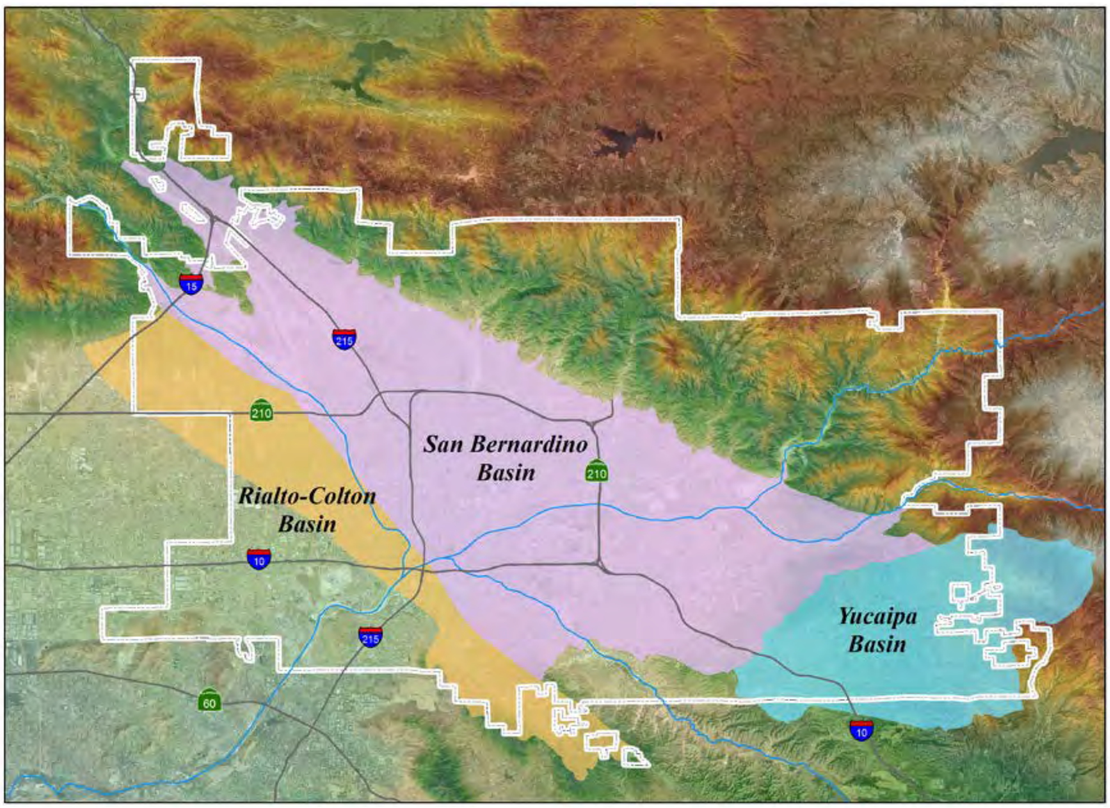
Annual Change in Groundwater Storage for the San Bernardino, Rialto-Colton and Yucaipa Basins

Fall 2023



March 2024

SAN BERNARDINO VALLEY | A REGIONAL WATER AGENCY SINCE 1954

Change in Groundwater Storage for the San Bernardino, Rialto-Colton And Yucaipa Basins

EXECUTIVE SUMMARY AND APPENDICES

SAN BERNARDINO VALLEY | A REGIONAL WATER AGENCY SINCE 1954

March 2024

San Bernardino Valley Municipal Water District

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ACKNOWLEDGMENT

Many public and private water agencies and various individuals have cooperated with the San Bernardino Valley Municipal Water District in furnishing the essential information upon which the Change in Storage Calculation is based.

Change in Groundwater Storage For the San Bernardino, Rialto-Colton And Yucaipa Basins 1934 – 2023

EXECUTIVE SUMMARY AND APPENDICES

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SUMMARY OF RESULTS

Background

The Change in Storage calculation provides an indicator, or "gauge", of current groundwater supplies and how they compare to past years. The San Bernardino Valley Municipal Water District (SBVMWD) has been calculating the change in groundwater storage for the San Bernardino Basin (SBB) since 1970. The first calculation was completed for the years 1934 – 1960 by the State of California Department of Water Resources (DWR) and the results were summarized in Bulletin 104-5, Meeting Water Demands in the Bunker Hill-San Timoteo Area, Geology, Hydrology, and Operation-Economics Studies, Text and Plates (Olson, pp. 90 – 92). The DWR change in storage values were calculated using the Specific Yield Method (Olson, pp. 85 – 98) and a mathematical model developed by TRW, Incorporated, Redondo Beach, California (TRW). In 1980, SBVMWD updated the change in storage calculation to include the years 1961 – 1980 (Van Gelder). In the early 1990's, SBVMWD created a new change in storage model (SBVMWD Model) using software developed by Environmental Systems Research Institute (ESRI), Redlands, California. Like its predecessors, the SBVMWD Model calculates the change in groundwater storage (volume) using the Specific Yield Method which is based largely on the change in water level measurements and the soil porosity (for a detailed explanation of how the model works, see **Appendix: SBVMWD Change in Storage Methodology**). In 2014, SBVMWD began calculating the change in storage for the Yucaipa and Rialto-Colton Basin.

In 2019, SBVMWD performed a study to determine the total amount of usable groundwater storage in the San Bernardino Basin (SBB) and Rialto-Colton Basin (RC) using the Upper Santa Ana River Integrated Groundwater Model (Integrated SAR Model). The usable groundwater storage is the theoretical maximum volume of groundwater that can be stored from the bottom elevation of the aquifer to the maximum water level in the basin **(Calculation details can be found in Appendix: Total Usable Storage)**. Storage in the SBB is constrained by the goal to minimize, or eliminate, liquefaction potential in the Pressure Zone Area. In order to achieve this goal, water levels in the Pressure Zone must not be shallower than 50 feet below ground surface. The estimated total usable storage in the SBB is 5,690,000 acre-feet, Rialto-Colton Basin is 1,749,000 acre-feet, and the Yucaipa Basin is 2,796,000 acre-feet.

Calculation

SBVMWD calculates the change in groundwater storage in the San Bernardino, Rialto-Colton and Yucaipa Basins annually. The change is groundwater storage is based upon the the Basins geology, and field water level measurements from wells throughout the Basins. Storage is a important metric that SBVMWD uses to gauge the effectiveness of various water resource management activities, such as groundwater recharge. The annual change in storage is then a comparison of the current year's change in groundwater storage with the previous year's value.

The wells used in the SBVMWD Model are shown on Figure 1 and the static water level data for these wells is illustrated on Figure 2. A comparison of current water levels to the first historic low water level/year is shown on Figure 3.

Summary of 2023 Results

Due to the current drought which began in 1998, the volume of groundwater in storage for the San Bernardino Basin (SBB) and Rialto-Colton Basins continues to be at or near historic lows. With more than average to wet conditions across the region in Water Year 2022-2023 and the high amount of imported water through the State Water Project (100% Table A allocation in 2023), the gain in groundwater storage was moderate to high for Subbasins in the San Bernardino Basin and relatively flat for Rialto-Colton and Yucaipa Basins.

The change in storage results are summarized in the table below:

Basin	Total Usable Storage (acre-feet)	2023 Change in Storage (acre-feet)	2023 Total Storage (acre-feet)	Percent Full (%)	Change from 2022
Rialto-Colton Basin	1,749,000	11,307	1,520,028	87%	0.6%
San Bernardino Basin	5,690,000	222,760	4,881,235	86%	3.9%
Yucaipa Basin	2,796,000	10,712	2,253,171	81%	0.4%
	10,235,000	**244,779**	**8,654,434**		

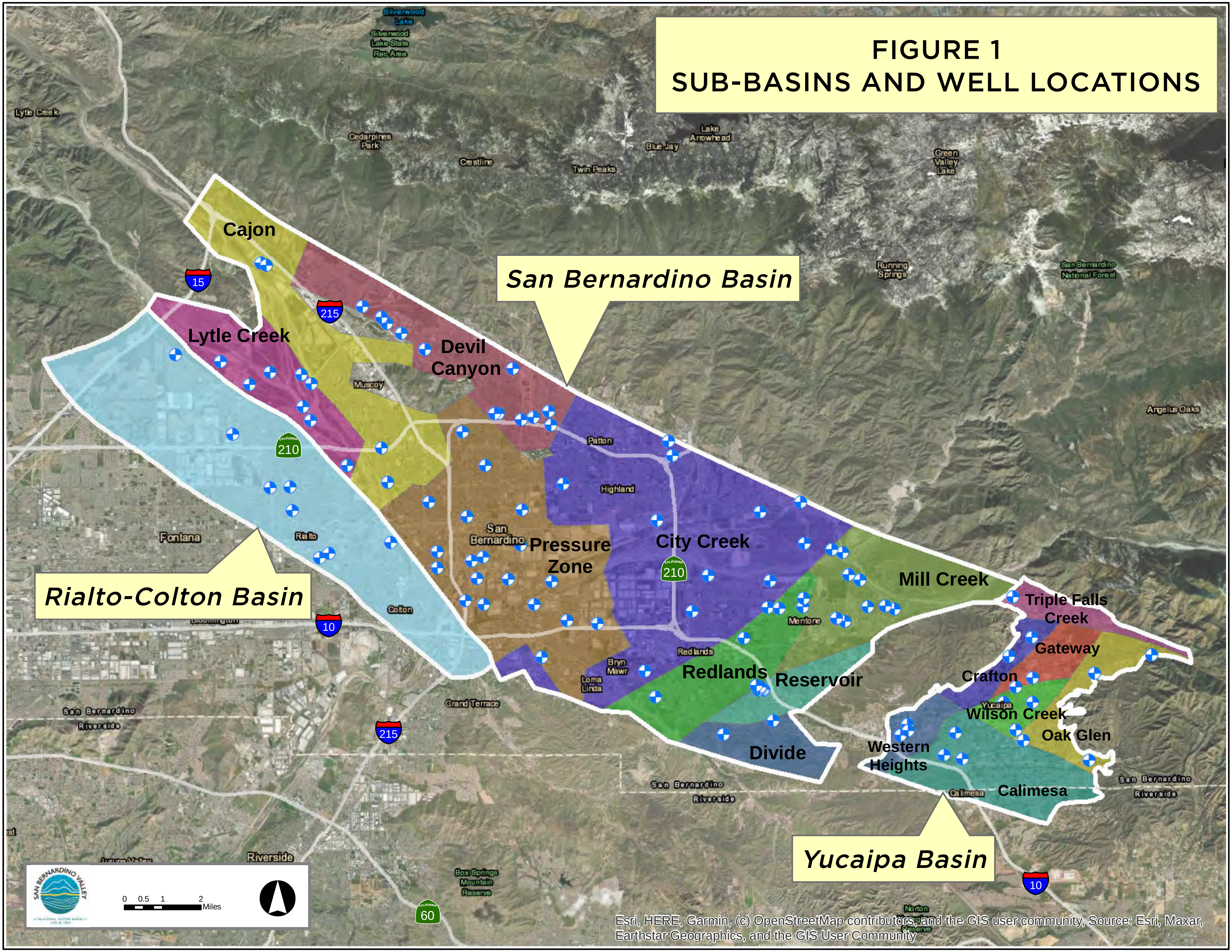
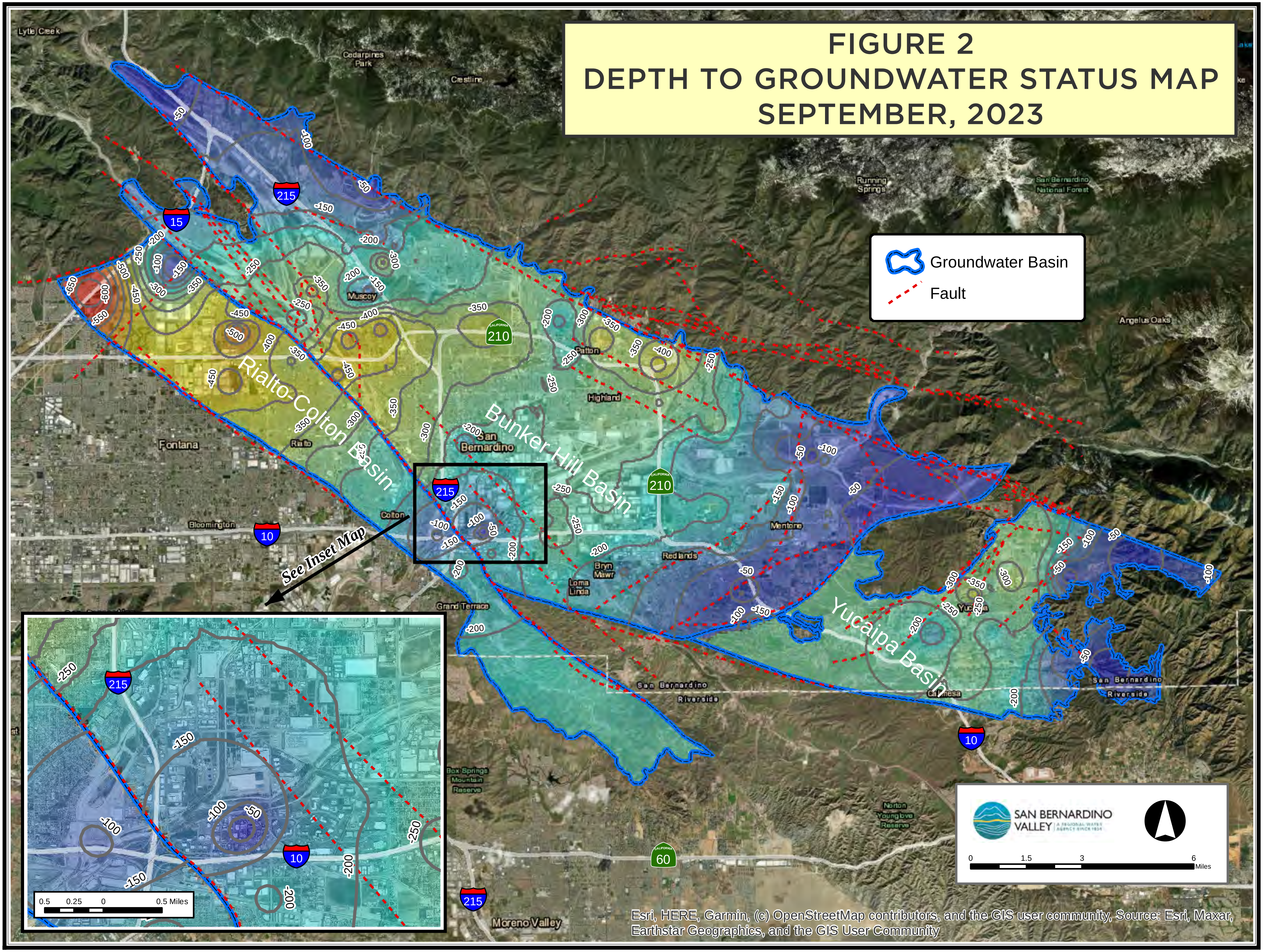


FIGURE 1
SUB-BASINS AND WELL LOCATIONS

FIGURE 2
DEPTH TO GROUNDWATER STATUS MAP
SEPTEMBER, 2023



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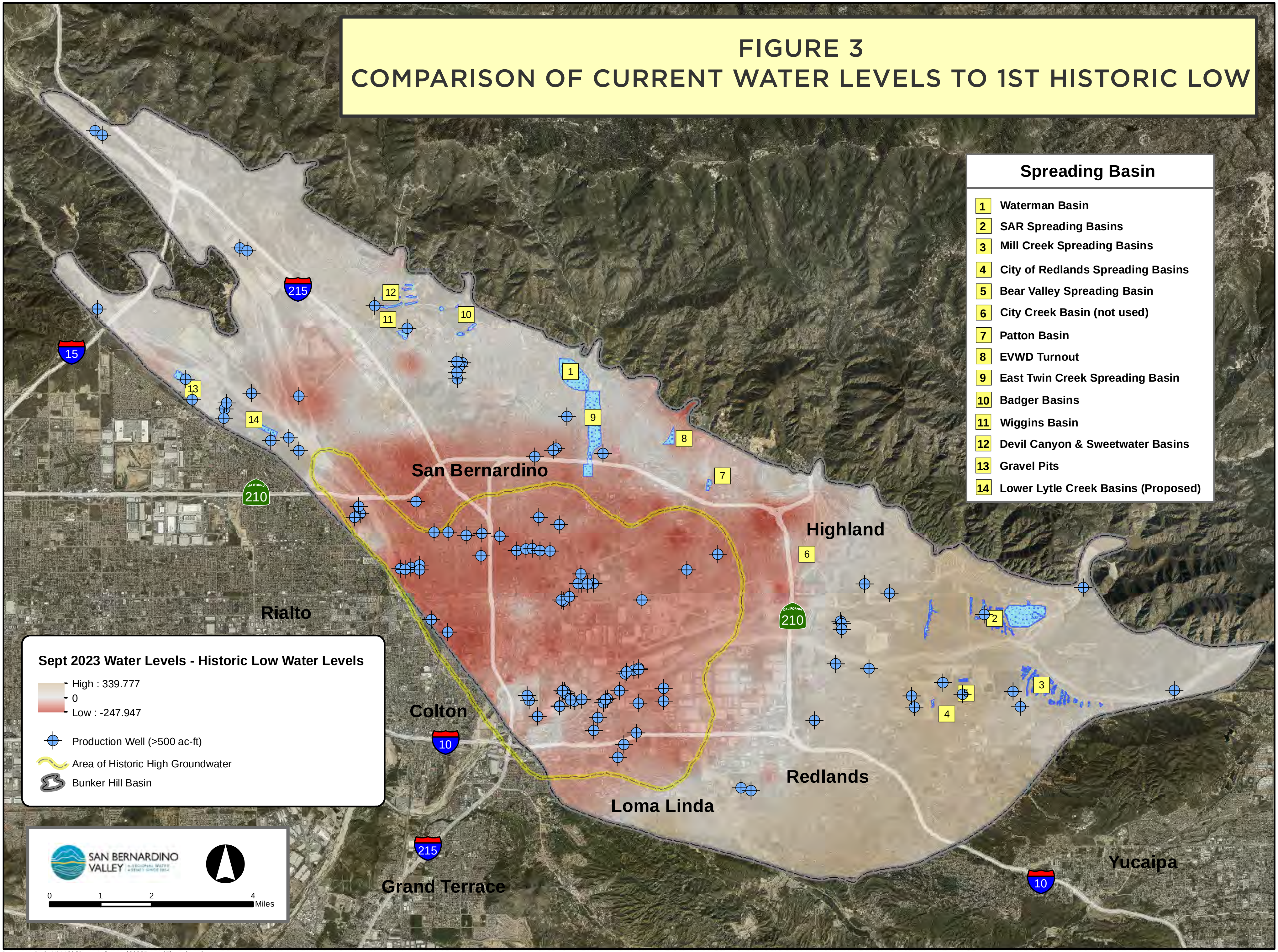

FIGURE 3
COMPARISON OF CURRENT WATER LEVELS TO 1ST HISTORIC LOW

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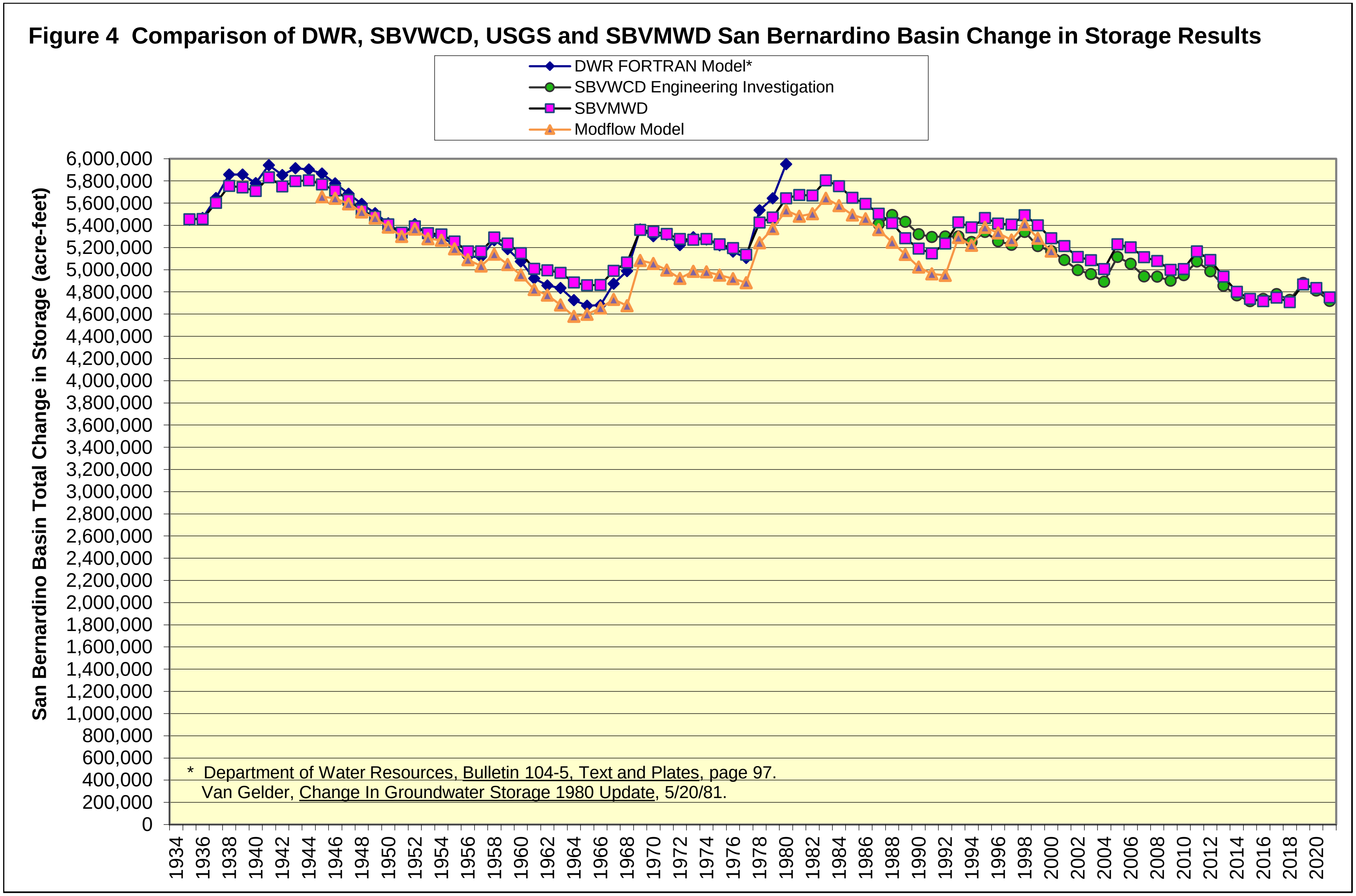
Figure 4 Comparison of DWR, SBVWCD, USGS and SBVMWD San Bernardino Basin Change in Storage Results
DWR FORTRAN Model*
SBVWCD Engineering Investigation
SBVMWD
Modflow Model
San Bernardino Basin Total Change in Storage (acre-feet)
* Department of Water Resources, Bulletin 104-5, Text and Plates, page 97.
Van Gelder, Change In Groundwater Storage 1980 Update, 5/20/81.

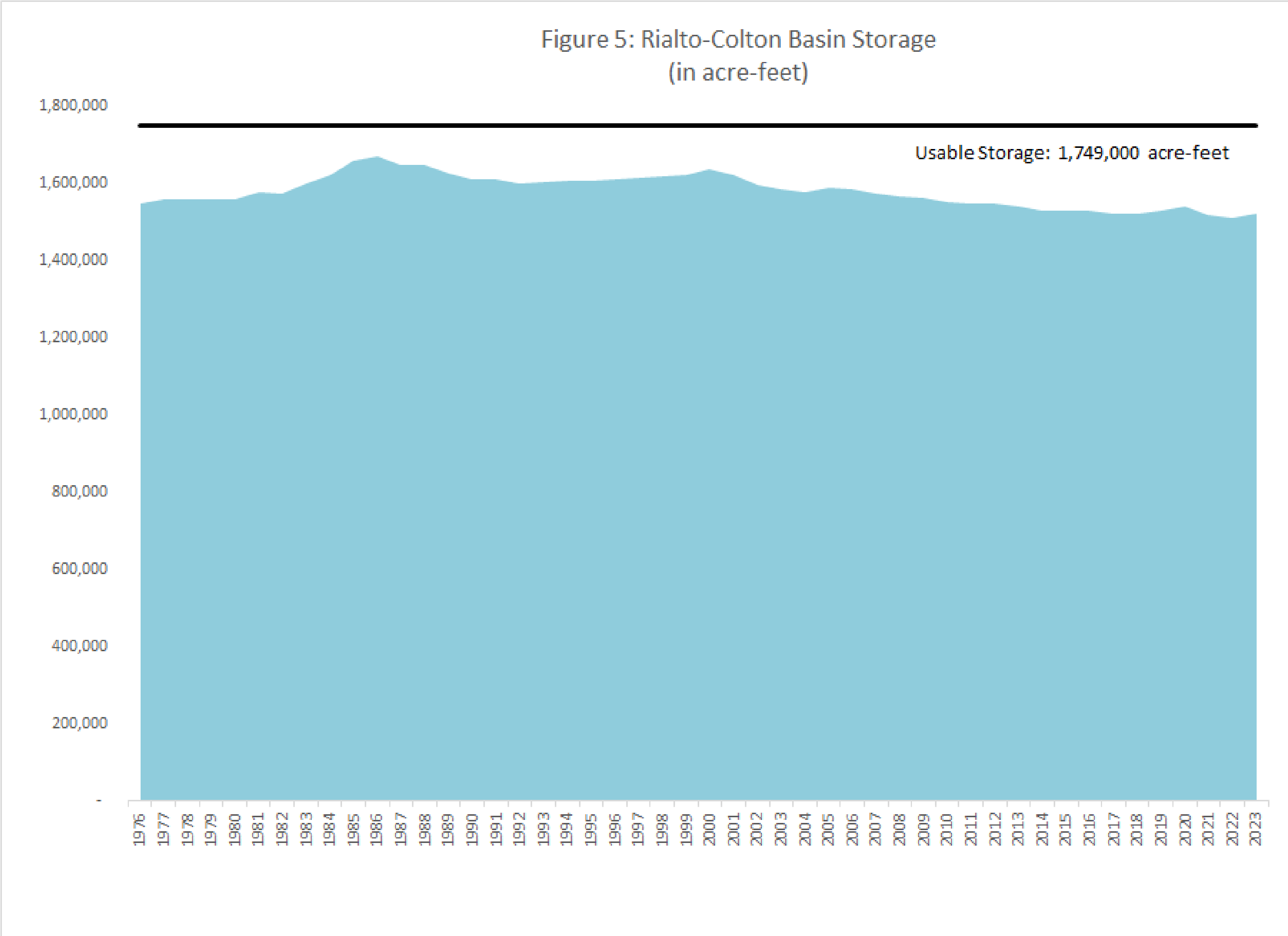
Figure 5: Rialto-Colton Basin Storage
(in acre-feet)
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
-
Usable Storage: 1,749,000 acre-feet
1976
1977
1978
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2023

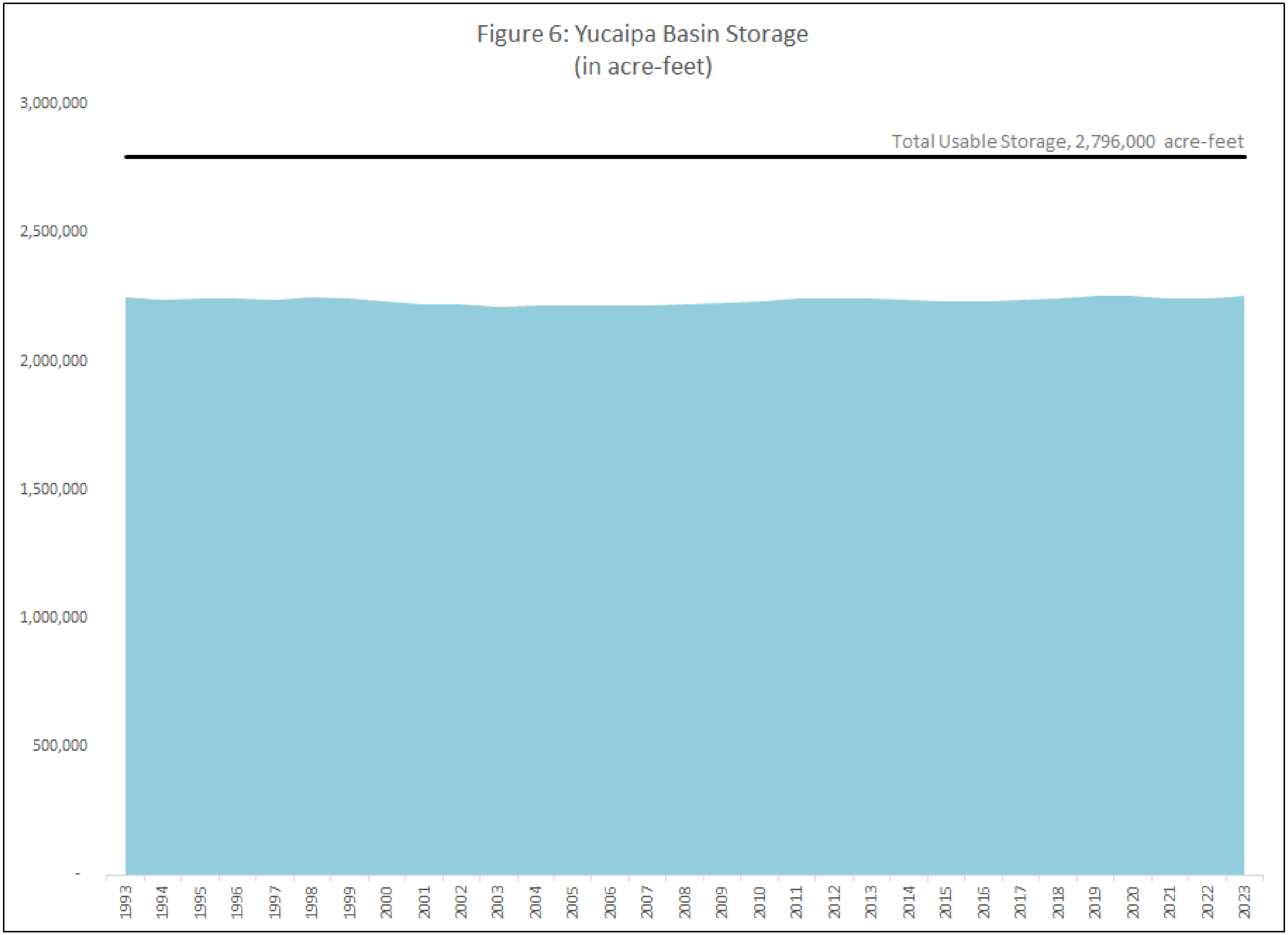

Figure 6: Yucaipa Basin Storage
(in acre-feet)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-
Total Usable Storage, 2,796,000 acre-feet
1993
1994
1995
1996
1997
1998
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2023

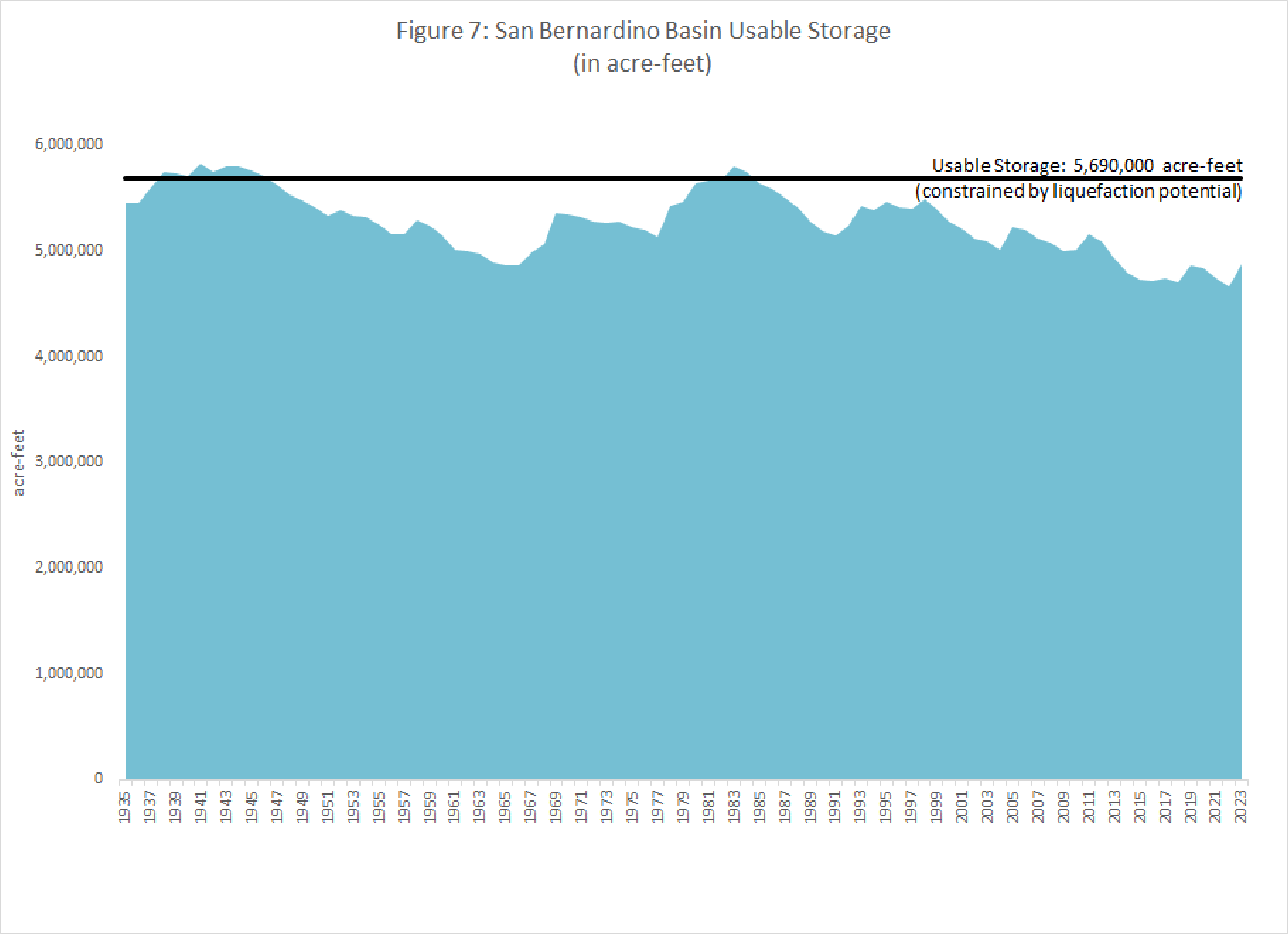


Figure 7: San Bernardino Basin Usable Storage
(in acre-feet)
Usable Storage: 5,690,000 acre-feet
(constrained by liquefaction potential)
acre-feet
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1935 1937 1939 1941 1943 1945 1947 1949 1951 1953 1955 1957 1959 1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021 2023

The calculations in the SBB and Yucaipa are performed for each individual sub-basin. The increase or decrease of individual sub-basin change in storage values are influenced by a variety of factors such as local precipitation, groundwater production, groundwater recharge, proximity to river and creeks, and water conservation.

Figure 8. 2023 Change in Storage for the San Bernardino Basin, by sub-basin.

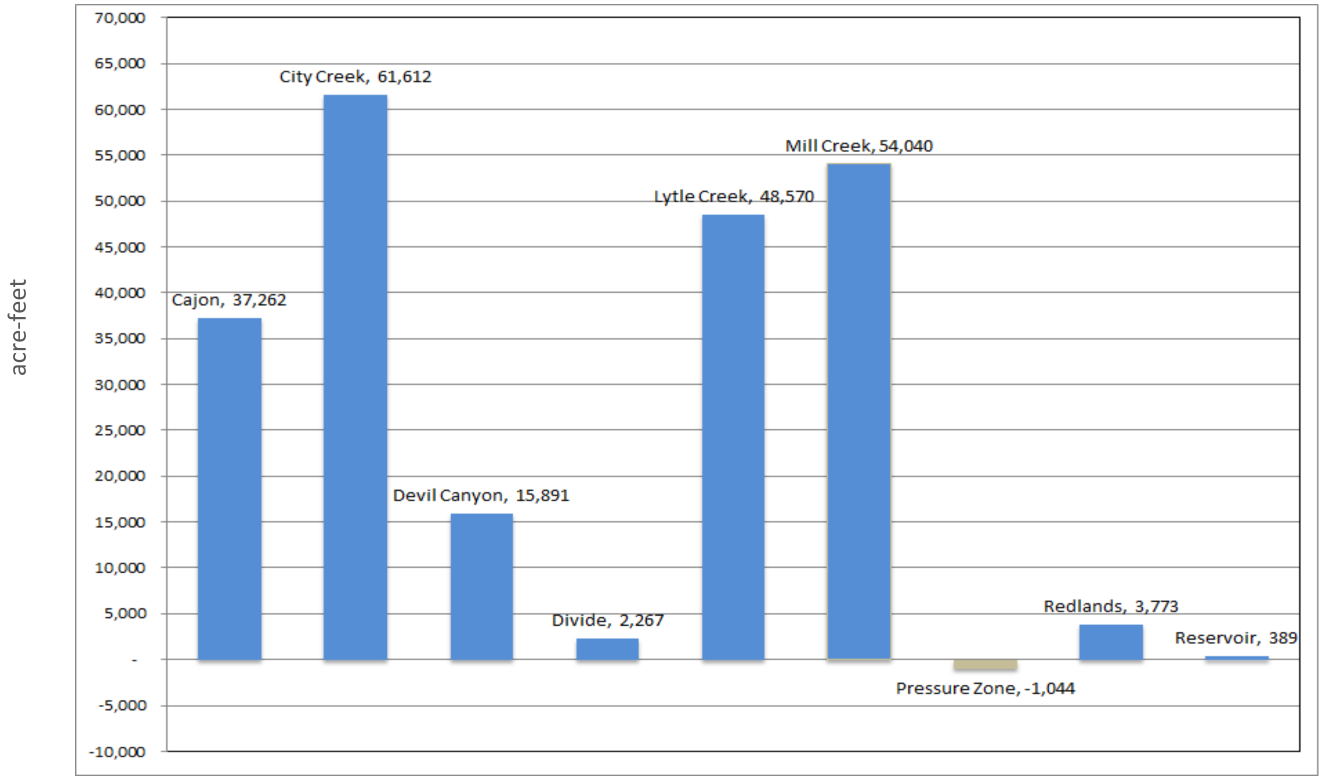
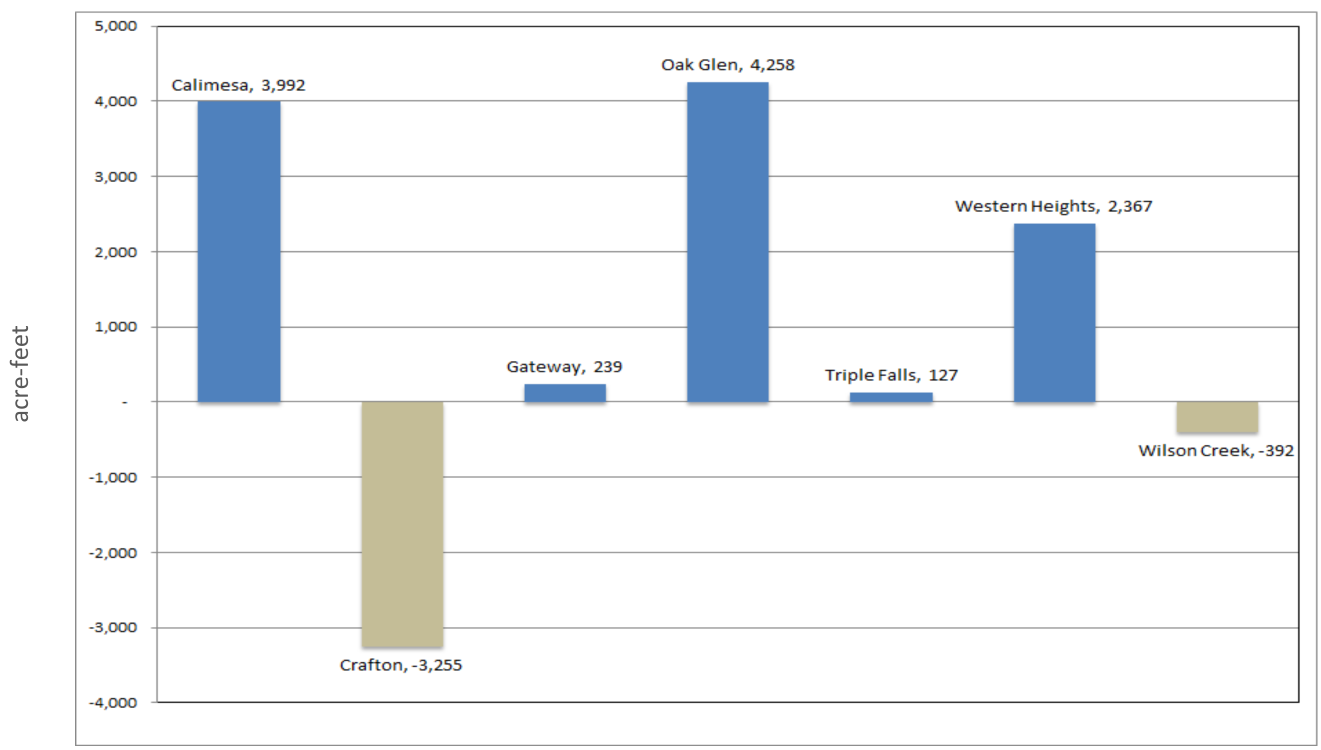


Figure 9. 2023 Change in Storage for the Yucaipa Basin, by sub-basin.



Notes for 2023

The following summarizes the new content or changes made to the Change in Storage Report Plan last year. Static water levels for the following wells were not available and were estimated:

City of Redlands - Lee, BV Judson, No. 32, Mentone Acres

City of San Bernardino - Devil Canyon No. 2, Cajon No. 2, Mill & D, 16th & Sierra

East Valley Water District - Plant No. 6, Plant No. 54

City of Riverside - Gage Well 51-1

West Valley Water District - Well No. 5A

Yucaipa Valley Water District - January 2024 measurement used for YVWD Well No. 9

2. Bibliography

1) Basin Groundwater Storage Data, San Bernardino Valley Municipal Water District library call number GB 1025, C2 S26, 1934 – 1990.

2) Department of Water Resources (DWR), Meeting Water Demands in the Bunker Hill - San Timoteo Area, Geology, Hydrology, and Operation—Economics Studies, Text and Plates, February 1971.

3) Final Statement, 2011 Regional Water Management Plan, Basin Technical Advisory Committee, September 2011.

4) Motokane, Earl S., "Evaluation of the Base Period for the Bunker Hill-San Timoteo Area Investigation". Meeting Water Demands in the Bunker Hill - San Timoteo Area, Geology, Hydrology, and Operation—Economics Studies, Text and Plates, February 1971, pp. 123 – 129.

5) Olson, L.J. and Stig J. Johanson, "Specific Yield and Storage Determination". Meeting Water Demands in the Bunker Hill - San Timoteo Area, Geology, Hydrology, and Operation—Economics Studies, Text and Plates, February 1971.

6) San Bernardino Valley Water Conservation District (SBVWCD), Engineering Investigation of the Bunker Hill Basin, 2011-2012, March 2012.

7) Southern California Earthquake Center (SCEC), University of Southern California. Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Liquefaction Hazards in California, March 1999.

8) TRW, Incorporated. Simulation Program for Planned Utilization of the San Bernardino Valley and Riverside Ground Water Basins, Second Report, Report No. 07143-6001-R000, October 1967.

9) Utah Geological Survey web site (UGS):
http://geology.utah.gov/utahgeo/hazards/liquefy.htm

10) University of Washington (UW) web site:
http://www.ce.washington.edu/~liquefaction/html/what/what1.html

11) Van Gelder, Randy, Change in Groundwater Storage 1980 Update, May 20, 1981.

12) Western San Bernardino Watermaster (Watermaster), Annual Report of the Western-San Bernardino Watermaster for Calendar Year 1997, August 1, 2001.

APPENDIX

Change in Groundwater Storage Data for the San
Bernardino Basin, Yucaipa Basin and Rialto-Colton Basin.

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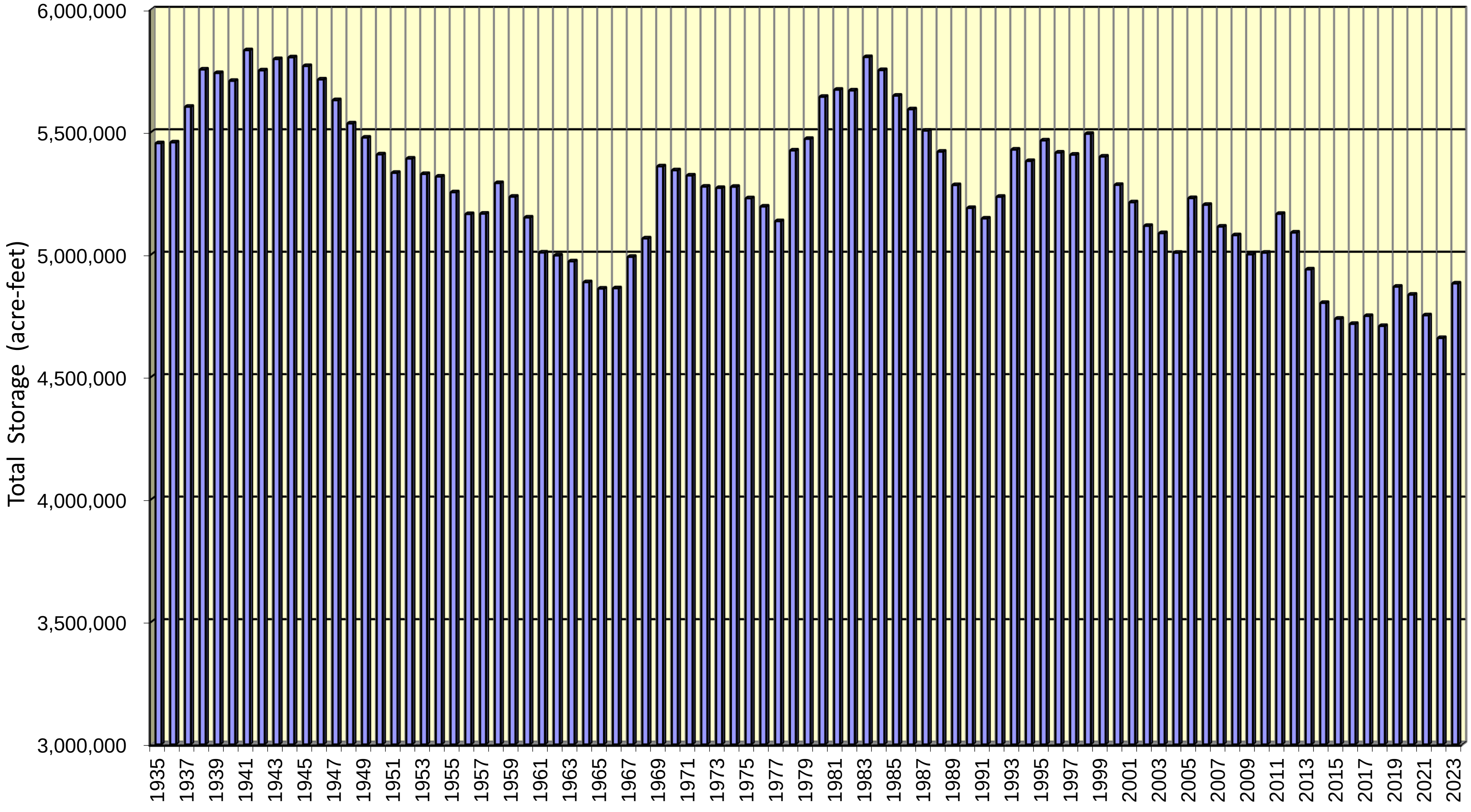
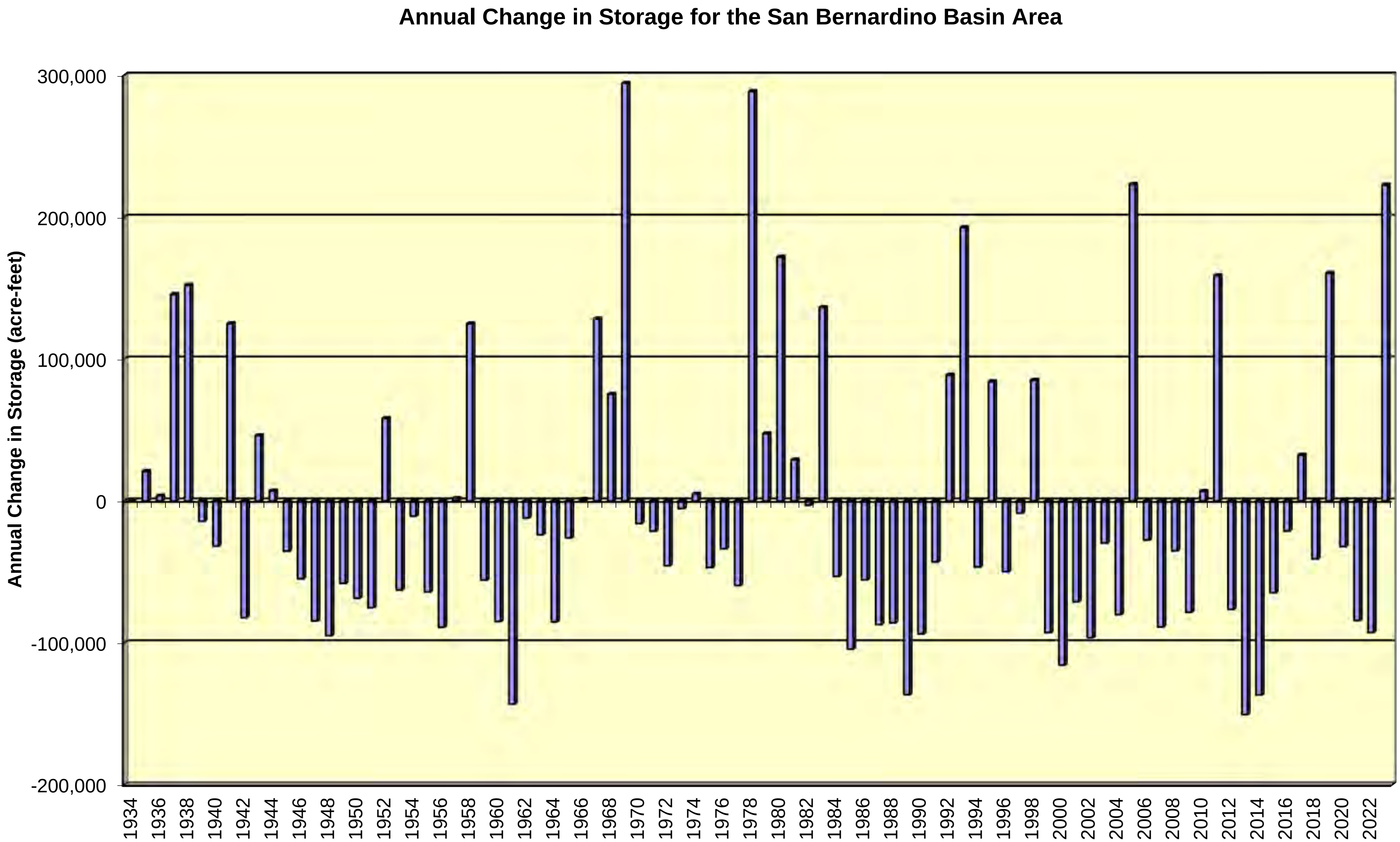
Total Storage for the San Bernardino Basin Area




Annual Change in Storage for the San Bernardino Basin Area
Annual Change in Storage (acre-feet)
300,000
200,000
100,000
0
-100,000
-200,000
1934
1936
1938
1940
1942
1944
1946
1948
1950
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1956
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1960
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2020
2022

San Bernardino Valley Municipal Water District

Change In Storage for the San Bernardino Basin Area 1934 - Present

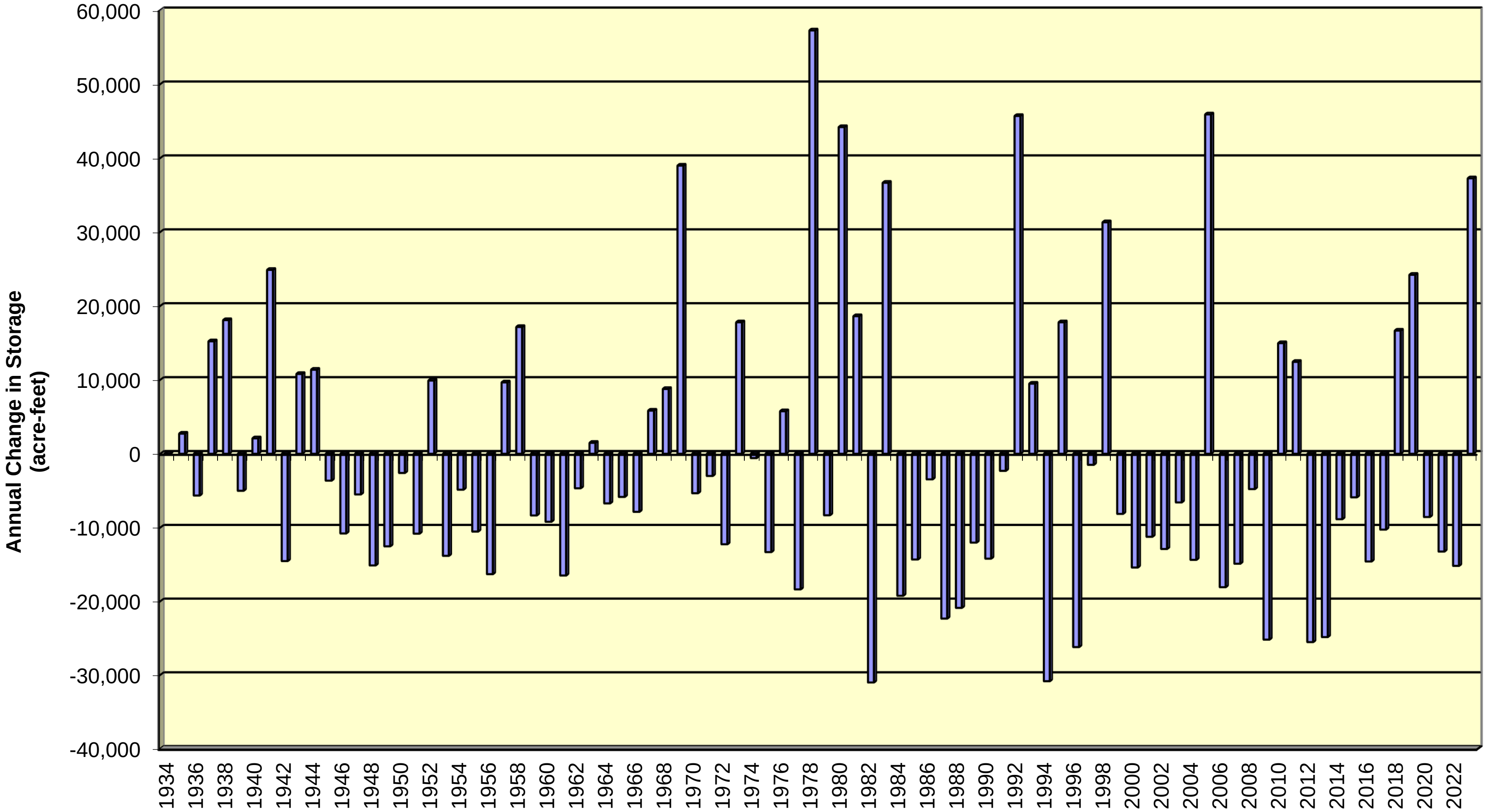
(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Total Groundwater Storage (acre-feet)
1934	n/a	n/a	0
1935	6	20,870	5,453,785
1936	2	3,523	5,457,308
1937	23	145,589	5,602,897
1938	22	152,096	5,754,993
1939	3	-14,377	5,740,616
1940	-5	-31,859	5,708,757
1941	17	125,012	5,833,769
1942	-11	-82,317	5,751,452
1943	7	46,073	5,797,525
1944	0	7,091	5,804,616
1945	-5	-35,507	5,769,109
1946	-9	-54,920	5,714,189
1947	-12	-84,528	5,629,661
1948	-16	-94,909	5,534,752
1949	-9	-58,045	5,476,707
1950	-13	-68,538	5,408,169
1951	-12	-75,214	5,332,955
1952	11	58,167	5,391,122
1953	-7	-62,735	5,328,387
1954	1	-10,727	5,317,660
1955	-10	-64,100	5,253,560
1956	-14	-89,030	5,164,530
1957	0	1,777	5,166,307
1958	20	124,903	5,291,210
1959	-8	-55,773	5,235,437
1960	-13	-84,913	5,150,524
1961	-18	-143,069	5,007,455
1962	4	-12,103	4,995,352
1963	-6	-23,803	4,971,549
1964	-12	-85,205	4,886,344
1965	0	-26,059	4,860,285
1966	4	1,190	4,861,475
1967	19	128,403	4,989,878
1968	9	75,169	5,065,047
1969	39	294,367	5,359,414
1970	2	-15,864	5,343,550
1971	-4	-21,340	5,322,210
1972	-7	-45,689	5,276,521
1973	1	-5,303	5,271,218
1974	1	4,776	5,275,994
1975	-5	-46,965	5,229,029
1976	-6	-33,740	5,195,289
1977	-9	-59,633	5,135,656
1978	38	288,634	5,424,290
1979	5	47,368	5,471,658
1980	21	171,822	5,643,480
1981	2	28,937	5,672,417
1982	4	-3,042	5,669,375
1983	16	136,343	5,805,718
1984	-7	-53,164	5,752,554

San Bernardino Valley Municipal Water District

Change In Storage for the San Bernardino Basin Area 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Total Groundwater Storage (acre-feet)
1985	-13	-104,413	5,648,141
1986	-8	-55,577	5,592,564
1987	-12	-87,184	5,505,380
1988	-13	-85,879	5,419,501
1989	-16	-136,477	5,283,024
1990	-13	-93,632	5,189,392
1991	0	-42,951	5,146,441
1992	11	88,692	5,235,133
1993	30	192,725	5,427,858
1994	-6	-46,564	5,381,294
1995	13	84,107	5,465,401
1996	-3	-49,809	5,415,592
1997	-4	-8,523	5,407,069
1998	4	85,136	5,492,205
1999	-10	-92,827	5,399,378
2000	-13	-115,680	5,283,698
2001	-11	-71,069	5,212,629
2002	-15	-96,300	5,116,329
2003	-6	-29,706	5,086,623
2004	-8	-80,017	5,006,606
2005	33	223,178	5,229,784
2006	-2	-27,539	5,202,245
2007	-14	-88,767	5,113,478
2008	-4	-35,158	5,078,320
2009	-16	-78,417	4,999,903
2010	7	6,803	5,006,706
2011	18	158,805	5,165,511
2012	-13	-76,469	5,089,042
2013	-22	-150,503	4,938,539
2014	-11	-136,683	4,801,856
2015	-9	-64,702	4,737,154
2016	-1	-21,154	4,716,000
2017	4	32,381	4,748,381
2018	-6	-40,905	4,707,476
2019	23	160,522	4,867,998
2020	-4	-32,174	4,835,458
2021	-9	-84,340	4,751,118
2022	-10	-92,643	4,658,475
2023	35	222,760	4,881,235

Annual Change in Storage for the Cajon Sub-Basin



San Bernardino Valley Municipal Water District
Change In Storage for the Cajon Sub-basin 1934 - Present

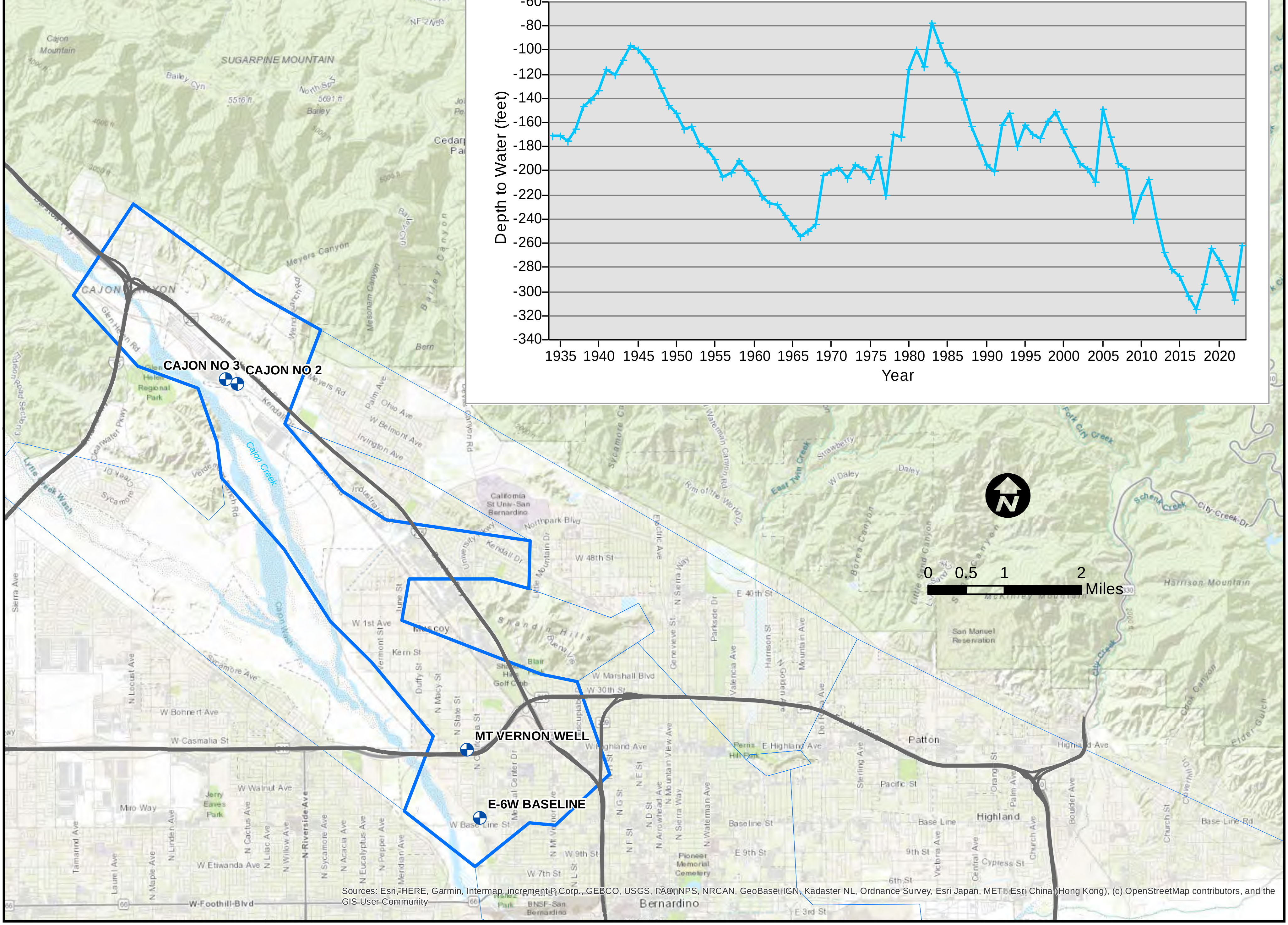
(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	1	2,727	2,727
1936	-5	-5,653	-2,926
1937	10	15,215	12,289
1938	19	18,080	30,369
1939	6	-5,005	25,364
1940	8	2,091	27,455
1941	17	24,881	52,336
1942	-4	-14,541	37,795
1943	11	10,803	48,598
1944	12	11,376	59,974
1945	-3	-3,632	56,342
1946	-8	-10,790	45,552
1947	-9	-5,498	40,054
1948	-15	-15,133	24,921
1949	-14	-12,542	12,379
1950	-7	-2,595	9,784
1951	-13	-10,817	-1,033
1952	2	9,903	8,870
1953	-14	-13,833	-4,963
1954	-5	-4,860	-9,823
1955	-9	-10,534	-20,357
1956	-14	-16,316	-36,673
1957	3	9,655	-27,018
1958	9	17,153	-9,865
1959	-9	-8,349	-18,214
1960	-8	-9,204	-27,418
1961	-13	-16,502	-43,920
1962	-5	-4,666	-48,586
1963	-1	1,479	-47,107
1964	-9	-6,714	-53,821
1965	-8	-5,836	-59,657
1966	-9	-7,858	-67,515
1967	4	5,840	-61,675
1968	6	8,771	-52,904
1969	41	38,982	-13,922
1970	3	-5,336	-19,258
1971	4	-3,004	-22,262
1972	-9	-12,262	-34,524
1973	11	17,783	-16,741
1974	-3	-579	-17,320
1975	-9	-13,326	-30,646
1976	19	5,760	-24,886
1977	-32	-18,387	-43,273
1978	51	57,276	14,003
1979	-2	-8,324	5,679
1980	55	44,197	49,876
1981	17	18,611	68,487
1982	-15	-31,017	37,470
1983	36	36,661	74,131
1984	-16	-19,249	54,882

San Bernardino Valley Municipal Water District

Change In Storage for the Cajon Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	-16	-14,328	40,554
1986	-9	-3,458	37,096
1987	-22	-22,350	14,746
1988	-22	-20,895	-6,149
1989	-15	-12,038	-18,187
1990	-17	-14,210	-32,397
1991	-6	-2,305	-34,702
1992	38	45,699	10,997
1993	10	9,487	20,484
1994	-27	-30,849	-10,365
1995	17	17,786	7,421
1996	-7	-26,213	-18,792
1997	-3	-1,497	-20,289
1998	14	31,321	11,032
1999	7	-8,134	2,898
2000	-14	-15,417	-12,519
2001	-16	-11,244	-23,763
2002	-13	-12,902	-36,665
2003	-5	-6,578	-43,243
2004	-11	-14,377	-57,620
2005	61	45,908	-11,712
2006	-23	-18,090	-29,802
2007	-22	-14,901	-44,703
2008	-5	-4,780	-49,483
2009	-41	-25,204	-74,687
2010	20	14,969	-59,718
2011	13	12,439	-47,279
2012	-33	-25,541	-72,820
2013	-27	-24,855	-97,675
2014	-15	-8,858	-106,533
2015	-5	-5,889	-112,422
2016	-16	-14,595	-127,017
2017	-12	-10,269	-137,286
2018	21	16,661	-120,625
2019	30	24,209	-96,416
2020	-10	-8,563	-104,979
2021	-13	-13,245	-118,224
2022	-18	-15,195	-133,419
2023	45	37,262	-96,157

Cajon Sub-Basin & Wells



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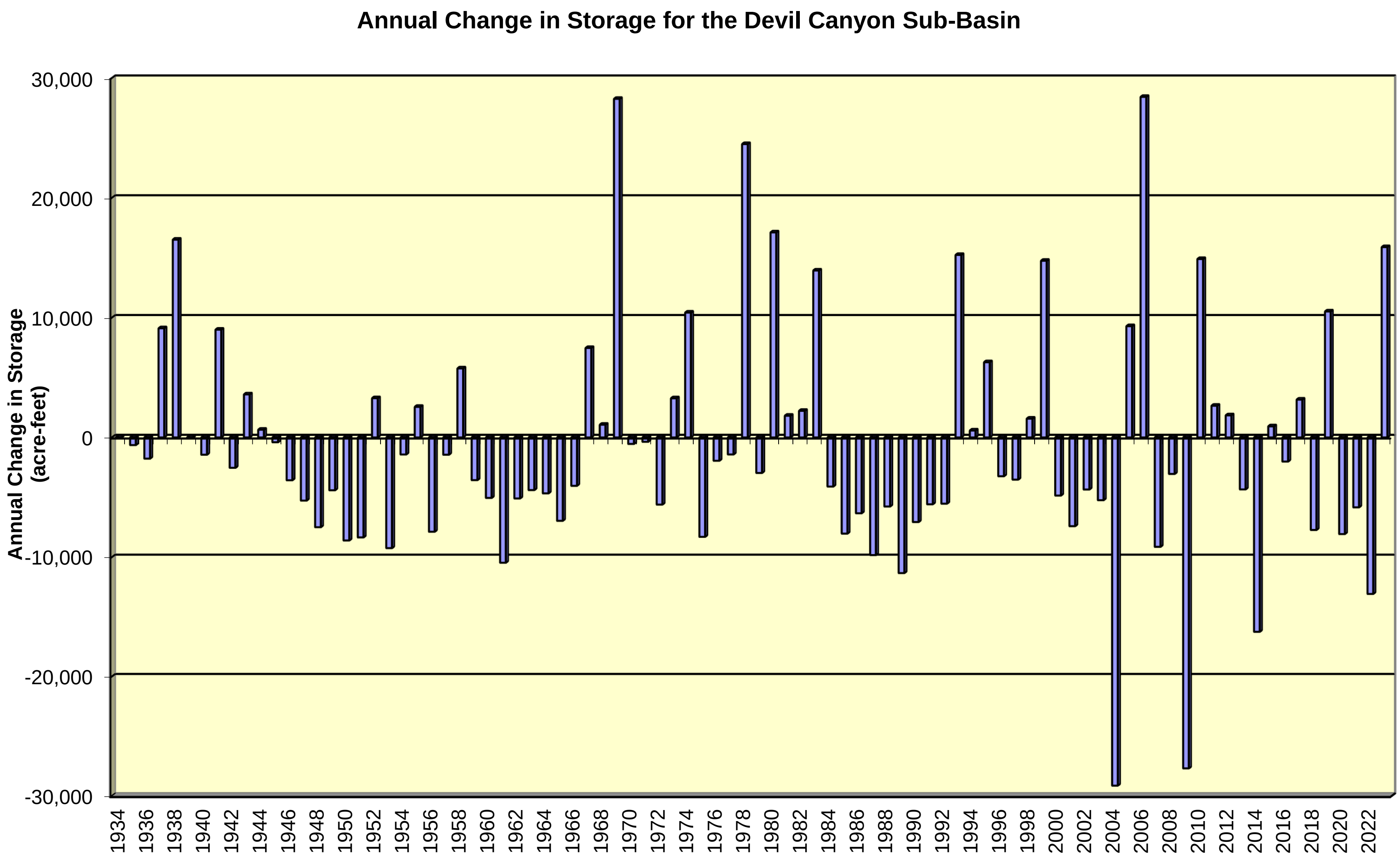

Annual Change in Storage for the Devil Canyon Sub-Basin
Annual Change in Storage (acre-feet)
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
1934
1936
1938
1940
1942
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2022

San Bernardino Valley Municipal Water District
Change In Storage for the Devil Canyon Sub-basin 1934 - Present

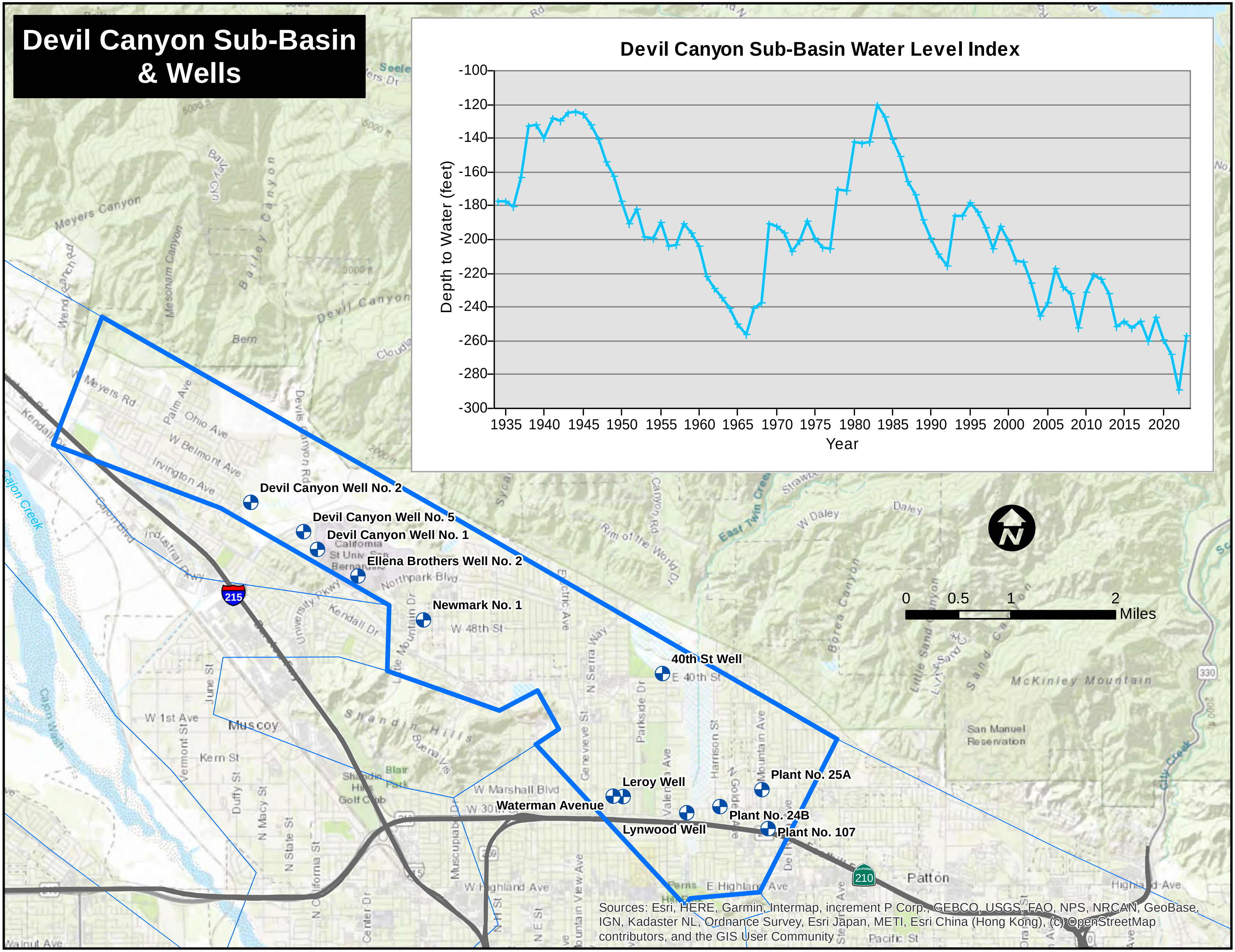
(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	0	-635	-635
1936	-3	-1,769	-2,404
1937	17	9,114	6,710
1938	31	16,514	23,224
1939	1	-45	23,179
1940	-8	-1,440	21,739
1941	12	8,997	30,736
1942	-2	-2,536	28,200
1943	5	3,596	31,796
1944	1	646	32,442
1945	-2	-399	32,043
1946	-6	-3,572	28,471
1947	-9	-5,269	23,202
1948	-13	-7,490	15,712
1949	-8	-4,409	11,303
1950	-15	-8,602	2,701
1951	-14	-8,346	-5,645
1952	9	3,277	-2,368
1953	-17	-9,239	-11,607
1954	-1	-1,422	-13,029
1955	9	2,555	-10,474
1956	-14	-7,872	-18,346
1957	1	-1,442	-19,788
1958	13	5,764	-14,024
1959	-6	-3,562	-17,586
1960	-8	-5,048	-22,634
1961	-17	-10,460	-33,094
1962	-8	-5,093	-38,187
1963	-5	-4,393	-42,580
1964	-7	-4,666	-47,246
1965	-10	-6,959	-54,205
1966	-6	-4,037	-58,242
1967	16	7,468	-50,774
1968	3	1,062	-49,712
1969	47	28,267	-21,445
1970	-2	-542	-21,987
1971	-4	-364	-22,351
1972	-12	-5,604	-27,955
1973	7	3,270	-24,685
1974	12	10,425	-14,260
1975	-10	-8,298	-22,558
1976	-6	-1,945	-24,503
1977	-1	-1,418	-25,921
1978	36	24,493	-1,428
1979	-1	-2,963	-4,391
1980	29	17,117	12,726
1981	-1	1,812	14,538
1982	1	2,224	16,762
1983	22	13,938	30,700
1984	-7	-4,102	26,598

San Bernardino Valley Municipal Water District

Change In Storage for the Devil Canyon Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	-13	-8,029	18,569
1986	-11	-6,328	12,241
1987	-15	-9,819	2,422
1988	-8	-5,764	-3,342
1989	-15	-11,326	-14,668
1990	-11	-7,063	-21,731
1991	-9	-5,576	-27,307
1992	-8	-5,528	-32,835
1993	30	15,236	-17,599
1994	0	579	-17,020
1995	9	6,283	-10,737
1996	-6	-3,236	-13,973
1997	-10	-3,519	-17,492
1998	-12	1,572	-15,920
1999	13	14,749	-1,171
2000	-9	-4,853	-6,024
2001	-11	-7,407	-13,431
2002	-1	-4,345	-17,776
2003	-13	-5,237	-23,013
2004	-20	-29,138	-52,151
2005	8	9,289	-42,862
2006	21	28,432	-14,430
2007	-11	-9,131	-23,561
2008	-3	-3,047	-26,608
2009	-20	-27,693	-54,301
2010	20	14,894	-39,407
2011	10	2,648	-36,759
2012	-2	1,844	-34,915
2013	-9	-4,336	-39,251
2014	-20	-16,248	-55,499
2015	4	929	-54,570
2016	-4	-2,011	-56,581
2017	4	3,160	-53,421
2018	-12	-7,723	-61,144
2019	14	10,517	-50,627
2020	-13	-8,063	-58,690
2021	-8	-5,836	-64,526
2022	-19	-13,075	-77,601
2023	32	15,891	-61,710

Devil Canyon Sub-Basin & Wells



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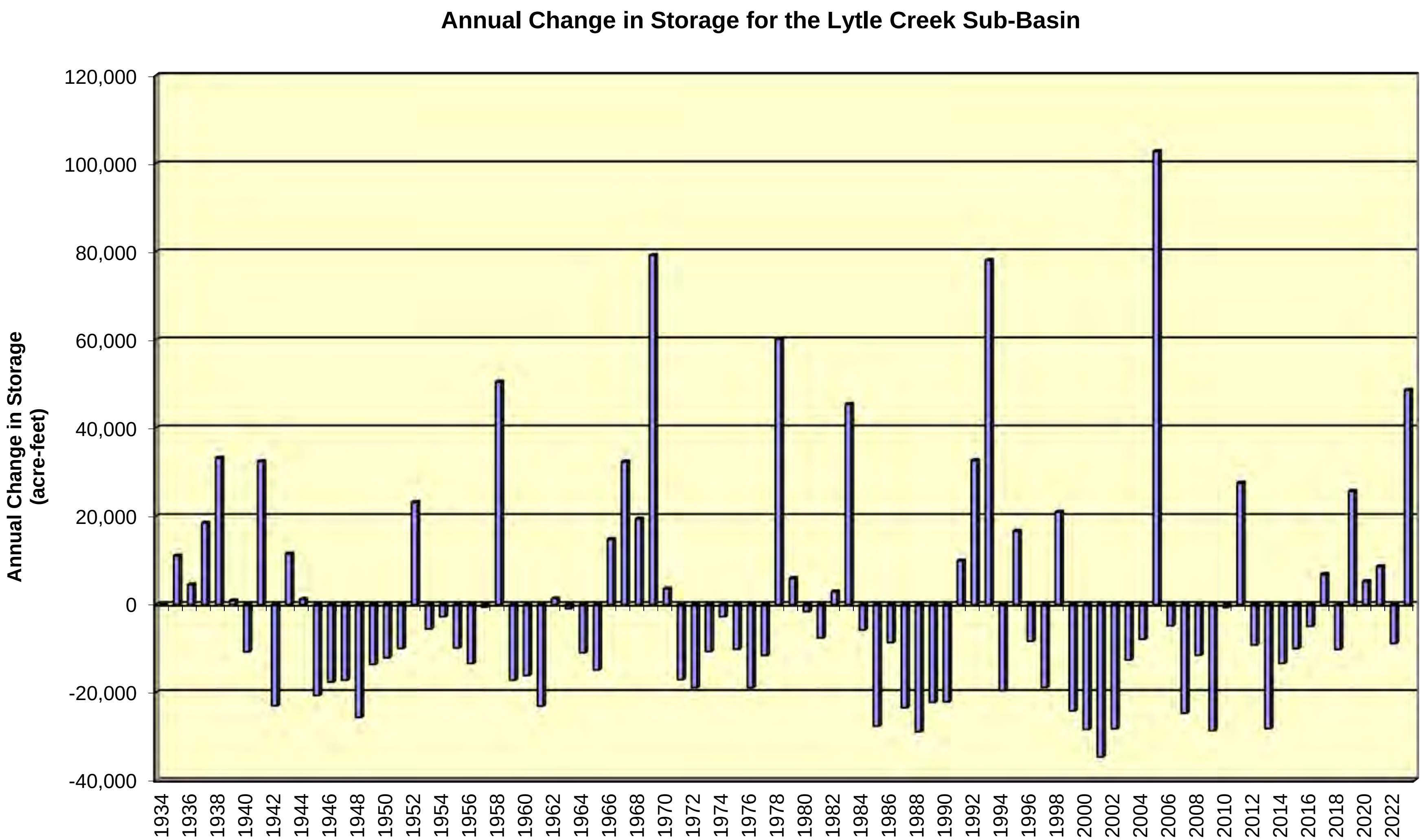

Annual Change in Storage for the Lytle Creek Sub-Basin
Annual Change in Storage (acre-feet)
120,000
100,000
80,000
60,000
40,000
20,000
0
-20,000
-40,000
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
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San Bernardino Valley Municipal Water District

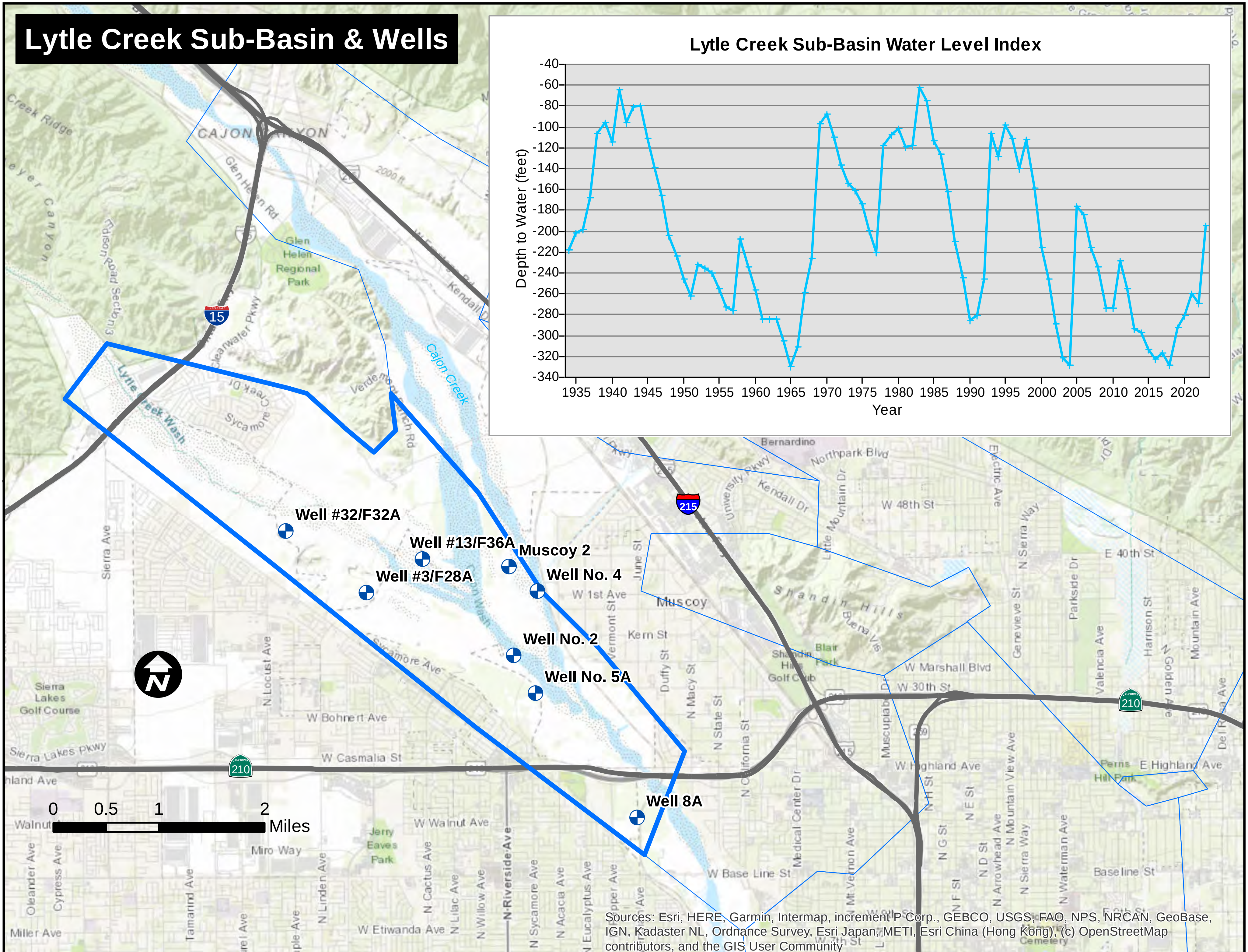
Change In Storage for the Lytle Creek Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	16	11,039	11,039
1936	3	4,524	15,563
1937	30	18,561	34,124
1938	62	33,297	67,421
1939	9	926	68,347
1940	-18	-10,717	57,630
1941	50	32,509	90,139
1942	-32	-22,956	67,183
1943	15	11,515	78,698
1944	2	1,224	79,922
1945	-32	-20,656	59,266
1946	-27	-17,567	41,699
1947	-27	-17,153	24,546
1948	-39	-25,594	-1,048
1949	-19	-13,579	-14,627
1950	-22	-12,057	-26,684
1951	-17	-9,964	-36,648
1952	30	23,256	-13,392
1953	-3	-5,523	-18,915
1954	-4	-2,738	-21,653
1955	-14	-9,853	-31,506
1956	-18	-13,361	-44,867
1957	-3	-596	-45,463
1958	68	50,451	4,988
1959	-26	-17,150	-12,162
1960	-22	-16,108	-28,270
1961	-28	-23,046	-51,316
1962	0	1,366	-49,950
1963	1	-885	-50,835
1964	-21	-10,938	-61,773
1965	-25	-14,831	-76,604
1966	18	14,805	-61,799
1967	53	32,429	-29,370
1968	33	19,431	-9,939
1969	129	79,194	69,255
1970	9	3,552	72,807
1971	-21	-17,053	55,754
1972	-27	-18,851	36,903
1973	-17	-10,643	26,260
1974	-7	-2,741	23,519
1975	-13	-10,131	13,388
1976	-26	-18,859	-5,471
1977	-20	-11,573	-17,044
1978	103	60,162	43,118
1979	10	5,964	49,082
1980	6	-1,588	47,494
1981	-18	-7,544	39,950
1982	1	2,912	42,862
1983	56	45,372	88,234
1984	-13	-5,730	82,504

San Bernardino Valley Municipal Water District

Change In Storage for the Lytle Creek Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	-38	-27,599	54,905
1986	-13	-8,602	46,303
1987	-36	-23,422	22,881
1988	-47	-28,867	-5,986
1989	-35	-22,178	-28,164
1990	-41	-22,083	-50,247
1991	5	9,959	-40,288
1992	35	32,721	-7,567
1993	139	78,106	70,539
1994	-21	-19,516	51,023
1995	30	16,655	67,678
1996	-13	-8,288	59,390
1997	-29	-18,815	40,575
1998	27	21,005	61,580
1999	-46	-24,144	37,436
2000	-57	-28,334	9,102
2001	-31	-34,576	-25,474
2002	-42	-28,205	-53,679
2003	-33	-12,542	-66,221
2004	-6	-7,866	-74,087
2005	153	102,835	28,748
2006	-9	-4,791	23,957
2007	-31	-24,651	-694
2008	-18	-11,482	-12,176
2009	-40	-28,620	-40,796
2010	0	-640	-41,436
2011	45	27,617	-13,819
2012	-27	-9,196	-23,015
2013	-38	-28,135	-51,150
2014	-4	-13,325	-64,475
2015	-17	-9,983	-74,458
2016	-9	-4,919	-79,377
2017	6	6,867	-72,510
2018	-12	-10,171	-82,681
2019	36	25,745	-56,936
2020	12	5,260	-51,676
2021	22	8,618	-43,058
2022	-14	-8,828	-51,886
2023	68	48,570	-3,316



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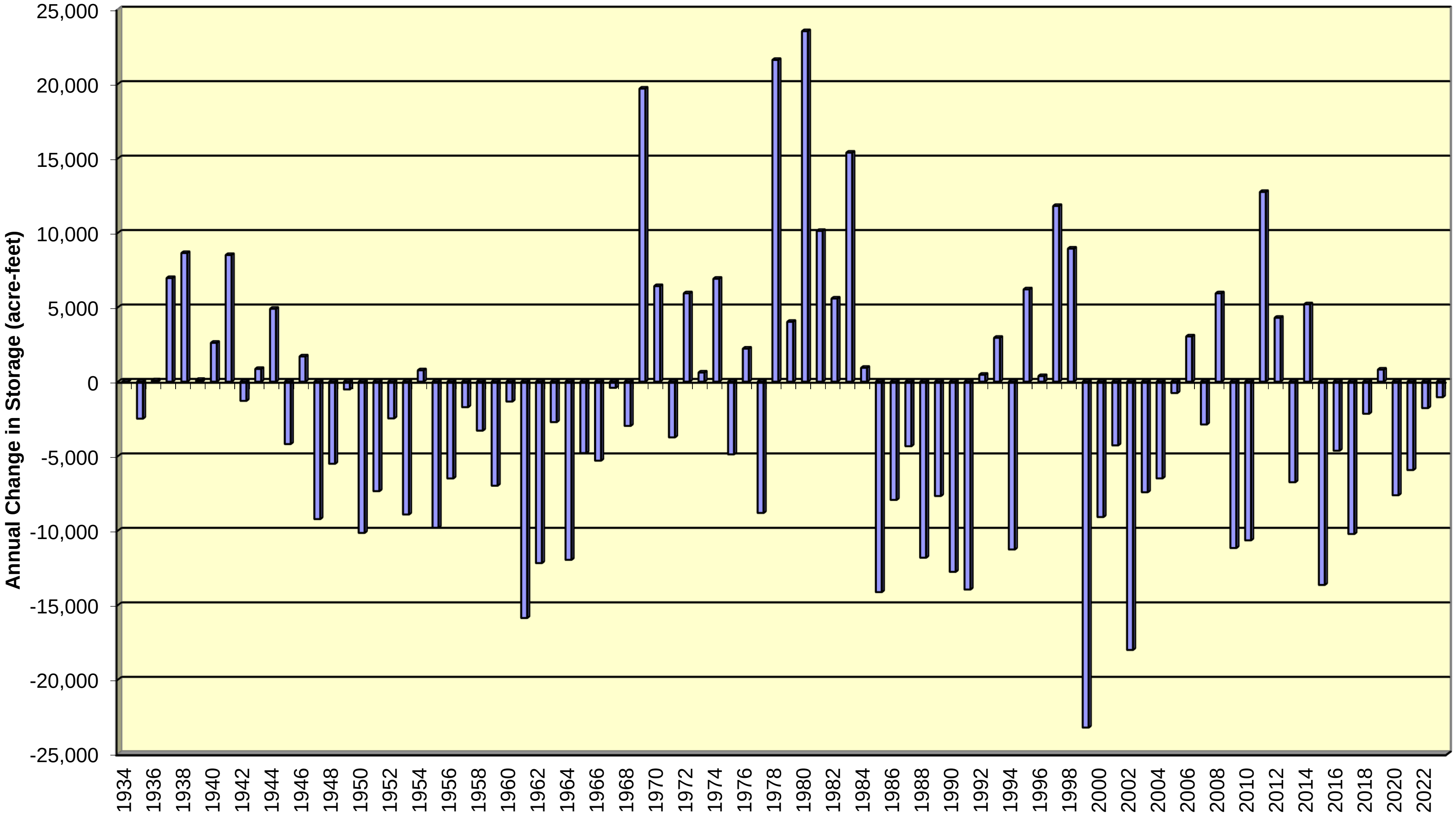
Annual Change in Storage for the Pressure Zone Sub-Basin



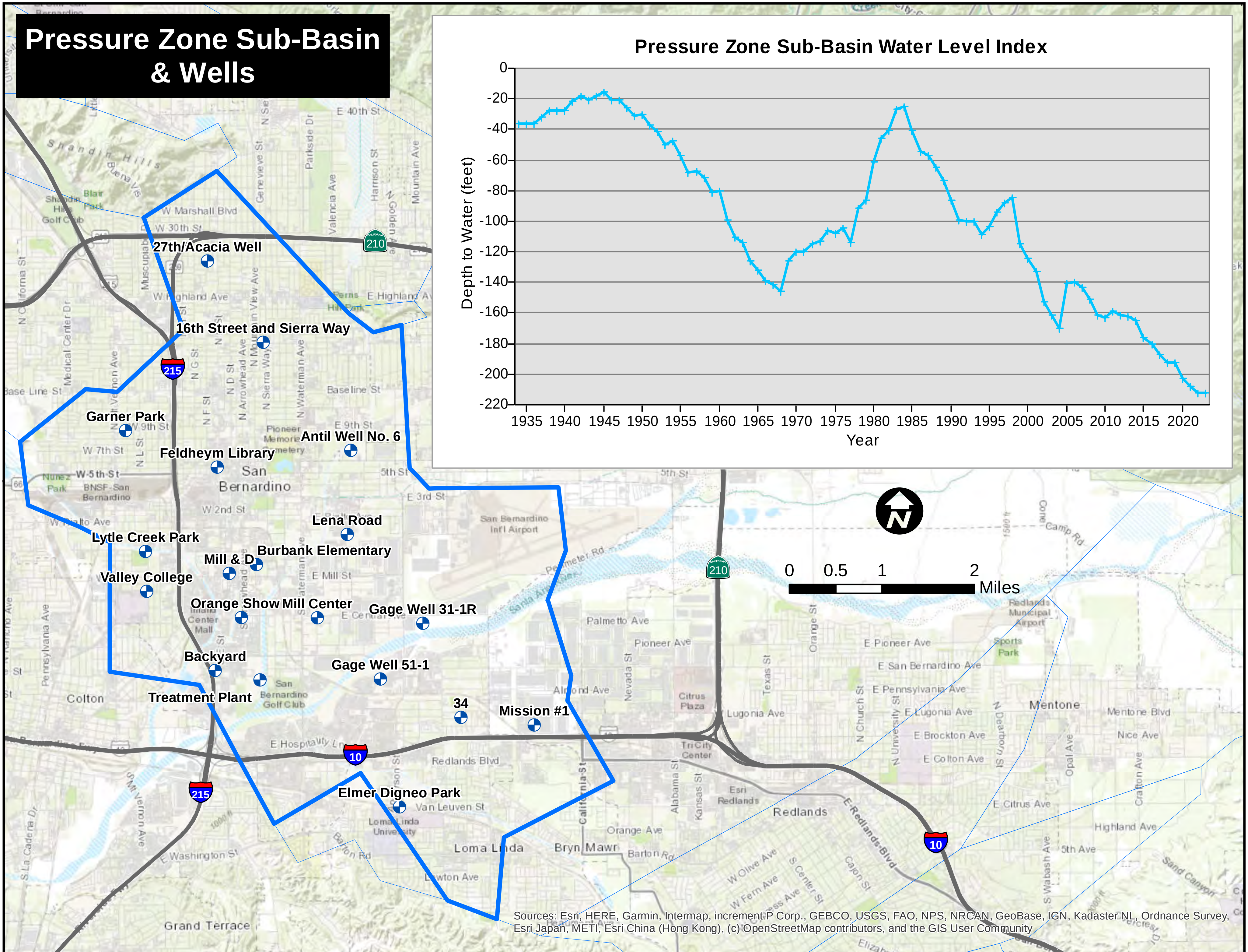
San Bernardino Valley Municipal Water District

Change In Storage for the Pressure Zone Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	-3	-2,484	-2,484
1936	1	89	-2,395
1937	8	6,961	4,566
1938	9	8,638	13,204
1939	1	121	13,325
1940	2	2,610	15,935
1941	7	8,507	24,442
1942	-3	-1,289	23,153
1943	1	853	24,006
1944	6	4,893	28,899
1945	-6	-4,190	24,709
1946	3	1,694	26,403
1947	-11	-9,229	17,174
1948	-6	-5,514	11,660
1949	0	-519	11,141
1950	-7	-10,156	985
1951	-7	-7,354	-6,369
1952	-4	-2,467	-8,836
1953	-9	-8,921	-17,757
1954	2	763	-16,994
1955	-9	-9,810	-26,804
1956	-12	-6,500	-33,304
1957	1	-1,713	-35,017
1958	-5	-3,289	-38,306
1959	-9	-6,988	-45,294
1960	1	-1,334	-46,628
1961	-19	-15,866	-62,494
1962	-11	-12,182	-74,676
1963	-3	-2,718	-77,394
1964	-12	-11,963	-89,357
1965	-6	-4,795	-94,152
1966	-8	-5,307	-99,459
1967	-3	-412	-99,871
1968	-4	-2,972	-102,843
1969	20	19,683	-83,160
1970	6	6,418	-76,742
1971	1	-3,741	-80,483
1972	5	5,932	-74,551
1973	2	612	-73,939
1974	7	6,910	-67,029
1975	-2	-4,883	-71,912
1976	3	2,218	-69,694
1977	-9	-8,818	-78,512
1978	22	21,610	-56,902
1979	5	4,020	-52,882
1980	25	23,540	-29,342
1981	15	10,127	-19,215
1982	6	5,581	-13,634
1983	14	15,379	1,745
1984	1	930	2,675

San Bernardino Valley Municipal Water District
Change In Storage for the Pressure Zone Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	-15	-14,130	-11,455
1986	-13	-7,945	-19,400
1987	-3	-4,335	-23,735
1988	-8	-11,820	-35,555
1989	-9	-7,680	-43,235
1990	-13	-12,770	-56,005
1991	-13	-13,955	-69,960
1992	-1	463	-69,497
1993	0	2,947	-66,550
1994	-9	-11,268	-77,818
1995	5	6,202	-71,616
1996	9	376	-71,240
1997	6	11,802	-59,438
1998	4	8,938	-50,500
1999	-26	-23,219	-73,719
2000	-9	-9,093	-82,812
2001	-8	-4,280	-87,092
2002	-20	-18,009	-105,101
2003	-9	-7,427	-112,528
2004	-9	-6,495	-119,023
2005	-1	-762	-119,785
2006	1	3,037	-116,748
2007	-4	-2,876	-119,624
2008	-7	5,932	-113,692
2009	-10	-11,169	-124,861
2010	-2	-10,655	-135,516
2011	4	12,742	-122,774
2012	-2	4,292	-118,482
2013	0	-6,753	-125,235
2014	-3	5,195	-120,040
2015	-11	-13,648	-133,688
2016	-5	-4,638	-138,326
2017	-7	-10,231	-148,557
2018	-6	-2,155	-150,712
2019	0	810	-149,902
2020	-10	-7,629	-157,531
2021	-6	-5,936	-163,467
2022	-5	-1,775	-165,242
2023	0	-1,044	-166,286



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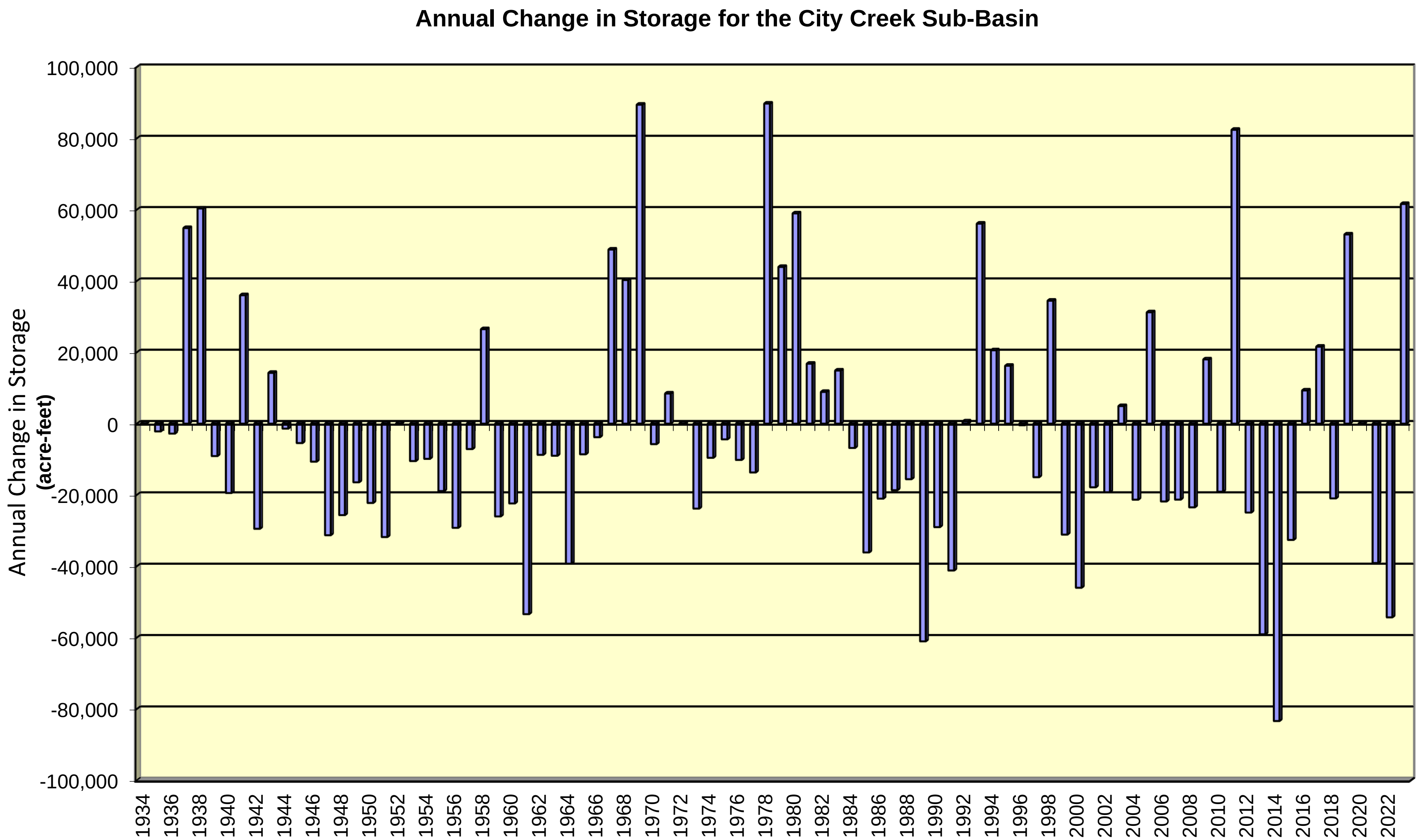

Annual Change in Storage for the City Creek Sub-Basin
Annual Change in Storage
(acre-feet)
100,000
80,000
60,000
40,000
20,000
0
-20,000
-40,000
-60,000
-80,000
-100,000
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
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San Bernardino Valley Municipal Water District

Change In Storage for the City Creek Sub-basin 1934 - Present

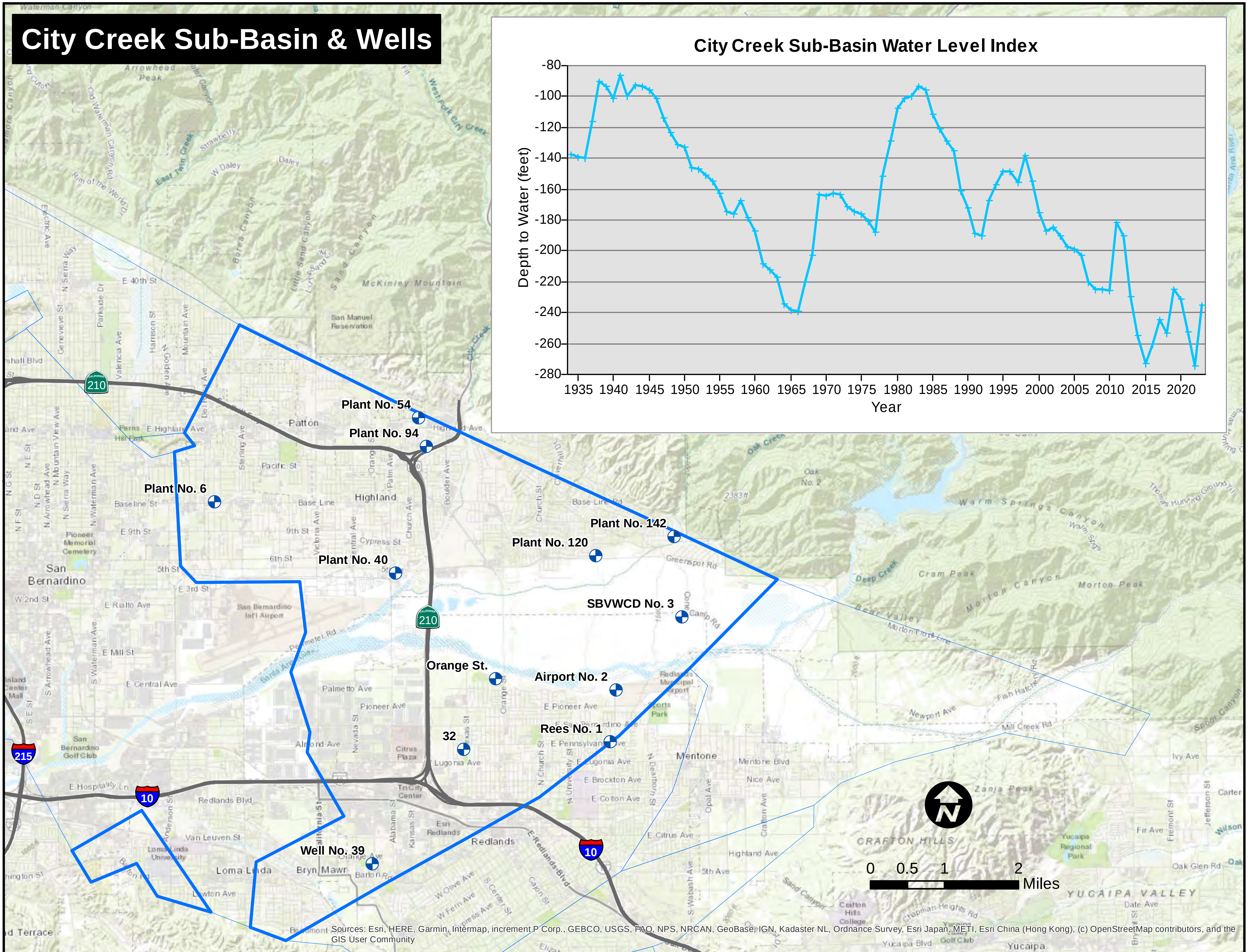
(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	-1	-2,179	-2,179
1936	-1	-2,802	-4,981
1937	24	54,853	49,872
1938	26	60,340	110,212
1939	-3	-9,101	101,111
1940	-8	-19,467	81,644
1941	15	36,016	117,660
1942	-13	-29,496	88,164
1943	7	14,244	102,408
1944	-1	-1,406	101,002
1945	-2	-5,458	95,544
1946	-6	-10,667	84,877
1947	-12	-31,299	53,578
1948	-10	-25,663	27,915
1949	-7	-16,455	11,460
1950	-16	-22,241	-10,781
1951	-13	-31,812	-42,593
1952	-1	-21	-42,614
1953	-4	-10,500	-53,114
1954	-4	-9,873	-62,987
1955	-8	-18,914	-81,901
1956	-12	-29,231	-111,132
1957	-2	-7,142	-118,274
1958	9	26,490	-91,784
1959	-11	-26,023	-117,807
1960	-9	-22,382	-140,189
1961	-21	-53,413	-193,602
1962	-4	-8,760	-202,362
1963	-5	-9,015	-211,377
1964	-17	-39,262	-250,639
1965	-4	-8,605	-259,244
1966	-1	-3,808	-263,052
1967	20	48,813	-214,239
1968	17	40,290	-173,949
1969	40	89,460	-84,489
1970	-1	-5,746	-90,235
1971	2	8,443	-81,792
1972	-1	-318	-82,110
1973	-8	-23,831	-105,941
1974	-3	-9,592	-115,533
1975	-2	-4,410	-119,943
1976	-5	-10,186	-130,129
1977	-7	-13,696	-143,825
1978	36	89,758	-54,067
1979	22	43,951	-10,116
1980	21	58,966	48,850
1981	7	16,804	65,654
1982	2	8,897	74,551
1983	6	14,890	89,441
1984	-3	-6,823	82,618

San Bernardino Valley Municipal Water District

Change In Storage for the City Creek Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	-16	-36,130	46,488
1986	-9	-21,038	25,450
1987	-8	-18,659	6,791
1988	-6	-15,578	-8,787
1989	-26	-61,028	-69,815
1990	-11	-29,017	-98,832
1991	-16	-41,190	-140,022
1992	-2	616	-139,406
1993	23	56,087	-83,319
1994	10	20,573	-62,746
1995	8	16,221	-46,525
1996	0	-453	-46,978
1997	-7	-15,021	-61,999
1998	15	34,478	-27,521
1999	-14	-31,118	-58,639
2000	-20	-46,018	-104,657
2001	-15	-17,857	-122,514
2002	1	-19,242	-141,756
2003	-5	4,923	-136,833
2004	-8	-21,327	-158,160
2005	1	31,225	-126,935
2006	-2	-21,828	-148,763
2007	-17	-21,308	-170,071
2008	-5	-23,474	-193,545
2009	1	18,017	-175,528
2010	-3	-19,089	-194,617
2011	44	82,409	-112,208
2012	-7	-24,934	-137,142
2013	-40	-59,051	-196,193
2014	-23	-83,353	-279,546
2015	-18	-32,605	-312,151
2016	12	9,302	-302,849
2017	8	21,585	-281,264
2018	-7	-20,972	-302,236
2019	24	53,058	-249,178
2020	0	-135	-249,313
2021	-19	-39,081	-288,394
2022	-23	-54,302	-342,696
2023	40	61,612	-281,084

City Creek Sub-Basin & Wells



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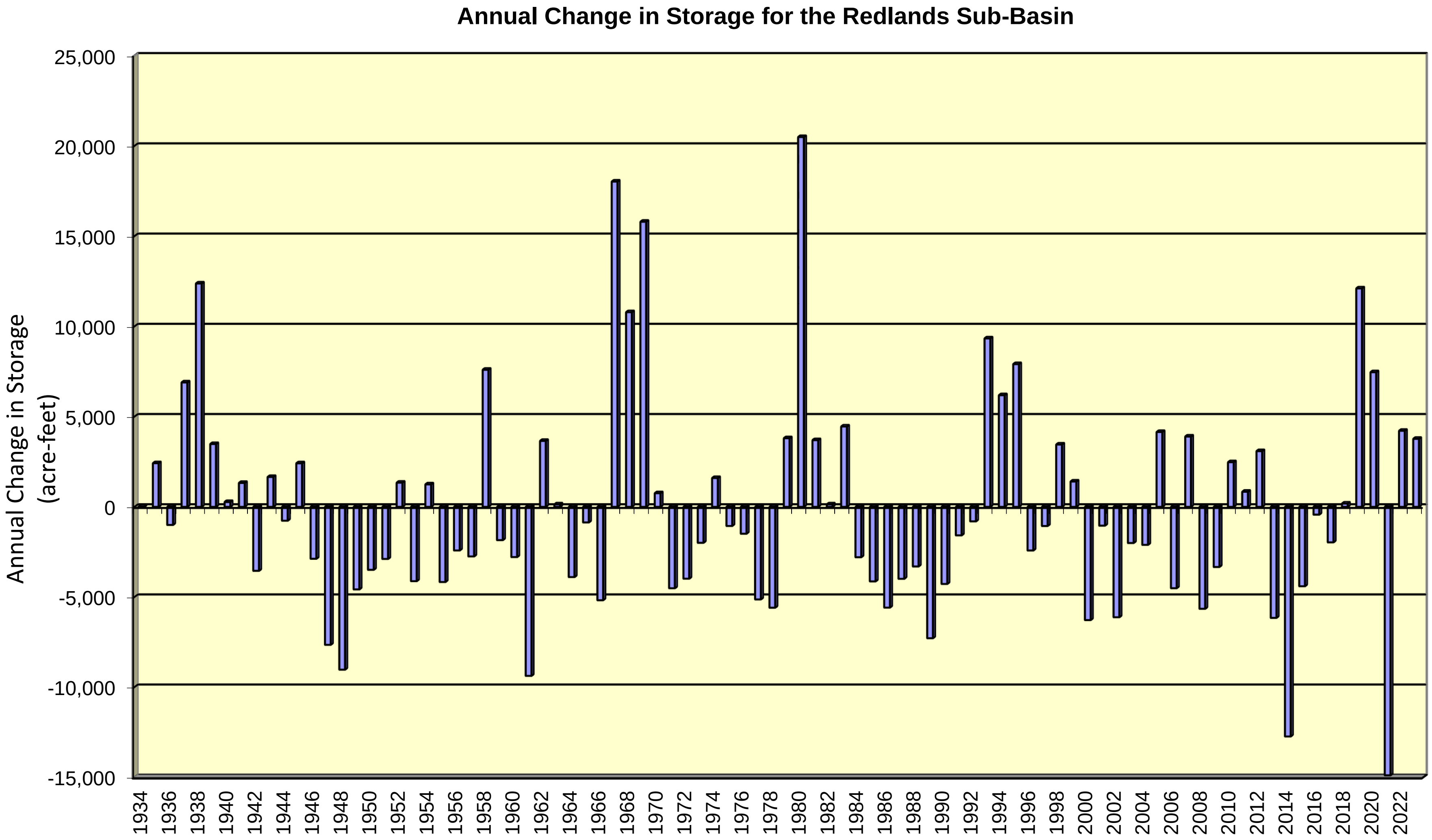

Annual Change in Storage for the Redlands Sub-Basin
Annual Change in Storage
(acre-feet)
25,000
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
1934
1936
1938
1940
1942
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1946
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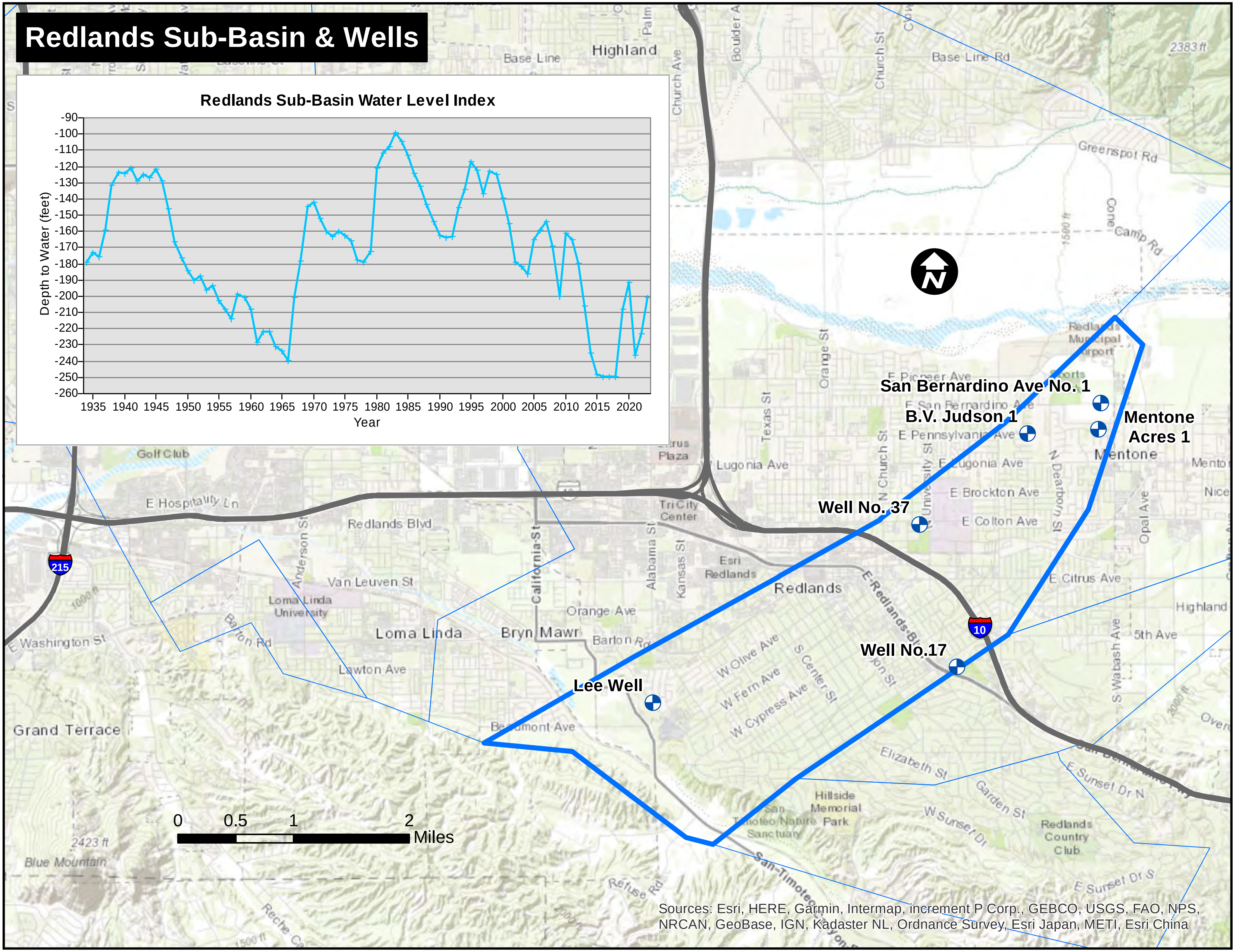
2022

San Bernardino Valley Municipal Water District
Change In Storage for the Redlands Sub-basin 1934 -Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	5	2,422	2,422
1936	-2	-1,000	1,422
1937	16	6,898	8,320
1938	28	12,380	20,700
1939	8	3,484	24,184
1940	-1	272	24,456
1941	3	1,330	25,786
1942	-8	-3,543	22,243
1943	4	1,658	23,901
1944	-2	-764	23,137
1945	5	2,417	25,554
1946	-7	-2,877	22,677
1947	-17	-7,651	15,026
1948	-20	-9,030	5,996
1949	-10	-4,575	1,421
1950	-8	-3,489	-2,068
1951	-6	-2,885	-4,953
1952	3	1,342	-3,611
1953	-9	-4,118	-7,729
1954	3	1,246	-6,483
1955	-9	-4,166	-10,649
1956	-5	-2,414	-13,063
1957	-6	-2,745	-15,808
1958	15	7,599	-8,209
1959	-2	-1,842	-10,051
1960	-7	-2,781	-12,832
1961	-20	-9,375	-22,207
1962	7	3,658	-18,549
1963	0	140	-18,409
1964	-9	-3,892	-22,301
1965	-2	-860	-23,161
1966	13	-5,177	-28,338
1967	39	18,026	-10,312
1968	23	10,790	478
1969	34	15,801	16,279
1970	3	759	17,038
1971	-10	-4,512	12,526
1972	-8	-3,981	8,545
1973	-3	-1,990	6,555
1974	4	1,601	8,156
1975	-3	-1,055	7,101
1976	-4	-1,485	5,616
1977	-12	-5,133	483
1978	24	-5,591	-5,108
1979	7	3,805	-1,303
1980	22	20,494	19,191
1981	9	3,700	22,891
1982	4	140	23,031
1983	9	4,455	27,486
1984	-5	-2,791	24,695

San Bernardino Valley Municipal Water District
Change In Storage for the Redlands Sub-basin 1934 -Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	-9	-4,131	20,564
1986	-11	-5,586	14,978
1987	-8	-3,988	10,990
1988	-11	-3,303	7,687
1989	-10	-7,285	402
1990	-9	-4,273	-3,871
1991	-1	-1,576	-5,447
1992	1	-802	-6,249
1993	18	9,337	3,088
1994	12	6,189	9,277
1995	17	7,913	17,190
1996	-5	-2,416	14,774
1997	-15	-1,057	13,717
1998	14	3,457	17,174
1999	-2	1,407	18,581
2000	-15	-6,279	12,302
2001	-15	-1,040	11,262
2002	-24	-6,120	5,142
2003	-3	-2,001	3,141
2004	-4	-2,104	1,037
2005	21	4,150	5,187
2006	6	-4,510	677
2007	5	3,900	4,577
2008	-15	-5,652	-1,075
2009	-14	-3,331	-4,406
2010	5	2,475	-1,931
2011	-4	840	-1,091
2012	-15	3,089	1,998
2013	-26	-6,156	-4,159
2014	-20	-12,738	-16,897
2015	-13	-4,400	-21,297
2016	1	-428	-21,725
2017	-2	-1,965	-23,690
2018	-2	186	-23,504
2019	30	12,107	-11,397
2020	18	7,464	-3,933
2021	-29	-14,892	-18,825
2022	13	4,217	-14,608
2023	22	3,773	-10,835



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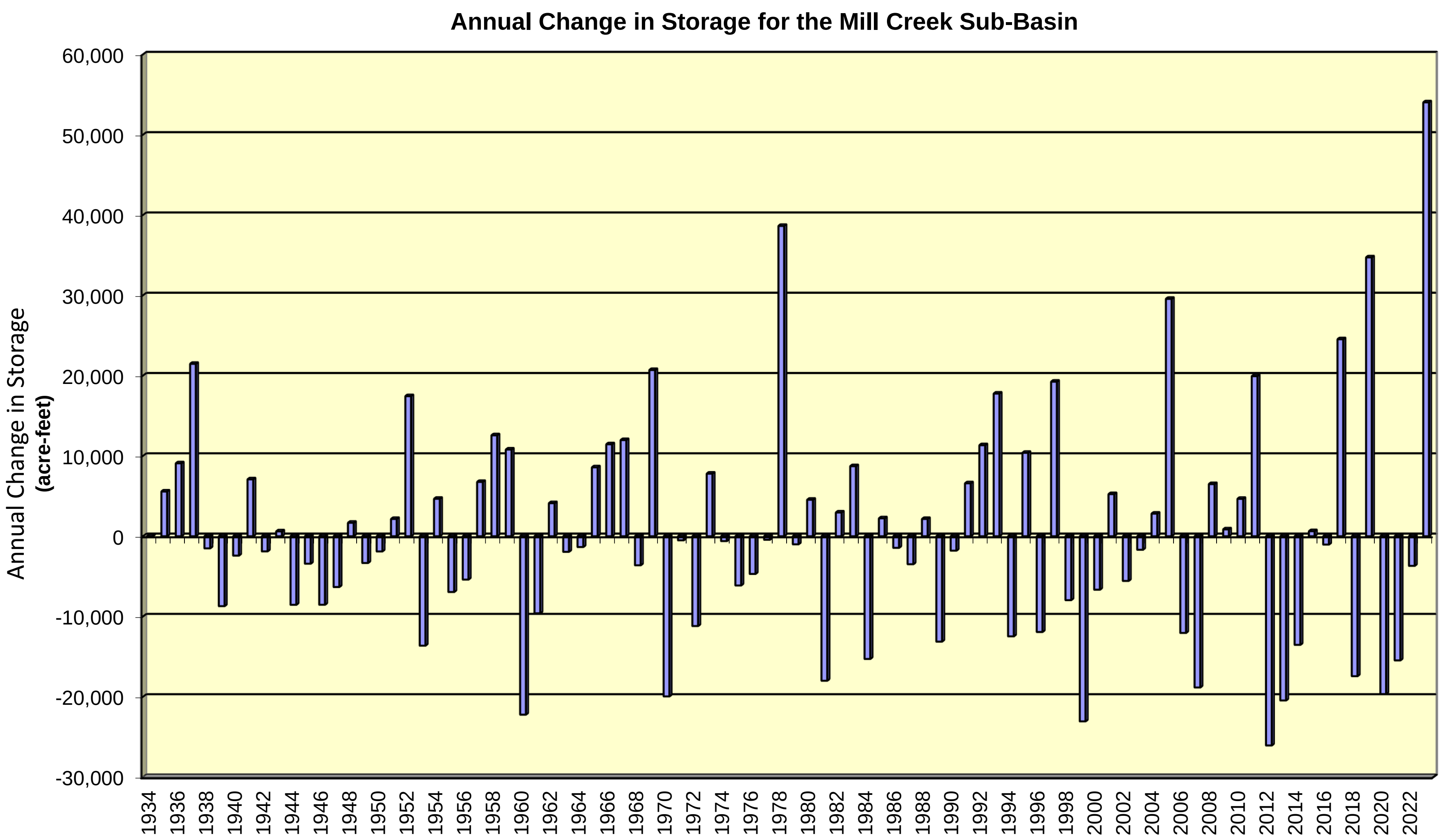
Annual Change in Storage for the Mill Creek Sub-Basin
Annual Change in Storage
(acre-feet)
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
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1982
1984
1986
1988
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1996
1998
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2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

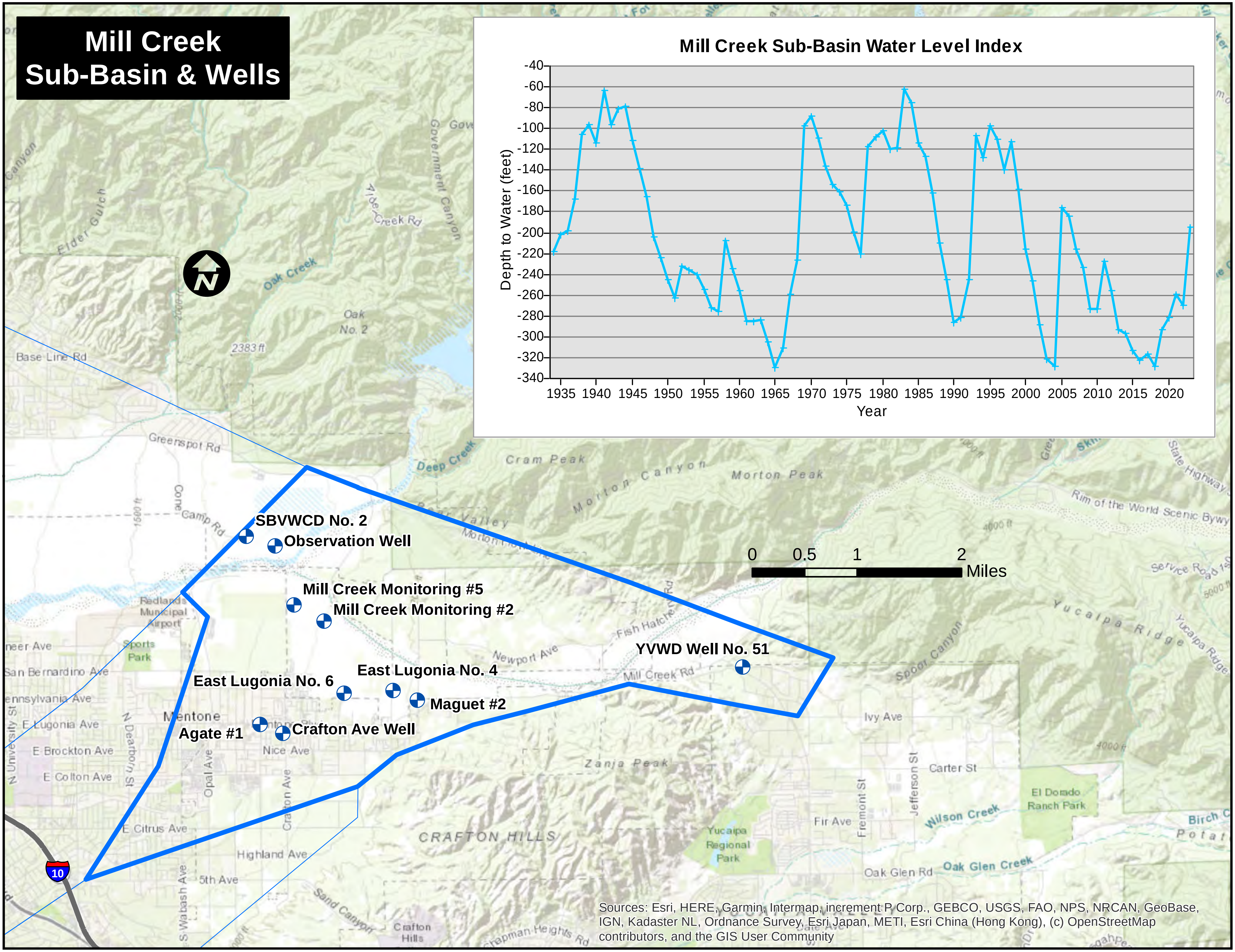
San Bernardino Valley Municipal Water District

Change In Storage for the Mill Creek Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	11	5,575	5,575
1936	20	9,081	14,656
1937	30	21,472	36,128
1938	-4	-1,506	34,622
1939	-16	-8,705	25,917
1940	-3	-2,412	23,505
1941	15	7,081	30,586
1942	-8	-1,883	28,703
1943	3	608	29,311
1944	-14	-8,542	20,769
1945	-3	-3,421	17,348
1946	-13	-8,531	8,817
1947	-13	-6,322	2,495
1948	4	1,677	4,172
1949	-5	-3,332	840
1950	-5	-1,890	-1,050
1951	3	2,151	1,101
1952	29	17,447	18,548
1953	-22	-13,629	4,919
1954	8	4,664	9,583
1955	-13	-6,947	2,636
1956	-11	-5,394	-2,758
1957	14	6,767	4,009
1958	25	12,574	16,583
1959	10	10,797	27,380
1960	-32	-22,220	5,160
1961	-17	-9,592	-4,432
1962	8	4,121	-311
1963	-3	-1,939	-2,250
1964	-3	-1,344	-3,594
1965	17	8,585	4,991
1966	18	11,449	16,440
1967	17	11,973	28,413
1968	-6	-3,615	24,798
1969	31	20,705	45,503
1970	-29	-19,947	25,556
1971	-3	-507	25,049
1972	-15	-11,184	13,865
1973	12	7,794	21,659
1974	-1	-605	21,054
1975	-11	-6,130	14,924
1976	-7	-4,694	10,230
1977	4	-440	9,790
1978	53	38,652	48,442
1979	-3	-1,001	47,441
1980	10	4,546	51,987
1981	-29	-17,993	33,994
1982	4	2,958	36,952
1983	14	8,723	45,675
1984	-23	-15,284	30,391

San Bernardino Valley Municipal Water District
Change In Storage for the Mill Creek Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	5	2,232	32,623
1986	-3	-1,445	31,178
1987	-5	-3,482	27,696
1988	1	2,148	29,844
1989	-20	-13,125	16,719
1990	-3	-1,796	14,923
1991	12	6,593	21,516
1992	16	11,338	32,854
1993	26	17,767	50,621
1994	-19	-12,468	38,153
1995	17	10,390	48,543
1996	-18	-11,923	36,620
1997	24	19,248	55,868
1998	-16	-7,957	47,911
1999	-27	-23,059	24,852
2000	0	-6,656	18,196
2001	-7	5,243	23,439
2002	-20	-5,565	17,874
2003	3	-1,681	16,193
2004	5	2,811	19,004
2005	43	29,567	48,571
2006	-18	-12,042	36,529
2007	-35	-18,835	17,694
2008	15	6,498	24,192
2009	-8	856	25,048
2010	18	4,657	29,705
2011	43	19,938	49,643
2012	-32	-26,058	23,585
2013	-54	-20,455	3,130
2014	-14	-13,527	-10,397
2015	-8	629	-9,768
2016	11	-1,035	-10,803
2017	46	24,536	13,733
2018	-42	-17,429	-3,696
2019	72	34,735	31,039
2020	-38	-19,658	11,381
2021	-28	-15,459	-4,078
2022	-6	-3,691	-7,769
2023	101	54,040	46,271



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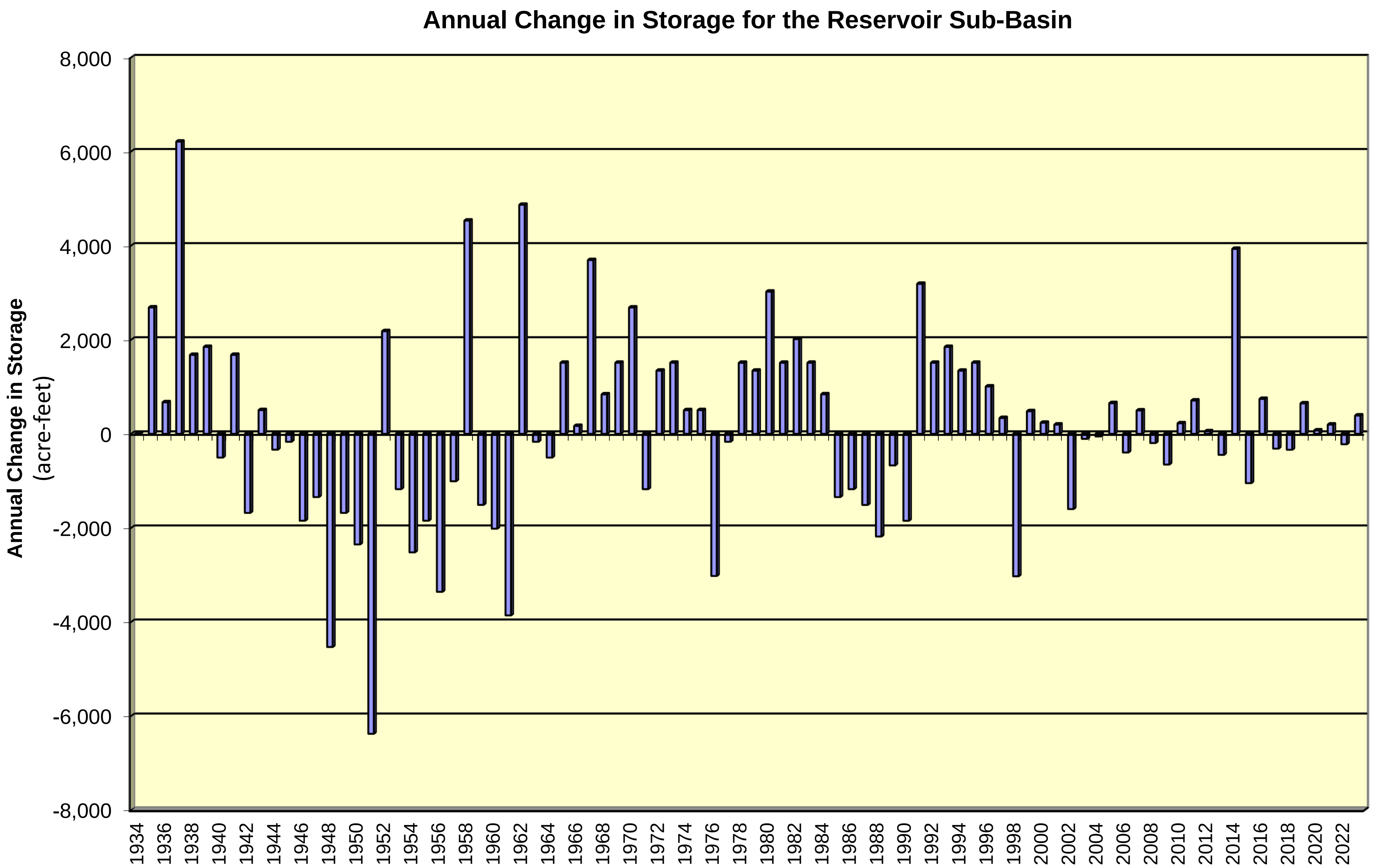

Annual Change in Storage for the Reservoir Sub-Basin
Annual Change in Storage
(acre-feet)
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
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2018
2020
2022

San Bernardino Valley Municipal Water District

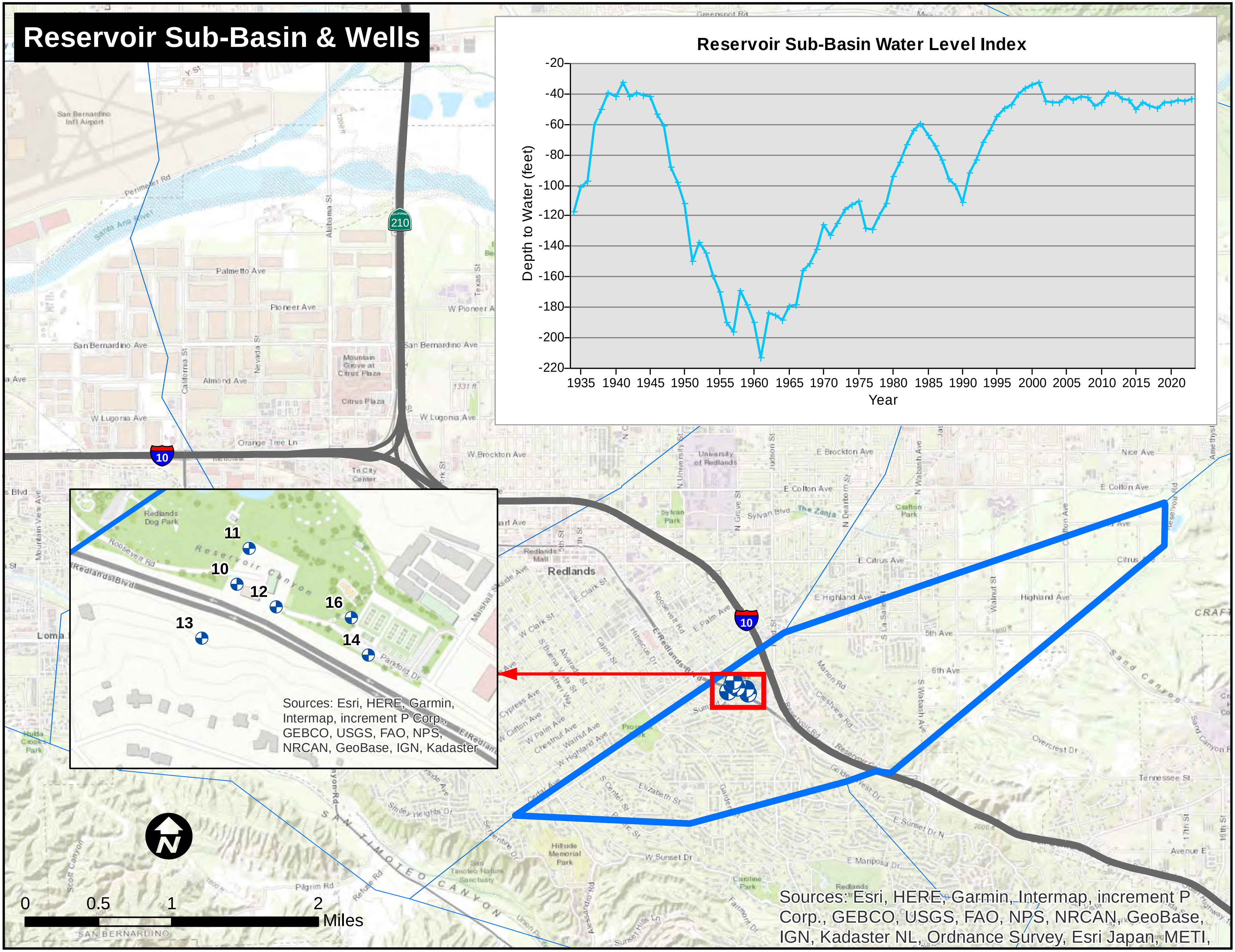
Change In Storage for the Reservoir Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	16	2,686	2,686
1936	4	671	3,357
1937	37	6,211	9,568
1938	10	1,678	11,246
1939	11	1,847	13,093
1940	-3	-504	12,589
1941	10	1,679	14,268
1942	-10	-1,679	12,589
1943	3	504	13,093
1944	-2	-336	12,757
1945	-1	-168	12,589
1946	-11	-1,846	10,743
1947	-8	-1,343	9,400
1948	-27	-4,532	4,868
1949	-10	-1,679	3,189
1950	-14	-2,350	839
1951	-38	-6,378	-5,539
1952	13	2,182	-3,357
1953	-7	-1,175	-4,532
1954	-15	-2,518	-7,050
1955	-11	-1,846	-8,896
1956	-20	-3,358	-12,254
1957	-6	-1,007	-13,261
1958	27	4,532	-8,729
1959	-9	-1,510	-10,239
1960	-12	-2,015	-12,254
1961	-23	-3,860	-16,114
1962	29	4,868	-11,246
1963	-1	-168	-11,414
1964	-3	-504	-11,918
1965	9	1,511	-10,407
1966	1	168	-10,239
1967	22	3,693	-6,546
1968	5	839	-5,707
1969	9	1,511	-4,196
1970	16	2,685	-1,511
1971	-7	-1,175	-2,686
1972	8	1,343	-1,343
1973	9	1,511	168
1974	3	503	671
1975	3	504	1,175
1976	-18	-3,021	-1,846
1977	-1	-168	-2,014
1978	9	1,510	-504
1979	8	1,343	839
1980	18	3,022	3,861
1981	9	1,510	5,371
1982	12	2,015	7,386
1983	9	1,510	8,896
1984	5	840	9,736

San Bernardino Valley Municipal Water District

Change In Storage for the Reservoir Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	-8	-1,343	8,393
1986	-7	-1,175	7,218
1987	-9	-1,511	5,707
1988	-13	-2,182	3,525
1989	-4	-671	2,854
1990	-11	-1,847	1,007
1991	19	3,189	4,196
1992	9	1,511	5,707
1993	11	1,847	7,554
1994	8	1,342	8,896
1995	9	1,511	10,407
1996	6	1,007	11,414
1997	2	336	11,750
1998	-13	-3,027	8,723
1999	4	481	9,204
2000	2	236	9,440
2001	1	197	9,637
2002	-12	-1,598	8,039
2003	-1	-106	7,933
2004	0	-54	7,879
2005	4	652	8,531
2006	-2	-396	8,135
2007	2	497	8,632
2008	-1	-195	8,437
2009	-5	-652	7,785
2010	2	224	8,009
2011	6	708	8,717
2012	0	55	8,773
2013	-4	-446	8,327
2014	-1	3,931	12,258
2015	-6	-1,047	11,211
2016	4	743	11,954
2017	-2	-314	11,640
2018	-2	-338	11,302
2019	4	647	11,949
2020	1	72	12,021
2021	1	197	12,218
2022	-1	-220	11,998
2023	2	389	12,387



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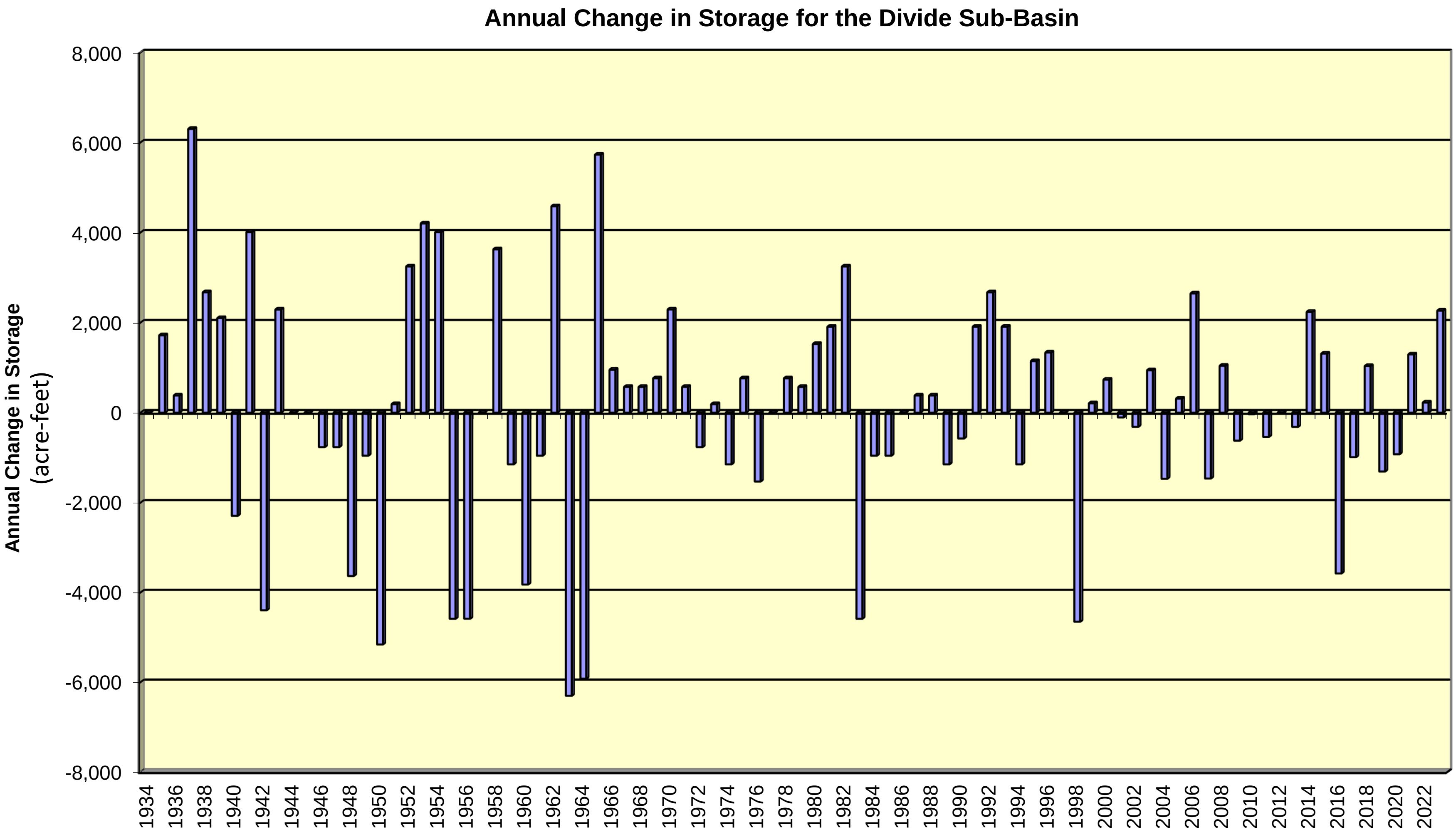

Annual Change in Storage for the Divide Sub-Basin
Annual Change in Storage
(acre-feet)
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
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1964
1966
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2016
2018
2020
2022

San Bernardino Valley Municipal Water District
Change In Storage for the Divide Sub-basin 1934 - Present

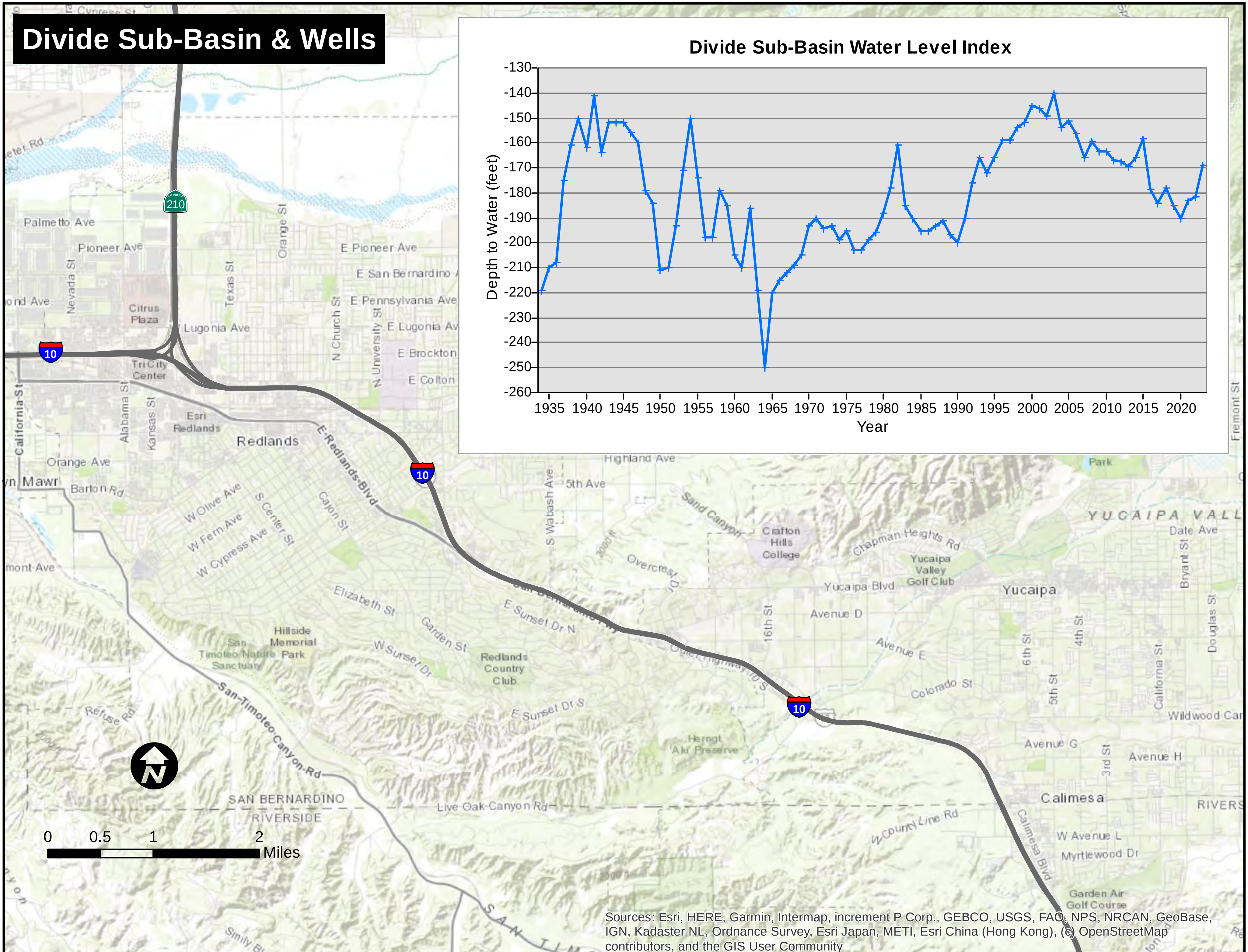
(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1934	0	n/a	0
1935	9	1,719	1,719
1936	2	382	2,101
1937	33	6,304	8,405
1938	14	2,675	11,080
1939	11	2,101	13,181
1940	-12	-2,292	10,889
1941	21	4,012	14,901
1942	-23	-4,394	10,507
1943	12	2,292	12,799
1944	0	0	12,799
1945	0	0	12,799
1946	-4	-764	12,035
1947	-4	-764	11,271
1948	-19	-3,630	7,641
1949	-5	-955	6,686
1950	-27	-5,158	1,528
1951	1	191	1,719
1952	17	3,248	4,967
1953	22	4,203	9,170
1954	21	4,011	13,181
1955	-24	-4,585	8,596
1956	-24	-4,584	4,012
1957	0	0	4,012
1958	19	3,629	7,641
1959	-6	-1,146	6,495
1960	-20	-3,821	2,674
1961	-5	-955	1,719
1962	24	4,585	6,304
1963	-33	-6,304	0
1964	-31	-5,922	-5,922
1965	30	5,731	-191
1966	5	955	764
1967	3	573	1,337
1968	3	573	1,910
1969	4	764	2,674
1970	12	2,293	4,967
1971	3	573	5,540
1972	-4	-764	4,776
1973	1	191	4,967
1974	-6	-1,146	3,821
1975	4	764	4,585
1976	-8	-1,528	3,057
1977	0	0	3,057
1978	4	764	3,821
1979	3	573	4,394
1980	8	1,528	5,922
1981	10	1,910	7,832
1982	17	3,248	11,080
1983	-24	-4,585	6,495
1984	-5	-955	5,540

San Bernardino Valley Municipal Water District

Change In Storage for the Divide Sub-basin 1934 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1985	-5	-955	4,585
1986	0	0	4,585
1987	2	382	4,967
1988	2	382	5,349
1989	-6	-1,146	4,203
1990	-3	-573	3,630
1991	10	1,910	5,540
1992	14	2,674	8,214
1993	10	1,911	10,125
1994	-6	-1,146	8,979
1995	6	1,146	10,125
1996	7	1,337	11,462
1997	0	0	11,462
1998	5	-4,651	6,811
1999	2	210	7,021
2000	7	734	7,755
2001	-1	-105	7,650
2002	-3	-314	7,336
2003	9	943	8,279
2004	-14	-1,467	6,812
2005	3	314	7,126
2006	5	2,649	9,775
2007	-10	-1,462	8,313
2008	7	1,042	9,355
2009	-4	-621	8,734
2010	0	-32	8,702
2011	-4	-537	8,165
2012	-1	-20	8,145
2013	-2	-315	7,830
2014	-2	2,240	10,070
2015	-4	1,312	11,382
2016	-4	-3,573	7,809
2017	-6	-988	6,821
2018	6	1,036	7,857
2019	-7	-1,306	6,551
2020	2	-922	5,629
2021	2	1,294	6,923
2022	1	226	7,149
2023	13	2,267	9,416

Divide Sub-Basin & Wells



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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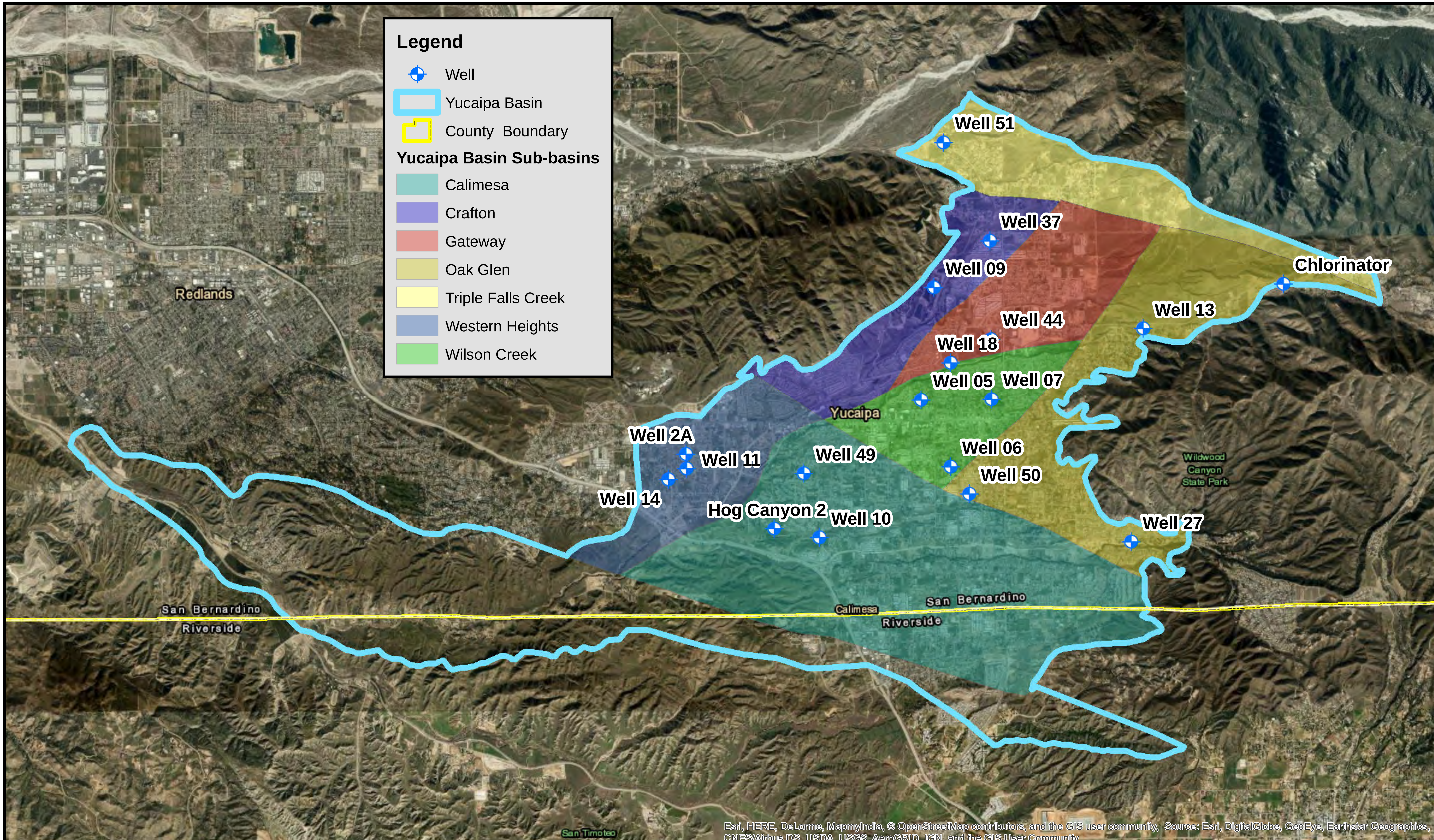


Document Path: Y:\1422ChangeInStorage\CISYucaipaBasin.mxd

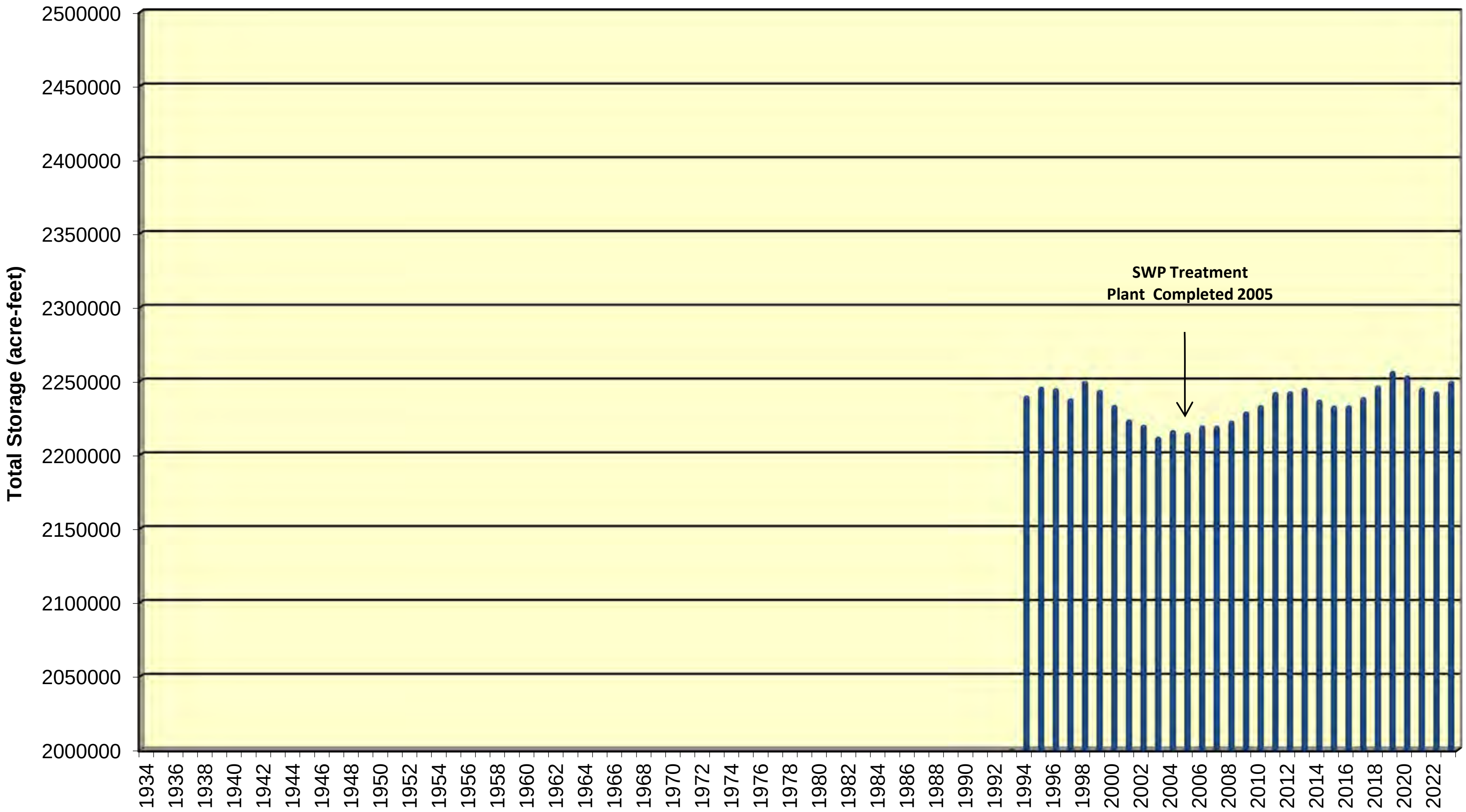
San Bernardino Valley Municipal Water District

YUCAIPA BASIN SUB-BASINS AND WELL LOCATIONS

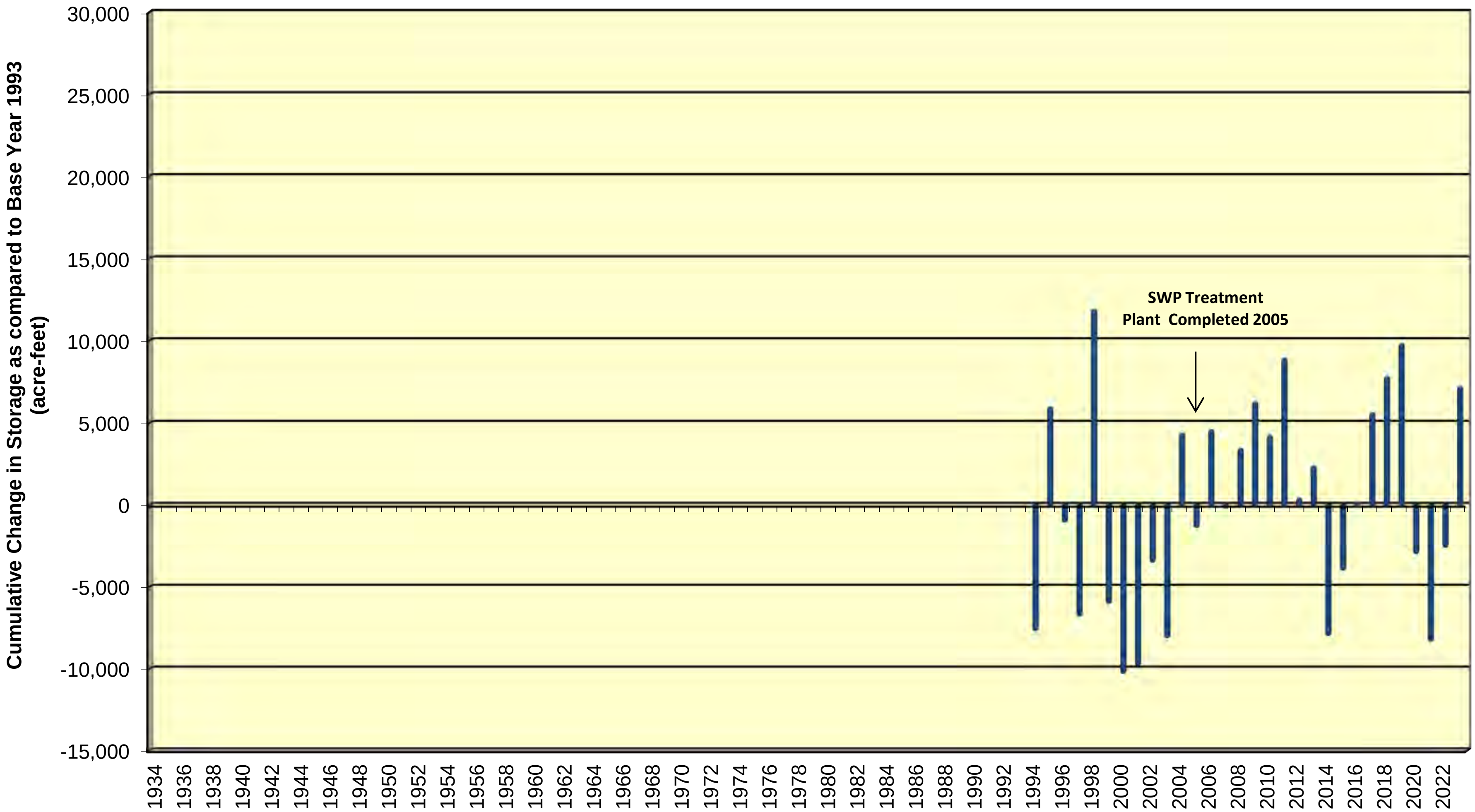
0 0.5 1 2 3 4 Miles

Source: Geoscience Support Services, Inc. (Sub-Basin Boundaries)

Total Storage for the Yucaipa Basin



Annual Change in Storage for the Yucaipa Basin

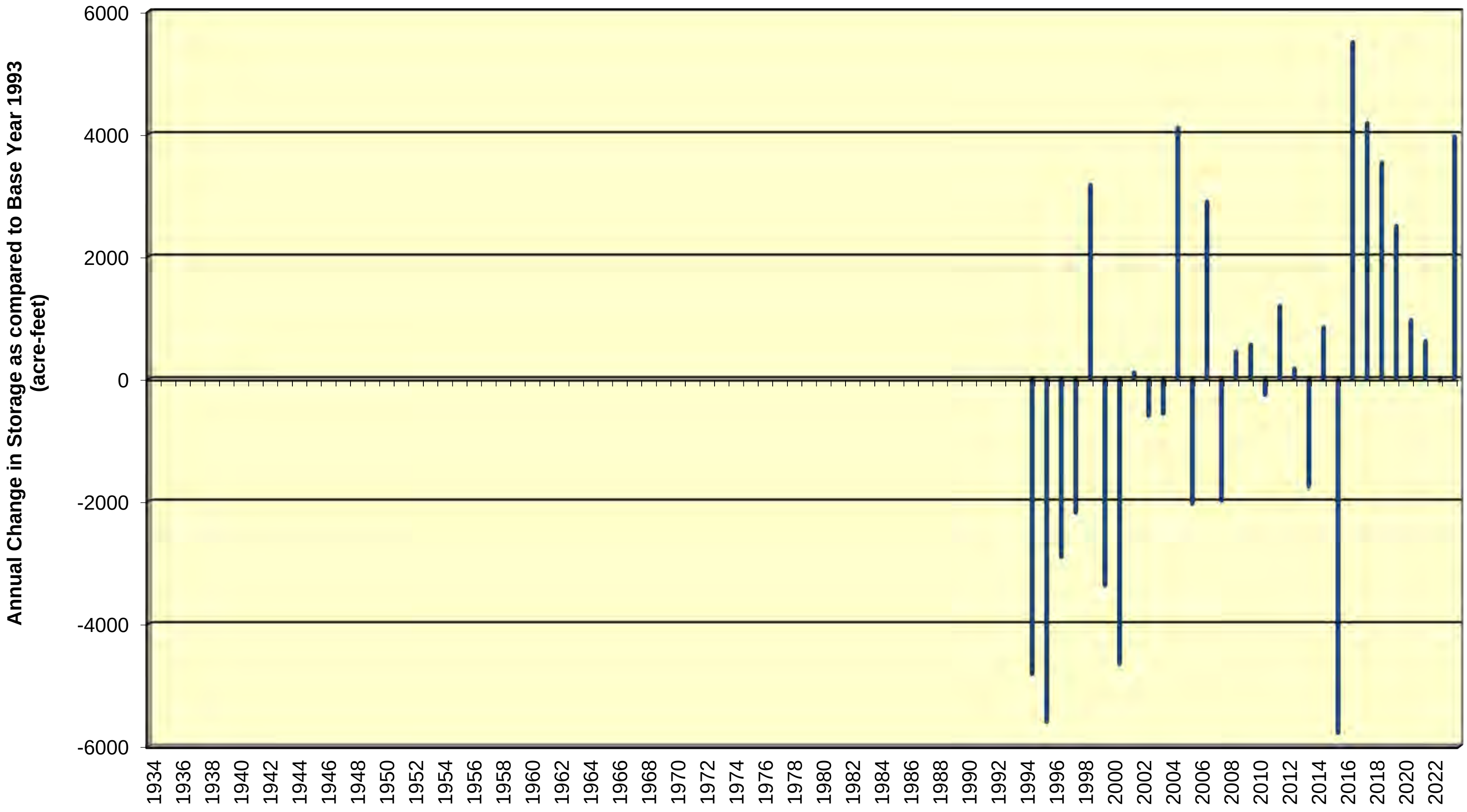


San Bernardino Valley Municipal Water District

Change In Storage for the Yucaipa Basin 1993 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Total Groundwater Storage (acre-feet)
1993	0	0	2,247,503
1994	-3	-7,695	2,239,808
1995	10	5,985	2,245,793
1996	0	-1,088	2,244,705
1997	-7	-6,827	2,237,878
1998	13	11,912	2,249,790
1999	-7	-6,049	2,243,741
2000	-10	-10,319	2,233,422
2001	-14	-9,841	2,223,581
2002	-2	-3,536	2,220,045
2003	-10	-8,151	2,211,894
2004	2	4,389	2,216,283
2005	2	-1,418	2,214,865
2006	4	4,602	2,219,467
2007	1	-238	2,219,229
2008	3	3,462	2,222,691
2009	7	6,314	2,229,005
2010	6	4,260	2,233,265
2011	11	8,942	2,242,207
2012	4	434	2,242,641
2013	3	2,392	2,245,033
2014	-11	-8,006	2,237,027
2015	-1	-4,027	2,233,000
2016	-3	157	2,233,157
2017	4	5,644	2,238,801
2018	10	7,819	2,246,620
2019	6	9,818	2,256,438
2020	-5	-3,005	2,253,433
2021	-12	-8,355	2,245,078
2022	-5	-2,619	2,242,459
2023	6	10,712	2,253,171

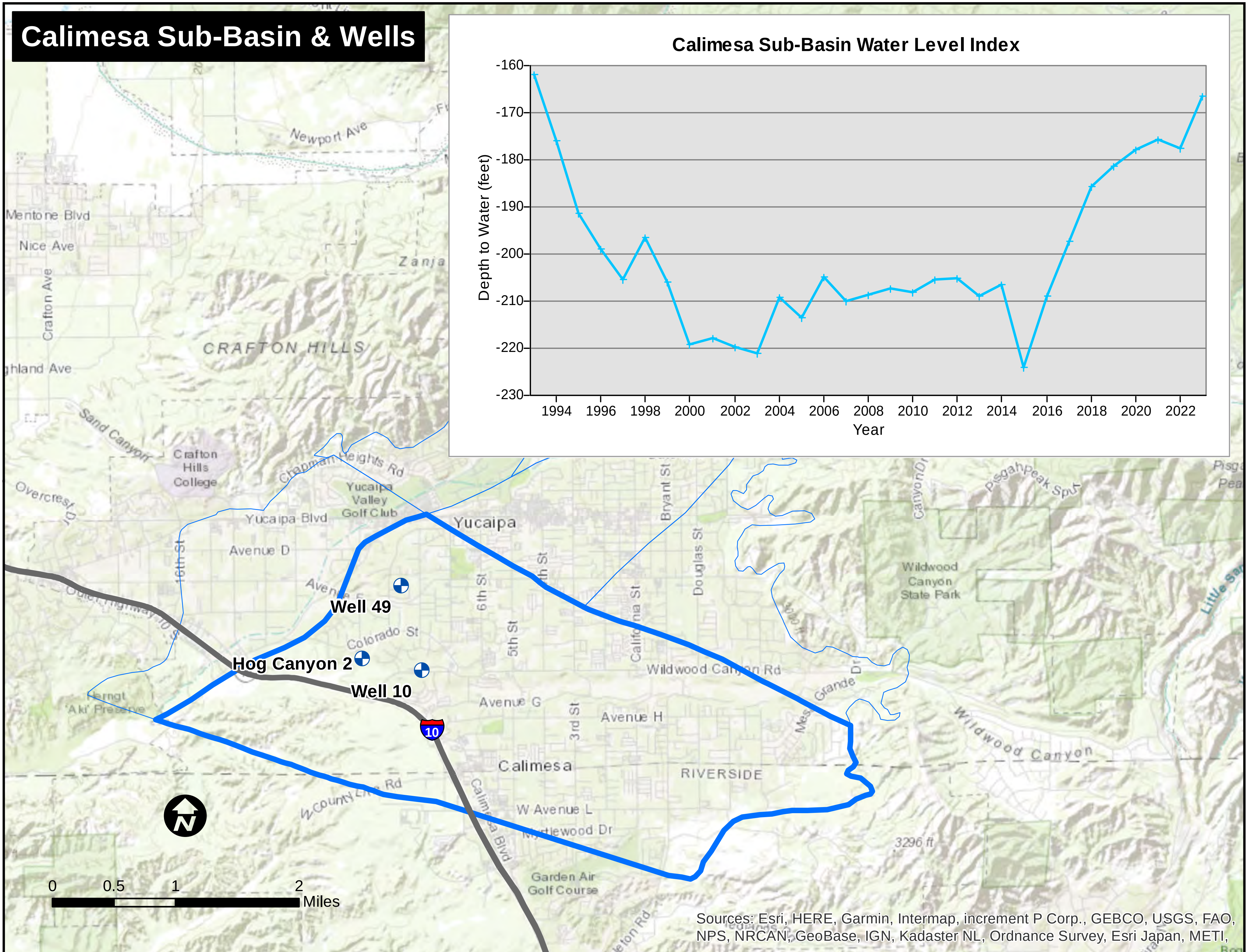
Annual Change in Storage for the Calimesa Sub-Basin



San Bernardino Valley Municipal Water District

Change In Storage for the Calimesa Sub-Basin 1993 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1993	0		
1994	-14	-4,853	-4,853
1995	-15	-5,633	-10,486
1996	-8	-2,943	-13,429
1997	-6	-2,216	-15,645
1998	9	3,197	-12,448
1999	-10	-3,404	-15,852
2000	-13	-4,688	-20,540
2001	1	136	-20,404
2002	-2	-632	-21,036
2003	-1	-601	-21,637
2004	12	4,130	-17,507
2005	-4	-2,070	-19,577
2006	9	2,925	-16,652
2007	-5	-2,026	-18,678
2008	1	475	-18,203
2009	1	590	-17,613
2010	-1	-291	-17,904
2011	3	1,223	-16,681
2012	0	199	-16,482
2013	-4	-1,791	-18,273
2014	2	872	-17,401
2015	-17	-5,814	-23,215
2016	15	5,531	-17,684
2017	12	4,209	-13,475
2018	12	3,559	-9,916
2019	4	2,527	-7,389
2020	4	989	-6,400
2021	2	647	-5,753
2022	-2	-61	-5,814
2023	10	3,992	-1,822



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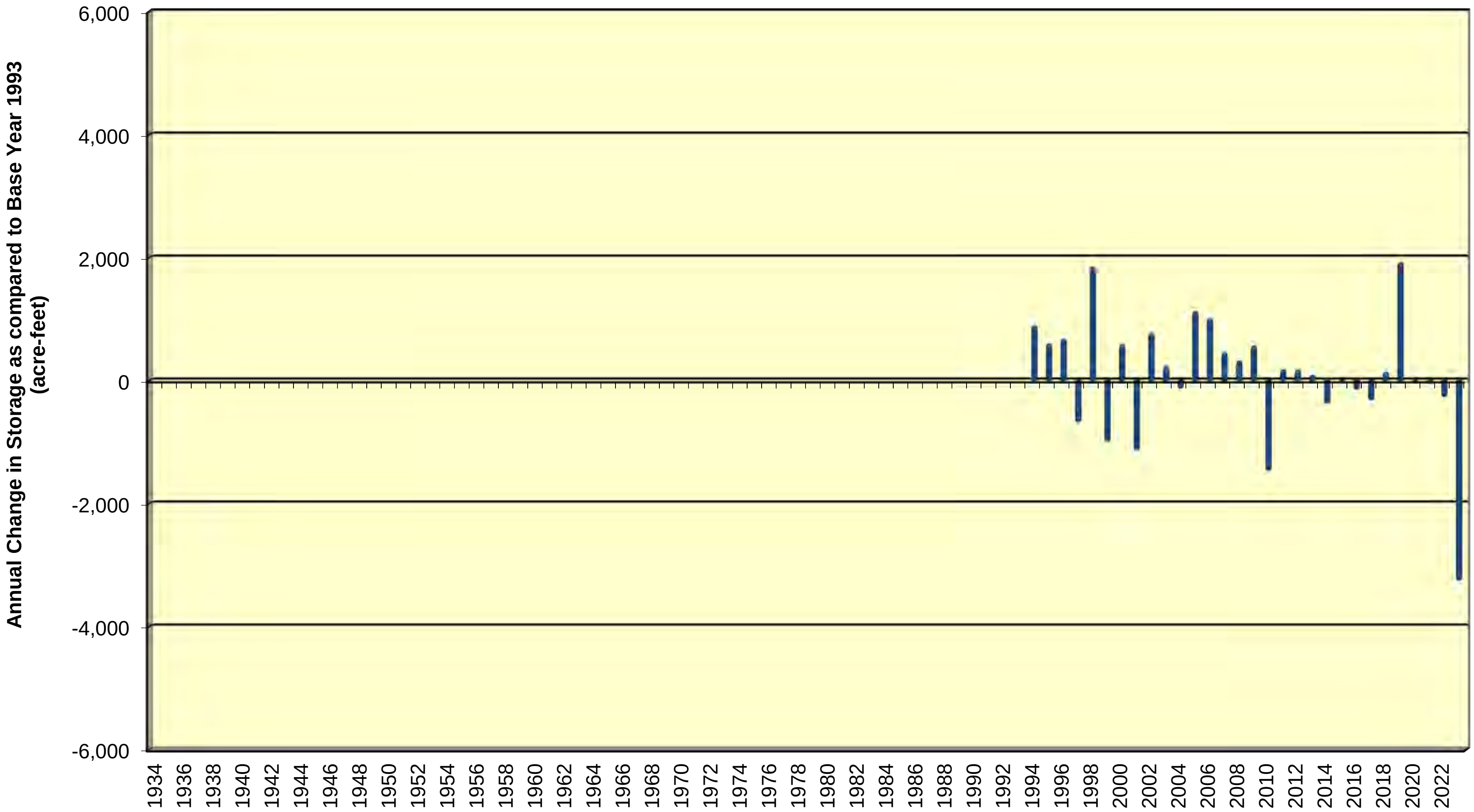
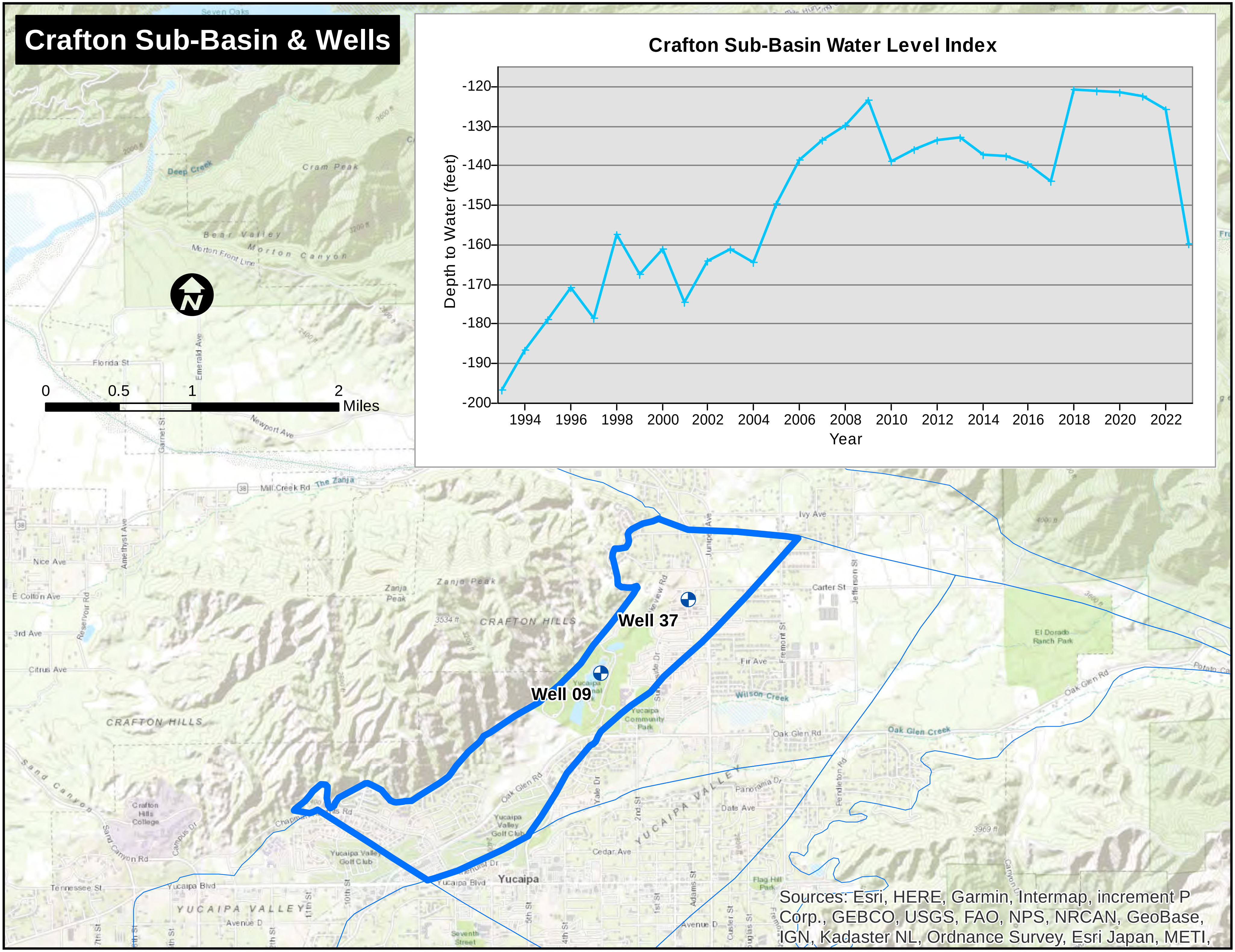
Annual Change in Storage for the Crafton Sub-Basin



San Bernardino Valley Municipal Water District
Change In Storage for the Crafton Sub-Basin 1993 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1993	0		
1994	10	898	898
1995	8	602	1,500
1996	8	676	2,176
1997	-8	-678	1,498
1998	21	1,857	3,355
1999	-10	-1,000	2,355
2000	7	590	2,945
2001	-14	-1,139	1,806
2002	10	770	2,576
2003	3	234	2,810
2004	-4	-132	2,678
2005	15	1,132	3,810
2006	11	1,014	4,824
2007	5	459	5,283
2008	4	326	5,609
2009	7	568	6,177
2010	-16	-1,471	4,706
2011	3	180	4,886
2012	2	173	5,059
2013	1	91	5,150
2014	-5	-379	4,771
2015	0	-18	4,753
2016	-2	-150	4,603
2017	-4	-324	4,279
2018	1	139	4,418
2019	23	1,923	6,341
2020	0	-23	6,318
2021	-1	-59	6,259
2022	-3	-268	5,991
2023	-34	248	6,239

Crafton Sub-Basin & Wells



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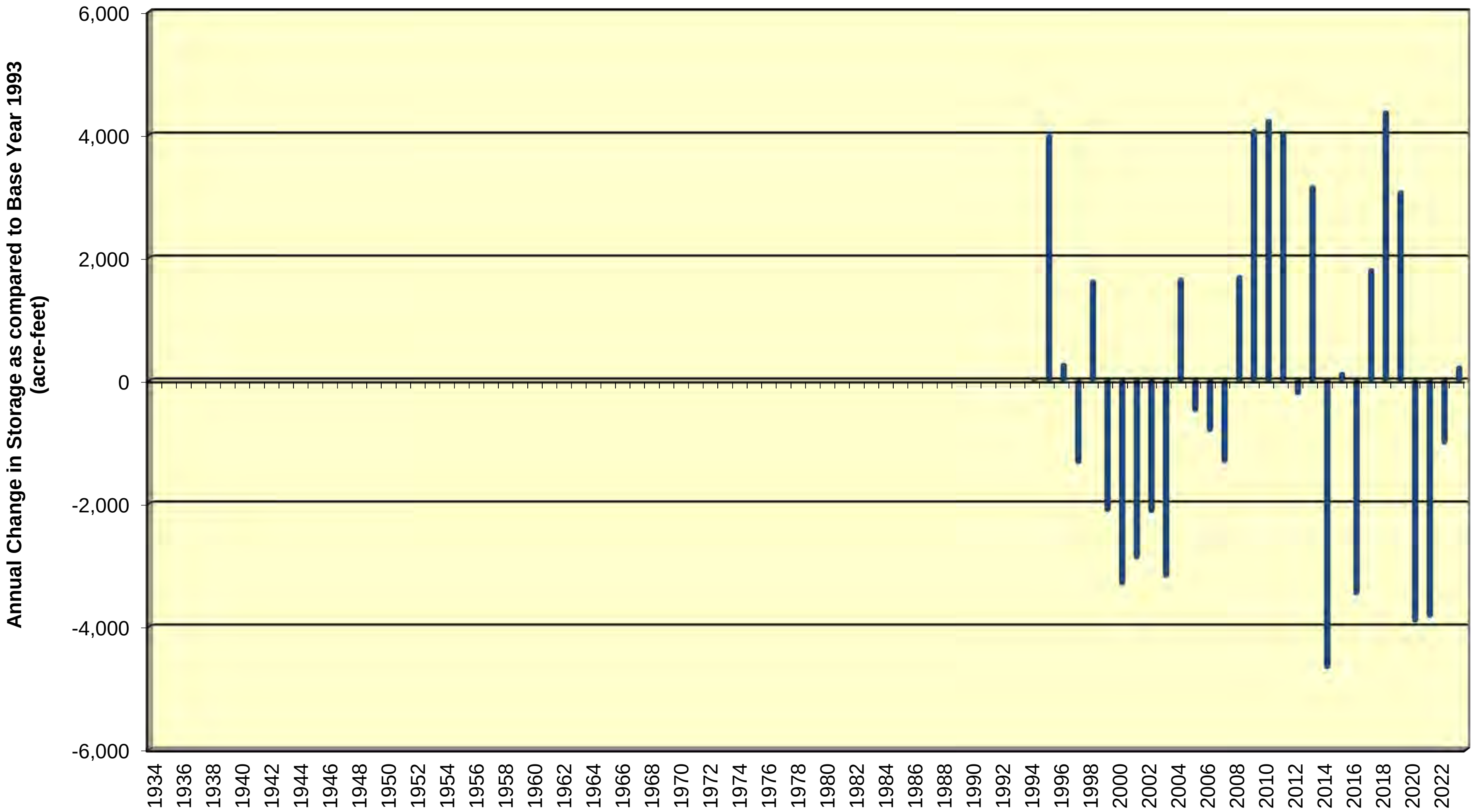
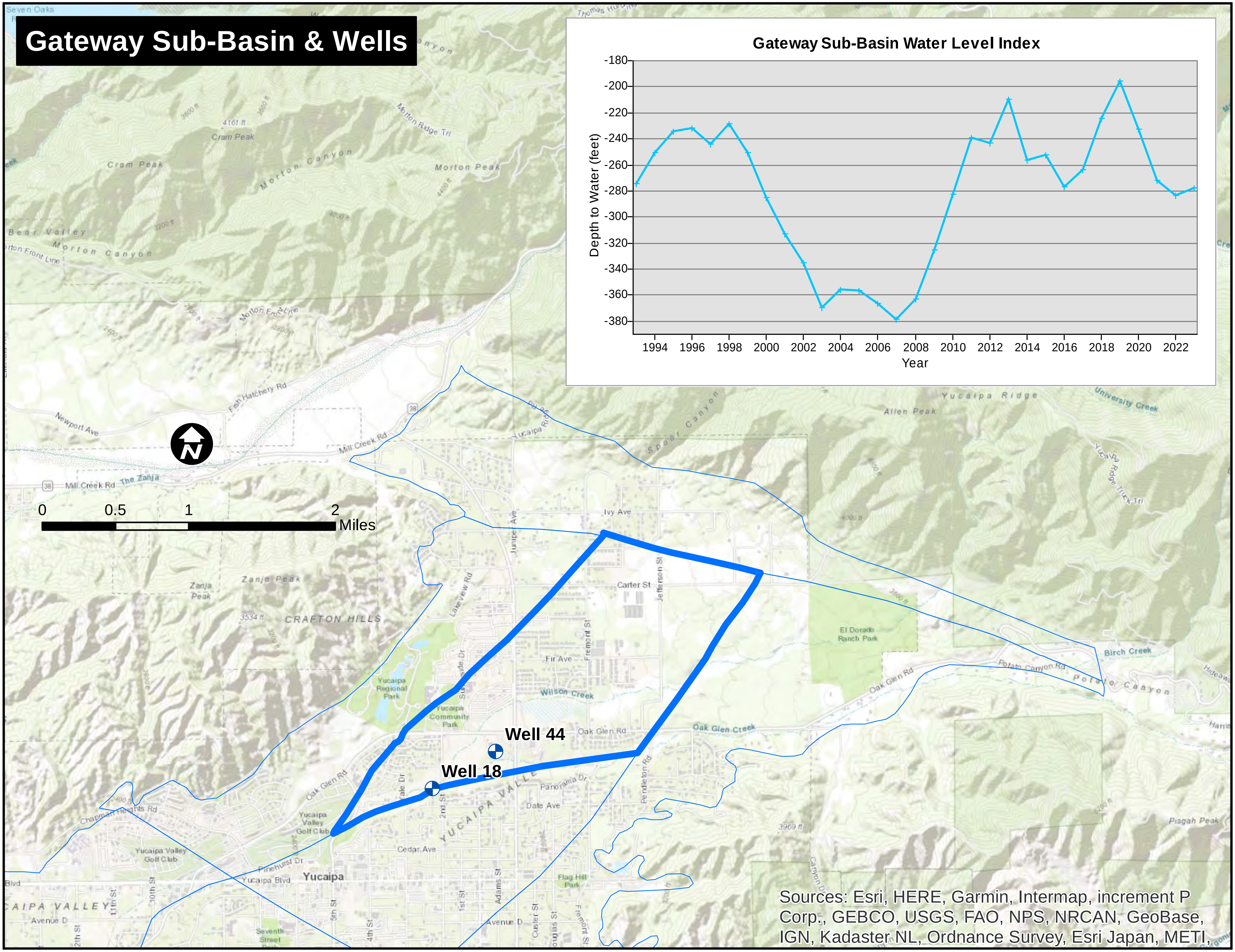
Annual Change in Storage for the Gateway Sub-Basin



San Bernardino Valley Municipal Water District

Change In Storage for the Gateway Sub-Basin 1993 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1993	0		
1994	24	36	36
1995	16	4,009	4,045
1996	2	284	4,329
1997	-12	-1,361	2,968
1998	16	1,642	4,610
1999	-22	-2,139	2,471
2000	-34	-3,331	-860
2001	-28	-2,906	-3,766
2002	-22	-2,156	-5,922
2003	-35	-3,209	-9,131
2004	14	1,673	-7,458
2005	-1	-514	-7,972
2006	-9	-833	-8,805
2007	-12	-1,342	-10,147
2008	16	1,712	-8,435
2009	37	4,089	-4,346
2010	42	4,254	-92
2011	44	4,041	3,949
2012	-4	-237	3,712
2013	34	3,179	6,891
2014	-47	-4,692	2,199
2015	4	136	2,335
2016	-25	-3,492	-1,157
2017	13	1,827	670
2018	39	4,393	5,063
2019	29	3,093	8,156
2020	-37	-3,936	4,220
2021	-39	-3,859	361
2022	-12	-1,037	-676
2023	6	239	-437



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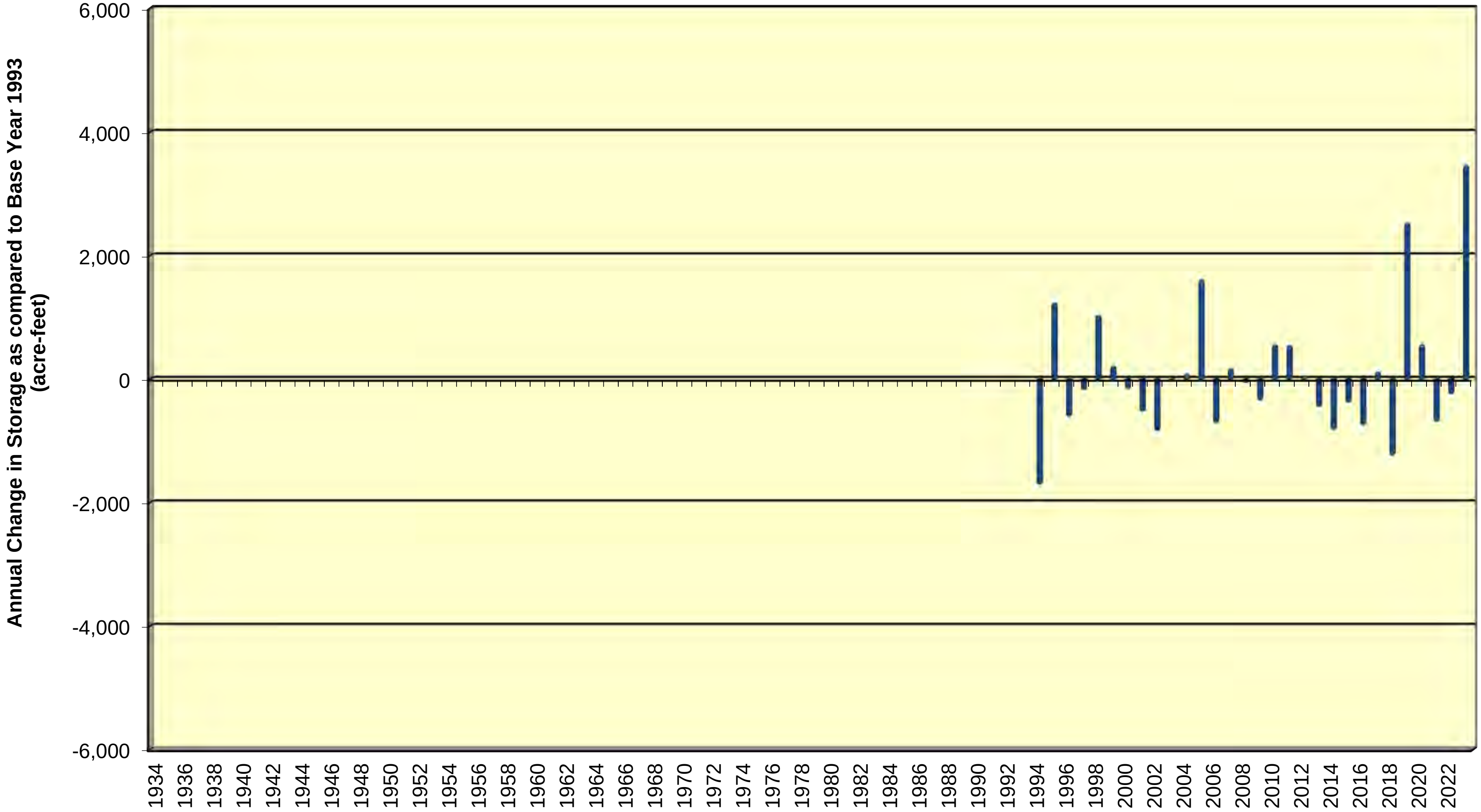
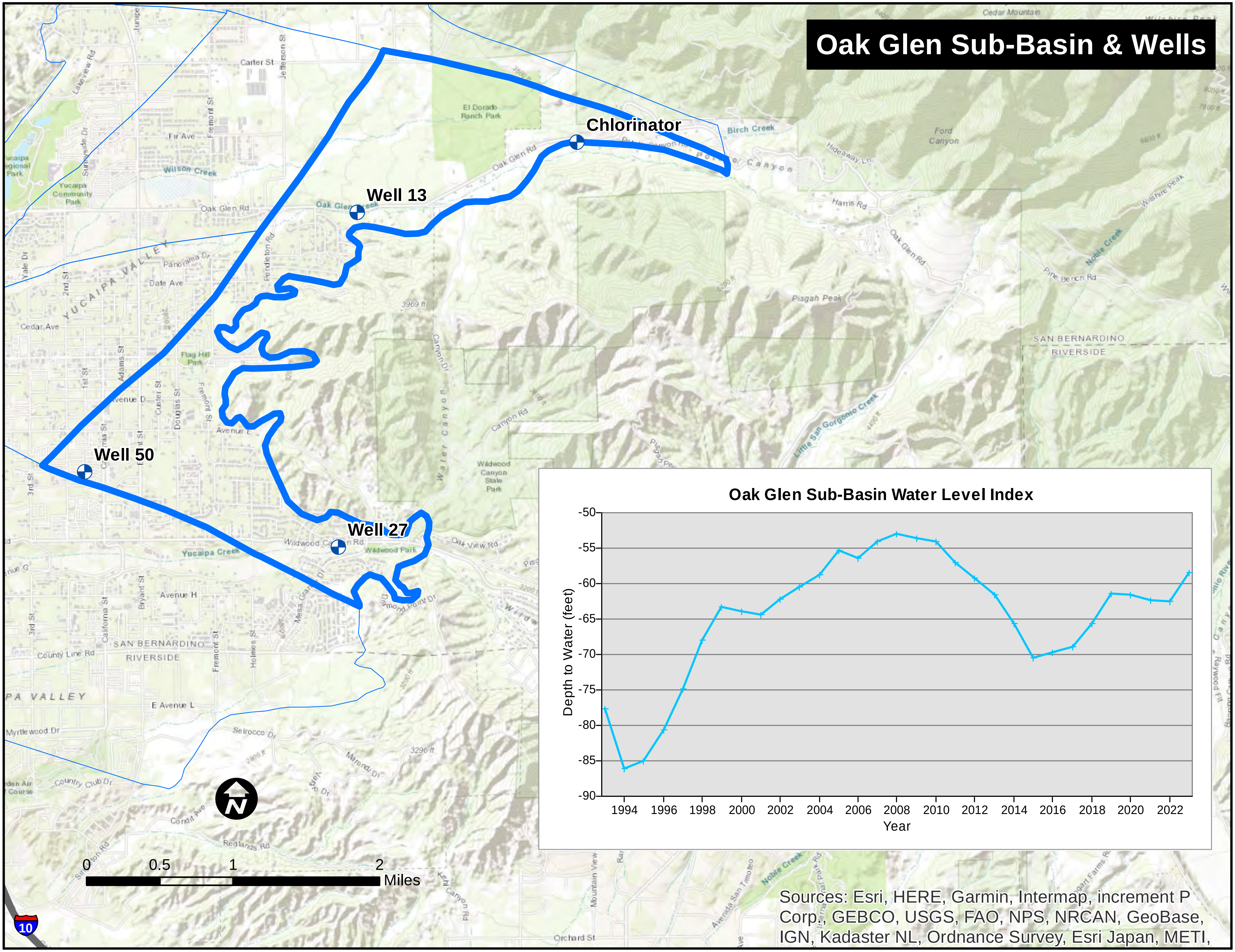
Annual Change in Storage for the Oak Glen Sub-Basin



San Bernardino Valley Municipal Water District
Change In Storage for the Oak Glen Sub-Basin 1993 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1993	0		
1994	-11	-1,713	-1,713
1995	8	1,230	-483
1996	-4	-609	-1,092
1997	-1	-184	-1,276
1998	7	1,033	-243
1999	2	211	-32
2000	-1	-165	-197
2001	-4	-531	-728
2002	-6	-843	-1,571
2003	0	0	-1,571
2004	1	83	-1,488
2005	10	1,612	124
2006	-5	-715	-591
2007	1	171	-420
2008	0	-65	-485
2009	-3	-349	-834
2010	3	558	-276
2011	4	544	268
2012	-1	42	310
2013	-2	-454	-144
2014	-5	-827	-971
2015	-3	-383	-1,354
2016	-5	-751	-2,105
2017	2	116	-1,989
2018	-1	-1,240	-3,229
2019	9	2,528	-701
2020	2	558	-143
2021	-3	-694	-837
2022	-2	-244	-1,081
2023	32	4,258	3,177



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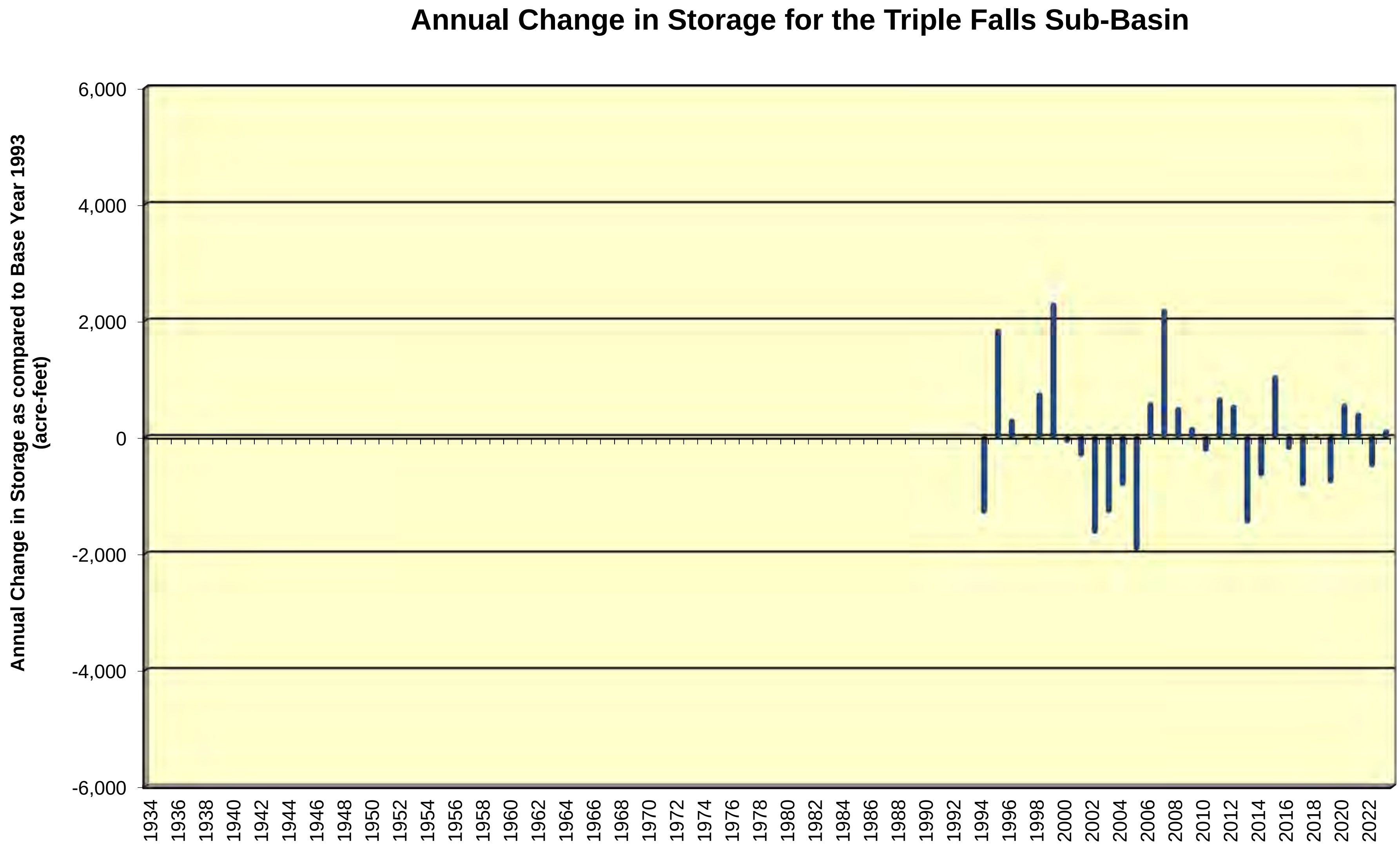
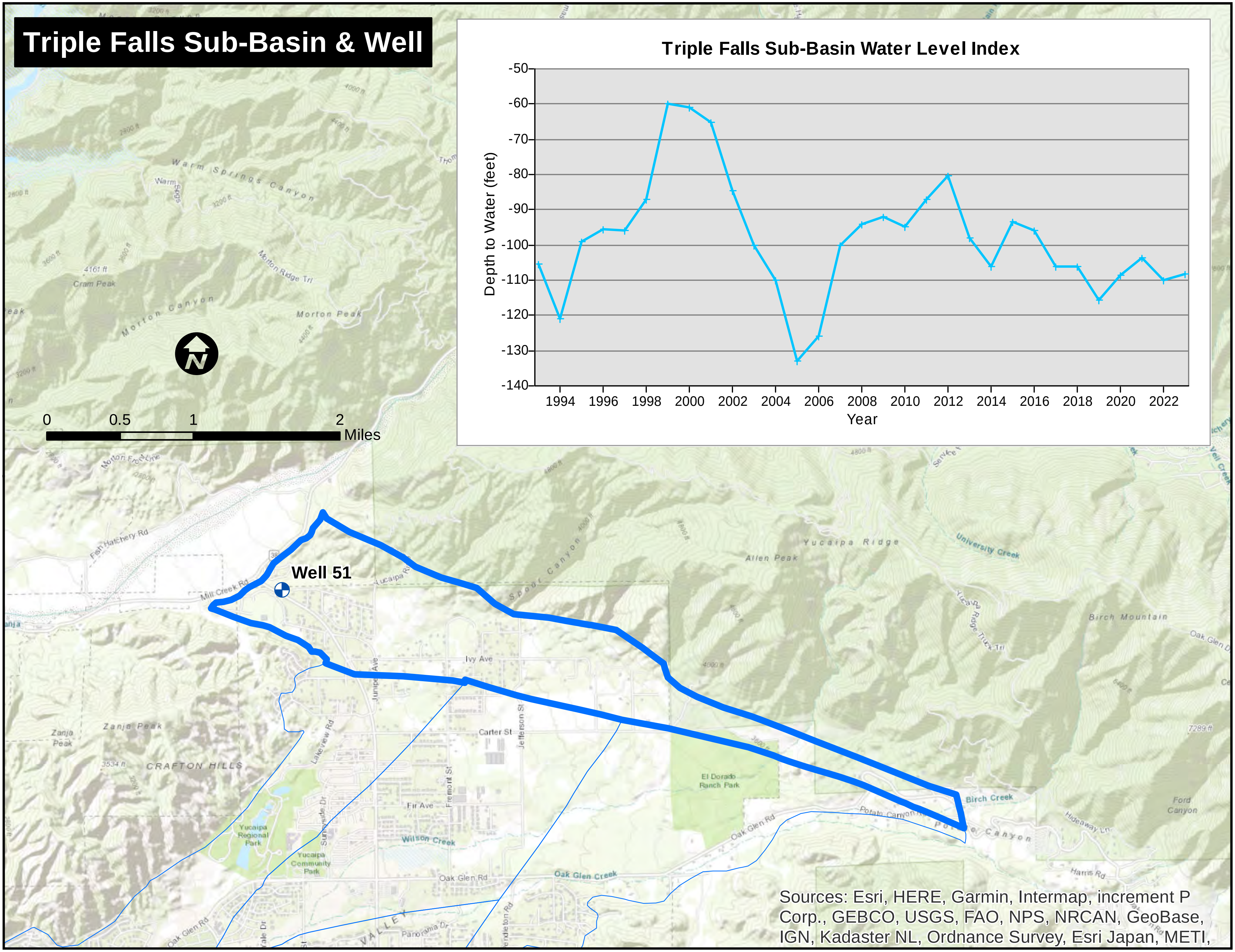


Annual Change in Storage for the Triple Falls Sub-Basin
Annual Change in Storage as compared to Base Year 1993 (acre-feet)
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

San Bernardino Valley Municipal Water District

Change In Storage for the Triple Falls Sub-Basin 1993 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1993	0		
1994	-16	-1,313	-1,313
1995	22	1,855	542
1996	4	313	855
1997	-1	-51	804
1998	9	763	1,567
1999	27	2,305	3,872
2000	-1	-102	3,770
2001	-4	-339	3,431
2002	-20	-1,661	1,770
2003	-15	-1,304	466
2004	-10	-847	-381
2005	-23	-1,949	-2,330
2006	7	594	-1,736
2007	26	2,202	466
2008	6	508	974
2009	2	169	1,143
2010	-3	-254	889
2011	8	678	1,567
2012	7	551	2,118
2013	-18	-1,483	635
2014	-8	-677	-42
2015	13	1,059	1,017
2016	-3	-220	797
2017	-10	-848	-51
2018	0	-3	-54
2019	-9	-792	-846
2020	7	575	-271
2021	5	415	144
2022	-6	-516	-372
2023	2	127	-245



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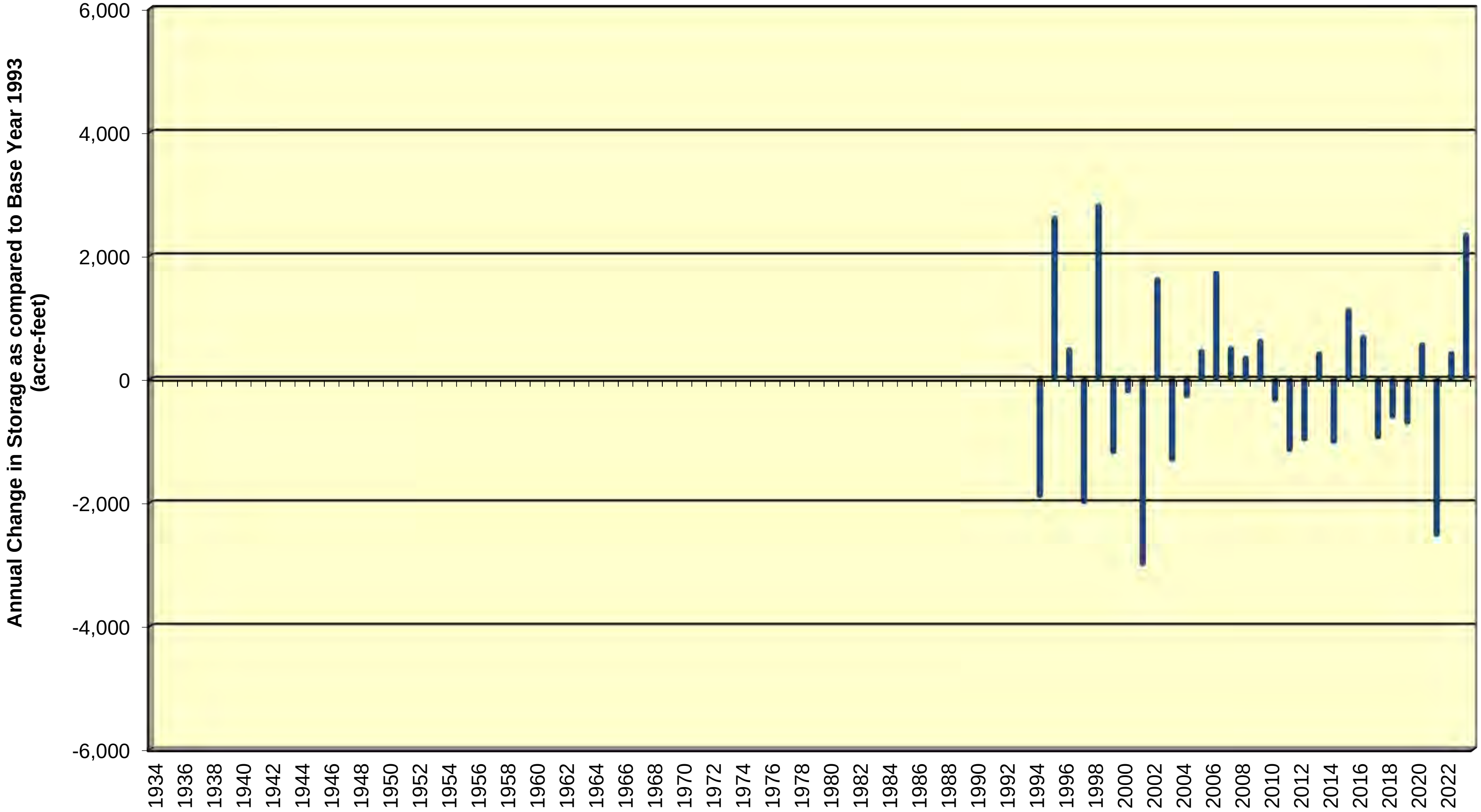
Annual Change in Storage for the Western Heights Sub-Basin

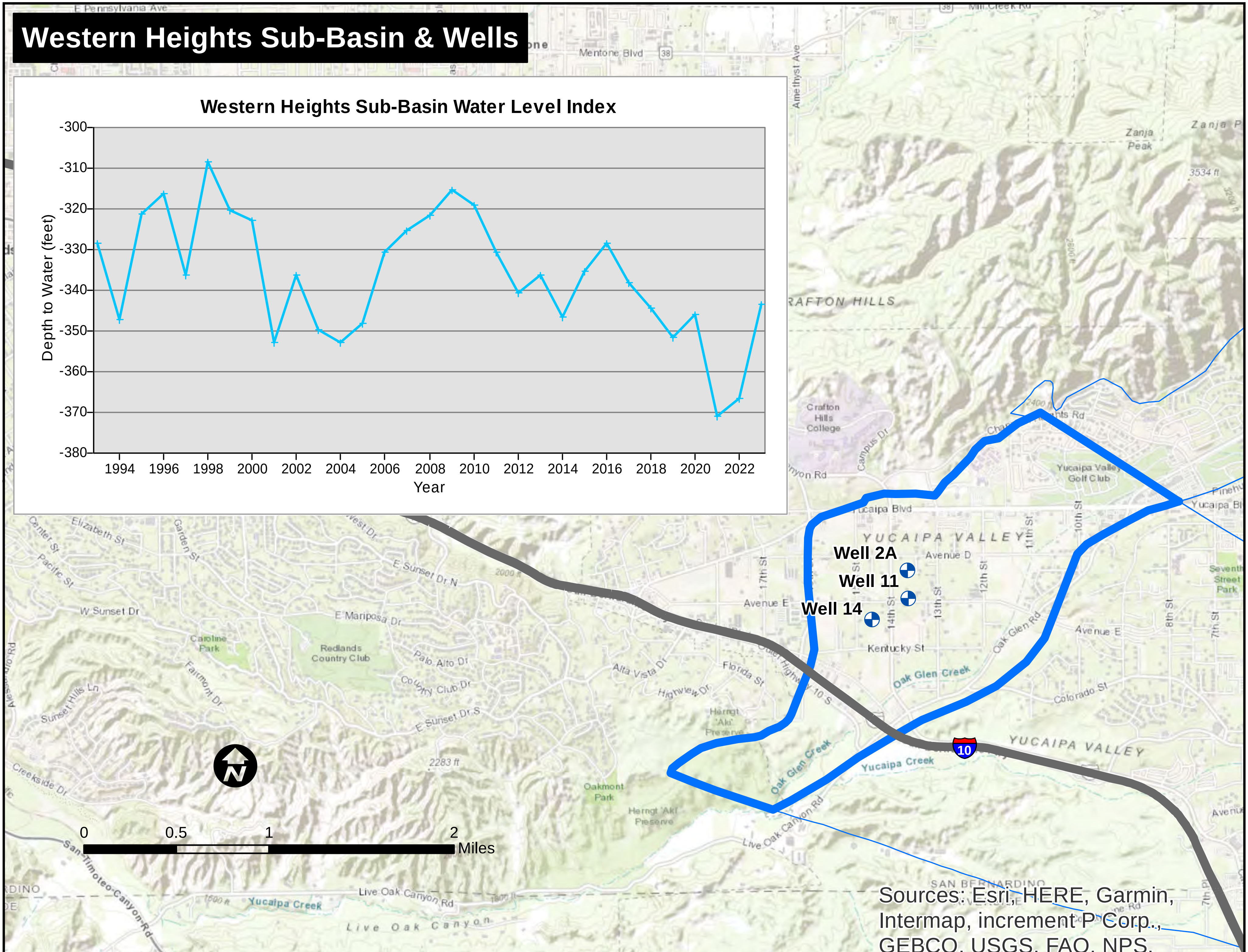


San Bernardino Valley Municipal Water District

Change In Storage for the Western Heights Sub-Basin 1993 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1993	0		
1994	-19	-1,929	-1,929
1995	26	2,640	711
1996	5	507	1,218
1997	-20	-2,030	-812
1998	28	2,842	2,030
1999	-12	-1,218	812
2000	-2	-233	579
2001	-30	-3,035	-2,456
2002	16	1,644	-812
2003	-13	-1,343	-2,155
2004	-3	-307	-2,462
2005	5	480	-1,982
2006	17	1,746	-236
2007	5	537	301
2008	4	371	672
2009	6	644	1,316
2010	-4	-375	941
2011	-12	-1,189	-248
2012	-10	-1,016	-1,264
2013	4	444	-820
2014	-10	-1,054	-1,874
2015	11	1,149	-725
2016	7	711	-14
2017	-10	-981	-995
2018	-6	-644	-1,639
2019	-7	-746	-2,385
2020	6	589	-1,796
2021	-25	-2,557	-4,353
2022	4	450	-3,903
2023	24	2,367	-1,536

Western Heights Sub-Basin & Wells



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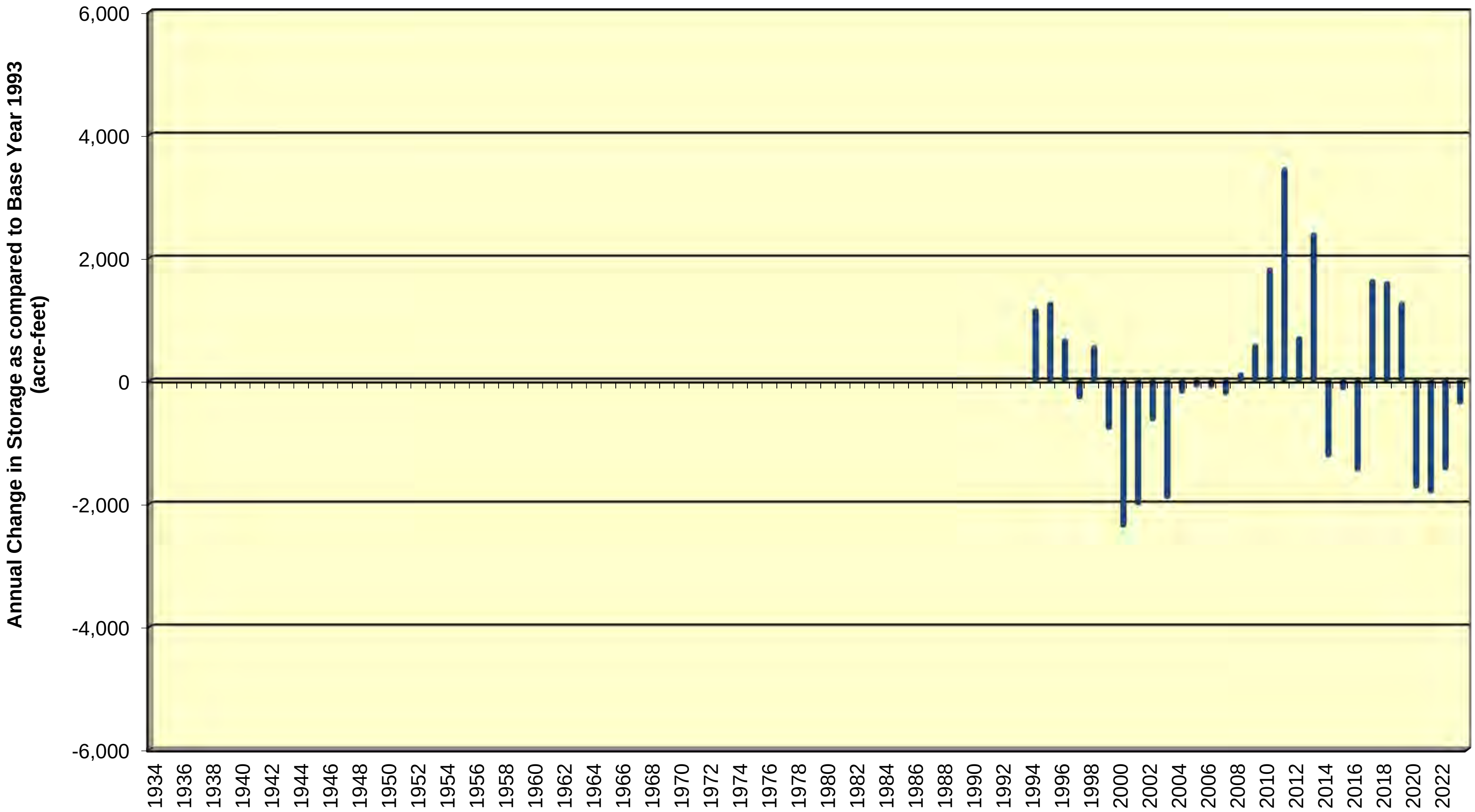
Annual Change in Storage for the Wilson Creek Sub-Basin

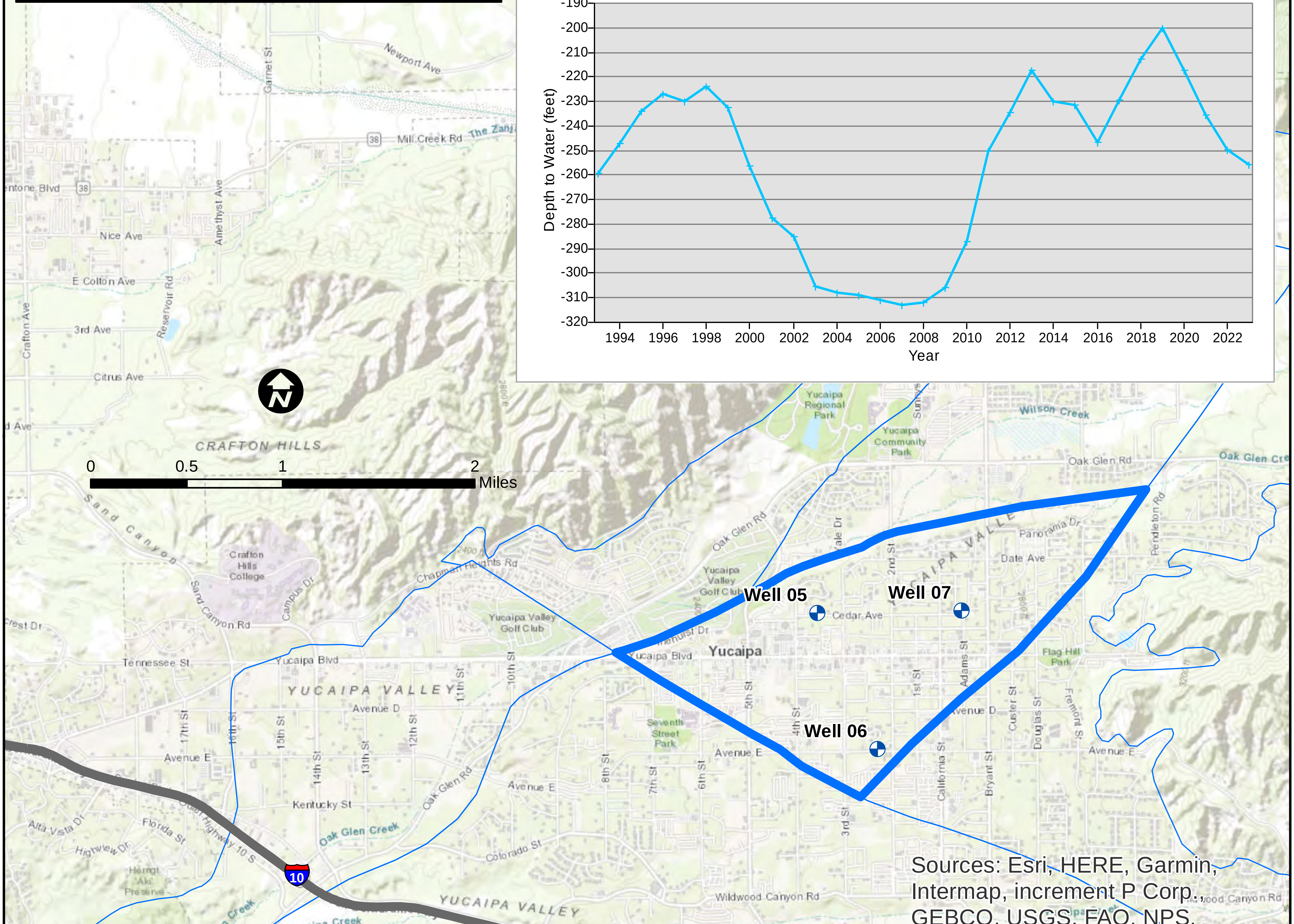


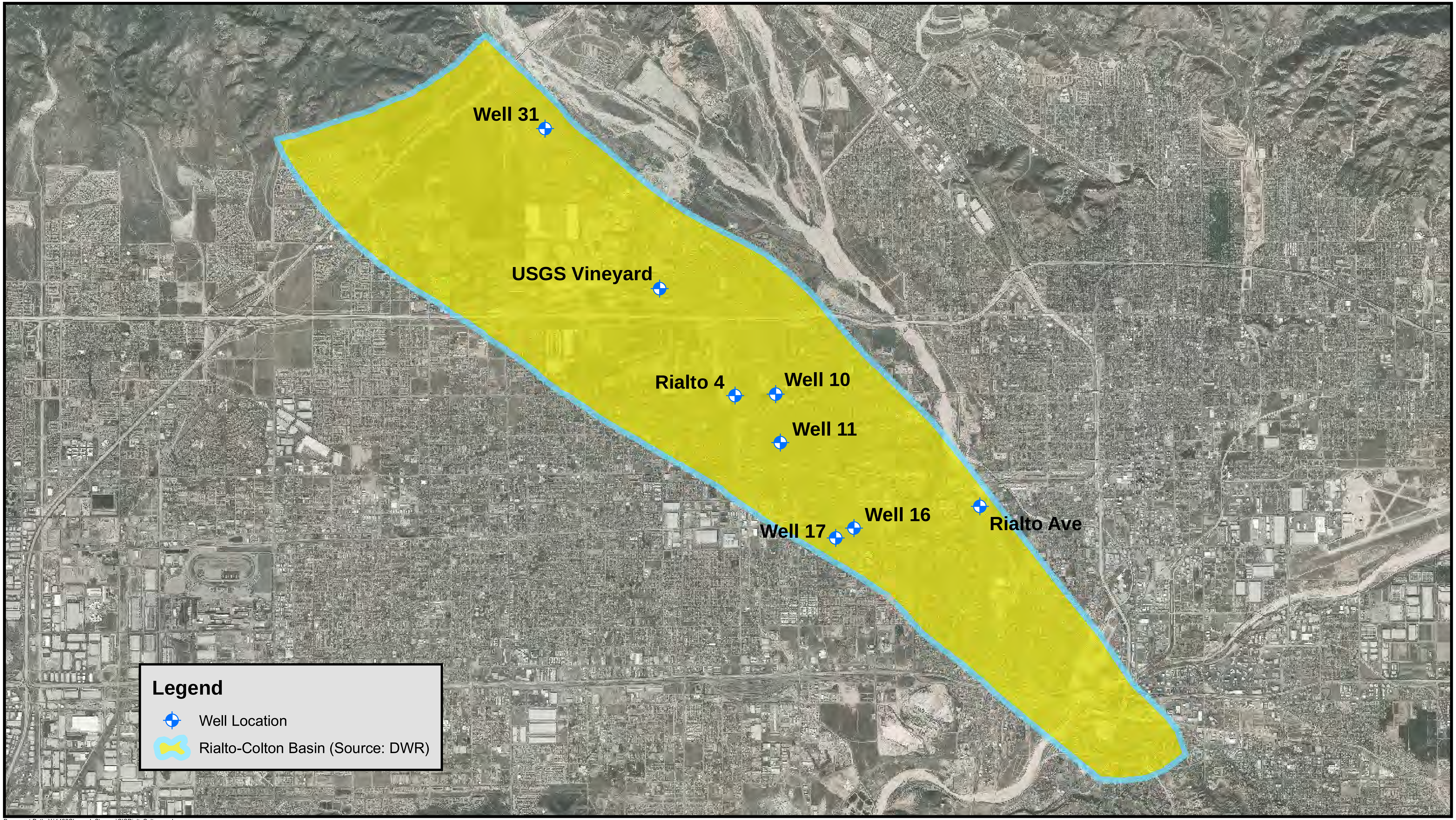
San Bernardino Valley Municipal Water District

Change In Storage for the Wilson Creek Sub-Basin 1993 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1993	0		
1994	12	1,179	1,179
1995	13	1,282	2,461
1996	7	684	3,145
1997	-3	-307	2,838
1998	6	578	3,416
1999	-9	-804	2,612
2000	-23	-2,390	222
2001	-21	-2,027	-1,805
2002	-8	-658	-2,463
2003	-20	-1,928	-4,391
2004	-3	-211	-4,602
2005	-1	-109	-4,711
2006	-2	-129	-4,840
2007	-2	-239	-5,079
2008	1	135	-4,944
2009	6	603	-4,341
2010	19	1,839	-2,502
2011	37	3,465	963
2012	16	722	1,685
2013	17	2,406	4,091
2014	-13	-1,249	2,842
2015	-2	-156	2,686
2016	-15	-1,472	1,214
2017	17	1,645	2,859
2018	17	1,615	4,474
2019	12	1,285	5,759
2020	-17	-1,757	4,002
2021	-18	-1,833	2,169
2022	-14	-1,459	710
2023	-6	-392	318

Wilson Creek Sub-Basin & Wells





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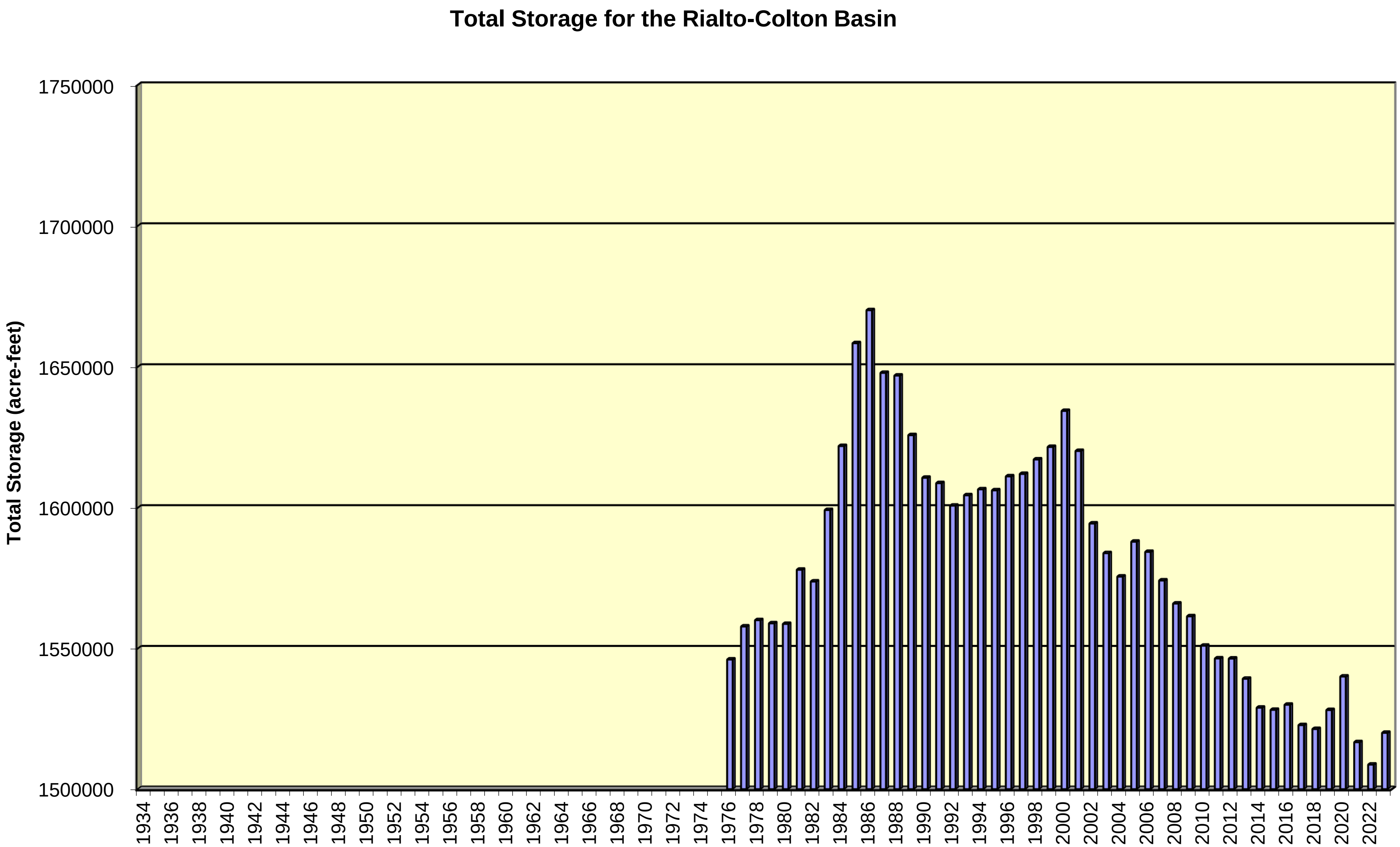
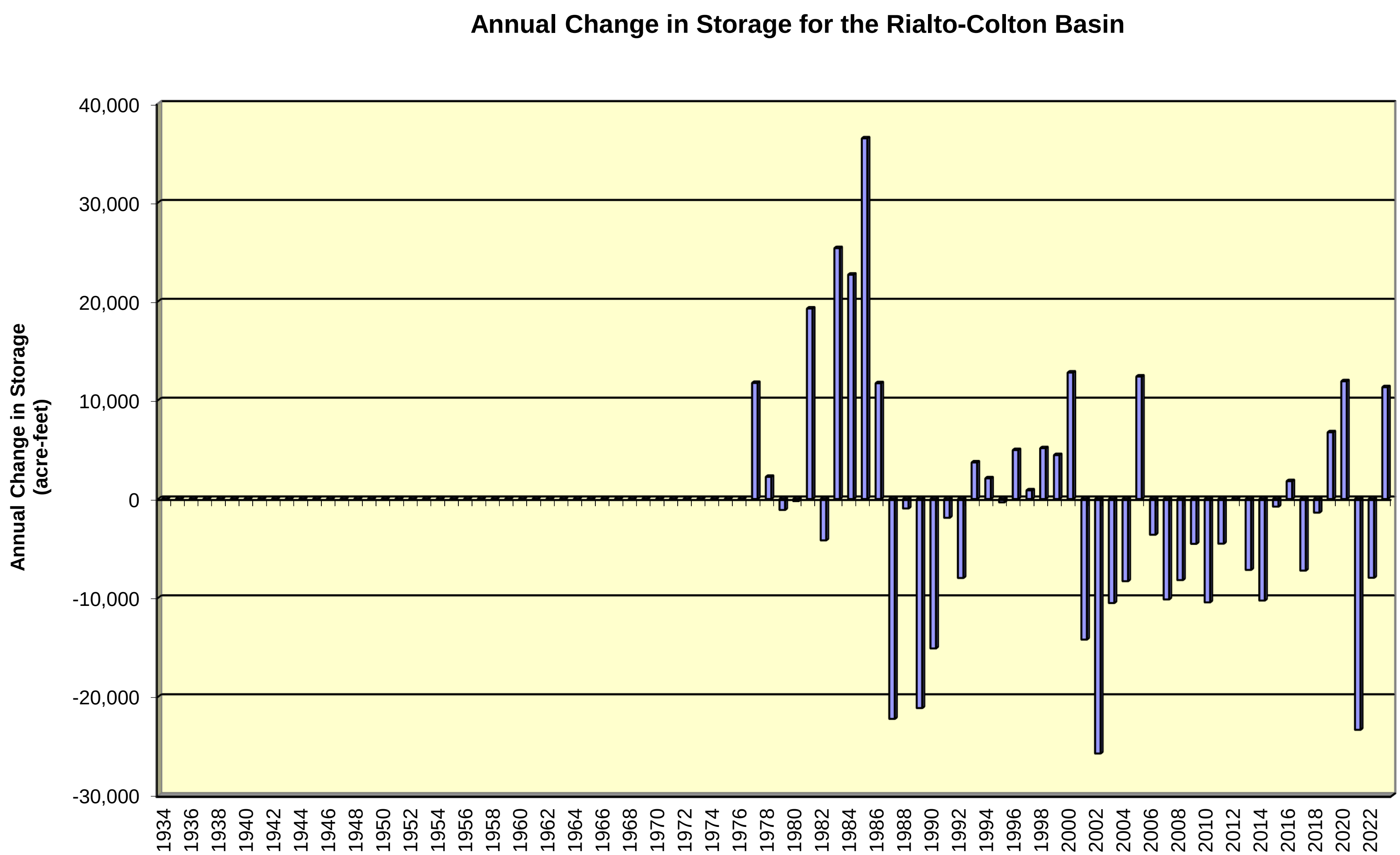
SAN BERNARDINO VALLEY | A REGIONAL WATER AGENCY SINCE 1954

RIALTO-COLTON BASIN AND WELL LOCATIONS

0 0.5 1 2 3 4 Miles



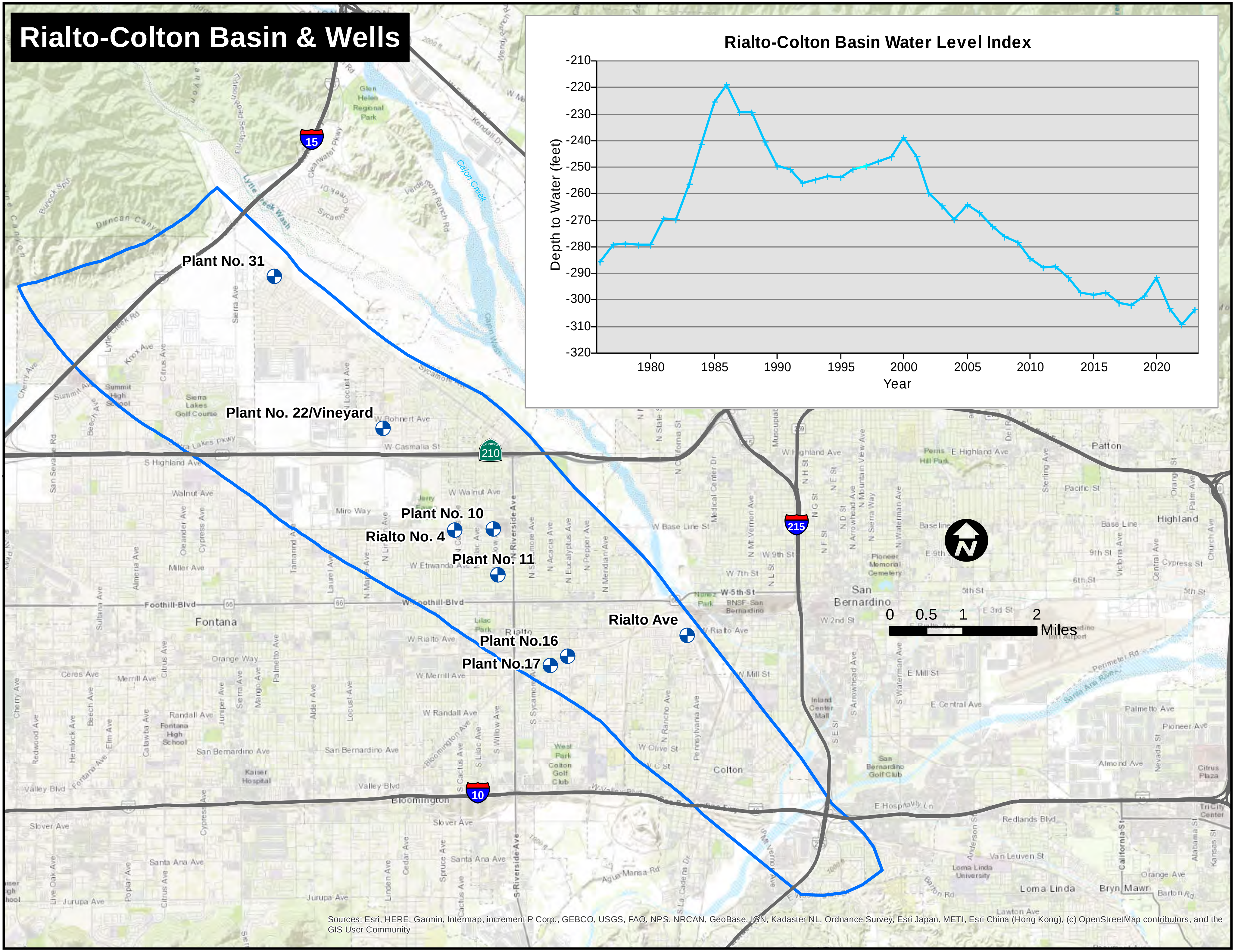
Total Storage for the Rialto-Colton Basin
Total Storage (acre-feet)
1750000
1700000
1650000
1600000
1550000
1500000
1934 1936 1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022



Annual Change in Storage for the Rialto-Colton Basin
Annual Change in Storage (acre-feet)
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

San Bernardino Valley Municipal Water District
Change In Storage for the Rialto-Colton Basin 1976 - Present

(1) Year	(2) Basin Index (ft.)	(3) Annual Change in Groundwater Storage (acre-feet)	(4) Cummulative Change in Groundwater Storage (acre-feet)
1976			-58,354
1977	7	11,742	-46,612
1978	0	2,239	-44,373
1979	0	-1,111	-45,484
1980	0	-218	-45,702
1981	10	19,268	-26,434
1982	0	-4,188	-30,622
1983	13	25,380	-5,242
1984	15	22,698	17,456
1985	16	36,486	53,942
1986	6	11,707	65,649
1987	-10	-22,232	43,417
1988	0	-962	42,455
1989	-11	-21,142	21,313
1990	-9	-15,111	6,202
1991	-2	-1,905	4,297
1992	-5	-7,992	-3,695
1993	1	3,695	0
1994	1	2,087	2,087
1995	-1	-339	1,748
1996	3	4,948	6,696
1997	1	868	7,564
1998	2	5,137	12,701
1999	2	4,439	17,140
2000	8	12,786	29,926
2001	-8	-14,217	15,709
2002	-14	-25,730	-10,021
2003	-5	-10,524	-20,545
2004	-5	-8,315	-28,860
2005	6	12,383	-16,477
2006	-3	-3,618	-20,095
2007	-5	-10,157	-30,252
2008	-4	-8,206	-38,458
2009	-2	-4,537	-42,995
2010	-6	-10,454	-53,449
2011	-3	-4,521	-57,970
2012	1	-48	-58,018
2013	-4	-7,173	-65,191
2014	-6	-10,274	-75,465
2015	-1	-774	-76,239
2016	1	1,803	-74,436
2017	-4	-7,245	-81,681
2018	-1	-1,382	-83,063
2019	3	6,748	-76,315
2020	7	11,908	-64,407
2021	-12	-23,338	-87,745
2022	-6	-7,970	-95,715
2023	5	11,307	-84,408



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APPENDIX: SBVMWD CHANGE IN STORAGE METHODOLOGY

List of Figures

List of Tables

A. INTRODUCTION

The San Bernardino Valley Municipal Water District was incorporated on February 17, 1954. The District is one of 29 contractors of the California State Water Project (SWP) and has the fifth largest annual entitlement to SWP water at 102,600 acre-feet. The District takes delivery of SWP water through the Devil Canyon Powerhouse on the East Branch of the California State Aqueduct.

The District serves a population of about 600,000 people within a 328 square mile area in the east San Bernardino Valley. Currently, there are over 33 miles of 12-inch to 78-inch diameter pipelines in the District's delivery system. The system includes 28 service connections to deliver both native and SWP water for direct delivery or groundwater recharge within the District's boundary. Groundwater recharge is conducted to lessen the impact of increasing well production from the various groundwater basins within the District's boundary and to help the District meet certain legal obligations.

One of the legal obligations imposed on the District is the responsibility for maintaining the "safe yield" of the San Bernardino Basin Area. The safe yield is a theoretical maximum amount of water that may be removed from the basin on an annual basis without degrading the usable water supply. For the San Bernardino Basin Area, this amount has been set by the Western-San Bernardino Watermaster at 232,100 acre-feet/yr (Watermaster, pg. 24).

One method of accounting for groundwater that enters or leaves a basin area is to estimate the change in groundwater volume, or storage, using a network of observation wells. The change in groundwater elevation for these observation wells along with the given soil characteristics can be used to approximate the change in groundwater storage.

B. THE SBVMWD CHANGE IN STORAGE MODEL

B.1 Background

The San Bernardino Valley Municipal Water District (SBVMWD) has been calculating the change in groundwater storage for the San Bernardino Basin area since 1970. The first calculation was completed for the years 1934 – 1960 by the State of California Department of Water Resources (DWR) and the results were summarized in Bulletin 104-5, Meeting Water Demands in the Bunker Hill-San Timoteo Area, Geology, Hydrology, and Operation-Economics Studies, Text and Plates (Olson, pp. 90 – 92). The DWR change in storage values were calculated using the Specific Yield Method (Olson, pp. 85 – 98) and a mathematical model developed by TRW, Incorporated, Redondo Beach, California (TRW). In 1980, SBVMWD updated the change in storage calculation to include the years 1961 – 1980 (Van Gelder). In the early 1990's, SBVMWD created a new change in storage model using GRID software developed by Environmental Systems Research Institute (ESRI), Redlands, California. GRID was selected because it allowed a finer model resolution and because it was able to interpolate surfaces or create contour maps from a spatial distribution of data points. The differences between the two models are summarized in Table B.1.1.

Table B.1.1. Differences between DWR model and SBVMWD Model.

Item	DWR Model	SBVMWD Model
Method of Analysis	Specific Yield Method	Specific Yield Method
Sub-basin boundaries	DWR Bulletin No. 104-5	DWR Bulletin No. 104-5
Wells (quantity)	75	See main report
Water Levels	Constant across "nodes"	Interpolated from given data
Specific Yield	DWR Bulletin No. 45	DWR Bulletin No. 45
Computer Software	FORTRAN IV	ESRI GRID® Software
Model resolution (cell size)	75 "nodes" (cells): Smallest cell= 589 acres Largest cell = 1,778 acres	335,758 cells: Uniform cell size: 100 ft. square (.23 acre)

Although the two models use different computer programs and a different quantity of wells (many of the wells used in the original study have since been abandoned) to calculate the change in groundwater storage, the results obtained from the two models are similar (see Figure B.1.1). The difference in the results can be mostly attributed to the improved capabilities of the SBVMWD model.

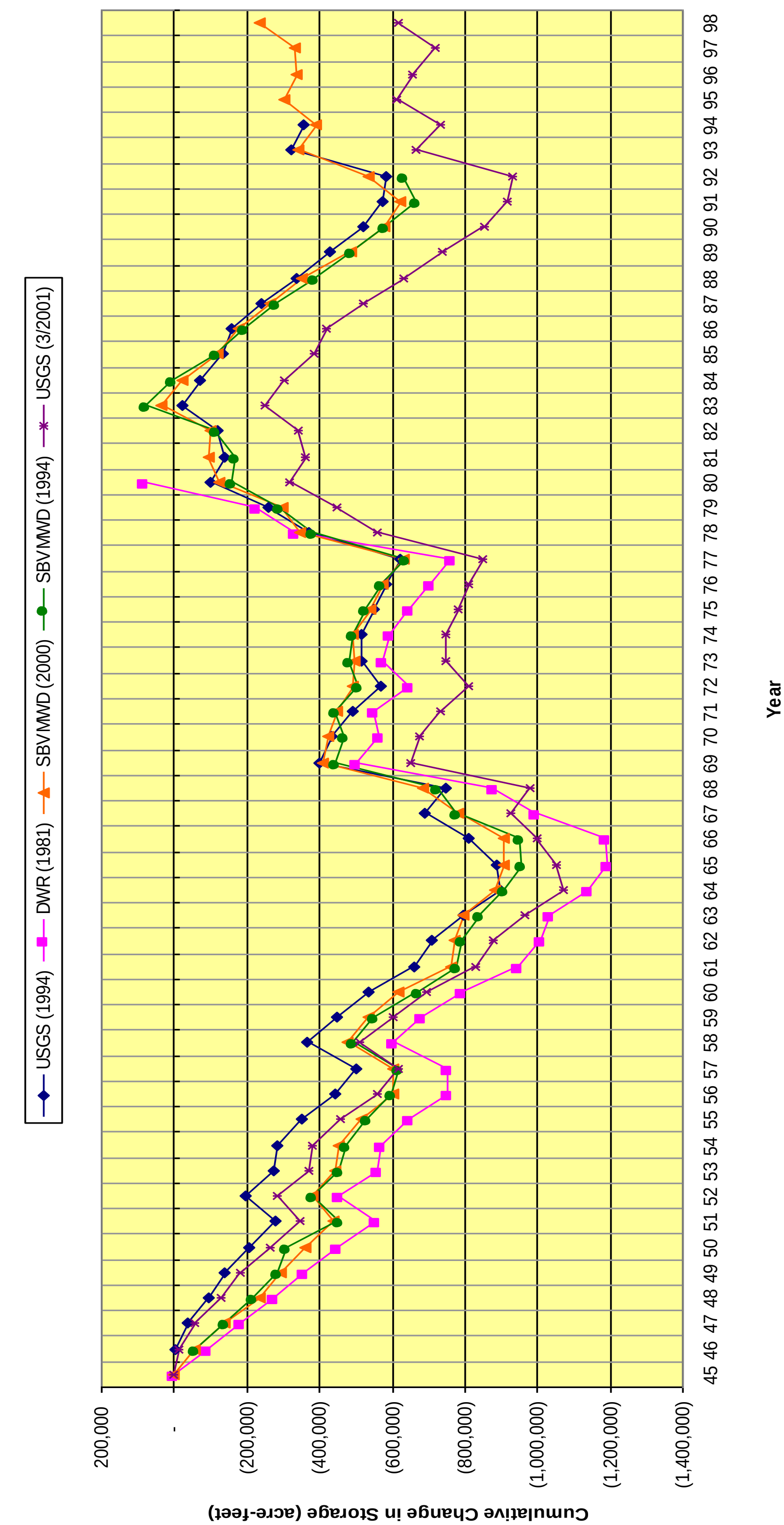

Figure B.1.1. Comparison of DWR FORTRAN Model, USGS MODFLOW Model and SBVMWD GRID Model Results

Geologists divided the DWR model for the San Bernardino Basin Area into 75 polygons (see Table B.1.2), or "nodes", using the Theissen method of polygon construction. The nodes were drawn to surround an area where the soil characteristics, specific yield, and groundwater surface could be assumed constant. The change in storage was computed for each individual node using the Specific Yield Method. The sum of the change in storage for all of the nodes was the change in storage for the San Bernardino Basin area.

Table B.1.2. Quantity of Theissen Polygons ("Nodes") for the Department of Water Resources Bulletin 104-5.

Area No.	Designation	No. of Nodes
1	Cajon	8
2	Devil Canyon	4
3	Lytle Creek	10
4	Pressure Zone	16
5	City Creek	19
6	Redlands	5
7	Mill Creek	8
8	Reservoir	3
9	Divide	2
	TOTALS	**75**

The surface area of the smallest node was 589 acres and the surface area of the largest node was 1,778 acres. The large node, or model cell size, provides one of the largest differences between the SBVMWD model and the DWR model. The SBVMWD model has been divided into a uniform, square cell size of 100 feet per side (0.23 acre). This smaller cell size of the SBVMWD model allows values to be more accurately assigned to each model cell based upon the given contour maps instead of assuming constant values across large areas like the DWR model. For example, each model uses storage coefficients from DWR's Bulletin No. 45 (Eckis). The specific yield data from Bulletin No. 45 is presented on a contour map (Eckis, Plate E). The SBVMWD model is able to convert this contour map into a grid which contains a unique specific yield value for each of its 335,758 model cells. In contrast, the DWR model must assume a single, constant specific yield across each of its 75 larger nodes. The larger number of model cells in the SBVMWD model allows it to use a more accurate representation of the specific yield contour map in the change in groundwater storage calculation.

In addition to providing a more accurate representation of the specific yield contour map, the SBVMWD model also provides a more accurate representation of the water levels within each sub-basin. The DWR model assumes a constant water level across each of its 75 nodes. This constant groundwater surface across each node causes the DWR model to produce a groundwater surface with a “stair step” appearance. The finer resolution and ability of the SBVMWD model to interpolate a groundwater surface within each sub-basin from the given well data. This produces a water level surface that is more representative of the true surface than the “stair step” surface generated by the DWR model.

In conclusion, the DWR model and SBVMWD model produce similar results. The difference between the two models is most likely due to the finer model resolution and the interpolation capabilities of the newer SBVMWD model.

In the Yucaipa basin there was little water level data before 1993. To provide some consistency between the SBBA and Yucaipa calculations, a base year was chosen for the Yucaipa calculation that is equivalent to the SBBA base year. The change in storage results for the SBBA (figure 2) reveal that 1993 is essentially the same as 1934 the SBBA base year. Therefore, since data was not available in the Yucaipa basin back to 1934, the equivalent year 1993 was selected as the base year for the Yucaipa calculation. The results of the Yucaipa model are plotted on figures 6. Figure 6 provides the Yucaipa results on a different scale. The beginning trend of the Yucaipa basin CCIS results is similar to the SBBA which provides confidence in the results.

B.2 Method of Analysis

The San Bernardino Valley Municipal Water District (SBVMWD) Change in Storage (CIS) model calculates the cumulative change in storage (CCIS) using a spatial distribution of available wells and the Specific Yield Method, as put forth in the Department of Water Resources' Bulletin 104-5 (Olson, pg. 85). This method calculates the change in storage based upon an adaptation of the simple mathematical equation for calculating volume, (length * width * height).

$$\mathbf{CCIS = (h_{present\ year} - h_{base\ year})SA} \qquad \textbf{(Equation B.2.1)}$$

where,

CCIS = Cumulative change in storage, acre-feet

$(h_{present\ year} - h_{base\ year})$ = Change in saturated thickness, ft.

$h_{present\ year}$ = Depth to groundwater, present year

$h_{base\ year}$ = Depth to groundwater, base year (1934)

S = Specific Yield, dimensionless

A = Area, acres

In Equation B.2.1, "length * width" is given by the surface area, A, of the basin and "height" is given by, $(h_{present\ year} - h_{base\ year})$, the change in saturated thickness. The specific yield simply adjusts the volume calculation to account for the fact that only the pore space in the soil is available for water storage. Figure B.2.1 illustrates the Specific Yield Method.

Given the cumulative change in storage values for a series of years, these cumulative values can be used to calculate the annual change in groundwater storage. The annual change in groundwater storage is simply the difference between a year's cumulative change in storage and the previous year's cumulative change in storage (Equation B.2.2).

$$\mathbf{ACIS_{present\ year} = CCIS_{present\ year} - CCIS_{previous\ year}} \qquad \textbf{(Equation B.2.2)}$$

where,

ACIS = Annual Change in Storage for the present year, acre-feet

$CCIS_{present\ year}$ = Cumulative Change in Storage for the present year, acre-feet

$CCIS_{previous\ year}$ = Cumulative Change in Storage for the previous year, acre-feet

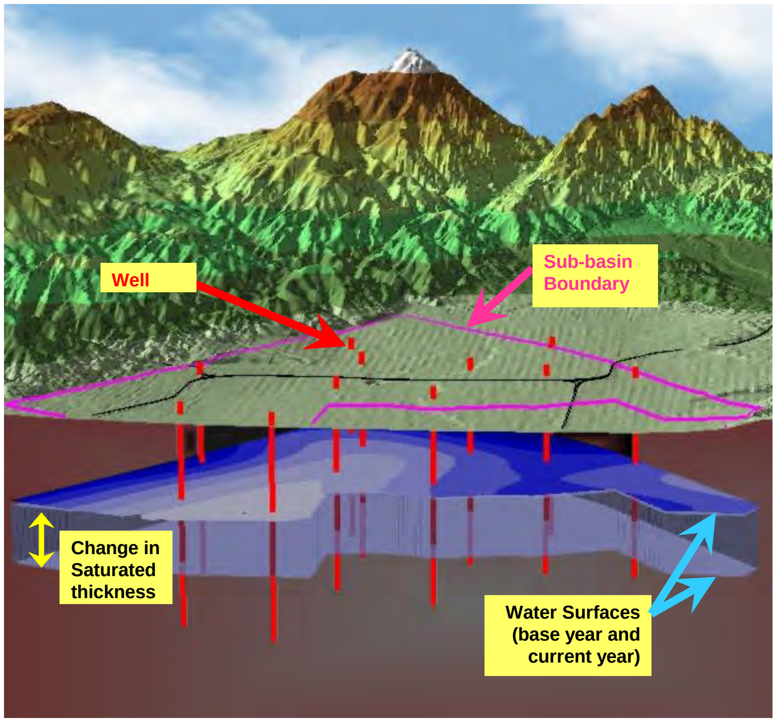

Figure B.2.1. Illustration of the Specific Yield Method for calculating the change in groundwater storage (Equation B.2.1).

B.3 Technical Approach

Each of the variables in the cumulative change in storage calculation (Equation B.2.1) varies depending upon the geographic position within the Basin Area and can be spatially represented by a contour map. The SBVMWD Change in Storage model was written in Environmental Systems Research Institute's (ESRI) GRID software because it allows contour maps to be converted into "grids" and used directly in the simple mathematical equation for the cumulative change in storage.

When a contour map is converted into a grid, the software essentially breaks the contour map down into smaller, user-defined pieces called cells. The GRID software stores a unique value within each grid cell depending upon its geographic location. For example, each cell in the depth to groundwater grid contains a unique value for the depth to groundwater based upon its geographic position in the grid. Figure B.3.1 illustrates the conversion of a contour map into a grid**.** The user has the flexibility to control the cell size. The smaller the cell size, the more representative of the actual contour map. However, there is a trade-off between cell size and processing speed. Since the software performs calculations on each individual grid cell, a finer grid requires more calculations and, therefore, takes longer to process. Thus, the challenge is to select the largest cell size possible without significantly impacting the results. The cell size for the SBVMWD CIS model is 100 feet square.

Once the contour maps have been converted to grids, these grids are used in Equation B.2.1. When the GRID software uses grids in any algebraic equation, the results are stored in a new grid. For example, when two grids are multiplied, the software essentially lays the two grids on top of one another and multiplies the values in each individual grid cell on a cell-by-cell basis. The results are stored in a new grid and are located in the same geographic cell location as the two values used in the calculation. The same logic applies to the cumulative change in storage calculation. The software generates the change in saturated thickness grid by subtracting one water level grid from the other. The change in saturated thickness grid (height) is then multiplied by the specific yield grid (unit less) and then multiplied by the cell size (area) which results in a grid containing the cumulative change in storage in each cell (see Figure B.3.2). The cumulative change in storage for the entire area is simply the summation of the individual cell values.

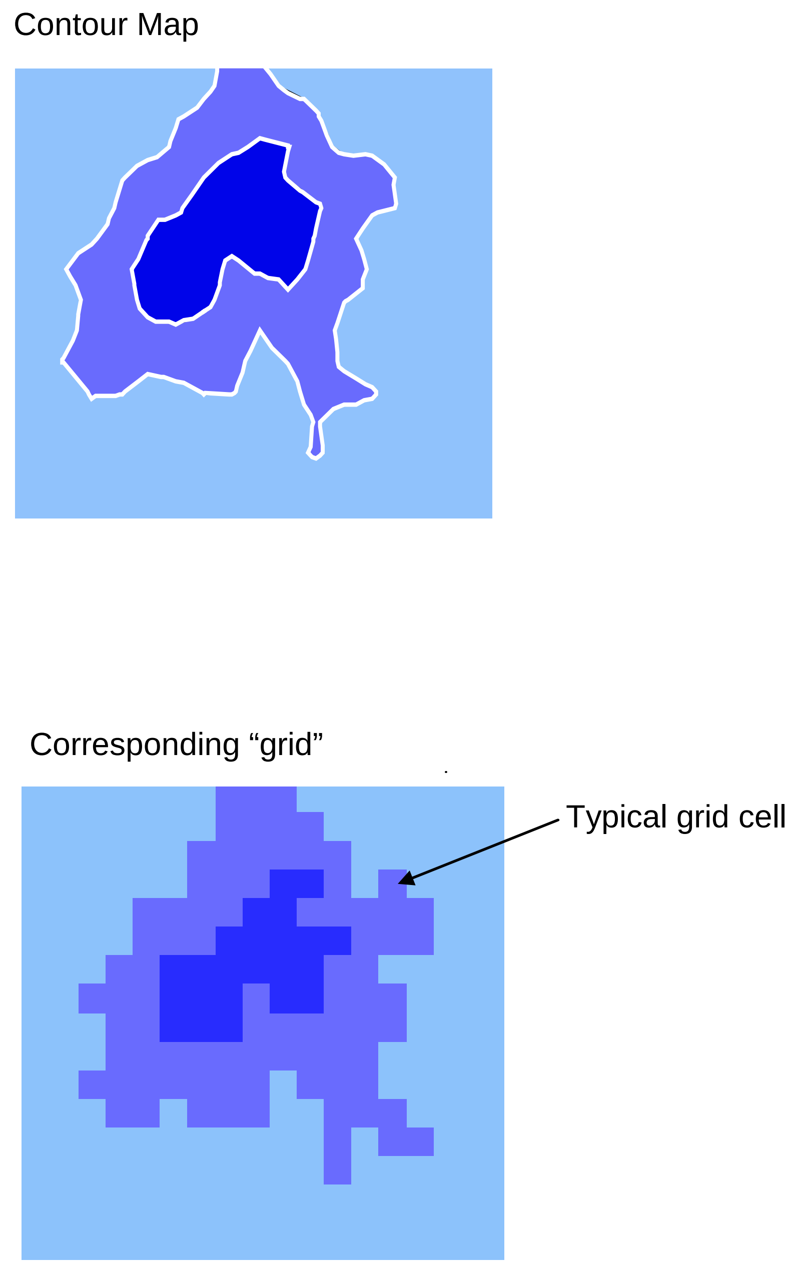

Figure B.3.1. Grid representation of a contour map.

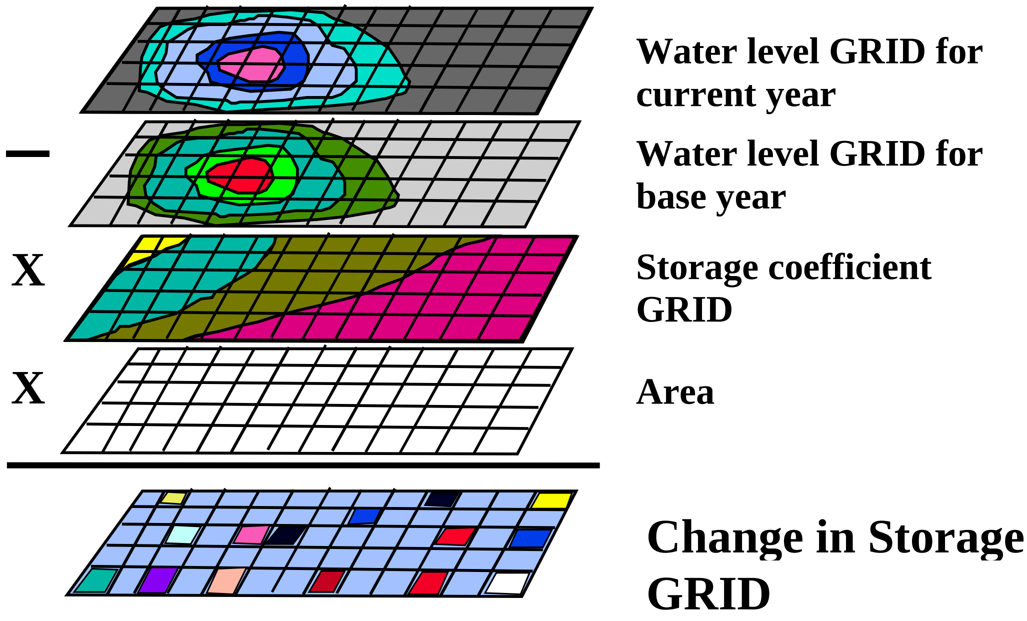

Figure B.3.2. Grid representation of Equation B.2.1.

The SBVMWD model uses the calendar year instead of the water year (October through September). Calendar years were chosen so that the SBVMWD model results would be coincident with the United States Geological Survey groundwater model results which are dependent upon local pumping records kept by calendar year.

B.4 Data

Sub-basin boundaries. For the San Bernardino Basin area, the SBVMWD Change in Storage model used the same sub-basins identified in the Department of Water Resources (DWR) Bulletin 104-5 (DWR, Plate 14) (Basin Groundwater Storage Data). DWR Geologists divided the San Bernardino Basin area into nine sub-basins based upon the known hydrologic barriers (faults) in the valley. In the Yucaipa Basin area, the CIS is calculated across the entire Basin Area. This may be later refined as more is learned about this Basin Area.

Well Locations. In the San Bernardino Basin area, wherever possible, the change in storage model used the same wells used in Bulletin 104-5. However, many of the original wells have since been abandoned and are no longer available for measurement. Whenever one of the original wells was unavailable, an attempt was made to find a "replacement well" in the same vicinity. If a replacement well was not available in the same vicinity, an effort was made to find an additional well within the sub-basin that would improve the spatial distribution of data points. In addition to geographic location, replacement wells were selected based upon the following criteria:

1. *Public ownership*. Because public water agencies tend to be more diligent at data collection, SBVMWD limited its selection of replacement wells to those owned by public water agencies.

2. *Similar hydrograph.* A hydrograph is a plot of the static water level over time. The hydrograph for each replacement well was compared to the hydrograph of the well it was replacing to ensure that the replacement well was measuring water levels from the same aquifer as the original well.

In the Yucaipa Basin area, wells were selected across the Basin Area.

Static depth to water. Like the DWR model, the SBVMWD Change in Storage model uses the highest, annual fall (September - December) static (pump OFF) depth-to-water measurement for each well. The fall season was selected because it follows the summer months during which basin water levels are drawn down to their lowest levels due to the high pumping demands. Fall is also chosen because the cooler fall weather causes pumping rates to dramatically decline and allows the water surface to recover to a level that is more representative of the static water surface.

Static water level data was obtained directly from the well owners and was verified to be static by reviewing the well's hydrograph. Large downward "spikes" in the data were investigated by comparing the depth of the spike to the estimated cone of depression. If the depth of the spike was similar to the cone of depression, that data point was assumed to be dynamic (pump ON) and the data point was eliminated from the analysis. When points were eliminated, or missing from the data, a straight-line interpolation was performed between the known points. Although there is some error associated with assigning points by straight-line interpolation, it was felt that omitting points from the overall interpolation of the water surface would cause a larger error in the analysis.

Before the depth to water data could be used in the Change in Storage model, it had to first be converted into a grid surface. The annual depth to water grids for each sub-basin were interpolated using the highest fall measurements and the Inverse Distance Weighted method of interpolation. Interpolation was intentionally performed separately within each sub-basin to eliminate the potential problem of interpolating across sub-basin boundaries, which are groundwater barriers.

Specific Yields. The specific yield is "the ratio of the volume of water that will drain under the influence of gravity to the volume of saturated rock" (Heath, pp. 28-29). The specific yield values used for the SBBA and Yucaipa Area were obtained from the Department of Water Resources report entitled South Coastal Basin Investigation Geology and Ground Water Storage Capacity of Valley Fill, Bulletin No. 45 (Eckis, Plate E) (see Figure B.4.1).

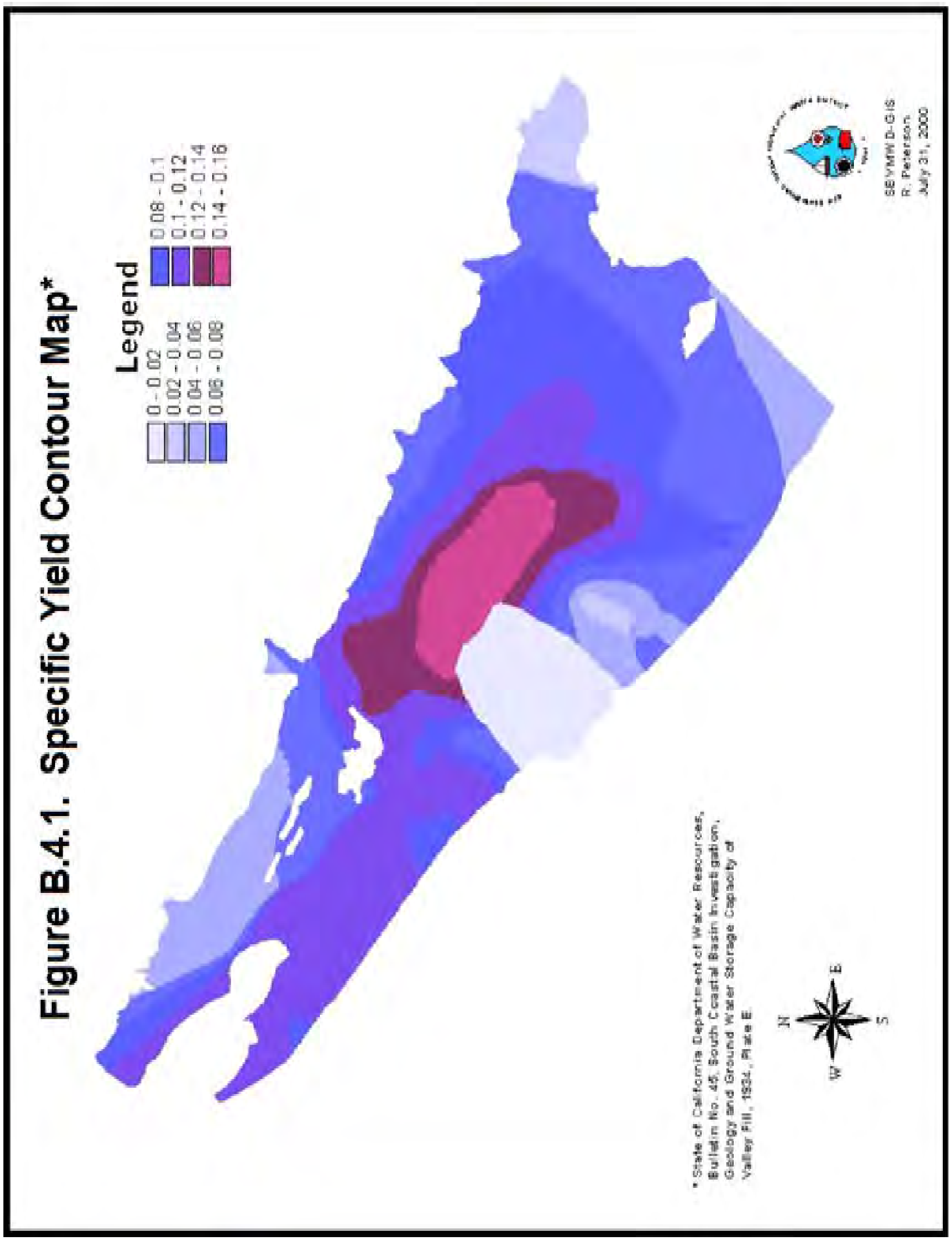

Figure B.4.1. Specific Yield Contour Map*

C. Bibliography

Basin Groundwater Storage Data, San Bernardino Valley Municipal Water District library call number GB 1025, .C2 S26, 1934 – 1990.

Department of Water Resources (DWR), Meeting Water Demands in the Bunker Hill - San Timoteo Area, Geology, Hydrology, and Operation—Economics Studies, Text and Plates, February 1971.

Eckis, Rollin, South Coastal Basin Investigation Geology and Ground Water Storage Capacity of Valley Fill, Bulletin No. 45, State of California Department of Public Works, Division of Water Resources, 1934.

Heath, Ralph C., Basic Ground-Water Hydrology, United States Geological Survey Water-Supply Paper 2220, United States Government Printing Office, 1983.

Motokane, Earl S., "Evaluation of the Base Period for the Bunker Hill-San Timoteo Area Investigation". Meeting Water Demands in the Bunker Hill - San Timoteo Area, Geology, Hydrology, and Operation—Economics Studies, Text and Plates, February 1971, pp. 123 – 129.

Olson, L.J. and Stig J. Johanson, "Specific Yield and Storage Determination". Meeting Water Demands in the Bunker Hill - San Timoteo Area, Geology, Hydrology, and Operation—Economics Studies, Text and Plates, February 1971.

TRW, Incorporated. Simulation Program for Planned Utilization of the San Bernardino Valley and Riverside Ground Water Basins, Second Report, Report No. 07143-6001-R000, October 1967.

Van Gelder, Randy, Change in Groundwater Storage 1980 Update, May 20, 1981.

Western San Bernardino Watermaster (Watermaster), Annual Report of the Western-San Bernardino Watermaster for Calendar Year 1997, August 1, 1998.

Usable Groundwater in Storage Estimation for the San Bernardino, Rialto-Colton, Riverside, and Arlington Groundwater Basins – Summary Report

PREPARED FOR:

San Bernardino Valley Municipal Water District &
Western Municipal Water District

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GEOSCIENCE

THIS REPORT IS RENDERED TO SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT AND WESTERN MUNICIPAL WATER DISTRICT AS OF THE DATE HEREOF, SOLELY FOR THEIR BENEFIT IN CONNECTION WITH ITS STATED PURPOSE AND MAY NOT BE RELIED ON BY ANY OTHER PERSON OR ENTITY OR BY THEM IN ANY OTHER CONTEXT. AS DATA IS UPDATED FROM TIME TO TIME, ANY RELIANCE ON THIS REPORT AT A FUTURE DATE SHOULD TAKE INTO ACCOUNT UPDATED DATA.

THIS DOCUMENT HAS BEEN CHECKED FOR COMPLETENESS, ACCURACY, AND CONSISTENCY BY THE FOLLOWING PROFESSIONALS:

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USABLE GROUNDWATER IN STORAGE ESTIMATION FOR THE SAN BERNARDINO, RIALTO-COLTON, RIVERSIDE, AND ARLINGTON GROUNDWATER BASINS

SUMMARY REPORT

CONTENTS

FIGURES, TABLES, and APPENDIX

FIGURES

FIGURES (continued)

FIGURES (continued)

TABLES

TABLES (continued)

TABLES (continued)

APPENDIX

Ltr.	Description
(Attached)	
A	RPU Comments and GEOSCIENCE Responses on Draft Useable Storage Technical Memorandums

ACRONYMS AND ABBREVIATIONS

Abbrev.	Description
acre-ft/yr	acre-feet per year
amsl	above mean sea level
bgs	below ground surface
DWR	State of California Department of Water Resources
ft	feet
GEOSCIENCE	GEOSCIENCE Support Services, Inc.
gpm	gallons per minute
HCP	Habitat Conservation Plan
Integrated SAR Model	Upper Santa Ana River Integrated Model
RUWMP	Regional Urban Water Management Plan
RPU	City of Riverside Public Utilities
SAR	Santa Ana River
SBBA	San Bernardino Basin Area (includes the Bunker Hill and Lytle Groundwater Basins)
TM	technical memorandum
Valley District	San Bernardino Valley Municipal Water District
USGS	United States Geological Survey
UWMP	Urban Water Management Plan
Western	Western Municipal Water District
WVWD	West Valley Water District

USABLE GROUNDWATER IN STORAGE ESTIMATION FOR THE SAN BERNARDINO, RIALTO-COLTON, RIVERSIDE, AND ARLINGTON GROUNDWATER BASINS

SUMMARY REPORT

1.0 INTRODUCTION

GEOSCIENCE Support Services, Inc. (GEOSCIENCE) was tasked by San Bernardino Valley Municipal Water District (Valley District) and Western Municipal Water District (Western) to estimate the amount of usable groundwater in storage for the San Bernardino Basin Area (SBBA), Rialto-Colton, Riverside, and Arlington Groundwater Basins (Figure 1) using the existing Upper Santa Ana River Integrated Groundwater Model (Integrated SAR Model). The goal of this study was to determine the usable amount of groundwater storage that is available to get through prolonged drought and identify any impacts associated with declining storage levels. Specifically, this study encompassed the following scope of work:

- Task 1 - Estimate the Amount of Usable Storage,
- Task 2 - Estimate the Amount of Groundwater that Can Be Extracted Using Existing Wells,
- Task 3 - Identify Facility Needs, If Any, to Access Groundwater if Water Levels Decline and Estimate the Number of Years of Groundwater in Storage,
- Task 4 - Final Report, and
- Task 5 - Project Management and Meetings.

During the project, Tasks 1 through 3 were summarized in individual technical memorandums (TMs; GEOSCIENCE, 2019a, 2019b, and 2020a). This summary report satisfies Task 4 and incorporates the material from the previous three TMs. Also incorporated are responses to any comments received on the draft TMs, including comments from City of Riverside Public Utilities (RPU) on draft TM-2 and TM-3 (see Appendix A). Results of Tasks 1, 2, and 3 are presented in Sections 2, 3, and 4, respectively.

2.0 ESTIMATION OF THE USEABLE AMOUNT OF GROUNDWATER CURRENTLY IN STORAGE

2.1 Methodology and Tools

The usable amount of groundwater currently in storage is the volume of groundwater stored between the current water level and the bottom elevation of the aquifer. The volume of storage can be calculated using the following equation:

$$V = A * (WL - Bot) * SY$$

Where:

- V: Storage Volume
- A: Basin Area
- WL: Current Water Level Elevation
- Bot: Bottom Elevation of Aquifer
- SY: Specific Yield

To account for spatial variation of the parameters used to calculate the amount of groundwater in storage, the existing model grid for the Integrated SAR Model was used. The grid size of this model has an area of 100 ft by 100 ft. Therefore, the storage can be calculated using the following equations:

$$V_i = A_i * (WL_i - Bot_i) * SY_i$$
$$V_{Basin} = \Sigma V_i$$

Where:

- V_i: Storage Volume in the i^{th} Model Grid
- A_i: Area of the i^{th} Model Grid (i.e., 100 ft x 100 ft)
- WL_i: Current Water Level Elevation in the i^{th} Model Grid
- Bot_i: Bottom Elevation of Aquifer in the i^{th} Model Grid
- SY_i: Specific Yield in the i^{th} Model Grid
- V_{Basin}: Usable Amount of Groundwater Storage in Groundwater Basin (e.g., SBBA, Rialto-Colton, Riverside, or Arlington Basin)

Calculating the usable amount of groundwater currently in storage therefore requires current water level elevations, bottom elevation of aquifer, and specific yield values. The 3-D lithologic models developed for the SBBA, Rialto-Colton, Riverside, and Arlington Basins were used to determine the specific yield for each model grid.

2.2 Reference Elevation Determination

Many factors are associated with the ultimate development of potential groundwater and therefore affect the total usable storage and amount of usable groundwater in storage. These factors may be physical (e.g., low well yields or subsidence due to declining water levels), chemical (e.g., contaminated or poorer quality water), economic (e.g., excessive costs with increased pump lifts), environmental (e.g., need to maintain water levels for stream baseflow or other habitat considerations), or legal (e.g., water level requirements in the 1961 Decree Index Wells in the Rialto-Colton Basin and 1969 Western Judgement Index Wells in the Rialto-Colton and North Riverside Basins). For the purpose of this study, multiple storage calculations were made for the amount of groundwater in storage between the bottom of the aquifer (see Figure 2) and a given reference elevation. The reference elevation changes depending on the factor being considered. The following table summarizes the factors used to develop reference elevations for the calculation of storage for each groundwater basin.

Table 2-1. Summary of Reference Elevation Scenarios —Factors used to Determine Reference Elevations for the Calculation of Storage

Basin	Reference Elevation Scenario	Factor Being Considered							
		Total Usable Storage	Current Ground-Water in Storage	When Subsidence Risk Increases	When Low Yield Areas Stop Producing Water	When Wells Need to be Deepened	When Water for Habitat is Affected	When Water Levels Fall Below 1961 Decree Requirements	When Water Levels Fall Below 1969 Judgment Requirements
San Bernardino Basin Area	SBBA-BL*	X							
	SBBA-C		X						
	SBBA-Sub			X					
	SBBA-LY				X				
	SBBA-DW					X			
Rialto-Colton	RC-BL	X							
	RC-C		X						
	RC-LY				X				
	RC-DW					X			
	RC-61							X	
	RC-69								X
Riverside	R-BL	X							
	R-C		X						
	R-LY				X				
	R-DW					X			
	R-Hab						X		
	R-69								X
Arlington	A-BL	X							
	A-C		X						
	A-LY				X				

*Note: in the SBBA, the total usable storage calculation takes into consideration a maximum reference elevation of 50 ft below ground surface (bgs) in the Pressure Zone to avoid issues related to liquefaction.

2.2.1 Total Usable Storage

For reference scenarios under total usable storage conditions, the reference elevation was defined as the water surface elevation following a very wet hydrologic period with water levels managed at 50 ft below ground surface (bgs) in the Pressure Zone in SBBA. The reference elevation in the Pressure Zone in SBBA was defined as at least 50 ft bgs to avoid issues related to liquefaction. Since liquefaction is most likely to occur at shallow depths, 50 ft bgs is typically considered an adequate cutoff for liquefaction investigations (Matti and Carson, 1991; Martin and Lew, 1999). Outside the Pressure Zone, the model-simulated water surface elevation from the Integrated SAR Model Baseline Scenario following a very wet hydrologic period (1983 hydrology) was used for the reference elevation. This water surface elevation represents a very wet hydrologic period water level surface with Pressure Zone water levels managed at 50 ft bgs. The predicted depth to water for the total useable storage elevation is shown in Figure 3.

2.2.2 Current Groundwater in Storage

As a part of the Integrated SAR Model project, Fall 2016 water level data were collected for the SBBA, Rialto-Colton, Riverside, and Arlington Groundwater Basins. For the purpose of this study, the Fall 2016 water level was defined as the current water level and reference elevation. Fall 2016 water level contours (Figure 4) were therefore used to assign a current water level elevation to each model grid cell.

2.2.3 When Subsidence Risk Increases

Tolman and Poland (1940) reported that land subsidence is a function of slow drainage of aquitards (interbeds of fine-grained sediments) contained within permeable aquifer zones. When declining artesian heads reduces pore pressure to the point that applied stress exceeds preconsolidation stress, land subsidence (virgin compaction) occurs. Land subsidence due to declining groundwater levels has historically been reported in the SBBA. At least one foot of subsidence has occurred in the Pressure Zone near the Raub well field. Generally, an acceptable subsidence rate is assumed to be 1 ft/100 years (GEOSCIENCE, 1991). Reference elevation contours for the SBBA Pressure Zone were therefore developed based on control points with the lowest water level during the period from 1966 through 2016 (see Figure 5). The historical lowest water level can be considered to be the preconsolidation stress. As long as water levels are maintained at or above this level in the Pressure Zone, land subsidence potential as a result of delayed aquitard drainage is considered to be very small. Additional groundwater decline below the lowest observed groundwater level in areas of historical subsidence is assumed to create a risk of additional subsidence.

Unlike in the SBBA, there has been no observed subsidence in the Rialto-Colton, Riverside, and Arlington groundwater basins – particularly during the drought period from 1945 through 1965 that produced subsidence in the Pressure Zone of the SBBA. In addition, these basins lack thick sequences of fine-grained sediments, as are found in the SBBA. Therefore, due to the lack of historical observed subsidence and the lack of significant interbedded fine-grained sediments, the area outside of the Pressure Zone is not considered to have land subsidence risk.

2.2.4 When Low Yield Areas Stop Producing Water

Lower yield zones may reduce or preclude groundwater in storage from being extracted. These include shallow areas that are prone to becoming unsaturated and areas of fine-grained material. For example, a lower yield area was found northwest of Barrier J in the Rialto-Colton Basin. Figure 6 shows lower yield zones based on the annual average production during the period from 2012 through 2016. In general, annual average production within lower yield zones is below 100 acre-ft/yr. For the purpose of this study, the reference elevation for when low yield areas will stop producing water was assumed to be the same as the Fall 2016 water levels (Figure 4), but areas within lower yield zones were excluded from the calculation. In other words, the usable amount of groundwater in storage within a lower yield zone was assumed to be zero.

2.2.5 When Wells Need to be Deepened

When water level drops below the top of the well screen, the pumping rate of a well may be reduced. If the impact of water level declines on the pumping rate is great enough, a replacement well may be needed. For the purpose of this study, pumping rate and the total length of screen was assumed to be a linear relationship. Therefore, the reference elevation for when wells need to be deepened was calculated by using the following equation.

$$Well\ Deepening\ Elevation = Top\ of\ Screen\ Elevation - (Total\ Length\ of\ Screen\ \times \frac{Average\ Pumping\ Rate - Threshold\ of\ Pumping\ Rate}{Average\ Pumping\ Rate})$$

It was assumed that 250 gpm represents a reasonable threshold between an adequate pumping well (with average pumping greater than 250 gpm) and an abandoned well or well with low efficiency (average pumping less than 250 gpm). Based on pumping records, approximately 50% of the wells in the SBBA, Rialto-Colton, Riverside, and Arlington Basins have an average pumping rate that exceeds 250 gpm during the period from 2012 through 2016 (Figure 7).

As an example of the reference elevation calculation considering the cost of a new well as a limiting factor, consider a well that is screened from 1,000 ft amsl to 600 ft amsl (see inset figure below). The total length of screen is therefore 400 ft. Assuming the average pumping rate of this well is 500 gpm, the reference elevation for this well is calculated as follows:

$$1{,}000\ ft\ amsl - \frac{500\ gpm - 250\ gpm}{500\ gpm} \times 400\ ft = 800\ ft\ amsl$$

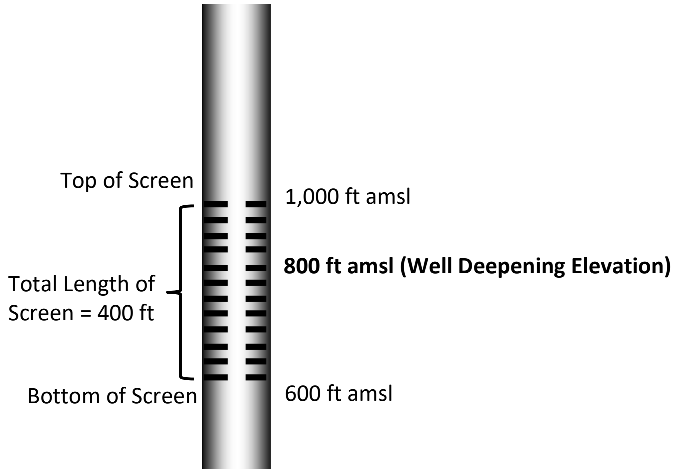

Figure 8 shows the control points used to develop well deepening elevation contours. Wells that pump less than 250 gpm were assumed to be low-efficiency producers and not viable candidates for well replacement if water levels fell below their screened intervals. These wells were excluded from the set of control points. The number of wells included/excluded from this analysis are also summarized in the following table.

Table 2-2. Number of Wells Included/Excluded in Development of Reference Elevation Contours to Reduce the Need for Replacement Wells

Basin	Total Well Count for Wells Included in Well Deepening Elevation Development	Total Well Count for Wells Excluded from Well Deepening Elevation Development	Cumulative Capacity of Wells Excluded from Well Deepening Elevation Development [gpm]
SBBA	570	276	4,557
Rialto-Colton	43	18	711
Riverside	35	164	2,163
Arlington	5	32	651

2.2.6 When Water for Habitat is Affected

Figure 9 shows a footprint area of rising water in the SAR near Riverside Narrows. Wet and dry hydrologic periods cause natural variability in groundwater levels. For the purposes of calculating usable storage, lowering of groundwater levels in rising water areas will affect the amount of groundwater available for habitat. Therefore, usable groundwater storage in these areas was excluded from the usable storage calculation under this scenario run. Similar to the lower yield scenario, the reference elevation for when water for habitat is affected was assumed to be the same as the Fall 2016 water levels (Figure 4), but the area of known rising water in Riverside Basin was excluded.

2.2.7 When Water Levels Fall Below 1961 Decree Requirements

Pumping rates for all wells within the 1961 Decree boundary are dependent on the average spring-high water level elevation of Rialto Basin Index Wells (i.e., Rialto No. 4, WVWD No. 11, and WVWD No. 16). Figure 10 shows the location of the three index wells and the 1961 Decree boundary. The 1961 Rialto Decree was triggered in the 1960s, and more recently in 2007. At this later date, the total amount of groundwater storage in Rialto-Colton was approximately 1,574,000 acre-ft (Valley District, 2020).

2.2.8 When Water Levels Fall Below 1969 Judgment Requirements

According to the 1969 Western Judgment, extractions from the Colton Basin Area and Riverside Basin Area within San Bernardino County shall be limited so as to maintain water levels at or above 822.04 ft amsl (Fall 1963 water levels) for three index wells (i.e., Johnson 1, Flume 2, and Flume 5). Figure 11 shows the location of the three index wells specified in the 1969 Western Judgment. The 1969 Western Judgment requirement was first triggered in 2018 and continued into 2020. The highest storage in Rialto-Colton during this period was approximately 1,528,000 acre-ft (Valley District, 2020).

2.3 Assigning Specific Yield Values to the Model Grid

A specific yield value was assigned to each model grid cell based on lithologic type from the existing 3-D lithologic models for the SBBA, Rialto-Colton, Riverside, and Arlington Groundwater Basins. Lithologic types in the lithologic model were assigned a specific yield value based on those listed in the U.S. Geological Survey (USGS) Water Supply Paper 1662-D (Johnson, 1967) and California State Department of Public Works Division of Water Resources (now Department of Water Resources, DWR) Bulletin 45 (1934). As shown in attached Table 1, the specific yield values range from 0.01 to 0.2.

2.4 Usable Amount of Groundwater Currently in Storage

The usable amount of groundwater currently in storage for the SBBA, Rialto-Colton, Riverside, and Arlington Groundwater Basins was estimated using the equations outlined in Section 2.1 and data developed in Sections 2.2 and 2.3. The estimated total usable storage and amount of groundwater currently in storage under various reference elevation scenarios are summarized in attached Table 2.

The following sections provide the summary of total usable storage and groundwater currently in storage by basin.

2.4.1 San Bernardino Basin Area

The total usable groundwater storage and usable storage thresholds for the SBBA are summarized in Figure 2-1 below. As shown, the total usable storage was estimated to be 5,690,000 acre-ft. The total usable storage was previously estimated to be 5,976,000 acre-ft[1] by DWR (1986). The difference between DWR's estimated value and the current usable storage calculation is due to (1) additional knowledge on the bottom elevation of the aquifer system gained from the drilling of wells and geophysical studies conducted since DWR performed their study; (2) more accurate specific yield values derived from 3-D lithologic models; and (3) the difference in the "top" of the usable storage (the current usable storage calculation is constrained to a water level that does not cause liquefaction whereas the DWR calculation used land surface as the "top" of the usable storage). Also, outside of the Pressure Zone area, the current "top" of usable storage is defined using the water surface elevation as described in Section 2.2.1.

The current groundwater in storage is 4,716,000 acre-ft. When the storage level falls below 4,465,000 acre-ft, low yield areas will stop producing water. The low yield area represents approximately 9,100 acres (see Figure 6). The storage excluded from this low yield area was approximately 251,000 acre-ft. When the storage level declines below 3,236,000 acre-ft, new wells may be required or existing wells deepened. When the storage level declines below 2,690,000 acre-ft, the risk of land subsidence increases.

[1] As shown in Table 1 of the DWR (1986) report, the groundwater storage of 5,976,000 acre-ft is the sum of 4,296,000 acre-ft for the Bunker Hill Subarea and 1,680,000 acre-ft for the Bunker Hill Pressure Subarea. Plate 1 of the DWR (1986) report shows that the "Bunker Hill" Subarea also includes Lytle Basin.

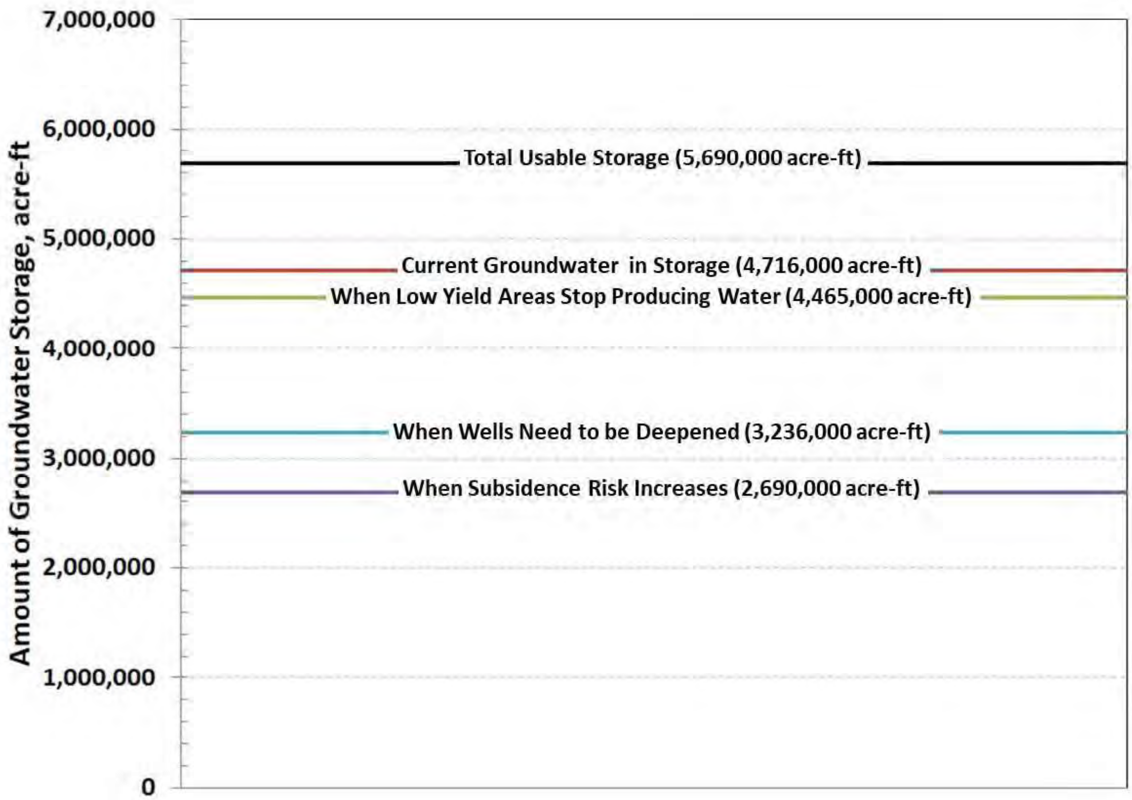

Figure 2-1. Total Usable Storage and Usable Groundwater in Storage – San Bernardino Basin Area

2.4.2 Rialto-Colton Basin

The total usable groundwater storage and usable storage for the Rialto-Colton Basin are summarized in Figure 2-2 below. As shown, the total usable storage is 1,749,000 acre-ft. The total usable storage for the Rialto-Colton Basin was previously estimated to be 2,517,000 acre-ft by DWR (1986). This difference reflects changes in the bottom elevation of the aquifer systems and specific yield values used for the current usable storage calculation. In addition, the reference (top) elevation used for total usable storage calculation was defined as the water surface elevation described in Section 2.2.1.

The current groundwater in storage is 1,530,000 acre-ft. Factors affecting usable groundwater in storage affect the basin when storage falls below 1,528,000 acre-ft (when water levels fall below 1969 Judgment requirements) to when storage falls below 784,000 acre-ft (when new wells are needed or existing wells need to be deepened). When storage falls below 1,278,000 acre-ft, lower yield areas will stop producing water. The low yield area is approximately 2,600 acres (see Figure 6). The storage excluded from this low yield area was approximately 252,000 acre-ft.

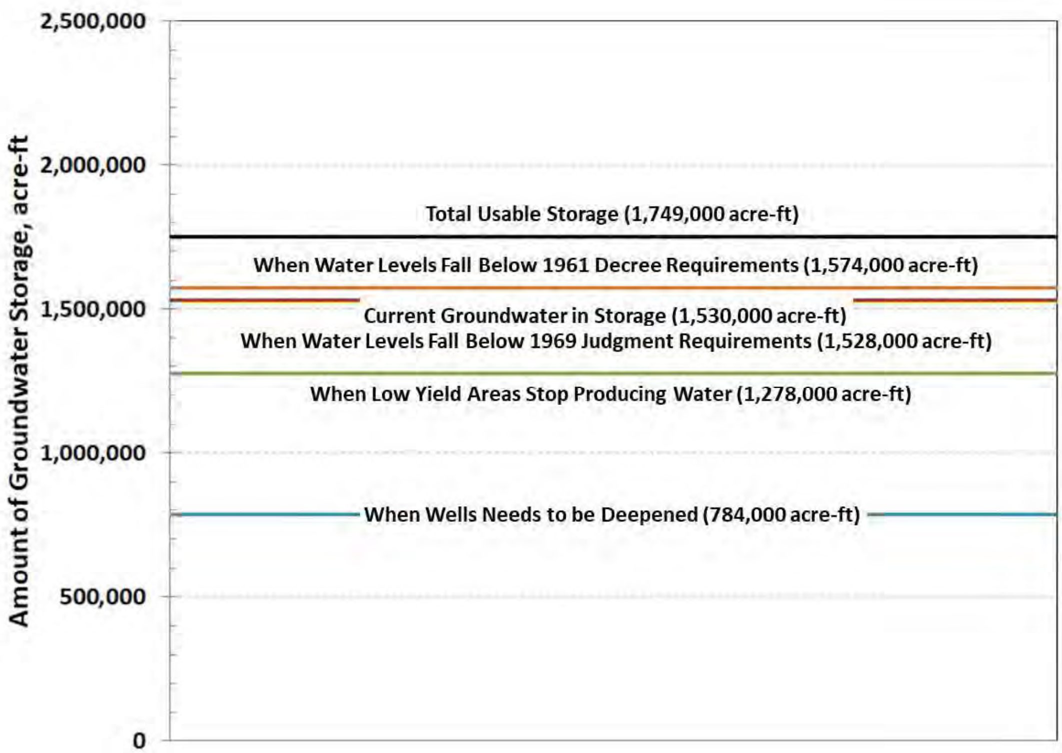

Figure 2-2. Total Usable Storage and Usable Groundwater in Storage – Rialto-Colton Basin

2.4.3 Riverside Basin

The total usable groundwater storage and usable storage for the Riverside Basin are summarized in Figure 2-3 below. As shown, the total usable storage is 810,000 acre-ft while current usable storage is 722,000 acre-ft. When water levels fall below 1969 Judgment requirements, storage in the basin is approximately 720,000 acre-ft. When storage in the basin falls below 688,000 acre-ft, water available for habitat is affected. When storage falls below 558,000 acre-ft, lower yield areas will stop producing water. The low yield area is approximately 9,500 acres (see Figure 6). The storage excluded from this low yield area was approximately 164,000 acre-ft. When the storage level declines below 349,000 acre-ft, new wells may be required or existing wells deepened.

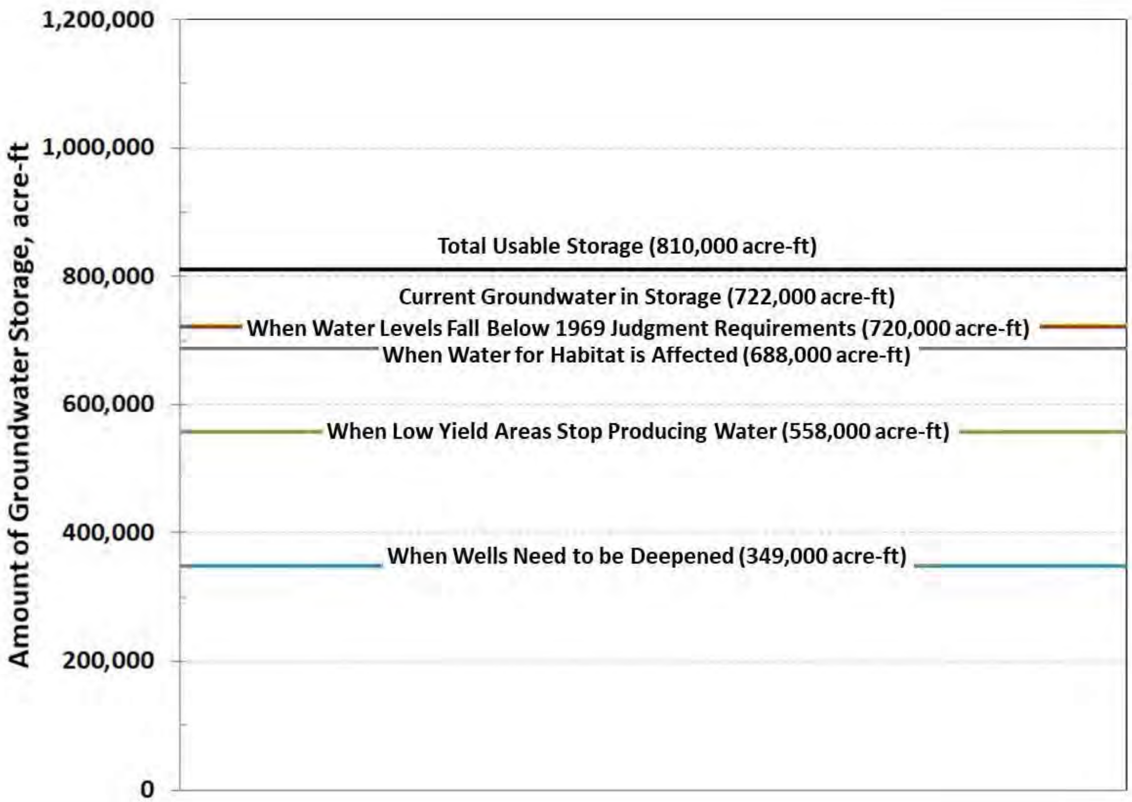

Figure 2-3. Total Usable Storage and Usable Groundwater in Storage – Riverside Basin

2.4.4 Arlington Basin

The total usable groundwater storage and usable storage for the Arlington Basin are summarized in Figure 2-4 below. As shown, the total usable storage was estimated to be 95,000 acre-ft and the current groundwater in storage is 56,000 acre-ft. When the storage level falls below 48,000, low yield areas will stop producing water. The low yield area is approximately 2,100 acres (see Figure 6). The storage excluded from this low yield area was approximately 8,000 acre-ft.

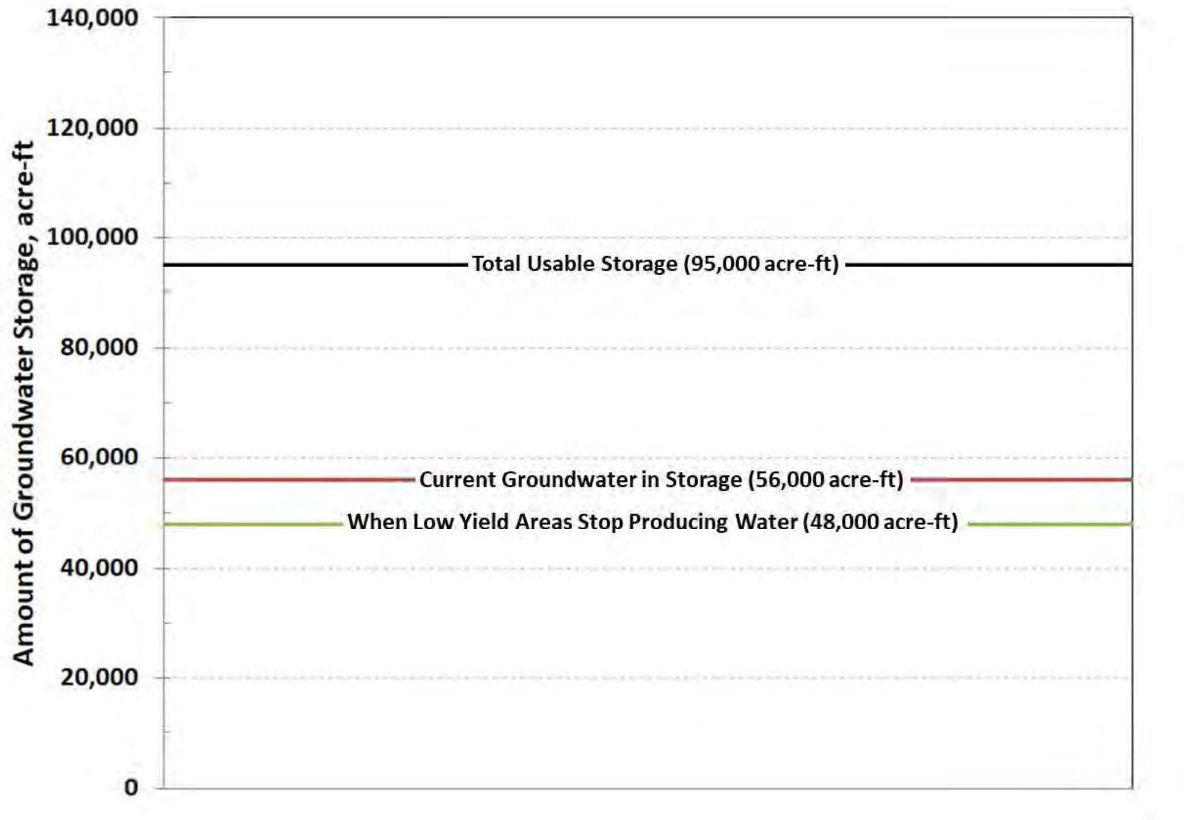

Figure 2-4. Total Usable Storage and Usable Groundwater in Storage – Arlington Basin

3.0 AMOUNT OF GROUNDWATER THAT CAN BE EXTRACTED USING EXISTING WELLS

As discussed in Section 2.0, the amount of groundwater in storage was quantified under various conditions including:

Item 1. Total usable storage,
Item 2. Current groundwater in storage,
Item 3. When subsidence risk increases,
Item 4. When lower yield areas stop producing water,
Item 5. When wells need to be deepened,
Item 6. When water for habitat is affected,
Item 7. When water levels fall below 1961 Rialto Basin Decree requirements, and
Item 8. When water levels fall below 1969 Western Judgment requirements.

These items were then used to estimate the amount of groundwater that can be extracted using existing wells (i.e., Task 2), which is summarized below.

3.1 Methodology

The amount of groundwater that can be extracted using existing wells under current conditions (see Figure 3-1 below) was calculated as the difference between the current groundwater in storage (Item 2; Section 2.2.2) and groundwater storage when wells need to be deepened (Item 5; Section 2.2.5).

The amount of groundwater that can be extracted using existing wells under full basin conditions (see Figure 3-2 below) was calculated as the difference between the total usable storage (Item 1; Section 2.2.1) and groundwater storage when wells need to be deepened (Item 5; Section 2.2.5).

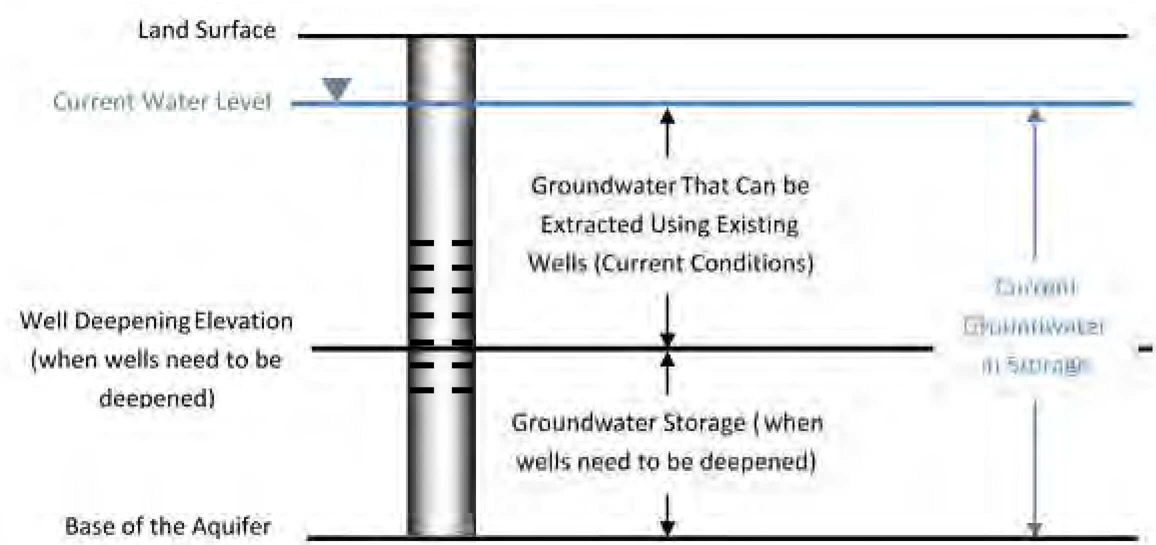

Figure 3-1. Groundwater That Can Be Extracted Using Existing Wells – Current Conditions

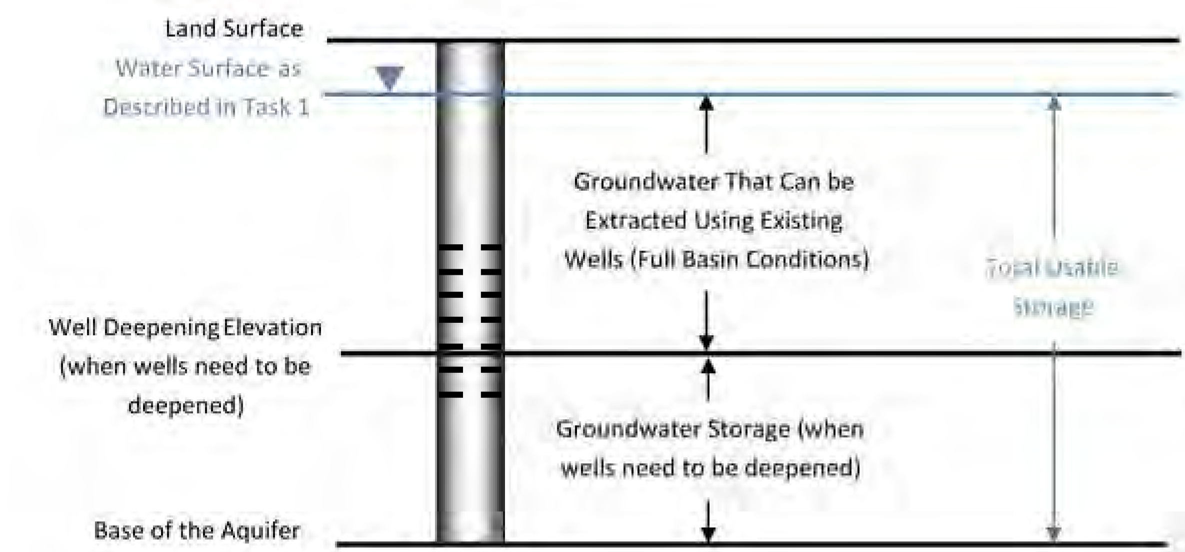

Figure 3-2. Groundwater That Can Be Extracted Using Existing Wells – Full Basin Conditions

3.2 Groundwater that Can be Extracted Using Existing Wells

Based on the results from Task 1 (see Section 2.0), the following table summarizes the groundwater that can be extracted using existing wells for each basin under current conditions and full basin conditions.

Table 3-1. Groundwater that Can be Extracted Using Existing Wells

Basin	(Item 1) Total Usable Storage [acre-ft]	(Item 2) Current Groundwater in Storage [acre-ft]	(Item 5) Groundwater Storage When Wells Needed to Be Deepened [acre-ft]	Amount of Groundwater That Can be Extracted Using Existing Wells [acre-ft]	
				(Item 2 – Item 5) Current Conditions	(Item 1 – Item 5) Full Basin Conditions
SBBA	5,690,000	4,716,000	3,236,000	1,480,000	2,454,000
Rialto-Colton	1,749,000	1,530,000	784,000	746,000	965,000
Riverside	810,000	722,000	349,000	373,000	461,000
Arlington	95,000	56,000	0*	56,000	95,000

* Wells with a capacity greater than 250 gpm were assumed to already be drilled to the base of the aquifer. Well logs for wells in Arlington Basin pumping greater than 250 gpm were reviewed. Based on the well log descriptions, the existing wells were completed to the depth of the productive aquifer. Below the screened depth, the material as described in the drillers logs is not anticipated to yield significant additional production in this analysis.

As shown in the table above, the amount of groundwater in storage that can be extracted using existing wells under current conditions was estimated to be 1,480,000 acre-ft for the SBBA, 746,000 acre-ft for the Rialto-Colton Basin, 373,000 acre-ft for the Riverside Basin, and 56,000 acre-ft for the Arlington Basin. The amount of groundwater in storage that can be extracted using existing wells under full basin conditions was estimated to be 2,454,000 acre-ft for the SBBA, 965,000 acre-ft for the Rialto-Colton Basin, 461,000 acre-ft for the Riverside Basin, and 95,000 acre-ft for the Arlington Basin.

3.3 Wells that Need to be Deepened to Extract Additional Groundwater

The amount of groundwater in storage that cannot be extracted using existing wells[2] was estimated to be 3,236,000 acre-ft for the SBBA, 784,000 acre-ft for the Rialto-Colton Basin, 349,000 acre-ft for the Riverside Basin, and 0 acre-ft for the Arlington Basin (see Item 5 in Table 3-1 above). To extract this water above the bedrock, certain wells would need to be deepened and drilled 40 ft into the bedrock to allow for a pump chamber. Wells that could be deepened to allow additional extraction of water in

[2] Wells used for the analysis are listed in Tables 3 through 5. Private wells were not considered.

storage were identified and are shown on Figure 12. The potential amount these wells could be deepened and the associated well information is summarized in Tables 3 through 5 for the SBBA, Rialto-Colton, and Riverside Basins, respectively. Additional available well capacity from deepening was estimated based on well capacity, screen length, and potential deepening. Wells with additional capacity less than 100 gpm after deepening were also indicated in the tables. At these locations, deepening would not yield significant additional well capacity.

3.4 Groundwater Production Constraints Due to Reduced Storage/Water Level

For the purpose of this study, baseline groundwater production was assumed to be the average of the last five years of pumping (i.e., 2012 through 2016). Well production was assumed to decrease linearly as water level decreases along the screened length of the well. Below a well production threshold of 250 gpm (400 acre-ft/yr), a well was assumed to be inefficient or abandoned. Reduced production when water levels drop to the well deepening elevation (when wells need to be deepened) was calculated as the difference between baseline groundwater production and groundwater production threshold (see Tables 3 through 5). Table 3-2 below summarizes the reduction in production when water level drops to the well deepening elevation for each basin.

Table 3-2. Estimated Reduction in Groundwater Production When Water Levels Reach the Well Deepening Elevation

Basin	Baseline Groundwater Production [acre-ft/yr]	Baseline Groundwater Production for Subset of Wells with Screened Interval Information* [acre-ft/yr]	Estimated Reduced Groundwater Production for Subset of Wells with Screened Interval Information when they Reach the Well Deepening Elevation* [acre-ft/yr]	Percent Reduction for the Wells with Screened Interval Information* [%]
SBBA	183,600	108,600	73,100	67%
Rialto-Colton	17,700	5,000	3,000	60%
Riverside	83,100	9,800	6,100	62%
Arlington	7,100	NA	NA	NA

* A total of 102 existing wells (88 wells for SBBA, 5 wells for Rialto-Colton, and 9 wells for Riverside) were used in this analysis (see Tables 1 through 3). This analysis was limited to the wells with screened interval information. Wells without screened interval information were therefore excluded.

NA = Not Applicable

As shown in the table above, the percent reduction in groundwater production from baseline groundwater production for wells with screened interval information due to water levels reaching the well deepening elevation was 67%, 60%, and 62% for the SBBA, Rialto-Colton, and Riverside Basins, respectively.

3.5 Limitations

Potential deepening depth provides useful information to estimate the potential additional length of screen or determine if a replacement well is needed. However, this analysis does not account for clay layers or poorly producing layers that exist within the aquifer. While there may be additional depth within a well, an agency might not pursue adding additional screen if the aquifer below the existing screened elevation is not productive. The estimated percentage of fines below the screened interval, which was based on the lithologic model, is provided in Tables 3 through 5.

For the purpose of this study, the majority of existing municipal wells were included in this analysis. However, since screened interval information was unavailable for some wells belonging to various water agencies, these wells were excluded in Tables 3 through 5.

4.0 POTENTIAL LOCATIONS FOR ADDITIONAL PUMPING AND ESTIMATION OF THE NUMBER OF YEARS OF GROUNDWATER IN STORAGE

This section presents the results of Task 3, which includes an estimation of the total number of years' worth of groundwater that is available in the SBBA, Rialto-Colton, Riverside, and Arlington Basins with existing wells, assuming all wells are drilled to bedrock. Since results indicated that existing facilities and infrastructure are not capable of producing the amount of groundwater available, an evaluation was made to identify locations in the basin favorable for additional extraction. The ultimate goal of the evaluation was to identify areas in the SBBA, Rialto-Colton, Riverside, and Arlington Groundwater Basins that would allow groundwater extractions of available water to be maximized while minimizing potential groundwater impacts, including the risk of potential liquefaction, land subsidence, and interference with clean-up of contaminant plumes.

4.1 General Approach

In order to assess the total number of years' worth of groundwater in storage, model scenarios were run using the calibrated Integrated SAR Model (GEOSCIENCE, 2020b), starting with current water levels and assuming current and "ultimate" (2040) pumping demands. It was also assumed that all existing wells were drilled to bedrock so that the total number of years' worth of groundwater available can be estimated. The Integrated SAR Model was then run for a period of 25 years assuming (1) extended drought conditions, (2) average conditions, and (3) Habitat Conservation Plan (HCP) base period (i.e., historical hydrologic conditions for the period from 1966 through 1990). During the scenario runs, the volume of groundwater storage was calculated by the model. If there was still storage available after the 25-year simulation, the number of years' worth of groundwater was extrapolated until the amount of storage was zero.

Results of the Task 3 modeling scenarios (amount of groundwater available with existing wells, assuming all wells are drilled to bedrock) were also compared to those obtained for Task 2 (amount of groundwater available with existing wells; Section 3.0). The results indicated that existing facilities and infrastructure are not capable of producing the amount of groundwater available, even with existing wells deepened according to the findings of Task 2. Therefore, an evaluation was made to identify locations in the basin favorable for additional extraction (i.e., installation of new groundwater production wells). Since the groundwater flow model takes the location and timing of recharge and discharge into account and is able to track changes in groundwater levels across the basins, it is able to provide a good indication of where new wells could be located to take advantage of available storage which may otherwise not be accessible with existing facilities.

The major assumptions for the Task 3 model scenarios are summarized in the table below.

Table 4-1. Model Scenario Assumptions for Task 3

Basin	Model Scenario	Hydrology	State Water Project	Stormwater Recharge	Recycled Water Recharge	Groundwater Pumping*	
SBBA Rialto-Colton Riverside Arlington	SAR-T3-1	Dry	Projected Table A Allocation	SAR SG diversion capacity of 500 cfs	None	2015 Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this
	SAR-T3-2	Dry	Projected Table A Allocation	SAR SG diversion capacity of 500 cfs	None	2040 Projected Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this
	SAR-T3-3	Average	Projected Table A Allocation	SAR SG diversion capacity of 500 cfs	None	2015 Pumping	plus a reliability factor of 10%
	SAR-T3-4	Average	Projected Table A Allocation	SAR SG diversion capacity of 500 cfs	None	2040 Projected Pumping	plus a reliability factor of 10%
	SAR-T3-5	HCP (1966-1990)	Projected Table A Allocation	SAR SG diversion capacity of 500 cfs	None	2015 Pumping	plus a reliability factor of 10%

*All model scenarios assume existing wells are drilled to bedrock.

Under dry hydrologic conditions, the amount of groundwater available is less because recharge is lower. Conversely, more groundwater is available for extraction under average or wet hydrologic conditions because there is more recharge. 2015 pumping conditions represent current pumping while 2040 projected pumping conditions represent the "ultimate" condition. The "ultimate" condition represents groundwater pumping to meet future projected water demands in 2040 estimated in 2015 Regional Urban Water Management Plans (RUWMPs) (GEOSCIENCE, 2019c). This modeling analysis provides "bookend" results. Under dry and average hydrologic conditions, Run SAR-T3-3 (average hydrology and 2015 pumping) represents the best-case scenario while Run SAR-T3-2 (dry hydrology and 2040 projected pumping) represents the worst-case scenario. Run SAR-T3-5 (HCP 1966-1990 hydrology and 2015 pumping) has the same assumptions as Run SAR-T3-3 but includes all variation in hydrology seen for the period from 1966 through 1990 (dry, average, and wet).

4.1.1 Hydrology

The SBBA Precipitation Index represents the average precipitation from gaging stations at Big Bear Dam, Lytle Creek, and Mill Creek. The cumulative departure from mean annual precipitation using the Precipitation Index is shown on Figure 13 for the time period from water years 1931 through 2019. Per comments from Western Municipal Water District, dry, average, and wet hydrologic conditions were selected based on the average and standard deviation of Precipitation Index annual precipitation over this period. If the Precipitation Index for a given year fell within the average precipitation of the period of record minus half of one standard deviation (24.0 inches) and the average precipitation plus half of one standard deviation (38.1 inches), the given year was considered to be average. If the Precipitation Index for a given year fell above the average precipitation of the period of record plus half of one standard deviation (38.1 inches), that year was considered to reflect wet hydrologic conditions. Conversely, if the Precipitation Index for a given year fell below the average precipitation of the period of record minus half of one standard deviation (24.0 inches), it was considered to be dry.

Figure 14 shows the distribution of dry, average, and wet years for the period from 1966 through 1990. This period coincides with the HCP base period. The number of years for dry, average, and wet hydrologic conditions during the period from 1966 through 1990 are summarized in the table below.

Table 4-2. Summary of Hydrologic Conditions (1966 – 1990)

SBBA Precipitation Index [inches]	Hydrologic Condition	Number of Years
< 24.0 (Average – ½ SD)	Dry	11 (44%)
24.0 – 38.1	Average	7 (28%)
>38.1 (Average + ½ SD)	Wet	7 (28%)

SD = Standard Deviation

In order to simulate dry (Scenarios SAR-T3-1 and SAR-T3-2) or average (Scenarios SAR-T3-3 and SAR-T3-4) hydrologic conditions in the model scenario runs, historical precipitation from the HCP base period was used to create two 25-year hydrologic sequences: one for dry conditions (Figure 15), and one for average conditions (Figure 16). As shown on the hydrologic sequences, the observed Precipitation Index from 1966 through 1990 that was classified as either dry or average was repeated until a 25-year simulation period was reached. These annual precipitation sequences were then applied in the predictive model scenarios to represent the corresponding hydrologic condition for that run (i.e., dry or average). None of the scenario runs consider a sequence of wet hydrology since it is considered very unlikely that there will be 25 consecutive years of wet hydrology. However, Scenario SAR-T3-5 does simulate the observed hydrology from the HCP base period (1966 through 1990) which includes wet years, as shown in Figure 14.

While the Precipitation Index was used to characterize each hydrologic year as wet, dry, or average, actual precipitation data from local stations were used for the model scenarios. The Precipitation Index was considered appropriate for classifying hydrology because it is reflective of the source of flow for the main tributaries of the Santa Ana River, which run through the SBBA, and originate at higher elevation (represented by these three gages).

4.1.2 Groundwater Pumping

The modeling scenarios considered two pumping assumptions: current (2015) and ultimate (2040) from the 2015 San Bernardino Valley RUWMP (WSC, 2016a). To be consistent with the RUWMP, a factor of 10% was added to reflect increased demand in dry years, and a 10% reliability factor was added to all assumed pumping. In all of the model scenarios, water levels in pumping wells were constrained by the top of the bedrock (i.e., consolidated sedimentary rocks).

Additional UWMPs were used to develop 2040 pumping assumptions, including:

- 2015 Urban Water Management Plan for Riverside Public Utilities Water Division (WSC, 2016b),
- 2015 Urban Water Management Plan – Rubidoux Community Services District (K&S, 2016), and
- 2015 Urban Water Management Plan – Western Municipal Water District (RMC, 2016).

Estimated total demand for 2020 and 2040 is summarized below, by basin.

Table 4-3. Projected Water Demand

Water Demand	San Bernardino Basin Area	Rialto-Colton	Riverside North
	[acre-ft/yr]		
2020	217,000	24,259	35,752
2040	247,164	25,038	38,010

Source: 2015 San Bernardino Valley RUWMP (WSC, 2016a)

4.1.3 Imported Water Recharge

Average annual imported water recharge in the SBBA was assumed to be 33,400 acre-ft/yr during the 25-year simulation period, based on DWR's future projection for Table A allocation. Predictive model runs assumed that no imported water recharge occurred in Rialto-Colton, Riverside, and Arlington Basins.

4.2 Results of Scenario Runs

4.2.1 Estimated Years of Groundwater Available in Storage

Initial groundwater storage for the scenario runs was assumed to be current groundwater in storage calculated from Task 1 (Section 2.4). Comparisons of groundwater in storage between the five scenario runs for the SBBA, Rialto-Colton, Riverside, and Arlington Groundwater Basins are provided on Figures 17 through 20, respectively. As shown on the figures, all scenarios result in declining cumulative change in groundwater storage over the 25-year simulation period, with an exception of SAR-T3-5. Groundwater in storage depletes the quickest under SAR-T3-2 conditions (2040 pumping under dry hydrology), while SAR-T3-5 conditions (2015 pumping and HCP hydrology) result in a theoretically infinite number of years of available groundwater in storage (with the exception of Arlington Basin). The average annual change in groundwater storage under the five scenario runs is summarized in the following table and in attached Tables 6 through 25.

Table 4-4. Average Annual Change in Groundwater Storage – Task 3 Scenario Runs

Scenario	Hydrology	Groundwater Pumping		San Bernardino Basin Area	Rialto-Colton	Riverside	Arlington
				[acre-ft/yr]			
SAR-T3-1	Dry	2015 Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-59,720	-9,440	-5,750	-3,040
SAR-T3-2	Dry	2040 Projected Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-86,510	-13,450	-11,540	-6,680
SAR-T3-3	Average	2015 Pumping	plus a reliability factor of 10%	-28,140	-4,900	-1,010	-2,250
SAR-T3-4	Average	2040 Projected Pumping	plus a reliability factor of 10%	-51,900	-8,320	-4,860	-6,200
SAR-T3-5	HCP (1966-1990)	2015 Pumping	plus a reliability factor of 10%	18,520	2,000	20	-2,080

Note: A positive sign indicates an increase in groundwater storage and a negative sign represents a decline in groundwater storage.

As shown in the table above, the change in current storage for the scenario runs ranges from approximately 18,520 to -86,510 afy in the SBBA, 2,000 to -13,450 afy in Rialto-Colton, 20 to -11,540 afy in Riverside, and -2,080 to -6,680 afy in Arlington.

4.2.1.1 San Bernardino Basin Area

Model-simulated groundwater storage in the SBBA at the end of 25 years is shown on Figure 17 for the scenario runs. As shown, there is still storage available after 25-year simulation under all scenario conditions. Therefore, the number of years' worth of groundwater was extrapolated for each scenario until the amount of storage was zero. As shown on Figure 21, the number of years of groundwater in storage is estimated to be 81 years, 57 years, 172 years, and 96 years for SAR-T3-1, SAR-T3-2, SAR-T3-3, and SAR-T3-4, respectively. SAR-T3-5 shows an increase in groundwater storage by an annual average of 18,520 acre-ft/yr (theoretically infinite under the assumed scenario conditions). The average annual change in groundwater storage for the SBBA is shown in Tables 6 through 10. Change in storage and the number of years of groundwater in storage is also summarized in the following table.

Table 4-5. Scenario Results for the SBBA

Model Scenario	Hydrology	Groundwater Pumping		Average Annual Change in Groundwater Storage*	The Number of Years of Groundwater in Storage
SAR-T3-1	Dry	2015 Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-59,720	81
SAR-T3-2	Dry	2040 Projected Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-86,510	57
SAR-T3-3	Average	2015 Pumping	plus a reliability factor of 10%	-28,140	172
SAR-T3-4	Average	2040 Projected Pumping	plus a reliability factor of 10%	-51,900	96
SAR-T3-5	HCP (1966-1990)	2015 Pumping	plus a reliability factor of 10%	18,520	Theoretically Infinite

* A positive sign indicates an increase in groundwater storage and a negative sign represents a decline in groundwater storage.

4.2.1.2 Rialto-Colton Basin

Model-simulated groundwater storage in Rialto-Colton Basin at the end of 25 years is shown on Figure 18 for the scenario runs. As shown, there is still storage available after 25-year simulation for all scenarios. Therefore, the number of years' worth of groundwater was extrapolated for each scenario until the amount of storage was zero. As shown on Figure 22, the number of years of groundwater in storage is estimated to be 161 years, 113 years, 310 years, and 184 years for SAR-T3-1, SAR-T3-2, SAR-T3-3, and SAR-T3-4, respectively. SAR-T3-5 shows an increase in groundwater storage by an annual average of 2,000 acre-ft/yr (theoretically infinite under the assumed scenario conditions). The average annual change in groundwater storage for Rialto-Colton Basin is shown in Tables 11 through 15. The change in storage and the number of years of groundwater in storage is also summarized in the following table.

Table 4-6. Scenario Results for Rialto-Colton Basin

Model Scenario	Hydrology	Groundwater Pumping		Average Annual Change in Groundwater Storage*	The Number of Years of Groundwater in Storage
SAR-T3-1	Dry	2015 Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-9,440	161
SAR-T3-2	Dry	2040 Projected Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-13,450	113
SAR-T3-3	Average	2015 Pumping	plus a reliability factor of 10%	-4,900	310
SAR-T3-4	Average	2040 Projected Pumping	plus a reliability factor of 10%	-8,320	184
SAR-T3-5	HCP (1966-1990)	2015 Pumping	plus a reliability factor of 10%	2,000	Theoretically Infinite

* A positive sign indicates an increase in groundwater storage and a negative sign represents a decline in groundwater storage.

4.2.1.3 Riverside Basin

Model-simulated groundwater storage in Riverside Basin at the end of 25 years is shown on Figure 19 for the scenario runs. As shown, there is still storage available after 25-year simulation for all scenarios. Therefore, the number of years' worth of groundwater was extrapolated for each scenario until the amount of storage was zero. As shown on Figure 23, the number of years of groundwater in storage is estimated to be 127 years, 65 years, 717 years, and 149 years for SAR-T3-1, SAR-T3-2, SAR-T3-3, and SAR-T3-4, respectively. SAR-T3-5 shows an increase in groundwater storage by an annual average of 20 acre-ft/yr (theoretically infinite under the assumed scenario conditions). The average annual change in groundwater storage for Riverside Basin is shown in Tables 16 through 20. The change in storage and the number of years of groundwater in storage is also summarized in the following table.

Table 4-7. Scenario Results for Riverside Basin

Model Scenario	Hydrology	Groundwater Pumping		Average Annual Change in Groundwater Storage*	The Number of Years of Groundwater in Storage
SAR-T3-1	Dry	2015 Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-5,750	127
SAR-T3-2	Dry	2040 Projected Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-11,540	65
SAR-T3-3	Average	2015 Pumping	plus a reliability factor of 10%	-1,010	717
SAR-T3-4	Average	2040 Projected Pumping	plus a reliability factor of 10%	-4,860	149
SAR-T3-5	HCP (1966-1990)	2015 Pumping	plus a reliability factor of 10%	20	Theoretically Infinite

* A positive sign indicates an increase in groundwater storage and a negative sign represents a decline in groundwater storage.

4.2.1.4 Arlington Basin

Model-simulated groundwater storage in Arlington Basin at the end of 25 years is shown on Figure 20 for the scenario runs. As shown, model-simulated groundwater storage indicates a depletion of storage within the 25-year simulation period for all scenarios except SAR-T3-5. Therefore, the amount of years' worth of groundwater available is taken directly from the predictive model scenario results for Scenarios SAR-T3-1 through SAR-T3-4. The number of years' worth of groundwater for SAR-T3-5 was extrapolated from the end of the model simulation period (i.e., 25 years) until the amount of storage was zero. As shown on Figure 24, the number of years of groundwater in storage is estimated to be 14 years, 7 years, 25 years, 7 years, and 26 years for SAR-T3-1, SAR-T3-2, SAR-T3-3, SAR-T3-4, and SAR-T3-5, respectively. The average annual change in groundwater storage for Arlington Basin is shown in Tables 21 through 25. The change in storage and the number of years of groundwater in storage is also summarized in the following table.

Table 4-8. Scenario Results for Arlington Basin

Model Scenario	Hydrology	Groundwater Pumping		Average Annual Change in Groundwater Storage*	The Number of Years of Groundwater in Storage
SAR-T3-1	Dry	2015 Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-3,040	14
SAR-T3-2	Dry	2040 Projected Pumping	plus a factor of 10% for dry years and an additional reliability factor of 10% on top of this	-6,680	7
SAR-T3-3	Average	2015 Pumping	plus a reliability factor of 10%	-2,250	25
SAR-T3-4	Average	2040 Projected Pumping	plus a reliability factor of 10%	-6,200	7
SAR-T3-5	HCP (1966-1990)	2015 Pumping	plus a reliability factor of 10%	-2,080	26

*A negative sign represents a decline in groundwater storage

4.2.2 Identify Locations for Additional Pumping

An evaluation was made to identify locations in the basin favorable for additional extraction based on the model-calculated saturated thickness after 10 years under scenario SAR-T3-2 (worst-case scenario), current production, and existing well locations. As shown on Figure 25, six locations were identified as areas favorable for additional pumping (four in the SBBA, one in Rialto-Colton, and one in Riverside). In general, saturated thickness within these locations is above 200 ft and no production wells are currently found in these locations. Since saturated thickness in the Arlington Basin is below 100 ft, new pumping wells in this basin are not anticipated to yield significant additional production.

New wells may be added to the locations identified in Figure 25 to allow for the extraction of additional water in storage. In order to estimate the possible quantity of new wells in each groundwater basin, the distance between new production wells was estimated. Based on a well field project near SBBA (GEOSCIENCE, 2011), two production wells may be located as close to 500 ft with acceptable interference. However, this spacing may not be physical possible given other constraints including existing development and infrastructure. For the purpose of this study, it was assumed that the minimum distance between two new production wells would be 0.5 miles. A well siting study would be necessary to determine feasibility of well construction in these areas. The table below summarizes the number of new wells that may be added assuming a minimum spacing of 0.5 miles, number of wells that are currently screened to bedrock, and number of wells that would need to be deepened to extract additional groundwater.

Table 4-9. Number of New Wells that May be Added at Identified Locations for Additional Pumping

Basin	Number of Wells that are Currently Screened to Bedrock[1]	Number of Wells that Need to Be Deepened to Extract Additional Groundwater[2]	Number of New Wells that May be Added at Identified Locations for Additional Pumping[3]
SBBA	13	77	14
Rialto-Colton	7	4	4
Riverside	1	7	1
Arlington	5	0	0

1. Wells with average pumping greater than 250 gpm were used to estimate the quantity of wells that are currently screened to bedrock.
2. Wells with additional capacity less than 100 gpm after deepening were excluded (refer to Tables 1-3 in TM 2 for more details).
3. Locations were identified based on areas favorable for additional extraction (see Figure 13).

5.0 REFERENCES

DWR (State of California Department of Public Works, Division of Water Resources), 1934. South Coastal Basin Investigation – Geology and Ground Water Storage Capacity of Valley Fill. Bulletin No. 45.

DWR (State of California Department of Water Resources), 1986. San Bernardino-San Gorgonio Water Resources Management Investigation.

GEOSCIENCE (GEOSCIENCE Support Services, Inc.), 1991. Subsidence Thresholds in the North County Area of Santa Clara Valley. Prepared for CH2M Hill.

GEOSCIENCE, 2011. Results of Drilling, Construction, Development, and Testing Baseline Feeder Replacement Well – 9th Street North. Prepared for San Bernardino Valley Municipal Water, dated May 9, 2011.

GEOSCIENCE, 2019a. Usable Groundwater in Storage Estimation for the San Bernardino, Rialto-Colton, Riverside, and Arlington Groundwater Basins – Technical Memorandum No. 1: Estimate the Usable Amount of Groundwater Currently in Storage. Prepared for San Bernardino Valley Municipal Water District and Western Municipal Water District, dated June 3.

GEOSCIENCE, 2019b. Usable Groundwater in Storage Estimation for the San Bernardino, Rialto-Colton, Riverside, and Arlington Groundwater Basins – Technical Memorandum No. 2: Quantify the Amount of Groundwater That Can Be Extracted Using Existing Wells. Prepared for San Bernardino Valley Municipal Water District and Western Municipal Water District, dated June 3.

GEOSCIENCE, 2019c. Upper Santa Ana River Integrated Model - TM No. 5A: Predictive Scenario Results – Part 1. Prepared for San Bernardino Valley Municipal Water, dated January 31, 2019.

GEOSCIENCE, 2020a. Usable Groundwater in Storage Estimation for the San Bernardino, Rialto-Colton, Riverside, and Arlington Groundwater Basins – Technical Memorandum No. 3: Identify Facility Needs, If Any, to Access Groundwater if Water Levels Decline and Estimate the Number of Years of Groundwater in Storage. Draft. Prepared for San Bernardino Valley Municipal Water District and Western Municipal Water District, dated February 20.

GEOSCIENCE, 2020b. 2020. Upper Santa Ana River Integrated Model - TM No. 3: Model Calibration. Prepared for San Bernardino Valley Municipal Water District, dated February 11.

Johnson, A.I., 1967. Specific Yield – Compilation of Specific Yields for Various Materials. United States Geological Survey Water-Supply Paper 1662-D. U.S. Department of the Interior, U.S. Geological

Survey, in cooperation with the California Department of Water Resources, United States Government Printing Office: Washington.

K&S (Krieger & Stewart Engineering Consultants), 2016. Rubidoux Community Services District 2015 Urban Water Management Plan. Prepared for Rubidoux Community Services District, dated July 2016.

Martin, G.R. and M. Lew, 1999. Recommended Procedures for Implementation of DMG Special Publication 117, Guidelines for Analyzing and Mitigating Liquefaction Hazards in California. March, 1999.

Matti, J.C. and S.E. Carson, 1991. Liquefaction Susceptibility in the San Bernardino Valley and Vicinity, Southern California – A Regional Evaluation. U.S. Geological Survey Bulletin 1898, 1991.

Tolman, C.F. and J.F. Poland, 1940. Ground Water, Salt-Water, Infiltration, and Ground-Surface Recession in Santa Clara Valley, Santa Clara County, California. American Geophysical Union Transactions.

RMC, 2016. 2015 Urban Water Management Plan Update. Prepared for Western Municipal Water District, dated June 2016.

Valley District (San Bernardino Valley Municipal Water District), 2020. Change in Groundwater Storage for the San Bernardino, Rialto-Colton and Yucaipa Basins. Dated March 2020.

WSC (Water Systems Consulting, Inc.), 2016a. 2015 San Bernardino Valley Regional Urban Water Management Plan. Prepared for San Bernardino Valley Municipal Water District, East Valley Water District, City of Loma Linda, City of Redlands, City of San Bernardino Municipal Water Department, West Valley Water District, Yucaipa Valley Water District, City of Colton, City of Rialto, and Riverside Highland Water Company, dated June 2016.

WSC, 2016b. 2015 Urban Water Management Plan for Riverside Public Utilities Water Division. Prepared for RPU, dated June 2016.