Thesis

The Devil's Gate Reservoir and it's Effect upon Pasadena's Water Supply.

by

John Honsaker Jr.

Class of Nineteen Hundred and Twenty-two

Department of Civil Engineering

California Institute of Technology

Pasadena, California

-1922-

TABLE OF CONTENTS.

* * *

PART 1.

DEVIL'S GATE RESERVOIR

The Devil's Gate Dam has been of great benefit to Pasadena's water supply, in that it prevents a large amount of the flood waters of the Arroyo Seco being wasted into the ocean. The capacity of the reservoir created by this dam is 4600 acre-feet and the height of the spillway above the stream bed is approximately 89 feet. The dam was built primarily for flood control but I believe as a means of flood control it is inadequate. If we take for example the flood of February 1914, we see that in one day, February 20, 7380 acre-feet of water came down the Arroyo Seco. This is enough to fill the reservoir one and one-half times. The following day 3640 acre-feet of water came down, or almost enough to fill the reservoir again. Therefore a reservoir of only 4600 acre-feet capacity could not be used to prevent a flood such as occurred in 1914. The next flood occurred in 1921 and 1922, but was far from being as large as the one previously mentioned. In three days (December 19, 20, and 21, 1921) enough water (4609 acre-feet) came down the Arroyo to fill the reservoir. By proper operation of the gates a flood of such a character might be controlled so that no damage would be done further down the stream, but this would mean that the reservoir would have to be emptied or practically emptied after the first storm and there would then be a large waste of water down the Arroyo.

There has been a great deal of discussion as to the proper way to operate the gates of the dam so as to obtain the maximum conservation of water and at the same time prevent excess flood damage further down the Arroyo. At the present time I believe that Engineer Reagan of the Flood Control District has issued orders that the reservoir be operated entirely for flood control up until May 1 of each year. This means that after every storm occurring before May 1, the water collected behind the dam will be let out as soon as it is possible without causing flood damage. Any water coming down the Arroyo after May 1 will be conserved. This will mean that the dam will be of very little use for conservation purposes, because rainfall data show that almost all the storms worth noting occur before May 1.

I believe that the conservation of the water is as important if not more important than the attempt to control the floods for two reasons: first, because of the high value of water in Southern California, and second, because a repetition of the 1914 floods will cause great damage below whether the dam is there or not. I would suggest that the reservoir be kept approximately one-half full if possible until May 1 of each year and from then on all the water coming down the Arroyo should be held back. This would mean that if a storm occurred before May 1 large enough to fill the reservoir more than one-half full, enough of the water would be let out as soon as possible, with the least damage below, until the reservoir contained one-half its maximum capacity again. Thus the maximum floods occurring, say, once in 10 years would overflow the dam and cause some damage further down the Arroyo, but it would also mean that during the dry years when the water is greatly needed all the water coming down the Arroyo Seco would be conserved and allowed to percolate into the underground basins. The benefit derived from the conservation of of the water I believe would be greater than the damage caused by a flood once in 10 years.

The following data and mass curves show that only for three years during the last 12 years was there any danger of floods. Of these three the flood of 1914 and 1915 could be handled without any damage by keeping the reservoir one-half full as stated above. The floods of 1921 and 1922 might cause slight damage, whereas the large one of 1913 and 1914 could not be prevented from doing damage in any way unless a larger storage reservoir be created. The last curve shows the capacity of the reservoir for different heights of the water behind the dam.

YEAR	MONTH	RUN-OFF IN ACRE-FEET	SUMMATIONS OF FLOW IN ACRE-FEET
	December	252	252
	April	1650	1902
1910	May	587	2,489
&	June	260	2,749
1911	July	109	2,858
	August	64	2,922
	September	214	3,136
	October	146	3,282
	November	111	3,393
1911	December	105	3,498
&	May	208	3,706
1912	June	591	4,297
	July	170	4,467
	August	34	4,501
	September	25	4,526
	October	42	4,568
	November	39	4,607
	December	39	4,646
	January	273	4,919
1912	April	243	5,162
&	May	145	5,307
1913	June	96	5,403
	July	58	5,461
	August	34	5,495
	September	15	5,510
	October	31	5,541
	November	305	5,846
	December	296	6,142
	January	8,120	14,262
1913	February	19,100	33,362
&	March	2,880	36,242
1914	April	1,010	37,252
	May	564	37,816
	June	334	38,150
	July	137	38,287
	August	93	38,380
	September	105	38,485
	October	97	38,582
	November	40	38,622
	December	793	39,415
	January	1,380	40,795
1914	February	3,560	44,355
&	March	1,020	45,375
1915	April	553	45,928
	May	732	46,660
	June	283	46,943
	July	84	47,027
	August	46	47,073
	September	49	47,122

YEAR	MONTH	RUN-OFF IN ACRE-FEET	SUMMATIONS OF FLOW IN ACRE-FEET
	October	47	47,169
	November	102	47,271
	April	579	47,850
1915	May	379	48,229
&	June	183	48,412
1916	July	84	48,496
	August	55	48,551
	September	49	48,600
	October	357	48,957
	November	453	49,410
	December	947	50,357
	January	793	51,150
1916	February	1,420	52,570
&	March	984	53,554
1917	April	420	53,974
	May	323	54,297
	June	120	54,417
	July	36	54,453
	August	23	54,476
	September	8	54,484
	October	13	54,497
	November	32	54,529
	December	55	54,584
	January	63	54,647
1917	February	644	55,291
&	March	3,860	59,151
1918	April	530	59,681
	May	244	59,925
	June	102	60,027
	July	34	60,061
	August	18	60,079
	September	24	60,103
	October	34	60,137
	November	112	60,249
	December	258	60,507
	January	95	60,602
1918	February	343	60,945
&	March	383	61,328
1919	April	131	61,459
	May	109	61,568
	June	39	61,607
	July	4	61,611
	August	6	61,617
	September	14	61,631

YEAR	MONTH	RUN-OFF IN ACRE-FEET	SUMMATIONS OF FLOW IN ACRE-FEET
	October	39	61,670
	November	54	61,724
	December	275	61,999
	January	94	62,093
1919	February	399	62,492
&	March	1,800	64,292
1920	April	613	64,905
	May	225	65,130
	June	103	65,233
	July	25	65,258
	August	5	65,263
	September	8	65,271
	October	17	65,288
	November	48	65,336
	December	69	65,405
	January	298	65,703
1920	February	173	65,876
&	March	750	66,626
1921	April	175	66,801
	May	1,090	67,891
	June	411	68,302
	July	105	68,407
	August	15	68,422
	September	12	68,434
	October	20	68,454
	November	26	68,480
1921	December	8,213	76,693
&	January	4,474	81,167
1922	February	6,294	87,460
	March	3,080	90,541

FLOOD OF 1914

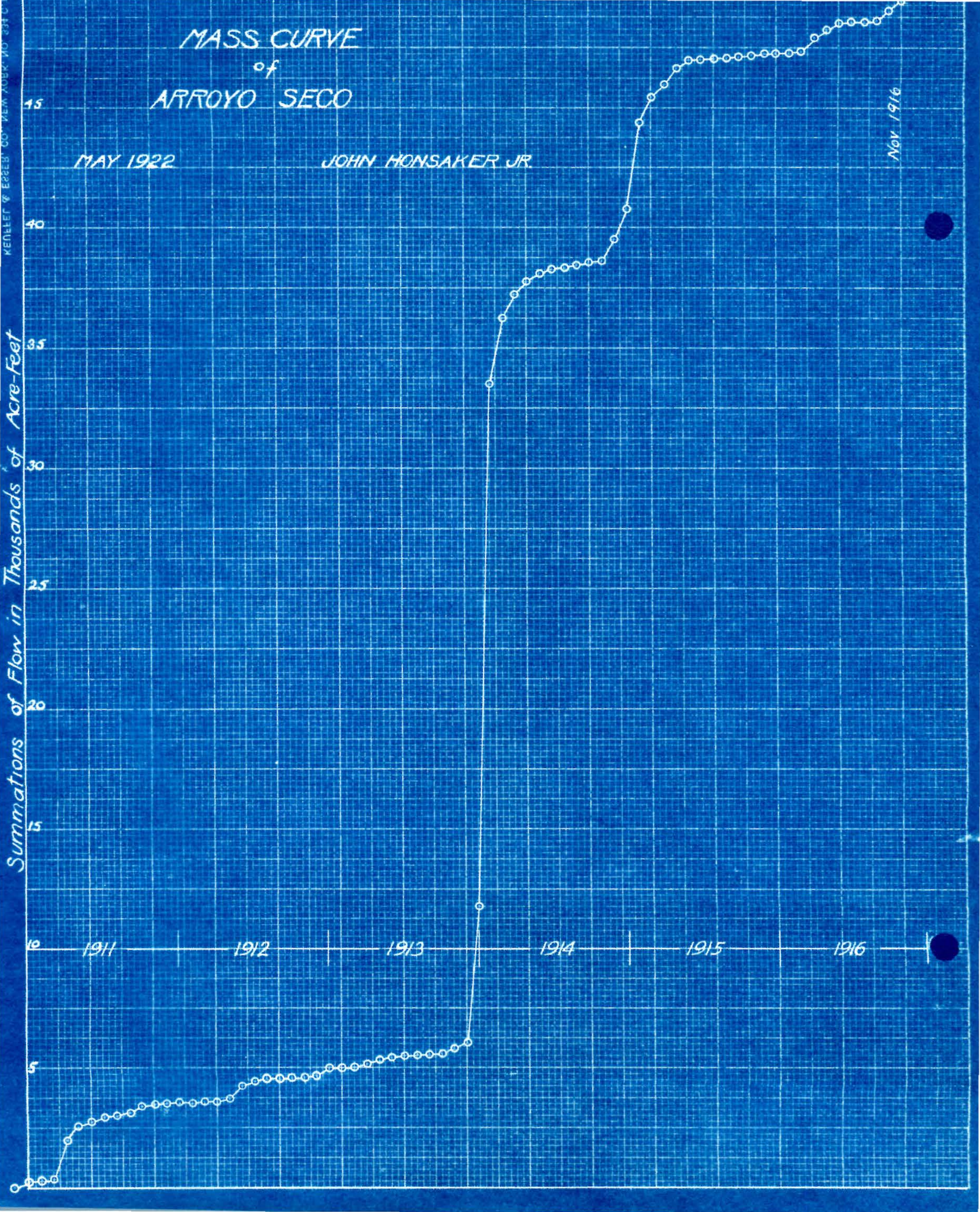
	JANUARY 1914			FEBRUARY 1914		
DAY	SECOND FEET	RUN-OFF IN ACRE-FEET	SUMMATIONS OF FLOW IN ACRE-FEET	SECOND FEET	ACRE-FEET	SUMMATIONS OF FLOW IN ACRE-FEET
1	11	22	22	60	120	8,287
2	8	16	38	51	102	8,389
3	5.5	11	49	38	76	8,465
4	4	8	57	36	72	8,537
5	3	6	63	32	64	8,601
6	2.5	5	68	29	58	8,659
7	2.5	5	73	24	48	8,707
8	2.5	5	78	23	46	8,753
9	2.5	5	83	21	42	8,795
10	2.5	5	88	20	40	8,835
11	2.5	5	93	18	36	8,871
12	2.5	5	98	16	32	8,903
13	2.5	5	103	15	30	8,933
14	4	8	111	14	28	8,961
15	24	48	159	14	28	8,989
16	67	134	293	14	28	9,017
17	160	320	613	14	28	9,045
18	497	984	1,597	684	1,368	10,413
19	39	78	1,675	712	1,424	11,837
20	19	38	1,713	3,690	7,380	19,217
21	13	26	1,739	1,820	3,640	22,857
22	10	20	1,759	852	1,704	24,561
23	8	16	1,775	528	1,056	25,617
24	19	38	1,813	349	698	26,315
25	386	772	2,585	230	460	26,775
26	1,750	3,500	6,085	145	290	27,065
27	500	1,000	7,085	99	198	27,263
28	257	514	7,599	79	158	27,421
29	132	264	7,863			
30	87	174	8,037			
31	65	130	8,167			

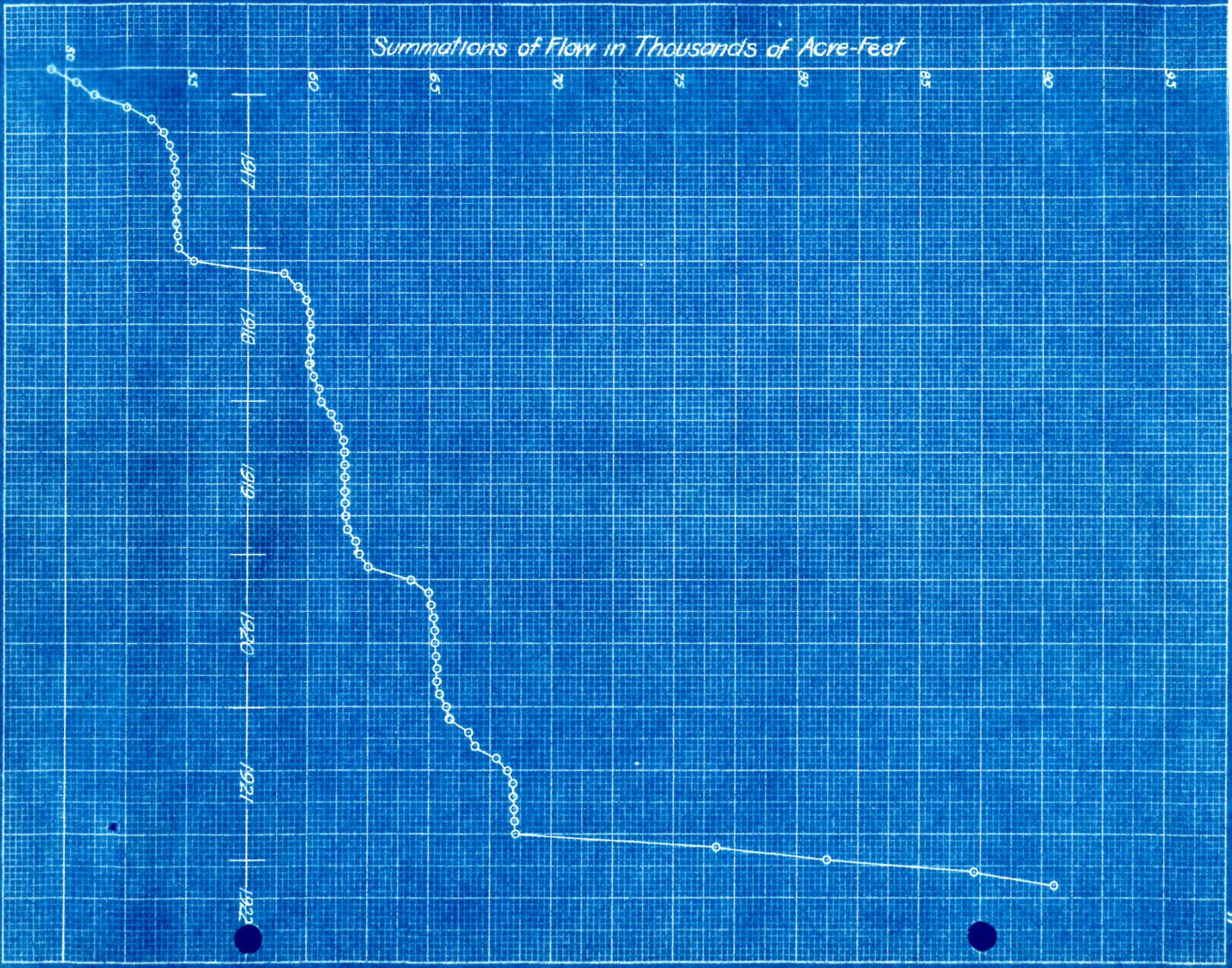
FLOODS OF 1921 & 1922

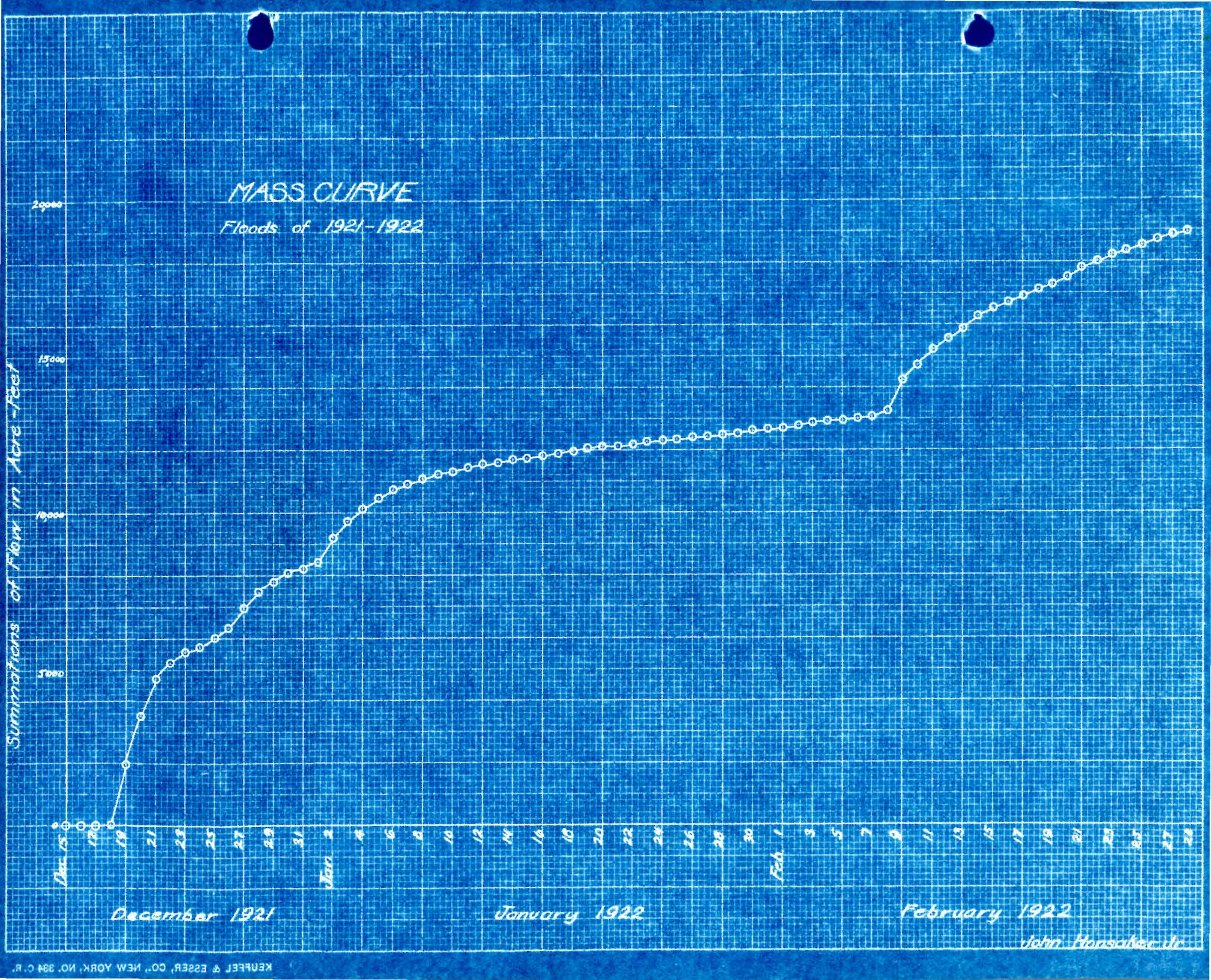
DAY	DECEMBER 1921 RUN-OFF IN ACRE-FEET	DECEMBER 1921 SUMMATIONS OF FLOW IN ACRE-FEET	JANUARY 1922 RUN-OFF IN ACRE-FEET	JANUARY 1922 SUMMATIONS OF FLOW IN ACRE-FEET
1	1.4	1.4	206	8,419
2	1.4	2.8	812	9,231
3	2.2	5.0	526	9,757
4	1.4	6.4	404	10,161
5	1.2	7.6	288	10,449
6	.6	8.2	252	10,701
7	.6	8.8	206	10,907
8	.6	9.4	168	11,075
9	.6	10.0	138	11,213
10	.6	10.6	124	11,337
11	.6	11.2	110	11,447
12	.6	11.8	96	11,543
13	.6	12.4	86	11,629
14	.6	13.0	78	11,707
15	.6	13.6	74	11,781
16	.6	14.2	68	11,849
17	.6	14.8	64	11,913
18	4.0	19	64	11,977
19	1,960.	1,979	62	12,039
20	1,600	3,579	60	12,099
21	1,124	4,703	56	12,155
22	504	5,207	54	12,209
23	376	5,583	52	12,261
24	178	5,761	50	12,311
25	220	5,981	48	12,359
26	376	6,357	52	12,411
27	616	6,973	46	12,457
28	484	7,457	44	12,501
29	360	7,817	52	12,553
30	242	8,059	72	12,625
31	154	8,213	62	12,687

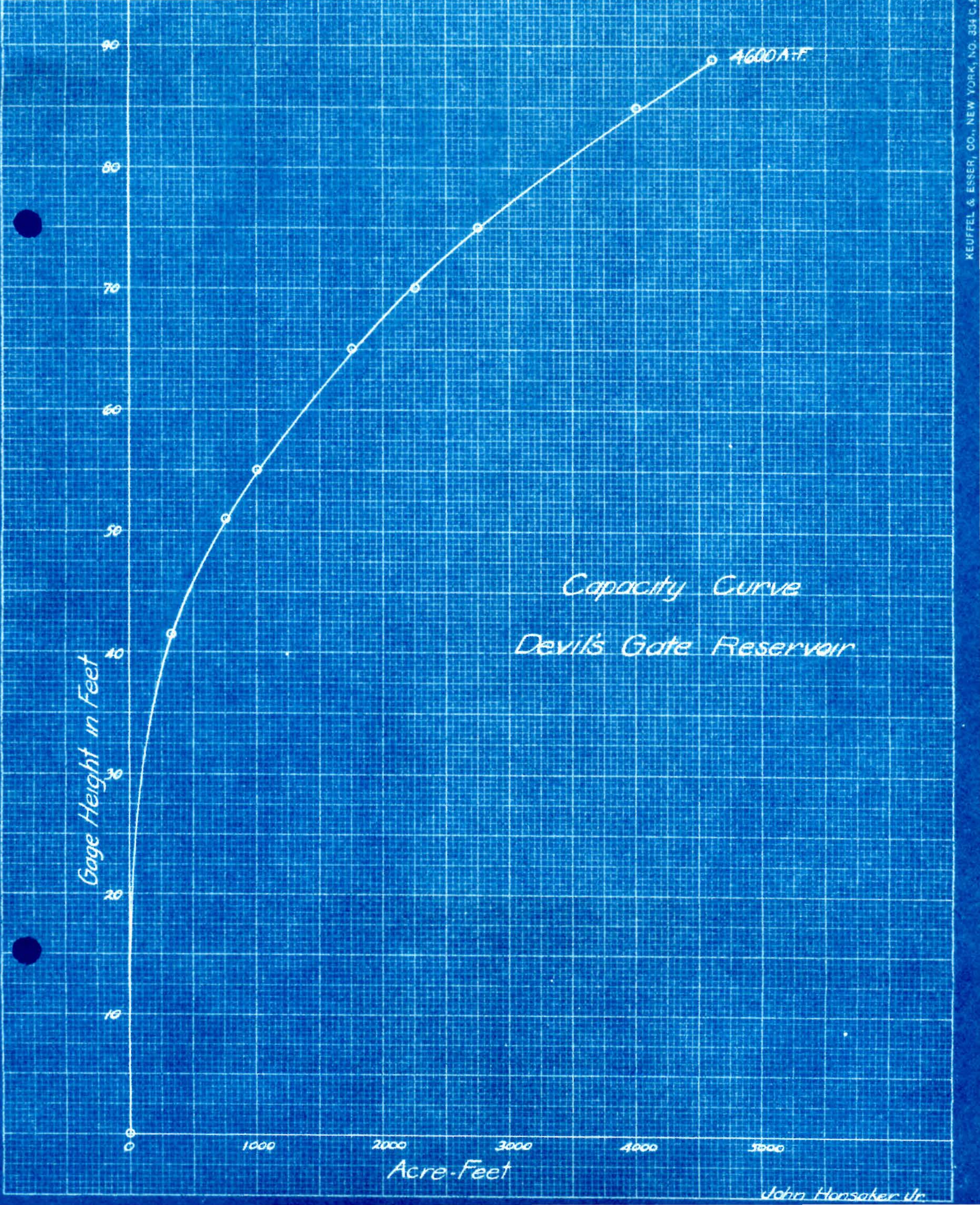
F E B R U A R Y 1 9 2 2

DAY	RUN-OFF IN ACRE-FEET	SUMMATIONS OF FLOW IN ACRE-FEET
1	54	12,741
2	52	12,793
3	50	12,843
4	50	12,893
5	54	12,947
6	56	13,003
7	56	13,059
8	206	13,265
9	958	14,225
10	492	14,715
11	486	15,201
12	392	15,593
13	338	15,931
14	302	16,233
15	260	16,493
16	230	16,723
17	200	16,923
18	176	17,099
19	158	17,257
20	290	17,547
21	250	17,797
22	200	17,997
23	192	18,189
24	176	18,365
25	172	18,537
26	158	18,695
27	154	18,849
28	132	18,931


MASS CURVE
of
ARROYO SECO
MAY 1922
JOHN HONSAKER JR.
Nov 1916
Summations of Flow in Thousands of Acre-Feet
45
40
35
30
25
20
15
10
5
1911
1912
1913
1914
1915
1916


Summations of Flow in Thousands of Acre-Feet
50
55
60
65
70
75
80
85
90
95
1917
1918
1919
1920
1921
1922


MASS CURVE
Floods of 1921-1922
Summations of Flow in Acre-Feet
20,000
15,000
10,000
5000
0
December 1921
January 1922
February 1922



4600 A-F.
Capacity Curve
Devil's Gate Reservoir
Gage Height in Feet
Acre-Feet
0
10
20
30
40
50
60
70
80
90
1000
2000
3000
4000
5000
John Hansaker Jr.
KEUFFEL & ESSER CO., NEW YORK, NO. 334 C.

PART 2.

PASADENA'S UNDERGROUND WATER SUPPLY

Boundary of Pasadena Basin.

The City of Pasadena obtains the principle part of its water supply from what are known as the upper and lower Pasadena Basins.

The drainage area of the Upper basin is about 30 square miles at Devils Gate and it covers an area of about 6000 acres. The mountains are the northern boundary of the Upper Pasadena water-basin. It extends from Eaton's Canyon, about 4 miles east of the Arroyo to the village of La Canada about 2½ miles west of the Arroyo. It is bounded on the south, from La Canada to Devil's Gate, by the San Rafael Hills and from Devil's Gate to Eaton's Canyon, it is bounded by Monk's Hill and an underground dyke extending both west and north-east from the hill.

The water in the Lower Basin directly below the Monk Hill Dyke is about 200 feet below the level of the water in the Upper Basin. The area covered by the Lower Basin is about 18000 acres. The Lower, or Main Pasadena Basin, is bounded on the north by the upper basin just described; on the west, by an underground dyke extending along the east bank of the Arroyo from Devil's Gate to the south city limits; and on the south and east by Raymond Hill and the underground dyke known as Raymond Hill Dyke, which extends both west and northeast from the hill. The northeast arm of the dyke extends to the mountains at the Santa Anita Wash, and as it passes below Sierra Madre it seems to join with the underground base of the mountains.

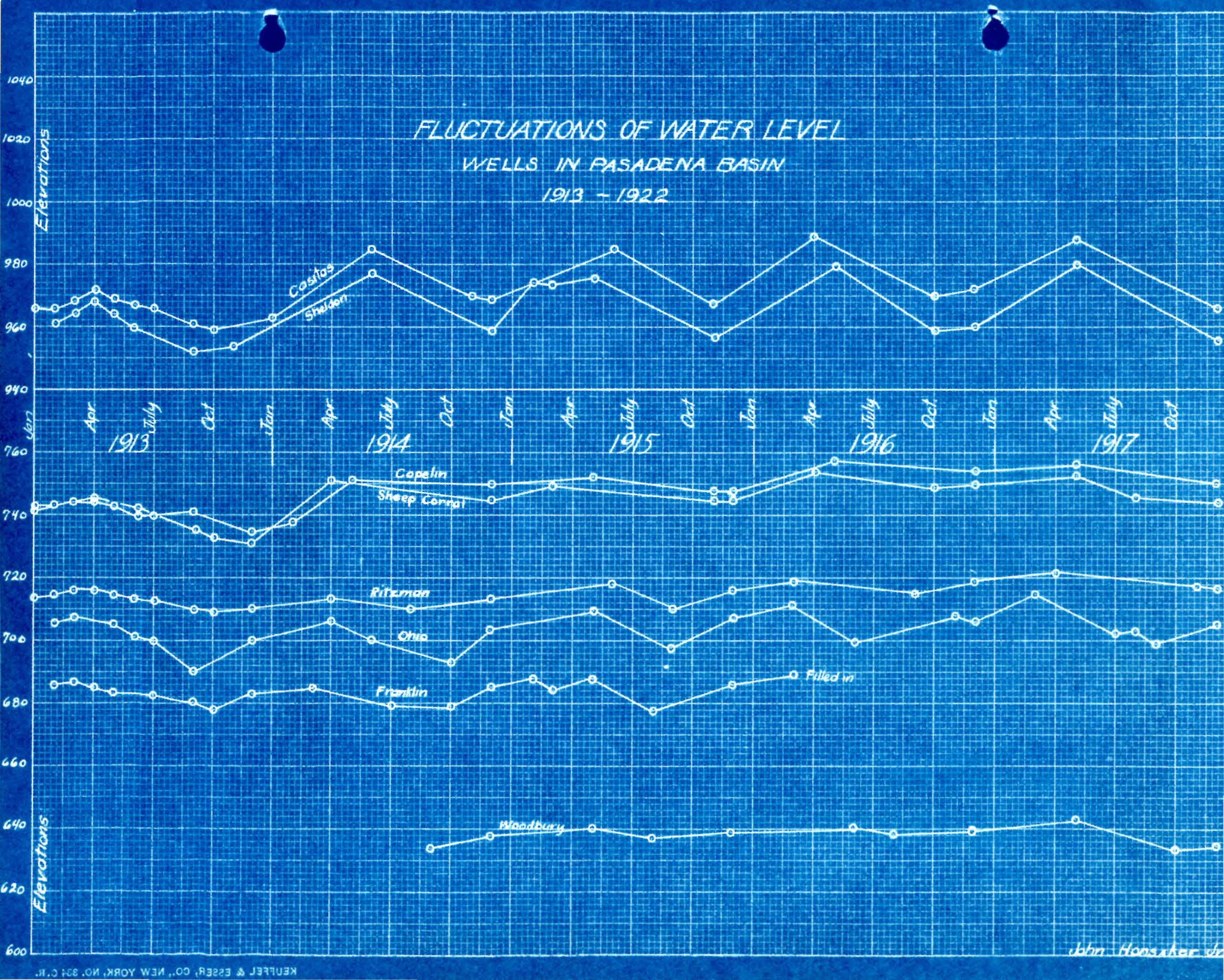
THE EFFECT OF DEVIL'S GATE RESERVOIR UPON THE UNDERGROUND WATER LEVEL

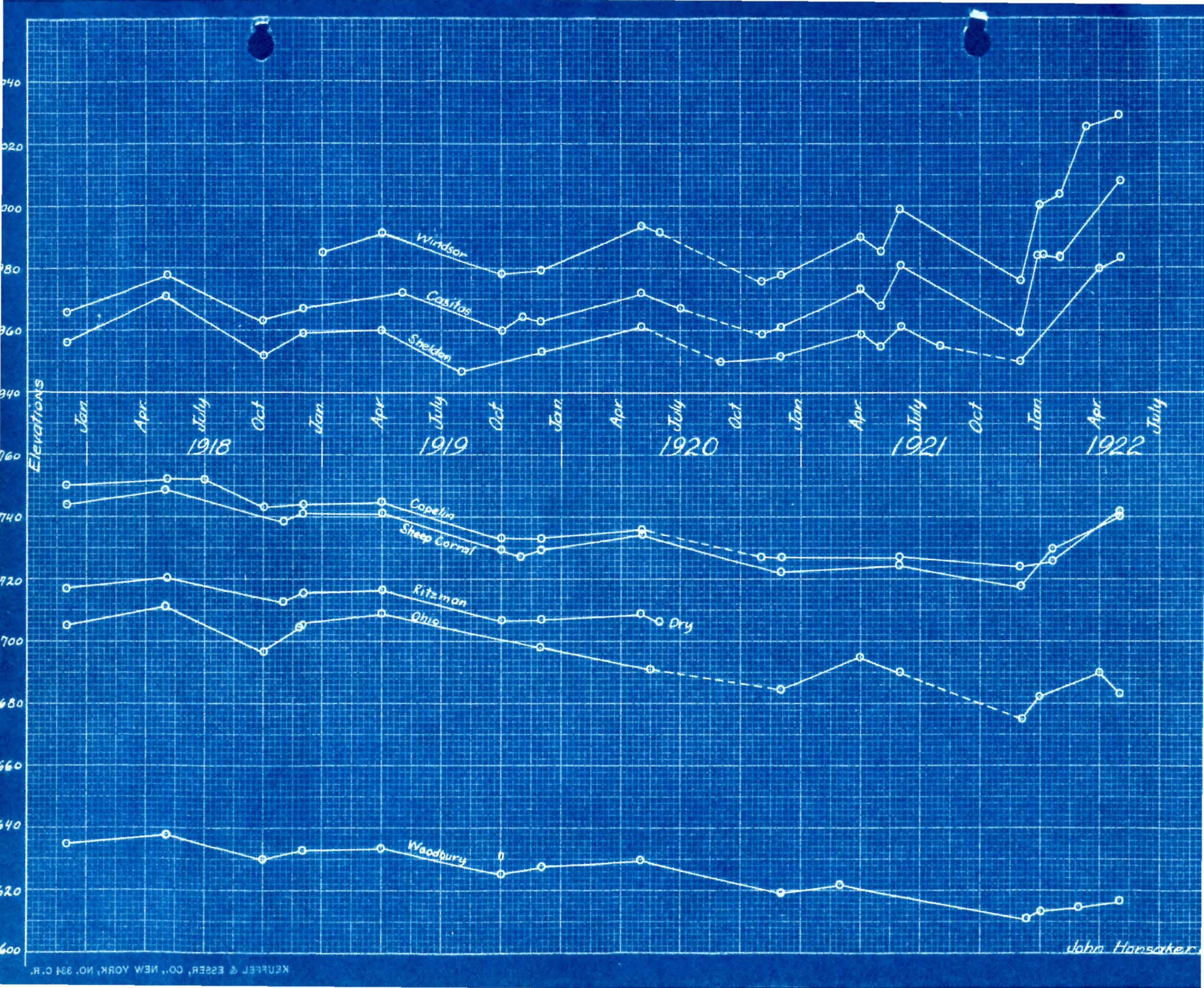
The underground water supply of Pasadena has been heavily drawn upon during the years from 1917 to 1921, and the water levels in both the upper and lower basins have been steadily becoming lower as shown by the curves of water levels for different wells at the end of this part. In the summer of 1921 the water level of the upper basin was higher than in the summer of 1920 because of the water from the late rains in May 1921 being caught behind the Devil's Gate Dam and allowed to percolate into the ground, whereas in the summer of 1921 the water level in the lower Pasadena basin was the lowest it has ever been. According to Chief Engineer S.B.Morris of the Pasadena Water Department, it takes the water that is caught behind the dam six months to flow underground from the upper part of the lower basin to the lower part of the basin. The curves show the effect that the Devil's Gate Lake has upon the water level in the underground basins. There is a marked rise in the level of the water in the wells in the upper basin after the waters from the storms in May 1921 were stored behimd the dam. The flood waters from the storms occuring from December 1921 to March 1922 that were stored behind the dam caused a rapid rise in the water level in the upper basin so that by May 1922 the wells in this basin showed a water level that was the highest it had been in 10 years, the level having risen about 40 feet in four months. The level of the water in the lower basin is also rising although at a much slower rate.

The data for the following curves was kindly furnished by Mr. Morris.

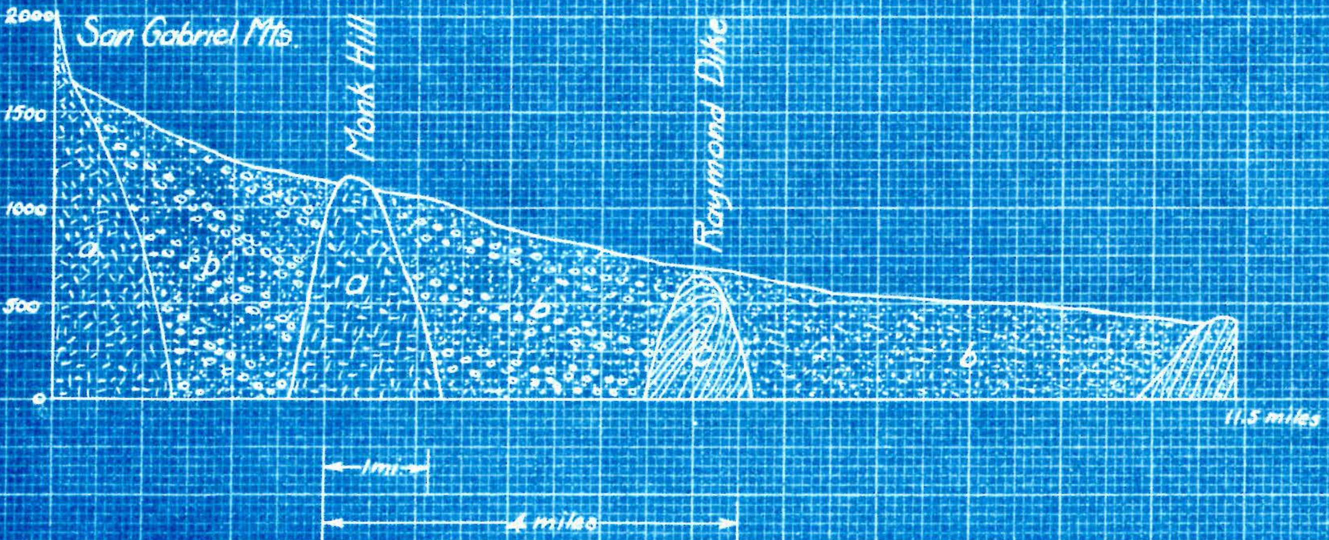
YEAR	CASITAS Month	Elev.	SHELDON Month	Elev.	COPELIN Month	Elev.	CORRAL Month	Elev.	RITZMAN Month	Elev.
1913	Jan.	966	Feb.	961	Jan.	743	Jan.	741	Jan.	714
	Apr.	972	Apr.	968	Apr.	745	Apr.	744	Apr.	716
	July	966	Sept.	952	June	740	June	742	Oct.	709
	Oct.	959	Nov.	954	Dec.	735	Nov.	731	Dec.	710
1914	Jan.	963			Feb.	738	Apr.	751	Apr.	713
	June	965	June	977	May	751			Aug.	710
	Nov.	970			Dec.	750	Dec.	745	Dec.	713
	Dec.	969	Dec.	959						
1915			Feb.	975	May	752	Mar.	750	June	718
	June	985	Mar.	974	Nov.	748			Sept.	710
	Nov.	968	May	976	Dec.	748	Nov.	745	Dec.	716
	Dec.	971	Nov.	977						
1916	Apr.	989	May	980	May	758	Apr.	754	Mar.	719
	Oct.	970	Oct.	959			Oct.	749	Sept.	716
	Dec.	972	Dec.	960	Dec.	754	Dec.	750	Dec.	719
1917	May	988	May	980	May	756	May	755	Apr.	722
							Aug.	746	Nov.	717
	Dec.	966	Dec.	956	Dec.	750	Dec.	744	Dec.	717
1918	May	978	May.	971	May	752	May	749	May	720
	Oct.	963	Oct.	952	July	752	Nov.	739	Nov.	712
	Dec.	967	Dec.	959	Oct.	743	Dec.	741	Dec.	715
					Dec.	744				
1919	Apr.	972	Apr.	960	Apr.	745	Apr.	741	Apr.	717
	Oct.	960	Aug.	947	Oct.	732	Oct.	730	Oct.	707
	Nov.	964	Dec.	952	Dec.	733	Dec.	730	Dec.	707
	Dec.	963								
1920	May	972	May	961	May	736	May	734	May	709
	July	967	Sept.	950	Nov.	727			June	706
	Nov.	959	Dec.	952	Dec.	727	Dec.	722		
	Dec.	961							Dry	Dry
1921	Apr.	973	Apr.	959						
	May	968	May	955	June	727	June	724		
	June	981	June	961	Dec.	724	Dec.	718		
	Dec.7	[illegible]	Aug.	955						
	Dec.									
	20	984								
1922	Jan.	984	Apr.1	980	Jan.		Jan.	730		
	Feb.	984	May.1	983	25	726	25			
	May.				May 1	742	May 1	740		
	1	1008								

YEAR	OHIO Month	OHIO Elev.	FRANKLIN Month	FRANKLIN Elev.	WOODBURY Month	WOODBURY Elev.	WILLSON Month	WILLSON Elev.
1913	Feb. Mar. Sept. Dec.	706 707 690 700	Feb. Mar. Oct. Dec.	686 687 678 683				
1914	Apr. June Oct. Dec.	706 700 693 703	Mar. July Oct. Dec.	686 679 679 685	Sept. Dec.	634 638		
1915	May Sept. Dec.	710 698 707	Feb. Mar. May Aug. Dec.	683 684 688 678 686	May Aug. Dec.	640 637 639		
1916	Mar. June Nov. Dec.	711 700 708 706	Mar. FILLED IN	689	June Aug, Dec.	640 638 640		
1917	Mar. July Aug. Sept. Dec.	715 702 703 699 705			May Oct. Dec.	643 634 635		
1918	May Oct. Dec.	711 697 705			May Oct. Dec.	638 630 633		
1919	Apr. Aug. Dec.	709 690 698			Apr. Oct. Dec.	634 625 628	Jan. Apr. Oct. Dec.	985 991 978 979
1920	May 1 May 15 Dec.	702 691 685			May Dec.	630 620	May June Nov. Dec.	994 991 976 978
1921	Apr. June Dec.1 Dec. 30	695 690 676 682			Mar. Dec. 15 Dec. 30	622 611 613	Apr. May June Dec.15 Dec.30	990 985 999 976 1000
1922	Apr.1 May 1	690 683			Feb. May	615 617	Jan. 1 Jan.30 Mar.15 May 1	1002 1004 1025 1029


FLUCTUATIONS OF WATER LEVEL
WELLS IN PASADENA BASIN
1913 – 1922
Elevations
1040
1020
1000
980
960
940
760
740
720
700
680
660
640
620
600
Casitas
Sheldon
Jan
Apr
July
Oct
1913
1914
1915
1916
1917
Copelin
Sheep Corral
Ritzman
Ohio
Franklin
Filled in
Woodbury
Elevations



Windsor
Casitas
Sheldon
Copelin
Sheep Corral
Ritzman
Ohio
Dry
Woodbury
Elevations
Jan
Apr
July
Oct
1918
1919
1920
1921
1922
980
960
940
740
720
700
680
640
600
John Hansaker



Diagrammatic Section across San Gabriel Valley from Millard Canyon through Monk Hill and Oak Knoll: (a), granite rocks, (b), alluvium, (c), sandstone and shale.

John Hansaker Jr.

Part 3.

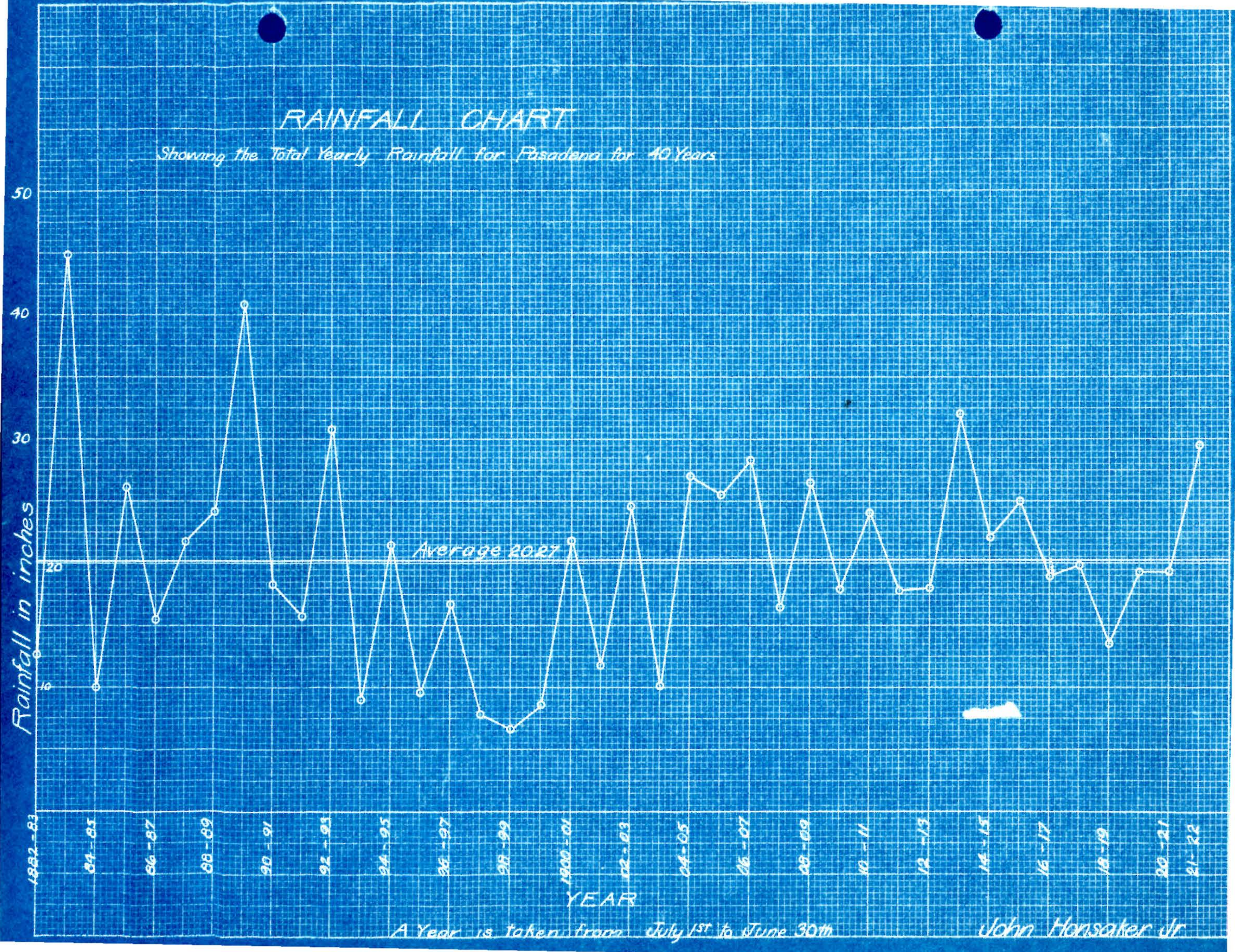
RAINFALL RECORDS

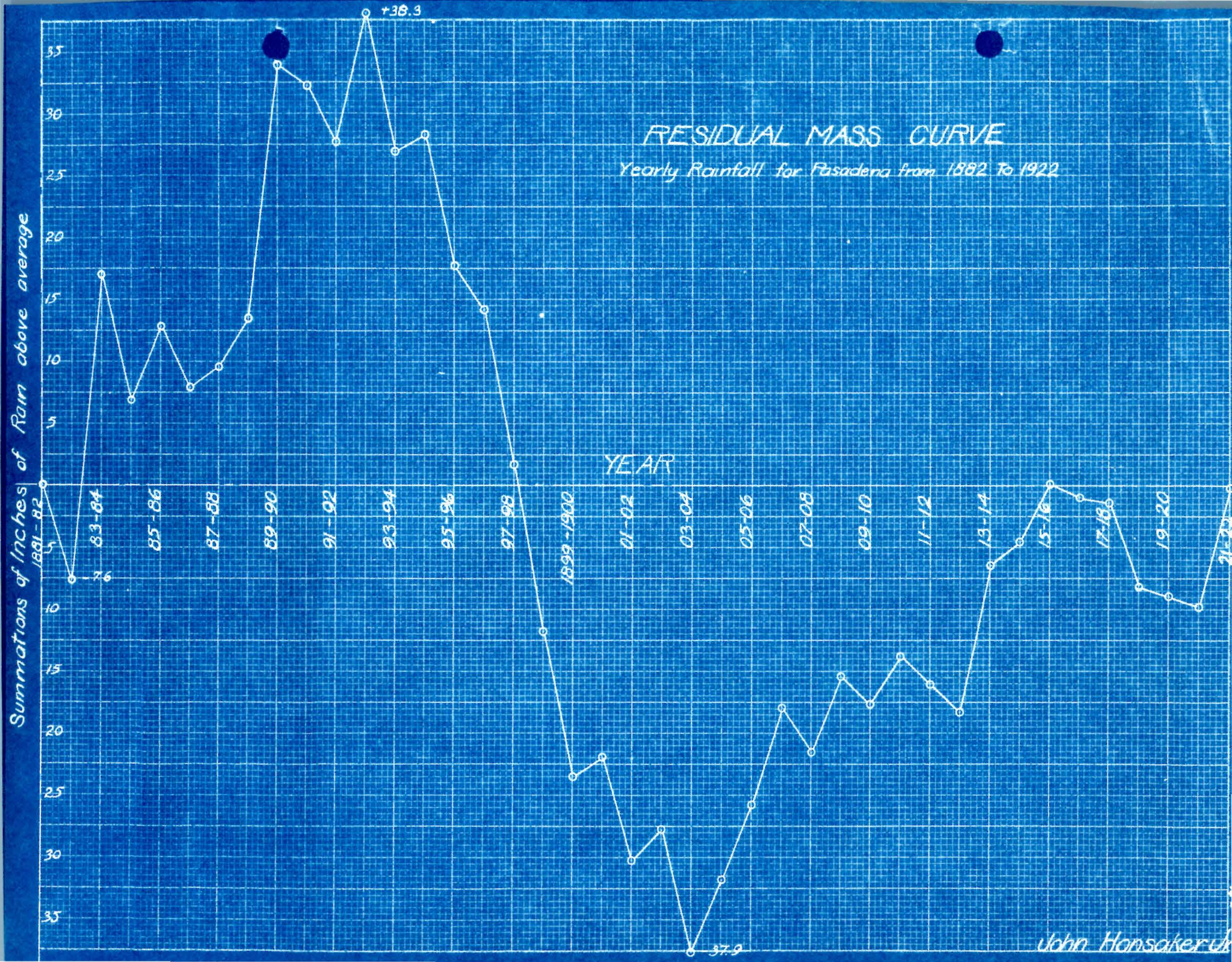
It is because of the scarcity of rainfall in Southern California that water has such a high value. The average rainfall for Pasadena for the past fourty years is 20.275 inches per annum. This is much higher than in other parts of Southern California, the average for Los Angeles being only about 15 inches and for San Diago it is less than 10 inches. A period of wet years will be followed by a period of dry years as a rule, and it is because of this prolongation of a dry period that the water situation in Southern California is serious. There must be an adequate source of supply so that if a period of dry years comes there will be sufficient water. The Devil's Gate Reservoir is a great aid in this direction, in that it holds back the floods of wet years and thus stores the water underground to be drawn upon during a period of dry years. During a dry year no water at all will reach the dam site so that in that case the underground supply will have to be drawn upon or else some other outside source of supply found.

The following Residual Mass Curve shows how a period of wet years will be followed by a number of dry years. These periods are probably 10 years of more in length but they cannot be absolutely determined. An attempt was made by the writer to derive a formula giving the runoff of a drainage area in terms of the annual rainfall and slope of the country, but no such formula appears possible for streams in Southern California. It might be possible to get two formulas, one for flood years and another for ordinary years.

YEAR	SEASONAL RAINFALL IN IN.	DIFFERENCE FROM AVERAGE RAINFALL	SUMMATIONS OF DIFFERENCES
1882-83	12.67	- 7.60	- 7.60
1883-84	44.93	+24.76	+17.16
1884-85	10.00	-10.27	+ 6.89
1885-86	26.11	+ 5.84	+12.73
1886-87	15.5	- 4.77	+ 7.96
1887-88	21.77	+ 1.60	+ 9.56
1888-89	24.20	+ 3.93	+13.49
1889-90	40.89	+20.62	+34.11
1890-91	18.34	- 1.83	+32.28
1891-92	15.75	- 4.52	+27.76
1892-93	30.71	+10.54	+38.30
1893-94	8.91	-11.36	+26.94
1894-95	21.53	+ 1.35	+28.30
1895-96	9.61	-10.56	+17.74
1896-97	16.64	- 3.63	+14.11
1897-98	7.93	-12.34	+ 1.77
1898-99	6.64	-13.63	-11.86
1899-00	8.54	-11.73	-23.59
1900-01	21.85	+ 1.58	-22.01
1901-02	11.89	- 8.28	-30.29
1902-03	24.56	+ 2.49	-27.80
1903-04	10.19	-10.08	-37.88
1904-05	27.07	+ 6.80	-31.08
1905-06	25.49	+ 5.22	-25.86
1906-07	28.22	+ 7.95	-17.91
1907-08	16.51	- 3.76	-21.67
1908-09	26.53	+ 6.26	-15.41
1909-10	17.99	- 2.28	-17.69
1910-11	24.15	+ 3.98	-13.71
1911-12	17.80	- 2.47	-16.18
1912-13	18.04	- 2.13	-18.31
1913-14	32.12	+11.85	- 6.46
1914-15	22.02	+ 1.85	- 4.61
1915-16	25.02	+ 4.75	+ .14
1916-17	19.08	- 1.09	- .95
1917-18	19.83	- .44	- 1.39
1918-19	13.61	- 6.66	- 8.05
1919-20	19.39	- .88	- 8.93
1920-21	19.41	- .86	- 9.79
1921-22	29.55	+ 9.28	- .51

Total 810.99 in.
Average for 40 yrs. 20.275 in.


RAINFALL CHART
Showing the Total Yearly Rainfall for Pasadena for 40 Years
Rainfall in inches
50
40
30
20
10
Average 20.27
1882-83
84-85
86-87
88-89
90-91
92-93
94-95
96-97
98-99
1900-01
02-03
04-05
06-07
08-09
10-11
12-13
14-15
16-17
18-19
20-21
21-22
YEAR
A Year is taken from July 1st to June 30th
John Hunsaker Jr.


RESIDUAL MASS CURVE
Yearly Rainfall for Pasadena from 1882 To 1922
Summations of Inches of Rain above average
YEAR
+38.3
-7.6
-37.9
1881-82
83-84
85-86
87-88
89-90
91-92
93-94
95-96
97-98
1899-1900
01-02
03-04
05-06
07-08
09-10
11-12
13-14
15-16
17-18
19-20
John Hansaker

Part 4.

CONCLUSIONS

The conclusion drawn from this report is that although the Devil's Gate Reservoir is a great aid to Pasadena's water supply, another source of water supply must be found sooner or later. There are several possible means of bringing water from other water sheds to serve Pasadena's needs. One of these that seems feasible is to obtain water from the Los Angeles Aqueduct and store it behind a dam constructed at Sycamore Canyon. There is a good dam site there and according to Engineer Morris of the Pasadena Water Department, a dam 200 feet high, creating a reservoir with 4 or 5 times the capacity of the Devil's Gate Lake, could be built at a cost of $2,000,000 for storing this water. Although there is a great amount of water from this aqueduct being allowed to flow into the sea each year there would apparently be difficulty in getting Los Angeles to let Pasadena have this water. Another possible source is to build a dam in the Tejunga Creek and by means of about two and one-half miles of tunnels bring the water to Pasadena. At the present time Los Angeles has a hold on the Tejunga, and even if it were possible to obtain the water rights from Los Angeles it would be a very expensive project because of the long tunnels. The Tejunga is a poor water producing area and it has only about one-third the runoff per square mile that the San Gabriel water-shed has. The maximum rainfall occurs in the West Fork because the clouds catch upon the high ridge in front. The water from the San Gabriel water-shed might also be brought to serve Pasadena's needs, but the construction of a dam would be expensive because of the few good dam sites. Still another drainage area near Pasadena that is not utilized as yet for water supply is the water-shed around Little Bear Lake. Like most of the other projects this also has its faults, the main trouble being because of the excessive amounts of tunnels that would have to be constructed to bring the water to Pasadena.

It seems evident that some additional source of water supply must be procured in the near future, and I firmly believe that some of the above projects could serve this need, but it would take a careful investigation into each one to finally determine which one is the best.

APPENDIX A

A PORTION OF THE REPORT BY CHIEF ENGINEER, S.B.MORRIS, OF THE MUNICIPAL WATER DEPARTMENT MADE TO CITY MANAGER, C.W.KOINER, SEPTEMBER 2nd, 1921.

WATER CONSERVATION

Beginning with January, 1914, the Department has spread flood waters on the gravels of the Arroyo Seco below the mouth of the canyon in order to replenish the underground water basin and provide more water to be taken out again either by gravity through about a mile of tunnels at Devil's Gate or by the several wells and pumping plants operated by the City. The following table shows the quantity of water conserved in each year in this manner in addition to the normal percolation in the stream channel compared with rainfall at Pasadena and run-off from 16.4 square miles of Arroyo Seco Canyon as measured by the United States Geological Survey:

Year Ending June 30	Rainfall in Inches	Water Spread on Gravels: Cubic Feet	Acre Feet	Runoff 16.4 Sq.Mi. Ac.Ft.
1914	34.12	147,300,000	3,390	33,000
1915	22.02	106,900,000	2,460	8,640
1916	25.09	145,700,000	3,350	18,900
1917	19.08	107,000,000	2,460	5,584
1918	19.83	39,000,000	895	5,618
1919	13.61	12,470,000	286	1,528
1920	19.39	51,560,000	1,184	3,638
1921	19.41	12,890,000	296	Not compiled
		622,820,000	14,321	
Average 8 years		77,852,000	1,790	

DEVIL'S GATE DAM

In addition to the water conserved by water spreading, very beneficial effect was obtained by the Devil's Gate Dam which effectively prevented any water from going to waste the past season down the Arroyo Seco. The 69,700,000 cubic feet, or 1,100 acre feet, of water caught by the dam this spring has been of great assistance in furnishing adequate water this summer. The water levels of the upper or Monks Hill underground basin have been higher this summer than last year, while in the lower or Raymond Hill Basin the water has been lower than in any previous year.

It was only through the co-operation of the County Board of Supervisors and the Chief Engineer of the Flood Control District in installing temporary wooden collapsible gates when there was insufficient time and funds for the placing of the permanent gates that the flood waters were held back and permitted to penetrate into the underground basin. Contract has now been awarded by the District to the Llewellyn Iron Works for the construction and installation of the permanent hydraulically operated steel gates which are to be installed before the next winter.

DEVIL'S GATE TUNNELS

During the past year the work of concreting the timbered sections of the main Devil's Gate Tunnels was completed. This involved the lining with concrete of 3796 feet of tunnels and the lining and in some cases sinking and lining of 1099 feet of tunnel shafts. Now all this concrete work is completed and the tunnels are prepared to safely stand the additional strain which will be put upon them when the Devil's Gate Reservoir is rapidly filled. That portion of the tunnels passing under the stream bed of the Arroyo Seco was bulkheaded off with concrete in order to force greater filtration before any flood waters can penetrate into the tunnels and flow into the distribution reservoirs. Percolation through the gravel into the tunnels, however, proved so rapid after the flood water reached the dam that it was necessary to shut off the tunnel water for several days until the water cleared up again.

The activities in developing our present underground water resources by additional wells and by the installation of deep well pumps in place of pit type of pumps is not adding to Pasadena's permanent water supply, but it does make the procurement of water locally more efficient and enables the City to pass more safely through a short cycle of dry years. Procurement of a permanent additional source of water supply is absolutely necessary to the maintenance of our present City development. This matter is now receiving the serious consideration and study of the City administration, and I know it is not necessary to further emphasize the fact here. Too much hope cannot be placed in the relief offered by the construction of the Devil's Gate Dam as the drainage area of but 30 square miles is not sufficient to take care of the demands of Pasadena and surrounding areas. The annual water supplied by this Department itself is nearly two times the surface capacity of the Devil's Gate Reservoir. During a very dry season no water reaches the dam site at all.