variable | Horizontal location within the aquifer | -- | feet | -- |
| $h_f$ | calculated | Freshwater head above sea level at location x | -- | feet | -- |
| $K_h$ | parameter | Horizontal hydraulic conductivity of the aquifer | 3652.5 | ft/yr | CH2MHILL, 1995 |
| $\rho_f$ | constant | Density of fresh water | 1 | g/cm$^3$ | Standard |
| $\rho_s$ | constant | Density of salt water | 1.026 | g/cm$^3$ | Standard |
| $\alpha$ | constant | Elasticity of the aquifer materials | 1.00E-08 | Pa$^{-1}$ | Freeze and Cherry, 1979 |
| $\beta$ | constant | Compressibility of water | 4.40E-10 | Pa$^{-1}$ | Freeze and Cherry, 1979 |
| $S_s$ | parameter | Specific storage of the confined aquifer | 0.00002 | ft$^{-1}$ | Yates et al., 1990 |
| $Q'_0$ | parameter | Freshwater flux to the ocean per foot of shoreline prior to pumping | 19600 | ft$^3$/yr/ft of coastline | Yates et al., 1990 |
| $Q'_w$ | input | Rate of pumping per foot of shoreline | -- | ft$^3$/yr/ft of coastline | -- |
| $\Delta t$ | input | Time period over which pumping is applied | -- | years | -- |
| z | calculated | Depth to saltwater interface below sea level | -- | feet | -- |
| L | calculated | Length from the discharge point to the toe of the wedge | -- | feet | -- |

## Table 10.3-8: Average Water Quality for Westside Basin Monitoring Wells

| | Calcium | n | Magnesium | n | Sodium | n | Potassium | n | Total Alkalinity | n | Chloride | n | Sulfate | n | Specific Conductance | n | Total Dissolved Solids | n | Hardness as $CaCO_3$ | n | pH | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***North Westside Basin*** | | | | | | | | | | | | | | | | | | | | | | |
| Kirkham MW-130 | 28.5 | 3 | 25.8 | 3 | 26.3 | 3 | 1.5 | 3 | 123 | 3 | 33.3 | 13 | 33.5 | 3 | 447 | 14 | 258 | 14 | 172 | 4 | 8.0 | 4 |
| Kirkham MW-255 | 28.1 | 3 | 30.3 | 3 | 22.4 | 3 | 1.4 | 3 | 133 | 3 | 36.3 | 13 | 30.0 | 3 | 460 | 14 | 274 | 14 | 196 | 4 | 7.9 | 4 |
| Kirkham MW-385 | 56.1 | 3 | 7.4 | 3 | 25.8 | 3 | 4.9 | 3 | 119 | 3 | 34.6 | 13 | 64.2 | 3 | 455 | 14 | 285 | 14 | 166 | 4 | 8.1 | 4 |
| Kirkham MW-435 | 46.9 | 3 | 4.0 | 3 | 35.2 | 3 | 7.4 | 3 | 113 | 3 | 31.2 | 13 | 60.3 | 3 | 445 | 14 | 277 | 14 | 132 | 4 | 8.2 | 4 |
| Ortega MW-125 | 26.8 | 3 | 22.1 | 3 | 26.3 | 3 | 1.3 | 3 | 106 | 3 | 30.8 | 14 | 36.3 | 2 | 436 | 14 | 257 | 13 | 147 | 4 | 7.9 | 4 |
| Ortega MW-265 | 14.4 | 3 | 12.4 | 3 | 20.9 | 3 | 1.0 | 3 | 81 | 2 | 26.1 | 14 | 12.2 | 2 | 353 | 13 | 210 | 12 | 86 | 3 | 8.1 | 3 |
| Ortega MW-400 | 16.2 | 3 | 12.7 | 3 | 22.7 | 3 | 1.4 | 3 | 90 | 2 | 23.0 | 14 | 10.7 | 3 | 274 | 14 | 178 | 14 | 92 | 3 | 8.2 | 3 |
| Ortega MW-475 | 13.3 | 3 | 1.9 | 3 | 43.2 | 3 | 3.1 | 3 | 78 | 3 | 28.9 | 14 | 14.1 | 3 | 285 | 14 | 173 | 14 | 42 | 4 | 8.3 | 4 |
| Taraval MW-145 | 29.4 | 3 | 25.8 | 3 | 29.6 | 3 | 1.8 | 3 | 132 | 2 | 36.6 | 13 | 24.4 | 3 | 483 | 14 | 296 | 14 | 171 | 3 | 7.9 | 3 |
| Taraval MW-240 | 21.8 | 3 | 20.1 | 3 | 23.1 | 3 | 1.7 | 3 | 104 | 2 | 34.2 | 14 | 18.9 | 3 | 376 | 14 | 228 | 14 | 137 | 3 | 7.8 | 3 |
| Taraval MW-400 | 18.4 | 3 | 15.4 | 3 | 21.9 | 3 | 1.6 | 3 | 90 | 2 | 27.2 | 14 | 26.3 | 2 | 308 | 14 | 189 | 12 | 116 | 3 | 8.2 | 3 |
| Taraval MW-530 | 11.7 | 2 | 5.4 | 2 | 51.1 | 2 | 2.4 | 2 | 120 | 2 | 24.6 | 14 | 8.8 | 2 | 326 | 14 | 199 | 14 | 56 | 3 | 8.4 | 3 |
| Zoo MW-275 | 20.4 | 5 | 18.7 | 4 | 37.3 | 4 | 4.4 | 5 | 115 | 4 | 67.0 | 12 | 7.3 | 4 | 466 | 14 | 264 | 13 | 116 | 5 | 8.6 | 5 |
| Zoo MW-450 | 22.5 | 5 | 25.4 | 5 | 41.7 | 5 | 2.6 | 5 | 134 | 4 | 43.8 | 12 | 18.8 | 5 | 483 | 14 | 287 | 14 | 142 | 5 | 8.4 | 5 |
| Zoo MW-565 | 27.6 | 4 | 10.2 | 4 | 67.5 | 4 | 3.4 | 4 | 167 | 3 | 53.2 | 13 | 7.3 | 3 | 503 | 13 | 293 | 13 | 103 | 4 | 8.3 | 4 |
| SWM MW-57 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | 160.1 | 8 | 53.0 | 1 | 1191 | 8 | 667 | 7 | -- | 0 | -- | 0 |
| SWM MW-140 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | 60.8 | 8 | 39.0 | 1 | 675 | 8 | 381 | 7 | -- | 0 | -- | 0 |
| Edgewood School | 24.7 | 2 | 25.3 | 2 | 25.2 | 3 | 1.4 | 2 | 116 | 4 | 30.5 | 4 | 35.9 | 4 | 448 | 4 | 258 | 3 | 170 | 4 | 7.4 | 4 |
| Elk Glen 2 | 34.6 | 5 | 37.1 | 5 | 27.1 | 5 | 1.0 | 4 | 142 | 5 | 40.2 | 6 | 52.4 | 6 | 575 | 6 | 367 | 6 | 227 | 6 | 7.7 | 6 |
| LMMW1S | 60.4 | 4 | 90.4 | 4 | 102.1 | 4 | 2.8 | 4 | 317 | 4 | 252.5 | 4 | 108.3 | 4 | 1545 | 4 | 853 | 4 | 568 | 4 | 6.8 | 4 |
| LMMW1D | 30.0 | 2 | 45.0 | 2 | 47.5 | 2 | 3.2 | 2 | 161 | 2 | 105.0 | 2 | 27.5 | 2 | 781 | 2 | 435 | 2 | 265 | 2 | 7.9 | 2 |
| LMMW-2S | 40.0 | 4 | 32.7 | 4 | 59.5 | 4 | 2.9 | 4 | 214 | 4 | 95.0 | 4 | 30.5 | 4 | 777 | 4 | 417 | 4 | 260 | 4 | 7.5 | 4 |
| LMMW-2D | 41.1 | 4 | 33.6 | 4 | 58.9 | 4 | 3.2 | 4 | 222 | 4 | 95.3 | 4 | 30.4 | 4 | 790 | 4 | 432 | 4 | 258 | 4 | 7.5 | 4 |
| LMMW3S | 45.5 | 11 | 50.6 | 10 | 46.1 | 11 | 1.8 | 10 | 310 | 10 | 51.9 | 10 | 28.5 | 10 | 786 | 10 | 453 | 10 | 287 | 9 | 7.2 | 10 |
| LMMW3D | 29.8 | 11 | 32.1 | 11 | 42.0 | 11 | 1.9 | 10 | 180 | 10 | 76.5 | 11 | 13.3 | 11 | 600 | 11 | 339 | 11 | 204 | 10 | 7.6 | 11 |
| LMMW4SS | 37.1 | 2 | 41.5 | 2 | 33.0 | 2 | 1.7 | 2 | 194 | 1 | 55.5 | 1 | 44.5 | 1 | 624 | 1 | 464 | 1 | 244 | 1 | 7.3 | 1 |
| LMMW6D | 27.8 | 11 | 28.4 | 10 | 36.9 | 11 | 1.4 | 10 | 127 | 10 | 52.7 | 11 | 32.5 | 11 | 556 | 11 | 334 | 11 | 186 | 10 | 8.0 | 11 |
| LMMW7SS | 43.2 | 3 | 44.4 | 3 | 55.6 | 3 | 1.4 | 3 | 240 | 2 | 44.4 | 2 | 46.4 | 2 | 753 | 2 | 476 | 2 | 271 | 2 | 7.6 | 2 |
| (NE) Windmill | 28.6 | 1 | 36.2 | 1 | 30.6 | 1 | 1.7 | 1 | 174 | 2 | 48.0 | 2 | 36.0 | 2 | 575 | 2 | 269 | 2 | 221 | 2 | 7.5 | 2 |
| New GG Park (N) Lake | 26.0 | 4 | 31.6 | 4 | 27.8 | 4 | 1.1 | 4 | 143 | 4 | 42.7 | 4 | 27.5 | 4 | 505 | 4 | 304 | 4 | 193 | 4 | 7.6 | 4 |
| New GG Park (S) Windmi | 29.5 | 4 | 35.8 | 4 | 28.0 | 4 | 1.5 | 4 | 149 | 5 | 42.8 | 4 | 43.7 | 3 | 562 | 4 | 340 | 4 | 234 | 4 | 7.9 | 4 |
| (NW) Windmill | 20.0 | 1 | 24.3 | 1 | 24.6 | 1 | 1.3 | 1 | 140 | 3 | 42.7 | 3 | 20.0 | 3 | 467 | 3 | 173 | 2 | 174 | 3 | 7.8 | 3 |
| Olympic Club #8 | 38.5 | 1 | 39.7 | 1 | 46.0 | 1 | 2.0 | 1 | 189 | 1 | 84.0 | 1 | 30.5 | 1 | 685 | 1 | -- | 0 | -- | 0 | 8.1 | 1 |
| Pine Lake Prod Well | 32.7 | 1 | 33.4 | 1 | 36.4 | 1 | 1.1 | 1 | 144 | 1 | 35.3 | 1 | 37.0 | 1 | 565 | 1 | 336 | 1 | 244 | 1 | 7.2 | 1 |
| (S) Windmill | 26.5 | 3 | 29.1 | 3 | 26.1 | 3 | 1.4 | 3 | 133 | 4 | 40.3 | 5 | 26.7 | 5 | 476 | 5 | 262 | 4 | 185 | 5 | 7.7 | 5 |
| West Sunset Playground | 17.5 | 9 | 18.1 | 9 | 23.0 | 9 | 1.0 | 9 | 88 | 8 | 28.1 | 9 | 28.7 | 9 | 353 | 9 | 222 | 9 | 124 | 9 | 8.5 | 9 |
| (S) Sunset Playground | 30.2 | 3 | 32.6 | 3 | 36.8 | 3 | 1.3 | 3 | 159 | 2 | 41.7 | 3 | 33.0 | 3 | 573 | 3 | 366 | 3 | 205 | 3 | 7.4 | 3 |
| CPS MW-190 | 44.2 | 3 | 44.7 | 3 | 44.4 | 3 | 1.5 | 3 | 267 | 3 | 42.3 | 3 | 44.0 | 3 | 725 | 3 | 413 | 3 | 295 | 3 | 7.6 | 3 |
| CPS MW-270 | 29.9 | 3 | 23.0 | 3 | 46.0 | 3 | 1.5 | 3 | 171 | 3 | 70.3 | 3 | 9.7 | 3 | 552 | 3 | 297 | 3 | 168 | 3 | 7.9 | 3 |
| LMPS MW-155 | 26.7 | 4 | 25.0 | 4 | 36.5 | 3 | 2.2 | 4 | 106 | 4 | 38.6 | 3 | 45.7 | 3 | 492 | 2 | 317 | 4 | 175 | 3 | 7.7 | 4 |
| LMPS MW-270 | 24.2 | 4 | 17.6 | 4 | 55.9 | 4 | 1.5 | 4 | 127 | 4 | 43.7 | 3 | 34.7 | 3 | 522 | 3 | 323 | 4 | 134 | 4 | 7.8 | 3 |
| LMPS MW-440 | 19.3 | 4 | 21.2 | 4 | 30.8 | 4 | 1.3 | 4 | 109 | 4 | 50.3 | 3 | 8.0 | 3 | 412 | 3 | 247 | 4 | 135 | 4 | 8.2 | 4 |
| ***South Westside Basin*** | | | | | | | | | | | | | | | | | | | | | | |
| Burlingame-S | 49.5 | 9 | 33.3 | 9 | 423 | 9 | 5.0 | 9 | 240 | 9 | 342 | 9 | 448 | 9 | 2,401 | 8 | 1,393 | 9 | -- | 0 | 7.3 | 8 |
| Burlingame-M | 31.4 | 9 | 19.0 | 9 | 69.7 | 9 | 3.1 | 9 | 181 | 9 | 82.3 | 9 | 61.9 | 9 | 656 | 8 | 464 | 9 | -- | 0 | 7.2 | 8 |
| Burlingame-D | 35.6 | 9 | 20.9 | 9 | 83.2 | 9 | 4.6 | 9 | 206 | 9 | 64.1 | 9 | 43.3 | 9 | 596 | 8 | 402 | 9 | -- | 0 | 7.3 | 8 |
| SFO-D | 55.0 | 9 | 34.3 | 9 | 179 | 8 | 9.2 | 9 | 234 | 9 | 609 | 9 | 76.4 | 9 | 2,036 | 9 | 1,202 | 9 | -- | 0 | 7.5 | 8 |
| SFO-S | 423.7 | 9 | 519.7 | 9 | 4,689 | 9 | 66.9 | 9 | 610 | 9 | 9,910 | 9 | 802 | 9 | 30,757 | 7 | 16,300 | 8 | -- | 0 | 7.3 | 9 |

Notes:

(1) Data from SFPUC 2010 Annual Groundwater Monitoring Report (SFPUC, 2011). Data marked "anomalous or questionable result" were removed from these averages.

(2) n is the number of samples included in the average.

(3) All analytes except Specific Conductance and pH are reported in units of milligrams per liter; Specific Conductance is reported in micromhos per centimeter, while pH is reported in pH units.

# Attachment A

## Analytical Approach

# Attachment A: Analytical Approach

## A. Analytical Approach

Because the numerical groundwater model is not perfectly suited to simulating the occurrence of seawater intrusion, an analytical approach to the problem of seawater intrusion is also applied in this section. This method combines a physical treatment of the relation between freshwater head and the depth to the seawater interface with a Darcy's Law approach to relating freshwater flux to the location of the interface. This approach does not explicitly deal with the problem of the transition zone (i.e., it assumes a sharp interface). It should be noted that the analytical solutions presented here deal with simplified aquifer constructions, and are not meant to exactly model reality, but rather provide another useful estimate of the future occurrence of seawater intrusion under a variety of conditions.

### A.1. Ghyben-Herzberg Relation

The analytical solution to seawater intrusion was first developed in the late nineteenth (Badon-Ghyben, 1888) and early twentieth (Herzberg, 1901) centuries. Independently of each other, these two investigators found that the seawater-freshwater interface in coastal aquifers occurs at a depth below sea level about 38 times the freshwater head at a given location (Cheng and Ouazar, 1999). This is due to the difference in densities between seawater and freshwater.

Assuming that the seawater and freshwater zones are in approximate hydrostatic equilibrium, the pressure in each zone is defined based on the head in the aquifer:

$$p_s = zg\rho_s$$

$$p_f = g\rho_f\left(z + h_f\right)$$

where $p_s$ is the pressure on the seawater side of the interface, $z$ is the depth (below msl) to the interface, $g$ is the acceleration due to gravity, $\rho_s$ is the density of seawater, $p_f$ is the pressure on the freshwater side of the interface, $\rho_f$ is the density of freshwater, and $h_f$ is the water table elevation (height above msl). Because the pressure must be the same on both sides of this interface, these two equations can be related:

$$zg\rho_s = g\rho_f\left(z + h_f\right)$$

$$z = \frac{\rho_f}{\rho_s - \rho_f} h_f$$

With standard values of density for freshwater (1.0 g/cm$^3$) and seawater (1.026 g/cm$^3$), this equates to:

$$z = 38h_f$$

With this proportionality in mind, a schematic of a simplified aquifer can be constructed (Figure 10.3-3). The shape of the head profile in this schematic is dictated by the flux through the aquifer and the hydraulic conductivity (see Section A.3.4); the seawater-freshwater interface and the freshwater head gradient both steepen approaching the discharge point because the freshwater flux (which is assumed to be equal at all horizontal locations up to the discharge point) must pass through a progressively smaller thickness of freshwater aquifer. According to Darcy's law (see Section A.3.4), the flux is proportional to the product of the aquifer thickness and the head gradient, so as the freshwater aquifer thickness declines the head gradient must increase to compensate.

For this simplified treatment of a coastal aquifer, a number of assumptions are made:

- Flow is steady, i.e., flow does not change over time.
- The interface between the seawater and freshwater sections of the aquifer is sharp, i.e., there is no transition zone.
- The seawater portion of the aquifer is under hydrostatic conditions, i.e., there is no flow within this section of the aquifer.
- Flow in the freshwater aquifer is essentially horizontal, which amounts to the Dupuit-Forchheimer assumption in an unconfined aquifer.
- The aquifer top (where applicable) and base (whether a fine-grained layer or the bedrock surface) are horizontal.

The first assumption listed, that of steady flow, runs counter to the purpose of this TM, i.e., determining how changes in the flow regime will affect seawater intrusion. However, considering the timescales involved in seawater intrusion, the assumption of steady flow is safe for a screening-level analysis.

## A.2. Upconing of the Seawater-Freshwater Interface

While the Ghyben-Herzberg relationship can predict the depth to the interface between freshwater and salt water in the aquifer away from active wells, in the vicinity of these wells the relationship does not hold. If a well is screened over only a portion of the aquifer, the reduced pressure around the screen leads to upward movement of groundwater below the well. The Ghyben-Herzberg relationship assumes horizontal flow, while, with a well that is not screened across the entire aquifer thickness, a significant component of vertical flow exists in the vicinity of the well. If a seawater-freshwater interface exists below the well, the upward movement of groundwater deflects this interface upward, a process called "upconing."

Bouwer (1978) developed a solution to the location of the interface below a well when upconing is occurring. This method starts with the results of the Ghyben-Herzberg solution (i.e., the depth to the interface at the well location), and modifies them slightly to determine the extent of upconing:

$$Z = \frac{\rho_f}{\rho_s - \rho_f} \frac{Q}{2\pi K z_i}$$

where $Z$ is the height of the cone beneath the center of the well (measured from the location of the interface determined by the Ghyben-Herzberg relationship), $Q$ is the discharge in the well, $K$ is the horizontal hydraulic conductivity, and $z_i$ is the depth of the Ghyben-Herzberg interface below the bottom of the well.

# Attachment A: Analytical Approach

## A.3. Key Data Sets

The specifics of the analytical method are described in Section A.4 below. For the solutions provided below, the pertinent data are the freshwater head, the flux of freshwater into the ocean, the horizontal hydraulic conductivity of the aquifer, the thickness of the aquifer, and the location of the discharge of freshwater into the ocean. Most of these numbers can be derived directly from the numerical groundwater model, but the purpose of this section is to provide an analysis of the issue of seawater intrusion that is as independent of the numerical model as possible. Therefore, values for these variables and parameters will be based on independent estimates from previously published reports or actual field observations. The numerical model will be used to provide values of freshwater head under the various model scenarios, as the effects of the changes in the pumping regime have not been independently quantified.

### A.3.1. Freshwater Head

The freshwater head in the aquifer is determined based on field measurements of depth to groundwater in the various monitoring wells present throughout the Basin. These measurements are not a perfect method for determining the head in the aquifer for several reasons. For this analysis, horizontal flow is assumed, meaning that there is no vertical head gradient within the aquifer. In any column of an actual aquifer, the head is not the same everywhere, and the wells in the monitoring network sample across a fairly tightly constrained thickness of the aquifer. Head can also vary significantly between layers in a stacked aquifer structure such as that present in the Westside Basin, although the monitoring well network was constructed carefully to not sample multiple layers. The monitor well network also does not sample all horizontal locations in the aquifer. The monitor well is a discrete point within a continuous and extensive aquifer, and the data measured within a network of monitor wells must not be considered to capture all variability within the aquifer.

With these caveats in mind, head must be defined for this analysis based on actual measurements from the existing monitoring well network, the details of which are summarized in Section 2.2.2 above. Head has been measured in the North Westside Basin since 2002 for the Zoo cluster, 2003 for the Thornton Beach cluster, 2004 for the Kirkham, Ortega, and Taraval clusters, and 2006 for the South Windmill cluster. Hydrographs for these wells are presented in the annual groundwater monitoring reports for the Westside Basin (i.e., SFPUC, 2011). These hydrographs, along with head values measured at some wells further inland (e.g., the West Sunset Playground well), are used to assess current conditions according to the analytical method.

In addition to the current conditions, future conditions will be assessed. To do so, head levels predicted by the numerical model will be considered in relation to the freshwater head needed at each monitoring location to prevent seawater intrusion to occur at that point.

### A.3.2. Horizontal Hydraulic Conductivity

Horizontal hydraulic conductivity ($K_h$) is an empirical proportionality constant that dictates the degree to which an aquifer allows water to pass through it. This parameter is not easily predicted based solely on the physical properties of the aquifer, although numerous hydrologic textbooks provide ranges of values for typical rocks and unconsolidated deposits (i.e., Freeze and Cherry, 1979, p.29). Instead, $K_h$ is usually determined at individual wells using aquifer tests, calculated based on established time-drawdown relationships. These tests have been performed at a number of locations in the Basin in the past, and this section summarizes those published values.

In the North Westside Basin, $K_h$ values were collected from various references by Phillips et al. (1993). These values, measured mostly in Golden Gate Park or along the Pacific coast between Golden Gate Park and Lake Merced, varied from 5 to 31 ft/d, with an average value of 17.3 ft/d, an arithmetic mean of 16.5 ft/d, and a geometric mean of 15.4 ft/d.

CH2M HILL (1995) performed a seawater intrusion model analysis on the North Westside Basin. $K_h$ was determined for three model layers, roughly corresponding (from lowest to highest) with the Merced Formation, the Colma Formation, and the surficial dune sands (plus unconfined portions of the Colma Formation). While initial estimates were based on the values presented in Phillips et al. (1993), calibration of the model resulted in values of $K_h$ of 10 ft/d for the upper two layers and 8 ft/d for the lowest layer. While these calibrated values are useful for giving additional insight into the likeliness of values within the existing range, they cannot be considered to be exact, due to the non-uniqueness inherent in a numerical solution within a complex model domain.

LSCE (2005) presented the results of an aquifer test performed at the South Sunset Playground well. The constant-rate test was run for 4.6 days at an average discharge rate of 409 gallons per minute. Using the Cooper-Jacob method, the aquifer transmissivity was determined to be about 27,100 gallons per day per foot (gpd/ft). No aquifer thickness is reported, so $K_h$ cannot be calculated (transmissivity, $T$, is equal to the product of $K_h$ and the aquifer thickness, $B$).

Rather than choose a single value of $K_h$ for the Pacific Coast, a range of values (5 to 31 ft/d) will be used. The part of the analytical method that uses values of $K_h$ (see Section A.6) was not performed for the Bay Coast due to the lack of an independent estimate for freshwater flux (see Section A.3.4).

### A.3.3. Aquifer Thickness

The aquifer thickness is likely the most likely parameter to determine accurately. The aquifer materials are well-defined at the individual well locations and can be interpolated in between. The movement of a seawater-freshwater interface through a real aquifer happens in a very complex manner, due to the heterogeneity of the aquifer.

Seawater tends to intrude along the base of an aquifer, atop a relatively impermeable layer (Figure 10.3-3). In a complex aquifer, with multiple low-permeability lenses, the seawater may intrude at multiple levels, depending on the continuity of these lenses; for a seawater intrusion front to intrude along a low-permeability lens surrounded on both top and bottom by higher-permeability aquifer layers, that lens must stretch continuously into the saline portion of the aquifer (i.e., Figure 5.2 in Bear, 1999). Until the intrusion front comes on-land, the area where it resides (i.e., offshore) is very poorly understood because no sediment profiles have been constructed beneath the Ocean or the Bay. Low-permeability layers that are very extensive onshore may be assumed to be continuous to the ocean floor, but this is unsure.

# Attachment A: Analytical Approach

According to the cross-sections presented in LSCE (2010), all of the clay layers are discontinuous in the North Westside Basin (i.e., Figure 8 in Appendix A of LSCE, 2010). In the northernmost two cross-sections perpendicular to the coast (J-J' and Z-Z'), clay layers are either specifically discontinuous (i.e., J-J') or thin enough that they are unlikely to be continuous from the Great Highway a significant distance offshore. The southernmost cross-section north of Lake Merced (Y-Y') does have a thick, seemingly continuous clay layer present between the Shallow and Primary Production Aquifers, as well as a series of clay layers between the Primary Production and Deep Aquifers, so the analysis may have to consider the aquifer in three sections in this southern area. For completeness, both a sectioned aquifer and a non-sectioned aquifer will be considered. At the coast, the aquifer thickness varies from 450 ft at Golden Gate Park to 510 ft at the Ortega cluster to 630 ft at the Zoo cluster. If the area of the Zoo cluster is partitioned into three aquifers, their thicknesses are approximately 60, 290, and 120 ft (Shallow, Primary Production, and Deep Aquifers, respectively).

The same cross-sections do not extend all the way into the Bay (LSCE, 2010). However, the two southernmost cross-sections perpendicular to the Bay (N-N' and O-O') indicate that most or all of the subsurface sediments are made up of fine-grained sediments from at least the Bay Plain into the San Francisco Bay. Again, as with the North Westside Basin, there are no sediment profiles beneath the Bay itself, but it is safe to assume that the deposits in this area are continuous. Because the cross-sections do not stretch offshore, the aquifer thicknesses given here are measured at South Airport Boulevard. At cross-section N-N', the aquifer thickness is about 170 ft, while the thickness at cross-section O-O' is about 130 ft.

### A.3.4. Freshwater Flux

The flux of freshwater toward the Ocean (or Bay) is important for keeping the seawater-freshwater interface offshore. Unlike the groundwater head elevation, this flux is not monitored directly anywhere in the Basin. Few estimates have been made of the flux. Yates et al. (1990) used a water budget calculation for 1988 to determine that a total of 0.45 acre-feet (af) (19,600 cubic feet) of outflow occurred per foot of coastline in the Golden Gate Park area, while about 640 af of freshwater flowed into the Ocean in the Lake Merced area. Outflows have not previously been estimated for the coastline between these two areas. Outflows have also not been independently estimated for the Bay Coast.

Flux can also be calculated based on Darcy's Law, which is an empirical relationship between the head gradient in an aquifer and the flux through it:

$$Q' = -KBi$$

where $Q'$ is the flux through the aquifer [$L^3/T$], $K$ is the hydraulic conductivity [L/T], $B$ is the aquifer thickness [L], and $i$ is the head gradient [L/L]. The values of $K$ and $B$ are discussed in Sections A.3.2 and A.3.3 above. Values of $i$ can be determined based on values of head (see Section A.3.1).

## A.4. Seawater Wedge Toe Location Methodology

An analytical solution can be created for the location of the toe of the seawater intrusion wedge under both unconfined and confined conditions using a combination of the Ghyben-Herzberg

# Attachment A: Analytical Approach

solution and Darcy's Law. This analytical solution has previously been developed in various sources, for example Bear (1972) and Strack (1976).

### A.4.1. Unconfined Solution

A schematic of seawater intrusion into an unconfined aquifer is shown in Figure 10.3-3a. At any location within the freshwater aquifer, Darcy's Law can be used to relate the head gradient to the flux through the aquifer. To do this, the basic version of Darcy's Law presented in Section A.3.4 is modified by replacing the aquifer thickness (*B* in the above equation) with the thickness of freshwater above the seawater wedge in the interface area and expressing the head gradient in terms of the change in freshwater head over distance:

$$Q' = -K(z + h_f)\frac{dh_f}{dx}$$

where *Q'* is the freshwater flux through the aquifer and *x* is measured as the distance seaward from the toe of the seawater wedge (*x* = 0). The Ghyben-Herzberg solution relates *z* to $h_f$ using the relationship between $\rho_s$ and $\rho_f$, and can be used to remove *z* from this equation:

$$Q' = -Kh_f\left(\frac{\rho_s}{\rho_s - \rho_f}\right)\frac{dh_f}{dx}$$

which can be rearranged to:

$$Q' = -\frac{K}{2}\left(\frac{\rho_s}{\rho_s - \rho_f}\right)\frac{dh_f^2}{dx}$$

This equation can be solved by integrating over *x* (and rearranged):

$$\frac{\rho_s - \rho_f}{\rho_s}\frac{2Q'x}{K} = -h_f^2 + const$$

The constant in this equation is the freshwater head at *x* = 0, the location of the toe of the wedge:

$$\frac{\rho_s - \rho_f}{\rho_s}\frac{2Q'x}{K} = h_f^2\Big|_{x=0} - h_f^2$$

Evaluated at *x* = *L*, the assumed location of freshwater discharge (and the point where the freshwater head ($h_f$) and aquifer thickness diminish to zero), the equation becomes:

$$h_f^2\Big|_{x=0} = \frac{\rho_s - \rho_f}{\rho_s}\frac{2Q'L}{K}$$

The Ghyben-Herzberg solution also contains a relationship for the value of $h_f$ at *x* = 0 (because at this point the value of *z* is by definition to the aquifer thickness, as thickness of the seawater wedge in the freshwater aquifer is equal to zero), which can then replace the left-hand side of the equation:

$$h_f^2\Big|_{x=0} = \left(\frac{\rho_s - \rho_f}{\rho_f}\right)^2 b^2$$

$$\left(\frac{\rho_s - \rho_f}{\rho_f}\right)^2 b^2 = \frac{\rho_s - \rho_f}{\rho_s}\frac{2Q'L}{K}$$

where *b* is the thickness of the aquifer lying below sea level (note the difference from the entire aquifer thickness, *B*, introduced above; $b = B - h_f$). Finally, this equation can be rearranged to solve for *L* as a function of *Q'*:

$$L = \frac{\rho_s}{\rho_f}\frac{\rho_s - \rho_f}{\rho_f} b^2 \frac{K}{2Q'}$$

It should be noted that this solution does not depend on the freshwater head, except as its gradient affects the value of *Q'*. The values of $\rho_s$ and $\rho_f$ are constant, so applying this simplified solution requires knowledge of *K* (Section A.3.2), *b* (Section A.3.3), and *Q'* (Section A.3.4).

### A.4.2. Confined Solution

A schematic for seawater intrusion in a confined aquifer is given in Figure 10.3-3b. In terms of the parameters involved in the analytical solution, the difference between the two aquifer constructions is that the thickness of the confined aquifer changes only due to the shape of the seawater wedge at the base of the aquifer, whereas the thickness of the unconfined aquifer also changes due to the changing water table surface. Because the entire thickness of the aquifer is, by definition, at or below the elevation of the assumed discharge point of the aquifer, *b* in the following equation is equal to *B* in Section A.3.3.

The Darcy's Law application for a confined aquifer is given by the equation:

$$Q' = -K(z - d)\frac{dh_f}{dx}$$

where d is the depth from msl to the top of the aquifer. The Ghyben-Herzberg solution can then be used to replace the value of *z*:

$$Q' = -K\left(\frac{\rho_f}{\rho_s - \rho_f} h_f - d\right)\frac{dh_f}{dx}$$

This equation can then be integrated over *x*:

$$Q'x = -K\left(\frac{\rho_f}{\rho_s - \rho_f}\frac{h_f^2}{2} - h_f d\right) + const$$

# Attachment A: Analytical Approach

Again, this constant is defined by solving for the value of $h_f$ at $x$ = 0:

$$Q'x = K\frac{\rho_f}{\rho_s - \rho_f}\frac{h_f^2\big|_{x=0} - h_f^2}{2} - Kd\left(h_f\big|_{x=0} - h_f\right)$$

Solving at $x = L$:

$$Q'L = K\frac{\rho_f}{\rho_s - \rho_f}\frac{h_f^2\big|_{x=0} - h_f^2\big|_{x=L}}{2} - Kd\left(h_f\big|_{x=0} - h_f\big|_{x=L}\right)$$

The Ghyben-Herzberg solution equates the freshwater head with the various vertical aquifer parameters. This changes depending on location. At $x$ = 0, the location of the toe of the wedge, the depth to the interface is equal to about 38 times the freshwater head above msl; this depth is equal to the aquifer thickness (*b*) plus the depth to the top of the aquifer (*d*):

$$h_f\big|_{x=0} = \frac{\rho_s - \rho_f}{\rho_f}(b+d)$$

At the coast, the depth to the interface is equal to the depth of the aquifer, as the freshwater thickness diminishes to zero:

$$h_f\big|_{x=L} = \frac{\rho_s - \rho_f}{\rho_f}d$$

These values can be substituted into the equation above:

$$Q'L = \frac{K}{u}\frac{[u(b+d)]^2 - [ud]^2}{2} - Kd[u(b+d) - ud]$$

where:

$$u = \frac{\rho_s - \rho_f}{\rho_f}$$

Rearranging the above equation and simplifying yields:

$$Q'L = Ku\frac{(b+d)^2 - d^2}{2} - Kubd$$

$$Q'L = Ku\left(\frac{b^2 + 2bd + d^2 - d^2}{2} - bd\right)$$

$$Q'L = Ku\left(\frac{b^2}{2} + bd - bd\right)$$

# Attachment A: Analytical Approach

Rearranging this equation can be used to express the intrusion length (*L*) in terms of the freshwater flux (*Q'*):

$$L = \frac{\rho_s - \rho_f}{\rho_f} b^2 \frac{K}{2Q'}$$

It should be noted that the depth to the top of the aquifer (*d*) does not appear in the solution for intrusion length for a confined aquifer. As with the unconfined solution, the values of *K*, *Q'*, and *b* must be known to use this solution.

## A.5. Exclusion Head Methodology

As implied by the analytical solutions presented in Section A.4, there is a simple relationship between freshwater head ($h_f$) and aquifer thickness (*b*) at the location of the most extensive intrusion of the seawater wedge into an unconfined freshwater aquifer, termed the toe of the wedge:

$$h_{f,toe} = \frac{\rho_s - \rho_f}{\rho_f} b$$

It should be remembered that the value of *b* used in this formulation is the thickness of the aquifer below sea level only. For a confined aquifer, the freshwater head is:

$$h_{f,toe} = \frac{\rho_s - \rho_f}{\rho_f} (b + d)$$

where b is the aquifer thickness and d is the depth below sea level of the top of the aquifer.

This simple relationship for freshwater head at the toe can be used as a management tool; to prevent intrusion from reaching any given location in the freshwater aquifer, the toe of the seawater wedge must be kept seaward of the location. To do so, the freshwater head at that location must be kept above the level at which it would be were the toe of the wedge to reach that location. This head is here termed the "exclusion head," and is equivalent to the "potential constraint" used in a management study by Mantoglou (2003), which showed this approach to be a conservative management tool.

To apply the exclusion head methodology, the parameter *b* (and *d* where conditions are confined) must be defined. The exclusion head is then calculated using assumed values of the densities of seawater and freshwater (see Section A.1).

## A.6. Rate of Seawater Intrusion at Golden Gate Park

In an effort to quantify the rate of seawater intrusion into the freshwater aquifer under various pumping conditions, a simplified mathematical model was created to estimate the change in the position of the toe of the seawater wedge over time. This mathematical model is based on the analytical model presented in Section A.4. The model was developed by assuming that the movement of the wedge could be described by assuming that the interface moves in the short

# Attachment A: Analytical Approach

term due to changes in the amount of freshwater present in the aquifer. This section describes the development of the model and its application to an idealized case designed to resemble conditions at the South Windmill Cluster in Golden Gate Park. A similar analysis was not performed for the Bay Coast because of the lack of an independent estimate of freshwater flux (see Section A.3.4).

The theory behind this method is that the movement of the seawater-freshwater interface can be described by assuming that the well pumping over a given time period can be converted to a volume of water removed. This approach makes a number of assumptions, most of which are similar to the analytical method for estimating the intrusion length (see Section A.4). Additional assumptions include:

- The pumping rate is a small percentage of the freshwater flux.
- The aquifer thickness landward of the intrusion wedge toe is approximately constant.
- The discharge point does not move from the coast.
- The system is unconfined and functions as a single aquifer.

The second assumption greatly simplifies the mathematical solution. Implicit in this assumption is that the head gradient landward of the wedge toe is approximately flat; this does not introduce substantial error into the analysis because head gradients in permeable alluvial sediments are typically very flat compared to the total aquifer thickness; Yates et al. (1990) reported a maximum gradient in the North Westside Basin of 0.035 ft/ft in the Lake Merced area, with typical gradients on the order of 0.010 ft/ft, including in the Golden Gate Park area). It should be noted that the analytical solution presented below does not depend on the head or head gradient directly, so the assumption of a constant aquifer thickness (and therefore flat gradient) does not preclude freshwater flux toward the ocean and is an appropriate approximation.

The last assumption is required because the confined solution is much more complicated than is the unconfined solution, due to the effects of aquifer elasticity and water compressibility (together contributing to the specific storage of the confined aquifer). This assumption is applicable at the western end of Golden Gate Park because the -100 foot clay is absent, leaving the Shallow and Primary Production Aquifers in direct communication; this implies that they can be considered a single aquifer. Elsewhere in the North Westside Basin, where the clay layers are present, this assumption would not apply.

As shown in Section A.4, the intrusion length into the aquifer (i.e., the distance from the discharge point to the toe of the wedge) is equal to:

$$L = \frac{K}{2Q_0'} \frac{\rho_s}{\rho_f} \frac{\rho_s - \rho_f}{\rho_f} b^2$$

where $Q'_0$ is the initial freshwater flux per foot of coastline before modification by pumping (all other terms are defined in Section A.4). The volume of water within any slice of the aquifer of infinitesimal width dx is equal to:

$$dV' = h_f n_e \frac{\rho_s}{\rho_s - \rho_f} dx$$

# Attachment A: Analytical Approach

where $n_e$ is the effective porosity of the aquifer[6]. Integrating from the coast to the toe of the wedge, the total initial volume of freshwater per foot of coastline above the wedge is equal to:

$$V_0' = -\left(\frac{\rho_s}{\rho_s - \rho_f}\right)^2 \frac{n_e K}{3Q_0'}\left[\left[\left(\frac{\rho_s - \rho_f}{\rho_f}\right)^2 b^2 - \frac{\rho_s - \rho_f}{\rho_f}\frac{2Q_0' L_0}{K}\right]^{3/2} - \left[\left(\frac{\rho_s - \rho_f}{\rho_f}\right)^2 b^2\right]^{3/2}\right]$$

which, when substituting the above equation for computing L, simplifies to:

$$V_0' = \frac{n_e K}{3Q_0'}\left(\frac{\rho_s}{\rho_f}\right)^2 \frac{\rho_s - \rho_f}{\rho_f} b^3$$

Pumping removes a volume of water from the aquifer ($V'_w$) that is equal to the product of the pumping rate and the time over which it is applied:

$$V_w'(t) = Q_w'(t - t_0)$$

where $Q'_w$ is the pumping rate, $t$ is the time, and $t_0$ is the time when pumping was initiated. In this case, the pumping rate must be converted to an equivalent flux per foot of shoreline, which implies that the pumping in the basin results in a uniform decrease in the freshwater flux rate. This pumping from the aquifer induces some movement of the intrusive wedge inland (as extra recharge would move the wedge closer to the ocean). The volume of water removed from the aquifer from the new location of the toe of the wedge to the coast is equal to the volume of water removed from the aquifer. The volume of freshwater contained in the aquifer from the location of the new toe to the coast prior to pumping is equal to the volume of freshwater above the seawater-freshwater interface plus the volume of water in the stretch of aquifer that becomes intruded by the wedge during its movement. Assuming that the freshwater head is approximately flat landward of the toe of the wedge, the freshwater head is equal everywhere to its value at the toe of the wedge, which is equal to:

$$h_{f,toe} = \frac{\rho_s - \rho_f}{\rho_f} b$$

The volume of freshwater in the aquifer that becomes intruded by the wedge is equal to:

$$V_i' = n_e b \frac{\rho_s}{\rho_f}\left(L(t) - L_0\right)$$

where $L(t)$ is the distance from the coast to the toe of the wedge at time $t$. The total volume of freshwater in the aquifer from the coast to the new location of the wedge of the toe prior to pumping is:

[6] Note that this assumes that the intruding seawater does not interact with the non-effective porosity of the aquifer, i.e. $n - n_e$. In reality, this non-effective porosity will lead to (very slightly) lower salinity behind an intruding wedge, and the leaving of salts behind by a retreating wedge.

# Attachment A: Analytical Approach

$$V'_{0,Total} = V'_0 + V'_i = \frac{n_e K}{3Q'_0}\left(\frac{\rho_s}{\rho_f}\right)^2 \frac{\rho_s - \rho_f}{\rho_f} b^3 + n_e\left(L(t) - L_0\right)\frac{\rho_s}{\rho_f} b$$

The wedge at time *t* has a volume equal to:

$$V'_t = V'_{0,Total} - V'_w(t)$$

Combining this with earlier equations produces an equation for the total volume of freshwater above the transient wedge at time *t*:

$$V'_t = \frac{n_e K}{3Q'_0}\left(\frac{\rho_s}{\rho_f}\right)^2 \frac{\rho_s - \rho_f}{\rho_f} b^3 + n_e\left(L(t) - L_0\right)\frac{\rho_s}{\rho_f} b - Q'_w\left(t - t_0\right)$$

Assuming the value of $Q'_0$ is not significantly changed by the pumping, this volume can also be computed by:

$$V'_t = -\left(\frac{\rho_s}{\rho_s - \rho_f}\right)^2 \frac{n_e K}{3Q'_0}\left[\left[\left(\frac{\rho_s - \rho_f}{\rho_f}\right)^2 b^2 - \frac{\rho_s - \rho_f}{\rho_f}\frac{2Q'_0 L(t)}{K}\right]^{3/2} - \left[\left(\frac{\rho_s - \rho_f}{\rho_f}\right)^2 b^2\right]^{3/2}\right]$$

The assumption that $Q'_0$ is not changed significantly is only applicable if the value of $Q'_w$ is small compared to $Q'_0$, i.e., most of the initial freshwater flux is not captured by the wells. Results based on values of $Q'_w$ that represent a significant fraction of $Q'_0$ should be used with caution. The value of $Q'_0$ reported by Yates et al. (1990) was 19,600 $ft^3$/yr per foot of coastline; the pumping entailed by the SFGW Project is about 8,810 $ft^3$/yr per foot of coastline above the pumping reported by Yates et al. (1990) for Scenario 3a, and about 9,220 $ft^3$/yr per foot of coastline above for Scenario 3b; the large magnitude of these changes relative to the initial freshwater flux indicates that this assumption is not completely valid in this case, and the results should be considered approximate.

These two values for the total volume of freshwater can be equated to each other. The equation for the value of $L_0$ can be substituted into this equation to simplify it to:

$$Q'_w\left(t - t_0\right) - n_e b \frac{\rho_s}{\rho_f} L_0 = \left(\frac{\rho_s}{\rho_f}\right)^2 \frac{2 n_e b^2}{3 L_0^{1/2}}\left[L_0 - L(t)\right]^{3/2} - n_e b \frac{\rho_s}{\rho_f} L(t)$$

or

$$\frac{Q'_w\left(t - t_0\right)}{n_e b}\frac{\rho_f}{\rho_s} = \frac{\rho_s}{\rho_f}\frac{2b}{3L_0^{1/2}}\left(L_0 - L(t)\right)^{3/2} + \left(L_0 - L(t)\right)$$

This equation cannot be solved for $L(t)$ using separation of variables. Instead, this model must be solved iteratively. This iterative solution can be performed in any spreadsheet software

# Attachment A: Analytical Approach

(e.g., Microsoft Excel) by minimizing the difference between the specified pumping rate and the pumping rate calculated using the equation above by optimizing values of $L(t)$.

## A.7. Effect of a Sloping Aquifer Base

The above analytical methods assume a horizontal aquifer. As shown in LSCE (2010), the actual aquifer bases in the North Westside Basin have been shown to be sloped toward the Ocean. A similar analytical method assuming a sloping aquifer base could not be constructed because the solution is inseparable. Abarca et al. (2007) performed numerical simulations that investigated the effect of a sloping aquifer boundary, both parallel and perpendicular to the coastal boundary. Their results indicated that a slope toward the Ocean slightly decreases the intrusion length into an aquifer, but not substantially. The presence of a slope parallel to the coast, on the other hand, can greatly increase the length of seawater intrusion into the lowest parts of the aquifer base. Mulligan et al. (2007) demonstrate that freshwater flux tends to be concentrated in paleochannels, which would represent the low points in the aquifer base demonstrated by Abarca et al. (2007) to be locations of greater intrusion; the concentration of freshwater flux into these same areas may keep this intrusion at bay.

# APPENDIX D-7

# Task 10.2 Technical Memorandum, Assessment of Groundwater-Surface Water Interactions for the Regional Groundwater Storage and Recovery Project and the San Francisco Groundwater Supply Project

The hydrographs referenced in Section 5.16, Hydrology and Water Quality, are Figures 10.2-11a through 10.2-14b

*This page intentionally left blank*

Kennedy/Jenks Consultants
303 Second Street, Suite 300 South
San Francisco, California 94107
415-243-2150
FAX: 415-896-0999

# Technical Memorandum 10.2

# Assessment of Groundwater-Surface Water Interactions

for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

1 May 2012

Prepared for

San Francisco Public Utilities Commission
525 Golden Gate Avenue, 10th Floor
San Francisco, CA 94102

K/J Project No. 0864001

# Supplemental Explanation for Hydrographs - TM10.2

This supplemental explanation is prepared to address discrepancies on several graphs presented in TM 10.2.

First, the x-axis on several graphs showing model results was shifted. The x-axis is named Scenario Year which should correspond to a water year[1]. However, the graph template was plotted using a calendar year, so the intervals on the x-axis represent the period from January to December. The result is that the graph is shifted 3-months later relative to Scenario Year.

Second, the shaded area representing the Design Drought was added manually and because of this process, it was not presented consistently on the graphs. By definition per the PEIR, the 8.5-year Design Drought includes one Hold year before the 7.5-year Take period. In addition, the Design Drought needs to be shifted 3-months later for the x-axis issue to be consistent with the model output. The Design Drought should be shown as Scenario Years 35.5 to 44.0 on the shifted x-axis.

The following is a list of figures in TM 10.2 where the Design Drought shaded area is shown slightly different and does not match the correct display of the Design Drought. The figures should be viewed based on the correct representation of the Design Drought as explained above.

- Figures 10.2-8 through 10.2-15 (a total of 13 figures) have the shifted x-axis. The Design Drought should be shown as Scenario Years 35.5 to 44.0 on the shifted x-axis.

[1] A water year is October 1 of the previous year to September 30 of the current (named) year.

1 May 2012

# Task 10.2 Technical Memorandum

## San Francisco Public Utilities Commission

## Assessment of Groundwater-Surface Water Interactions for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Prepared For: Greg Bartow and Jeff Gilman, SFPUC

Prepared by: Michael Maley, Dennis Orlowski, Sevim Onsoy and Matt Baillie, Kennedy/Jenks Consultants

---

## 1. Introduction

This Technical Memorandum (TM) was prepared to document work performed by Kennedy/Jenks Consultants (Kennedy/Jenks) for the San Francisco Public Utilities Commission (SFPUC) pursuant to the amended Task Order (TO) authorizations CUW30103-TO-1.12 of the Regional Groundwater Storage and Recovery (GSR) Project and CUW30102-TO-2.7 of the San Francisco Groundwater Supply (SFGW) Project. These projects are funded by the SFPUC's Water System Improvement Program (WSIP).

### 1.1. Objective

Implementation of the proposed GSR and SFGW Projects may influence groundwater levels within portions of the Westside Groundwater Basin (Basin). Depending on the magnitude of the potential changes in groundwater levels, existing and planned beneficial uses of major surface water features (lakes, streams, and wetlands) located within the Basin and connected to groundwater could be affected. Evaluation of the potential effects of groundwater / surface water (GW/SW) interaction is a key management issue for the long-term sustainability of the groundwater resources and the overall management of the Basin.

This TM was prepared to evaluate the potential interaction between groundwater and surface water for various surface water bodies overlying the Basin as a result of implementing the individual GSR and SFGW Projects, as well as combining both projects with other reasonably foreseeable future projects. For this evaluation, potential changes in future groundwater levels due to the operation of the GSR and SFGW Projects are assessed with respect to the potential to affect GW/SW interactions. Included as part of the evaluation is information related to past, current, and future conditions in the subsurface related to GW/SW interaction, along with a conceptual discussion of the mechanisms that control GW/SW interactions. The TM also includes an evaluation of the possible future groundwater conditions resulting from the implementation of the GSR and SFGW Projects as well as other reasonably foreseeable future projects. This evaluation is based upon the groundwater model scenarios developed based on the existing Westside Basin Groundwater Model (HydroFocus, 2007, 2009, and 2011) as described in TM-10.1.

### 1.2. General Approach

The general approach used to evaluate GW/SW interaction is first to identify the surface water features of interest in the Basin and to evaluate the existing GW/SW interactions for these features. Then in light of the degree of GW/SW interactions, the potential for the identified surface water features to be affected by the GSR and SFGW Projects is assessed based on an analysis of the changes in groundwater conditions in the Basin. Since each surface water feature may react differently depending upon the local conditions, each of the identified surface water features is evaluated separately.

This TM is part of a series of technical memoranda that address various aspects of the GSR and SFGW Projects. Two of these with significant data and analysis that are pertinent to this TM include the following:

- Task 8B Technical Memorandum No.1 Hydrologic Setting of the Westside Basin (referred to as TM#1) (LSCE, 2010).
- Task 10.1 Groundwater Modeling Analysis for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project (referred to as TM-10.1).

For each of the surface water features under consideration, the available documentation related to surface water hydrology, local hydrogeology, studies related to GW/SW interactions, and past or present management activities was reviewed. From this information, the following aspects of each surface water feature were addressed:

- Lake / Stream Characteristics: General descriptions of each surface water body, including physical characteristics, any anthropogenic modifications performed to the natural features and the historical use of the water body.
- Local Hydrogeology: An evaluation of the hydrogeologic conditions existing in the area of each surface water feature, with a focus on the conditions that are most likely to affect the GW/SW interaction process at a particular location (e.g., relative water levels for groundwater and surface water bodies and the presence or absence of major clay layers).
- Groundwater / Surface Water Interactions: A summary of available documented evidence for GW/SW interactions at a particular surface water body location.
- Managed Lake / Stream Levels: Where applicable, a summary of reported management activities intended to control water levels at a particular surface water feature.

The primary quantitative tools for evaluating potential future groundwater conditions are model scenarios developed using the existing Westside Basin Groundwater-Flow Model (Westside

Basin Groundwater Model) developed by HydroFocus (2007, 2009, and 2011). The development of the model scenarios is documented in TM-10.1. The Westside Basin Groundwater Model is considered a reasonable tool for regional, basin-wide assessment, but it has limited ability to evaluate GW/SW interactions on a local scale. Therefore, analysis of the potential effects with respect to GW/SW interactions is based on an empirical evaluation of the surface water hydrology and GW/SW interactions.

The Lake Merced Lake-Level Model is an empirical / conceptual quantitative tool, (referred to as the Lake-Level Model in this TM), used to evaluate changes in Lake Merced with respect to the GW/SW interactions. The Lake-Level Model is a spreadsheet-based water balance model that incorporates the key surface water components as well as groundwater-surface water interactions. The development of the Lake-Level Model is discussed in TM-10.1, Attachment 10.1-H.

### 1.3. GSR and SFGW Project Descriptions

The GSR Project is a conjunctive use project that would allow for increased groundwater supplies in the southern portion of the Westside Basin (South Westside Basin) during periods of drought when SFPUC surface water supplies become limited (MWH, 2008). The GSR Project will be designed to provide up to 60,500 acre-feet (af) of stored groundwater to help meet the SFPUC's system demands during the last 7.5 years of SFPUC's Design Drought. The SFPUC plans to install 16 new production wells for the GSR Project to recover the stored groundwater. Under the Draft GSR Operating Agreement, the SFPUC would "store" water in the South Westside Basin through the mechanism of in-lieu recharge by providing surface water as a substitute for groundwater pumping by the City of Daly City (Daly City), the City of San Bruno (San Bruno), and California Water Service Company (Cal Water). Daly City, San Bruno, and Cal Water are collectively referred to as the Partner Agencies (PAs). During shortages of SFPUC system water due to drought, emergencies, or scheduled maintenance, the PAs would return to pumping from their existing wells. During drought periods the SFPUC would extract groundwater from their new wells as long as a positive balance exists in the SFPUC Storage Account.

The SFGW Project would provide a reliable, local source of high-quality groundwater in the northern portion of the Westside Basin (North Westside Basin). The SFGW Project would construct up to six wells and associated facilities in the western part of San Francisco and extract an annual average of up to 4.0 million gallons per day (mgd) of groundwater from the North Westside Basin (SFPUC, 2009b). The extracted groundwater, which would be used both for regular and emergency water supply purposes, would be blended in small quantities with imported surface water before entering the municipal drinking water system for distribution. The SFGW Project includes two phases. In Phase One, SFPUC would build four new municipal supply groundwater wells at the Lake Merced Pump Station, West Sunset Playground, South Sunset Playground, and the Golden Gate Park Central Pump Station. In Phase Two, SFPUC would modify two existing irrigation wells (South Windmill Replacement and North Lake) in Golden Gate Park, converting them into municipal water supply wells.

The locations of the proposed GSR and SFGW Project wells and the existing and proposed PA municipal wells are shown on Figure 10.2-1. Additional detailed discussion of the GSR and SFGW Projects and pumping conditions under each project is provided in TM-10.1.

### 1.4. Daly City Vista Grande Drainage Basin Improvements Project

Daly City prepared the Vista Grande Drainage Basin Alternatives Analysis in 2011 based on the recommendations of the Vista Grande Watershed Plan. The purpose of the alternatives analysis is to develop and evaluate alternatives that will reduce or eliminate flooding of the canal, reduce erosion along Lake Merced, and provide other potential benefits such as habitat enhancement and lake level augmentation. The recommended program outlined in the plan includes:

- Partial replacement of the existing Vista Grande Canal to incorporate a gross solid screening device;
- Construction of a treatment wetland, and diversion and discharge structure to route some stormwater (and authorized non-stormwater) flows from the Vista Grande Canal to South Lake Merced;
- Replacement of the existing Vista Grande Tunnel to expand the capacity and
- Replacement of the existing outfall structure at Fort Funston. (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012).

Daly City's Vista Grande Drainage Basin Alternatives Analysis recommended the South Lake Merced Alternative in which stormwater flow from the Vista Grande Canal would be diverted to Lake Merced (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012). In the assessment of GW/SW interactions, the use of Lake Merced as part of the Vista Grande Drainage Basin Improvements Project for Daly City is considered a reasonably foreseeable future projects.

## 2. Conceptual Understanding

This section presents a basic framework for understanding the natural hydrogeologic processes and anthropogenic factors that can affect GW/SW interactions in the Westside Basin.

### 2.1. Surface Water Hydrology

Located within the Westside Basin are several prominent surface water features that could potentially be influenced by implementation of the GSR, SFGW Projects and other reasonably foreseeable future projects. These surface water features include the following:

- Lake Merced is a 300-acre freshwater lake located in the southwestern corner of San Francisco just north of the San Francisco County-San Mateo County line (Figure 10.2-2). Lake Merced is a major natural habitat for many species of birds and waterfowl, and is a popular recreational venue offering fishing, boating, bicycling, and wildlife viewing opportunities.
- Pine Lake is a 3-acre freshwater lake located north-northeast of Lake Merced in the westernmost portion of Pine Lake Park, which is adjacent to Stern Grove (Figure 10.2-2). Pine Lake (also known as Laguna Puerca) is one of the few natural lakes that still exist in San Francisco.
- The Golden Gate Park Lakes consist of twelve lakes or ponds located within Golden Gate Park (GGP) in the northernmost extent of the Westside Basin (Figure 10.2-3). The lakes provide a multitude of benefits in GGP, including wildlife habitat, recreation, and ornamental purposes.
- Three principal streams, along with their tributaries, exist in the South Westside Basin area: Colma Creek, San Bruno Creek, and Millbrae Creek in San Mateo County (Figure 10.2-1).

These surface water features are identified as the primary focus of this TM. Specific characteristics, local hydrogeology, and the potential for GW/SW interactions for each of the surface water features are discussed in more detail later in this TM.

### 2.2. Westside Groundwater Basin

This section provides an brief overview of the physical setting and hydrogeology of the Westside Basin to provide relevant context for the analysis presented in this TM. More detailed descriptions of the evaluations of the hydrogeology of the Westside Basin are presented in TM#1 (LSCE, 2010) and TM-10.1. In the Westside Basin, there are three regional aquifer systems, commonly referred to as the Shallow Aquifer, Primary Production Aquifer, and Deep Aquifer, as briefly described below and shown on Figure 10.2-4:

- The Shallow Aquifer is present in the northern part of the Basin, in the vicinity of Lake Merced and the southern portion of the Sunset district of San Francisco. The base of the Shallow Aquifer is defined as the top of the “-100 foot clay.”

- The Primary Production Aquifer is present throughout the Basin, overlying the “W-clay” where present. Where the W-clay is not present in locations to the south (in the South San Francisco area), the Primary Production Aquifer is divided into shallow and deep units separated by a clay unit at an elevation of approximately -300 feet mean sea level (msl).
- The Deep Aquifer underlies the W-clay, and thus its extent is limited to the generally-known extent of that clay unit.

The three aquifer systems are separated by thick, extensive clay units (e.g., the -100 foot clay and W-clay). Because of the discontinuous nature of these clay layers, the Basin is considered to be a semi-confined aquifer system where limited flow occurs between the different aquifer systems.

### 2.3. Conceptual Understanding of Groundwater-Surface Water Interactions

The phrase “groundwater-surface water interaction” refers to the movement of water between areas beneath the land surface (groundwater) and areas above the ground surface, such as streams, lakes, and wetlands (surface water). The conceptual understanding of this process provides the basic framework for understanding the natural processes that affect GW/SW interactions.

Several general conditions are required for the GW/SW interactions to occur. First, the depth to groundwater (or water table) has to be sufficiently shallow in relation to the bottom of surface water bodies such as streams, lakes, and wetlands. While there does not have to be an actual connection between surface water and the groundwater table to result in some degree of GW/SW interaction, there cannot be significant distance between the two. For instance, if the water table is tens or hundreds of feet below the level of the surface water, then GW/SW interactions are likely negligible.

In addition to the presence of a relatively shallow water table, there also has to be a relatively permeable pathway in the subsurface between the surface water body and groundwater. In other words, the presence of a low permeability clay deposit composing a lakebed might block, or at least greatly limit, the transfer of water flow between the lake and underlying groundwater. A higher permeability lakebed of sand would, on the other hand, allow the transfer of water for a more dynamic GW/SW interaction system. However, even with a natural sand lakebed, settling of silt and organic-rich sediments from the water column to the lake bottom over time would reduce the permeability of the lake bottom. Because of the presence of low permeability sediments on the lake bottom, groundwater interactions can often occur primarily through sediments along the edges of the lake.

Surface water bodies (e.g., lakes and streams) can interact with groundwater in three basic ways (Figure 10.2-5): 1) they can gain water from inflow of groundwater through the streambed or lakebed (gaining system); 2) they can lose water to groundwater by outflow through the streambed or lakebed (losing system); or 3) they can do both, gaining water in some reaches and losing water in others. The relative difference between the elevations of the surface water and the water table determines the relative direction of water flow. For groundwater to discharge into a surface water body, the groundwater level has to be higher than the water level in the surface water body. In this case the stream is considered to “gain” flow through the contribution of groundwater. Conversely, for surface water to be able to seep to groundwater, the level of the groundwater table near the stream has to be lower than the level of the stream surface. Under this condition the stream is considered to “lose” water to the groundwater system. A stream can be both gaining and losing at various reaches along its course, depending on the relative water levels at a specific location.

The seepage rate between the lakebed or streambed and the groundwater system is controlled by the permeability of the subsurface geology and the thickness and character of the streambed or lakebed. If the sediments at the bottom of the lake or stream are composed of clayey materials, then the rate of seepage may be low and the levels in the surface water body may not be in equilibrium with groundwater. Conversely, if the lake or stream has a sandy bottom, then the rate of seepage may be high and the groundwater levels may closely mimic the surface water.

Lakes and streams can be connected to the groundwater system by a continuous saturated zone, such as that depicted on Figure 10.2-5, or they can be disconnected from groundwater by an intervening unsaturated zone. In the latter case, as shown on Figure 10.2-6, the water table might exhibit a discernible mound beneath the stream, if the recharge rate through the streambed and unsaturated zone is greater than the rate of lateral flow of groundwater away from the mound. An important feature of streams that are disconnected from groundwater is that pumping of shallow groundwater near the stream does not affect the flow of the stream near the pumped wells. On the other hand, streams in connection with groundwater could be affected by such pumping (Winter, et al., 1998).

Another type of GW/SW interaction occurs when water from a surface water body moves into adjacent shallow sediments along the margin of the stream or lake. This process, termed “bank storage”, is a dynamic process in which an increase in water level in the surface water body creates a corresponding rise of the water table in these shallow sediments. The difference between bank storage and seepage to an aquifer is that the water in bank storage is not lost to the surface water body; rather the bank storage process provides a temporary storage for surface water during high water periods and a source of water during low water periods. The water can remain in this temporary storage if the water in the shallow sediments is not hydraulically connected to an underlying aquifer system. This can occur if a geologic feature, such as a laterally continuous clay layer, separates the shallow sediments from the underlying aquifer.

## 3. Groundwater-Surface Water Analysis

To evaluate groundwater conditions resulting from the operations of the GSR and SFGW Projects, a series of model scenarios was developed using the Westside Basin Groundwater-Flow Model. The development of the model scenarios is documented in TM-10.1. This section provides an evaluation of model-predicted changes in groundwater conditions with respect to the GW/SW interactions resulting from the implementation of the GSR and SFGW Projects.

### 3.1. Modeling Scenarios

Five model scenarios were constructed and simulated to evaluate the potential groundwater and related hydrological effects from the GSR and SFGW Projects and other reasonably foreseeable future projects. The following is a summary of the five scenarios used for the groundwater model analysis:

- Scenario 1 - Existing Conditions: Scenario 1 represents Existing Conditions and does not include the SFPUC Projects (either the GSR or SFGW Project). Groundwater pumping by the PAs and irrigation pumping are representative of the existing pumping conditions (as of June 2009). The PA pumping was established based on historical pumping rates, using the median of the 1959-2009 pumping data for individual agencies.
- Scenario 2 - GSR Project: Scenario 2 represents implementation of the GSR Project operations including: “put” periods when groundwater pumping by SFPUC and the PAs does not occur, except for exercising of the wells, and groundwater is placed into storage in the SFPUC Storage Account through in-lieu recharge; “hold” periods when the PAs are pumping and no in-lieu recharge is occurring because the SFPUC Storage Account is full; and “take” periods when both SFPUC and the PAs are pumping from the South Westside Basin.
- Scenario 3a - SFGW Project (3 mgd): For Scenario 3a, the four new wells constructed for the SFGW Project would pump at an annual average rate of 3.0 mgd; however, the two existing irrigation wells would remain irrigation wells, and their pumping rates would be the same as in Scenario 1.
- Scenario 3b - SFGW Project (4 mgd): For Scenario 3b, the four new wells constructed for the SFGW Project and the two modified irrigation wells in Golden Gate Park would pump at an annual average rate of 4.0 mgd. Irrigation in Golden Gate Park is assumed to be replaced by the Westside Recycled Water Project. Total combined pumping in the Westside Basin for Scenario 3b is slightly less than Scenario 3a, because the total SFGW Project pumping in Scenario 3b would increase by 1.0 mgd, whereas the irrigation pumping that is replaced would be slightly more than 1.0 mgd.
- Scenario 4 - Cumulative Scenario: Scenario 4 represents the implementation of both the GSR and SFGW Projects (Scenarios 2 and 3b) along with other reasonably foreseeable future projects. The other foreseeable projects are discussed in more detail in TM-10.1, but primarily include the Daly City Vista Grande Drainage Basin Improvements Project

(which increases stormwater diversions into Lake Merced) and minor variations in irrigation pumping based upon the planned build-out of the Holy Cross cemetery.

Table 10.2-1 presents a summary of the estimated Basin-wide average pumping rates corresponding to each of the model scenarios. Note that in addition to the pumping by the proposed GSR and SFGW Project wells, average pumping rates are also provided for the PA wells and for irrigation and other non-potable uses in the Basin.

As discussed in TM-10.1, the strongest predictive capability of the Westside Basin Groundwater-Flow Model is its ability to forecast relative changes in water levels over time, rather than to estimate the absolute water levels. Therefore, it is more appropriate to analyze the results of the groundwater model using differences in water levels relative to a base case rather than absolute groundwater elevations. Scenario 1 represents the Existing Conditions and forms the base case against which the results for the GSR and SFGW Projects, and the Cumulative Scenario, are compared.

To allow for the model scenarios to be directly comparable, all five model scenarios are set up using similar initial conditions and background hydrology. All of the modeled scenarios have the same projected simulation period of 47.25 years and use initial groundwater conditions that represent June 2009 conditions. All five model scenarios use the same hydrologic sequence and include the 8.5-year Design Drought period used in the Program Environmental Impact Report (PEIR; SFPUC, 2007; SFPUC, 2009a). The Design Drought repeats the December 1975 to March 1978 drought period following the dry conditions of July 1987 to November 1992. To incorporate the Design Drought, the historical hydrological sequence was rearranged. A more detailed discussion of the development of the background hydrology is presented in TM-10.1.

The GSR-Only Scenario and the Cumulative Scenario (Scenarios 2 and 4) involve the SFPUC Storage Account, which is a book account tracking of the volume of groundwater stored in the Basin from in-lieu recharge during put periods minus the amount of groundwater pumped from the SFPUC Storage Account during take periods. As part of the initial conditions, the accrued volume in the SFPUC Storage Account at the start of the model scenarios is approximately 20,000 acre-feet (af) based on records of in-lieu exchange with the Partner Agencies prior to July 2009. During the Design Drought, the SFPUC Storage Account is taken from a full condition of 60,500 af to an empty condition of no in-lieu storage available at the end of the Design Drought. During the Recovery Period following the Design Drought, the scenarios include a 3-year put period that adds 20,000 af to the SFPUC Storage Account. Using this condition, the SFPUC Storage Account begins and ends with 20,000 af for both Scenarios 2 and 4. This allows for a more direct comparison while evaluating the long-term changes in groundwater levels and storage without having to factor in differences in the amount of in-lieu storage.

## 3.2. MODFLOW Model

The existing Westside Basin Groundwater-Flow Model (HydroFocus, 2007, 2009 and 2011) was used as one of the quantitative tools to evaluate the groundwater component of GW/SW interactions as a result of the GSR and SFGW Projects. The setup and results of the MODFLOW model scenarios are documented in TM-10.1.

A limitation of this MODFLOW model is that the groundwater model has difficulty in accurately simulating the absolute Lake Merced levels, although it is capable of reproducing the trends and relative changes seen in the available historical data. The model generally reproduces the lake levels and trends during the period from 1972 to 1995. During the first 14 years (1958 to 1972) and the last 13 years of the simulation (1996 - 2009), simulated lake levels were consistently 2 to 3 feet higher than measured lake levels, with differences as high as 7 feet (HydroFocus, 2011). Since the simulation of absolute lake levels was necessary for the analysis presented in this TM, the Lake Merced Lake-Level Model was used. The Lake-Level Model is described in the next section.

### 3.3. Lake Merced Lake Level Model

Because of the limitations of the MODFLOW model in simulating absolute Lake Merced levels, the assessment of the GW/SW interactions for Lake Merced utilizes the Lake Model. A more complete discussion of the development of the Lake Model is included in TM-10.1, Attachment 10.1-H. Below is a summary of the application of the model to the evaluation of Lake Merced for the GSR and SFGW Projects, and the Cumulative Scenario.

The Lake Merced Lake-Level Model is a spreadsheet-based water-balance that applies a rule-based approach for the water balance. Each water balance component is calculated independently. The model sums up the inflows and outflows from Lake Merced on a monthly time scale, and that sum represents the net change in water volume in the lake for that month. Based on this net change in water volume, a new lake level is calculated.

The Lake Merced Lake-Level Model was calibrated to historical lake levels over a 70-year period from October 1939 to June 2009 (Figure 10.2-7). This period includes a representative sample of hydrological conditions including wet, normal and dry precipitation years. Overall, the Lake Merced Lake-Level Model closely follows both long-term and short-term historical trends. Further details of the model and its development and adaption for use with the GSR and SFGW projects are discussed in TM-10.1, Attachment 10.1-H.

# 4. Lake Merced

This section provides a summary of the climatic, hydrological, and hydrogeological data representative of the physical setting of Lake Merced. Elevations for Lake Merced are typically reported using San Francisco City Datum (City Datum), which is 11.37 feet higher than NAVD88, and 8.62 feet higher than NGVD 1929 (LSCE, 2002). In other words 0.0 feet City Datum is equal to 11.37 feet NAVD88 and 8.62 feet NGVD 1929. Lake Merced lake levels are reported in City Datum for this TM.

## 4.1. Lake Merced Conditions

Lake Merced is a freshwater lake located in the southwestern corner of San Francisco approximately 0.25 mile east of the Pacific Ocean, and bounded by Skyline Boulevard, Lake Merced Boulevard, and John Muir Boulevard. Lake Merced is within the North Westside Groundwater Basin, just north of the San Francisco County-San Mateo County line (Figures 10.2-1 and 10.2-2).

### 4.1.1. Physical Setting

Lake Merced consists of four inter-connected lakes - North Lake, South Lake, East Lake and Impound Lake (Figure 10.2-2). North and East lakes are joined through a narrow channel and these lakes are separated from South Lake by natural or man-made barriers. A conduit between North and South lakes allows water to flow between the two lakes when the lake elevation in either lake is approximately 3.35 feet (City Datum) or higher. When lake levels drop below that elevation, the North and South lakes are separated and typically exhibit different elevations. When the lake elevation in the North and South lake is above 5.0 feet (City Datum), then water can flows between the two lakes. The South and Impound lakes are also partially separated by a low berm. Flow between the South and Impound Lakes is restricted below an elevation of approximately 4.3 feet (City Datum).

The only physical outlet from Lake Merced is an overflow structure, also known as spillway, near the midpoint of the southwestern side of South Lake at an elevation of 13 feet (City Datum). The spillway is a 30-inch-diameter pipe that connects to the existing Daly City Tunnel immediately downstream of the tunnel connection to the Vista Grande Canal. The estimated capacity for the overflow is approximately 400 cubic feet per second (cfs) in its current configuration (Kennedy/Jenks, 2009, Jacobs, 2011b).

Lake Merced is a major natural habitat for many species of waterfowl and other birds, and is a popular recreational venue offering fishing, boating, bicycling, and wildlife viewing opportunities. However, prior to the mid-1930s, Lake Merced was used as a potable water supply source for the City of San Francisco (City). After the City began receiving water from the Hetch-Hetchy Aqueduct system in 1935, Lake Merced became an emergency and irrigation water supply source only. In 1950, San Francisco Recreation and Parks District was given the authority to manage the lake for recreational and ecological purposes. In addition to these types of uses, Lake Merced continues to serve as an emergency non-potable water supply for the City and County of San Francisco (SFPUC, 2010).

### 4.1.2. Lake Merced Hydrology

Currently, Lake Merced is replenished primarily by direct precipitation on the lake surface, local runoff from the immediately surrounding land area, and shallow groundwater inflow. Because the portion of subsurface inflow has been reduced from historical rates, short-term lake levels are quite sensitive to annual changes in precipitation, and the lake is also slower to recover from drought conditions (LSCE, 2004).

Urbanization of the Basin has resulted in substantial reductions in the amount of surface water that previously flowed into Lake Merced. The original watershed that drained into Lake Merced is estimated at approximately 6,320 acres; however, the current watershed is estimated to be approximately 650 acres (SFSU, 2005; Pezzetti and Bellows, 1998). The current watershed is defined by the adjacent roadways, which include Lake Merced Boulevard, Skyline Boulevard, and John Muir Boulevard. Urbanization has obstructed natural springs and diverted stormwater runoff that historically was a major source inflow into Lake Merced. Most of these flows are now diverted away from the lake into the City's combined wastewater system. The increase in impervious surfaces within the Basin (e.g., roads, parking lots, buildings) also has reduced the amount of recharge to the local shallow groundwater system, further reducing the amount of subsurface water contributions to Lake Merced (LSCE 2004, 2005a, 2005b; SFPUC 2009).

Historically, water additions and pumping have occurred in Lake Merced. Lake additions were water inflows to the lake typically from surface supplies, periodically done by SFPUC at the Lake Merced Pump Station to maintain or raise lake levels. Recorded additions were identified based on SFPUC records and previously reported data (LSCE, 2002). Other lake additions were known to have occurred in the past; however, the records for these events were not available. Similarly, pumping of water from the lake for golf course irrigation and other uses was known to occur; however, no records are available of the duration and extent of this pumping.

A more detailed discussion of Lake Merced conditions including a detailed water balance study of historical conditions is provided in TM-10.1, Attachment 10.1-H.

### 4.1.3. History of Lake Levels

Lake levels have generally been measured daily in South Lake since 1926. Figure 10.2-7 shows Lake Merced surface water levels, as measured at South Lake, over the historical period from 1939 to 2009. Prior to the beginning of Hetch-Hetchy aqueduct water delivery to San Francisco in 1935, lake levels typically ranged from elevations of 0 to -10 feet City Datum. In the late 1930s to early 1940s, lake levels increased to over 13 feet City Datum, which is the approximate elevation of the spillway, and thus the maximum controlled lake level.

Water levels in Lake Merced started to decline in the 1940s. During the 1940s to late 1950s, lake level elevations varied between 8 and 13 feet City Datum. Between the late 1950s and early 1980s, the lake experienced a long-term declining trend when levels ranged between

4 and 10 feet City Datum (Figure 10.2-7). Previous reports indicate that the reasons for the overall decline in lake levels during this period were drought, increased municipal groundwater pumping in the Basin, and increased urbanization that diverted stormwater into the City's combined sewer and stormwater system (Pezzetti and Bellows, 1998).

During the late 1980s and early 1990s, Lake Merced water levels declined well below the historical averages measured in the 1950s through early 1980s. A lake level of about -3.2 feet (City Datum) measured in 1993 was the lowest observed since the 1930s (Figure 10.2-7). It is understood that this decline was due to a combination of factors including reductions in the watershed area, the 1987-1992 drought, and regional and local groundwater pumping (Metcalf & Eddy, Inc. 2008).

Water levels in Lake Merced have been recovering steadily since 1993, with substantial rise during the wet winters of 1997 and 1998. As of June 2009, the lake level was approximately 5.7 feet City Datum (Figure 10.2-7). Water level increases over the last 15 years are attributed to a combination of factors, including several years with above average precipitation, SFPUC water additions to the lake between 2002 and 2005, reduced pumping by Lake Merced area golf courses as a result of recycled water deliveries, and reduced municipal pumping as part of the Pilot Conjunctive Use Study.

### 4.2. Groundwater-Surface Water Interactions

Lake Merced overlies the North Westside Basin, which is the northern portion of the greater Westside Groundwater Basin (Westside Basin). From north to south, the North Westside Basin underlies a portion of the Sunset District in San Francisco from Golden Gate Park to the San Francisco/San Mateo County line. From west to east, the North Westside Basin extends from the Pacific Ocean to inland bedrock exposures generally associated with Mount Sutro and Mount Davidson (LSCE, 2002, 2004).

Lake Merced is hydraulically connected to the unconfined Shallow Aquifer (LSCE, 2002, 2004). Previous hydrogeological investigation also provided some evidence that the surface of the lake is essentially an exposed part of the water table that defines the upper boundary of the Shallow Aquifer (Yates et al., 1990). Groundwater monitoring during the SFPUC's 2002 and 2003 water additions to Lake Merced further demonstrated that the shallow aquifer is in full hydraulic connection with Lake Merced (LSCE, 2004). During these events, 70 to 80 percent of the volume of water additions contributed to lake storage and the remaining 20 to 30 percent contributed to net outflow and evaporative losses during the water addition periods.

Currently, the direction of groundwater flow in the unconfined Shallow Aquifer is predominantly to the southwest; however, north of Lake Merced groundwater flow appears to be more westward toward the ocean (SFPUC, 2009b). Groundwater pumping in the South Westside Basin has resulted in a shift in the groundwater flow direction from northwesterly to southerly in the Lake Merced-northern San Mateo County area of the Westside Basin. The general groundwater flow direction in the deeper portion of the aquifer system (Primary Production Aquifer and Deep Aquifer) exhibits a more pronounced north to south flow direction than in the

Shallow Aquifer, likely due to greater pumping stresses in the deeper aquifer to the south. In addition, interpretation of deeper groundwater levels shows that the groundwater has a steeper gradient toward the pumping depression than the Shallow Aquifer (LSCE, 2002).

In 2009, an aquifer test was performed at the Lake Merced Pump Station (LMPS) Test Well located along the east shore of South Lake (note that this well is labeled as "Lake Merced Pump Station Well" on Figure 10.2-1). The LMPS Test Well is completed in the Primary Production Aquifer. The purpose of conducting the test was to characterize the yield of the LMPS Test Well and aquifer properties within the well's area of influence. Important conclusions derived from the aquifer test were that: 1) pumping and recovery responses in the LMPS Test Well and a nearby deep monitoring well (LMPS MW-440) (both completed in the Primary Production Aquifer) were consistent with a completely confined aquifer system; and 2), the Lake Merced / Shallow Aquifer system is unconfined and hydraulically separated from the pumped interval (within the Primary Production Aquifer) by multiple confining layers (LSCE, 2011). The results from the 2009 LMPS Test Well aquifer test substantiate the results of previous investigations which indicate that the Lake Merced / Shallow Aquifer system is, in the vicinity of Lake Merced, hydraulically isolated from the underlying Primary Production Aquifer system.

### 4.3. Daly City Vista Grande Drainage Basin Improvements Project

The City of Daly City prepared the Vista Grande Drainage Basin Alternatives Analysis to evaluate alternatives that would reduce or eliminate flooding, reduce erosion along Lake Merced, and provide other potential benefits such as habitat enhancement and lake level augmentation. The recommended program, known as the South Lake Merced Alternative, includes:

- Partial replacement of the existing Vista Grande Canal to incorporate a gross solid screening device;
- Construction of a treatment wetland, and diversion and discharge structure to route some stormwater (and authorized non-stormwater) flows from the Vista Grande Canal to South Lake Merced;
- Replacement of the existing Vista Grande Tunnel to expand the capacity and
- Replacement of the existing outfall structure at Fort Funston. (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012).

For this analysis, the 75 cubic-feet-per-second (cfs) scenario of the Lake Merced Alternative of the Vista Grande Drainage Basin Alternatives Analysis (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012) has been selected. The 75-cfs flow represents a minimum flow threshold (or cutoff volume) for diversions to Lake Merced. In other words, all flows in the Vista Grande Canal that are greater than or equal to 75 cfs would be diverted to Lake Merced (Brown and Caldwell, 2010). Flows of this magnitude are generally associated with stormwater discharges. Stormwater flows are calculated to occur in every year, and range from 19 to 681 afy with an average of 207 afy (Brown and Caldwell, 2010).

The Lake Merced Alternative scenarios also include provisions for an engineered wetland and modification of the Lake Merced spillway (Brown and Caldwell, 2010). In the 75-cfs scenario, the average baseflow in the Vista Grande Canal is assumed to be diverted into an engineered wetland for treatment and then discharge to Lake Merced on an ongoing basis. Baseflows have been estimated to range from 18 to 26 af per month (Kennedy/Jenks, 2009).With respect to the spillway modification, it is assumed that the spillway would be lowered from its existing elevation of 13 feet City Datum to 9.5 feet City Datum. This lower spillway elevation is used in the Cumulative Scenario (Scenario 4).

## 4.4. Lake Merced Model Results

For the analysis of GW/SW interactions, the Westside Basin Groundwater-Flow Model was used to evaluate groundwater conditions and derive the magnitude and direction of flux of groundwater-surface water interactions. This output from the Westside Basin Groundwater-Flow Model was used as an input to the Lake-Level Model. The Lake Level model was then used to evaluate absolute lake levels. This approach therefore takes advantage of the strengths of both models.

### 4.4.1. Model Descriptions

The Westside Basin Groundwater-Flow Model is a numerical (MODFLOW) groundwater model that has the capability to evaluate the effect of changes in groundwater pumping and other stresses on groundwater levels in the Lake Merced area. This model also has the capacity to calculate fluxes such as the flux between Lake Merced and groundwater. As described previously, because the model is regional and calibrated only to historical conditions, its strength lies in the assessment of relative (rather than absolute) changes.

The Lake-Level Model is a spreadsheet-based mass balance model that is used to evaluate changes in water levels of Lake Merced. MODFLOW treats Lake Merced as a boundary condition using the LAK3 package, which relies upon a mass balance approach to calculate lake levels. The Lake-Level Model uses a site-specific characterization of Lake Merced that is more complex and accurate than that used by the MODFLOW model. Some of the key advantages of the Lake-Level Model include the following:

- The model allows changes in the surface area of Lake Merced as a function of lake level (as based on measured bathymetry data). This is essential for an accurate simulation of absolute lake levels, because key water balance components (such as precipitation and evaporation) are dependent upon the lake surface area. These components are described as follows:
    - The precipitation input accounts for rainfall falling directly onto the lake. For example, during dry periods, when lake levels decline and portions of the lakebed may be exposed, the model simulates this precipitation as stormwater runoff, only a fraction of which actually reaches the lake.

- Evaporation is dependent on the surface area of the lake open to the atmosphere. For example, if lake levels decline, then the surface area also declines, and the overall evaporation losses also decline.

- The model dynamically simulates changes in lake volume. For example, at lower lake levels, the volume of the lake is smaller; therefore, the volume of water required to change the lake level by a certain amount is less than at higher lake levels.
- The Lake-Level Model includes a more complete evaluation of stormwater runoff than the Westside Basin Groundwater-Flow Model. The Lake-Level Model incorporates varied land surface types within the limited lake watershed area, including high runoff coefficients for the paved areas surrounding the lake.
- The Lake-Level Model accounts for flooding events resulting from overflows of the Vista Grande Canal. These are short-term, high-volume events that can substantially affect lake levels. There is a method for estimating overflows from flood events under existing conditions for the Vista Grande Canal used for Scenarios 1, 2, 3a and 3b, and a separate method for estimating stormwater inflows from the Vista Grande Drainage Basin Improvements Project for Scenario 4.
- The Lake-Level Model is superior to the Westside Basin Groundwater-Flow Model in simulating absolute historical lake levels (see TM-10.1).

The primary limitation of the Lake-Level Model is that the GW/SW interactions are based on assumptions of annual average groundwater flux into or out of Lake Merced. To address this limitation, the MODFLOW-calculated groundwater flux for Lake Merced was used. This flux is calculated on a monthly basis and dynamically incorporates the effects of changing groundwater levels. An earlier version of the Lake-Level Model used a generalized assumption for groundwater-surface water interactions, because the model was developed to support projects in which groundwater conditions were assumed to remain stable. For the GSR and SFGW Project scenarios, the groundwater levels are changing; therefore, a different approach was required. The use of the MODFLOW model results was considered a more reliable method than developing a new approach within the spreadsheet model. The combined approach therefore provides the best available analysis of the possible changes to Lake Merced water levels that could be attributed to the GSR and SFGW Projects.

A more detailed discussion of the Westside Basin Groundwater-Flow Model and the Lake-Level Model is provided in TM-10.1.

### 4.4.2. Model Analysis Approach

The results of the Lake-Level Model for each of the five model scenarios are shown on Figure 10.2-8 (absolute lake levels) and 10.2-9 (changes in lake level relative to Scenario 1). These figures show the changes in the elevation of Lake Merced over time. Each scenario is based upon a resequenced hydrology and includes the Design Drought (see TM-10.1).

Summary statistics for the simulated lake levels from the Lake-Level Model are provided in Table 10.2-2. These summary statistics provide another basis of comparison to evaluate the relative change from the Existing Conditions (Scenario 1) to the simulation results for Scenarios 2, 3a, 3b and 4. Additional statistical data are provided in Attachment 10.2-A. The summary statistics are:

- Lake Levels Assessment denotes the percentage of time that the simulated lake levels occur in the specified elevation bands. The percentage of time that the lake levels occur between 1 and 13 feet (City Datum) are calculated in 2-foot bands. The percentage for lake levels less than 1 foot (City Datum) is grouped into a single band.
- Monthly Lake Levels are presented for the entire simulation for the mean, 95 percentile and 5 percentile. These statistics provide a means to evaluate the average, upper and lower lake levels experienced during the simulation. Using the 95 and 5 percentile eliminates any short-term extremes and provides a more consistent method for comparison.
- Annual Range of Lake Levels is the difference between the maximum and minimum lake level for each water year (October to September) for the 47 full water years included in the simulation. The range provides a method to evaluate whether the lake level fluctuations during a water year vary due to the effects of the project.

The groundwater flux to Lake Merced as simulated by the MODFLOW model and incorporated into the Lake-Level Model is presented in Figures 10.2-10a and 10.2-10b. The Figure 10.2-10a shows the simulated flux values. Positive values represent groundwater flow into Lake Merced and negative values represent flow from Lake Merced to groundwater. These flux values show considerable seasonal and annual fluctuations. To facilitate the evaluation, the Figure 10.2-10b presents the groundwater flow relative to Scenario 1.

The evaluation of groundwater levels uses simulated groundwater levels from the Westside Basin Groundwater-Flow Model Layers 1 and 4 at selected monitoring well locations. The following four monitoring well clusters, representing different parts of Lake Merced (Figure 10.2-2), were selected to evaluate model-predicted changes in groundwater levels:

- LMMW-1 (Figure 10.2-11), located along the west shore of the South Lake
- LMMW-2 (Figure 10.2-12), located between the North and South Lakes
- LMMW-3 (Figure 10.2-13), located adjacent to the west shore of Impound Lake
- LMMW-4 (Figure 10.2-14), located north of North Lake

On each figure, the upper hydrograph shows model-simulated groundwater elevations in feet (NGVD 29), while the lower pane shows the difference between the groundwater levels of each scenario and those of Scenario 1. Positive differences indicate that a given project scenario has a higher groundwater elevation relative to Scenario 1, while negative results indicate that a given project scenario has a lower groundwater elevation relative to Scenario 1.

The following is a discussion of the results of the model analysis for the GSR and SFGW Project Scenarios and the Cumulative Scenario.

#### 4.4.3. Scenario 1 – Existing Conditions

Scenario 1 represents a continuation of Existing Conditions without either the GSR or SFGW Projects, and defines the background conditions including wet, normal and dry precipitation years. As discussed in TM-10.1, the hydrologic sequence used for all scenarios includes the Design Drought from Scenario Years 36 to 44. Water levels in Lake Merced clearly respond to these climatic variations (Figure 10.2-8). Initially, the lake levels show a sharp increase representing a period of above-average precipitation during Scenario Years 1 to 4. The period from Scenario Years 4 through 16 shows a steady decline in lake levels to about 1.5 feet during a dry period (City Datum). From Scenario Years 16 to 36, lake levels fluctuate in response to climatic conditions but show an overall increasing trend and rise to over 11 feet (City Datum). During the Design Drought period from Scenario Years 36 to 44, lake levels decline sharply to a minimum value of -0.8 feet (City Datum). Following the Design Drought, the lake levels recover to about 5 feet (City Datum).

Summary statistics for simulated lake levels for Scenario 1 are presented in Table 10.2-2 to provide another basis of comparison to evaluate the simulation for Scenarios 2, 3a, 3b and 4. The mean monthly lake level for Scenario 1 is 6.3 feet (City Datum) with an upper and lower lake level represented by the 95 and 5 percentile as 11.3 feet and 1.1 feet (City Datum). Lake levels occur below 3 feet (City Datum) about 13 percent of the simulation period for Scenario 1. The mean annual range of lake levels is 1.6 feet.

In the Lake Merced area, these climatic variations are seen more clearly in simulated groundwater levels in Model Layer 1 for all four locations (Figures 10.2-11 to 10.2-14), whereas groundwater levels in Model Layer 4 show less variability. Groundwater levels are generally higher for locations to the north and lower for locations to the south, which is characteristic of the Westside Basin. This pattern reflects the influence of groundwater pumping in the South Westside Basin. For Lake Merced, this means that there is a higher net outflow of lake water to groundwater in the South and Impound Lakes and more inflow of groundwater to Lake Merced in the North and East Lakes.

Figure 10.2-10a shows the flux of groundwater to Lake Merced based on the MODFLOW model. The overall pattern indicates that the GW/SW interaction is strongly influenced by the climatic conditions used for the simulation. The climatic conditions result in positive net flux for higher precipitation periods showing a net inflow of groundwater to Lake Merced. During the lower precipitation periods, the flux has negative values for a net loss of lake water to groundwater in response to groundwater level declines.

#### 4.4.4. Scenario 2 – GSR Project

Scenario 2 represents the operation of the GSR Project, which is located in the South Westside Basin. The GSR Project contains put periods when in-lieu groundwater storage occurs with minimal pumping by SFPUC or the PAs, hold periods with no in-lieu recharge and normal pumping by the PAs and a full SFPUC Storage Account, and take periods when there is combined pumping by SPFUC and the PAs and no in-lieu recharge. The pumping assumptions used for the GSR Project are presented in Table 10.2-1, with further details provided in TM-10.1.

The level of Lake Merced under Scenario 2 shows a similar pattern of response to climatic variations as Scenario 1 (Figure 10.2-8). Lake levels increase by about 5 feet as compared to Scenario 1 during Scenario Years 1 through 10 (Figure 10.2-9). Under Scenario 2, the relative difference remains at about 5 feet higher than Scenario 1 until the start of the Design Drought in Scenario Year 36. There are two take periods from Scenario Years 10 through 36. Relative to Scenario 1, there is little change in Lake Merced lake levels in response to those take periods. During the Design Drought with 7.5 years of pumping by both SFPUC and the PAs, lake levels drop to their lowest level of -2.5 feet (City Datum), which is less than 1 feet lower than the lowest lake level for Scenario 1 at the end of the Design Drought period (Figure 10.2-8).

During the put period following the Design Drought, the lake levels rise to about 1 foot (City Datum), but the rise in lake levels for Scenario 2 is less than for Scenario 1. At the end of the simulation, the Scenario 2 lake-levels are about 4 feet lower compared to Scenario 1. The interpretation of this response is that the aquifer is taking time to recover from the combined (SFPUC and PA) pumping, which results in lower groundwater levels and slows down the recovery of Lake Merced as well. Additional discussion on the effects of Scenario 2 on regional groundwater levels is provided in TM10.4.

Table 10.2-2 provides summary statistics for lake levels for Scenario 2, and additional statistical data are provided in Attachment 10.2-A. The monthly mean lake level over the simulation period is 9.1 feet (City Datum), which is 2.8 feet higher than the mean level for Scenario 1. Lake levels occur below 3 feet (City Datum) about 2 percent of the simulation period for Scenario 2. This is a lower percentage than in Scenario 1 (where low lake levels occur for 13 percent of the simulation period).

In the Lake Merced area, the effects of GSR Project pumping are clearly seen in groundwater levels in the Primary Production Aquifer (Model Layer 4), whereas groundwater levels in the Shallow Aquifer (Model Layer 1) show more fluctuation related to climatic conditions (Figures 10.2-11 to 10.2-14). There are also variations from north to south across Lake Merced. In the Shallow Aquifer (Model Layer 1), groundwater levels following the Design Drought at the LMMW-3 location (Figure 10.2-13a) are about 10 feet lower than those at LMMW-4 (Figure 10.2-14a) to the north. In the Primary Production Aquifer (Model Layer 4), groundwater levels following the Design Drought at the LMMW-3 location (Figure 10.2-13b) are about 35 feet lower than those at LMMW-4 (Figure 10.2-14b) to the north. The effects of GSR Project pumping are more clearly evident in the southern locations. These include effects in both the Shallow and Primary Production Aquifers. The northern locations show little effect of GSR Project pumping upon the Shallow Aquifer and only a minor response in the Primary Production Aquifer.

Figure 10.2-10b shows the simulated net flux of groundwater to Lake Merced. In comparison to Scenario 1, a higher net inflow of groundwater into Lake Merced is estimated under Scenario 2 for Scenario Years 1 through 38 (Figure 10.2-10b). However, early through the Design Drought period, the response switches to a higher net outflow of groundwater from Lake Merced into the aquifer. This is interpreted as the lake responding to the lower groundwater conditions caused by the operation of the GSR Project with both the GSR and PA wells operating throughout the Design Drought.

#### 4.4.5. Scenarios 3a and 3b – SFGW Project

Scenarios 3a and 3b simulate the operation of the SFGW Project, which is located in the North Westside Basin. The pumping assumptions used for Scenarios 3a and 3b are presented in Table 10.2-1. Scenario 3a assumes 1.142 mgd of irrigation pumping in Golden Gate Park and 3.0 mgd of pumping for municipal water supply throughout the North Westside Basin. Scenario 3b assumes 4.0 mgd of pumping for municipal water supply, and replacing irrigation pumping in Golden Gate Park with recycled water. In comparison to Scenario 3a, Scenario 3b assumes 0.142 mgd less pumping overall. Because of this minor change in pumping, the regional response of groundwater levels to these scenarios is very similar; therefore, the results for Scenarios 3a and 3b are discussed together.

During Scenario Years 1 and 2, Lake Merced levels tend to track those of Scenario 1. Afterwards, however, the level of Lake Merced clearly shows the effects of increased pumping in the North Westside Basin from the SFGW Project (Figure 10.2-8). The change in Lake Merced levels relative to Scenario 1 shows a steady decrease during Scenario Years 3 through 15 for both Scenarios 3a and 3b (Figure 10.2-9). However, during Scenario Years 15 through 44 (when the lake levels in Lake Merced vary in response to climatic conditions), there is an approximately stable difference (of about 9 to 10 feet) between the lake levels simulated in Scenarios 3a and 3b and those simulated in Scenario 1. During Scenario Years 44 to the end of the simulation, the lake levels for Scenarios 3a and 3b recover faster than Scenario 1, but the lake levels are still about 7 feet lower than in Scenario 1 (Figure 10.2-9). However, this faster recovery is due Lake Merced having a substantially smaller surface area at lower lake levels. This is incorporated into the Lake-Level Model so that an equal volume of water added to Lake Merced would result in a greater lake level rise because the volume of the lake is substantially smaller when the lake level is low. Additional information is included in TM10.1-Attachment 10.2-H, which provides more detail on the construction of the model.

Table 10.2-2 provides summary statistics for lake levels for Scenarios 3a and 3b, and additional statistical data are provided in Attachment 10.2-A. For Scenario 3a, the mean lake level over the simulation period is -1.3 feet (City Datum), which is 7.6 feet lower than the mean level for Scenario 1. Lake levels occur below 3 feet (City Datum) about 83 percent of the simulation period for Scenario 3a, as compared to only 13 percent for Scenario 1. For Scenario 3b, the monthly mean lake level over the simulation period was -1.9 feet (City Datum), which is 8.2 feet lower than the mean level for Scenario 1. Lake levels below 3 feet (City Datum) occur for about 85 percent of the simulation period for Scenario 3b.

In the Lake Merced area, the effects of the SFGW Project pumping are observed in groundwater levels in both the Shallow and Primary Production Aquifers (Model Layers 1 and 4) (Figures 10.2-11 to 10.2-14). There are also variations from north to south across Lake Merced.

In the Shallow Aquifer (Model Layer 1), groundwater elevations following the Design Drought at the LMMW-3 location (Figure 10.2-13a) are about 10 feet lower than those at LMMW-4 (Figure 10.2-14a) to the north. In the Primary Production Aquifer (Model Layer 4), groundwater elevations following the Design Drought at the LMMW-3 location (Figure 10.2-13b) are about 40 feet lower than those at LMMW-4 (Figure 10.2-14b) to the north. The groundwater levels at the LMMW-3 location (Figures 10.2-13b) in Model Layer 4 are substantially lower than those at the LMMW-4 location (Figures 10.2-14b) to the north. This reflects the proximity of the LMMW-3 location to the SFGW Project well at the Lake Merced Pump Station.

Figure 10.2-10b shows the net flux of groundwater to Lake Merced. Comparing Scenarios 3a and 3b to Scenario 1 with respect to groundwater flux (Figure 10.2-10b), it can be seen that there is a higher net outflow from Lake Merced to groundwater under Scenarios 3a and 3b relative to Scenario 1. This relative difference is greatest near the beginning of the simulation; however, as the simulation continues, this difference gradually diminishes during the remainder of the simulation. During the Design Drought, the groundwater flux in Scenarios 3a and 3b is similar to that of Scenario 1. As the relative difference in net outflow diminishes, the relative difference between simulated lake levels for Scenarios 3a and 3b and Scenario 1 becomes consistent as well (Figure 10.2-9).

#### 4.4.6. Scenario 4 – Cumulative Scenario

Scenario 4 represents the combined operations of the GSR and SFGW Projects along with other reasonably foreseeable future projects. Scenario 4 uses the same pumping assumptions as Scenario 2 for the GSR Project and Scenario 3b for the SFGW Project. The most pertinent foreseeable future project for Lake Merced is the Daly City Vista Grande Drainage Basin Improvements Project, which is described in Section 4.3. For reference, the key features of this project are repeated as follows:

- Lowering of the existing spillway elevation from 13 feet City Datum to 9.5 feet City Datum.
- Diversion of all Vista Grande Canal stormwater flows in excess of 75 cfs directly into Lake Merced. These flows generally range from 19 to 681 afy with an average of 207 afy (Brown and Caldwell, 2010).
- Diversion of Vista Grande Canal baseflow through an engineered wetland (for treatment prior to discharge) and into Lake Merced. Baseflows were estimated to range from 18 to 26 af per month.

The water levels of Lake Merced for Scenario 4 show a similar pattern to Scenario 2 (GSR Project) but are consistently 2 to 4 feet lower due to the effects of SFGW Project pumping (Figure 10.2-8). Relative to Scenario 1 (Figure 10.2-9), the lake levels are generally within 3 feet higher or lower than Scenario 1 until Scenario Year 44 (the end of the Design Drought). For Scenario Years 44 to the end of the simulation, the lake levels are about 4 to 5 feet lower than Scenario 1. This is a similar pattern to that observed for Scenario 2. During the Design Drought, the lake levels under Scenario 4 drop to -4.9 feet (City Datum); this value is 4.1 feet lower than the lowest lake level under Scenario 1.

The lowering of the spillway level to 9.5 feet (City Datum) has an effect on the long-term lake levels for Scenario 4, resulting in a loss of storage in the lake such that there is less water available in the lake at the beginning of drought periods. However, this is somewhat counteracted by the inflow of stormwater from the Vista Grande Canal, which augments the volume of water in the lake.

Table 10.2-2 provides summary statistics for lake levels for Scenario 4, and additional statistical data are provided in Attachment 10.2-A. The monthly mean lake level over the simulation period is 6.1 feet (City Datum), which is 0.2 feet lower than the mean level for Scenario 1. Lake levels occur below 3 feet (City Datum) about 16 percent of the simulation period for Scenario 4, as compared to 13 percent for Scenario 1.

In the Lake Merced area, the groundwater levels tend to parallel those of Scenario 2 but at an elevation that is about 2 to 4 feet lower (Figures 10.2-11 to 10.2-14). The difference in groundwater levels varies from north to south across Lake Merced. Groundwater levels in the LMMW-3 location (Figures 10.2-13ab) are lower than those for LMMW-4 (Figures 10.2-14ab) to the north. However, the difference relative to Scenario 2 is greater in the northern locations. This is because of SFGW Project pumping.

Figure 10.2-10b shows the net flux of groundwater to Lake Merced. A higher portion of the net outflow from Lake Merced to the groundwater is estimated under Scenario 4 than in Scenario 1 throughout the simulation period. This is due to the continuous augmentation of stormwater and baseflow from the Vista Grande Canal to Lake Merced. With the increase in lake levels, the net outflow is a natural process that equilibrates the shallow groundwater levels with Lake Merced. Scenario 4 therefore has a distinctly different pattern of groundwater flux than that observed in the other scenarios.

## 4.5. Summary

This section summarizes the results of the evaluation of groundwater-surface water interaction based on the modeling analysis using the Lake-Level Model and the Westside Basin Groundwater-Flow model.

Scenario 2 (GSR Project) generally results in higher lake levels than Scenario 1 for most of the simulation period. During the Design Drought (in which the extended period of pumping from SFPUC and PA wells occurs over a 7.5-year take period), the simulated lake levels for Scenario 2 are below those of Scenario 1 toward the end of the Design Drought period. The lowest lake level estimated under Scenario 2 is -2.5 feet (City Datum) toward the end of the Design Drought period, which is similar to the lowest historical lake level of -3.2 (City Datum) experienced in 1993.

Scenarios 3a and 3b (SFGW Project) result in lake levels that are substantially lower than Scenario 1 for the entire simulation period. Lake levels decline during the first approximately 15 years of operation of the SFGW Project. During the final approximately 30 years of the simulation, lake levels are consistently about 10 feet lower than the Existing Conditions Scenario. The lowest lake levels for Scenario 3a and 3b are about 7 feet lower than the lowest historical lake level experienced in 1993 of -3.2 feet (City Datum).

Scenario 4 (Cumulative Scenario) includes operation of the GSR and SFGW Projects using the assumptions of Scenario 2 and 3b. In addition, other reasonably foreseeable future projects such as the Daly City Vista Grande Drainage Basin Improvements Project, are included. This Project would augment Lake Merced with stormwater and baseflow from the Vista Grande Canal. The result of the Cumulative Scenario is that the simulated lake levels are similar to Scenario 1. They also tend to mimic the pattern from Scenario 2 (GSR Project) but at a lower elevation (by about 3 to 4 feet) as a result of SFGW Project pumping. The lowest lake level under Scenario 4 is -4.9 feet (City Datum), which is about 1.5 feet lower than the lowest historical lake level experienced in 1993.

# 5. Pine Lake

Pine Lake, also known as Laguna Puerca, is located about 0.5 mile north-northeast of Lake Merced in the westernmost portion of the Stern Grove and Pine Lake Park (Figures 10.2-1 and 10.2-2).

## 5.1. Physical Setting and Lake Conditions

Pine Lake is a relatively shallow lake that is approximately 3.4 acres in area. It has been used only for recreational purposes and has never served as a water supply source. Records related to historic conditions and lake levels in Pine Lake are sparse until the past 10 to 15 years. In November 2004, the lake level was reported to be very low, at an elevation of 33.5 feet (NGVD 29; 24.9 feet City Datum). The design water level elevation for Pine Lake was established at 40.1 feet (NGVD 29, or 31.5 feet City Datum; SFDPW, 2005b), which is about 4 feet higher than average historic lake levels and about 7 feet higher than the lake level in 2004.

Pine Lake has changed physically over time. It is reported that in the 1930s, about one third of the total lake area at its eastern end was filled in to accommodate additional park development. Pine Lake has also become shallower over time. In the early 1900s the depth of the lake was reportedly around 20 feet; during the period of low lake levels in the early 2000s, maximum lake depths were only 7 to 8 feet (SFDPW, 2001; Bennett Consulting Group, 2005). The historic shallowing of Pine Lake was attributed to a combination of long-term sedimentation and local declines in groundwater levels (Pilat, 2002). It is also likely that intense urbanization in the area surrounding Pine Lake reduced the amount of natural inflow to the lake.

To address declining water level and ecological issues in Pine Lake, during the past decade SFRPD conducted studies and capital improvement projects. As part of a capital improvement project completed in 2007 (Pine Lake and Pine Lake Meadow Improvement Project), SFRPD performed substantial water quality and habitat upgrades at Pine Lake. The improvements included the eradication of invasive plants, which were replaced with native vegetation, installation of a new pump in the Stern Grove well, and construction of a 6-inch diameter pipe from the well to an outlet channel that drains to Pine Lake.

Lake levels in Pine Lake currently are maintained by adding groundwater from the nearby 270-foot-deep Stern Grove well. Based on discussions with the well's operator, the Stern Grove Well is operated for 24 hours at a time with a pumping rate of about 270 gpm. The well is operated about 3 to 4 times each year to maintain the Pine Lake design water level. At that pumping rate and operational period, the total volume of groundwater added annually to Pine Lake to maintain the water level is approximately 4.8 acre-feet. At the design lake level, Pine Lake would be about 10 to 12 feet deep under the current lakebed configuration. The San Francisco Recreation and Park Department (SFRPD) will continue groundwater pumping from the rehabilitated Stern Grove well as part of a long-term program to augment water levels in Pine Lake (SFRPD, 2010, LSCE, 2010).

### 5.2. Groundwater Conditions near Pine Lake

Pine Lake overlies the Shallow Aquifer, which in this area comprises the upper portion of the Colma Formation. Groundwater levels measured in monitoring well LMMW-5S, which is located near the western end of Pine Lake, have consistently been about 6 to 7 feet bgs over the past ten years or so. Generally, lake levels are slightly higher than nearby groundwater levels due to the ongoing additions to the lake from the Stern Grove well. The 270-foot-deep Stern Grove well pumps groundwater from below the clay aquitard that forms the base of the Shallow Aquifer (LSCE, 2010); therefore, pumping from the well is not considered to directly affect groundwater levels near the lake.

Groundwater levels around Pine Lake are monitored in wells LMMW-5SS and LMMW-5S. LMMW-5SS is a shallow well completed between 38 and 48 ft bgs, designed to evaluate the shallow sediments near the lake. LMMW-5S is completed between 65 and 85 ft bgs, and was designed to evaluate groundwater levels in the Shallow Aquifer. Groundwater level data are available from both of these wells since 2002 (SFPUC, 2009a, 2011). Reviewing these data indicates that:

- Groundwater elevations in LMMW-5SS typically range between 37 to 40 feet (NGVD 29); however, during a period of low levels in Pine Lake, groundwater levels declined to about 33 feet. Since 2008, groundwater levels have varied between 38 and 40 feet (NGVD 29). Variations in groundwater elevations measured in LMMW-5SS appear to closely approximate changes in lake levels in Pine Lake.
- Groundwater elevations in LMMW-5S have ranged from 31 to 36 feet (NGVD 29), but show a trend over time. From 2002 to 2006, groundwater levels in LMMW-5S varied within a narrow range of 31 to 33 feet (NGVD 29). Groundwater levels steadily rose by about 2 feet from 2006 to 2008. From 2008 to 2010, groundwater levels varied within a narrow range of 35 to 36 feet (NGVD 29).
- Groundwater elevations in LMMW-5SS have typically been about 1 to 4 feet higher than elevations observed in LMMW-5S.

In November 2004, SFRPD performed a test filling of the lake using groundwater from the Stern Grove well (SFDPW, 2005a, Bennett Consulting, 2005). The purpose of the test filling was to raise the lake level from 33.5 feet (NGVD 29; 24.9 feet City Datum) to 40.1 feet (NGVD 29; 31.5 feet City Datum). It was anticipated that it would take up to 15 days of pumping at 400 gpm to fill the lake to the desired level to compensate for losses to groundwater. Instead, lake levels rose to 1.15 feet over the desired level with only 8 days of pumping from the Stern Grove well. The total volume of groundwater added to the lake was about 14 acre-feet. During the test period, there were additional unquantified inflows into Pine Lake from precipitation and runoff.

Based on the results of this test filling project, there was less groundwater loss resulting from lake additions than was anticipated, and it was determined that levels in Pine Lake could be maintained at 40.1 feet (NGVD 29, or 31.5 feet City Datum) by periodic additions from the Stern Grove well.

During the lake-filling test, groundwater levels in well LMMW-5SS rapidly rose about 5 to 6 feet and leveled out at 40.2 feet (NGVD 29; 31.6 feet City Datum), near the level in Pine Lake. In well LMMW-5S, groundwater levels rose less than 1 foot during the test, and were about 8 feet lower than the lake level in Pine Lake at the end of the test.

The groundwater response to the lake-filling operations indicates that Pine Lake is well-connected to the shallowest groundwater near the lake (LMMW-5SS). Based on the groundwater responses and the ability to sustain levels in Pine Lake during the test filling, it appears that the shallowest groundwater, which is monitored by LMMW-5SS, seems to be in good hydraulic communication with Pine Lake. Lower groundwater elevations measured in LMMW-5S suggest that direct hydraulic communication of deeper parts of the Shallow Aquifer with Pine Lake may be limited. This limitation may be due to a geologic restriction such as the presence of shallow clay layers that are sufficiently extensive (laterally and vertically); however, insufficient data are available to confirm this interpretation. Limited hydraulic communication with the Shallow Aquifer is consistent with observations that water from the Stern Grove well is only required a few times per year to maintain levels in Pine Lake. If good hydraulic communication were established with the portion of the Shallow Aquifer represented by the groundwater elevations monitored in LMMW-5S, it would be difficult to maintain lake levels in Pine Lake without substantially more water from the Stern Grove well than has been used historically (SFRPD, 1994, 2010). Groundwater levels in the Shallow Aquifer suggest possible groundwater mounding beneath the lake due to leakage from the overlying sediments, but this leakage appears to be rate limited, likely due to the presence of a low-permeability layer.

### 5.3. Pine Lake Water Balance

To help evaluate the potential effects on Pine Lake water levels resulting from SFGW Project implementation, a water balance assessment of Pine Lake was performed. The purpose of the assessment was to evaluate whether the amount of additional pumping assumed for the Stern Grove well to maintain the water level in Pine Lake at elevation 40.2 feet (NGVD 29, or 31.5 feet City Datum) during operation of the SFGW Project was adequate based on the changes in groundwater elevations from the results of the MODFLOW model.

Under the conceptual model for Pine Lake, inflows are primarily precipitation, stormwater runoff and lake additions from the Stern Grove well, while outflows are primarily evapotranspiration and groundwater outflow. Because of the sparse availability of historical data, the water balance incorporated the results of the test filling operations (SFDPW, 2005a; Bennett Consulting, 2005).

During the operation of the SFGW Project, groundwater pumping in the North Westside Groundwater Basin is expected to lower groundwater levels in the Shallow Aquifer in the Pine Lake area. The water balance provides a means for estimating the additional volume of groundwater necessary to maintain Pine Lake under these conditions. The difference between the total inflow to and total outflow from Pine Lake was considered to represent the volume of groundwater needed from the Stern Grove well to maintain lake levels. Assumptions for the volume of pumping from the Stern Grove well used for the model scenarios are based on the water balance discussed above, and are shown on Table 10.2-1. In summary, these include:

- Under the Existing Conditions and GSR-Only Scenarios (1 and 2, respectively), pumping from the Stern Grove well needed to maintain lake levels in Pine Lake is estimated at 0.0043 mgd (4.8 afy). At the given operational rate and duration of approximately 270 gpm for 24 hours to fill the lake, lake filling is expected to occur about 4 times per year on average.
- For Scenario 3a, the amount of Stern Grove well pumping needed was 0.012 mgd (13.6 afy), which represents an increase of 0.008 mgd (8.8 afy) over the results for Scenario 1.
- For Scenarios 3b and 4, Stern Grove well pumping increased to 0.013 mgd (14.8 afy), which represents 0.009 mgd (10 afy) more pumping than under Scenario 1.

For the water balance assessment, some simplifying assumptions were applied. Since all the scenarios use the same background hydrology, the water balance components for precipitation, stormwater runoff, and evapotranspiration are unchanged between scenarios. Therefore, the differences between scenarios are related solely to changes in groundwater-surface water interactions.

Under the Existing Conditions Scenario (Scenario 1), we assumed that the pumping from the Stern Grove well needed to maintain lake levels in Pine Lake would be about 0.0043 mgd (4.8 afy) based on current operations (SFRPD, 2010). From the MODFLOW model, the average groundwater elevation for LMMW-5S is 33.24 feet (NGVD 29), which is 7.0 feet below the maintained Pine Lake lake-level of 40.2 feet (NGVD 29).

To determine the groundwater outflow from Pine Lake, a Darcy's Law approximation was applied. For this approximation, it is assumed that the hydraulic conductivity and cross sectional area of the lake are the same for all scenarios. Therefore, the change in groundwater discharge from Pine Lake is directly proportional to the change in groundwater gradient in the aquifer underneath the lake. The results of this assessment include:

- For Scenario 2, LMMW-5S had an average groundwater elevation of 35.6 feet (NGVD 29), which is 4.6 feet below the maintained Pine Lake level. Scenario 2 has higher groundwater levels in LMMW-5S than Scenario 1. Proportional to Scenario 1, Scenario 2 requires about 66% of the pumping from the Stern Grove well to maintain lake levels in Pine Lake as was required for Scenario 1. Estimated water needed to maintain lake levels is 0.0028 mgd (3.2 afy) for Scenario 2.
- For Scenario 3a, LMMW-5S had an average groundwater elevation of 20.7 feet (NGVD 29), which is 19.5 feet below the maintained Pine Lake level. Scenario 3a has lower groundwater levels in LMMW-5S than Scenario 1. Proportional to Scenario 1, Scenario 3a requires about 280% of the pumping from the Stern Grove well to maintain lake levels in Pine Lake as was required for Scenario 1. Estimated water needed to maintain lake levels is 0.0120 mgd (13.5 afy) for Scenario 3a.

- For Scenario 3b, LMMW-5S had an average groundwater elevation of 21.2 feet (NGVD 29), which is 19.0 feet below the maintained Pine Lake level. Scenario 3b has lower groundwater levels in LMMW-5S than Scenario 1. Proportional to Scenario 1, Scenario 3b requires about 270% of the pumping from the Stern Grove well to maintain lake levels in Pine Lake as was required for Scenario 1. Estimated water needed to maintain lake levels is 0.0117 mgd (13.1 afy) for Scenario 3b.
- For Scenario 4, LMMW-5S had an average groundwater elevation of 26.5 feet (NGVD 29) which is 13.7 feet below the maintained Pine Lake level. Scenario 4 has higher groundwater levels in LMMW-5S than Scenario 1. Proportional to Scenario 1, Scenario 4 requires about 200% of the pumping from the Stern Grove well to maintain lake levels in Pine Lake as was required for Scenario 1. Estimated water needed to maintain lake levels is 0.0085 mgd (9.5 afy) for Scenario 4.

Based on this analysis, the pumping assumptions used for the MODFLOW model for the Stern Grove Well are appropriate and conservative with respect to the volume of water needed to maintain lake levels at Pine Lake. The Stern Grove well is currently, and will continue to be, dedicated to maintaining the design water level in Pine Lake using groundwater pumped from the Primary Production Aquifer.

### 5.4. Groundwater Model Results

The Westside Basin Groundwater-Flow Model does not simulate Pine Lake as a discrete lake feature, nor does it explicitly account for the addition of groundwater pumped from the Stern Grove well to Pine Lake (HydroFocus, 2007, 2009, 2011). As discussed in Section 5.3, additional pumping from the Stern Grove well to maintain the Pine Lake water level is incorporated into the model assumptions. The Groundwater Model does simulate changes in the groundwater levels in the Shallow Aquifer beneath Pine Lake based on the effects of the GSR and SFGW Projects; however, it does not have the ability to simulate groundwater levels in the shallowest sediments (monitored by LMMW-5SS) which have been shown to be in good hydraulic communication with Pine Lake (Section 5.2). Consequently, the model cannot be used to evaluate specific changes in water levels in Pine Lake, or in seepage of lake water to the Shallow Aquifer, that might result from SFGW Project implementation.

However, it was possible to use the simulated groundwater levels for LMMW-5S to evaluate the general changes in groundwater conditions in the Shallow Aquifer during the simulation. Figure 10.2-15 shows hydrographs for the LMMW-5S location in Model Layer 1 for all five modeled scenarios. The upper figure pane shows absolute simulated groundwater levels (absolute hydrographs), whereas the lower pane depicts groundwater levels relative to Scenario 1 (relative hydrographs).

The relative hydrograph for Scenario 2 shows a general increase in groundwater levels of up to several feet at the LMMW-5S location over those of Scenario 1, until near the very end of the simulation period, when there is a very slight reduction below Scenario 1 levels after the Design Drought period. The absence of any extended periods of reduced groundwater levels illustrates that there is anticipated to be little to no effect of GSR Project pumping on groundwater levels in the Shallow Aquifer (Model Layer 1) in the portion of the Westside Basin near Pine Lake.

Implementation of the SFGW Project (Scenarios 3a and 3b) is expected to result in a relative decline in Shallow Aquifer groundwater levels near Pine Lake of about 15 to 16 feet by the end of the simulation period. For Scenario 4, the Shallow Aquifer relative decline is about 10 feet by the end of the simulation period. The higher groundwater levels under Scenario 4 than in Scenarios 3a and 3b represent the effects of the GSR Project in-lieu recharge operations in addition to increased groundwater recharge resulting from additions to Lake Merced from the Daly City Vista Grande Drainage Basin Improvements Project.

The lower groundwater levels simulated in the Shallow Aquifer during Scenarios 3a, 3b, and 4 are expected to increase the leakage rate from the shallowest sediments surrounding Pine Lake, but this would potentially be offset by the possible geologic control that limits the connection between the lake and the Shallow Aquifer (Section 5.2). Therefore, addition of groundwater from the Stern Grove well to Pine Lake is anticipated to successfully maintain water levels in Pine Lake at the desired lake level during operation of the SFGW Project and under the Cumulative Scenario.

## 5.5. Summary

Under the conceptual model for Pine Lake, inflows are primarily precipitation, stormwater runoff, and additions to the lake from the Stern Grove well. Outflows are primarily evapotranspiration and groundwater outflow. The nature of the interactions between the lake and the connected aquifer is principally outflow from the lake to the aquifer, as maintained lake levels are typically higher than groundwater levels. As discussed above, Pine Lake shows strong hydraulic communication with the shallowest sediments (monitored by LMMW-5SS), but does not appear to be in direct hydraulic communication with the Shallow Aquifer (monitored by LMMW-5S). However, there is evidence of groundwater mounding in the Shallow Aquifer, indicating a steady, but rate-controlled, leakage of groundwater from Pine Lake to the Shallow Aquifer via the shallowest sediments.

For the SFGW-Only and Cumulative Scenarios (3a, 3b, and 4), groundwater levels in the Shallow Aquifer beneath Pine Lake are projected to decline by approximately 10 to 16 feet relative to Scenario 1 (see Figure 10.2-15). Based on the conceptual model, these projected declines in shallow groundwater levels are anticipated to have the potential to increase groundwater leakage from Pine Lake. However, levels in Pine Lake are already maintained by additions of groundwater from the Stern Grove well, and this well is expected to continue to be dedicated to maintaining the design water level in Pine Lake in the future.

Groundwater levels in the Shallow Aquifer for the GSR-Only Scenario (2) are projected to be similar to or slightly higher than under Existing Conditions (Scenario 1). Therefore, operation of the GSR Project is not expected to affect levels in Pine Lake, or to lead to any change in lake additions operations from the Stern Grove Well.

# 6. Golden Gate Park Lakes

Golden Gate Park (GGP) is located along the northernmost extent of the North Westside Basin (Figure 10.2-1). Located within GGP are twelve lakes or ponds: Stow Lake, Spreckels Lake, North Lake, Lily Pond, Lloyd Lake, Elk Glen Lake, Metson Lake, Mallard Lake, South Lake, Middle Lake, Alvord Lake and Rainbow Falls Bowl. The locations of these lakes are shown on Figure 10.2-3.

## 6.1. Physical Setting and Lake Conditions

The GGP lakes provide a multitude of benefits, including wildlife habitat, recreation, and ornamental purposes. The largest GGP lakes are Stow, Spreckels, and North lakes, with approximate surface areas of 13, 6, and 4 acres, respectively. The other lakes range from about 0.5 to 2 acres in area (SFRPD, 1994). Alvord Lake and Rainbow Falls Bowl are both very small, with paved bottoms and containing fountains or falls, and are more properly water features than lakes.

The GGP lakes are mostly manmade or, in some cases, were drastically altered from pre-existing natural conditions. Approximately 100 years ago the man-made GGP lakes were excavated into the existing shallow soils. Elk Glen, Middle, and North lakes are believed to have originally been natural groundwater-fed ponds that were deepened, whereas the other lake locations may or may not have coincided with pre-existing natural surface water features.

The GGP lakes, with the exception of Elk Glen Lake, were constructed to be very shallow, with original depths generally less than 5 feet. As sediment has accumulated on their bottoms, the GGP lakes have become even shallower, on average by about 1 foot by 1994 (although the north portion of North Lake was deepened in 1990 to about 9 to 10 feet). The shallow GGP lakes are very susceptible to excessive algal growths that have substantial negative impacts on lake water quality (SFRPD, 1994).

It was recognized prior to construction that, with groundwater levels below the bottoms of the lakes, the lakes would likely go dry due to leakage to the aquifer. To minimize this potential leakage, most of the lakes were constructed with bottoms of gravelly clay. Lily Pond did not require this addition of material because it was an old shale quarry, and therefore possessed a natural gravelly clay bottom that already minimized leakage. The three lakes that were originally natural groundwater-fed ponds (Elk Glen, Middle, and North lakes) have been confirmed to be unlined.

A 1994 study determined that most of the GGP lakes, even those lined with clay material, do leak appreciable amounts of water. In 1994 it was estimated that the combined leakage from all of the GGP lakes was about 0.5 million gallons per day, with about 77% of the leakage occurring from the 3 unlined lakes. Some of the water lost from the GGP lakes is periodically made up by additions of groundwater pumped from wells located in GGP (SFRPD, 1994), while the rest is replenished by surface water flows (precipitation-derived runoff).

## 6.2. Groundwater Conditions in Golden Gate Park

Golden Gate Park is located in the northernmost part of the North Westside Basin, approximately 3 miles north of the Lake Merced area. The geology and hydrogeology of this area are somewhat different than near Lake Merced and Pine Lake. In this area, the bedrock surface slopes downward to the southwest from surface exposures in the east, and geophysical data indicate the presence of a buried bedrock valley beneath GGP. Additional discussion on the geology is presented in TM#1 (LSCE, 2010). The total thickness of sedimentary deposits on top of the bedrock thins from south to north in the North Westside Basin, from about 600 feet beneath Lake Merced to 400 feet beneath GGP (Figure 10.2-4). The “W-clay”, which forms the bottom of the Primary Production Aquifer throughout most of the basin, pinches out near the Ortega monitoring well cluster, and does not appear to exist north of this point (Figure 10.2-4). Similarly, the prominent shallower clay units present in the Lake Merced area, such as the -100-foot clay and the X-clay units, also appear to thin and pinch out near the Kirkham monitoring well cluster, just south of GGP (LSCE, 2010).

Because the -100-foot clay is not present in the GGP area, the Shallow Aquifer (as defined to the south) is not present in the GGP area. However, groundwater elevations measured in shallow wells located in GGP are typically several feet above the elevations recorded in wells screened deeper. This relationship indicates a downward vertical gradient, which implies downward vertical groundwater flow, similar to conditions seen in the Lake Merced area, where the Shallow Aquifer is prominently defined. In the GGP area, the horizontal component of groundwater flow in both the shallower and deeper portions of the Primary Production Aquifer is mostly due west, with a slight northwesterly component in some areas (SFPUC, 2009b).

Historic groundwater levels measured in wells located in GGP indicate that the groundwater surface (water table) throughout most of the park ranges from approximately 40 to 60 feet bgs, except in the western quarter of GGP, where the ground surface elevation drops fairly rapidly towards the Pacific Coast (HydroFocus 2009). At the Alvord-PW well location in the southeast corner of GGP, groundwater depths are typically about 40 to 60 feet bgs. To the west, at the Arboretum-4 well location, groundwater depths usually range from 40 to 50 feet bgs. In the central portion of GGP, near Elk Glen Lake, groundwater depths measured in the shallow USGS Elk Glen monitoring well range from about 40 to 45 feet bgs. Only at the far western edge of the GGP, right along the coast, do groundwater depths become shallower; the depth to groundwater is typically about 14 to 15 feet bgs. Additional information on groundwater levels is provided in TM-10.1, TM-10.4 and TM#1.

The average depths to groundwater within GGP noted above imply that the GGP lakes do not intersect the water table (unlike Lake Merced and Pine Lake to the south), and thus GW/SW interaction does not affect conditions in the GGP lakes. With few exceptions, the GGP lakes are very shallow, with present average depths on the order of only about 2 to 4 feet; even Elk Glen Lake, which is the deepest, is on average only about 6 feet deep. With average depths to groundwater in GGP of about 40 to 60 feet bgs, the GGP lakes are hydraulically separated from the water table.

Note that aquifer recharge provided by leakage from the GGP lakes is not considered a GW/SW interaction. The effect is only in one direction, because the water table is too far below the lake bottoms for changes in groundwater levels to affect lake levels. The water table beneath a particular lake might show evidence of mounding if the volume of seepage from the overlying lake is sufficiently high, but even then the water table remains well below the lake bottom. With implementation of the SFGW and GSR Projects, the GGP lakes are expected to continue to recharge the aquifer at the same rate because they would continue to be filled as before.

## 6.3. Managed Lake Levels

Some of the water lost to leakage from the GGP lakes is made up by additions from groundwater supply wells located within GGP. These wells, which are operated and maintained by SFRPD, are located east of Elk Glen Lake, at North Lake, and at the South Windmill location. Stow Lake, Elk Glen Lake, and South Lake receive water from these wells on a regular basis. The other lakes periodically receive make-up water from groundwater sources when operating engineers redirect discharges to them (SFRPD, 1994).

Historically, groundwater pumping information for the GGP wells was not maintained. However, in 2005 meters were installed in all three GGP production wells to quantify the amount of groundwater pumping in the park. In 2007, approximately 830 acre-feet of groundwater were pumped from the wells. In 2008 this amount increased to approximately 1,300 acre-feet of water (LSCE, 2010). A portion of this groundwater pumping is diverted into the Golden Gate Park lakes.

It has been recognized that water leakage from the GGP lakes recharges the underlying aquifer system. Because the water used to supplement the GGP lakes is obtained from this same aquifer system, most of the leakage from the GGP lakes is viewed as not being lost, but is instead largely considered to be circulated between the surface water and groundwater systems. The Westside Basin Groundwater-Flow Model assumes approximately 627 afy of groundwater recharge resulting from seepage from the lakes to the underlying aquifer; this rate is based on the results of a seepage investigation of the GGP lakes conducted by the San Francisco Department of Public Works (SFRPD, 1994).

## 6.4. Summary

The average depths to groundwater within GGP indicate that, unlike Lake Merced and Pine Lake to the south, the shallow GGP lakes do not intersect the water table and thus GW/SW interaction does not affect surface water conditions in the GGP lakes. As shown previously for other locations in the North Westside Basin, long-term operation of the GSR and SFGW Projects is expected to result in net decreases in groundwater levels in this area. This is particularly the case for the SFGW Project because the Project wells are to be installed within the North Westside Basin. Declining groundwater levels caused by operation of the SFGW wells would further reduce the likelihood of GW/SW interaction between the aquifer and the GGP lakes. Consequently, it is not expected that operation of either the SFGW Project, GSR Project, or the Cumulative Scenario would affect existing water level conditions within the GGP lakes.

# 7. Colma, San Bruno, and Millbrae Creeks

Three principal streams, along with their tributaries, exist in the South Westside Basin: Colma Creek, San Bruno Creek, and Millbrae Creek. Colma Creek is located in the central and southern portions of the South Westside Basin, originating near San Bruno Mountain and extending southwest and then southeast through South San Francisco before discharging into the Bay just north of the San Francisco International Airport. San Bruno Creek flows from the uplands along the west side of the Basin, and also discharges to the Bay at a location just south of the Colma Creek discharge. Millbrae Creek is in the southernmost part of the Basin, with its headwaters also located in the western uplands and with a discharge to the Bay south of the San Francisco International Airport (Figure 10.2-1).

## 7.1. Physical Setting and Stream Conditions

As is typical of surface water features located in heavily urbanized areas, much of the stream reaches of Colma Creek, San Bruno Creek, and Millbrae Creek have been channelized, buried, and/or lined with impervious materials. Almost the entire Colma Creek watershed is located within the Colma Creek Flood Control Zone, which was created in 1964 to construct flood control facilities in the creek to alleviate flooding in South San Francisco. Except for its upper reaches on San Bruno Mountain, all of historic Colma Creek and its tributaries have been diverted into engineered channels or underground storm drains. Similar alterations have also been made to San Bruno Creek and Millbrae Creek (Oakland Museum, 2010). These modifications have resulted in major changes to the natural hydrologic and ecologic processes that previously existed.

Colma Creek sometimes runs dry, believed to result at least in part from excessive groundwater use by non-native vegetation (e.g., eucalyptus trees) present in the headwaters of the Creek. In the upper reaches of Colma Creek, a headwaters restoration project is underway in which the non-native vegetation is being eradicated to both restore natural habitat and improve groundwater conditions (Cannon and Heath, 2005). In the lower Colma Creek watershed, along the mouth of the creek where it enters the San Francisco Bay, a habitat mitigation project is ongoing in which wetlands and native upland habitat are being constructed to restore features that were lost during construction of flood control facilities in the area.

## 7.2. Groundwater Conditions

In the portion of the South Westside Basin where Colma Creek is located (except for the eastern area closer to the Bay), the depth to groundwater ranges from many tens to hundreds of feet bgs, due to drawdown of the water table caused by intensive historic municipal pumping in the Daly City, South San Francisco, and San Bruno areas. Large production wells in these areas pump from the Primary Production and Deep Aquifers (the Shallow Aquifer is not present from the Daly City area southward).

Where the lower reaches of Colma Creek are located, in South San Francisco, the depth to groundwater is highly variable, depending largely on proximity to pumping wells and the depth of the aquifer being measured.

Where San Bruno and Millbrae Creeks are located, in South San Francisco and San Bruno, the groundwater in the Primary Production Aquifer is typically at elevations ranging from -100 to -200 feet (NGVD 29). However, in areas closer to the Bay, groundwater elevations are in the range of approximately 10 to -30 feet (NGVD 29), with the deeper levels corresponding to deeper monitoring wells.

### 7.3. Groundwater-Surface Water Interactions

Extensive modifications to Colma Creek, San Bruno Creek, and Millbrae Creek have effectively isolated almost all of the creek reaches from the underlying groundwater, precluding any substantial degree of GW/SW interaction with the creeks. Furthermore, groundwater beneath much of Colma Creek is far below ground surface, further reducing the likelihood of GW/SW interaction.

Even where groundwater levels are relatively shallow in the southernmost portion of the South Westside Basin, the heavy alteration of all three creeks (i.e., concrete lining) precludes exchanges between surface water and shallow groundwater.

Colma Creek is apparently in some degree of communication with shallow groundwater in its upper, least-altered reaches near San Bruno Mountain, because water use by stands of eucalyptus trees there is believed to deprive the Creek of some baseflow (Cannon and Heath, 2005). However, any shallow groundwater in this area exists in a highly localized system, far removed from the deeper groundwater of the Primary Production Aquifer, which exists at lower elevations in the Basin. Similar conditions are likely present for the unaltered upland portions of San Bruno Creek and Millbrae Creek.

### 7.4. Groundwater Model Results

The existence of thick deposits of low-permeability Bay Mud in San Bruno and portions of South San Francisco (Bay Plain area) also lessen the likelihood of GW/SW interaction in these areas (LSCE, 2010). The 2011 update to the Westside Basin Groundwater-Flow Model incorporated drain boundaries in Layer 1 of the Bay Plain area to simulate seepage to San Francisco Bay. Implementation of the drain boundaries reduced the occurrence of simulated water levels above land surface (i.e., flooding) in the Bay Plain area, but had minimal effect on simulated water levels further inland where the bulk of the major creek systems are located (HydroFocus, 2011).The simulated drainage averaged less than 120 afy, which is less than 1 percent of the volumetric budget. This equates to about 0.17 cubic feet per second (cfs) distributed among Colma, San Bruno, and Millbrae Creeks. The flow in these creeks is primarily stormwater runoff and other discharges. The total groundwater discharge is considered to be a very low percentage of the overall streamflow.

To evaluate the effects of the GSR and SFGW Projects on groundwater discharge to the creeks, the water balance for each scenario was evaluated using the data in TM10.1 Attachment TM 10.1-C. The discharge to the drains was limited to the South Westside Basin representing Colma, San Bruno and Millbrae Creeks. The average annual groundwater discharge to the creeks for Scenario 1 was 94 afy, or 0.13 cfs. For Scenarios 2 and 4, the average annual groundwater discharge to the creeks increased to 122 afy, or 0.17 cfs. This is similar to the results for the historical model (HydroFocus, 2011). For Scenarios 3a and 3b, the average annual groundwater discharge to the creeks was 93 afy, or 0.13 cfs. This is essentially the same as for Scenario 1. Based on the groundwater model results, there would be little to no change to groundwater discharge to Colma, San Bruno and Millbrae Creeks as a result of project operations.

## 7.5. Summary

Given the hydrogeologic conditions and substantial engineered modifications, it is unlikely that GW/SW interaction processes are present to any measureable extent for Colma, San Bruno, or Millbrae Creeks. Consequently, implementation of the SFGW Project, GSR Project, or the Cumulative Scenario is not expected to affect existing surface water conditions for Colma Creek, San Bruno Creek, or Millbrae Creek, or their respective tributaries.

## 8. Summary

The following discussion summarizes the results of the GW/SW interaction analysis for the principal surface water features identified in the Westside Groundwater Basin.

### 8.1. Lake Merced

Lake Merced is a freshwater lake located in the southwestern corner of San Francisco and is located within the North Westside Groundwater Basin, just north of the San Francisco County-San Mateo County line (Figures 10.2-1 and 10.2-2). Lake Merced consists of four inter-connected lakes - North Lake, South Lake, East Lake and Impound Lake (Figure 10.2-2).

This section summarizes the results of the evaluation based on the modeling analysis using the Lake-Level Model and the Westside Basin Groundwater-Flow Model.

Scenario 2 (GSR Project) generally results in higher lake levels than Scenario 1 for most of the simulation period. During the Design Drought (in which the extended period of pumping from SFPUC and PA wells occurs over the 7.5-year take period), the simulated Lake Merced levels are below those of Scenario 1 toward the end of the Design Drought period. The lowest lake level estimated under Scenario 2 is -2.5 feet (City Datum), which is similar to the lowest historical lake level of -3.2 (City Datum) experienced in 1993.

Scenarios 3a and 3b (SFGW Project) result in substantially lower lake levels for the entire simulation period relative to Scenario 1. Lake levels decline during the first approximately 15 years of operation of the SFGW Project. During the final approximately 30 years of the simulation, the lake levels are generally stable, remaining about 10 feet lower than the Existing Conditions Scenario. The simulated lake levels rise several feet compared to the Existing Conditions Scenario after the Design Drought period. The lowest lake levels for Scenarios 3a and 3b are about 7 feet lower than the lowest historical lake level experienced in 1993 of -3.2 feet (City Datum).

Scenario 4 (Cumulative Scenario) includes operation of the GSR and SFGW Projects using the assumptions for Scenario 2 and 3b. In addition, other reasonably foreseeable future projects such as the Daly City Vista Grande Drainage Area Improvements Project are included. This Project would augment Lake Merced with stormwater and baseflow from the Vista Grande Canal. The result of the Cumulative Scenario is that the simulated lake levels are similar to Scenario 1. They also tend to mimic the pattern from Scenario 2 (GSR Project) but at a lower elevation (by about 3 to 4 feet) as a result of SFGW Project pumping. The lowest lake level under Scenario 4 is -4.9 feet (City Datum), which is about 1.5 feet lower than the lowest historical lake level experienced in 1993.

### 8.2. Pine Lake

Pine Lake is a relatively shallow lake that is approximately 3 acres in area and located about 0.5 mile north-northeast of Lake Merced (Figures 10.2-1 and 10.2-2). The design water level elevation for Pine Lake is established at 40.2 feet (NGVD 1929, or 31.5 feet City Datum). Pine

Lake is already maintained by additions of groundwater from the Stern Grove well, and water additions from this well would continue to be necessary to maintain water levels in Pine Lake.

Pine Lake does not appear to be in direct hydraulic communication with the Shallow Aquifer. Rather, there is evidence of groundwater mounding in the Shallow Aquifer indicating a steady, but rate-controlled, leakage of groundwater from the shallowest sediments to the Shallow Aquifer.

For the SFGW Project and Cumulative Scenarios (Scenarios 3a, 3b and 4) groundwater levels in the Shallow Aquifer beneath Pine Lake are projected to decline by approximately 10 to 16 feet relative to the Existing Conditions (Scenario 1). However, based on the conceptual model, these projected declines in shallow groundwater levels are not considered to cause a substantial increase in groundwater leakage from Pine Lake. Therefore, proposed operations of the Stern Grove well are anticipated to maintain the design water level in Pine Lake.

Groundwater levels in the Shallow Aquifer for the GSR Project (Scenario 2) are projected to be similar to or slightly higher than the Existing Conditions. Therefore, operation of the GSR Project is not considered to affect water levels in Pine Lake or cause a change in lake additions from the Stern Grove Well during GSR Project operations.

## 8.3. Golden Gate Park Lakes

Golden Gate Park is located at the northernmost extent of the North Westside Basin (Figure 10.2-1). Twelve lakes or ponds -- Stow Lake, Spreckels Lake, North Lake, Lily Pond, Lloyd Lake, Elk Glen Lake, Metson Lake, Mallard Lake, South Lake, and Middle Lake, Alvord Lake and Rainbow Falls Bowl -- are located within Golden Gate Park (Figure 10.2-3).

The average depths to groundwater indicate that these shallow lakes do not intersect the water table and thus GW/SW interaction does not affect surface water conditions in the Golden Gate Park lakes. The operation of the GSR Project is not anticipated to affect this area; thus, no changes are anticipated for the Golden Gate Park lakes. The operation of the SFGW Project wells is expected to result in net groundwater decreases in this area. Declining groundwater levels caused by operation of the SFGW wells would further reduce the likelihood of GW/SW interaction processes occurring in the Golden Gate Park lakes. Consequently, it is not expected that operation of the SFGW Project, GSR Project, or the Cumulative Scenario will affect existing water level conditions within the Golden Gate Park lakes.

## 8.4. Colma, San Bruno, and Millbrae Creeks

Colma, San Bruno and Millbrae Creeks are located in the central and southern portions of the South Westside Basin (Figure 10.2-1). Given the hydrogeologic conditions and substantial engineered modifications made to Colma, San Bruno and Millbrae Creeks, it is unlikely that GW/SW interaction processes are present to any measureable extent for any of these creeks. The Westside Basin Groundwater-Flow Model showed no substantial effects of the operations of the GSR or SFGW Projects on the groundwater discharges to these creeks. Consequently, implementation of the SFGW Project, GSR Project, or the Cumulative Scenario is not anticipated to affect existing surface water conditions for Colma Creek, San Bruno Creek, or Millbrae Creek, or any of their respective tributaries.

## References

Bennett Consulting Group, 2005, Pine Lake Leakage Observations, letter to Judi Mosqueda, of San Francisco Department of Public Works, February 16, 2005.

Brown and Caldwell, 2010, Historical Rain Data and Flow Evaluation, Technical Memorandum No. 1, April 13, 2010 (revised), prepared for City of Daly City.

Cannon, J., and Heath M., 2005. Colma Creek Headwaters Restoration Project, San Bruno Mountain. Prepared for San Mateo County Environmental Services Agency, Parks and Recreation Division. Dated March 8, 2005.

City of Daly City, 2012, Web site for Vista Grande Drainage Basin Alternatives Analysis (2011) http://www.dalycity.org/City_Hall/Departments/public_works/Reports_1119/vistagrande_alts.htm

HydroFocus, 2007, *Westside Basin Groundwater-Flow Model (version 2.0), Historical Calibration Run (1959-2005) Results and Sensitivity Analysis*, 76p.

HydroFocus, 2009. *Westside Basin Groundwater Model: Updated Historical Simulation and Baseline Simulation Results (Technical Memorandum)*. Dated 05/20/2009.

HydroFocus, 2011. *Westside Basin Groundwater-Flow Model: Updated Model and 2008 No Project Simulation Results (Technical Memorandum)*. Dated 05/06/2011.

Jacobs Associates, 2011a, Vista Grande Drainage Basin Alternatives Analysis Report, Alternatives Evaluation Report Executive Summary, prepared for City of Daly City, February 7, 2011 (Final Draft),

Jacobs Associates, 2011b, Vista Grande Drainage Basin Alternatives Analysis Report, Volume 3 Lake Merced Alternative, prepared for City of Daly City, February 7, 2011 (Final Draft),

Kennedy/Jenks Consultants. 2009. San Francisco Water System Improvement Program (WSIP) Lake Merced Water Levels Restoration (CUW30101) Draft 100% Conceptual Engineering Report (prepared for SFPUC). January 2009.

Kennedy/Jenks Consultants. 2010. Lake Merced Water Quality Data Organization, Review, and Analysis (prepared for SFPUC). January 25, 2010.

Luhdorff & Scalmanini Consulting Engineers (LSCE), 2002. Conceptualization of the Lake-Aquifer System, Westside Ground-Water Basin, San Francisco and San Mateo Counties. Dated March 2002, Re-released July 2002.

Luhdorff & Scalmanini Consulting Engineers (LSCE). 2004. Update on the Conceptualization of the Lake-Aquifer System Westside Groundwater Basin San Francisco and San Mateo Counties. April 2004.

Luhdorff & Scalmanini Consulting Engineers (LSCE). 2005a. North Westside Groundwater Basin Management Plan City and County of San Francisco. Final Draft. April 2005.

Luhdorff & Scalmanini Consulting Engineers (LSCE). 2005b. Results of In-Lieu Recharge Demonstration, Fall 2002 Through Spring 2005, Westside Basin Conjunctive Use Pilot Project. October 2005.

Luhdorff & Scalmanini Consulting Engineers (LSCE). 2006. Hydrogeologic Conditions in the Westside Basin 2005 (prepared for SFPUC). November 2006.

Luhdorff & Scalmanini Consulting Engineers (LSCE), 2010. Task 8B Technical Memorandum No. 1, Hydrogeologic Setting of the Westside Basin. Dated 02/26/2010.

Luhdorff & Scalmanini Consulting Engineers (LSCE), 2011. Interpretation of Well and Aquifer Tests, Lake Merced Pump Station Test Well, July.

Metcalf & Eddy, Inc. 2008. Lake Merced Water Level Restoration Alternative Analysis Report (AAR). Prepared for San Francisco Public Utilities Commission. January 2008.

MWH. 2008. San Francisco Public Utilities Commission Water System Improvement Program Groundwater Conjunctive Use Project WSIP Project CUW30103, Conceptual Engineering Report, November 2008.

Oakland Museum, 2010. The Oakland Museum of California Creek and Watershed Information Source, Guide to San Francisco Bay Area Creeks. http://museumca.org/creeks/. Last accessed 06/30/10.

Pilat, K. 2002. Leaving A Lake Legacy: San Francisco Lakes in Peril (sponsored by the Neighborhood Parks Council). Dated 11/18/2002.

Pezzetti, Toni and Bellows, Michele. 1998. Feasibility Evaluation of Alternatives to Raise Lake Merced. San Francisco Public Utilities Commission by CH2M Hill and The Duffey Co., San Francisco, CA.

San Francisco Department of Public Works (SFDPW) 2001. Sigmund Stern Grove and Pine Lake Site Assessment. July 2001.

San Francisco Department of Public Works (SFDPW) 2005a. Correspondence from J. Mosqueda (CCSF Department of Public Works) to L. Anderson (Department of Public Health). Dated 5/11/2005. Re: Pine Lake Test Filling (includes attached letter report from Bennett Consulting Group, Inc., entitled “Pine Lake leakage observations”, dated 2/16/05).

San Francisco Department of Public Works (SFDPW). 2005b. Drawings from Contract 0850J, Pine Lake and Pine Lake Meadow Improvement Project, A Recreation & Park Commission Project, July 2005.

San Francisco Recreation and Parks Department (SFRPD), 1994. Concept Design Report for Lakes Rehabilitation, October 1994 (prepared by Ace Pacific)

San Francisco Recreation and Parks Department (SFRPD). 2010. Stern Grove and Pine Lake Park Improvement Plan. SFRPD website: http://www.sfgov.org/site/uploadedfiles/recpark/Capital_Improvement_Division_New/capital_plan_pages/districts/Stern%20Grove-Pine%20Lake%20Improvement%20Plan.pdf

San Francisco Public Utilities Commission (SFPUC), 2007, *SFPUC Water System Improvement Program Programmatic Environmental Impact Report.*

San Francisco Public Utilities Commission (SFPUC) 2009a. 2008 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California. Dated April 2009.

San Francisco Public Utilities Commission (SFPUC) 2009b. *Conceptual Engineering Report Groundwater Sub-Project B North Westside Basin Local Supply*, July 2009.

San Francisco Public Utilities Commission (SFPUC) 2010. Lake Merced Water Quality Data Report (published 03/22/2010, updated 03/25/2010 by Water Resources Planning) . SFPUC website: http://sfwater.org/detail.cfm/MC_ID/20/MSC_ID/179/C_ID/4965/ListID/1

San Francisco Public Utilities Commission (SFPUC), 2011, *2010 Annual Groundwater Monitoring Report, Westside Basin, San Francisco and San Mateo Counties, California, SFPUC, San Francisco, CA,* 230p..

San Francisco State University (SFSU) 2005. The Climatology of Lake Merced.

Winter, T. C.; Harvey, J. W.; Franke, O. L.; Alley, W. M., 1998, Ground water and surface water; a single resource, USGS, Circular 1139 , 79p.

Yates, E.B., S.N. Hamlin, and L.H. McCann, 1990, Geohydrology, water quality, and water budgets of Golden Gate Park and the Lake Merced area in the western part of San Francisco, California, *U.S. Geological Survey Water-Resources Investigations Report 90-4080*, U.S. Geological Survey, Sacramento, CA, 50p.

## Figure List

## Table List



## Attachment List

This page intentionally left blank

# Figures

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.2\20120327_TM\10-2_01_PartnerAgency_Wells.mxd




## Legend

- GSR Proposed Municipal Wells
- SFGW Proposed Municipal Wells
- Selected Representative Monitoring Wells
- Cal Water Municipal Wells
- Daly City Municipal Wells
- San Bruno Municipal Wells
- South Westside Groundwater Basin
- North Westside Groundwater Basin

CITY AND COUNTY OF SAN FRANCISCO
PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

**LOCATIONS OF SURFACE WATER FEATURES, PROPOSED GSR AND SFGW PROJECT WELLS, AND MONITORING WELLS IN THE WESTSIDE GROUNDWATER BASIN**

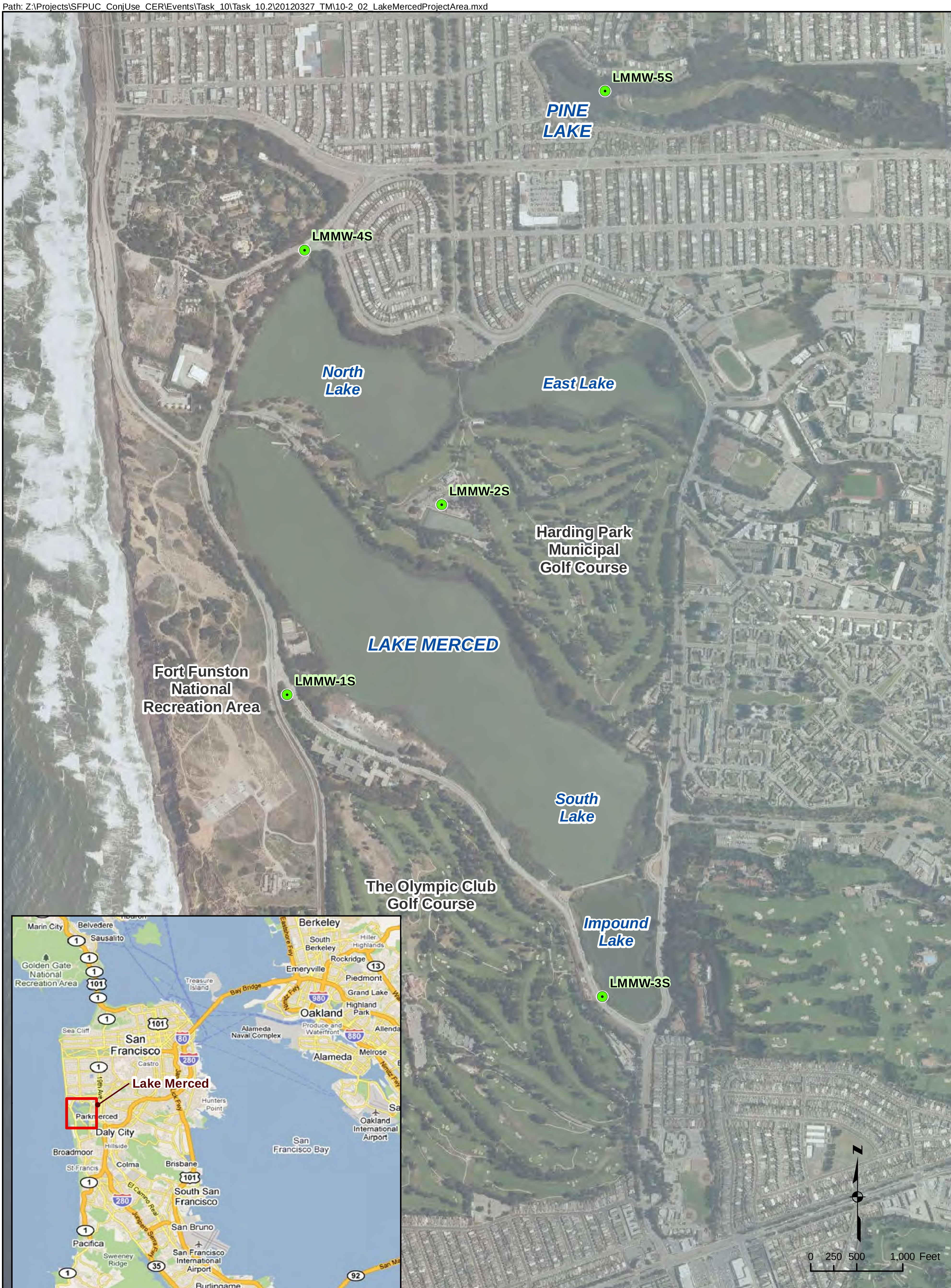
**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Figure
**10.2-1**

Date
May 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.2\20120327_TM\10-2_02_LakeMercedProjectArea.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

CITY AND COUNTY OF SAN FRANCISCO
**PUBLIC UTILITIES COMMISSION**
ENGINEERING MANAGEMENT BUREAU

**Legend**

Monitoring Wells in Lake Merced Area

**LAKE MERCED AND PINE LAKE**

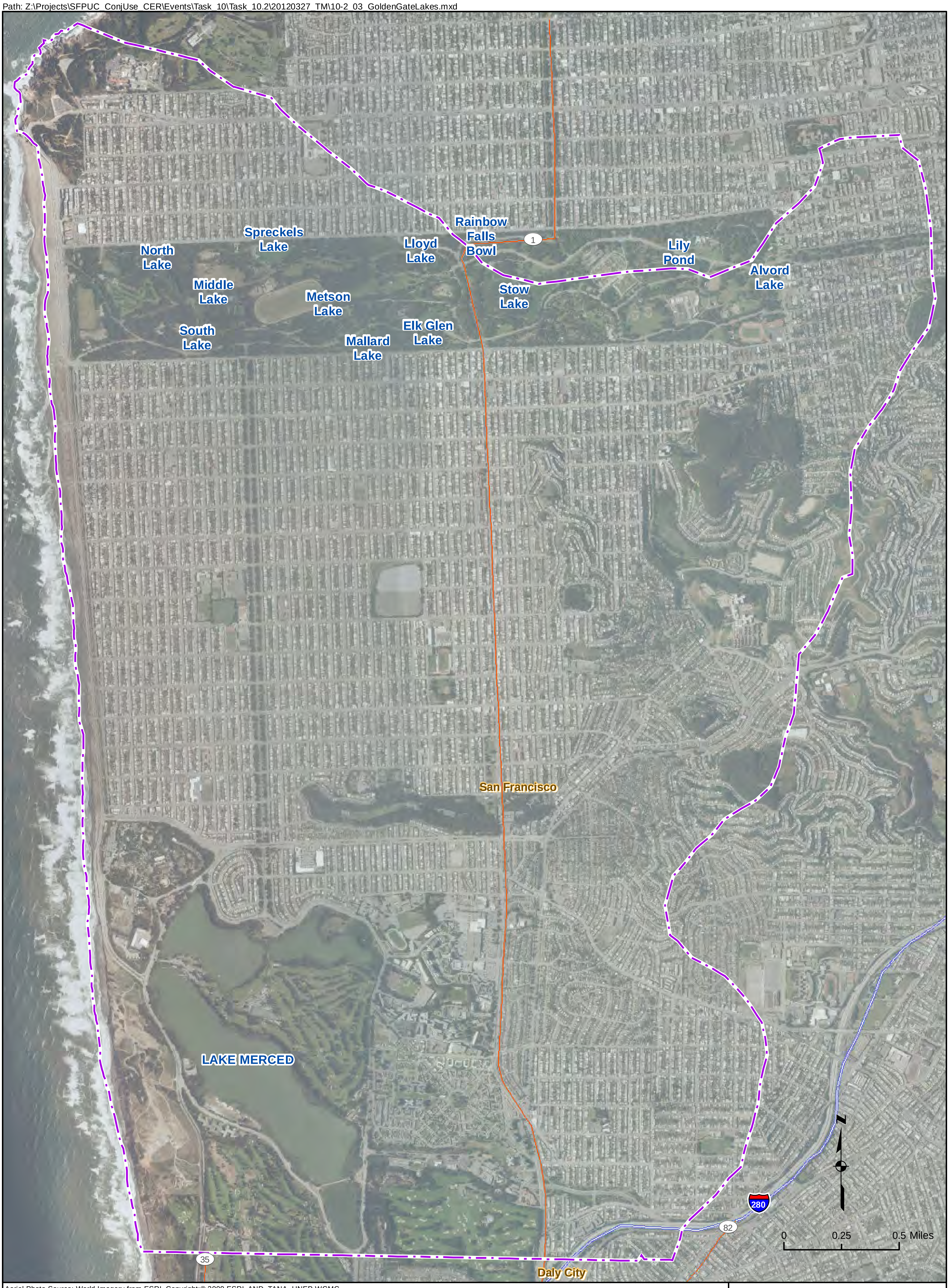
**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project

Figure **10.2-2**

Date May 2012

Path: Z:\Projects\SFPUC_ConjUse_CER\Events\Task_10\Task_10.2\20120327_TM\10-2_03_GoldenGateLakes.mxd




Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

**Legend**

North Westside Groundwater Basin

CITY AND COUNTY OF SAN FRANCISCO
**PUBLIC UTILITIES COMMISSION**
ENGINEERING MANAGEMENT BUREAU

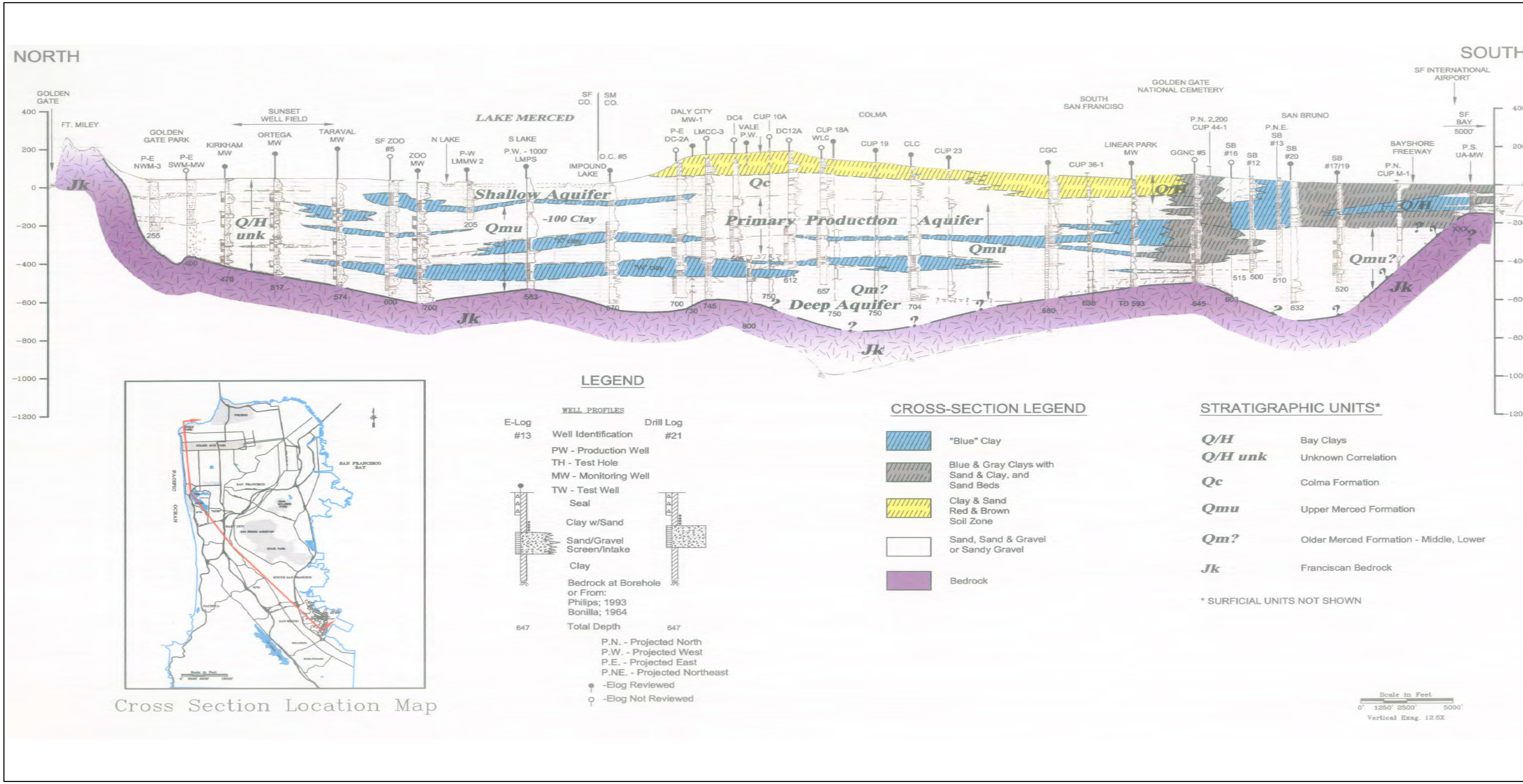
**GOLDEN GATE PARK LAKES**

**Kennedy/Jenks Consultants**
303 Second Street, Suite 300 South
San Francisco, CA 94107

Figure
**10.2-3**

Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Date
May 2012

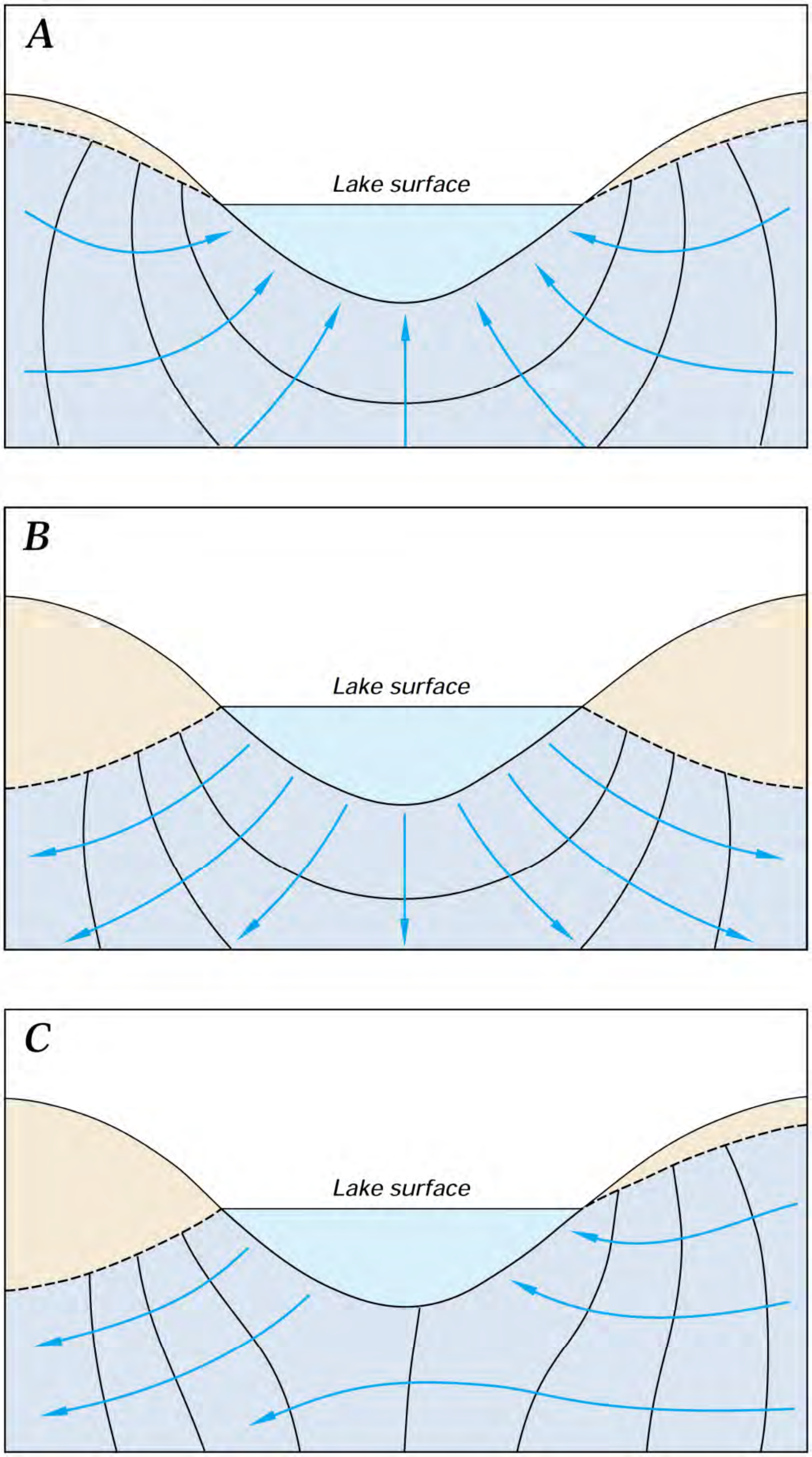



Source: Final Task 8B Technical Memorandum No.1, Hydrologic Setting of the Westside Basin, LSCE, May 2010.

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
And San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission
**Westside Basin Regional Subsurface Hydrogeology**
K/J 0864001
May 2012

**Figure 10.2-4**



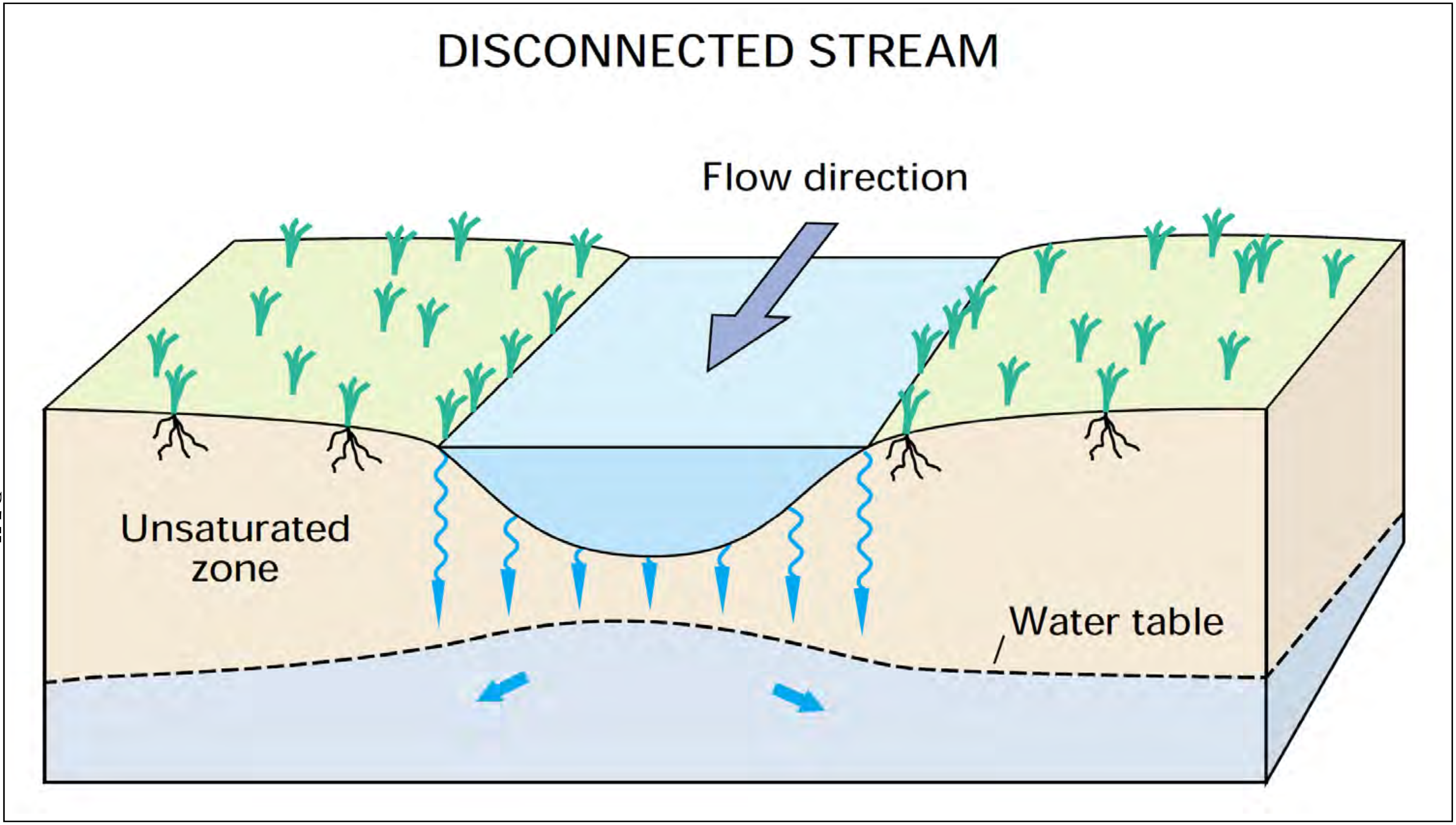

*Lakes can receive groundwater inflow (A), lose water as seepage to groundwater (B), or both (C). From Winter et al. (1998).*

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Interaction of Groundwater and Lakes**

K/J 0864001
May 2012
**Figure 10.2-5**



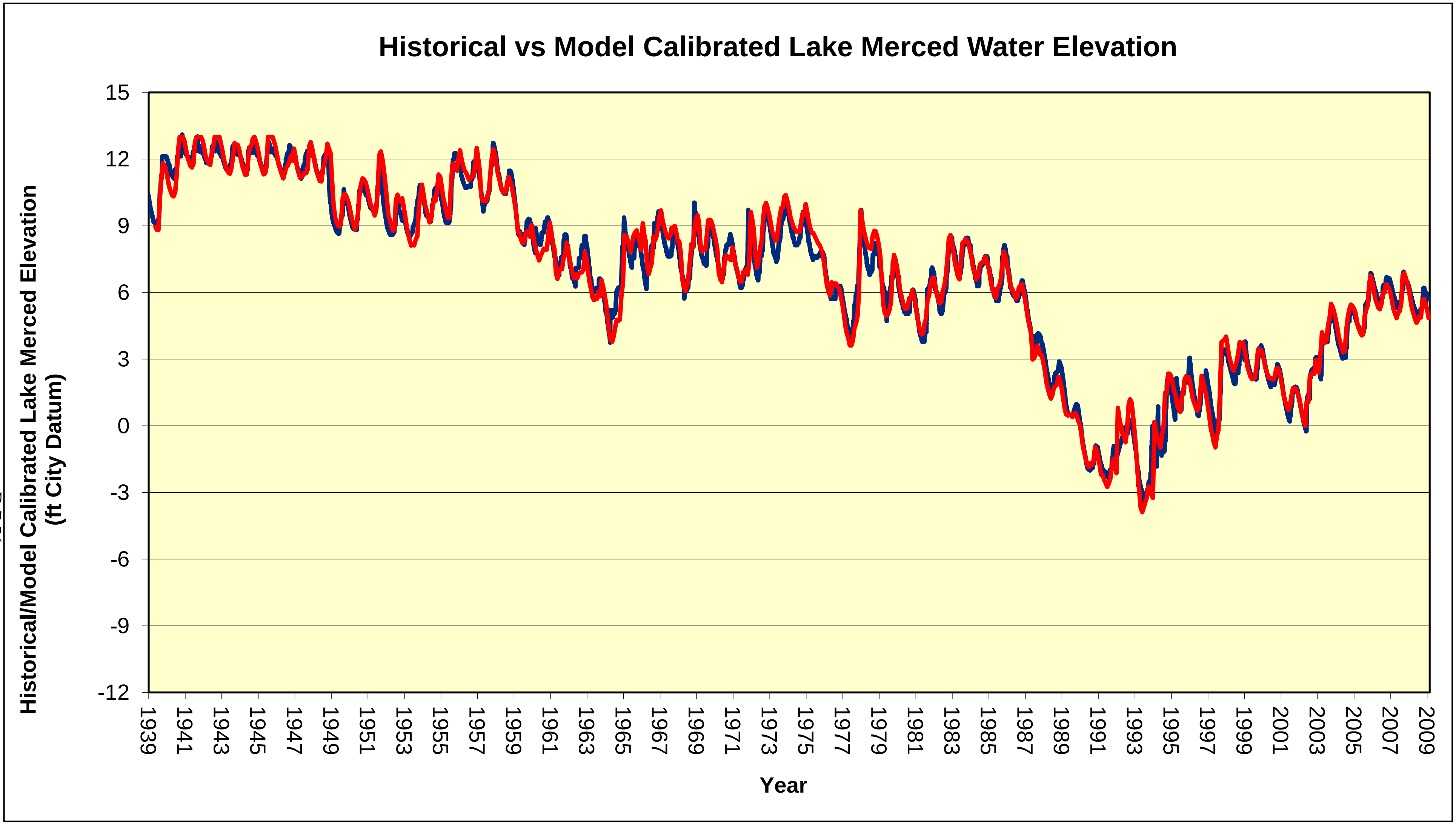

*Disconnected streams are separated from the groundwater system by an unsaturated zone. From Winter et al. (1998).*

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Disconnected Streams**

K/J 0864001
May 2012
**Figure 10.2-6**




Source: Historical Lake Merced water elevation data from the San Francisco Public Utilities Commission
City Datum = NGVD - 8.62 feet

**Legend**

Historical Measured Lake Elevation (feet City Datum)

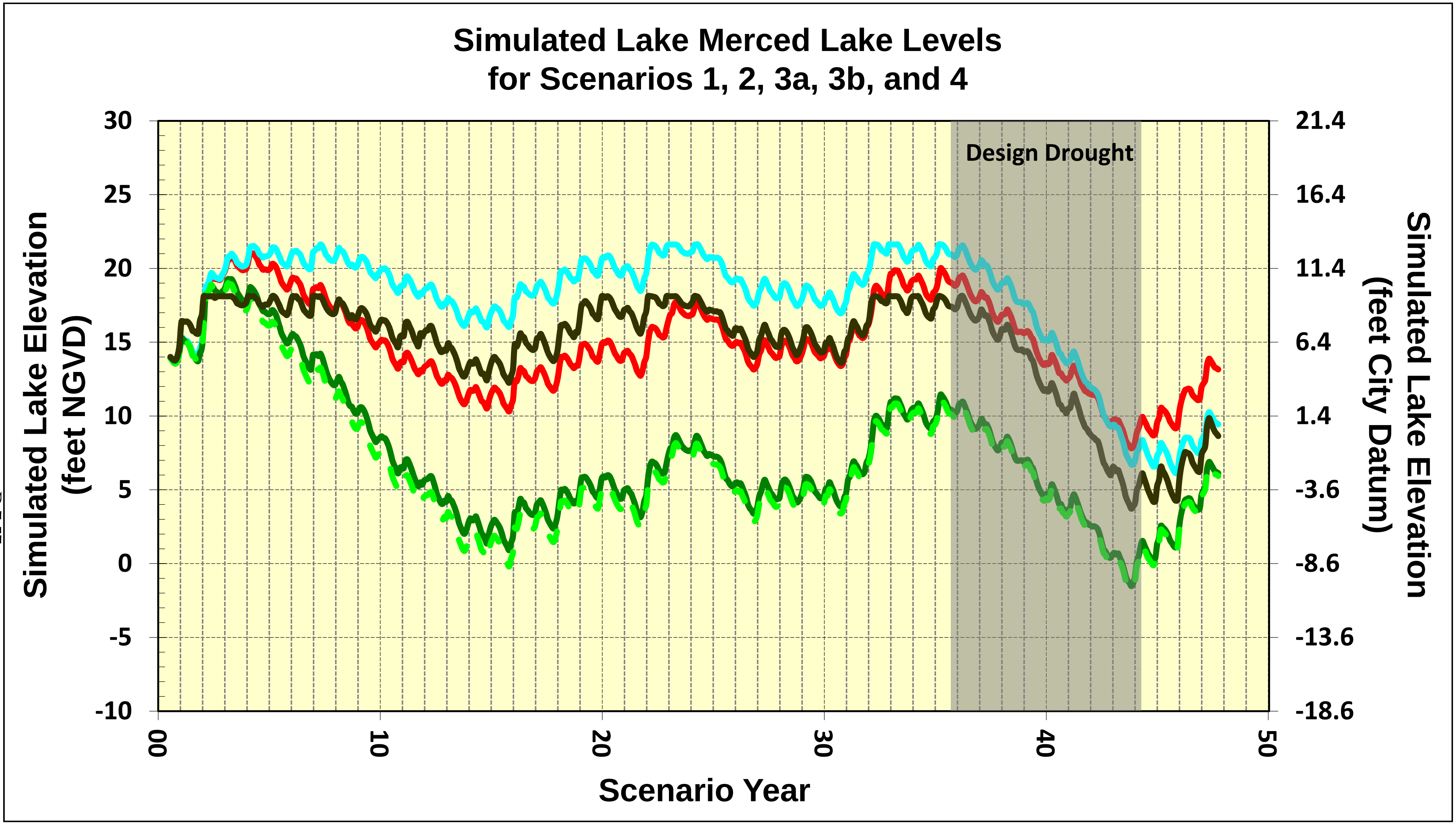
Model Calibrated Lake Elevation (feet City Datum)

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Historical Measured and Simulated Lake Merced Levels**

K/J 0864001
May 2012
**Figure 10.2-7**




Note: Zero elevation NGVD is equivalent to mean sea level NGVD. City Datum = NGVD - 8.62 feet.

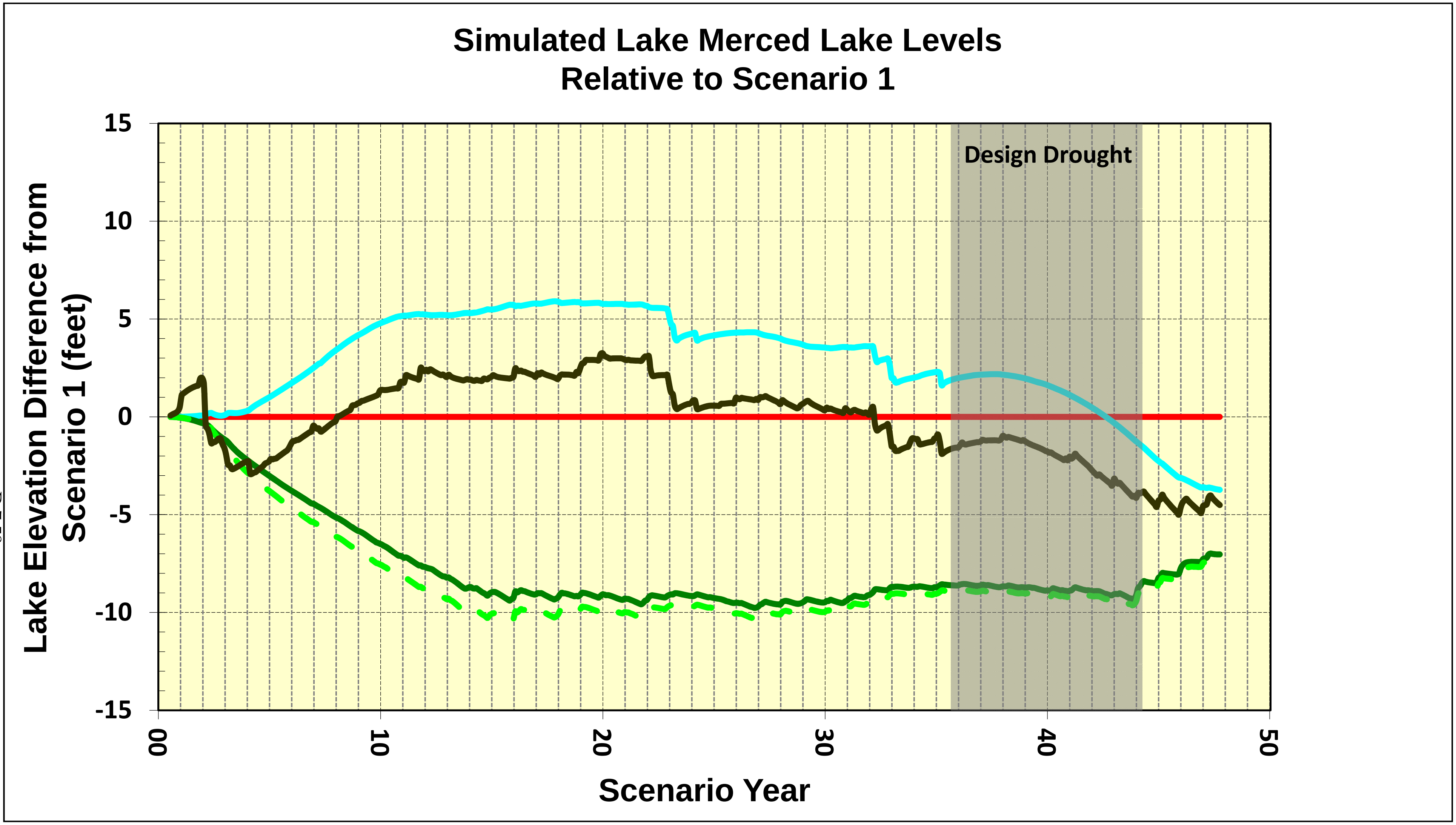
**Lake Levels:**
Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4


**Kennedy/Jenks Consultants**


Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Simulated Lake Merced Lake-Level Model Lake Levels**

K/J 0864001
May 2012
**Figure 10.2-8**




D.7-58

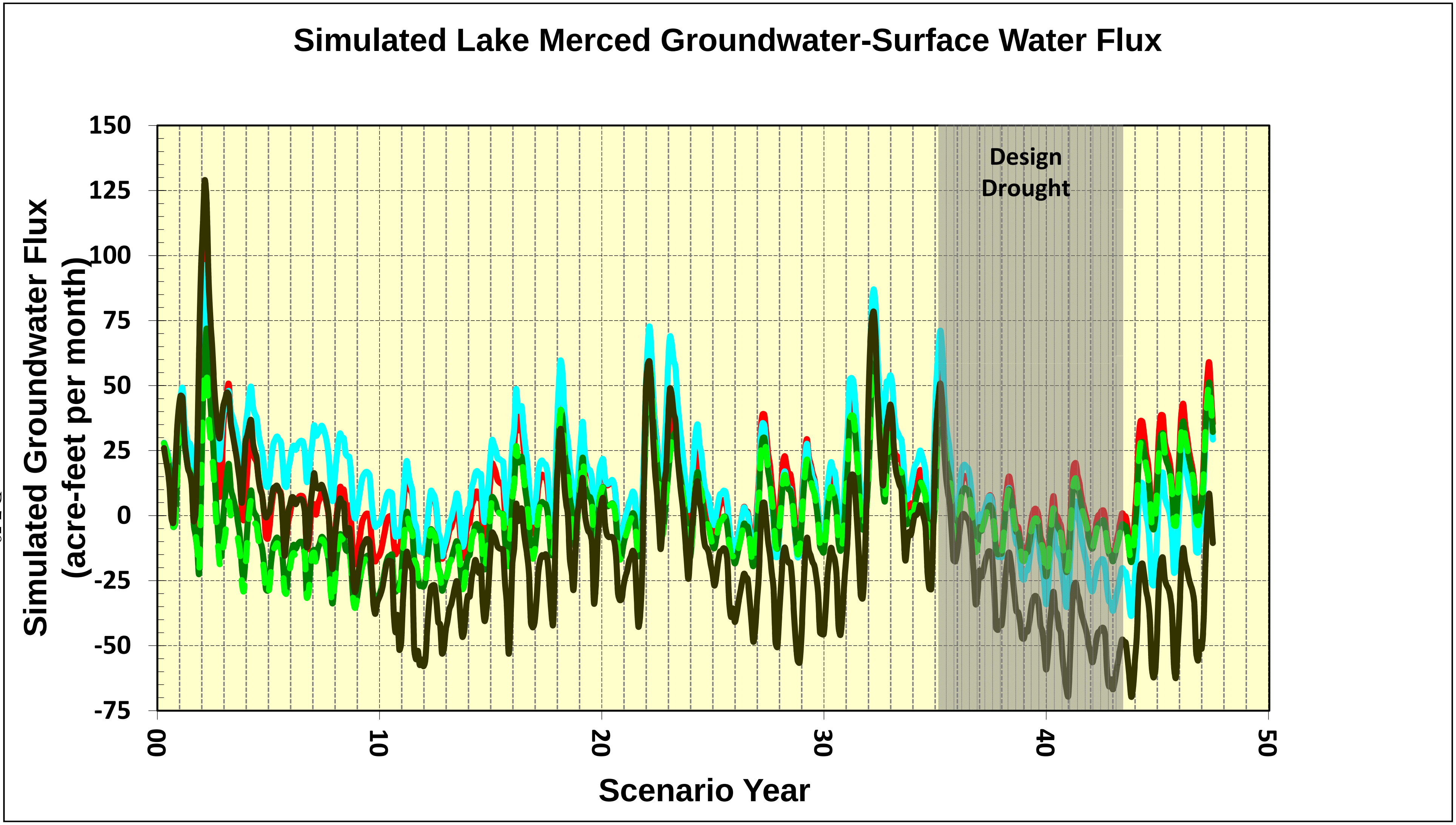
Lake Levels:
Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Simulated Lake Merced Lake-Level Model Lake Levels Relative to Scenario 1**

K/J 0864001
May 2012
**Figure 10.2-9**



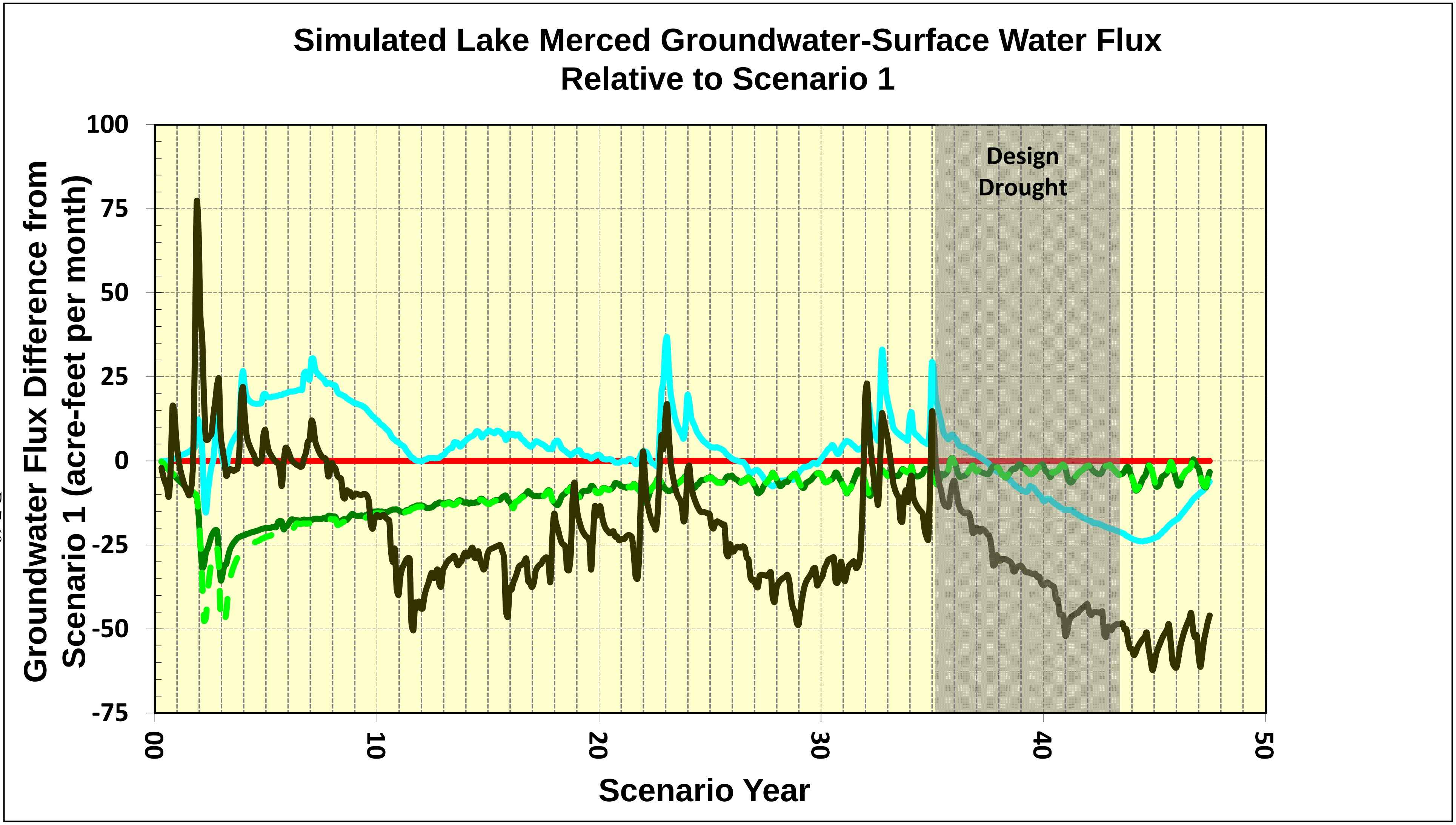

Model Flux:
Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Simulated Lake Merced Groundwater-Surface Water Flux**

K/J 0864001
May 2012
**Figure 10.2-10a**




Model Flux:
Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4

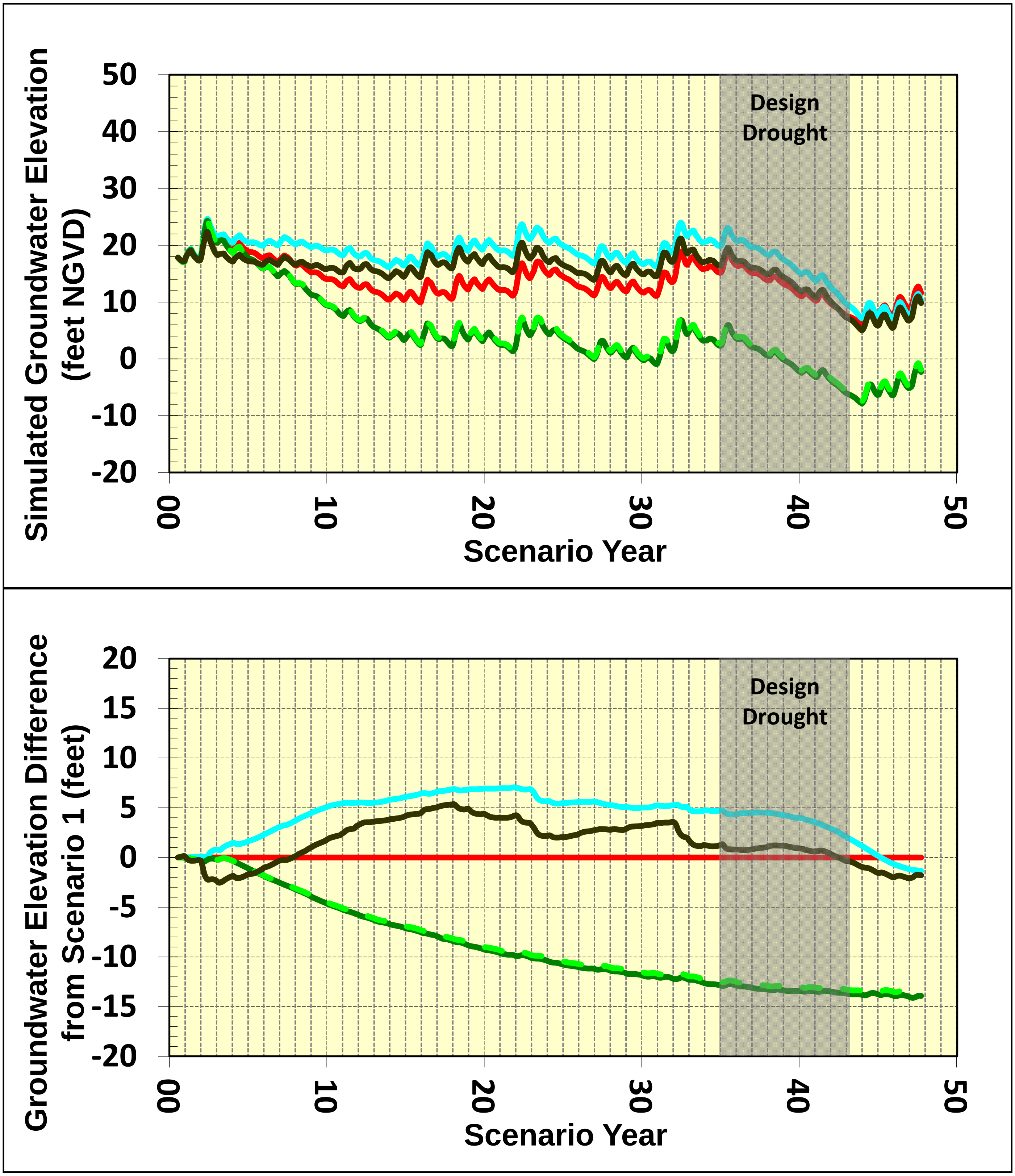
D.7-60

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Simulated Lake Merced Groundwater-Surface Water Flux Relative to Scenario 1**

K/J 0864001
May 2012
**Figure 10.2-10b**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

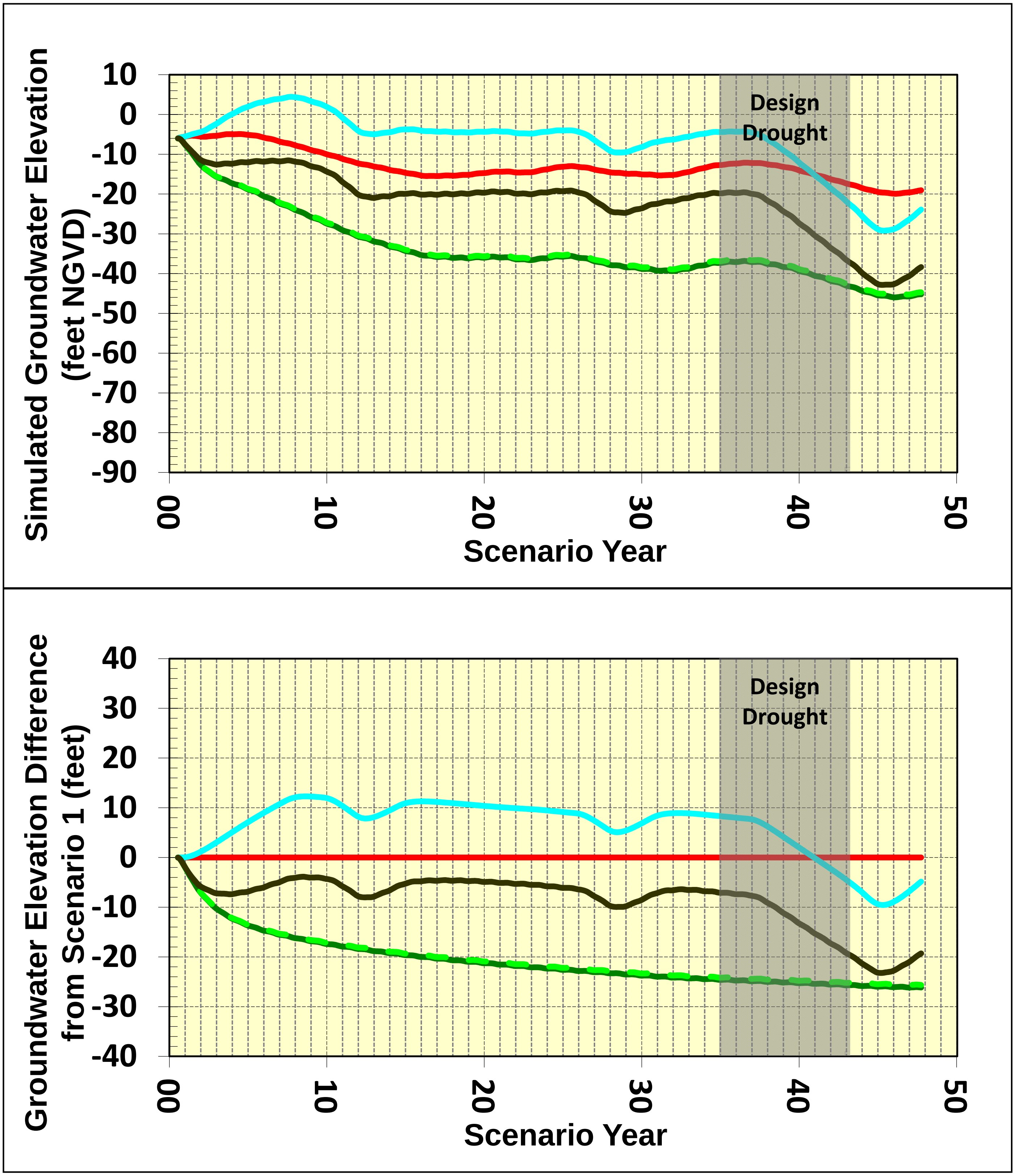
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for LMMW-1**

K/J 0864001
May 2012
**Figure 10.2-11a**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

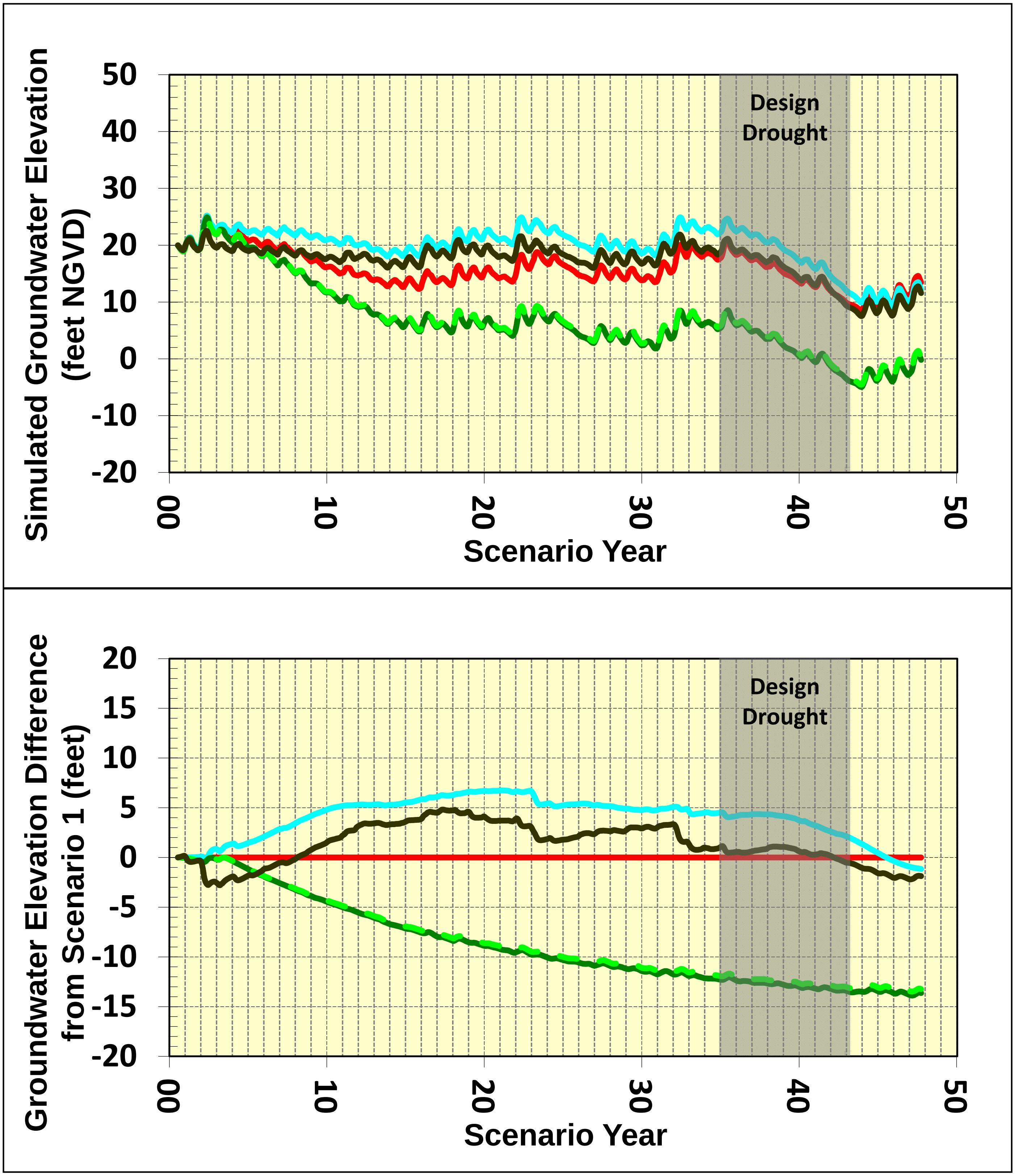
**Model Heads:**
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for LMMW-1**

K/J 0864001
May 2012
**Figure 10.2-11b**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

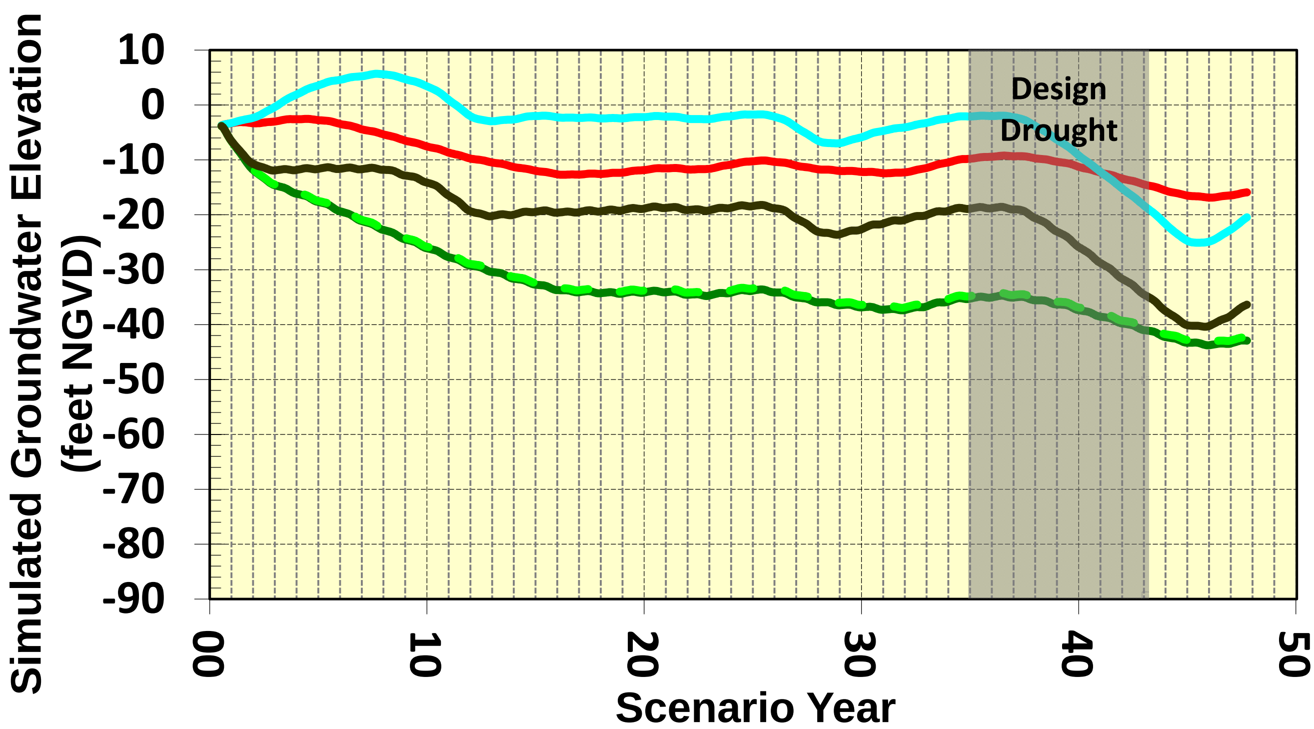
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

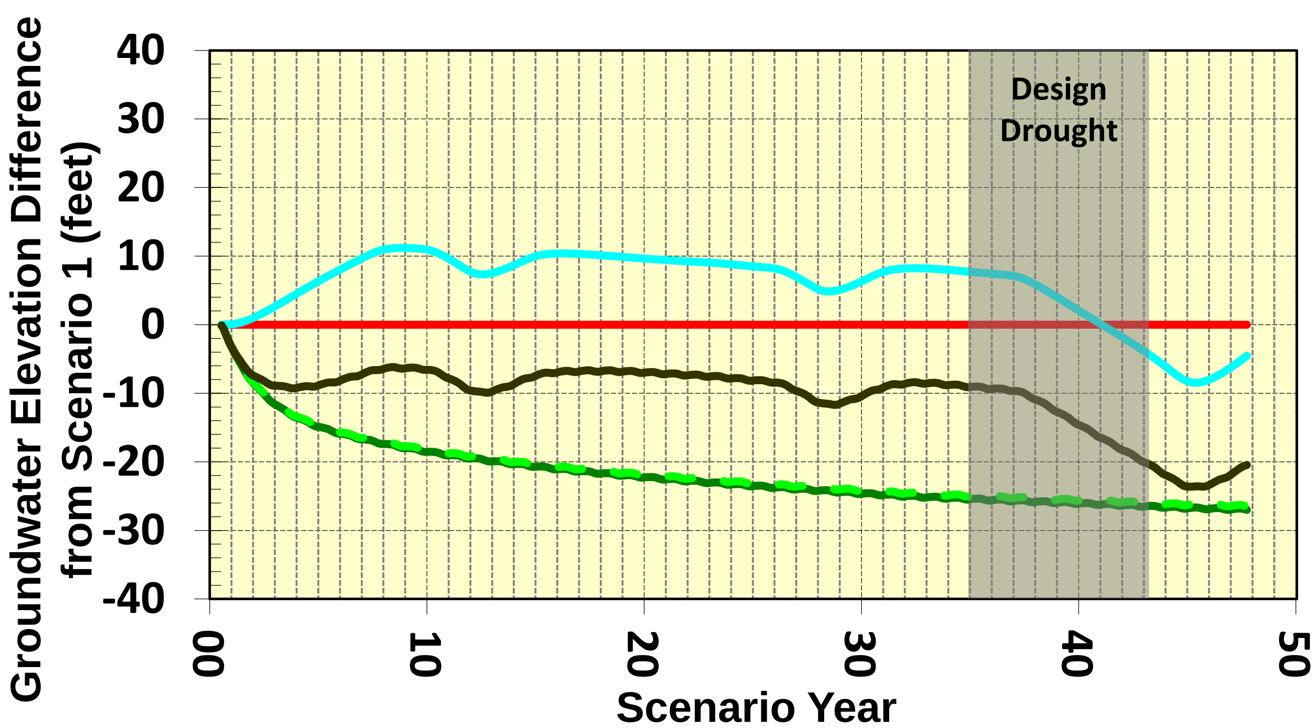
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for LMMW-2**

K/J 0864001
May 2012
**Figure 10.2-12a**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

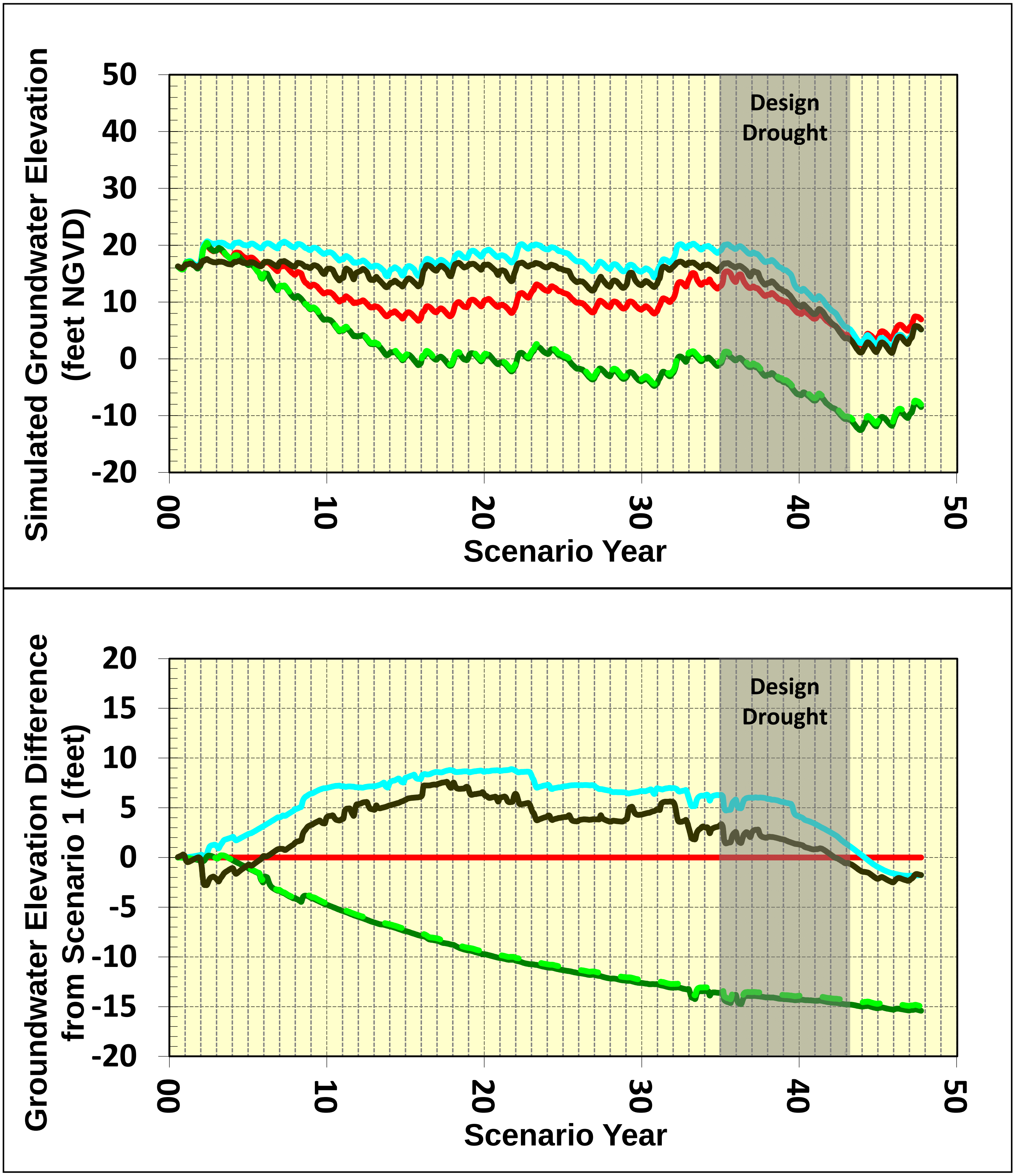
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for LMMW-2**

K/J 0864001
May 2012
**Figure 10.2-12b**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

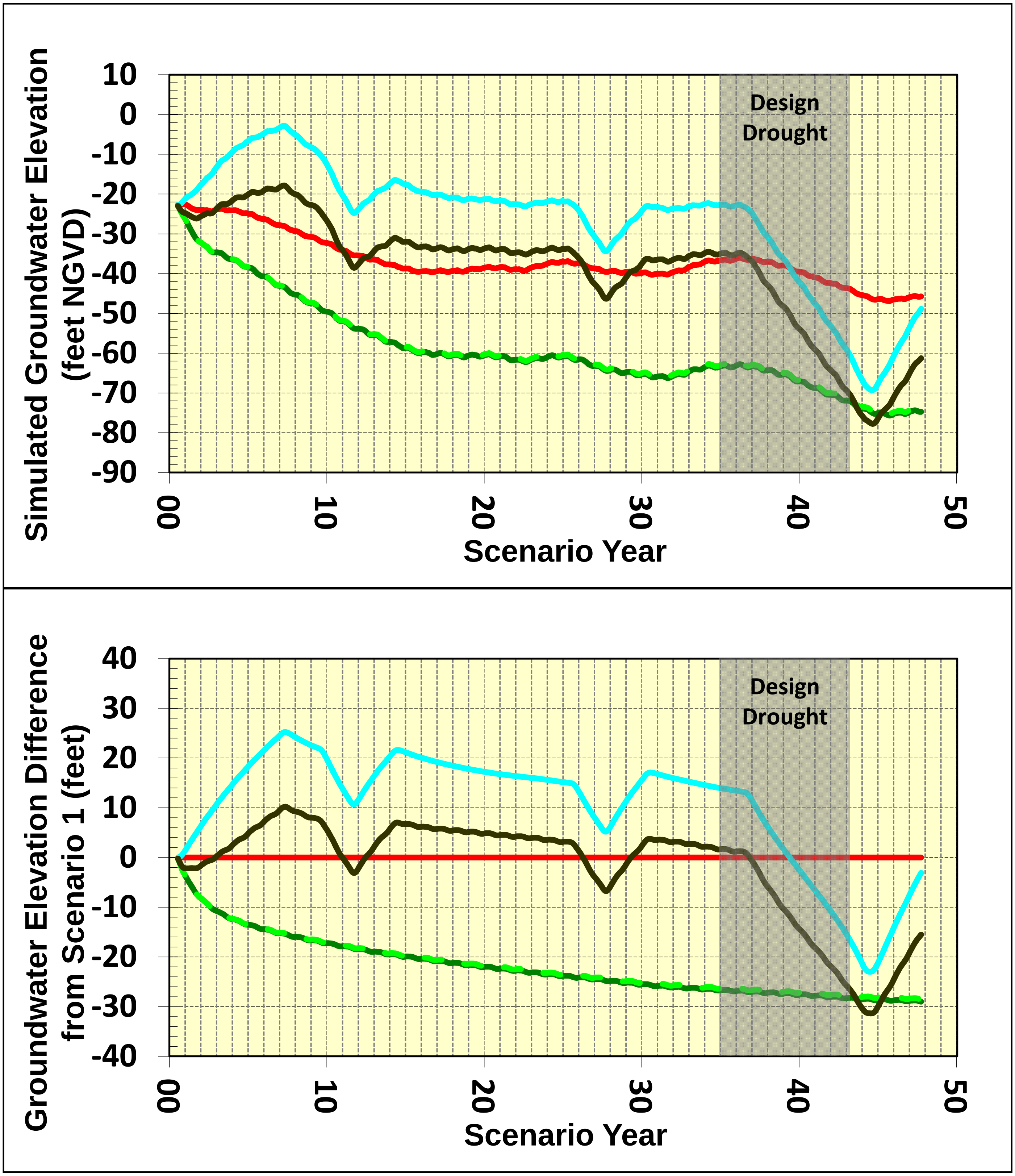
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for LMMW-3**

K/J 0864001
May 2012
**Figure 10.2-13a**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

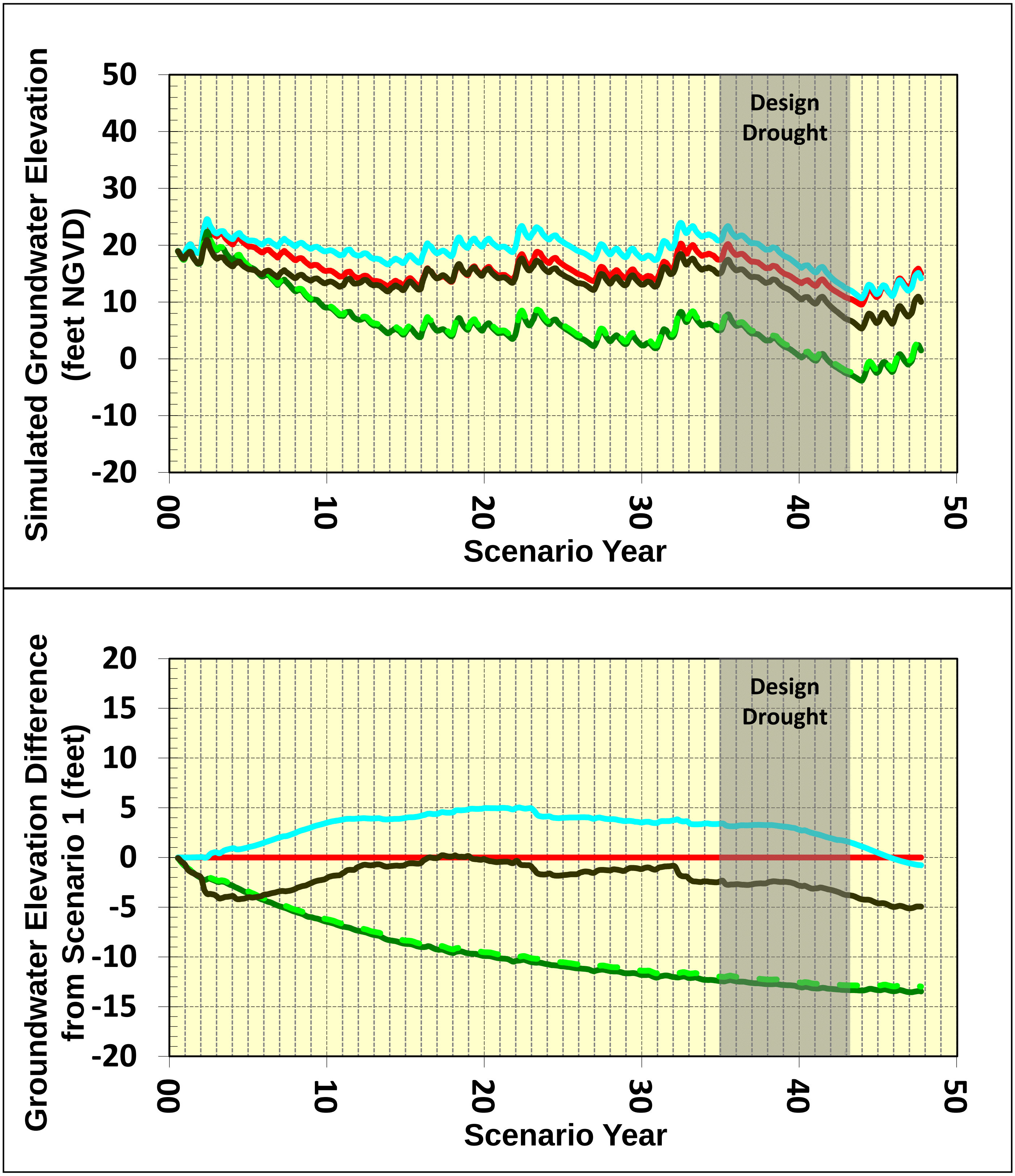
- **Scenario 1**
- **Scenario 2**
- **Scenario 3a**
- **Scenario 3b**
- **Scenario 4**

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for LMMW-3**

K/J 0864001
May 2012
**Figure 10.2-13b**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

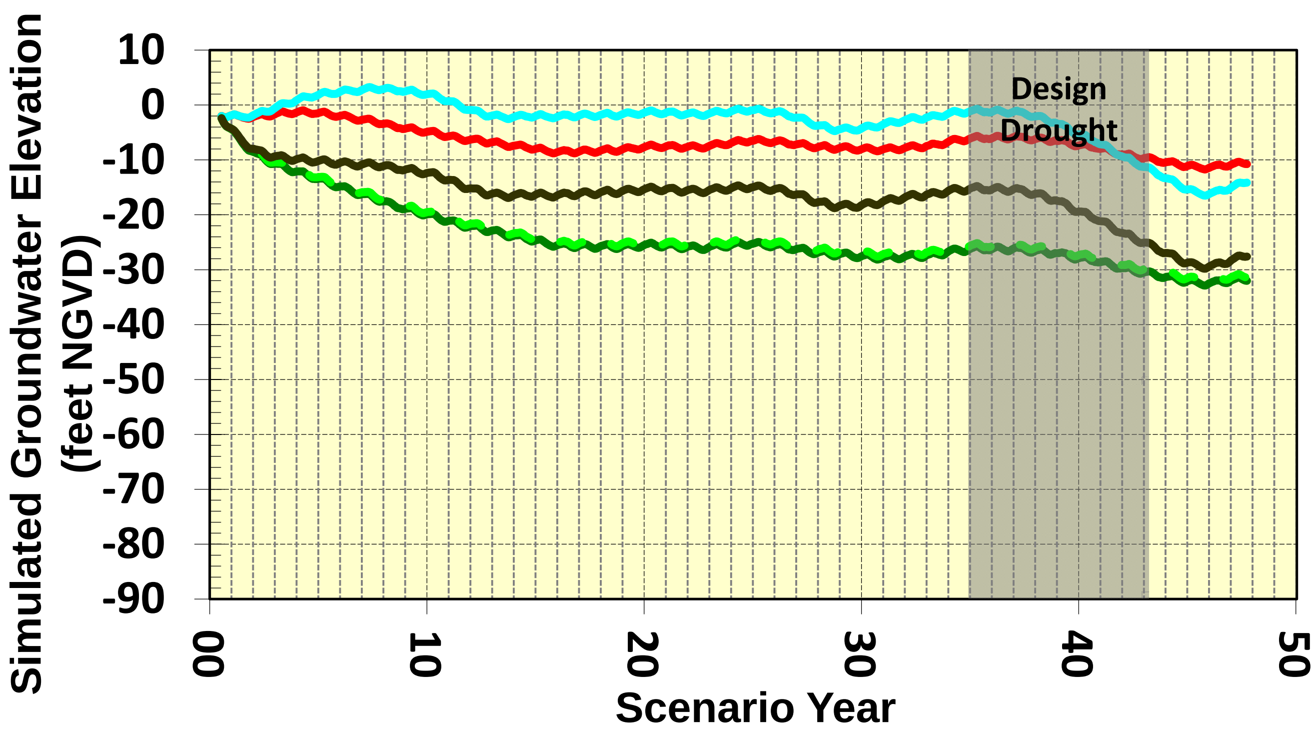
Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4

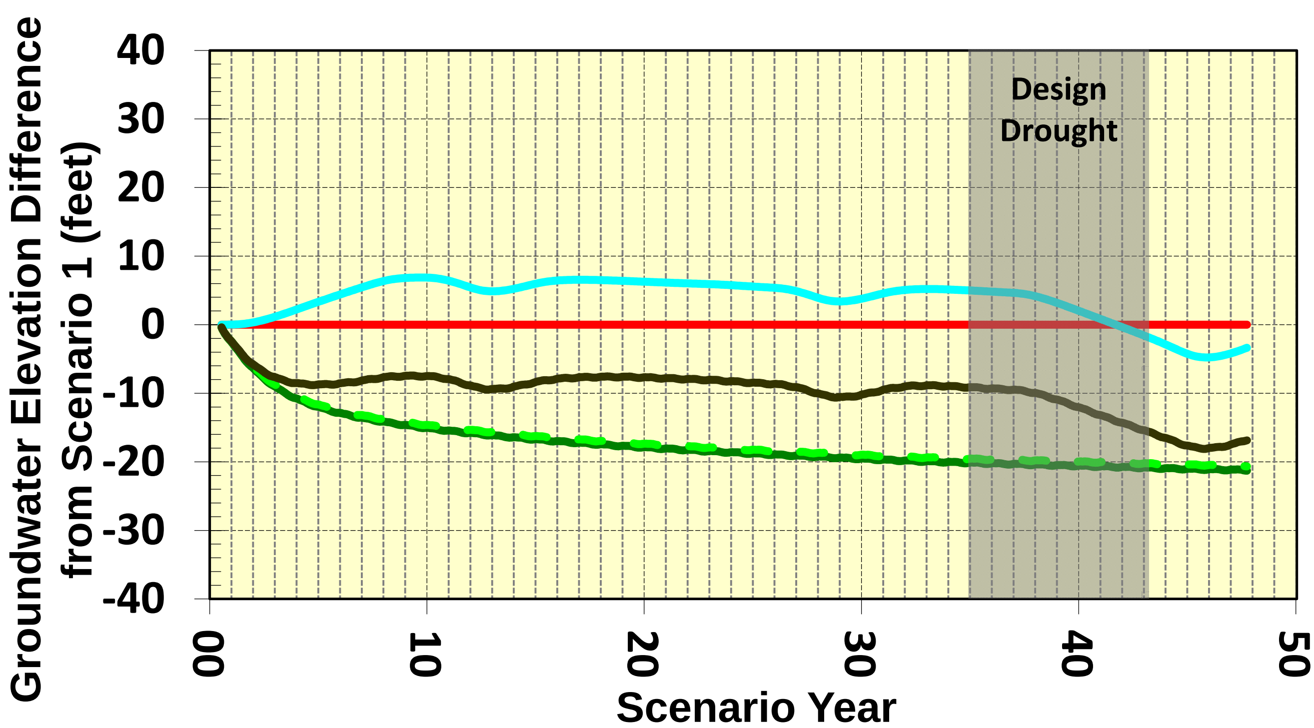
**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for LMMW-4**

K/J 0864001
May 2012
**Figure 10.2-14a**




Note: Zero elevation is equivalent to mean sea level NGVD.

**Model Heads:**

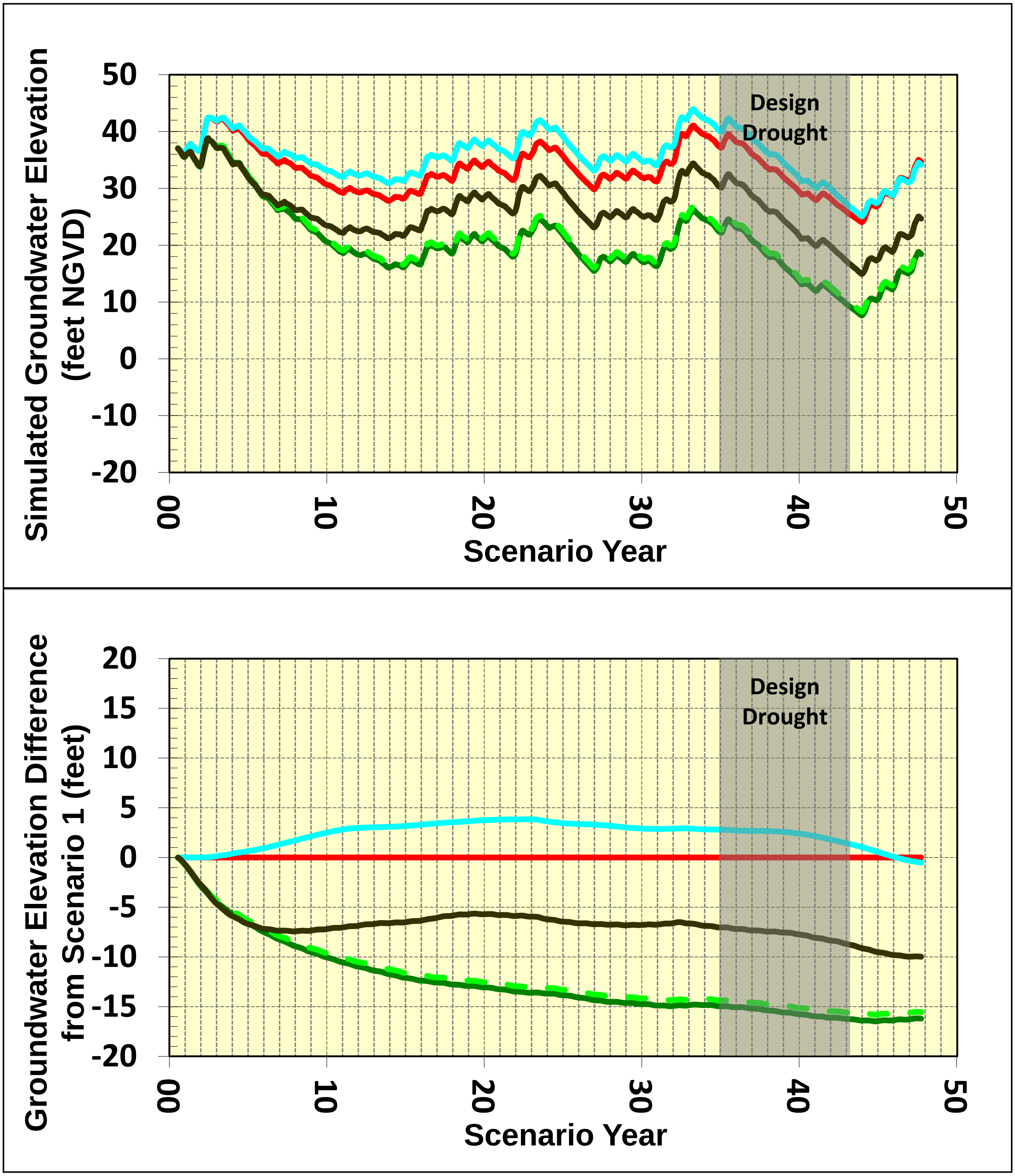
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 4 Hydrographs for LMMW-4**

K/J 0864001
May 2012
**Figure 10.2-14b**




**Note: Zero elevation is equivalent to mean sea level NGVD.**

**Model Heads:**

- **Scenario 1**
- **Scenario 2**
- **Scenario 3a**
- **Scenario 3b**
- **Scenario 4**

**Kennedy/Jenks Consultants**

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

**Model Layer 1 Hydrographs for LMMW-5**

K/J 0864001
May 2012
**Figure 10.2-15**

This page intentionally left blank

# Tables

# Table 10.2-1: Summary of Model Scenario Pumping Assumptions

| | | Scenario 1 | Scenario 2 | Scenario 3a | Scenario 3b | Scenario 4 |
|---|---|---|---|---|---|---|
| **Model Scenarios** | | **Existing Conditions** | **GSR** | **SFGW** | **SFGW** | **Cumulative** |
| **Establish Initial Conditions** | | Hydrologic Sequence | Hydrologic Sequence | Hydrologic Sequence | Hydrologic Sequence | Hydrologic Sequence |
| | June 2009 Condition | √ | √ | √ | √ | √ |
| **Model Scenario Simulation Period** | | | | | | |
| | 47.25 years (including Design Drought) Hydrologic Sequence: July 1996 to September 2003 -> October 1958 to November 1992 -> December 1975 to June 1978 -> July 2003 - September 2006 | | √ | √ | √ | √ |
| **Pumping Assumptions for Municipal Use** | | | | | | |
| **PA Municipal Wells (mgd)** | | | | | | |
| | "Take" Periods | 6.84 | 6.90 | 6.84 | 6.84 | 6.90 |
| | "Put" Periods | 6.84 | 1.38 | 6.84 | 6.84 | 1.38 |
| | "Hold" Periods | 6.84 | 6.90 | 6.84 | 6.84 | 6.90 |
| **GSR Project Proposed Municipal Wells (mgd)** | | | | | | |
| | "Take" Periods | 0.0 | 7.23 | 0.0 | 0.0 | 7.23 |
| | "Put" Periods | 0.0 | 0.04 | 0.0 | 0.0 | 0.04 |
| | "Hold" Periods | 0.0 | 0.04 | 0.0 | 0.0 | 0.04 |
| **SFGW Project Proposed Municipal Wells (mgd)** | | | | | | |
| | Year-Round Pumping | 0.0 | 0.0 | 3.0 | 4.0 | 4.0 |
| ***Total Municipal Pumping (PA + GSR + SFGW)*** | | | | | | |
| | ***"Take" Periods*** | ***6.84*** | ***14.13*** | ***9.84*** | ***10.84*** | ***18.13*** |
| | ***"Put" Periods*** | ***6.84*** | ***1.42*** | ***9.84*** | ***10.84*** | ***5.42*** |
| | ***"Hold" Periods*** | ***6.84*** | ***6.94*** | ***9.84*** | ***10.84*** | ***10.94*** |
| **Irrigation and Other Non-Potable Pumping Assumptions (mgd)[1]** | | | | | | |
| Golden Gate Park | Elk Glen (GGP) | 0.081 | 0.081 | 0.081 | 0.000 | 0.000 |
| | South Windmill (GGP) | 0.498 | 0.498 | 0.498 | 0.000 | 0.000 |
| | North Lake (GGP) | 0.563 | 0.563 | 0.563 | 0.000 | 0.000 |
| | ***Sub-Total*** | ***1.142*** | ***1.142*** | ***1.142*** | ***0.000*** | ***0.000*** |
| Golf Courses | Burlingame Golf Club | 0.150 | 0.150 | 0.150 | 0.150 | 0.150 |
| | California Golf No. 02 | 0.192 | 0.192 | 0.192 | 0.192 | 0.192 |
| | Green Hills No. 05 | 0.099 | 0.099 | 0.099 | 0.099 | 0.099 |
| | Lake Merced Golf No. 01 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| | Lake Merced Golf No. 02 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| | Lake Merced Golf No. 03 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 |
| | Olympic Club No. 09[2] | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| | SF Golf West | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |
| | ***Sub-Total*** | ***0.495*** | ***0.495*** | ***0.495*** | ***0.495*** | ***0.495*** |
| Cemeteries | Cypress Lawn No. 02 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| | Cypress Lawn No. 03 | 0.144 | 0.144 | 0.144 | 0.144 | 0.144 |
| | Eternal Home | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 |
| | Hills of Eternity No. 02 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| | Holy Cross No. 03[3] | 0.190 | 0.190 | 0.190 | 0.190 | 0.230 |
| | Home of Peace No. 02 | 0.039 | 0.039 | 0.039 | 0.039 | 0.039 |
| | Italian Cemetery | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 |
| | Olivet | 0.098 | 0.098 | 0.098 | 0.098 | 0.098 |
| | Woodlawn No. 02 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 |
| | ***Sub-Total*** | ***0.641*** | ***0.641*** | ***0.641*** | ***0.641*** | ***0.681*** |
| Other | Hillsborough Residents No. 1-12 | 0.291 | 0.291 | 0.291 | 0.291 | 0.291 |
| | Edgewood Development Ctr. | 0.009 | 0.009 | 0.009 | 0.009 | 0.009 |
| | Zoo No.05 | 0.321 | 0.321 | 0.321 | 0.321 | 0.321 |
| | Stern Grove | 0.004 | 0.004 | 0.012 | 0.013 | 0.013 |
| | ***Sub-Total*** | ***0.626*** | ***0.626*** | ***0.634*** | ***0.635*** | ***0.635*** |
| | ***Total Irrigation and Other Non-Potable Pumping*** | ***2.90*** | ***2.90*** | ***2.91*** | ***1.77*** | ***1.81*** |

Key:
afy - acre-feet per year
mgd - million gallons per day
PA - Partner Agencies
GGP - Golden Gate Park
GSR - Regional Groundwater Storage and Recovery
SFGW - San Francisco Groundwater Supply
SFPUC - San Francisco Public Utilities Commission

Notes:
(1) Pumping wells that are listed identify the wells in the model scenarios whose pumping assumptions were modified compared to the 2008 No-Project Scenario by HydroFocus (May, 2011, ver. 3.1), as a result of revised Soil Moisture Budget (SMB). Pumping rates for the three wells in GGP and the California Golf No. 02, Edgewood Development Center, Zoo No. 05, and Stern Grove wells were further modified compared to the results of revised SMB.
(2) Olympic Club No. 09 values include pumping for both Olympic Golf Club wells.
(3) Holy Cross No. 3 well irrigation pumping for Scenarios 1, 2, 3a, and 3b is based on the results of revised SMB. Based on the projected future build-out at the Holy Cross cemetery, an additional pumping of 0.04 mgd (45 afy) was estimated to occur under Scenario 4 (Cumulative).

# Table 10.2-2: Lake Merced Lake-Level Model Summary Statistics for Scenarios 1, 2, 3a, 3b, and 4

| | | Scenario 1 | Scenario 2 | Scenario 3a | Scenario 3b | Scenario 4 |
|---|---|---|---|---|---|---|
| | **Model Scenarios** | **Existing Conditions** | **GSR** | **SFGW** | **SFGW** | **Cumulative** |
| **Lake Level\ Assessment (*percentage of simulation duration with lake levels within specified ranges*)[1]** | | | | | | |
| Lake Level (feet City Datum) | > 11 | 7% | 40% | 0% | 0% | N/A[4] |
| | 9 – 11 | 17% | 30% | 5% | 4% | 19% |
| | 7 – 9 | 15% | 10% | 2% | 3% | 35% |
| | 5 – 7 | 28% | 6% | 7% | 5% | 24% |
| | 3 – 5 | 20% | 2% | 3% | 3% | 7% |
| | 1 – 3 | 9% | 2% | 10% | 9% | 3% |
| | < 1 | 4% | 10% | 73% | 76% | 13% |
| **Monthly Lake Level Statistics (*feet City Datum*)[2]** | | | | | | |
| | 95th Percentile | 11.3 | 12.9 | 9.1 | 8.5 | 9.5 |
| | Mean | 6.3 | 9.1 | -1.3 | -1.9 | 6.1 |
| | 5th Percentile | 1.1 | -0.8 | -7.5 | -8.1 | -2.7 |
| **Annual Lake Level Range Statistics (*feet*)[3]** | | | | | | |
| | 95th Percentile | 3.2 | 2.8 | 3.6 | 3.8 | 3.1 |
| | Mean | 1.6 | 1.5 | 1.8 | 1.8 | 1.6 |
| | 5th Percentile | 0.8 | 0.6 | 0.9 | 0.9 | 0.5 |



Key:
GSR - Regional Groundwater Storage and Recovery Project
SFGW - San Francisco Groundwater Supply Project

Notes:
Summary Statistics are from TM10.2-Attachment 10.2-A.

(1) Lake Level Assessment indicates the percentage of months in the simulation period for which lake levels in Lake Merced were within the specified range. Ranges are given in feet City Datum, which is equal to feet NGVD minus 8.62 feet.

(2) Monthly Lake Level Statistics provide the mean, 95th and 5th percentile of lake levels over the entire simulation period. The 95th Percentile value represents the level below which the Lake Merced lake level was simulated for 95% of the simulation period months. The 5th Percentile value represents the level below which the Lake Merced lake level was simulated for 5% of the simulation period months.

(3) Annual Lake Level Range is the difference between the highest and lowest lake level for a water year (October to September) and averaged over the 47 complete water years in the simulation. The 95th Percentile value represents the range below which 95% of the annual ranges in lake levels (maximum minus minimum levels over an October to September water year) fell. The 5th Percentile value represents the range below which 5% of the annual ranges in lake levels fell.

(4) Category is not applicable, because lake spillway elevation in Scenario 4 is 9.5 feet City Datum.

This page intentionally left blank

# Attachment 10.2-A

## Lake Merced Lake-Level Model Simulation Results for Lake Merced with Summary Statistics

# Explanation for TM10.2 - Attachment 10.2-A

The following sheets provide a summary of the Lake Merced Lake Model for Scenarios 1, 2, 3a, 3b and 4. These scenarios are described in more detail in TM 10.1 and the Lake Model is described in more detail in TM10.1 Attachment 10.1-H.

## Summary of Lake Conditions

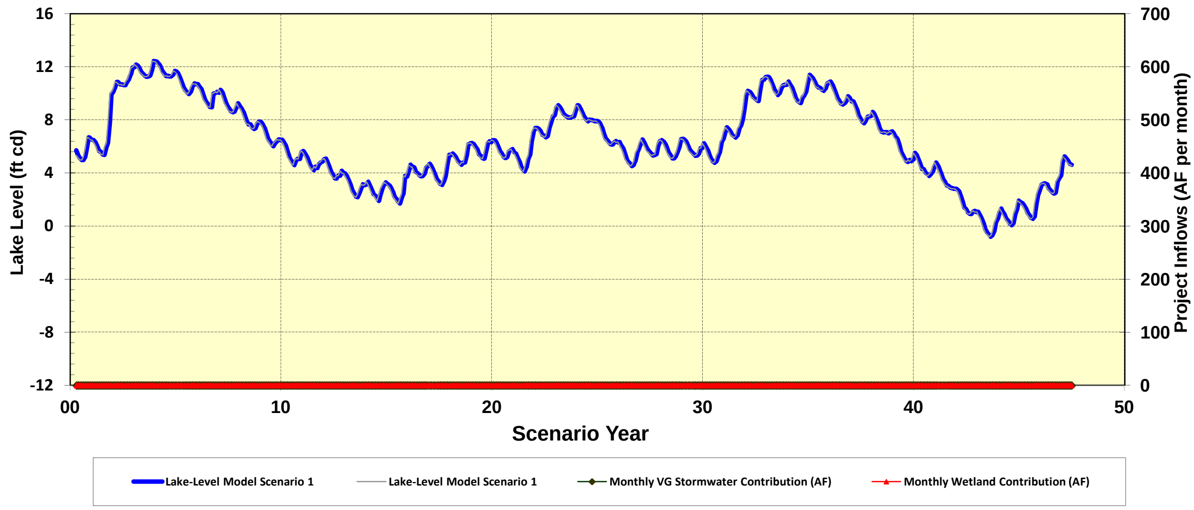
- Project Performance Summary denotes the percentage of time that the simulated lake levels occur in the specified elevation bands. The percentage of time that the lake levels occur between 1 and 13 feet (City Datum) are calculated in 2-foot bands. The percentage for lake levels less than 1 foot (City Datum) is grouped into a single band.
- Monthly Lake Level Summary provides the maximum, minimum and mean lake level for the entire simulation period. In addition, the 95$^{th}$, 90$^{th}$, 10$^{th}$ and 5$^{th}$ percentile lake levels are also provided to provide a basis of comparison of the lake level extremes.
- Monthly Lake Level Change Summary provides the range of month-to-month changes that occur over the entire simulation period.
- Lake Level Continuity provides the maximum length of time that lake levels remain within the specified range over the entire simulation period.
- The Average Annual Lake Elevation Summary provides the maximum, minimum and mean lake level for the 47 full water years (October to September) contained within the simulation. In addition, the 95$^{th}$, 90$^{th}$, 10$^{th}$ and 5$^{th}$ percentile lake levels are also provided to provide a basis of comparison of the lake level extremes.
- Annual Range of Lake Levels is the difference between the maximum and minimum lake level for each water year (October to September) for the 47 full water years included in the simulation. The range provides a method to evaluate whether the lake level fluctuations during a water year vary due to the effects of the project.

## Summary of Project Flows

- Spillway flows provides the number of water years (October to September) for the 47 full water years within specific flow rate bands for lake water flow over the Lake Merced spillway.
- Wetland contribution provides the number of water years (October to September) for the 47 full water years within specific flow rate bands for inflow into Lake Merced through an engineered wetland from water diverted from the Vista Grande Canal. This only occurs in Scenario 4 as part of the Vista Grande Drainage Basin Improvements Project.
- Vista Grande (VG) Stormwater Contribution provides the number of water years (October to September) for the 47 full water years within specific flow rate bands for inflow into Lake Merced from direct diversions of stormwater from the Vista Grande Canal. This only occurs in Scenario 4 as part of the Vista Grande Drainage Basin Improvements Project.
- Project Contribution provides the number of water years (October to September) for the 47 full water years within specific flow rate bands for inflow to or outflow from Lake Merced for the sum of all spillway flows, wetland contributions and Vista Grande stormwater contributions.

## Scenario 1 - SFPUC GSR and SFGW Project Technical Analysis

| Assumptions: | Initial Lake Level | Wetland Source | VG Stormwater | Diversion Elevation | Spillway |
|---|---|---|---|---|---|
| | 5.7 | none | none | 13.0 | 13 |




### Lake Conditions

**Project Performance Summary**

| *Monthly Lake Elevation (ft, City Datum)* | *Percent Time* |
|---|---|
| Above 11 feet | 7% |
| between 9 and 11 feet | 17% |
| between 7 and 9 feet | 15% |
| between 5 and 7 feet | 28% |
| between 3 and 5 feet | 20% |
| between 1 and 3 feet | 9% |
| Below 1 feet | 4% |
| **TOTAL** | **100%** |

**Monthly Lake Level Summary**

| *Percentile* | *Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 12.4 |
| 95th percentile | 11.3 |
| 90th percentile | 10.6 |
| Mean Lake Level | 6.3 |
| 10th percentile | 2.4 |
| 5th percentile | 1.1 |
| Minimum Lake Level | -0.8 |

**Monthly Lake Level Change Summary**

| *Percentile* | *Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 2.14 |
| 95th percentile | 0.61 |
| 90th percentile | 0.42 |
| Mean Lake Level | 0.00 |
| 10th percentile | -0.32 |
| 5th percentile | -0.37 |
| Minimum Lake Level | -0.48 |

**Lake Level Continuity**

| *Monthly Lake Elevation (ft, City Datum)* | Consecutive months |
|---|---|
| Above 11 feet | 30 |
| between 9 and 11 feet | 24 |
| between 7 and 9 feet | 18 |
| between 5 and 7 feet | 43 |
| between 3 and 5 feet | 25 |
| between 1 and 3 feet | 11 |
| Below 1 feet | 11 |

**Average Annual Lake Elevation Summary**

| *Percentile* | *Annual Average Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 11.8 |
| 95th percentile | 11.0 |
| 90th percentile | 10.4 |
| Mean Lake Level | 6.3 |
| 10th percentile | 2.7 |
| 5th percentile | 1.3 |
| Minimum Lake Level | 0.1 |

**Annual Range in Lake Levels**

| *Percentile* | *Lake Level Change (ft)* |
|---|---|
| Maximum Lake Level | 5.5 |
| 95th percentile | 3.2 |
| 90th percentile | 2.7 |
| Mean Lake Level | 1.6 |
| 10th percentile | 0.9 |
| 5th percentile | 0.8 |
| Minimum Lake Level | 0.2 |

### Project Flows

**Spillway Flows**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

**Wetland Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

**VG Stormwater Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

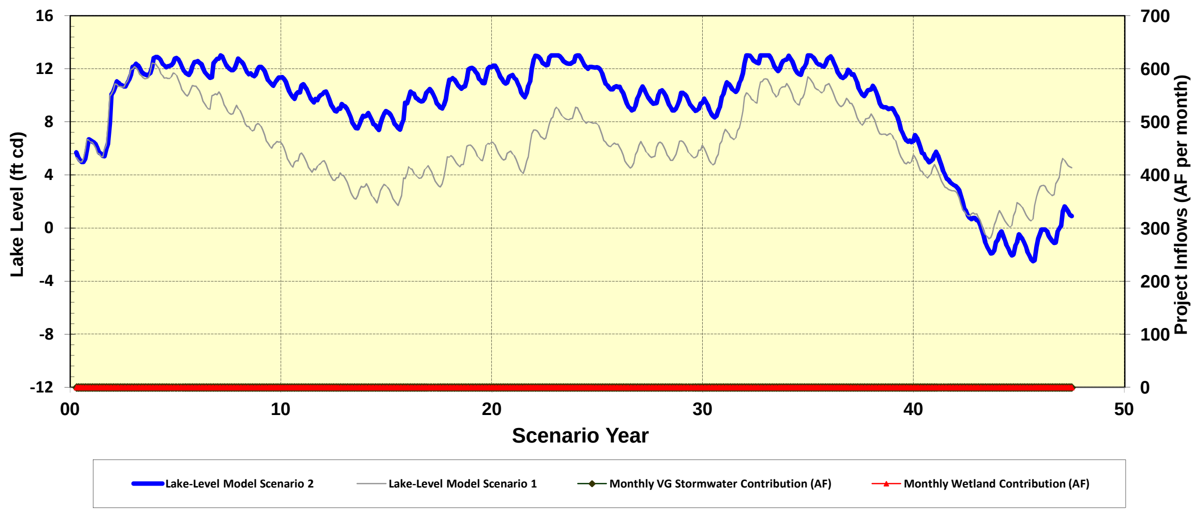
**Project Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Total Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

## Scenario 2 - SFPUC GSR and SFGW Project Technical Analysis

| Assumptions: | Initial Lake Level | Wetland Source | VG Stormwater | Diversion Elevation | Spillway |
|---|---|---|---|---|---|
| Units - Feet City Datum | 5.7 | none | none | 13.0 | 13 |




### Lake Conditions

**Project Performance Summary**

| Monthly Lake Elevation (ft, City Datum) | Percent Time |
|---|---|
| Above 11 feet | 40% |
| between 9 and 11 feet | 30% |
| between 7 and 9 feet | 10% |
| between 5 and 7 feet | 6% |
| between 3 and 5 feet | 2% |
| between 1 and 3 feet | 2% |
| Below 1 feet | 10% |
| **TOTAL** | **100%** |

**Monthly Lake Level Summary**

| Percentile | Lake Elevation (ft, City Datum) |
|---|---|
| Maximum Lake Level | 13.0 |
| 95th percentile | 12.9 |
| 90th percentile | 12.6 |
| Mean Lake Level | 9.1 |
| 10th percentile | 1.1 |
| 5th percentile | -0.8 |
| Minimum Lake Level | -2.5 |

**Monthly Lake Level Change Summary**

| Percentile | Lake Elevation (ft, City Datum) |
|---|---|
| Maximum Lake Level | 2.18 |
| 95th percentile | 0.59 |
| 90th percentile | 0.42 |
| Mean Lake Level | 0.00 |
| 10th percentile | -0.32 |
| 5th percentile | -0.36 |
| Minimum Lake Level | -0.52 |

**Lake Level Continuity**

| Monthly Lake Elevation (ft, City Datum) | Consecutive months |
|---|---|
| Above 11 feet | 80 |
| between 9 and 11 feet | 27 |
| between 7 and 9 feet | 33 |
| between 5 and 7 feet | 14 |
| between 3 and 5 feet | 10 |
| between 1 and 3 feet | 5 |
| Below 1 feet | 54 |

**Average Annual Lake Elevation Summary**

| Percentile | Annual Average Lake Elevation (ft, City Datum) |
|---|---|
| Maximum Lake Level | 12.8 |
| 95th percentile | 12.6 |
| 90th percentile | 12.4 |
| Mean Lake Level | 9.0 |
| 10th percentile | 0.8 |
| 5th percentile | -0.7 |
| Minimum Lake Level | -1.3 |

**Annual Range in Lake Levels**

| Percentile | Lake Level Change (ft) |
|---|---|
| Maximum Lake Level | 5.6 |
| 95th percentile | 2.8 |
| 90th percentile | 2.7 |
| Mean Lake Level | 1.5 |
| 10th percentile | 0.7 |
| 5th percentile | 0.6 |
| Minimum Lake Level | 0.2 |

### Project Flows

**Spillway Flows**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 37 |
| **Maximum** | 604 |
| **Minimum** | 0 |

| Flow (AFY) | Frequency (# of years) |
|---|---|
| 0 | 41 |
| 0 to 100 | 1 |
| 100 to 200 | 1 |
| 200 to 300 | 2 |
| 300 to 500 | 1 |
| >500 | 1 |
| **TOTAL** | **47** |

**Wetland Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| Flow (AFY) | Frequency (# of years) |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

**VG Stormwater Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| Flow (AFY) | Frequency (# of years) |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

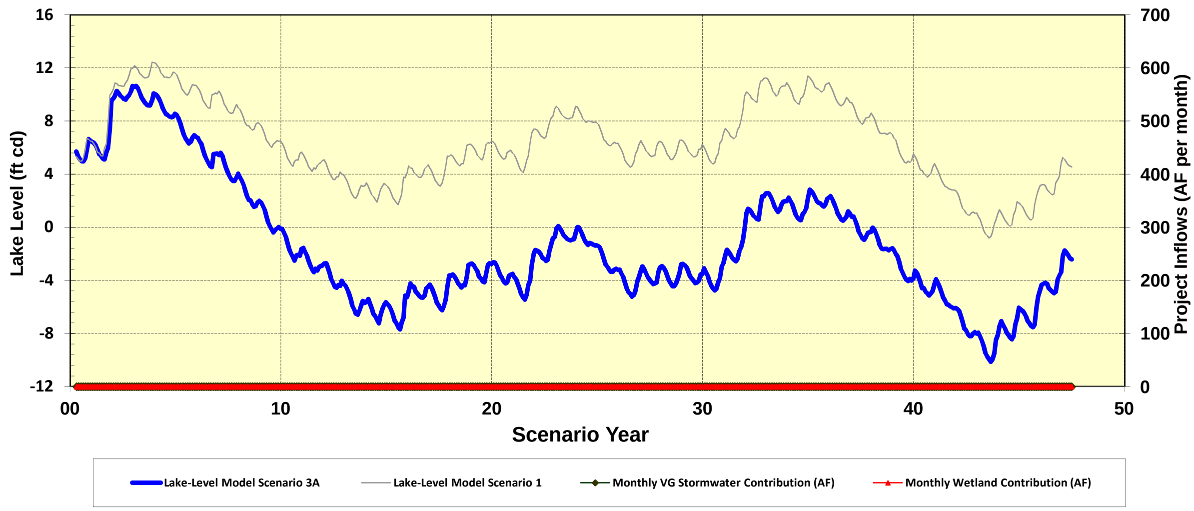
**Project Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 37 |
| **Maximum** | 604 |
| **Minimum** | 0 |

| Total Flow (AFY) | Frequency (# of years) |
|---|---|
| 0 | 41 |
| 0 to 100 | 1 |
| 100 to 200 | 1 |
| 200 to 300 | 2 |
| 300 to 500 | 1 |
| >500 | 1 |
| **TOTAL** | **47** |

# Scenario 3A - SFPUC GSR and SFGW Project Technical Analysis

| Assumptions: | Initial Lake | Wetland Source | VG Stormwater | Diversion Elevation | Spillway |
|---|---|---|---|---|---|
| Units - Feet City Datum | 5.7 | none | none | 13.0 | 13 |




**Lake Conditions**

**Project Performance Summary**

| *Monthly Lake Elevation (ft, City Datum)* | *Percent Time* |
|---|---|
| Above 11 feet | 0% |
| between 9 and 11 feet | 5% |
| between 7 and 9 feet | 2% |
| between 5 and 7 feet | 7% |
| between 3 and 5 feet | 3% |
| between 1 and 3 feet | 10% |
| Below 1 feet | 73% |
| **TOTAL** | **100%** |

**Monthly Lake Level Summary**

| *Percentile* | *Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 10.7 |
| 95th percentile | 9.1 |
| 90th percentile | 6.2 |
| Mean Lake Level | -1.3 |
| 10th percentile | -6.3 |
| 5th percentile | -7.5 |
| Minimum Lake Level | -10.1 |

**Monthly Lake Level Change Summary**

| *Percentile* | *Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 2.11 |
| 95th percentile | 0.65 |
| 90th percentile | 0.48 |
| Mean Lake Level | -0.01 |
| 10th percentile | -0.36 |
| 5th percentile | -0.42 |
| Minimum Lake Level | -0.51 |

**Lake Level Continuity**

| *Monthly Lake Elevation (ft, City Datum)* | Consecutive months |
|---|---|
| Above 11 feet | 0 |
| between 9 and 11 feet | 29 |
| between 7 and 9 feet | 12 |
| between 5 and 7 feet | 14 |
| between 3 and 5 feet | 12 |
| between 1 and 3 feet | 21 |
| Below 1 feet | 273 |

**Average Annual Lake Elevation Summary**

| *Percentile* | *Annual Average Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 10.1 |
| 95th percentile | 8.0 |
| 90th percentile | 6.0 |
| Mean Lake Level | -1.3 |
| 10th percentile | -6.0 |
| 5th percentile | -6.9 |
| Minimum Lake Level | -8.7 |

**Annual Range in Lake Levels**

| *Percentile* | *Lake Level Change (ft)* |
|---|---|
| Maximum Lake Level | 5.2 |
| 95th percentile | 3.6 |
| 90th percentile | 3.3 |
| Mean Lake Level | 1.8 |
| 10th percentile | 0.9 |
| 5th percentile | 0.9 |
| Minimum Lake Level | 0.2 |

**Project Flows**

**Spillway Flows**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

**Wetland Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

**VG Stormwater Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

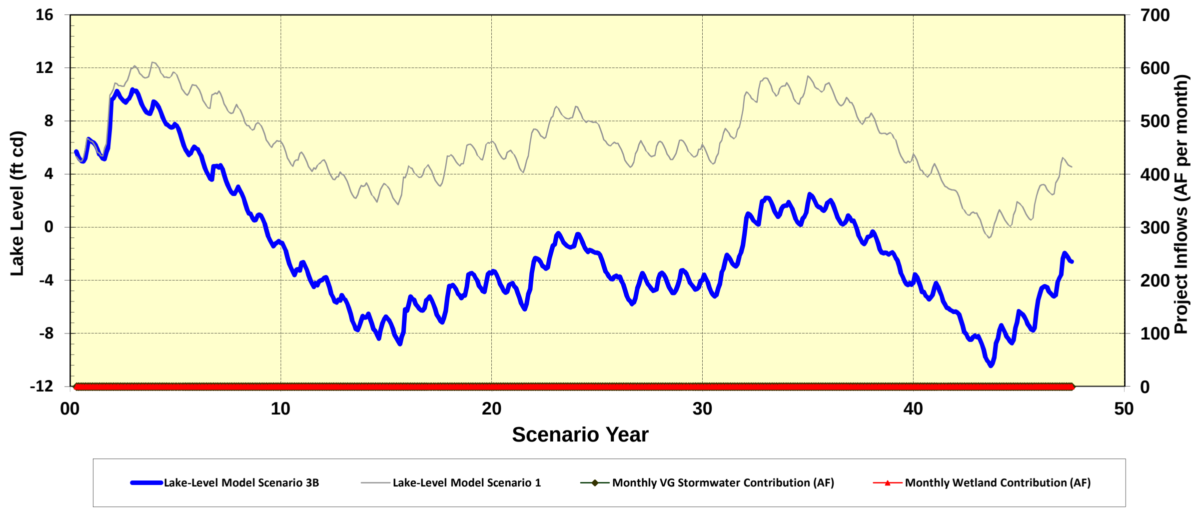
**Project Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Total Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

## Scenario 3B - SFPUC GSR and SFGW Project Technical Analysis

| Assumptions: | Initial Lake | Wetland Source | VG Stormwater | Diversion Elevation | Spillway |
|---|---|---|---|---|---|
| Units - Feet City Datum | 5.7 | none | none | 13.0 | 13 |




**Lake Conditions**

**Project Performance Summary**

| *Monthly Lake Elevation (ft, City Datum)* | *Percent Time* |
|---|---|
| Above 11 feet | 0% |
| between 9 and 11 feet | 4% |
| between 7 and 9 feet | 3% |
| between 5 and 7 feet | 5% |
| between 3 and 5 feet | 3% |
| between 1 and 3 feet | 9% |
| Below 1 feet | 76% |
| **TOTAL** | **100%** |

**Monthly Lake Level Summary**

| *Percentile* | *Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 10.4 |
| 95th percentile | 8.5 |
| 90th percentile | 5.7 |
| Mean Lake Level | -1.9 |
| 10th percentile | -7.1 |
| 5th percentile | -8.1 |
| Minimum Lake Level | -10.4 |

**Monthly Lake Level Change Summary**

| *Percentile* | *Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 2.11 |
| 95th percentile | 0.67 |
| 90th percentile | 0.48 |
| Mean Lake Level | -0.01 |
| 10th percentile | -0.36 |
| 5th percentile | -0.42 |
| Minimum Lake Level | -0.52 |

**Lake Level Continuity**

| *Monthly Lake Elevation (ft, City Datum)* | Consecutive months |
|---|---|
| Above 11 feet | 0 |
| between 9 and 11 feet | 19 |
| between 7 and 9 feet | 13 |
| between 5 and 7 feet | 14 |
| between 3 and 5 feet | 15 |
| between 1 and 3 feet | 18 |
| Below 1 feet | 282 |

**Average Annual Lake Elevation Summary**

| *Percentile* | *Annual Average Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 9.8 |
| 95th percentile | 7.5 |
| 90th percentile | 5.7 |
| Mean Lake Level | -1.9 |
| 10th percentile | -7.1 |
| 5th percentile | -7.5 |
| Minimum Lake Level | -9.0 |

**Annual Range in Lake Levels**

| *Percentile* | *Lake Level Change (ft)* |
|---|---|
| Maximum Lake Level | 5.1 |
| 95th percentile | 3.8 |
| 90th percentile | 3.3 |
| Mean Lake Level | 1.8 |
| 10th percentile | 1.0 |
| 5th percentile | 0.9 |
| Minimum Lake Level | 0.2 |

**Project Flows**

**Spillway Flows**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

**Wetland Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

**VG Stormwater Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

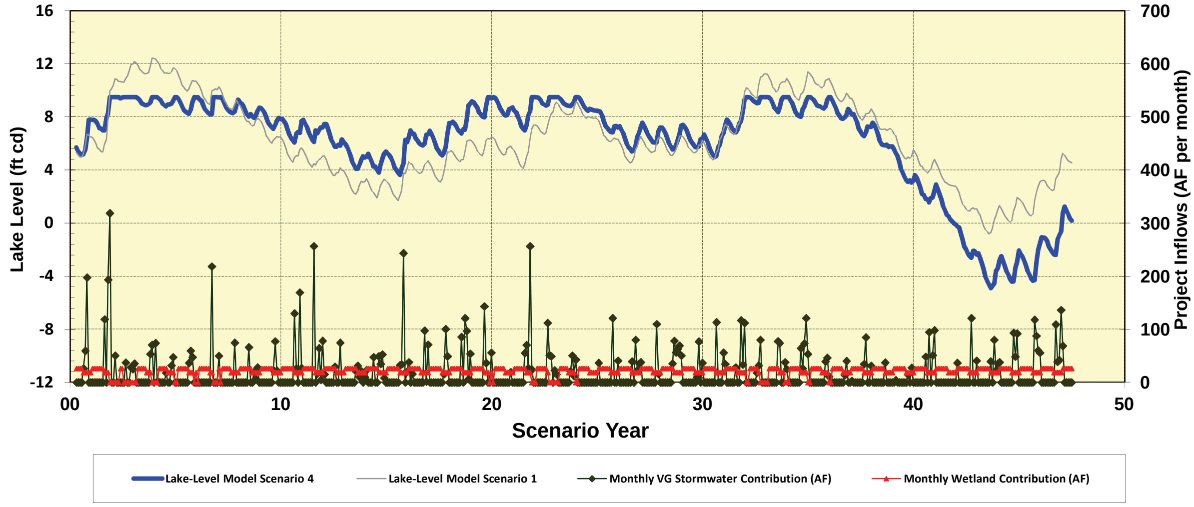
**Project Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 0 |
| **Maximum** | 0 |
| **Minimum** | 0 |

| *Total Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 47 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 0 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

# Scenario 4 - SFPUC GSR and SFGW Project Technical Analysis

| Assumptions: | Initial Lake Level | Wetland Source | VG Stormwater | Diversion Elevation | Spillway |
|---|---|---|---|---|---|
| Units - Feet City Datum | 5.7 | baseflow | baseflow | 9.5 | 9.5 |




**Lake Conditions**

**Project Performance Summary**

| *Monthly Lake Elevation (ft, City Datum)* | *Percent Time* |
|---|---|
| Above 11 feet | 0% |
| between 9 and 11 feet | 19% |
| between 7 and 9 feet | 35% |
| between 5 and 7 feet | 24% |
| between 3 and 5 feet | 7% |
| between 1 and 3 feet | 3% |
| Below 1 feet | 13% |
| **TOTAL** | **100%** |

**Monthly Lake Level Summary**

| *Percentile* | *Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 9.5 |
| 95th percentile | 9.5 |
| 90th percentile | 9.5 |
| Mean Lake Level | 6.1 |
| 10th percentile | -0.7 |
| 5th percentile | -2.7 |
| Minimum Lake Level | -4.9 |

**Monthly Lake Level Change Summary**

| *Percentile* | *Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 2.78 |
| 95th percentile | 0.83 |
| 90th percentile | 0.52 |
| Mean Lake Level | 0.02 |
| 10th percentile | -0.34 |
| 5th percentile | -0.39 |
| Minimum Lake Level | -0.54 |

**Lake Level Continuity**

| *Monthly Lake Elevation (ft, City Datum)* | Consecutive months |
|---|---|
| Above 11 feet | 0 |
| between 9 and 11 feet | 19 |
| between 7 and 9 feet | 26 |
| between 5 and 7 feet | 25 |
| between 3 and 5 feet | 12 |
| between 1 and 3 feet | 14 |
| Below 1 feet | 68 |

**Average Annual Lake Elevation Summary**

| *Percentile* | *Annual Average Lake Elevation (ft, City Datum)* |
|---|---|
| Maximum Lake Level | 9.5 |
| 95th percentile | 9.2 |
| 90th percentile | 9.1 |
| Mean Lake Level | 6.0 |
| 10th percentile | -0.2 |
| 5th percentile | -2.6 |
| Minimum Lake Level | -3.8 |

**Annual Range in Lake Levels**

| *Percentile* | *Lake Level Change (ft)* |
|---|---|
| Maximum Lake Level | 3.6 |
| 95th percentile | 3.1 |
| 90th percentile | 2.7 |
| Mean Lake Level | 1.6 |
| 10th percentile | 0.7 |
| 5th percentile | 0.5 |
| Minimum Lake Level | 0.2 |

**Project Flows**

**Spillway Flows**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 128 |
| **Maximum** | 1547 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 32 |
| 0 to 100 | 4 |
| 100 to 200 | 2 |
| 200 to 300 | 1 |
| 300 to 500 | 4 |
| >500 | 4 |
| **TOTAL** | **47** |

**Wetland Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 248 |
| **Maximum** | 277 |
| **Minimum** | 78 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 0 |
| 0 to 100 | 0 |
| 100 to 200 | 6 |
| 200 to 300 | 41 |
| 300 to 500 | 0 |
| >500 | 0 |
| **TOTAL** | **47** |

**VG Stormwater Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 198 |
| **Maximum** | 681 |
| **Minimum** | 0 |

| *Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 0 |
| 0 to 100 | 9 |
| 100 to 200 | 16 |
| 200 to 300 | 12 |
| 300 to 500 | 9 |
| >500 | 1 |
| **TOTAL** | **47** |

**Project Contribution**

| During operation | Volume (AFY) |
|---|---|
| **Average** | 574 |
| **Maximum** | 2362 |
| **Minimum** | 78 |

| *Total Flow (AFY)* | *Frequency (# of years)* |
|---|---|
| 0 | 0 |
| 0 to 100 | 0 |
| 100 to 200 | 0 |
| 200 to 300 | 1 |
| 300 to 500 | 24 |
| >500 | 22 |
| **TOTAL** | **47** |