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SRP789

SURPLUS WATERS

OF

SAN PEDRO RIVER

May 5, 1942

RAYMOND A. HILL, Consulting Engineer

Los Angeles, California - Phoenix, Arizona

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SUITE 1000 EDISON BUILDING
LOS ANGELES, CALIFORNIA

May 4, 1942

Ellinwood & Ross
Title & Trust Building
Phoenix, Arizona

Attention: Mr. William A. Evans

Dear Mr. Evans:

In your letter of March 28, 1942, you asked for our opinion as to the amount of surplus water in San Pedro River and as to the quantity of storage which would be needed to insure the delivery from such surplus of 15,000 acre feet annually into Gila River.

In brief, we find that during the past twelve years there was an average of 26,000 acre feet per year in San Pedro River at Tres Alamos which was neither consumed in transit nor diverted for irrigation use within San Carlos Project. We find further that this surplus can be so regulated as to provide for the delivery of 15,000 acre feet annually into Gila River by the operation of a reservoir having a net effective capacity of 50,000 acre feet. The initial gross capacity of the reservoir must be enough greater to compensate for the accumulation of roughly 800 acre feet of silt annually.

We invite your attention to the fact that an equal average gain in the water supply available to San Carlos Project from San Pedro River would result from the operation of a reservoir of 35,000 acre feet net effective capacity if this reservoir were operated for flood control. In such event, the amount of water so developed would vary widely from year to year, requiring that some system of credits and debits be adopted so that the interests of all parties concerned would be protected.

Our report, entitled "SURPLUS WATERS OF SAN PEDRO RIVER", is submitted herewith.

Very truly yours,

RAYMOND A. HILL

RAH:vr

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SRP791

TABLE OF CONTENTS

	Page
SURPLUS WATERS OF SAN PEDRO RIVER	1
RUNOFF OF SAN PEDRO RIVER	1
RUNOFF AT TRES ALAMOS DAM SITE	2
DIVERSIONS TO SAN CARLOS PROJECT	6
SOURCE OF WATER DIVERTED	9
Losses in Transit	10
Supply from Tributaries	11
USE OF SAN PEDRO WATER	12
Storable Surplus Based on Daily Flows	14
STORAGE REQUIREMENT	16
REQUIRED CONSERVATION STORAGE	18
Reserve for Silt	19
Total Required Storage	20
STORAGE REQUIRED FOR REGULATION	21
SUMMARY	22

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SRP792

LIST OF TABLES

Table		Page
I	TOTAL DIVERTED AT ASHURST-HAYDEN DAM	9
II	RELEASE FROM COOLIDGE RESERVOIR	9
III	USE AND LOSS OF TRIBUTARY WATER	11
IV	STORABLE SURPLUS BASED ON ANNUAL DIVERSIONS	14
V	SURPLUS AT TRES ALAMOS	16
VI	AREA AND CAPACITY OF TRES ALAMOS RESERVOIR	18

* * * * * * *

LIST OF PLATES

A	RELATION BETWEEN ANNUAL DISCHARGES OF SAN PEDRO RIVER AT TRES ALAMOS AND AT CHARLESTON AND FAIRBANK
B	DISCHARGE OF SAN PEDRO RIVER AT TRES ALAMOS BY MONTHS FROM 1921 to 1940
C	STORABLE SURPLUS AT TRES ALAMOS
D-1 to D-10	STAGE OF RESERVOIRS OPERATED FOR CONSERVATION AND FOR FLOOD CONTROL

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SURPLUS WATERS OF SAN PEDRO RIVER

San Pedro River is a potential source of additional water for use in the irrigation of lands within San Carlos Project, constructed and operated by the United States. Under present conditions, a considerable part of the flows of San Pedro River cannot be diverted to the Project because of the torrential character of the unregulated stream; on the other hand, most of the low flow of San Pedro River is diverted and used beneficially for irrigation within the San Carlos Project.

Any determination of the quantity of water which might be made available by storage and regulation of the floods of San Pedro River thus involves: first, the magnitude and time of occurrence of floods in San Pedro River; second, the use now being made of such waters; and third, the size of the reservoir needed for substantially complete regulation.

RUNOFF OF SAN PEDRO RIVER

San Pedro River is the principal tributary of Gila River between Coolidge Dam and Ashurst-Hayden Dam, the former being the storage dam of San Carlos Project and the latter being the diversion structure at the head of the canal system. San Pedro River rises in Sonora, Mexico, and flows in a northerly direction, entering Gila River a short distance above Kelvin, Arizona. The total drainage area is more than 4000 square miles.

4480

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Stream discharge measurements have been made at various points along the stream, but there is no long time continuous record near its mouth. The runoff from the upper 1000 square miles of the drainage basin has been measured at Palominas by the U. S. Geological Survey for most of the time since 1930. Further downstream a gaging station has been operated by the Geological Survey at Charleston for more than ten years and at Fairbank, a near-by location, in earlier years. The combined record at these stations covers most of the time from 1912 to date and constitutes the best record of runoff in San Pedro River.

These gaging stations, however, are located nearly 100 miles from the mouth of San Pedro River and consequently do not reflect the contributions to the stream flow from about half of the watershed nor losses due to irrigation use and channel evaporation between Charleston and Gila River. Both can be estimated with reasonable accuracy, however, by comparison with the records kept for about ten years at the gaging station near Mammoth, which is less than 20 miles from Gila River.

The total contribution of San Pedro River to the flow of Gila River can also be estimated from the gain in flow between Coolidge Dam and Kelvin, where stream gaging stations have been operated for many years. This is particularly true for the period since 1928, throughout which the flow of Gila River below Coolidge Dam has been regulated completely.

RUNOFF AT TRES ALAMOS DAM SITE

One of the few possible locations for a storage dam on San Pedro River is that known as Tres Alamos Dam Site, about 2 miles

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miles north of Benson. No record of stream flow at this point has been kept, so that the supply available for regulation must be estimated from stream discharge records at other points. One such study has been made by J. S. Gatewood of the U. S. Geological Survey in connection with certain investigations carried on by the United States with a view to construction of flood control works on San Pedro River.

The Gatewood estimate covers the period from October, 1912, to September, 1941, inclusive. Daily flows above 70 cfs at Charleston were considered by him as flood flows and were estimated by one method of procedure; the flows below 70 cfs were handled by a different but related method. The following is quoted from a memorandum prepared by Mr. Gatewood:

For days above 70 second-feet: For the 8 years and 7 months of simultaneous record, the Charleston record was listed in 9 divisions, each division respectively including all days from 100 to 200 second-feet, 201 to 300, 301 to 500, 601 to 700, 701 to 1,000, 1,001 to 1,500, 1,501 to 2,500, 2,501 to 4,000, and 4,001 up. The mean for all days in each division was determined. For the same calendar days, the same thing was done for Palominas and for Mammoth allowing one-day time interval to Mammoth. When completed, this study showed, for example, that for all days between 100 and 200 second-feet at Charleston, the mean was 132 second-feet, and that the corresponding means at Palominas and Mammoth, based on 8 years and 7 months of simultaneous record, were 76 and 152 second-feet respectively. Using drainage area as ordinate and these mean runoff figures as abscissa, a family of curves was plotted from the 9 sets of points. Smooth curves could be drawn through most of the sets; for the two highest divisions the curves were drawn to average the points, the maximum error between point and curve being 20% for the curve representing days above 4,001 second-feet. The shape of the curves between Charleston and Mammoth is not known for sure, but the maximum error possible appears to be less than 20%. Discharge at Tres Alamos was picked from these curves, entering with Charleston discharge as abscissa and reading Tres Alamos discharge where the curves intersected 2,490 square miles, the drainage area at Tres Alamos dam site. To facilitate use of the curves a relation table was made up, covering discharge as low as 70 second-feet and up to 2,500 second-feet at Charleston. Above that figure, discharge was

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computed from the curves by proportion. For discharge above the highest curve (4,910 second-feet at Charleston) the proportion at 4,910 second-feet was assumed to hold.

Discharge at Tres Alamos computed as above varies up and down with Charleston discharge variations. If precipitation between Charleston and Tres Alamos was more or less than that above Charleston, such additional variation would not be included. To give weight to precipitation variations, another factor was introduced, namely, the difference from normal of rainfall between Charleston and Tres Alamos to that above Charleston. Study of the Weather Bureau records showed that in the area above Charleston, precipitation records for Bisbee and Tombstone were available 1914 to date. No records prior to 1914 were readily available and the 1912 and 1913 records were not corrected for precipitation variation. Below Charleston and above Tres Alamos, Benson record was available 1914 to date, and Camille and Fairbank 1924 to date. Several other records were available for short periods, as Fort Huachuca, Elgin, Apache Powder Co., Cochise Stronghold, and Hereford but none were of sufficient length and continuity for this use. Unpublished as well as published records of the Weather Bureau were obtained.

It was assumed that only rainfall of 0.4 inch or more per day ? would cause appreciable runoff. For each of the five stations, Bisbee, Tombstone, Benson (1914-41) and Camille, Fairbank (1924-41), annual totals were computed for days of 0.4 inch or more precipitation. From these, it was found that normally, or on the average, 1914-23, 1.4 times the Benson precipitation equalled the mean of the Bisbee and Tombstone precipitation. Also, that for 1924-41, 1.3 times the mean of Fairbank, Camille, and Benson precipitation equalled the mean of Bisbee and Tombstone precipitation. Each storm 1914-41 was then studied taking the mean of precipitation above and below Charleston using the stations just mentioned. After allowing for the normal difference of 1.4 or 1.3 as determined above, the ratio of rainfall below Charleston to that above was determined. The difference between flow at Tres Alamos and at Charleston was then varied by the ratio, and the product added to Charleston to give a new Tres Alamos figure.

In computing and applying the precipitation variation factor, no ratio was applied when it was within 20% of normal, or when the precipitation on which it was based was less than 0.2 inch. In computing the ratio for each storm, all rainfall including that as little as 0.01 inch was used, on the theory that in a storm period any amount, no matter how little, would have its effect on the runoff. Ratios below about 0.5 or above about 3.0 were viewed with suspicion and investigated and thrown out or modified, as it was realized that the precipitation data are too scanty to give a complete and reliable picture of each storm.

After Tres Alamos discharge had been computed by the above methods, it was compared by inspection with the Mammoth record 1931-41, and with the difference between flow of Gila River at Kelvin and at San Carlos (later "at Coolidge Dam") 1912-30. In a few cases this comparison showed that computed flow at Tres Alamos was probably excessive, and it was arbitrarily cut. Also it showed, particularly in the winter, that small floods sometimes reached Mammoth or Kelvin

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which had not passed Gila-San Carlos or Charleston, and in the latter case, were therefore not reflected in the Tres Alamos records. In such cases an arbitrary estimate was made for Tres Alamos, based on the Mammoth or Kelvin record and on the precipitation distribution as shown by Weather Bureau records. For the December 1914 flood a special hydrographic study was made, estimating Tres Alamos from the Fairbank, Gila-San Carlos and Gila-Kelvin records. For the September 1926 flood a special study of the subdivided discharge record near Fairbank was made.

The final correction to Tres Alamos discharge was to subtract for diversions in the Benson area. Details are given below. For daily discharge above 150 second-feet at Charleston diversions were assumed as zero, because of washouts or because negligible. For dailies between 100 and 150 second-feet at Charleston 5 second-feet was subtracted and for dailies from 70 to 100 second-feet at Charleston (89 to 127 at Tres Alamos) half of the total diversions were subtracted. Method of computing total diversions is given below.

For days of 70 second-feet or less: Two actual discharge measurements are available. In March 1921, 3.4 second-feet was measured when Charleston showed 15.6 second-feet. In March 1942, 7.9 second-feet was measured when Charleston showed 17 second-feet. Estimates were made for other low periods such as that in June, on the average, when there are 20 second-feet at Charleston, Tres Alamos would be dry; in December, with Charleston at 20 second-feet, Tres Alamos would have 10 second-feet. Using such estimates relations were determined for different seasons of the year. The year was divided into five periods or seasons each representing a different condition of evaporation, transpiration, seepage loss, and diversion. The five divisions are:

December, January
March, August
May, June, first half of July
September, October, February, April
November, last half of July.

Using the low-flow measurements and estimates the lower end was determined for each of five curves, one for each of the above seasons. The curves were plotted using daily discharge at Charleston as ordinate and daily discharge at Tres Alamos dam site (diversions being deducted) as abscissa.

To determine the high end of the curves, a curve was plotted as determined from the high-water study for the range 70 to 100 second-feet. From this curve, diversions were subtracted, varying with the five seasons given above. The low-water curves were then completed, one for each season, by connecting the high ends as here described with the low ends or low points as described in the preceding paragraph.

Diversions were estimated from: (1) A seepage run in 1921 which showed a total of 33 second-feet diverted between Charleston and Tres Alamos, when Charleston flow was 16 second-feet. This shows that much

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of the diversion is re-diversion. (2) Total annual diversion figures given in Arizona Colorado River Commission's "Stream Flow Summary" p. 6, section 6. From these sources, and knowledge of practises in the Benson area, the consumptive use diversion (net loss to river) was estimated as follows, for the average and normal:

December, January	6 second-feet	744
March, August	20 second-feet	2480
May, June, first half of July	10 second-feet	1520
September, October, February, April	16 second-feet	3808
November, last half of July	12 second-feet	1104
		9656 AcFt

The December-January diversion is held high because of considerable artesian well diversion, which may not reach the river, even though it went unused. May, June, and first half of July diversion is held relatively low because of lack of flow to supply the needed greater diversion.

The consistency of the Gatewood estimate is indicated by the relation between the annual discharges as measured at Charleston and the estimated discharges at Tres Alamos for the same periods of time. It is our opinion that the Gatewood estimate is reasonable and that, while the flow on any individual day may be substantially in error, the differences will largely be compensating and thus be of no significance in a determination of the amount of water which may be developed by regulation in a storage reservoir of considerable size.

The above relationship is shown on Plate A, from which it appears that 20,000 acre feet is consumed or lost each year in transit through the valley between Charleston and Tres Alamos. This loss of 20,000 acre feet is only partially offset in dry years by inflow from the intervening drainage area, but in wet years there is an actual net gain between these points. The flow at Tres Alamos is about 5,000 acre feet more than the flow at Charleston in an average year, indicating an average contribution of 25,000 acre feet per year from the intervening drainage area.

2900 AF from Plate B + Charleston record for 1921-40 cy 1934-5

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From a study of the relation between the measured flow at Charleston and the measured flow at the gaging station near Mammoth a similar conclusion is indicated. In general, the flow at Mammoth during a year, expressed in acre feet, is twice as great as the difference between the flow at Charleston and 20,000 acre feet. In other words, the tributary contribution from Charleston to Mammoth is substantially 20,000 acre feet per year less than the flow passing Charleston.

From Tres Alamos to Mammoth there is apparently little additional net loss in transit, because the contribution from the generally unproductive watershed between these points is usually sufficient to offset any such losses. While occasional measurements have been made of the flow of San Pedro River at its mouth, no record exists from which a direct determination can be made of any losses below Mammoth. It is obvious, however, from the records of the flow of Aravaipa Creek, which joins San Pedro River not far above its mouth, that all losses below Mammoth are more than offset by tributary contributions.

The difference between the flow in Gila River at Kelvin and the quantity of water released from Coolidge Reservoir measures the total net tributary contribution with reasonable exactitude. From the relation between this difference and either the measured flow at Mammoth or the estimated runoff at Tres Alamos, it is apparent that about two thirds of the total tributary contribution originates in the San Pedro watershed in normal years, the proportion being somewhat less in dry years and somewhat greater in wet years. When the gain from Coolidge to Kelvin is compared with the flow of San Pedro River at Charleston, it is found also that the total annual discharge at Charleston less 20,000 acre feet is consistently equal to 20% of

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that gain. This relationship thus conforms with the other estimates of losses below Charleston. It may therefore be said with assurance that the 20,000 acre feet of water is consumed each year along San Pedro River from Charleston to Gila River, and that substantially all of this loss occurs above Tres Alamos.

DIVERSIONS TO SAN CARLOS PROJECT

Water stored in Coolidge Reservoir on Gila River constitutes the primary source of supply for lands in San Carlos Project. In the normal operation of this reservoir, water is released in an amount sufficient to make up the difference between the contribution of San Pedro River and other tributaries and the total demand for water for irrigation of project lands. Consequently, except for certain periods of drouth, the historical diversions at Ashurst-Hayden Dam determine the amount of water which could be used beneficially at the time.

Such diversions at Ashurst-Hayden Dam generally range from a minimum of about 6,000 acre feet per month in the winter to a maximum of about 50,000 acre feet per month in the summer; in occasional years, however, the maximum diversion has exceeded this quantity. The rate of diversion thus varies from an average of about 100 cfs in winter to about 800 cfs in summer, although there have been occasional days of no diversion and others on which more than 1000 cfs were taken into the Florence-Casa Grande Canal at Ashurst-Hayden Dam.

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The quantities diverted since Coolidge Dam was placed in service were as follows:

TABLE I

TOTAL DIVERTED AT ASHURST-HAYDEN DAM

(a) Year	Acre Feet	
1928		76267
1929	75,000	75190
1930	225,000	221427
1931	233,000	232906
1932	282,000	282060
1933	333,000	333350
1934	188,000	188260
1935	243,000	243170
1936	244,000	243670
1937	300,000	302460
1938	152,000	156170
1939	134,000	133716
1940	155,000	154588
1941		294527
14yr AV		209840

SC Proj Records Kollenborn

SOURCE OF WATER DIVERTED

During the same years the regulated release from Coolidge Reservoir was as follows:

TABLE II

RELEASE FROM COOLIDGE RESERVOIR

(a) Year	Acre Feet	
1928		87600
1929	28,000	27563
1930	220,000	220152
1931	214,000	213884
1932	279,000	279076
1933	340,000	339670
1934	169,000	168900
1935	190,000	190500
1936	236,000	235700
1937	298,000	298200
1938	152,000	151700
1939	123,000	122900
1940	143,000	143220
1941		234574
14yr AV		194188

USGS

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From the foregoing tabulations it might appear that the flow of Gila River impounded in Coolidge Reservoir was more than 90 percent of the water supply for San Carlos Project. Moreover, the tributary flow diverted is greater than the difference between the gross release from Coolidge Reservoir and the diversion into Florence-Casa Grande Canal because of losses in transit.

Losses in Transit

The loss of water from Coolidge Reservoir to Kelvin due to irrigation use and evaporation is largely obscured by tributary inflows which are greater during much of the year than the actual losses, but when the difference between the flow at Kelvin and the flow immediately below Coolidge Reservoir is computed by days, with allowance for the time of travel, the actual loss can be approximated.

Hydrographs of such daily differences show an apparent loss of 30 to 50 cfs between these points after the winter rains and before the summer rains, a period during which surface tributary flows are usually nominal. The same hydrographs, however, usually show an actual gain between Coolidge Dam and Kelvin in the winter months, even when there is little or no apparent tributary inflow. Obviously, there must be some loss in transit at all times after allowance is made for tributary contributions; this quantity is indefinite but probably amounts to a minimum of 10 cfs. This minimum loss, plus the observed gain during the winter at times of no floods in tributaries, thus constitutes a correction factor which must be added to the apparent loss in other months.

From the foregoing it has been estimated that the normal loss in transit of water flowing from Coolidge Dam to Kelvin at times of no tributary inflow would range from a minimum of 10 cfs in the winter

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to 80 cfs in the summer. Between Kelvin and Ashurst-Hayden Dam certain other losses would occur which should be about 25% of the loss above Kelvin. The annual gross loss from Coolidge Dam to Ashurst-Hayden Dam is thus a maximum of about 42,000 acre feet. The actual loss in any year varies somewhat, depending upon the number of days of release of water from Coolidge Reservoir; in some recent years of low release from Coolidge Reservoir the gross loss probably did not exceed 35,000 acre feet.

Supply from Tributaries

The total contribution to the supply of water actually diverted into Florence-Casa Grande Canal, which originated from tributaries entering Gila River below Coolidge Dam, can be computed by deducting the total release from Coolidge Reservoir from the total diversion and adding to the difference the losses in transit. The amount of tributary inflow which was either diverted at Ashurst-Hayden Dam or was consumed in transit along Gila River during each of the twelve years from 1929 to 1940, inclusive, was as follows:

TABLE III

USE AND LOSS OF TRIBUTARY WATER

Overest Tot. Trib. Inflow	Year	Hills est Total Trib. Flow Q ÷ %	Quantity Acre Feet	Proportion of Total Tributary Flow: loss CD-AH Q-(AH-CD)		loss CD-Kel ÷ loss CD-AH ÷ 1.25
	1929	100000	64,000	16373	64 %	12130
131545	1930	157200	44,000	42725	28 %	34200
177235	1931	196500	55,000	35978	28 %	28800
86603	1932	110000	44,000	41016	40 %	32800
45244	1933	67900	36,000	42320	53 %	33800
39137	1934	65600	59,000	39640	90 %	31700
160880	1935	202200	93,000	40330	46 %	32300
79158	1936	103900	53,000	45030	51 %	36000
92263	1937	116700	49,000	44740	42 %	35800
46324	1938	74600	41,000	36530	55 %	[illegible]
56464	1939	80300	45,000	34184	56 %	37400
129666	1940	158700	54,000	42632	34 %	34000
95047		121236	52091	40470	43	32364

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In the last column of the above table is shown the proportional amount of the total tributary flow which was either diverted at Ashurst-Hayden Dam or was consumed in transit along the course of Gila River. The total tributary flow was arrived at by adding the normal loss between Coolidge Dam and Kelvin to the net gain in the total flow between the same points. This method of calculation assumes that there was no material tributary contribution below Kelvin.

In 1940, for example, 155,000 acre feet were diverted at Ashurst-Hayden Dam. The release from Coolidge Reservoir was 143,000 acre feet, so that if there had been no channel loss, only 12,000 acre feet of tributary water would have been used. Actually, there were channel losses amounting to about 42,000 acre feet, making a total demand upon the tributary flow of 54,000 acre feet for the year. In the same year the net gain from Coolidge Dam to Kelvin amounted to 125,000 acre feet, after losses of about 33,000 acre feet. The total tributary contribution to Gila River was thus roughly 158,000 acre feet. The use and loss of tributary water hence amounted to 34 percent of the total tributary contribution, and 60 percent of the total passed Ashurst-Hayden Dam in 1940.

USE OF SAN PEDRO WATER

In the same year the discharge of San Pedro River near Mammoth was 74,000 acre feet. The loss between Mammoth and the mouth of the stream being nominal, it is presumptive that the same proportion; i.e. 34 percent, of the flow passing Mammoth was either diverted at Ashurst-Hayden Dam or was consumed in transit between Mammoth and that point of diversion. The quantity used or consumed thus amounted to

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26,000 acre feet, leaving 49,000 acre feet of storable surplus in 1940.

The runoff at Tres Alamos during 1940 has been estimated at 72,000 acre feet, so that the contribution to the flow of San Pedro River from tributary watersheds between Tres Alamos and Mammoth was 2,000 acre feet greater than losses in transit between these points. Consequently, only 23,000 acre feet of the flow which passed Tres Alamos went to make up the total demand upon the tributary flow of 54,000 acre feet for the year. The storable surplus at Tres Alamos thus amounted to 49,000 acre feet in 1940.

The flow at Charleston in the same year was 59,000 acre feet. From this total must be deducted 20,000 acre feet for losses below Charleston, leaving 39,000 acre feet as the contribution from the upper watershed which reached the mouth of the river. This quantity is 53 percent of the total at Mammoth, so that if all of the channel loss were charged against the flow passing Charleston, 13,000 acre feet of Charleston water would be deemed to have been consumed along Gila River or diverted at Ashurst-Hayden Dam. On the other hand, if the loss below Charleston be distributed between the tributary contribution and the flow passing Charleston, the proportion becomes 69:94, which gives 16,000 acre feet as the amount of Charleston water used or lost below the mouth of San Pedro River. An intermediate figure closer to the first case is probably most nearly representative of the true condition, so that it is estimated that the storable surplus at Charleston would be equal to the total runoff less the sum of 20,000 acre feet loss along the course of San Pedro River and 15,000 acre feet use and loss below the mouth of San Pedro River, leaving a net of 25,000

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acre feet for the year 1940.

In the following tabulation are shown the results of similar computations for the typical period from 1929 to 1940:

TABLE IV

STORABLE SURPLUS BASED ON ANNUAL DIVERSIONS

Quantities in Acre Feet

Year	At Tres Alamos	At Charleston
1929	20,000	8,000
1930	32,000	24,000
1931	52,000	37,000
1932	22,000	10,000
1933	13,000	2,000
1934	0	0
1935	27,000	14,000
1936	22,000	9,000
1937	39,000	20,000
1938	15,000	5,000
1939	23,000	12,000
1940	49,000	25,000
Average	26,000	14,000

See our Comp. table 12 we get 27350 av.

Storable Surplus Based On Daily Flows

Diversions to Florence-Casa Grande Canal during the summer are in the order of 800 cfs if there is sufficient water to meet this demand. When the tributary contribution to Gila River is small, the supply is naturally obtained by release of water from Coolidge Reservoir; at times of storm on the lower watersheds, the release from Coolidge Reservoir is restricted and the unregulated stream flow is used so far as practicable.

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Owing to the short duration of most of the storms and to the distance of Coolidge Reservoir from the point of diversion to the San Carlos Project, there is usually some reservoir water in the stream at times of flood in San Pedro River and other tributaries. The larger flood flows are usually caused by storms which occur at the time of rain in the valley areas, so that there are numerous occasions when flood flows in San Pedro River reach Ashurst-Hayden Dam while there is a relatively low irrigation demand.

The tributary flows which reach Gila River from other streams and from the lower portion of the San Pedro River watershed 72647 are generally as great as the quantity passing 45592 Tres Alamos, so that about one-half 38.5% of the total diversion of tributary water on days of flood would normally be from water originating above Tres Alamos. Under average conditions, therefore, it follows that, whenever the mean daily discharge at Tres Alamos is more than 300 cfs, the quantity in excess of that flow could be stored for subsequent use without encroachment upon the use now being made of such waters by San Carlos Project.

AV. For 1930-40
Cascabel at Wink = 21665
21665 x 1033 = 22400 of T.A.
SP at W. 61593 - 22400 = 39188
Gila inflow at Kelvin = 33464
33464 + 39188 = 72647
Trib flows = 72647
passing TA = 45592
Would be less than 300 if allowable on above basis

From the Gatewood estimate the volume of flood flows in excess of 300 cfs was determined. The surplus so found bears a consistent relationship to the total runoff as shown on Plate C, and is in accord with the estimates of storable surplus made on an annual basis. The relationship is that given in the following tabulation:

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TABLE V

SURPLUS AT TRES ALAMOS

Quantities in Acre Feet

Total Annual Discharge	Flow in Excess of 300 cfs	Present Use and Loss
10,000 12668	1,000 2483	9,000 1934
20,000	5,300	14,700
30,000	11,400	18,600
40,000 48009 Case 21-46 49580 TA "	18,500 25250 26079	21,500
50,000	26,300	23,700
60,000	34,500	25,500
70,000 71917	43,300 46750	26,700 1940
80,000	52,400	27,600
90,000	62,000	28,000
100,000	72,000	28,000
120,000 131853	92,000 112057	28,000 1922
150,000	122,000	28,000

Check 3 yr from unknown daily flow

The surplus in any future year, as determined from Table V, could properly be deemed to be the quantities of water which could be impounded in a reservoir at or near Tres Alamos without encroachment upon the present use of the waters of San Pedro River by San Carlos Project and by others between Tres Alamos and Ashurst-Hayden Dam. Furthermore, no deduction for losses in transit could properly be made in excess of those set forth in Table V, should such surplus water be impounded to augment the diversions now made for San Carlos Project from waters of San Pedro River.

STORAGE REQUIREMENT

The capacity of the storage reservoir which would be needed to regulate or conserve the surplus flow of San Pedro River will depend upon the location of the reservoir and the manner in which it will be

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SRP809

operated.

The most favorable known dam site structurally is at Charleston. However, it is apparent from the values in Table IV that it would be impracticable to add more than about 10,000 acre feet per year to the usable supply of San Carlos Project through construction of a dam at this point.

It is our understanding that it is proposed to develop 15,000 acre feet per year by storage of surplus flood flows of San Pedro River, and that the water so conserved would be used by the San Carlos Project as compensation for new diversions to be made from San Francisco River or other tributaries of Gila River above Coolidge Reservoir.

The reservoir on San Pedro River could thus be operated in either of two manners:

a. For the storage of only that portion of the flow which would not be consumed in transit or diverted at Ashurst-Hayden Dam, and for the subsequent release of impounded waters in the amount of 15,000 acre feet per year at such times and at such rates as to cause no increment loss in transit, or

Holdover

b. For the storage and regulation of all flows of San Pedro River entering the reservoir and for the release in the same year of the total impounded at such times and at such rates as would result in reduced losses in transit.

Regulation

The first case is equivalent to the diversion of the surplus water from the reservoir on San Pedro River to the point of use of the

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water which is to be diverted from San Francisco River, and necessitates that the operation of the reservoir be kept in the control of the agency which diverts from the upper tributary stream.

The second case assumes that the reservoir would be operated not only for the storage of surplus water, but for the regulation of the entire flow of San Pedro River to the best interest of the San Carlos Project, and under this condition the operation and control of the reservoir would necessarily lie with that Project. Under this condition, the gain in the water supply of San Carlos Project would vary widely from year to year, so that some system of credits and debits would need to be established to provide for more uniform diversions from an upper tributary.

regulation

REQUIRED CONSERVATION STORAGE

Tres Alamos Reservoir has been surveyed roughly by agencies of the United States, from which it appears that its area and capacity are about as shown on the following table:

TABLE VI

AREA AND CAPACITY OF TRES ALAMOS RESERVOIR

Depth of Water at Dam	Area in Acres	Capacity in Acre Feet
0	0	0
10	200	2,000
20	430	6,000
30	700	13,000
40	1050	22,000
50	1450	36,000
60	1900	54,000
70	2600	77,000

The net evaporation loss from the reservoir will be equal to the evaporation which would occur from the water surface, less the.

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evaporation and transpiration losses which now take place from the same area. Rainfall on the water surface is not a factor, because the estimates of runoff are for the flow at the dam site. This net loss will be close to 5 feet in depth per year, and for a reservoir of 50,000 acre feet capacity will amount to about 6,000 acre feet per year on the average.

If the reservoir be operated for the conservation of surplus flood waters, a net effective capacity of 50,000 acre feet will be required at or near Tres Alamos in order to insure the release annually of 15,000 acre feet. Such a reservoir would have filled and overflowed in 1921, in 1926, in 1931, and in 1940, as a result of the large flood flows occurring in the summer of each of these years. The same reservoir would have substantially filled in 1923, in 1932, in 1937, and in 1939, and depending upon the exact manner of operation, there might have been a small amount of spill in several of these years. The withdrawal of 15,000 acre feet per year from this reservoir, together with evaporation losses, would have substantially emptied the reservoir in 1926, in 1929, and in 1936.

Reserve For Silt

San Pedro River is a notoriously muddy stream which would bring large quantities of silt and sand into any reservoir constructed across its channel. Various estimates have been made of the amount of silt and sand carried by San Pedro River, ranging from about 1% to 3% by weight on the average. The higher value is probably more nearly representative. A relatively large amount of reserve capacity must, therefore, be provided in order that the effective storage capacity of the reservoir may not be reduced seriously.

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Silt as deposited in a reservoir has a dry weight after several years' compaction of about 80 lbs. per cubic foot, so that the volume of the silt load of San Pedro River after compaction would approximate 2% of the quantity of water. The average inflow to the reservoir at Tres Alamos would be roughly 50,000 acre feet per year, hence silt deposits would accumulate at an average rate of about 1,000 acre feet per year. Some part of the silt load would be dropped at the head of the reservoir, which would raise the stream bed, causing a flattening further upstream which in turn would induce silt deposition. At other times, when the reservoir was emptied, a certain amount of the silt in the reservoir basin would be eroded and carried through the outlets. Occasionally there would probably be silt flows through the reservoir, a phenomenon which has been observed frequently on the Rio Grande and which took place in Boulder Reservoir until the lower outlets were closed. For purposes of estimation, therefore, it is concluded that there would be an average net encroachment of 800 acre feet per year.

Total Required Storage

If it be assumed that provision must be made initially for the release of 15,000 acre feet per year from the stored surplus continuously during the next forty years, a reservoir of at least 80,000 acre feet effective capacity at the time of construction would be needed at Tres Alamos. If it be assumed, on the other hand, that the maximum rate of diversion from upper tributaries will prevail for only ten years, and that subsequently the diversions will be reduced about one-third, then it would be necessary to provide only about 60,000 acre feet of initial capacity. The 10,000 acre feet reserved for

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silt in this case would take care of accumulations during the early years, during which a high rate of diversion would be needed, and the smaller net capacity at the end of 40 years would still be great enough to permit the conservation of 10,000 acre feet per year.

STORAGE REQUIRED FOR REGULATION

Less storage will be needed for the regulation of flood flows in San Pedro River if the reservoir is practically emptied every year than would be necessary if the reservoir were operated to provide a supply of 15,000 acre feet each year in addition to that now used by San Carlos Project from San Pedro River. Operation of the reservoir primarily for flood control would also result in smaller losses in transit than is now the case and would permit of flexible operation of both Coolidge Reservoir and Tres Alamos Reservoir.

Under this condition, the normal procedure would be to impound all of the low flows, which are largely lost in transit under present conditions, and to regulate the flood flows to the amount which could be diverted into Florence-Casa Grande Canal without completely shutting off the supply from Coolidge Reservoir. Releases from the reservoir at Tres Alamos would generally be made during the period of flood inflow, and in many cases the reservoir would be partially emptied and refilled several times each year. As a result, as much additional water could be made available on the average to San Carlos Project with 35,000 acre feet of storage operated in this manner as could be developed by a reservoir of 50,000 acre feet effective capacity operated only to impound floods for subsequent release.

On Plates D-1 to D-15 are shown hydrographs of the flow of San Pedro River at Tres Alamos and the stages at which the reservoir

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would have been, if operated for conservation with the same quantity released each year, or if operated for flood regulation with different amounts released each year.

SUMMARY

In general, we find that there is a surplus of water in San Pedro River, after deduction of uses and losses in transit and diversions at Ashurst-Hayden Dam for use in San Carlos Project. During the years of operation of Coolidge Reservoir, this storable surplus has averaged about 14,000 acre feet at Charleston and about 26,000 acre feet per year at Tres Alamos. At the latter point, which is a potential reservoir site below the main irrigated areas on the San Pedro River, the amount of storable surplus has ranged from substantially nothing in the driest year of record to more than 100,000 acre feet in the years in which large floods occurred.

If a reservoir of 50,000 acre feet net effective capacity were constructed at Tres Alamos or at some point in that vicinity, 15,000 acre feet each year could be added to the supply now available for diversion to San Carlos Project. In order to insure that this capacity would be available at all times during the next forty years, a greater capacity would have to be provided to offset the accumulation of silt within the reservoir basin. If this were done initially, a reservoir of at least 80,000 acre feet capacity would be necessary. On the other hand, if the storage dam were of a type adapted to subsequent raising, a smaller gross capacity could be provided initially and the dam could subsequently be raised to offset the accumulation of silt. The latter procedure has advantage in that the future demand

Holdover

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for water may be less than 15,000 acre feet per year, in which case no enlargement of the reservoir would be needed.

Greater benefits would accrue from the operation of a reservoir on San Pedro River for flood regulation than will be possible if the operation be purely for conservation of surplus waters. A smaller reservoir would be required because it could be emptied substantially every year, thereby affording capacity which otherwise would not be available for impounding flood flows. Furthermore, there would be less evaporation loss from the reservoir and less loss in transit along the course of the stream. In brief, a reservoir of 35,000 acre feet effective capacity at Tres Alamos, operated for flood control, would provide at least as great a gain in water supply as a 50,000 acre foot reservoir operated for conservation.

If allowance be made initially only for the accumulation of silt during the first ten years of operation, assuming that provision be made for raising of the dam whenever needed thereafter, an initial capacity of 60,000 acre feet of storage should be provided at or near Tres Alamos if the reservoir is to be operated as a conservation measure under the control of the agency diverting from San Francisco River, or 45,000 acre feet of effective capacity should be provided initially if the reservoir is to be operated for flood control by or for the San Carlos Project.

In the former case, the storage and subsequent release of the surplus water of San Pedro River becomes a direct offset to new diversions from San Francisco River. In the latter case, the gain in supply to San Carlos Project, while averaging at least as much, will vary widely from year to year. This will require that some system

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SRP816

of credits and debits be adopted so that the interests of all parties concerned will be protected.

Raymond A. Hill
Phoenix, Arizona
May 4, 1942

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SRP8117

RELATION BETWEEN
ANNUAL DISCHARGES OF SAN PEDRO RIVER
AT TRES ALAMOS
AND
AT CHARLESTON AND FAIRBANK

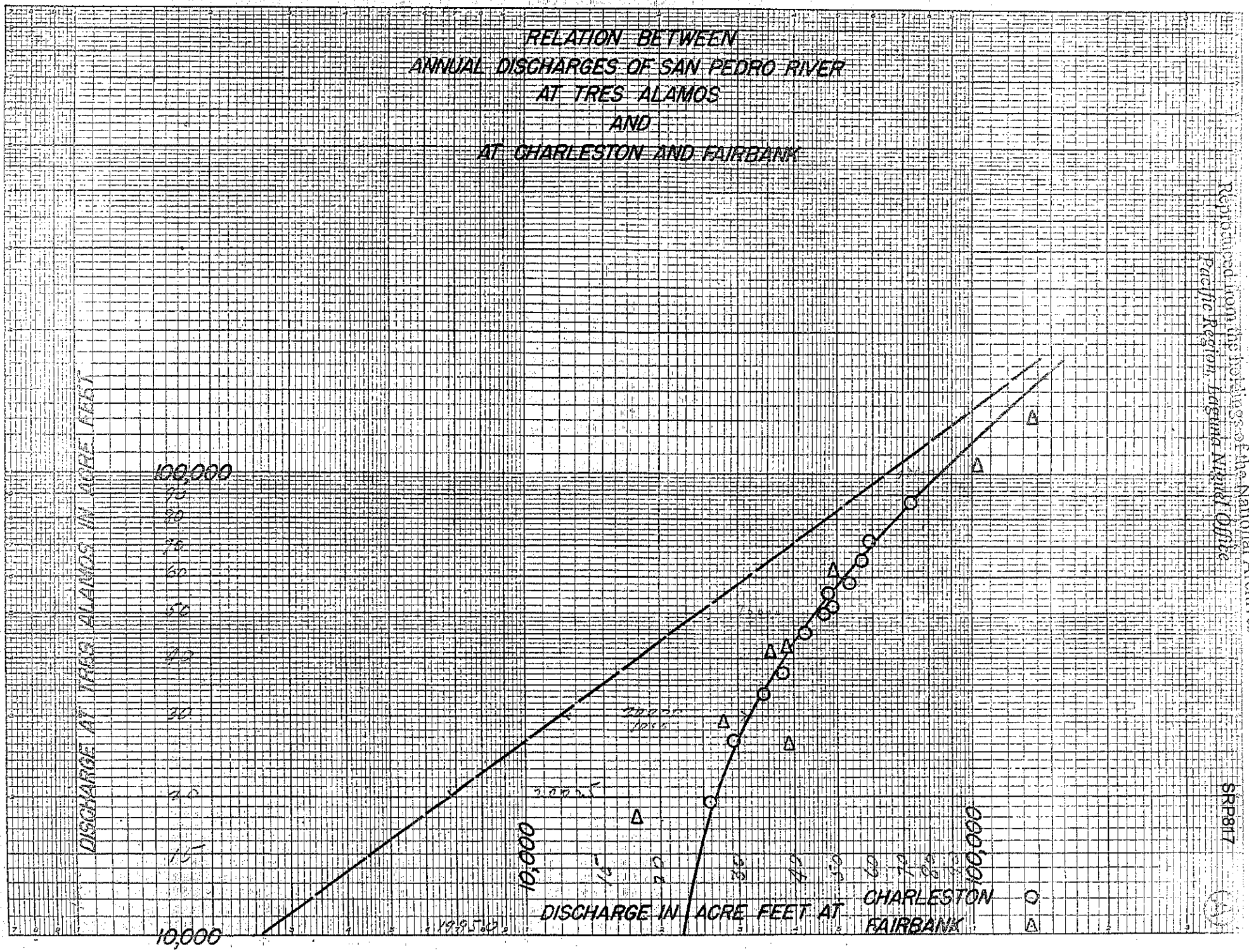

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Plate B
SRP818

DISCHARGE OF SAN PEDRO RIVER AT TRES ALAMOS DAM SITE

From Estimates by J. S. Gatewood
(United States Geological Survey)

Quantities in Acre Feet for Years 1921 to 1940 Inclusive

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL FOR YEAR
1921	369	56	246	0	0	222	48,430	52,810	2,110	93	0	307	105,000
1922	246	0	61	0	0	440	16,800	13,570	9,170	0	0	680	41,000
1923	553	0	123	0	0	0	22,280	25,180	4,310	377	1,170	7,720	61,700
1924	4,120	58	1,380	61	0	65	6,030	4,840	333	73	0	0	17,000
1925	61	0	123	0	0	10,980	16,280	11,790	2,050	343	244	369	42,200
1926	567	167	1,140	119	0	0	1,920	1,280	113,000	10,190	1,410	2,060	132,000
1927	1,480	603	615	476	0	0	7,030	12,390	1,800	246	179	1,050	25,900
1928	984	575	492	179	0	0	2,560	4,880	379	8,590	381	615	19,600
1929	553	278	369	119	0	0	34,050	11,880	6,570	1,400	0	637	55,900
1930	1,110	426	2,980	119	0	867	25,550	21,510	4,200	448	218	1,460	58,900
1931	891	5,440	494	0	0	167	5,670	43,940	18,840	7,140	879	3,930	87,400
1932	7,620	1,300	1,750	363	0	0	13,270	11,840	60	123	347	599	37,300
1933	1,340	774	430	60	0	0	9,600	4,370	7,200	1,980	52	651	26,500
1934	369	111	184	0	0	0	1,530	9,810	480	61	0	123	12,700
1935	1,210	998	688	60	0	0	791	32,750	8,040	123	1,800	3,380	49,800
1936	924	526	430	119	0	1,110	5,780	17,800	17,220	446	222	740	45,300
1937	1,070	1,740	470	119	0	1,750	5,730	44,490	7,540	1,650	0	908	65,500
1938	553	222	660	60	0	1,070	9,870	11,860	6,980	61	0	2,190	33,500
1939	492	167	246	0	0	0	9,000	34,060	6,750	569	60	492	51,800
1940	492	1,170	307	0	0	674	9,280	50,610	2,760	555	179	5,890	71,900

Av 52035
54355
exc 1934-5

Av Charles 51453
exc 1934-5
gain 7902

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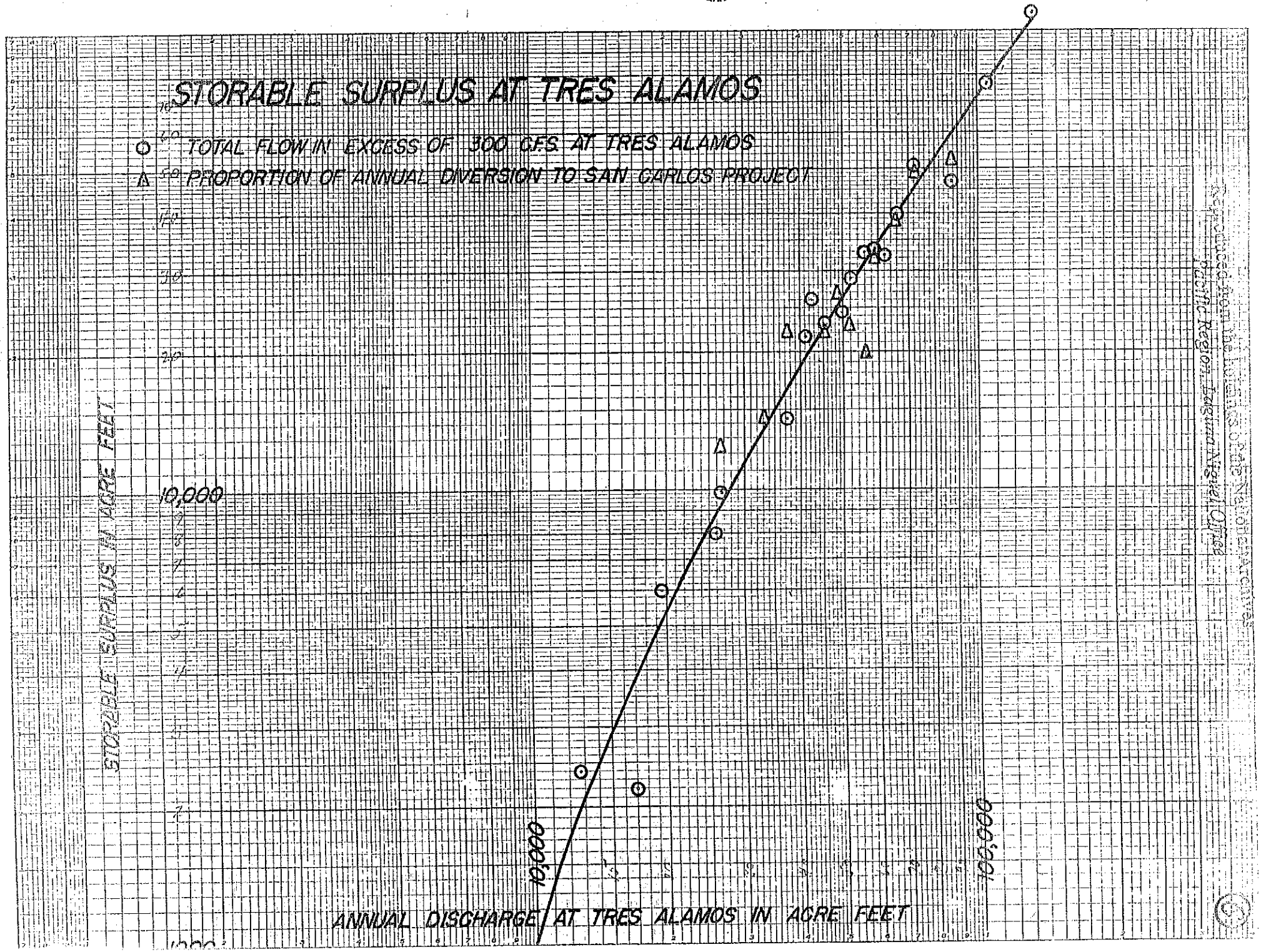

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SAN PEDRO RIVER AT TRES ALAMOS DAM SITE, NEAR BENSON, ARIZ.

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D-1

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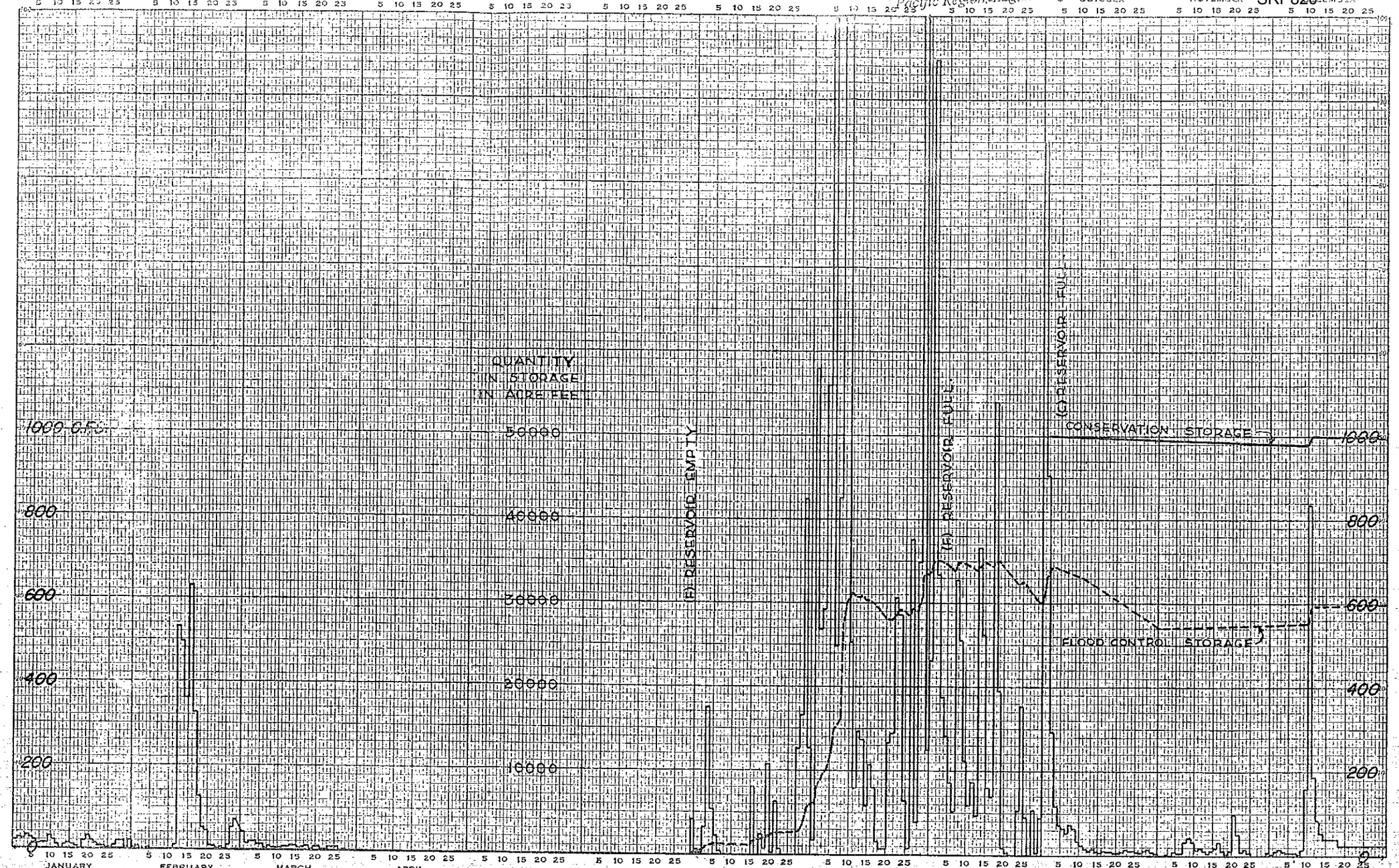

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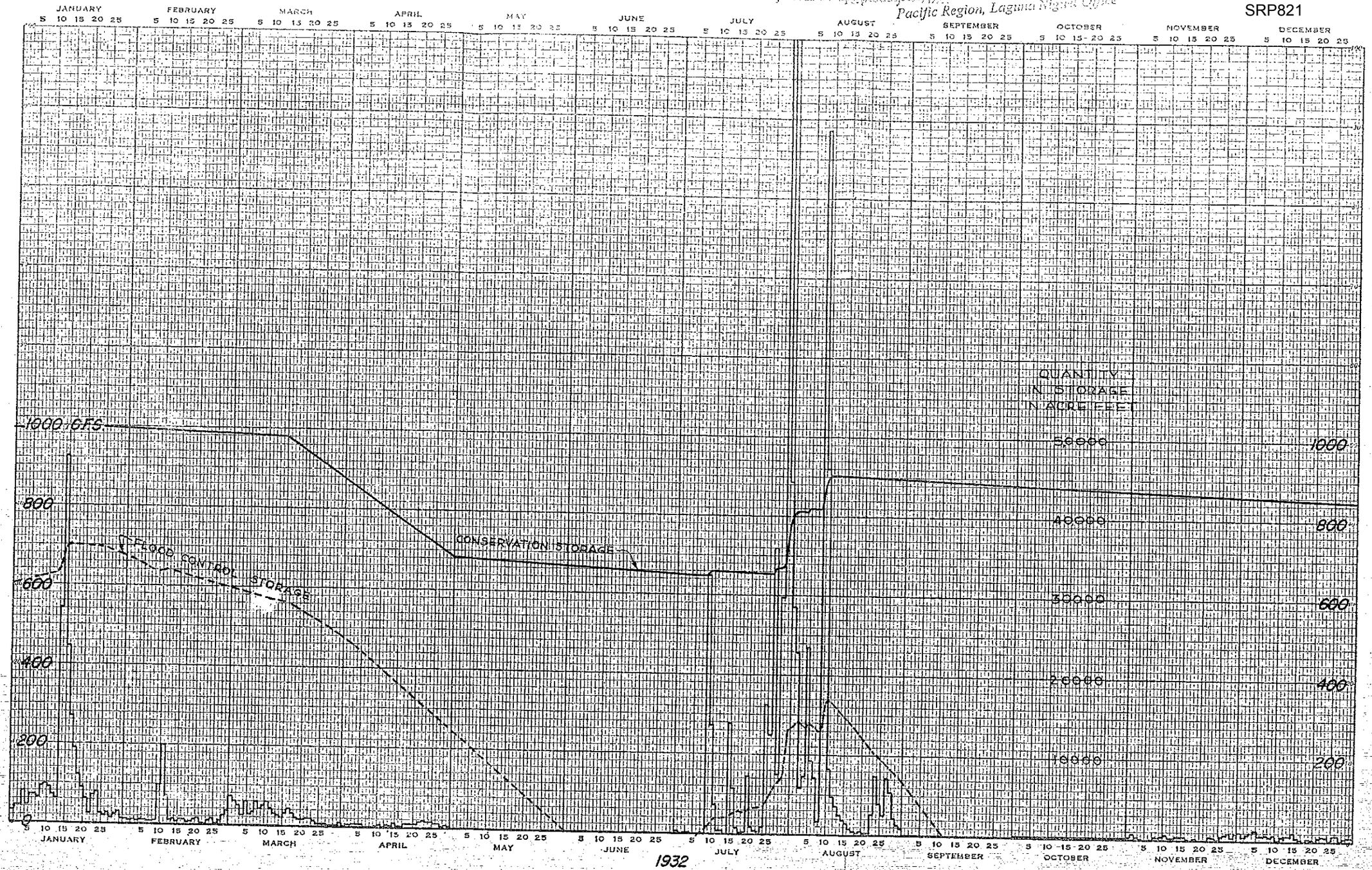
SAN PEDRO RIVER AT TRES ALAMOS DAM SITE, NEAR [illegible]



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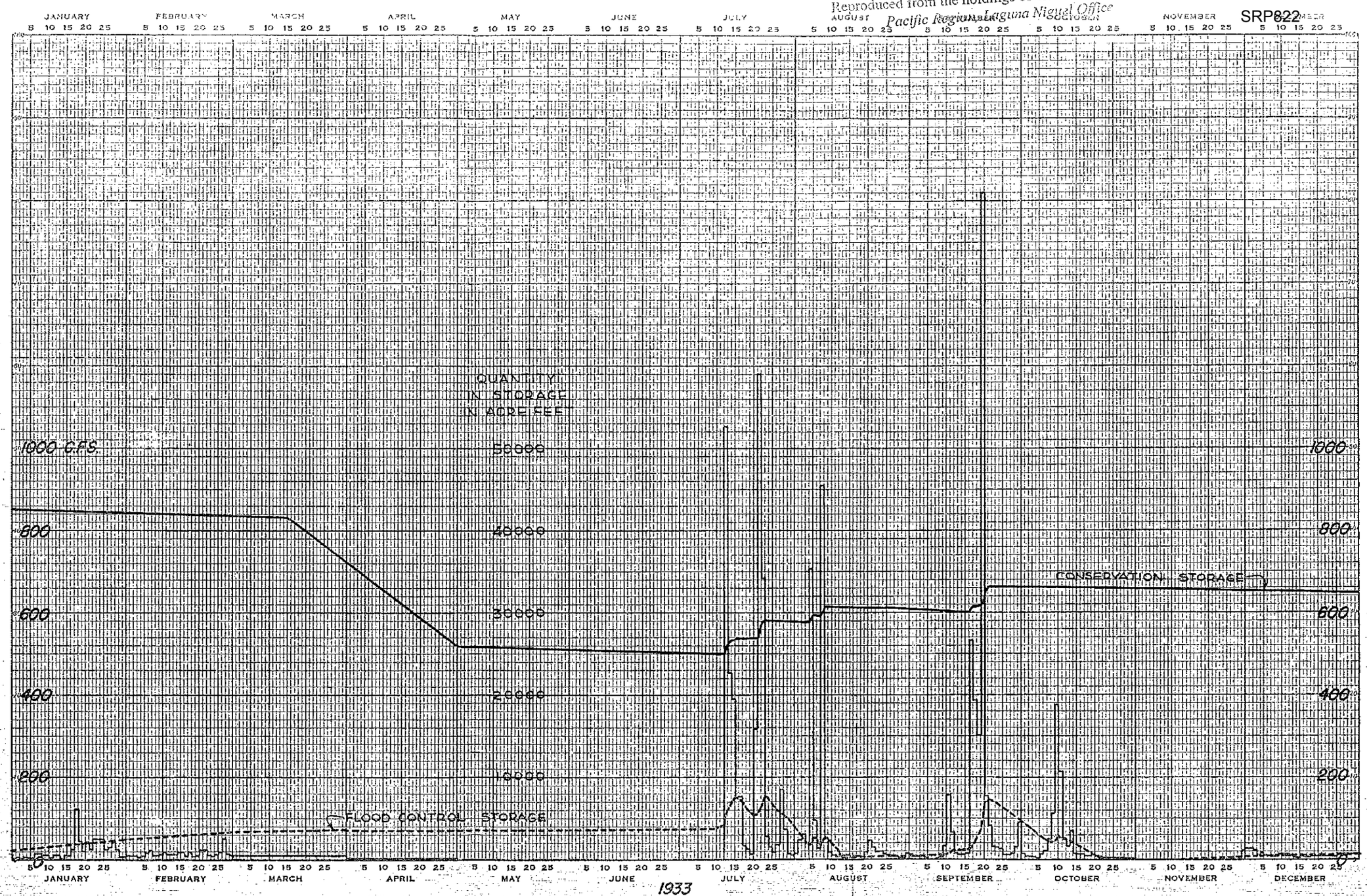

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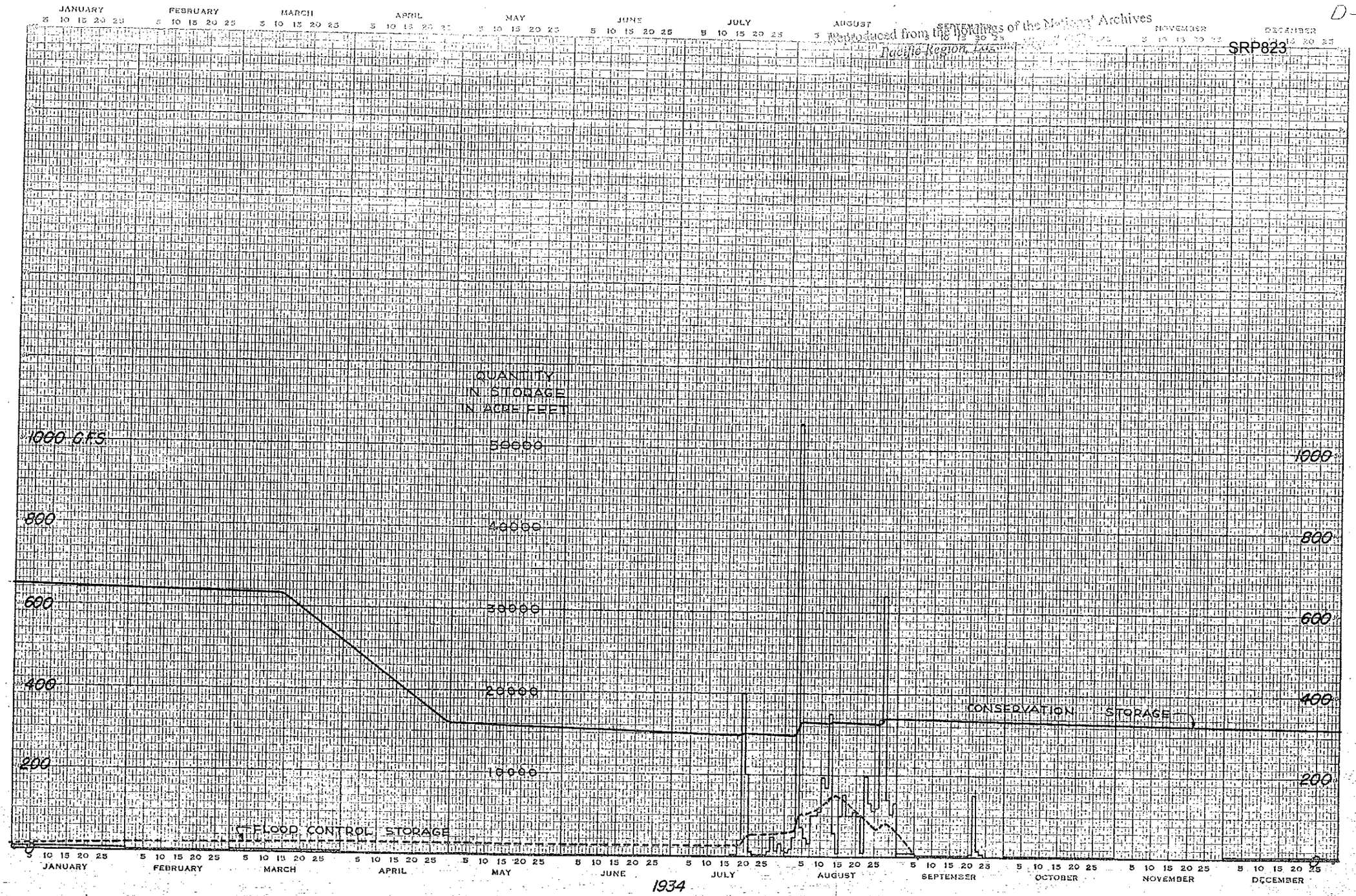

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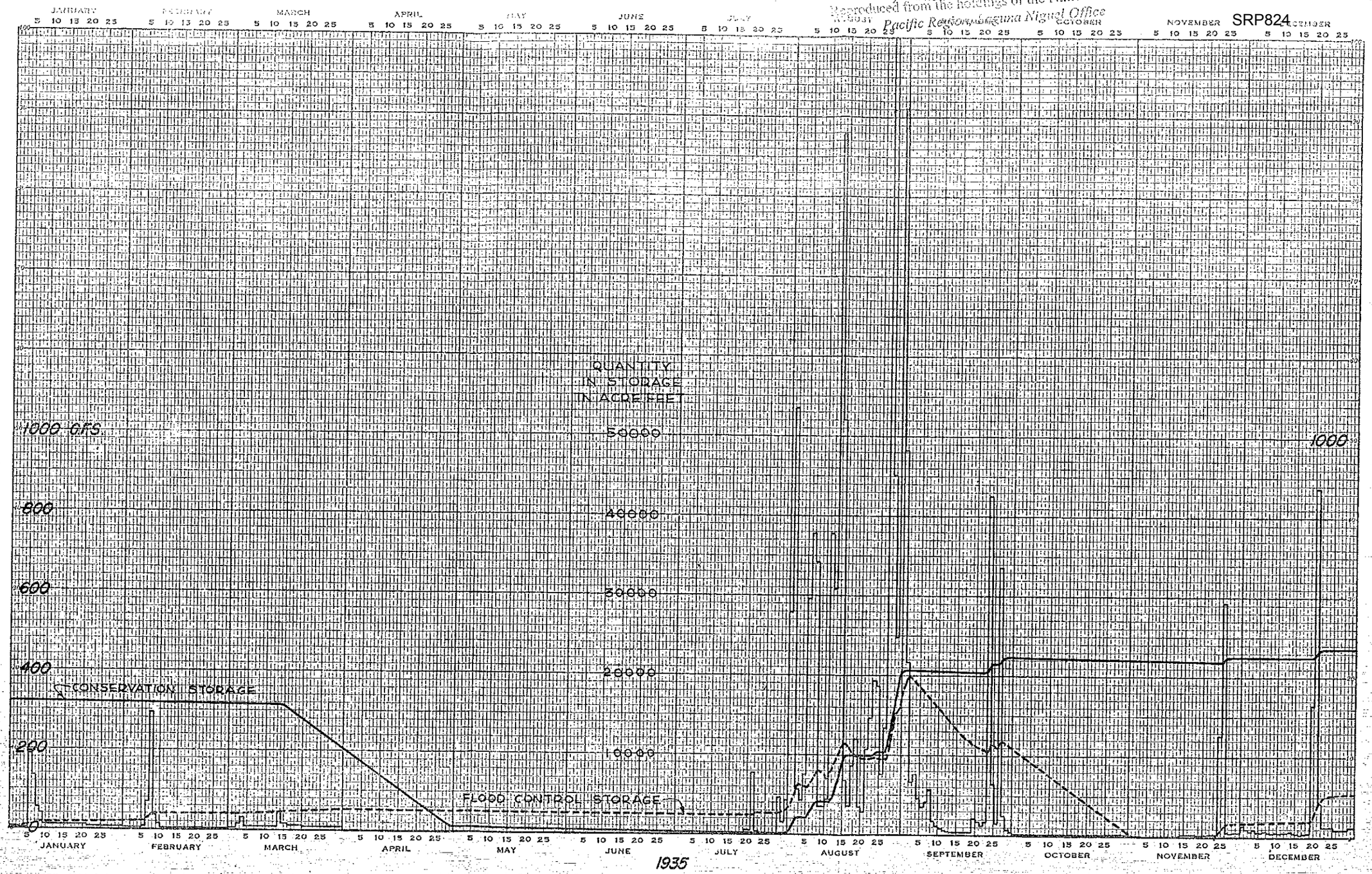

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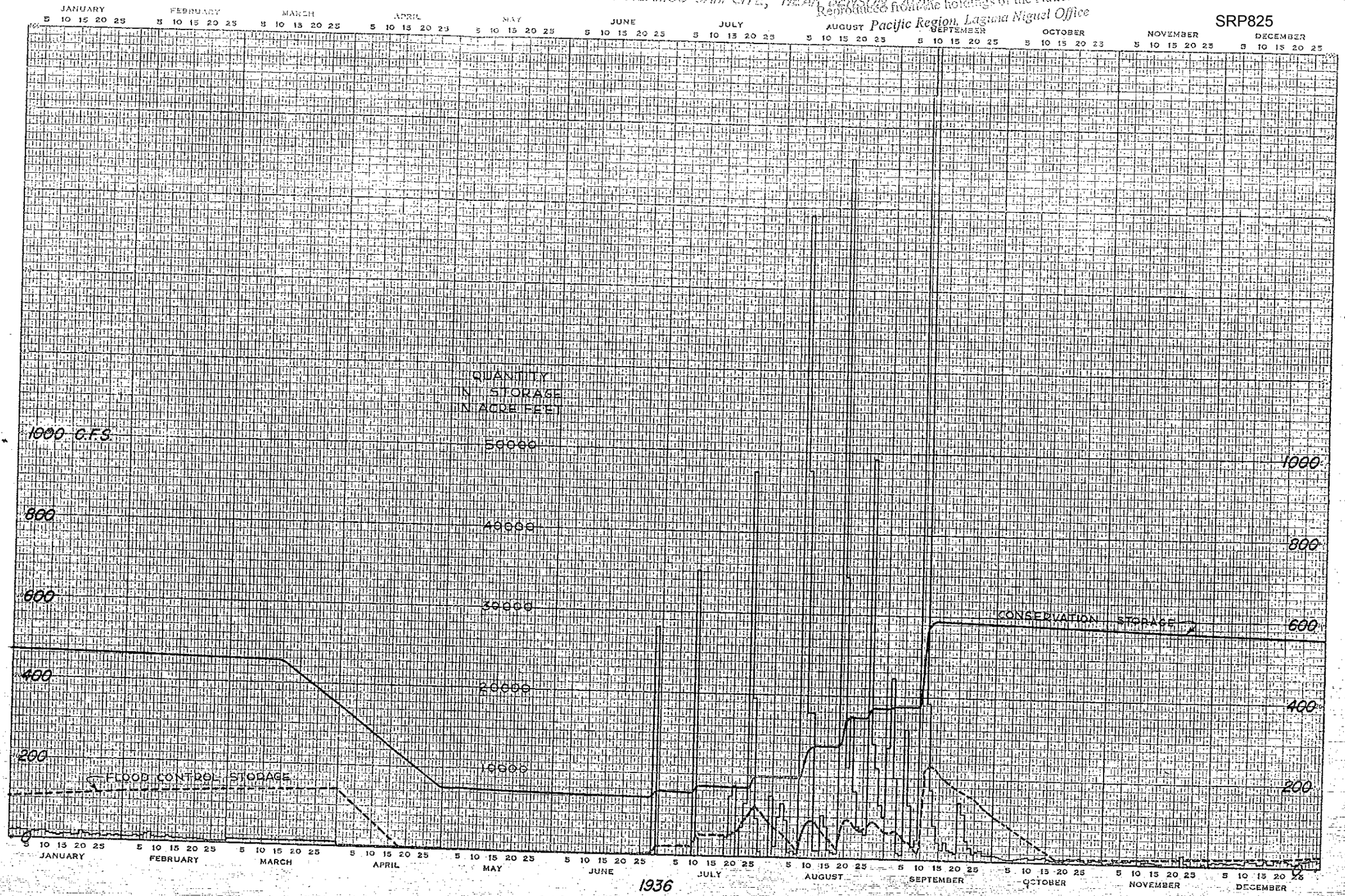

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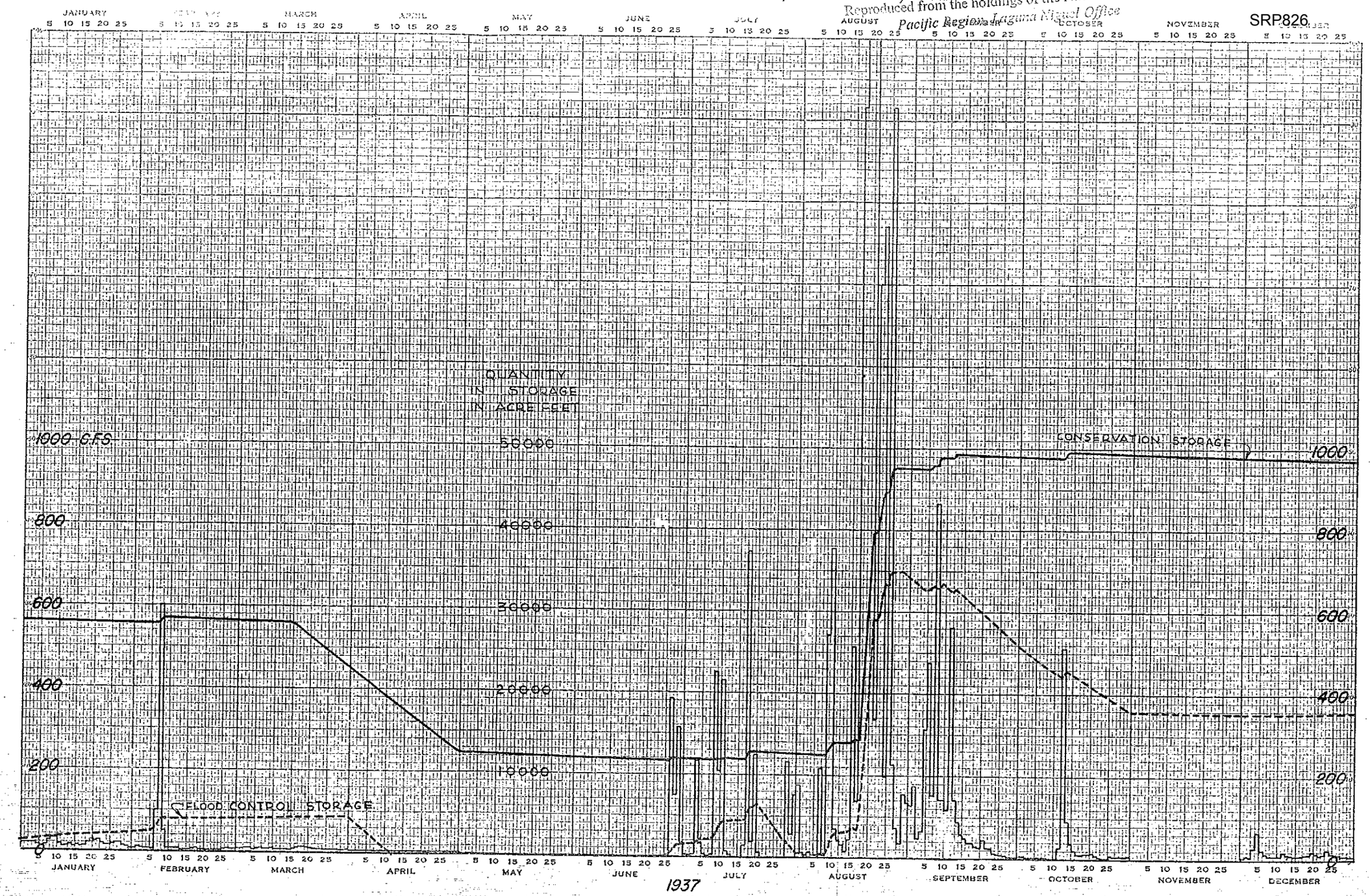

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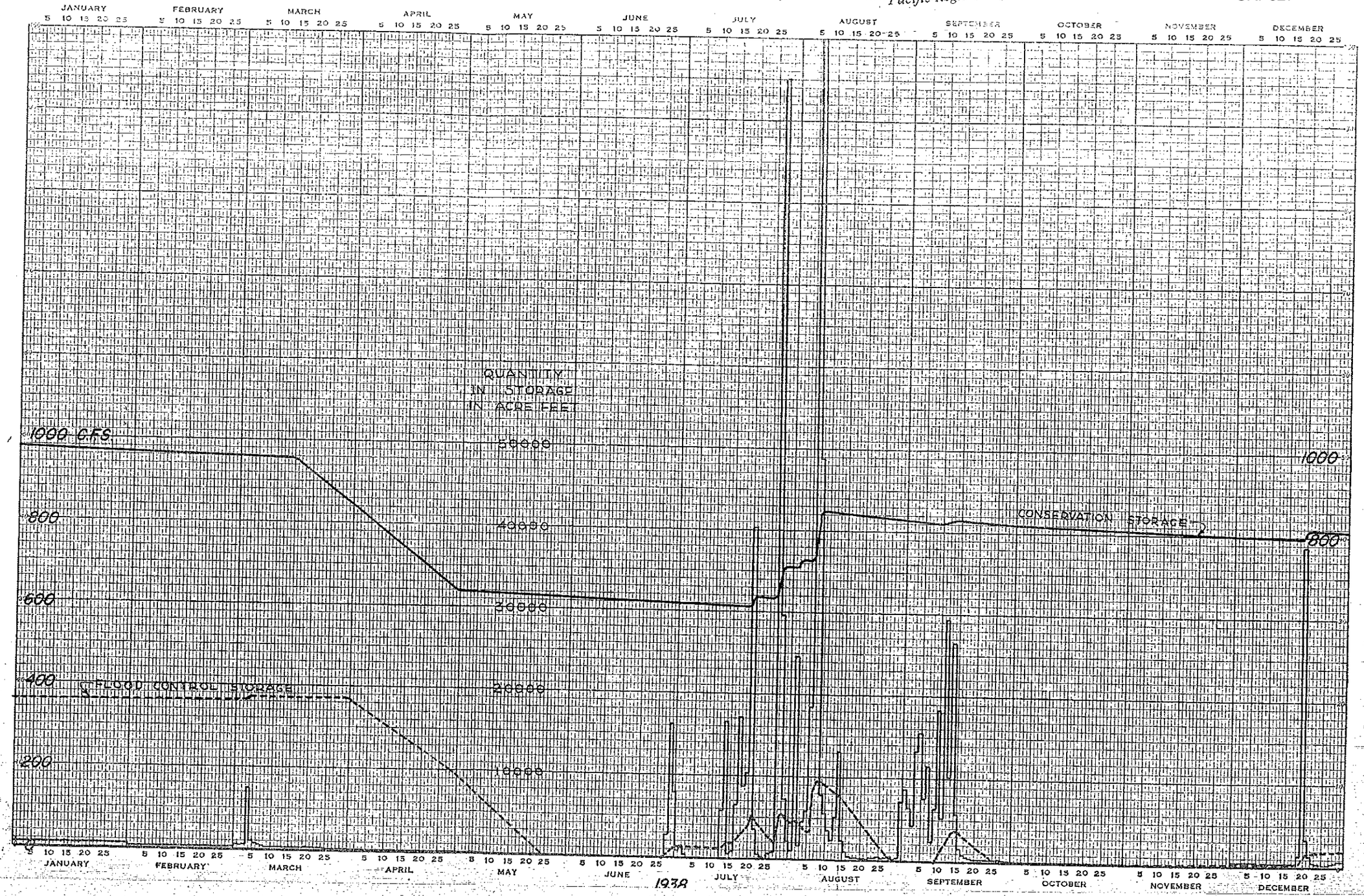

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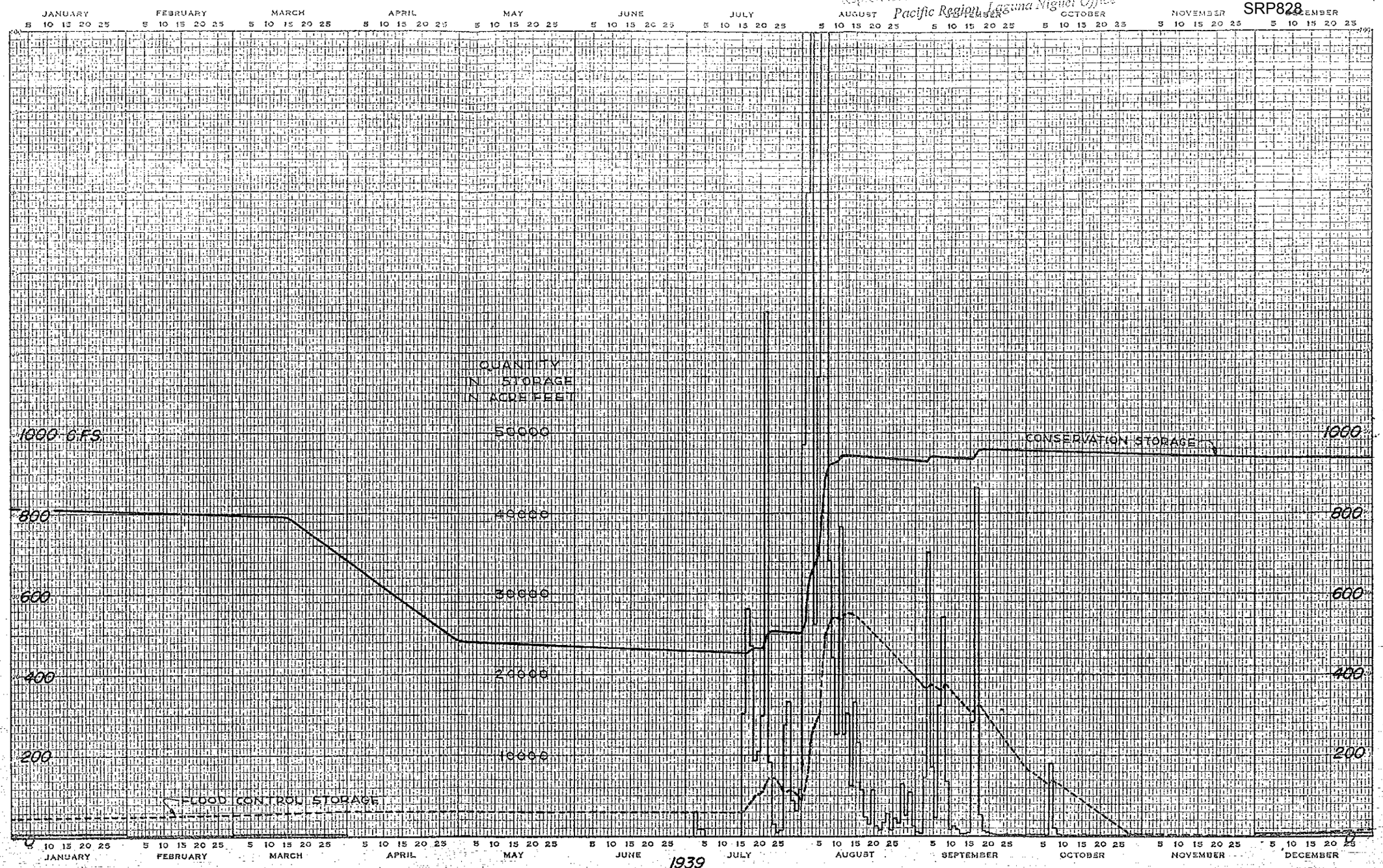

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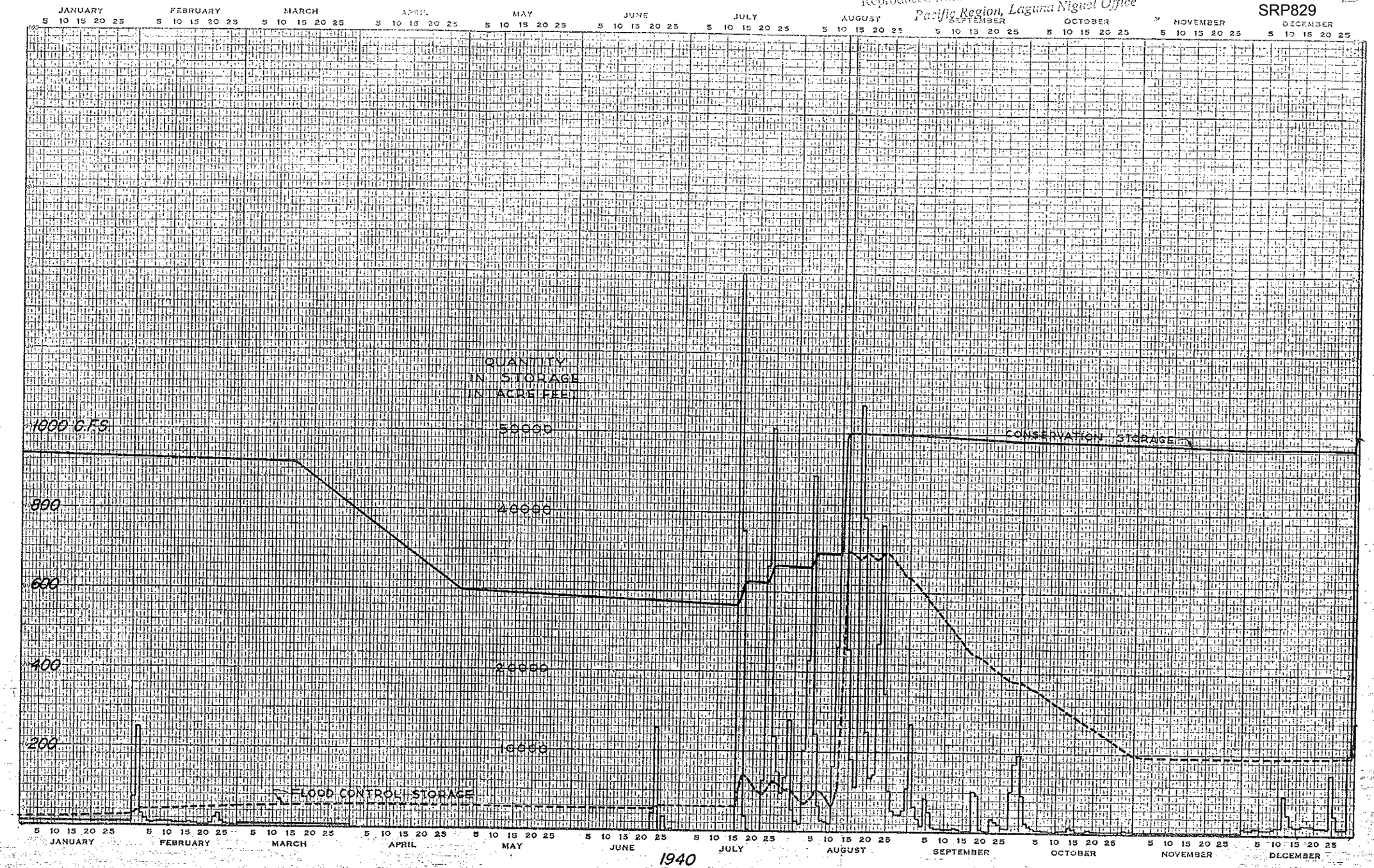

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