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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Ground Water Branch

GEOLOGY AND GROUND-WATER RESOURCES OF CAMP PENDLETON, CALIFORNIA

By

G. F. Worts, Jr. and R. F. Boss

With a section on

SURFACE-WATER RESOURCES

By

H. C. Troxell and Walter Hofmann

ADMINISTRATIVE REPORT
For U.S. Government use only

Prepared at the request of
the Department of the Navy

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Long Beach, California
July 1954

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GEOLOGY AND GROUND-WATER RESOURCES
OF CAMP PENDLETON, CALIFORNIA

By G. F. Worts, Jr. and R. F. Boss

SUMMARY AND CONCLUSIONS

This summary presents briefly the geologic features, the quantitative hydrologic estimates, and the quality of water data that pertain to the ground-water basins in the lower Santa Margarita River valley and in San Mateo, San Onofre, Las Flores, and Aliso Creek valleys, all on Camp Pendleton. These data are outlined below according to subject rather than basin by basin as was done in the text. By so doing, the summary provides a cross index of the findings of the investigation. Based on these findings, several conclusions are drawn regarding the adequacy of the water resources of Camp Pendleton.

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1. Water-bearing deposits.--The principal water-bearing deposits are the alluvium or valley fill, the San Mateo formation, and locally the terrace deposits. In the lower Santa Margarita River valley the alluvium supplies essentially all the water to Camp supply and irrigation wells. In San Mateo and San Onofre Creek valleys the alluvium and San Mateo formation supply essentially all the water to wells. In Las Flores and Aliso Creek valleys most of the water is supplied from the San Mateo formation and only a small part is supplied from the alluvium.

The maximum thickness of the alluvium in the several valleys is at the coast where it ranges from about 200 feet in the Santa Margarita River valley to only about 110 feet in Las Flores Creek valley. In the Santa Margarita River valley it yields water to wells at rates between 1,000 and 2,000 gpm with drawdowns between 10 and 20 feet. In the smaller valleys the yields are considerably less.

The maximum thickness of the San Mateo formation is estimated to be about 1,100 feet in the area between San Onofre and San Mateo Creek valleys. It yields water to wells at rates between 100 and 1,500 gpm with drawdowns of 20 to 100 feet.

The terrace deposits supply no water to wells for use, but locally in Cappo basin and in the coastal part of San Onofre Creek basin, the so-called 40-foot terrace deposit forms a usable ground-water storage reservoir that supplies water to the nearby pumped wells.

2. <u>Surface-water resources</u>.--The average annual surface-water inflow to the several valleys was computed for the period 1923-52. The estimated long-term average annual inflow is based on the average of two representative periods, 1923-44 and 1935-51. For the Santa Margarita River valley at De Luz dam site the computed average annual inflow is 37,600 acre-feet, which is for the natural stream regimen and in the future would probably be less owing to the operation of Nigger Canyon Dam upstream; for San Mateo Creek valley, including Cristianitos Creek, the computed annual inflow to the valley is 16,000 acre-feet; for San Onofre Creek valley, 4,000 acre-feet; for Las Flores Creek valley, including Piedra de Lumbre and Las Pulgas Creeks, 1,350 acre-feet; and for Aliso Creek valley, 270 acre-feet. These computed inflows are subject to a possible error of 20 percent. Thus, based on the natural stream regimen, the total long-term surface-water resources or supply of Camp Pendleton is estimated to be nearly 60,000 acre-feet a year.

More critical from the standpoint of Camp supply is the surface water available during acute short dry periods, such as the 6-year period 1946-51. For the Santa Margarita River valley, the computed inflow averaged only 8,400 acre-feet a year; for San Mateo Creek valley, 3,200 acre-feet; for San Onofre Creek valley, 720 acre-feet; and for Las Flores Creek valley, 130 acre-feet a year. Thus, during the critical 6-year dry period the average annual surface-water inflow to ground-water basins on Camp Pendleton totaled only about 12,500 acre-feet, or about 20 percent of the long-term annual inflow. This is about 4,500 acre-feet more than the total pumpage in 1952 for all uses on the Camp.

The wet periods, of course, provide an extremely large annual inflow. For the 6-year period 1937-42, the computed average annual surface-water inflow for all these streams on Camp Pendleton totaled about 112,000 acre-feet. This is nearly twice the computed long-term average inflow and about nine times the acute dry-period inflow.

3. Ground-water pumpage.--Pumpage for Camp supply, including the Fallbrook Naval Ammunition Depot and the Naval Hospital, and irrigation use in 1952 totaled about 8,000 acre-feet; Camp pumpage was 5,500 acre-feet and irrigation pumpage was 2,500 acre-feet. In the several valleys the pumpage in acre-feet for Camp supply and irrigation, respectively, was as follows: Santa Margarita, 4,350 and 1,450; San Mateo, 280 and 800; San Onofre, 470 and 160; Las Flores, 370 and 110; and Aliso, about 25 acre-feet for Camp use. The total pumpage during the preceding few years was essentially the same.

It was reported by the Public Works Office that the new Camps now under construction in Las Pulgas, San Onofre, and San Mateo Creek valleys each will require about 2,000 acre-feet a year, including the present pumpage for the old tent Camps. In addition, it was reported that planned and existing Camps supplied from the Santa Margarita River basin will require about 6,000 acre-feet a year. This suggests that the total pumpage for Camp Pendleton supply will be roughly 12,000 acre-feet a year. If the 1952 rate of irrigation pumpage is continued, the total would be between 14,000 and 15,000 acre-feet a year.

4. <u>Ground-water storage capacity</u>.--Estimates of ground-water storage capacity have been made for the several ground-water basins on Camp Pendleton by assigning values of specific yield to the materials logged in wells and applying the averages obtained to the volume of the deposits. For the lower Santa Margarita River valley the storage capacity in the three basins, which are Ysidora, Chappo, and Upper Basins, from 5 feet to 100 feet below land surface was estimated to be 48,000 acre-feet. Because Ysidora Basin is subject to sea-water intrusion, the usable storage capacity is reduced to the 40,000 acre-feet contained in the two upstream basins. Therefore, in the following quantitative section of the summary, the storage in Ysidora Basin is omitted.

For the remaining coastal basins on the Camp, the storage capacity was estimated from 5 feet below land surface down to sea level, except where the base of the water-bearing deposits is above sea level. The estimated storage capacities are as follows: San Mateo Creek basin, nearly 15,000 acre-feet; San Onofre Creek basin, 6,000 acre-feet; and Las Flores Creek basin, 8,400 acre-feet. Thus, excluding Ysidora Basin, the estimated ground-water storage capacity of the principal basins on Camp Pendleton totals nearly 70,000 acre-feet.

During the critical 6-year dry period 1946-51, water levels and storage declined to the historic low, which was reached in the fall of 1951. At that time the storage depletion in the basins totaled 25,000 acre-feet, or storage was about 65 percent of maximum capacity. The largest depletion, over 11,000 acre-feet, occurred in San Mateo Creek basin, the smallest, nearly 3,000 acre-feet, occurred in Las Flores Creek basin.

Following the wet winter of 1952, the basins were largely recharged, and the net depletion totaled only about 5,000 acre-feet, or storage was about 93 percent of maximum capacity. The largest storage recovery, about 10,000 acre-feet, occurred in San Mateo Creek basin, and the smallest, about 700 acre-feet, occurred in Las Flores Creek basin.

5. Perennial yield.--The perennial yield of the coastal ground-water basins of Camp Pendleton is the amount of water that can be pumped year after year without depleting storage to the point where a damaging amount of sea-water intrusion occurs. The yield of the four principal ground-water basins on the Camp has been estimated by an analysis of the recharge, discharge, and ground-water storage capacity. The records indicate that none of the basins ~~have~~ has been overdrawn, although conditions of local overdraft have developed near the coast in San Mateo Creek basin and in Ysidora Basin.

Because the storage capacity in all the basins is relatively small and because recharge during either the recent acute 6-year dry period or the longer less acute 14- to 15-year dry periods is also relatively small, the perennial yield of all the basins is limited to the supply during one or the other of these critical dry periods. Thus, the perennial yield is actually a short-term yield that is limited by the available water resources during dry periods. Accordingly, for each basin the perennial yield was estimated to be the total recharge less the unrecoverable natural discharge plus the storage capacity divided by the number of years spanning the most critical period of drought. The total recharge includes estimates of the seepage loss from streams and rainfall infiltration; the natural discharge includes estimates of evapotranspiration loss and ground-water outflow and overflow to the sea.

Using the method outlined above, the estimated short-term or projected perennial yields of the four principal basins are as follows: Lower Santa Margarita River basin, 10,000 acre-feet based on a 15-year dry period and on theoretical seepage loss; San Mateo Creek basin, 2,500 acre-feet based on an acute 6-year dry period (pumpage by city of San Clemente wells, 750 acre-feet in 1952, may reduce somewhat the amount available to the Navy); San Onofre Creek basin, 1,000 acre-feet based on an acute 6-year dry period; and Las Flores Creek basin 500 acre-feet based on a 14-year dry period. In addition, the estimated perennial yields for Aliso Creek and the coastal area between Las Flores Creek and Cocklebur Canyon total roughly 300 acre-feet. Thus, the total estimated yield of the Camp Pendleton ground-water basins is slightly more than 14,000 acre-feet. To this total, or to the yield of each basin, the sewage effluent returned to ground water in the basins should be added. However, excessive sewage return may cause a deterioration in the chemical quality of ground water by the introduction of such constituents as nitrate, boron, and increased chloride.

The yields of the principal basins could be increased somewhat by the reduction in evapotranspiration loss from areas of phreatophytes. This could be accomplished by periodic clearing of the water-loving trees and plants along the principal stream channels and areas of high water levels. It is estimated that if the evapotranspiration loss were reduced by one-half, the yield of San Mateo Creek basin could be increased by at least 500 acre-feet; San Onofre Creek basin, by about 200 acre-feet; and Las Flores Creek basin, by about 100 acre-feet; or a total increase in yield of nearly 1,000 acre-feet.

6. Relation of yield to pumpage.--A comparison of the estimated short-term or projected perennial yield with the 1952 pumpage indicates that the yield was not exceeded in any of the basins. However, excluding the pumpage for irrigation, the planned pumpage of about 2,000 acre-feet for each of the new Camps alone will exceed the yield during dry periods in San Onofre and Las Flores Creek basins by roughly 1,000 and 1,500 acre-feet a year respectively. For the Santa Margarita River basin, the planned pumpage for Camp use of about 6,000 acre-feet plus the 1952 rate of irrigation pumpage of 1,450 acre-feet would be about 2,000 acre-feet less than the projected yield. In San Mateo Creek basin pumpage for the new Camp plus one-half of the city of San Clemente pumpage at the 1952 rate would total nearly 2,400 acre-feet a year, or would be essentially equal to the estimated yield of 2,500 acre-feet.

On the other hand, during wet periods the yield is greatly increased over that for dry periods and accordingly more water could be pumped from the basins. Insufficient data are available to estimate with reasonable accuracy the yield during wet periods; the yield even if determined, however, would be of little practical value to the Navy inasmuch as without surface-water regulation, the short-term yield during the dry periods would control the amount available for planning and use. Therefore, on the basis of the reported requirements of 2,000 acre-feet a year for the new Camps in San Onofre and Las Flores Creek valleys, it appears feasible to consider the import of water from other sources to those basins.

7. Quality of water.--The quality of ground waters in Upper Basin and Chappo Basin in the lower Santa Margarita River valley, in the greater part of San Mateo Creek basin, and in San Onofre Creek basin is satisfactory for Camp use. In Las Flores and Aliso Creek basins the San Mateo formation supplies water of marginal quality, having chloride concentrations of between 150 and 200 ppm. In the lagoon area of the Santa Margarita River and beneath Stuart Mesa, the quality of water contained in the alluvium and San Mateo formation is extremely poor and appears to be a connate sea-water type.

For the 11-year period 1942-52, about one-half the total pumpage for Camp and irrigation use in the lower Santa Margarita River valley was supplied from Ysidora Basin. This heavy draft, which averaged 2,700 acre-feet a year for the period, combined with low recharge in the period 1946-51, caused water levels to be drawn down below sea level with the result that the natural seaward hydraulic gradient was reversed, and sea water of modified character moved inland from the lagoon area through the lower part of the alluvium in Ysidora Narrows rendering several wells in the basin unfit for Camp supply. Well 11/5-2H1, which was the deepest pumped well in the basin, started pumping water containing chloride in excess of 250 ppm in 1947. This condition indicates local overdraft in Ysidora Basin but does not imply overdraft in the entire lower Santa Margarita River basin.

Along the east side of San Mateo Creek basin, there is some suggestion of localized sea-water intrusion in irrigation well 9/7-14L1, which, of several nearby irrigation wells, is closest to the coast. The chloride content of water in this well increased to 203 ppm in 1951 compared to a chloride content of 70 to 80 ppm for native ground waters sampled in nearby wells. This suggested sea-water intrusion is the result of localized excessive drawdown in these wells near the coast and does not indicate basin-wide overdraft. This condition could be corrected by discontinuing the pumpage from irrigation wells 9/7-14F1 and 9/7-14L1.

8. Comments regarding the water supply.--Probably the most critical ground-water problem on Camp Pendleton has been the overdraft in and resulting intrusion of sea water of modified character into Ysidora Basin. In spite of the large runoff and recharge in 1952, the condition, although better, as of 1953 is still serious. The most feasible solution to the problem would be to eliminate, except for emergency use, all pumpage from Ysidora Basin and obtain the necessary replacement supply from Chappo Basin and particularly from Upper Basin where the pumpage is small. By so doing, the water levels in Ysidora Basin could recover and be maintained above sea level, a substantial seaward hydraulic gradient would be established, and in the course of 5 to 10 years the undesirable intruded water would be largely expelled from the basin. The water levels could be raised and the seaward hydraulic gradient artificially steepened by the spreading of treated sewage effluent in the river bed upstream from the area of intrusion between wells 10/5-35K1 and 11/5-2M1.

Any attempt to establish a barrier to sea-water intrusion in Ysidora Narrows prior to the expulsion of the intruded water would result in the entrapment of poor quality water on the inland (basin) side of the barrier. Obviously, the advantage of building such a barrier would be partially defeated if saline waters remained inland from it, because Ysidora Basin could not then be fully utilized.

After the intruded sea-water of modified character has been largely expelled from the basin, consideration could then be given to a barrier in Ysidora Narrows. The barrier could be one of several possible designs. For example, it might be possible to construct a clay cut-off wall to a depth of about 200 feet thereby truncating the alluvium which is the conduit for the inland movement of poor quality water. A barrier of this type is being considered by the California Water Pollution Control Board in nearby San Luis Rey River valley, but the cost is reported to be substantial. Consideration might be given to drilling a battery of recharge wells in the narrows to utilize treated and filtered sewage effluent. This would provide a fresh-water mound that would largely if not completely prevent inland movement of water of undesirable quality. If either method were employed successfully, Ysidora Basin could be pumped for Camp and/or irrigation use. The inclusion of this basin in the quantitative estimates of usable storage capacity would increase somewhat the yield of the lower Santa Margarita River basin.

In the coastal area a brief study of the ground-water conditions between Las Flores Creek basin and Cockleburr Canyon suggests that the area could be developed for a small supply which, including Aliso Creek basin, might yield 200 to 300 acre-feet a year to a small installation if desired. However, owing to the possibility of encountering water containing chloride in excess of 250 ppm, exploratory wells should be drilled first. To reduce the possibility of sea-water intrusion and encountering bedrock, the supply wells should be drilled not closer than about a mile from the coast nor closer than 0.5 mile from the consolidated rock outcrops along the foot of the San Onofre Hills.

With regard to the reported planned pumpage of 2,000 acre-feet for Camp supply in each of San Mateo, San Onofre, and Las Flores Creek basins where the yields are relatively small, consideration should be given to discontinuing the pumpage for irrigation. In the Santa Margarita River basin, however, the projected perennial yield of Chappo and Upper Basins during dry periods would be sufficient to support a combined Camp and irrigation pumpage of about 10,000 acre-feet--about 4,000 acre-feet more than in 1952, about 3,000 acre-feet more than in the water years 1948 and 1949, and only about 2,000 acre-feet more than the reported planned annual pumpage.

Thus, for San Onofre and Las Flores Creek basins, additional water will be required to meet the reported demand of the new Camps. Under future development there appears to be an insufficient surplus of ground water in the Santa Margarita River basin to consider the export of water to both of these Camps unless the pumpage for irrigation is discontinued. Accordingly, with the prospect of the ground-water supply being nearly fully utilized for Camp supply, the only other recourse, except for the Metropolitan aqueduct, is to develop the surplus surface-water runoff now wasting to the ocean.

The feasibility of constructing a dam on the lower Santa Margarita River at De Luz dam site to salvage a substantial part of the surface water now wasting to the ocean has been reported on by the U. S. Army Engineers (1949). According to that report the proposed dam would have a firm yield of 20,000 acre-feet a year—about twice the projected yield estimated for the ground-water basin downstream. Because as of this writing the waters of the Santa Margarita River are under litigation, no comments have been made regarding the future supply to the Navy from this source.

With regard to the other principal streams, the computed long-term average surface-water inflow to Las Flores and San Onofre Creek valleys, 1,350 and 4,000 acre-feet respectively, appears to be too small to consider for holdover storage even though dam sites on each may be feasible where the streams cut through the San Onofre Hills. However, in San Mateo Creek valley the long-term average inflow, excluding Cristianitos Creek, is about 12,500 acre-feet. If a satisfactory dam site can be located, it might be feasible to augment the supply of the new Camp in San Onofre Creek valley from this source. Until such time as the status of the proposed De Luz dam and water rights are settled, it might be feasible to augment the supply to the new Camp in Las Pulgas Creek valley by ground-water pumpage from the lower Santa Margarita River basin.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION AND REPORT

The investigation of the geology and water resources of Camp Pendleton, California, was started by the United States Geological Survey in 1950 at the request of the Department of the Navy. Two preliminary reports (Worts, 1951; and Worts, Boss, and Riley, 1952) have been released to the Navy outlining certain phases and findings of the work. The purpose of this report is to present the geology and hydrology of the lower Santa Margarita River valley; San Mateo, San Onofre, Las Flores, and Aliso Creek valleys; and other minor areas, all on Camp Pendleton, to provide the Navy with information regarding the adequacy of the water supply on these stream systems.

Specifically, the Navy[1/] requested that the report indicate the various opportunities within the Camp for developing a water supply, comments on the present water usage and practices, advice as to the observations to be made and the records to be kept to perpetuate the inventory of ground-water reserves, estimates of the amount that can be safely withdrawn from each source under different conditions, and comments as to the quality of water in the various areas. It was also requested that statements be made regarding the advisability of supplementing the yield of the Santa Margarita River system by diversion from one or more of the other streams on Camp Pendleton, and that the use of artificial recharge and returned sewage effluent be considered. Finally, it was requested that comments regarding the adequacy of the supply of the Fallbrook Naval Ammunition Depot and the Naval Hospital be included in the report.

1/ Reference: Letter of 26 June 1950 from A. D. Hunter, Deputy Chief of Bureau, to the U. S. Geological Survey pertaining to the objectives and cost of the investigation and report.

In order to furnish the Navy with the needed information for the several areas, this report: (1) Describes the geology of the Camp with particular reference to the water-bearing deposits; (2) computes the average annual surface-water inflow to and where possible the outflow from these valleys; (3) outlines the occurrence, source, and movement of ground water; (4) estimates the recharge to and discharge from the ground-water basins; (5) describes the water-level fluctuations in wells largely with respect to cyclic storage depletion and replenishment; (6) estimates the ground-water storage capacity of the principal basins; (7) estimates insofar as possible the perennial yield of the basins; and (8) describes the chemical quality of water for the basins with particular respect to sea-water intrusion along the coast.

In addition to the material contained in this report, a separate volume of appendixes[1/] has been prepared. It includes a description of the wells, the logs of wells, chemical analyses for well and river waters, records of water-level fluctuations in observation wells, and several cross indexes of well numbers. These data are referred to and used throughout this report and were used to compile the geologic sections, water-level profiles, water-level contour maps, and the hydrographs shown on plates 1 to 8 and 21 to 37 (at end of report).

Except for a two-month period during the construction of the Pauba Ranch exploratory well and for a nine-month period during the construction of test wells at the Twentynine Palms Marine Corps Training Center, both conducted at the request of the Navy, the work on the Camp Pendleton investigation was carried on continuously. Owing to the delays imposed by the work on these other projects, the completion of this report, with the oral approval of the Eleventh Naval District, was delayed by about one year.

1/ Appendixes: Tables of basic data to accompany report on geology and ground-water resources of Camp Pendleton, California, by G. F. Worts, Jr. and others, 1954.

The geologic and ground-water phases of the work have been carried on under the direction of A. N. Sayre, geologist in charge of the Ground Water Branch; and under the general supervision of J. F. Poland, district geologist in charge of ground-water investigations in California. The surface-water phases of the work have been carried on under the direction of J. V. B. Wells, engineer in charge of the Surface Water Branch; and under the general supervision of R. C. Briggs, district engineer in charge of surface-water investigations in California.

In addition to the authors, F. S. Riley and F. H. Olmsted, geologists, assisted in the geologic mapping and test-well drilling program. The aquifer-performance tests, collection of water samples, and operation of water-level recorders were largely conducted by W. J. Hiltgen.

LOCATION AND GENERAL FEATURES OF THE AREA

Camp Pendleton is in the northwest part of San Diego County, Calif., bordering on the Pacific Ocean, and is about 40 miles northwest of San Diego and 70 miles southeast of Los Angeles. The approximate location of the Camp is shown on the inset map of California on plate 1. The Camp occupies essentially the same area as the old Spanish land grant known as Rancho Santa Margarita y Las Flores, which was purchased by the Navy in 1942. It covers an area of about 210 square miles and has a northwest length of about 20 miles and an average northeast width of about 10 miles.

The Camp is traversed in whole or in part by five stream systems and one coastal area that are discussed in this report. In descending order of ground-water development these are: (1) The Santa Margarita River, which is near the south end of the Camp. In this report it is referred to as the lower Santa Margarita River valley and the ground-water basin underlying it is called the lower Santa Margarita River basin; (2) San Mateo and Cristianitos Creeks which in their lower courses together are termed San Mateo Creek valley. The underlying ground-water basin is called San Mateo Creek basin; (3) San Onofre Creek which in its lower course is termed San Onofre Creek valley. The underlying ground-water basin is called San Onofre Creek basin; (4) Las Flores, Piedra de Lumbre, and Las Pulgas Creeks are collectively called Las Flores Creek valley. On the seaward side of the San Onofre Hills the ground-water basin is referred to as Las Flores Creek basin; (5) Aliso Creek, which is a minor stream, also crosses the San Onofre Hills. On the seaward side of the hills it is called Aliso Creek valley and the underlying ground-water basin is called Aliso Creek basin; and (6) the coastal area, principally between Cockleburr Canyon and Las Flores Creek valley, is termed the coastal intervalley area. Because it is a minor area, no name was assigned to the underlying ground-water basin which is contiguous to those in Las Flores and Aliso Creek valleys (pl. 28).

Except for the coastal intervalley area, all the ground-water basins have been developed to varying degrees for Camp supply. In addition, in the first four areas listed above there is considerable pumpage for irrigation.

In the 1952 water year 1/ the pumpage for all uses on Camp Pendleton was about 8,000 acre-feet and was supplied from a total of about 40 wells--20 Camp-supply and 20 irrigation wells. Of this total about 5,500 was for Camp use, including the Fallbrook Naval Ammunition Depot and the Naval Hospital, and about 2,500 acre-feet was for irrigation use. The Camp and irrigation use, in acre-feet, by valleys was respectively as follows: Santa Margarita, 4,350 and 1,450; San Mateo, 280 and 790; San Onofre, 470 and 150; Las Flores, 370 and 110; and Aliso, about 50 for Camp use.

1/ Water year is from October 1 through September 30. Thus, the 1952 water year is from Oct. 1, 1951, through Sept. 30, 1952.

TEST-WELL DRILLING PROGRAM

As a part of this investigation 26 test wells and 1 test hole were drilled in 1951 on Camp Pendleton by contract between the Navy and Vaughan Maynard and Sons at a cost of about $40,000. The drilling was conducted under the technical supervision of the Geological Survey. Of these wells 14 were drilled in the lower Santa Margarita River valley, 3 in San Mateo, 4 in San Onofre, 3 test wells and 1 test hole in Las Flores, and 1 test well in Aliso Creek valleys. In addition, one test well was drilled at the mouth of Horno Canyon. Logs, water-level records, chemical analyses, and well data are contained in the appendixes accompanying this report. Table 10 shows the test-well numbers and the final U. S. Geological Survey numbers.

The data obtained from these wells were invaluable to the investigation. The wells provided a means of obtaining essential records on quality of water, type of material, and water-yielding character in areas where little or no information was available. Therefore, the authors are grateful for the inclusion of the test-well drilling program as a part of the investigation. Furthermore, the data obtained have benefited the Navy in that the findings of the report are considerably more complete; and information currently being obtained from the test wells will provide critical data on problems of sea-water intrusion, storage changes, and overdraft.

CONTINUING HYDROLOGIC INVENTORY OF CAMP PENDLETON

In May 1952 at the request of the Navy a program for a continuing ground-water and surface-water inventory for the 1953 fiscal year was submitted by the Geological Survey. This program was approved and funds were provided by the Navy for the execution of this program. Similarly, the Navy requested that the program be continued in the 1954 fiscal year. The continuing program is as follows:

"I. Ground Water Branch program.
   A. Continue periodic water-level measurements in observation wells in Santa Margarita River valley and in San Mateo, San Onofre, Las Flores, and Aliso Creek valleys.
   B. Continue periodic water sampling in key wells to check for sea-water intrusion in the principal valleys.
   C. Present a report after the end of the fiscal year, including:
      1. The findings of A and B.
      2. Water-level contour maps for yearly "high" and "low" levels for the principal valleys.
      3. Where available, a summary of ground-water pumpage by areas.
      4. The status of sea-water intrusion at valley mouths.
      5. The status of ground-water storage in principal valleys.
   D. Continue as technical advisor on ground-water problems and water-supply development at Camp Pendleton.

II. Surface Water Branch program.
   A. Continue operation and maintenance of the seven Navy-owned stream gages on De Luz, Las Flores, upper and lower San Onofre, upper and lower San Mateo, and Cristianitos Creeks.
   B. Present the data obtained from the gaging stations shortly after the end of the water year (September 30)."

In view of the threat of sea-water intrusion into the principal coastal valleys as outlined in this report, in order to keep the Navy and Marine Corps informed of other unfavorable hydrologic developments, to maintain the hydrologic inventory of surface water and ground water, and to be in a position to advise on the matters relating to artificial recharge, development of new supply wells or redevelopment of old wells, and other related problems, it is urged that the continuing program be carried on henceforth until such time as conditions warrant its conclusion.

PREVIOUS INVESTIGATIONS

Principal geologic investigations of the old Rancho Santa Margarita were made by Woodford (1925) and by several teams of geologists in connection with the so-called Pauba Ranch (Vail)-Rancho Santa Margarita (O'Neill) trial during the years 1926 to 1940. The exhibits from the trial were made available, and some were useful in the work. A small scale unpublished geologic map of the Rancho prepared by W. S. T. Smith and R. R. Morse (circa 1930) was also of some help in the work. However, essentially all the mapping shown on the geologic map (pl. 1) was done by the Geological Survey in the course of the investigation. The more detailed descriptions of the rocks herein classed as the basement complex were taken largely from the work by Larsen (1948).

The only joint hydrologic and geologic work done earlier was that of Ellis and Lee (1919). This report covered the western part of San Diego County and dealt only briefly with ground-water and geologic conditions on Camp Pendleton, which then was Rancho Santa Margarita.

Several brief hydrologic reports on the ground-water conditions in the Santa Margarita River valley and San Mateo, San Onofre, and Las Flores Creek valleys were prepared in 1936-45 by F. E. Green, hydrographic engineer; those in 1943-45 were prepared under the direction of the Public Works Officer, Camp Pendleton. These reports are typewritten and only a limited distribution was made. The basic data contained in these reports were useful in the preparation of this report and the appendixes.

ACKNOWLEDGMENTS

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GEOLOGY

By G. F. Worts, Jr., and R. F. Boss

PHYSIOGRAPHY

The area occupied by Camp Pendleton in general is a broad dissected seaward-sloping land mass. Fenneman (1931, p. 508 and pl. 1) has placed the area largely in the Lower California Province of the Pacific Mountain system, although it does embrace the southern end of the Angeles Section of the Pacific Border Province. However, owing to the existence of the ranges near and parallel to the coast, it is believed to have a closer physiographic relationship with the Lower California Province than with the Angeles Section. Jenkins (1943, p. 84) has placed this area in the Peninsular Ranges province.

Physiographically, the Camp Pendleton area is subdivided into six prominent parts, as follows: (1) The principal stream valleys that are entrenched in the surrounding features and drain generally southwestward from the mountainous inland area and across the general structural trend to the Pacific Ocean; (2) the coastal terraces which form benches up to 2 miles in width and which are discontinuously as much as 20 miles long; (3) the stream terraces along the sides of the principal valleys; (4) the San Onofre Hills immediately inland from the coastal terrace; (5) the rugged Santa Margarita Mountains or the highland area as referred to by Ellis and Lee (1919, pp. 34-35); and (6) the intervening area of moderate relief between the San Onofre Hills and the Santa Margarita Mountains.

Except for the principal stream valleys, the trend of the other features is northwest or parallel to the coast line, which in general is also a direct reflection of the main structural trend of the area.

Valley Areas

The principal stream valleys in descending order of magnitude are the Santa Margarita River, San Mateo Creek, San Onofre Creek, Las Flores Creek and Aliso Creek. In large part, these streams and their major tributaries cut across the dominant physiographic and structural features of the area at right angles indicating that their courses were largely established prior to uplift of the coastal block. All of these streams cut through the north-trending San Onofre Hills and its extensions, but only the Santa Margarita River system has cut through the high mountain mass southeast of the Elsinore fault.

In part, San Mateo and San Onofre Creeks are consequent upon the intervening area between the San Onofre Hills and the Santa Margarita Mountains where they have established courses on the relatively soft beds in the La Jolla formation. In these reaches their former courses are marked by terraces along the north sides and by steep canyon walls along the south sides indicating that southwestward tilting of the area has occurred.

Santa Margarita River Valley

The Santa Margarita River valley, which is the southernmost of the principal streams on the Camp, is formed by the confluence of the Temecula River (also called Temecula Creek) and Murrieta and Pechanga Creeks at the head of Temecula Canyon (also called Railroad Canyon) approximately 26 river miles from the coast (pl. 15) and at an altitude of about 1,000 feet. Below the junction the stream flows in a southwesterly direction for about 5 miles through Temecula Canyon whose steep walls have a relief of more than 1,000 feet. Downstream the river flows in deeply entrenched meanders and is joined successively by Rainbow Creek, Sandia Creek, and De Luz Creek. Approximately 10 miles from its origin the Santa Margarita River enters the Naval Reservation.

Downstream from the De Luz Creek-Santa Margarita River junction, which is at an altitude of 137 feet and 12 river miles from the coast, the river continues in the narrow canyon for a distance of 1.7 miles. The canyon has steep walls which rise to altitudes of over 600 feet on the west side and to over 300 feet on the east side. In this reach is the site of the proposed De Luz dam (pl. 1). The average river gradient between De Luz dam site and the coast is about 11.5 feet per mile. For the purposes of this report the valley below De Luz dam site has been termed the lower Santa Margarita River valley, and the relatively large ground-water basin in this lower valley has been called the lower Santa Margarita River basin. For convenience of treatment this basin has been divided into several parts, which are described below.

Near the north end of the Navy Hospital area the canyon spreads out to form an alluvial plain averaging a little over half a mile in width and extending about 2 miles downstream to a natural constriction just north of the Basilone Road ford. The ground-water basin beneath this alluvial plain, including the canyon reach below De Luz dam site, is called Upper Basin and has a surface area of about 860 acres. The valley sides are slightly lower and more gentle than those in the upstream canyon area.

Immediately downstream from the narrows above Basilone Road ford, the valley floor again widens to form another alluvial plain. This broad plain attains a maximum width of about 2 miles and extends downstream for a distance of 3.3 miles to another natural constriction in the valley at well 10/5-26L1.[1] The area of the plain is about 2,180 acres, and the

[1] For description of well-numbering system see p. 401.

area of terraces along the north side of the plain is about 460 acres. Beneath these two is the largest ground-water basin in the lower Santa Margarita River valley. This is called Chappo Basin and has a total surface area of about 2,640 acres.

Below the narrows, which forms the southern boundary of Chappo Basin, the alluvial plain again widens to form the surface of another ground-water basin named Ysidora Basin, which extends downstream to Ysidora gaging station--a distance of 2.7 miles (pl. 28). At the downstream end of the broad part of the basin the valley enters a narrow canyon called Ysidora Narrows. Ysidora Basin is considerably smaller than Chappo Basin and has a surface area of about 1,020 acres.

Downstream from Ysidora Narrows, which is 1.3 miles in length, the Santa Margarita River valley broadens to form a lagoon area, which is in part tidal and which extends 1.5 miles to the Pacific Ocean. It has a surface area of about 600 acres. A sand bar has been formed, principally by wave action, across the valley mouth. This bar separates the lagoon from the ocean except during times of flood.

In the lower Santa Margarita River valley the river channel probably is most typical of those found in semiarid regions. During the late spring, summer, and fall it is usually dry, but during winter floods it at times becomes a broad streamway discharging large amounts of water. Ellis and Lee (1919, pls. IX and X) show pictures taken in the valley--one before the flood of January 1916 and one afterwards. The flood carried out farm land, buildings, the Santa Fe Railroad, and reportedly flooded all three basins in the lower river valley. The present-day stream channel ranges in width from about 600 feet at De Luz dam site to about 1,000 feet in Chappo Basin.

San Mateo Creek Valley

San Mateo Creek proper rises in the so-called Santa Rosa or Murrieta plateau in Cleveland National Forest north of the Santa Margarita Mountains and south of the Elsinore Mountains at a maximum altitude of about 3,500 feet and flows southwest to the ocean for a distance of about 22 miles (pl. 15). Its principal tributary is the Cristianitos Creek system which rises in the western end of the Santa Margarita Mountains at an altitude of 2,500 feet and flows generally southward for 8 miles before joining San Mateo Creek at a point nearly 3 miles from the coast (pl. 15). Within the reservation the name San Mateo Creek valley includes the Cristianitos Creek system.

San Mateo Creek cuts a precipitous canyon through the Santa Margarita Mountains before debouching on to a valley floor about at the Naval Reservation boundary. This point is about 10 river miles from the mouth of the creek and at an altitude of 400 feet. Downstream for about 5 miles the valley trends southwest as far as the Basilone Road ford. The valley sides range in altitude from 800 to 1,200 feet. At Basilone Road ford the valley turns and trends due west for 2 miles. Along this reach the north side is bounded by a series of step-like terraces; whereas the south side of the valley butts against a sheer cliff that is a little over 600 feet high in the central part. At its junction with Cristianitos Creek, San Mateo Creek changes its course abruptly from due west to south-southwest.

San Mateo Creek valley is floored by a continuous alluvial plain throughout its extent on the Naval Reservation, which is approximately 10 miles in length. In its upper reaches the plain averages nearly 1,000 feet in width and increases to 2,000 feet just upstream from

Cristianitos Creek. Here, a narrow point of land jutting out from the south wall decreases the width of the plain to 900 feet. Below this point the alluvial plain reaches a maximum width of 4,000 feet and averages about 3,500 feet. In Cristianitos Creek valley the alluvial plain extends upstream from the junction across the reservation boundary. Within the reservation the plain averages about 1,000 feet in width and is about 2 miles in length.

The stream channels resemble the lower Santa Margarita River in that they are occupied by intermittent streams which, during periods of flood, carry large amounts of water. In the summer months the channel usually remains a dry wash. Within the reservation boundaries the stream channels of San Mateo and Cristianitos Creeks attain widths up to 1,500 feet, but average from 500 to 1,000 feet.

The average stream gradient of San Mateo Creek between the coast and the upper end of the alluvial plain is about 40 feet per mile. The average stream gradient of Cristianitos Creek between the junctions of San Mateo and Talega Creeks is about 44 feet per mile.

San Onofre Creek Valley

San Onofre Creek and its tributaries rise in the Santa Margarita Mountains at an altitude of over 3,100 feet and flow west-southwest to the Pacific Ocean-- a distance of about 12 river miles. The principal tributaries are Jardine Canyon and the north and south forks of San Onofre Creek. These streams join to form the main stem near Tent Camp 2 about 4 river miles from the ocean and at an altitude of about 200 feet. About 2.3 miles from the ocean the stream enters a gorge through the north end of the San Onofre Hills. The gorge, which has sides rising to altitudes of more than 900 feet, is only about 0.6 mile long. Downstream to the coast the valley widens and has ~~a~~ well-developed terraces along both sides.

In the headwater region San Onofre Creek valley has no developed alluvial plains. Downstream in Jardine Canyon and along the north fork are minor alluvial plains whose average width is about 500 feet. The south fork of San Onofre Creek has a rather extensive alluvial plain upstream from Tent Camp 2 where its width is about 1,000 feet and its length is almost 4 miles. Below Tent Camp 2 (pl. 28) the alluvial plain is fairly broad, averaging slightly less than 1,000 feet in width until it enters the gorge where it is only about 500 feet wide, and coastward the plain again widens to about 2,000 feet. Near and at the coast a low terrace has restricted the creek to a narrow channel along the north edge of the valley floor. Downstream from Tent Camp 2 the ground-water basin beneath the alluvial plain and beneath a part of the adjacent water-bearing deposits has been called San Onofre Creek basin.

The present-day stream channels of San Onofre Creek valley flow through ravines in the upper areas, and upon reaching the alluvial plains they increase in width and decrease in depth. In the central and downstream parts the channels average a little over 200 feet in width and are incised from 4 to 10 feet below the alluvial plains. Below the gorge the channel is somewhat braided with a few minor alluvial plains forming "islands" in the channel. The average stream gradient from Tent Camp 2 to the coast line is about 37 feet per mile.

Las Flores Creek Valley

Las Flores Creek is formed about 0.8 mile from the ocean by the junction of two principal tributary streams--Las Pulgas Creek, which is the larger, and Piedra de Lumbre Creek (pl. 1). This stream system is called Las Flores Creek valley and is about midway between the ends of the reservation. The alluviated area coastward from the San Onofre Hills embraces Las Flores Creek and the lower reaches of Las Pulgas and Piedra de Lumbre Creeks.

Las Pulgas Creek originates in the Santa Margarita Mountains approximately 10 miles from the ocean at an altitude of about 1,100 feet. Beginning about 2 miles upstream from Basilone Road, the stream crosses a relatively broad valley floor for a distance of 4.4 miles then enters a gorge cut through the San Onofre Hills. The sides of the gorge are very precipitous, rising to altitudes of over 800 feet, or nearly 700 feet above the canyon floor. Between the mouth of the gorge and the ocean, a distance of 2.2 miles, the valley floor widens to an average of 2,500 feet. Within this reach, the coastal terraces bordering the valley rise from 80 to more than 100 feet above the valley floor.

Between the coast and the San Onofre Hills the ground-water basin beneath the alluvial plain and beneath a part of the adjacent water-bearing deposits has been called Las Flores Creek basin.

The stream gradient of Las Flores Creek between the coast and the junction of Las Pulgas and Piedra de Lumbre Creeks is about 45 feet per mile. The gradients of Las Pulgas and Piedra de Lumbre Creeks between their junction and their gorges are about 34 and 63 feet per mile respectively.

Aliso Creek Valley

Aliso Creek is the smallest of the streams here considered and has an over-all length of only about 9 miles. It heads in the southeastern foothills of the Santa Margarita Mountains at an altitude of 700 feet. After descending from the foothills, the creek trends southwest and crosses a gently rolling area for a distance of about 5 miles before entering a narrow, sinuous gorge near the southern extremity of the San Onofre Hills. The alluviated part of this stream system is called Aliso Creek valley.

South of the gorge the valley widens, has become entrenched in the coastal terrace, and extends for a distance of nearly 2 miles to the Pacific Ocean. The average width of the alluvial plain is about 500 feet, and the height of the valley sides is between 20 and 60 feet. In this reach the stream gradient is about 45 feet per mile. The ground-water basin beneath this part of the alluvial plain is called Aliso Creek basin.

Terraces

Coastal Terraces

Among the most prominent physiographic features to be seen when crossing the reservation on U. S. Highway 101 are the coastal terraces. Along the seaward flanks of the San Onofre Hills at altitudes up to 1,300 feet are numerous benches marking positions of successively older and higher coastal terraces. In large part these surfaces are underlain by accumulations of marine and alluvial material deposited on old wave-cut benches whose inland extents are marked by ancient sea cliffs now largely obscured by the overburden. In some places, such as near Horno Canyon, the overburden is as much as 120 feet thick. The gently rolling surfaces of more extensive terraces are caused by deposition of alluvial materials from streams draining the seaward slope of the San Onofre Hills. Some streams, such as Horno Creek, have developed fans on the old terrace surfaces.

Upson (1951a) has assembled considerable data regarding the terraces and wave-cut benches with particular reference to southern Santa Barbara County; Poland and Piper (____) and Poland, Garrett, and Sinnott (____) have described certain terraces between Newport Beach and Santa Monica; and Woodring, et al (1946, pp. 113-116) have identified numerous terraces on the flanks of the Palos Verdes Hills.

Upson (1951a, p. 445) has suggested that the terraces at and below about 125 feet reflect world-wide positions of sea level; whereas the terraces at higher levels were formed during halts and uplifts of the rising land mass within and following the mid-Pleistocene orogeny. Along the coast of Camp Pendleton, the seaward surfaces of the principal coastal terrace deposits are found at altitudes of 40, 60, 80, 180-200, about 250, 350, 450, 550, 620, and 720-760 and remnants are found at higher altitudes. The so-called 60- and 80-foot terraces, which in large part are buried by alluvial fans deposited by minor streams, form the relatively broad surface upon which is U. S. Highway 101. This terrace is interrupted where cut by major stream valleys. Accordingly, it has been called the coastal intervalley area. Where extensive and underlain by water-bearing deposits, it forms a ground-water unit that presents possibilities for limited ground-water development.

Stream Terraces

Along the flanks of the principal stream valleys are benches or terraces of varying extent and development. During the several stands of the sea already described, the streams had time to become stabilized and graded to these ancient stands of sea level and developed relatively broad plains. Remnants of these former plains, now terraces, remain as evidence along the valley sides. Owing to the subsequent southwestward tilting of the land mass, the remnants of the higher terraces are best observed along the north sides of principally westward-draining streams such as San Onofre and San Mateo Creek valleys (pl. 1).

Although most of the stream terraces are of minor extent, the so-called 40-foot terrace is the most prominent in the principal valleys. In the lower Santa Margarita River valley, it is well developed and extensive around the north side of Chappo Basin; and in the lower course of San Onofre Creek valley, it is well preserved near the coast. Here the small community of San Onofre and U. S. Highway 101 are on the so-called 40-foot terrace.

Hills and Mountains

Inland from the coastal terraces are the hills and mountains which comprise three units as follows: The San Onofre Hills, the Santa Margarita Mountains, and an upland area of low relief between the two. These units are all parallel to each other and to the coast. Their general trend is in a northwest direction.

The northeastern or inland boundary of the main coastal terrace terminates abruptly at the base of a fairly high and steep-sloped range of hills referred to as the San Onofre Hills which are best developed between San Onofre and Las Flores Creeks, but extend southeastward as low hills to about the Santa Margarita River. They rise from an altitude of 400 feet near Ysidora Narrows to an altitude of 1,725 feet at San Onofre Mountain. The hills maintain their expression north to San Mateo Creek but are not definable to the north. Between San Onofre Creek and Horno Canyon the southwestern face of the hills slopes relatively steeply toward the coast, and on the northeastern or inland side there is a steep escarpment, which in places has the appearance of and may be a fault scarp. Woodford (1925, p. 165) quotes Fairbanks (1893, pp. 98-99) as stating:

> "After a careful study of the range the conclusion was reached that its [San Onofre Hills] origin was due to a great fault, represented by the very abrupt eastern slope, tilting the elevated portion to the west at a high angle."

South of San Onofre Creek, near the base of this scarp, there are numerous landslides and some direct evidence of faulting and minor folding. Between Horno Canyon and the Santa Margarita River valley there is considerable faulting parallel to and just north of the crest of the range.

The San Onofre Hills are underlain largely by the resistant San Onofre breccia which dips rather steeply to the southwest, and the topography reflects this structure. The fairly rugged relief of the hills is accentuated by the dense vegetation it supports, which is largely chaparral and sagebrush. The seaward side of the hills has been dissected by numerous minor canyons whose streams are graded to the coastal terrace along the inland side, but have incised slot-like trenches across the coastal terrace to the ocean.

The area bordering the San Onofre Hills on the northeast and extending inland to the Santa Margarita Mountains has been referred to as an area of old elevated terraces by Ellis and Lee (1919, p. 31) who state:

> "... the San Onofre Hills ... are flanked on the east by the dissected terrace, 300 to 500 feet high, which corresponds to the Linda Vista Mesa ...."

From San Onofre Creek southeast to the San Luis Rey River the topography is fairly gentle and undulating. The valleys have wide floors, and the peaks of the ridges are rounded and are relatively further apart. Although no marine terrace deposits were found on the tops of the ridges, it was noticed that there is a reasonably constant altitude of the crest-lines sloping from about 800 to 900 feet between Talega Canyon and San Mateo Canyon to 500 feet between the lower Santa Margarita River valley and the San Luis Rey River valley. Also, it is possible that the poorly preserved surface here exposed is a segment of the so-called Fallbrook Plain or surface, a part of which lies within the Fallbrook Naval Ammunition Depot (pl. 1).

That part of the reservation east of the Santa Margarita River and north of O'Neill Lake occupies what Ellis and Lee (1919, p. 43) have called the Fallbrook Plain. The plain is somewhat mushroom shaped with the town of Fallbrook near the north-central part, and is approximately 7 miles wide and 10 miles long. The elevation of the plain rises from about 500 feet on the south to 700 feet on the north.

Adjoining this area of gentle relief on the north and extending to the northeastern boundary of the Naval Reservation are the Santa Margarita Mountains, which rise to a maximum altitude of 3,187 feet in the headwaters of San Onofre Creek near the north-central part of the reservation. In general, the mountains trend northwest, are less prominent near the Santa Margarita River, and merge to the north with the Murrieta plateau, which has an average altitude of between 2,200 and 2,500 feet.

Except for the Santa Margarita River, all the principal streams crossing the reservation rise in the Santa Margarita Mountains or the plateau area to the north. The southwest-facing flank of the range is quite precipitous in the area northwest of the headwaters of Las Pulgas Creek. At the upper end of San Mateo Creek plain the mountains are exceptionally steep, rising from the valley floor at an altitude of about 400 feet to more than 1,800 feet in less than a mile.

Immediately east of the highest part of the mountains, there is a prominent northeast-trending fault scarp which is along the west side of Las Pulgas Creek and which probably extends into the headwaters of De Luz Creek. Southeast of the scarp the relief is considerably less rugged, and the altitude at places attains 1,500 feet but is commonly less than 1,000 feet.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

The water-bearing properties of the various geologic formations within Camp Pendleton are critical with respect to the supply of ground water available for Camp use. Those formations that yield water readily to wells have been studied in considerable detail; whereas those that yield little or no water have been mapped only enough to determine extent, position, and structure. Based on the geologic mapping, the results of the test-well drilling, the yields of wells, and related tests and studies, the formations have been segregated into two principal groups: The unconsolidated water-bearing deposits and the consolidated and essentially non-water-bearing rocks.

For each stratigraphic unit mapped and shown on plate 1, table 1 shows its age, thickness, and general lithologic character. In addition, a brief description of its water-bearing properties is given. In the following pages, the deposits and rocks are discussed in considerable detail and are arranged in order from youngest to oldest.

Table 1.- Stratigraphic units on Camp Pendleton, California

Geologic age		Formation and symbol on pl. 1	Thickness (feet)	General lithologic character	Water-bearing properties
QUATERNARY	Recent	Beach sand (Qs)	0-15	Sand, medium to coarse, well rounded.	Unconsolidated; not tapped by wells.
		--Unconformity--			
		Alluvium (Qal)	0-210	Boulders, gravel, sand, silt, and clay of fluvial origin except near coast where marine clays and sands interfinger; underlies principal alluvial plains and includes river-channel deposits. In lower Santa Margarita River valley it is composed of two members: Qalu, upper fine-grained member, and Qall, lower coarse-grained member.	Unconsolidated; in larger valleys yields water to wells at rates up to 3,000 gpm with 30-foot drawdown, but averages about 1,500 gpm. Yields less in smaller valleys. In lower Santa Margarita River valley the permeability is between 2,500 and 4,500 gpd per square foot determined from well tests. Upper member confines water locally in coastal segments of valleys.
		--Unconformity--			
	Pleistocene	Old dune sand (Qso)	0-50±	Largely medium to coarse sand on high terraces. May be wind-blown or old beach-sand deposits.	Unconsolidated, but above zone of ground-water saturation. Not tapped by wells.
		--Unconformity--			
		Terrace deposits (Qt)	0-120	Boulders, gravel, sand, silt, and clay of fluvial and marine origin; occur principally along coast and on north sides of major valleys.	Unconsolidated, but mostly above zone of ground-water saturation. Supplies water to test wells at mouth of San Onofre Creek and in Chappo Basin.
		--Unconformity--			
		Unnamed deposit (Qp)	0-80+	Boulders, gravel, sand, silt, and clay largely of marine origin. Underlies coastal terrace south of Las Flores Creek.	Unconsolidated, but mostly above zone of ground-water saturation. Penetrated by wells on coastal terrace.
	---?---?---	--Unconformity--			

Table 1.- Continued.

Geologic age		Formation and symbol on pl. 1	Thickness (feet)	General lithologic character	Water-bearing properties
TERTIARY	Pliocene	San Mateo formation (Tsm)	0-1,000+	Gravel, sand, silt, and sandy shale of marine origin. Massive, obscurely bedded; coarse series north of Aliso Creek, fine series to south. Underlies coastal terraces and hills at north end of Camp.	Largely unconsolidated; yields water to wells locally at rates up to 1,600 gpm with drawdown of 21 feet, but average about 700 gpm in north part of Camp. Permeability between 100 and 500 gpd per square foot determined from well tests. Quality fair to good to north, but poor at south end of Camp.
		--Unconformity--			
		Capistrano formation (Tcp)	0-500+	Shale, siltstone, and some conglomerate and sandstone of marine origin. Crops out at north end of Camp.	Largely consolidated; essentially non-water-bearing. May be tapped by a few deep wells in San Mateo Creek.
	---?---	--Unconformity--			
	Miocene	San Onofre breccia (Tso) and Temblor (?) formation (Tt?)	0-3,000±	Breccia, sandstone, and siltstone; of continental and marine origin; angular rock fragments up to 20 tons. Underlies San Onofre Hills; at north end of Camp may be interbedded with Temblor (?) formation.	Consolidated; tapped by test well 11/5-2P1 which yielded essentially no water and the water contained 392 ppm of chloride. Temblor (?) formation not tapped by wells; essentially non-water-bearing.
		--Unconformity--			
	Eocene	La Jolla formation (Tlj)	0-5,000±	Sandstone and shale; some conglomerate and siltstone; basal part contains lateritic clays. Underlies area between San Onofre Hills and Santa Margarita Mountains.	Consolidated; yields very minor amounts of water to test wells 10/5-23Q1 and 11/5-2P2; water contains 160 to 600 ppm of chloride. Tapped in part by supply well 10/5-14P1.
		--Unconformity--			

Table 1.- Continued.

Geologic age		Formation and symbol on pl. 1	Thickness (feet)	General lithologic character	Water-bearing properties
CRETACEOUS		Unnamed conglomerate (Ku)	0-500±	Conglomerate composed of metamorphic and granitic boulders in coarse sand matrix. Underlies small widely separated areas.	Consolidated; not tapped by wells; essentially non-water-bearing.
		---Unconformity---			
CRETACEOUS		Chico formation (Kc)	0-2,000±	Sandstone, coarse, massive; gray siltstone; gray shale; and some conglomerates near base. Well cemented. Exposed in Santa Margarita Mountains and foothills.	Consolidated; not tapped by wells; essentially non-water-bearing.
--?--		Major Unconformity			
TRIASSIC TO CRETACEOUS (?)		Basement complex (Bc)	(?)	Igneous and some metamorphic rocks of granodiorite, gabbro, tonalite slates, quartzite. Exposed in mountains and foothills along northeast part of Camp.	Consolidated and essentially non-water-bearing except where granitic rocks are deeply weathered. Wells drilled in weathered zone on the Naval Ammunition Depot yield water in small quantities. During dry periods the yields decrease.

Unconsolidated Deposits

The unconsolidated deposits consist of boulders, gravel, sand, silt, and clay which, where saturated, yield water to wells at rates up to several thousand gallons per minute. The materials are generally loosely compacted, and contain interconnected pore spaces through which ground water moves. Because of the voids, the deposits are also capable of storing appreciable quantities of ground water. These deposits are the source of supply for all Camp, irrigation, domestic, and stock wells.

The unconsolidated deposits, from youngest to oldest, are as follows: Beach sand of Recent age, the alluvium and channel deposits of Recent age, the old dune sand of probable Pleistocene (?) age, the terrace deposits of Pleistocene age, an unnamed deposit of probable Pleistocene (?) age, and the San Mateo formation of Pliocene age. They are discussed in the same order in the following sections of the report.

The alluvium and channel deposits are considered as one stratigraphic unit because the channel deposits differ from the alluvium only in that they represent the active part of the uppermost part of the alluvium. Furthermore, in all the valleys considered, historical reports suggest that essentially the entire surface extent of the alluvium has been inundated during flood flows. For example, in 1916 it was reported that the surface areas of Upper, Chappo, and Ysidora Basins were completely under water during the large floods of that year. Accordingly, no distinction has been made in the text or on the geologic map (pl. 1) between the currently active channel and the adjacent surface of the alluvium. The stream courses on plate 1 show the present location of channels in each of the stream valleys on the Camp.

Because the alluvium in each stream valley is distinct and different from that in the other stream valleys, the significant features and water-bearing properties of the alluvium in each are discussed separately. However, these deposits were laid down at essentially the same geologic time and therefore are all considered to be of the same age which is Recent. The order in which they are discussed is according to the size of stream system; that is, starting with the lower Santa Margarita River valley and ending with Aliso Creek valley.

Beach Sand

(Recent)

Deposits of beach sand extend the full length of the coast line. The sand has been and is being laid down largely by wave action, but in part has been blown into the lagoons where it rests unconformably upon the alluvium at the mouths of stream valleys. (See geologic sections E-E' and L-L' to O-O', pls. 4 and 6 to 8.) Elsewhere along the coast it rests unconformably on older rocks, largely on the San Mateo formation. Its extent is shown on the geologic map (pl. 1). Where the sea cliffs are undergoing active wave action, the sand deposit is too narrow to show on the map.

Across the mouths of streams wave and wind action have built beach ridges and dunes that locally attain a thickness of as much as 15 feet. The sand is porous and capable of transmitting water. At times the sand may contain some semiperched water at the base where it rests upon clay or tight material. However, the quantity of contained water is largely ephemeral as well as negligible; and therefore precludes the possibility of its development for a ground-water supply.

Alluvium in the Lower Santa Margarita River Valley

(Recent)

In the lower Santa Margarita River valley the alluvium is the principal source of ground-water supply. It supplies all the water for Camp supply and irrigation use at the south end of the reservation. Because all but the uppermost part of the alluvium is concealed, its character has been determined almost wholly from a study of over 90 logs of Camp supply, irrigation, stock, and test wells that pierce or enter it to various depths (appendix 2).

Stratigraphy.--The general character and lithology of the alluvium is shown graphically in geologic sections E-E' through K-K' (pls. 4 and 5), and the detailed descriptions of the materials penetrated are shown in the logs of wells (appendix 2). Section E-E' shows that the base of the alluvium rests unconformably on the older rocks underlying the basin. The average gradient along the base of the alluvium between De Luz dam site and the coast is about 18 feet per mile compared to the gradient on its present surface of only about 11.5 feet per mile.

The geologic sections show that about the lower half of the deposit is coarse grained, whereas about the upper half is fine grained. The distinction between the two is identifiable as far upstream as Upper Basin where the definition becomes poor, and the entire section is largely coarse sand and gravel. From this basin toward the coast it becomes increasingly more apparent; the upper half contains progressively less gravel and sand and progressively more sand and silt. The best definition between the two is on the east side of Ysidora Basin where the upper half is largely "clay" and silt. Near the coast evidence of marine invasion into the valley is indicated by numerous fossil shells encountered in drilling. Their presence indicates that some of the sand and clayey silt near the coast are of marine origin. The lower member also becomes somewhat fine grained toward the coast, but still retains a high percentage of coarse gravel and sand.

The two parts in general appear to be conformable with one another and have been called the upper and lower members of the alluvium. In appendix 2, which contains the well logs, the upper member has been identified by the symbol Qalu, and the lower member by the symbol Qall. Where no distinction has been made, the symbol Qal was used.

In Chappo and Ysidora Basins the lower member is the principal source of ground-water supply. In other major coastal valleys of California the lower part of the alluvium is also the principal source of ground-water supply. Poland and Piper (___) designated the lower member of the alluvium in the Santa Ana River coastal area the Talbert water-bearing zone and in the Los Angeles River coastal area the Gaspur water-bearing zone. Farther north along the coast, Upson and Thomasson (1951) and Worts (1951) distinguished the two members of the alluvium in the Santa Ynez and Santa Maria River valleys respectively. They are also identifiable in other major coastal basins farther north and in the San Diego County river basins to the south (Ellis and Lee, 1919).

Extent and thickness.--The areal extent of the upper member of the alluvium is represented by its limits as shown on the geologic map. Its thickness ranges from about 65 feet in test well 10/4-7Hl to a maximum of about 110 feet in Ysidora Basin and thins somewhat toward the coast where it is only about 70 feet thick.

The extent of the lower member is somewhat less than that of the upper member owing in part to the inward sloping sides of the valley walls. Geologic section I-I'(pl. 5) shows that the lower member is missing along the west side of Chappo Basin. Wells 10/5-13J1, 14P1, 14Q1, and 23Q2 encountered relatively thin deposits of the lower member of the alluvium. Thus, for that part of Chappo Basin west of the river and north of test well 10/5-23L1, the lower member is thin. Prior to the construction of supply well 10/5-23Q2 (abandoned) in 1952 the thinness of the productive lower member at that location was not suspected.

In the central part of Ysidora Basin, well 11/5-2B2 reportedly encountered "hill formation" at 104 feet (table 2A). On the basis of this well log and the log for well 11/5-2A2, geologic section E-E' shows two interpretations: (1) Assuming the log data to be correct, a bedrock high is shown in the center of the basin; and (2) assuming the log data to be incorrect, the full postulated thickness of the lower member of the alluvium is shown.

Section E-E' shows that the total thickness of the alluvium increases downstream from 120 feet at De Luz dam site to about 200 feet at the coast. Geophysical methods involving the use of seismic refraction and resistivity equipment were used in an attempt to ascertain the thickest part of the alluvium near test wells 10/5-26L1, 11/5-2N4, and 11/5-10E1. The data obtained were inaccurate as to the thickness of the alluvium, but were in large part accurate as to the location of the thickest part. On the basis of the data obtained from this work, the above-mentioned test wells were constructed. Wells 11/5-2N4 and 11/5-10E1 are believed to penetrate the thickest part of the alluvium, but on the basis of the profile established on the base of the alluvium by wells upstream and downstream, well 10/5-26L1 did not (pl. 4).

Water-bearing properties.--In Chappo and Ysidora Basins the lower member of the alluvium supplies water to Camp supply and irrigation wells at rates of between 1,000 and 1,500 gpm. When the wells were developed by test pumping they yielded water at rates up to 2,600 gpm. In Upper Basin, where both members of the alluvium yield water to wells, Camp supply wells have been tested at rates up to 2,000 gpm. The specific capacity[1/] of adequately constructed wells tapping the alluvium in Ysidora Basin is about 80 gpm per foot of drawdown for irrigation well 10/5-35H1 and supply well 11/5-2A1; in Chappo Basin between 100 to 150 gpm per foot of drawdown for supply wells 10/4-18R2, 10/5-23J1, and 10/5-24H1; and in Upper Basin about 200 gpm per foot of drawdown for hospital well 10/4-5D1. Thus, there is a substantial increase in specific capacity upstream which is due to a corresponding increase in coarseness and water-yielding character of the upper and lower members of the alluvium.

A crude estimate of permeability can be made by use of the specific capacity times a constant of about 2,000 divided by the saturated water-yielding thickness of the alluvium. In Ysidora Basin, these data suggest a permeability of 2,500 to 3,000 gallons a day per square foot; in Chappo Basin, of 2,500 to 3,500 gallons a day per square foot; and near the upstream end of Upper Basin, of about 4,000 to 4,500 gallons a day per square foot.

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1. Specific capacity is defined as the yield in gpm divided by the drawdown in feet, or gallons per minute per foot of drawdown.

In order to determine the coefficients of transmissibility, permeability, and storage coefficients 1/ of the alluvium more accurately, aquifer-rating tests were run on Camp-supply wells 10/4-7R1, in Upper Basin; 10/5-23J1, in Chuppo Basin; and 11/5-2A1, in Ysidora Basin, and on irrigation well 10/5-35K1, in Ysidora Basin. The data collected during the tests were used to obtain these coefficients by the Theis non-equilibrium graphical method as refined by Ferris (1945, pp. 9-12). Also, the data were used to obtain the coefficients by using the recovery method in the pumped well (Wenzel, 1942, pp. 123-129).

For Upper Basin, the results obtained from the test indicate a range in transmissibility from 610,000 to 730,000 gallons a day per foot. When these values are divided by the thickness of the saturated water-yielding deposits, values of permeability can be obtained. At well 10/4-7R1 the thickness was 136 feet. Therefore, the interpreted range in permeability is from 4,500 to 5,400 gallons a day per square foot. In order to be conservative in deriving quantitative estimates of underflow in the section on recharge, a permeability of 4,500 gallons a day per square foot has been used.

For Chuppo Basin the results obtained from the aquifer-rating tests on two wells indicate a range in transmissibility of 167,000 and 172,000 gallons a day per foot, and an interpreted range in permeability of 3,000 to 3,400 gallons a day per square foot. The values of permeability obtained suggest a decrease in permeability of about 1,500 gallons a day per square

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1/ Definitions: (1) Coefficient of transmissibility may be defined as the rate of flow of water in gallons per day through a vertical strip of the aquifer 1 foot wide and extending the full saturated height under a hydraulic gradient of 100 percent; and (2) Coefficient of permeability may be defined as the rate of flow in gallons of water a day through a cross-sectional area of 1 square foot of the aquifer under a hydraulic gradient of 100 percent; and (3) Coefficient of Storage may be defined as the volume of water that a unit decline of head releases from storage in a vertical prism of the aquifer of unit cross section; under water-table conditions (unconfined water) it is essentially equivalent to the specific yield.

foot between the pumped wells 10/4-7R1 and 10/5-23J1-- a distance of 2.6 miles. In this basin the values obtained apply only to the lower member of the alluvium.

For Ysidora Basin, the results obtained from the tests on two pumped wells and from nine observation wells indicate a range in transmissibility from 100,000 to 240,000 gallons a day per foot for the lower member of the alluvium. The wide range obtained is due in part to the wide range in thickness of the water-yielding deposits tapped by the observation and pumped wells. When the transmissibility is divided by the thickness of the aquifer tapped, the interpreted range in permeability is from 1,500 to 3,400 gallons a day per square foot, and the average for all observation wells used and for the pumped wells was about 2,500 gallons a day per square foot. This value is used in the section on ground-water discharge to derive quantitative estimates of ground-water outflow through Ysidora Narrows. In Ysidora Basin the values obtained apply largely to the lower member of the alluvium.

The aquifer-rating test data were analyzed to derive the coefficients of storage in the three basins. The range in values obtained was as follows: Upper Basin, 0.13 to 0.50; Chappo Basin, 0.0004 to 0.0012; and Ysidora Basin, 0.0002 to 0.09. The average of about 0.3 for Upper Basin, where water-table conditions exist, may be on the correct order of magnitude; but because the range is so great, the values were not used to refine the assigned specific-yield values used in the section on ground-water storage capacity. The smaller values of storage coefficient for Chappo and Ysidora Basin are within the range usually found where nearly perfect confinement exists, However, the range in values obtained is too low for the poor confinement that exists in these basins. The principal reason the values are so low is due to the shortness of the pump tests, which were only 48 hours. As a result, the finer materials did not have sufficient time to drain.

In Ysidora Basin a comparison of the storage coefficients obtained at the beginning and end of the tests showed that the storage coefficients were increasing with time. At the beginning of the test the values averaged about 0.0005 and near the end of the test the values averaged about 0.03. The latter value suggests a specific yield of nearly 3 percent, which is still too low for the upper member as a whole.

The range in values of permeability of the alluvium are of the same order of magnitude as those obtained in other relatively large coastal valleys of California. Poland and Piper (___) obtained permeabilities of 3,000 to 5,000 gallons a day per square foot for the lower member of the alluvium in the Los Angeles coastal area; Upson and Thomasson (1951, p. 76) obtained values of 1,200 to 5,100 gallons a day per square foot for the alluvium in the Santa Ynez River valley; and Worts (1951, pp. 38-39) obtained values of 1,500 to 4,500 gallons a day per square foot for the alluvium in the Santa Maria Valley area. A range in permeability of 2,500 to 4,500 gallons a day per square foot for the alluvium in the lower Santa Margarita River valley appears reasonable.

Finally, the character and water-bearing properties of the alluvium indicate that Upper Basin offers very good possibilities for additional ground-water development for Camp supply. Properly constructed wells should yield more than 1,000 gpm. The Navy Hospital well 10/4-5M1, which is near the upstream end of the basin, when developed by test pumping, yielded about 2,000 gpm with a drawdown of only 9 feet. The aquifer-rating test run on supply well 10/4-7M1 indicated that the well has a high screen loss, which induced an abnormally large drawdown, and is not representative of a properly constructed well.

Alluvium in San Mateo Creek Valley

(Recent)

The alluvium in San Mateo Creek valley, which includes that in both San Mateo and Cristianitos Creeks, is the principal source of ground-water supply; however, in the coastward 2.7 miles of the valley, some water is supplied locally from the underlying San Mateo formation. The subsurface extent and character of the alluvium was obtained from a study of 22 logs of wells drilled into and through the alluvium. In addition, the maximum thickness of the alluvium near the mouth of the valley was estimated by seismic geophysical methods (pl. 8, section O-O').

Extent, character, and thickness.--The general character of the alluvium is shown graphically in geologic sections O-O' and P-P' (pl. 8), and the detailed descriptions of the materials penetrated are shown in the logs of wells (appendix 2). Sections O-O' and P-P' show that the alluvium rests with marked unconformity upon the older formations. Numerous faults cut these older formations but, so far as could be determined, do not cut the alluvium. Accordingly, the base of the alluvium has a fairly well-defined profile. The average gradient along the base of the alluvium between well 8/6-33L1 and the coast is about 47 feet per mile compared to the gradient on its surface of about 35 feet per mile. On section O-O' the base of the alluvium upstream from supply well 9/7-11M2 is approximately controlled by plotting well logs encountering the greatest thickness of alluvium; coastward the gradient has been projected.

The logs show that the alluvium is composed of boulders, gravel, sand, and some silt and clay. In large part the alluvium is very coarse. Near the coast, the uppermost 10 to 25 feet of the alluvium is composed of sandy silt to silty clay. This poorly defined fine-grained unit may correspond to the well-defined upper member of the alluvium in the lower Santa Margarita River valley. However, because of its limited extent and thickness, it is not considered a separate unit in the San Mateo Creek valley. Thus, the extent of the alluvium as a single stratigraphic unit is defined by the surface limits shown on the geologic map (pl. 1).

The thickness of the alluvium ranges from about 35 feet at well 8/6-22R1 at the upper end of San Mateo Creek valley and from about 60 feet at well 8/7-36D1 in Cristianitos Creek to a postulated maximum of about 130 feet at and near the coast. However, test well 9/7-14M1, about 1,700 feet from the coast, penetrated only 80 feet of alluvium before entering the San Mateo formation; and therefore, it is believed that the well was not drilled through the thickest part of the alluvium.

Water-bearing properties.--Except for two wells in Cristianitos Creek valley and two in San Mateo Creek valley about a mile above the junction with Cristianitos Creek, all the large pumping wells, including new Camp supply wells 9/7-11H2 and 9/7-11M1, are downstream from the junction. Most wells in this area tap both the alluvium and the underlying San Mateo formation and derive water from both. However, the data indicate that most of the water is from the alluvium.

The yields of the wells range from about 600 to over 1,800 gpm with drawdowns between 20 and 96 feet. The specific capacity ranges from 20 to 35 gpm per foot of drawdown which, considering the character and thickness of the water-bearing materials tapped, appears to be somewhat low and raises some question as to the proper construction and development of the wells.

The relatively coarse-grained alluvium is receptive to rapid recharge from the creek system, particularly in the reaches above Cristianitos Creek junction. However, owing to the relatively rapid rate of depletion by natural drainage downstream, it is not considered advisable to develop large supply and irrigation wells upstream from the junction.

Alluvium in San Onofre Creek Valley

(Recent)

In San Onofre Creek valley the alluvium is the principal source of ground-water supply; however, in the coastward 1.5 miles of the valley, water is supplied locally and in considerable quantity from the underlying and adjacent San Mateo formation. The subsurface character and extent of the alluvium was obtained from a study of 12 logs of wells drilled through the alluvium. No seismic refraction or resistivity traverses were made in San Onofre Creek valley.

Extent, character, and thickness.--The general character of the alluvium is shown graphically in geologic sections M-M' and N-N' (pl. 7), and the detailed descriptions of the materials penetrated are shown in the logs of wells (appendix 2). Sections M-M' and N-N' show that the alluvium rests with marked unconformity upon the La Jolla formation, the San Onofre breccia, the San Mateo formation, and the 40-foot terrace deposit at the coast. The two faults shown cutting the older formations, so far as could be determined, do not cut the alluvium. Accordingly, the base of the alluvium has a fairly well-defined profile. The average gradient along the base of the alluvium between wells 9/6-16J1 and the coast is about 58 feet per mile compared to the gradient on its surface of about 44 feet per mile. On sections M-M' and N-N' the base of the alluvium upstream from test well 9/7-13P1 is controlled by well-log data; coastward the gradient of the base has been projected.

The logs show that the alluvium is composed of boulders, gravel, sand, and some clay and silt. In large part the alluvium is very coarse. Downstream from irrigation well 9/6-19D2 there is some indication that the upper part of the alluvium is fine-grained compared to the lower part. The logs of supply and irrigation wells 9/6-19D1-4 and test well 9/7-13P1 show considerable silt and clay along with coarser elements in the upper 40 to 50 feet of the alluvium. However, neither the physical character nor the hydrologic properties of the upper and lower parts are distinct enough to warrant their separation into two members as was done in the lower Santa Margarita River valley. Thus, the extent of the alluvium as a single stratigraphic unit is defined by the surface limits shown on the geologic map (pl. 1).

The thickness of the alluvium ranges from about 40 feet at the junction of the north and south forks of San Onofre Creek to a postulated maximum of about 100 feet at the coast.

Water-bearing properties.--Wells upstream from the Cristianitos fault obtain their supply wholly from the alluvium. Downstream from that fault, most wells obtain their supply largely from the alluvium but in part from the underlying San Mateo formation. New Camp-supply well 9/6-19C1, which was drilled about on the trace of the Cristianitos fault, derives all its supply from the alluvium; new Camp-supply well 9/6-19D4 and old supply well 9/6-19D1 obtain their supply largely from the alluvium but in part from the San Mateo formation.

The yields of newer wells tapping only the alluvium range from 600 to 800 gpm with drawdowns between 15 and 38 feet. The specific capacity ranges from 20 to 40 gpm per foot of drawdown. The yields of wells tapping both the alluvium and San Mateo formations range from 900 to 1,100 gpm with drawdowns between 10 and 30 feet. The specific capacity ranges from 30 to 100 gpm per foot of drawdown. Irrigation well 9/6-19D2 has the high yield of 1,100 gpm and the high specific capacity of 100 gpm per foot of drawdown, which is attributable in part to its second development, following partial failure due to sanding and caving of the surrounding formational sand and subsequent rejuvenation by sand-pumping and installing 400 tons of gravel packing outside the casing.

Wells 9/6-19D3 and 9/7-13J1 were drilled in 1952 for Camp supply, but had yields of only 30 and 200 gpm with drawdowns of 105 and 180 feet respectively. The reason for these poor yields in an area where good wells have been developed is not known, but it may have been due in large part to faulty technique in well construction.

The relatively coarse-grained character of the alluvium is conducive to fairly rapid recharge from the creek, particularly upstream from the Cristianitos fault trace. However, owing to the relatively rapid rate of depletion by natural drainage of ground water downstream, it is not considered advisable to develop large supply and irrigation wells upstream from the fault. Camp-supply wells 9/6-16J1 and 9/6-17H2 have been and are an unreliable source of supply for this reason. The wells have moderate yields in years of large recharge, but have poor yields after a period of several consecutive dry years after the deposits have been depleted by natural downstream drainage of ground water.

Alluvium in Las Flores Creek Valley

(Recent)

In Las Flores Creek valley the alluvium is relatively fine grained, and no Camp-supply or irrigation wells obtain their supply from this source. All these wells obtain their supply from the underlying San Mateo formation. The subsurface character and extent of the alluvium was obtained from a study of 18 logs of wells drilled through the alluvium. The seismic refraction and resistivity traverses made across the valley parallel to and north of U. S. Highway 101 did not furnish information on the position of the contact between the alluvium and the San Mateo formation. Thus, the base of the alluvium could not be determined by these methods.

Extent, character, and thickness.--The general character of the alluvium is shown graphically in geologic section L-L' (pl. 6), and the detailed descriptions of the materials penetrated are shown in the logs of wells (appendix 2). Section L-L' shows that the alluvium rests with marked unconformity on the La Jolla formation, the San Onofre breccia, and the San Mateo formation. No faults are known to cut the alluvium. Accordingly, the base of the deposit, although shown to be somewhat irregular, has a fairly well-defined profile. The average gradient along base between unused well 9/5-33C5 and the coast is about 50 feet per mile compared to the gradient on its surface of about 41 feet per mile. On section L-L' the base of the alluvium is interpolated between destroyed well 9/5-33C3 and test well 10/5-1E1; coastward from irrigation well 10/5-1E1 the base is projected.

The logs show that in the upstream part of the valley the alluvium is composed of boulders, gravel, sand, silt, and clay. In most instances, the coarser elements are in a matrix of silt and/or clay. In the main pumped area, the alluvium is composed largely of sandy clay or silty to clayey sand with a few lenses of poorly sorted gravel and sand. In test well 10/5-18L1, fragments of well-preserved "seaweed ?" were encountered in a basal gravel between 90 and 100 feet. In test well 10/6-24G1, fragments of decomposed wood, rushes, and possibly seaweed were encountered in the alluvium between 55 and 61 feet. The occurrence of the "seaweed ?" suggests that a part of the alluvium is of marine origin. There appears to be no semblance of recognizable upper and lower units in the alluvium of Las Flores Creek valley. Thus, the extent of the alluvium as a single stratigraphic unit is defined by the surface limits shown on the geologic map (pl. 1).

The thickness of the alluvium ranges from about 60 feet in wells 9/5-33Q1-5, to about 100 feet in test well 10/5-18L1 and in irrigation well 10/5-18Q1, to a postulated maximum of about 120 feet near the coast, and to about 100 feet at the coast.

Water-bearing properties.--The relatively large percentage of fine-grained materials in the alluvium make it a poor water-yielding deposit. Wells 9/5-33Q5 and 10/5-8E1, which tap only the alluvium in Las Pulgas Creek, are reported to have had very poor yields. The same is true for the few domestic and stock wells deriving water from the alluvium in Piedra de Lumbre and Las Flores Creeks. Accordingly, the Las Flores Creek ground-water basin is limited to that part of the valley where the alluvium is underlain by the San Mateo formation, which is the principal source of supply. Upstream from this basin wells giving adequate yields for Camp supply or irrigation appears very unlikely.

The generally fine-grained character of the alluvium prohibits rapid recharge from Las Flores Creek system even during periods of large runoff with the result that the basin is slow to recharge. However, the deposits do contain a relatively substantial ground-water storage capacity. Storage can seep slowly downward to the underlying San Mateo formation and thereby augment the ground-water supply.

Alluvium in Aliso Creek Valley

(Recent)

The alluvium in Aliso Creek valley is of relatively minor extent and thickness. Its extent is shown on the geologic map (pl. 1), and its thickness is shown by the logs of supply well 10/5-29L1 and test well 10/5-31A1 (appendix 2). In well 29L1 the thickness is about 32 feet and the log indicates that only the lower 6 feet of gravel and small boulders is water yielding. In test well 10/5-31A1 the thickness is about 54 feet and the log indicates that only the lower 5 to 12 feet is water yielding; the coarse elements above contain considerable silt and clay and would therefore yield little water to wells. It is believed that the San Mateo formation, which underlies the alluvium with moderate unconformity, yields most of the water to the two wells. The unnamed deposit of Pleistocene (?) age is not thought to underlie the alluvium except laterally along its sides.

The yields of wells which tap both the alluvium and San Mateo formation, are crudely 35 and 13 gpm with drawdowns of 12 and 25 feet respectively. The specific capacities are 3 and 0.5 respectively, which are quite low. It is believed that properly constructed wells would yield sufficient water to supply an additional small installation.

Old Dune Sand

(Pleistocene)

Resting unconformably upon the terrace deposits at altitudes of 100 to 300 feet above sea level are deposits of old dune sand or beach ridges ranging in thickness from a feather edge to 50 feet or more (pls. 1 and 2). These deposits are composed of poorly consolidated, light yellow to brick-red sand with a 2- to 3-foot bed of ferruginous cemented sand at the base. They underlie three generally parallel ridges trending northwest between the San Luis Rey River and Cockleburr Canyon. Because the sand rests upon the moderately old terrace deposits of Pleistocene age and because of their relatively high topographic position with respect to younger sand deposits and alluvium, the old dune sand is tentatively assigned to the Pleistocene age.

These deposits resemble what Ellis and Lee (1919, pp. 39 and 68) refer to as beach ridges on the Linda Vista Mesa. L. G. Hertlein and U. S. Grant (1944, pp. 18-19) in discussing the beach ridges of the San Diego area state:

> "These ridges may be due to the accumulation of beach material just beyond the reach of the waves during a temporary halt of the regressing sea, or some of them may have been formed in the same manner as offshore bars."

They also mention the controlling effect the ridges have on the drainage pattern and point to a resulting trellis drainage of some canyons just east of the town of La Jolla. This controlling effect of the ridges on the drainage may account for the trellis-type drainage of Newton Canyon, which drains into the Santa Margarita River.

The old dune sand, although for the most part quite porous and capable of transmitting water, is far above the zone of ground-water saturation. Locally, where the sand rests on the terrace deposits which in turn rest on the San Onofre breccia, some ground water derived from rain may be contained in the lower part. However, the old dune sand is not considered to be a source of ground-water supply.

Terrace Deposits

(Pleistocene)

Extent, character, and thickness.--The terrace deposits occur principally along the coast and the sides of principal stream valleys. Plate 1 shows an extensive deposit along the coast and higher isolated remnants along the seaward flank of the San Onofre Hills, along the north sides of San Mateo and San Onofre Creeks, and in Chappo Basin. These deposits are of Pleistocene age and are largely of fluvial (stream) but partly of marine origin. The marine terrace deposits are limited principally to a few feet of well-rounded gravel and sand resting unconformably upon the San Mateo formation or upon the unnamed deposit of Pleistocene (?) age along the coast, and overlain by, or locally interbedded with, thick sections of stream-terrace deposits. Test well 9/7-24M1, on the terrace south of San Onofre Creek, penetrated 34 feet of marine terrace deposits containing well-rounded, buff to yellow cobbles, gravel, sand, and little clay. Along the coast, these materials are cross-bedded, white to light yellow, and are poorly consolidated. Elsewhere, the deposits rest with considerable unconformity on all older formations in the area.

The stream-laid terrace deposits along the coast reach a maximum known thickness at the mouth of Horno Canyon. Here test well 10/6-3P1 (pl. 3, section C-C') penetrated 120 feet of poorly sorted gravel and sand with a fairly tight clay binder. To the south the deposits are thinner, contain less gravel, and include some cross-bedded sands. To the north the deposits also are thinner, and grade laterally into marine terrace deposits.

The higher coastal terrace deposits are largely nonmarine; they and the higher stream terrace deposits are composed of subrounded, poorly sorted, buff to light brown gravel, sand, and some clay. They range in thickness from a feather edge to 40 or 50 feet. A few of the lower terraces near the mouths of the principal streams contain near their bases well-preserved fossil shells, mostly pectens and gastropods.

One stream terrace deposit is of significance to the occurrence of ground water. This is the so-called 40-foot terrace deposit so named because its surface at the coast is about 40 feet above sea level, and along the sides of several principal streams its surface is 40 to 50 feet above the surface of the alluvium. Principal areas underlain by the 40-foot terrace deposit are at the mouth of San Onofre Creek and on the northwest side of Chappo Basin (pl. 1).

Two test wells were drilled to determine the character and water-bearing properties of the 40-foot terrace deposit. Test well 10/5-13C1 was drilled in the northwest part of Chappo Basin and penetrated 73 feet of poorly sorted subrounded buff cobbles, gravel, sand, and some clay. The well bottomed at 85 feet in the La Jolla formation. Test well 9/7-24D1 was drilled near the mouth of San Onofre Creek and penetrated 113 feet of poorly sorted tan to gray gravel, sand, silt, and clay. Some well-preserved fragments of redwood and rushes were encountered in the basal gravel.

Water-bearing properties.--Most of the terrace deposits shown on plate 1 are above the zone of ground-water saturation and therefore do not yield water to wells. However, where resting on consolidated rocks, they may contain minor amounts of water near their bases. The coastal terraces and in part some of the stream terraces adjacent to the alluvium are sufficiently permeable to transmit rain downward to ground-water bodies in the underlying or adjacent unconsolidated formations and deposits.

The so-called 40-foot terrace deposit contains ground water principally in the northwest part of Chappo Basin and near the mouth of San Onofre Creek. Minor amounts of ground water are contained in remnants adjacent to the alluvium, but the amount of water contained is relatively negligible. Deposits along the north side of San Mateo Creek above the junction with Cristianitos Creek and in San Onofre Creek are believed to be quite thin and therefore would contain little ground water. In Chappo Basin, test well 10/5-13G1 taps about 20 feet of water in the lower part of the 40-foot terrace deposit, and on development test by the air-lift method yielded only a few gallons per minute. The low yield is believed due in part to the thinness of the saturated water-bearing deposits, but largely to the inability to clean out the drilling mud that had invaded the deposits.

At the mouth of San Onofre Creek, test well 9/7-24M1 taps about 82 feet of water in the 40-foot terrace deposit, and about 37 feet of saturated San Mateo formation. When developed by the air-lift method the well yielded about 200 gpm with an unknown drawdown, but estimated by the driller to be between 20 and 30 feet. Unused well 9/7-23A1, formerly a public-supply well for the San Onofre Cafe, derived its supply entirely from the terrace deposits. However, no discharge or drawdown data are available for the well, but the owner reported that it had a "good yield."

Thus, the yield of the 40-foot terrace deposit locally is probably relatively high. However, in Chappo Basin the deposits are too thin for development, and in San Onofre Creek valley the deposits are too close to the ocean to risk development. Nevertheless, the deposit in both valleys contains a moderate amount of ground water in storage.

Unnamed Deposit
(Pleistocene ?)

Extent and character.--Overlying the San Mateo formation with minor to moderate unconformity and underlying the terrace deposits with minor unconformity is an unnamed deposit presumed to be of Pleistocene age. Its character and extent suggest that it may be a terrace deposit either underlying or forming the base of the so-called 80-foot terrace deposit. The unnamed deposit consists of unconsolidated, interbedded, and cross-bedded boulders, gravel, sand, silt, and clay chiefly of marine origin. Exposures of the deposit along the beach cliff were traced from the southeast side of San Onofre Creek valley to just south of Cockleburr Canyon (pl. 1). No inland outcrops were found between San Onofre Canyon and Las Flores Canyon, but along both sides of Las Flores and Aliso Creek valleys and Cockleburr Canyon the deposit is exposed.

The thickness of the deposit ranges from a feather edge to an exposed maximum of about 60 feet in Las Flores and Aliso Creek valleys. Along the coast north of Las Flores Creek valley, the deposit thins rapidly to only a few feet. Because of its thinness in this reach, it is not shown on the geologic map. Similarly, the deposit thins rapidly south of Cockleburr Canyon and is absent along the sides of the Santa Margarita River valley near the coast. Hence, it is shown as pinching out just south of Cockleburr

Canyon. In Las Flores and Aliso Creek valleys, the unnamed Pleistocene (?) deposit is traceable inland for about $1\frac{1}{2}$ miles where it pinches out between the San Mateo formation and the overlying terrace deposits.

Faults observed in exposures along the coast reveal offsets in the older formations, but not in the unnamed deposit. Except for a slight seaward dip, there appears to be essentially no deformation of the deposit. However, the base as exposed along the coast descends from a height of 30 to 40 feet above sea level north of Las Flores Creek valley to 10 to 15 feet above sea level at the creek mouth. Slight downwarping may have occurred in the central part of the coastal area where the thickest section of the deposit is exposed.

As is indicated by plate 1 the deposit was laid down upon the warped and eroded surface of the San Mateo formation. Between San Onofre Canyon and Las Flores Canyon there is an angular unconformity between the San Mateo formation and the unnamed deposit.

Water-bearing properties.--Because the unnamed deposit of Pleistocene (?) age is largely above the zone of ground-water saturation and because no known wells derive water from the deposit, its water-bearing properties are not known. In the coastal intervalley area, the deposit is significant in that it is capable of transmitting rain that infiltrates through the overlying terrace deposits downward to ground water in the underlying San Mateo formation.

San Mateo Formation

(Pliocene)

Extent and character.--The largest exposed area of the San Mateo formation is between San Onofre Creek and San Mateo Creek on the west side of the Cristianitos fault. Here it underlies the low hills between the two creeks and extends inland from the ocean about 2 miles (pl. 1). A small exposure was observed just south of San Onofre Creek near the base of the San Onofre Hills, also on the ~~east~~ west of the fault. The beach cliff reveals very good exposures extending, with minor interruptions, from San Mateo Creek to the Santa Margarita River. The formation underlies a large part of the coastal terrace, and in the vicinity of Las Pulgas Canyon, outcrops were found a little over 2 miles inland from the coast. In the lagoon area of the Santa Margarita River valley both sides reveal exposures of probable San Mateo formation underlying the coastal terrace.

The formation was named by Woodford (1925) from its development in the vicinity of San Mateo Creek and was considered a doubtful correlative of the San Diego Pliocene. Ellis and Lee (1919, pp.59-60) extended the San Diego formation as far north as the area considered in this report, but Hanna (1926, p. 217) has demonstrated that in the area south of the Camp some of the material considered to be Pliocene by Ellis and Lee was of Eocene age. Hertlein and Grant (1944, p. 63) assign a tentative age of middle Pliocene to the San Diego formation. If the San Mateo formation is correlative with the San Diego formation then its age of course would also be middle Pliocene.

Thickness.--A measured section of the San Mateo formation made in the area between San Onofre and San Mateo Creeks showed that it consists of coarse, poorly sorted yellow-brown pebbly sand that is somewhat cross-bedded near the coast. To the east and higher in the section the sand is very massive fairly soft coarse-grained, and has a very distinctive orange-buff color. Gravel beds are composed of poorly sorted very well-rounded igneous pebbles, cobbles, and boulders in a gray-brown coarse sandy matrix.

Measured section of about the upper two-thirds (?) of the San Mateo formation, exposed along the north side of San Onofre Creek in the NW¼SW¼ sec. 18, T. 9 S., R. 6 W.

(Measured from top to bottom of exposure)

Material	Thickness (feet)
Sand, coarse, some fine; gravel, 30 to 100 mm, well-rounded; and some interstitial fine sand and silt; massive, poorly sorted, loosely consolidated, porous, arkosic, light yellow-brown. (Erosion has removed upper part of formation.)	310+
Sand, coarse, some fine; gravel (pebbles), very coarse, fewer than in top unit; and a very white fine sandy to silty matrix; thin ferruginous-stained zones common near top; massive, poorly sorted, loosely consolidated, porous, arkosic, light yellow-gray to nearly white	290
Sand, very coarse, some fine; gravel (pebbles), 30 to 40 mm forming about 25 percent of deposit; and silty to fine sandy matrix; poorly sorted, loosely consolidated, porous, arkosic, light yellow-brown. Typical marine cross-bedding with long sweeping fore-set beds in the lower part; fore-set beds range in thickness from several inches to several feet and composed principally of fine-grained light brown-gray silty sand. (Base concealed beneath alluvium.) 1/	140+
Total	740+

1/ An additional thickness of about 350 feet is suggested by the log of irrigation well 9/6-19D2, which taps a part of the San Mateo formation concealed beneath the alluvium in San Onofre Creek valley and enters the underlying San Onofre breccia (table 2A).

Geologic sections A-A' and B-B' suggest that the thickness of San Mateo formation near the Santa Margarita River valley may be on the order of 1,000 feet (pl. 2). However, the basal contact as shown is inferred and is based on the assumption that the base is parallel to the dips exposed above at land surface.

South of San Onofre Creek along the beach the exposures of the San Mateo formation consist of gray and orange fine-grained bedded sandstone and silt with some gray mudstone interbedded. This grades laterally into a massive relatively loose poorly sorted sand with a prominent orange color. Exposures in the vicinity of Newton Canyon reveal the upper part of the formation to be fine-grained. The material is composed of relatively soft gray to buff micaceous sand and some pebbly sand containing abundant veinlets of gypsum.

Plate 1 shows that the San Mateo formation has been only slightly deformed. Except near faults, the dips range from 3 to 7 degrees. Near faults the dips are as much as 15 to 25 degrees.

The logs of wells show that the San Mateo formation is not everywhere largely a massive sand deposit (table 2A). Supply wells 10/5-18N4, in Las Flores Creek basin; 9/6-19D3 (abandoned), 9/6-19D4, and 9/7-13J1 (abandoned) in San Onofre Creek basin; and 9/7-11E1 (abandoned), 9/7-11E2, and 9/7-11M1 in San Mateo Creek basin all encountered substantial sections of fine-grained materials. These materials were largely sand and clay, but some shale beds were also encountered. Obviously, the existence of fine-grained deposits in the San Mateo formation is critical with respect to the yields of wells and to the storage capacity of the deposit.

Stratigraphically the San Mateo formation overlies unconformably the Capistrano formation and the San Onofre breccia. In several places the formation is either in exposed or inferred fault contact with older deposits.

In the area just southeast of the Cristianitos Creek and San Mateo Creek junction the San Mateo formation appears to be in part in depositional contact with the underlying Capistrano formation. This also appears to be true on the northwest side of Cristianitos Creek. The contact from just south of the hills separating San Mateo Creek and San Onofre Creek to Basilone Road is in fault contact in part against San Onofre breccia and Temblor (?) formation and in part with the Capistrano formation. This fault contact extends southeastward across the base of the San Onofre Hills to the sea cliff at the beach. The sea-cliff exposure of the fault shows the San Mateo sands in normal fault contact with thin-bedded sandy to silty shales apparently of the Capistrano formation. From this fault contact for a distance of about 3 miles to the southeast the sea cliff has undergone extensive slumping and landsliding as a result of wave action undermining the sea cliff (pl. 1). The area is covered with a heavy growth of vegetation and the relationship of the Capistrano to the San Mateo formation is indeterminable. Similarly, in the vicinity of Horno Canyon the cliff has undergone minor slumping that has masked the relationship.

The inland side of the segment of San Mateo formation underlying the coastal terrace at the foot of the San Onofre Hills is very possibly in fault contact with the San Onofre breccia. Test well 10/6-3P1 was drilled in the vicinity of Horno Canyon north of U. S. Highway 101 to a depth of 170 feet. The well penetrated 120 feet of terrace deposits and entered the San Onofre breccia for a distance of 50 feet without passing through any of the San Mateo formation which is exposed in the sea cliff only 1,500 feet away. In the vicinity of Las Pulgas Canyon near the base of the San Onofre Hills, the San Mateo formation is faulted against the breccia.

Water-bearing properties.--The San Mateo formation yields water at relatively high rates and of satisfactory quality in the lower reaches of San Mateo Creek, San Onofre Creek, and Las Pulgas Canyon (tables 1A and appendix 4). The finer phases of the formation are poorly water bearing, but the coarser sands and gravels are very productive. Test wells drilled in San Onofre Creek valley show that the formation yields considerable quantities of ground water. Test well 9/7-13P1, which taps the alluvium and the San Mateo formation, when developed by air lift produced about 100 gpm with a drawdown of only about 13 feet; and test well 9/7-14R3, which also taps both deposits, yielded about 150 gpm with a drawdown of about 6 feet. Both of these wells penetrated considerable thicknesses of the coarse sand in the San Mateo formation. Old supply well 9/7-24A1 derives its water entirely from the San Mateo formation and yields about 300 gpm.

In Las Pulgas Creek test well 10/5-18R2, which taps water only in the San Mateo formation, produced about 100 gpm with a very slight drawdown. This well was drilled to a depth of 300 feet. Camp-supply well 10/5-18R3 was drilled about 15 feet away from this well to a depth of 282 feet. During the 48-hour development test, the well produced 1,600 gpm with a drawdown of 21 feet. On the other hand, supply well 10/5-18R4, which tapped a substantial section of fine-grained beds in the San Mateo formation, yielded about 800 gpm with a drawdown of 118 feet (table 1A).

In San Mateo Creek, supply wells 9/7-11F2 and 9/7-11H1, drilled through 100 to 120 feet of alluvium and into the San Mateo formation for about 100 feet, encountered relatively poor water-yielding deposits in the San Mateo formation. Most of the water yielded to the wells is from the alluvium. Accordingly, the yields of these wells, which were tested at 1,600 and 1,500 gpm with drawdowns of 75 and 48 feet respectively, can be expected to decrease as the water levels in the alluvium decline during dry periods and increase again during wet periods.

Near the mouth of the Santa Margarita River valley, the yields of test wells 11/5-4M1 and 11/5-9J1 were relatively low. Here the San Mateo formation is composed of light gray fine-grained "running" sand, and the quality is extremely poor.

The data collected during the construction of the new Camp-supply wells in 1952 and 1953 show that the specific capacity of the wells drilled in the San Mateo formation ranges from 7 gpm per foot of drawdown in well 10/5-18M4 to 75 in well 10/5-18M3, which is only 1,000 feet away. For the irrigation and supply wells deriving the bulk of their supply from the San Mateo formation, the average specific capacity is on the order of 25 gpm per foot of drawdown.

In San Mateo Creek valley, one brief aquifer-rating test was run on irrigation well 9/7-11P1 to determine the coefficients of transmissibility and permeability of the San Mateo formation at that place. The data obtained from the test indicate that the transmissibility is about 25,000 gallons a day per foot and that the permeability is about 200 gallons a day per square foot.

Consolidated Rocks

The consolidated rocks consist of the rock types that are cemented, such as sandstone; fine grained and compacted, such as shale; metamorphosed or baked, such as slate and quartzite; and crystalline such as granite, tonalite, and gabbro. Owing to the extremely fine-grained character, or absence of interstitial voids in these rock types, essentially no water can be withdrawn from them. However, where they have become fractured by deformation or faulting or decomposed through long exposure to the elements, limited or minor quantities of water can be withdrawn from them.

The consolidated rocks, from youngest to oldest, comprise the following: The Capistrano formation of upper Miocene to lower Pliocene age, the San Onofre breccia and Temblor (?) formation of middle Miocene age, the La Jolla formation of Eocene age, an unnamed conglomerate and the Chico formation of Cretaceous age, and the basement complex of Triassic to Cretaceous (?) age. These formations are shown on plate 1 and are discussed in descending order or from youngest to oldest on the following pages.

Capistrano Formation

(Pliocene to Miocene)

The Capistrano formation is exposed in the extreme northwestern part of the Camp on the western side of Cristianitos Canyon and in San Mateo Canyon (pl. 1). It is also doubtfully exposed along the coast in a few slumped and obscured areas. Woodford (1925, p. 216) describes the composition of the formation as thin-bedded dark gray micaceous shale with foraminifera and other fossil organisms. There are also occasional limestone nodules and fine sandstone beds. Reed (1933, p. 238) reports the formation as having a total thickness of about 1,200 feet. White (1952) has described the stratigraphy of the formation between Dana Point and San Clemente. He concludes that there are two lithologic units. The upper one is a yellow-brown siltstone separated by a disconformity from the lower one, which is a dark brown sandstone with limestone beds and concretions.

The material exposed in the bluffs along the west side of San Mateo Creek is thinly laminated siltstone and thin beds of fine to medium-grained sandstone with an occasional 2- to 6-inch bed of calcareous shale. Some of the siltstone is black and organic. Beds of gypsum up to ½-inch thick are common and a yellow powdery sulphur (?) mineral (Jarosite ?) is locally abundant. The thickness of the formation was not measured, but on the Camp is probably no more than 1,000 feet.

On the west side of Cristianitos Canyon the Capistrano formation appears to be in fault contact with the La Jolla formation. Woodford (1925, p. 216) states that it is nearly or quite conformable with the underlying Monterey shales and that it may properly belong to the Monterey formation. Locally, however, it is overlain unconformably by the San Mateo formation and is believed to rest unconformably upon the San Onofre breccia.

The age of the formation has been in doubt. White (1952) states that the upper unit has a "fauna of upper-lower Pliocene age correlative with upper Repetto beds," and that the lower unit has upper Miocene fauna of Delmontian age. He also believes the lower unit resembles the Malaga mudstones of the Palos Verdes Hills.

Because no information is available from well logs, the water-bearing characteristics are not known. The apparent abundance of shale and siltstone would indicate that it is essentially non-water-bearing.

San Onofre Breccia and Temblor (?) Formation

(Middle Miocene)

The San Onofre breccia was described in considerable detail by Woodford (1925) who has described it as a facies of the Temblor formation, which is middle Miocene in age. It is believed that the Temblor formation is interbedded with the San Onofre breccia in a small area between San Onofre and San Mateo Creeks (pl. 1).

The San Onofre breccia underlies the greater part of the San Onofre Hills and is mappable from the San Luis Rey River nearly to San Mateo Creek, a distance of about 17 miles (pl. 1). The maximum width of exposure is about 2 miles just northwest of San Onofre Mountain. To the southeast, in the vicinity of San Luis Rey River, the exposed width diminishes to about a mile.

Woodford (1925, p. 182) states that the breccia may extend from San Pedro to Los Coronados Islands near San Diego. On the basis of lithology, areal continuity, and stratigraphic position, Woodford considers the main area between Newport Bay and Oceanside to be approximately contemporaneous. The largest single exposed portion of the facies is that part underlying Camp Pendleton.

The San Onofre breccia, as the name implies, is composed essentially of angular rock fragments or blocks contained in a hard matrix. It is interbedded with thin beds of gray, gray-green, and brown sandstone, grit, siltstone, and some pebble and cobble conglomerates. The most noticeable constituent of the breccia is a blue or green amphibole schist. Numerous other metamorphic rock types, such as quartz-amphibole schist, and saussurite gabbro are also included. The rock fragments vary in size from small pebbles to very large boulders. A little over a mile northwest of Horno Canyon, just north of the old highway, a very large boulder was found that measured 15 by 25 by 25 feet and probably weighs over 500 tons. There is a paucity of boulders this size, but ones measuring 5 feet on a side are rather common in the San Onofre Mountain region but occur with diminishing frequency to the southeast.

The breccia has two types of matrices: Earthy and sandy. Woodford (1925, pp. 225, 235) states that the two contrasting matrices implies contrasting conditions of deposition; the earthy type is mostly continental and is probably a fanglomerate in which no fossils were found. The bulk of the breccia matrix composing San Onofre Mountain is of this type. The sandy type is of marine origin and was found only in the central mass of breccia overlying the earthy type in the San Onofre Hills; it is somewhat more common to the southeast. Fossil oyster fragments were noted at one locality along the old highway approximately 2 miles northwest of Horno Canyon. Some fossil molds were found in the sands and were interpreted as being walrus tusk molds.

Stratigraphically, the San Onofre breccia overlies unconformably the La Jolla formation. Near the Santa Margarita River the degree of unconformity is slight, and in general the degree of unconformity becomes more angular to the northwest. In several areas, principally near San Onofre Creek, the breccia is in fault contact with the Capistrano and San Mateo formations.

The thickness of the San Onofre breccia was determined indirectly by plotting carefully measured strikes and dips along four lines of section. These data have been used in part to compile geologic sections A-A' through D-D' (pls. 2 and 3). From south to north the thickness in general increases as follows: Near the Santa Margarita River, about 1,500 feet; a half mile south of Aliso Creek, about 2,500 feet; in Horno Canyon over 3,000 feet; and in San Onofre Creek, about 2,500 feet.

In general, the strike of the breccia changes from about N. 35° W. near the Santa Margarita River to N. 45° W. near San Onofre Mountain. The dip increases from an average of about 15° SW. near the Santa Margarita River to 30° SW. near San Onofre Mountain. However, as is shown on plate 1, both the strike and dip vary locally owing to minor flexures and faults.

Two test wells were drilled into the breccia. One of these, test well 11/5-2F1, was drilled to a depth of 300 feet entirely in the San Onofre breccia to test the water-bearing properties and the quality of water. Because the beds penetrated by this well, roughly the lower one-quarter of the formation, dip about 11° to the southwest, the actual thickness of the breccia penetrated is about 290 feet. Of this about 40 percent was logged as clay and gravel, 7 percent as sand and gravel, and 53 percent as clay, sand, and gravel. The particles of gravel and sand size are composed largely of schist fragments. (See table 2A.) When developed by air lift the well produced a very small discharge, less than 5 gpm with a drawdown of at least 200 feet.

The other test well, 10/6-3P1, was drilled to a depth of 170 feet, the bottom 50 feet of which was in breccia. An approximate percentage composition of the breccia as logged in this well is clay and gravel, 10; sand and gravel, 28; and clay, sand, and gravel, 62. (See table 2A.) The water level in the well is about 120 feet below land surface or about at the contact between the breccia and the overlying terrace deposits. The well yielded no water when developed and purged by the air-lift method.

In general, the water-yielding properties of the San Onofre breccia are very poor. The calcite cement and interstitial clay render it too consolidated to yield water to wells. The earthy variety lacking cement is so poorly sorted that the porosity and permeability are very low. It is concluded that the San Onofre breccia is essentially non-water bearing.

Between San Onofre and San Mateo Creeks, massive beds of fine-grained, in part calcareous, gray biotite sandstone and banded siltstone of marine origin interfinger with the beds of breccia on the east side of the Cristianitos fault (pl. 1). The relationship between the two units was worked out in some detail, and it was found that a very rapid facies change occurs. In a distance of several hundred feet, the San Onofre breccia changes from its typical character to the massive gray sandstone and siltstone beds. Isolated beds of breccia were found at several horizons interbedded with the sandstone and persisted for distances of from 300 to about 3,000 feet.

Because there still remains some question as to the geologic name to assign to this formation that is interbedded with the breccia and because the unit is of no consequence to the ground-water hydrology, for the purposes of this report the unit has been tentatively assigned to the Temblor (?) formation, which Woodford (1925) has indicated is equivalent in stratigraphic position to the San Onofre breccia.

La Jolla Formation

(Eocene)

Extent and character.--The area between the San Onofre Hills and the Santa Margarita Mountains, consisting mostly of a rolling-hill type of topography, is underlain by rocks of Eocene age. Woodford (1925, p. 177) assigned these rocks to the Tejon formation, although he states that the evidence was inconclusive as to whether they should be assigned to the Tejon or the Meganos formations, but suggested the former. Wilmarth (1938, p. 2,124) uses the restricted definition of the Tejon formation which gives it an upper Eocene age. Hanna (1926, pp. 207-213), while mapping the geology of the La Jolla quadrangle, San Diego County, assigned the name La Jolla formation to the lower three members of the Eocene in that area. Stratigraphically, from oldest to youngest, the members are: The Delmar sand, the Torrey sand, and the Rose Canyon shale. The Delmar sand is composed of coarse-grained to fine-grained sandstone that grades into brown and green arenaceous shales. The Torrey sand is coarse porous unconsolidated white to light-brown, usually cross-bedded, sand. The Rose Canyon shale is composed of mudstone, shale, fine sand, conglomerate, and minor beds of limestone.

Hanna states that the La Jolla formation is overlain by the Poway conglomerate which is considered to be of Tejon age. Fossil evidence from the Poway conglomerate correlates with the type Tejon, but the fauna of the La Jolla formation does not generally occur in either the Tejon or Meganos. Hanna (1926, p. 215) concludes:

"The La Jolla formation is considered, therefore, as stratigraphically between the Meganos and Tejon formations or approximately equivalent to the Domengine."

Although the three members of the La Jolla formation were not traced into the area covered by this report, cursory field examination of both areas suggests a probable similar sequence and correlation. Furthermore, because the Tejon is restricted to the upper Eocene, it was decided to assign the Eocene sediments of the reservation to the La Jolla formation rather than to the Tejon. Accordingly, the Eocene rocks on the reservation have been designated the La Jolla formation.

Plate 1 shows that the La Jolla formation extends in a band from the southeast end of the reservation to the northwest end--a distance of 20 miles. Its greatest width, about 4 miles, is southeast of the Santa Margarita River. To the northwest between Piedra de Lumbre Canyon and San Onofre Creek the width narrows to approximately 1½ miles, and northwestward to the boundary its width increases to about 3 miles.

In the southeastern part of the Camp the La Jolla formation rests unconformably on the unnamed conglomerate of Cretaceous (?) age, the Chico formation, and the basement complex. In the area southeast of Las Pulgas Creek it rests largely on the basement complex but locally on the unnamed conglomerate. Northwest of Las Pulgas Creek it overlies the Chico formation (pl. 1).

The basal part of the formation is almost everywhere represented by a series of lateritic clays and sandstones, variegated in color (red to yellowish-lavender), which Smith and Morse (1930) refer to as the "Tierra Colorada." Above this basal unit the formation consists of poorly sorted cross-bedded light-gray sediments ranging from fine sandstone to pebble conglomerate, massive soft gray to occasionally ferruginous-stained coarse-grained sandstone, and some greenish-gray sandy shale.

Near the middle the formation is characterized by soft to moderately hard well-bedded green to brown sandstone beds. The green beds are usually thick and coarse-grained and are separated by the laminated, thin fine-grained brown sandstone beds. Also included are a few poorly sorted and poorly consolidated light-gray to brown siltstone and siltstone containing some granules; and also a few cross-bedded conglomeratic sandstone beds near the top.

The upper part of the formation is composed of fine to coarse, gray and some brown, soft to moderately hard, locally cross-bedded sandstone containing zones of medium-grained sandstone alternating with layers of more finely laminated fine sandstone and siltstone.

The principal minerals comprising the sandstone beds are quartz, feldspars, and some mafics. In general the feldspar content is high, in places as much as 50 percent of the total minerals present. Thus, the sandstones can be classified as arkosic, and were probably derived from the granitic masses to the east.

The thickness of the La Jolla formation was carefully determined indirectly along three sections on the reservation by obtaining numerous strikes and dips for control. These data were used for the preparation in part of geologic sections A-A' through D-D' (pls. 2 and 3). Near the Santa Margarita River, section B-B' suggests that the thickness of the

La Jolla formation is on the order of 5,000 feet. Near Horno Creek section C-C' suggests that the thickness is nearly 4,000 feet, and section D-D' suggests that the thickness is in excess of 2,500 feet. Minor faulting and local warping may account for a part of the indicated thickness at the south end and for the apparent thinning to the northwest, but it is believed that the thickness at the north end of the reservation is somewhat less than at the south end.

The dip of the beds is generally to the southwest, ranging from 8° to 24°. However, the strike changes progressively from an average of N. 30° W. at the south end of the Camp to N. 45° W. at the north (pl. 1).

Water-bearing properties.--Field examination of the La Jolla formation indicated that a few of the sandstone beds were poorly or loosely cemented; accordingly, where saturated, those beds might yield water to wells. In addition, it was known that supply well 10/5-14P1, which was drilled in Chappo Basin to a depth of 320 feet, entered the La Jolla formation at a depth of 122 feet and, based on the water quality, derives some of its supply from this formation. However, this well probably derives most of its water from the overlying alluvium.

In order to determine the water-bearing properties and the quality of water in the La Jolla formation, test wells 10/5-23Q1 and 11/5-2K2 were drilled to depths of 290 and 300 feet respectively entirely in the formation. The materials penetrated were varicolored shales with interbedded sandy and silty shales, fine- to medium-grained sandstones of varying degrees of hardness, and some light-colored limey sandstone beds. In test wells 23Q1 and 2K2 there were only about 21 and 17 feet respectively of soft sandstone (table 25). This suggests that only about 6 percent of the formation would yield water.

These two test wells, when first developed by air lift, had discharges of about 60 gpm with drawdowns of crudely 150 feet. Subsequently, when the wells were tested with a portable pump, the yields were less than 2 gpm with drawdowns of 20 to 25 feet. The large discrepancy in yields is probably due to the "wash" water introduced into the wells during their development. The tests with the portable pump indicate that the La Jolla beds penetrated by these wells are essentially non-water bearing.

As is indicated in the section on quality of water in the La Jolla formation, it is possible that ground water is supplied through joints and fractures rather than through the few doubtfully permeable soft sandstone beds. Even the few soft sandstone beds encountered in the test-well drilling contained few voids between the sand grains. The decomposition products of the feldspars largely filled the interstitial pores. Thus, the La Jolla formation, where saturated, yields only very minor quantities of water to wells but under a favorable hydraulic gradient, is capable of transmitting some water to the alluvium over a long period of time.

Unnamed Conglomerate

(Cretaceous ?)

Three minor areas of conglomerate were found on the reservation, the most extensive of which is near the headwaters of Pilgrim Creek (pl. 1). The two other localities occur (1) just east of Basilone Road about 1½ miles north-northwest of the Santa Margarita River, in secs. 1 and 6, T. 10 S., R. 5 W.; and (2) about a mile southwest of Horno Summit in secs. 25 and 30, T. 9 S., R. 5 W. The conglomerate is composed of metamorphic rocks and granodiorite boulders in a coarse to very coarse granitic sand matrix; this detrital assemblage is suggestive of an eastern source area for the conglomerate. Its maximum observed thickness is about 200 feet, and its inferred thickness as shown on geologic section E-E' (pl. 2) is on the order of 500 feet.

The exposure near the headwaters of Pilgrim Creek is about a square mile in areal extent and rests upon the basement rocks; that north of the Santa Margarita River is about half as large and also rests upon the basement rocks; and the exposure southwest of Horno Summit rests with slight unconformity upon the Chico formation and is overlain with considerable unconformity by the La Jolla formation of Eocene age. The relationship at this latter locality presents the key to its probable age. The stratigraphic position suggests that this conglomerate is an ancient stream-channel deposit developed upon the post-Chico erosion surface. In turn, it has been largely removed by erosion prior to the deposition of the La Jolla formation. Thus, the conglomerate is probably of late Cretaceous or Paleocene age. For the purposes of this report it is tentatively assigned a Cretaceous (?) age.

Because the conglomerate is best exposed in Pilgrim Creek, the name "Pilgrim Creek" conglomerate is suggested. However, for the purposes of this report, further consideration of this mappable unit as a new formation is not undertaken. Furthermore, owing to its limited extent and substantial cementation, the conglomerate is considered to be essentially non-water bearing.

Chico Formation

(Cretaceous)

The Chico formation, which is of late Cretaceous age, is exposed in a 2- to 4-mile strip along the western flank of the Santa Margarita Mountains between the headwaters of Piedra de Lumbre Creek and the northwest boundary of the reservation. (See pl. 1 and sections C-C' and D-D', pl. 3.) The southeastern extremity is in fault contact with the Eocene. Elsewhere it rests with a major unconformity upon the basement rocks.

Woodford (1925, p. 173) measured a section northeast of San Juan Capistrano and found the Chico to have a thickness of about 3,200 feet, of which the lower two-thirds was almost entirely conglomerate and breccia with a lithology somewhat comparable to the Trabuco formation. North of this area on the southwest side of the Santa Ana Mountains, Eckis (1934, p. 42) found a massive red conglomerate named the Trabuco formation unconformably overlying the basement complex and in turn overlain conformably by a section of conglomerate, sandstone and shale containing Chico fossils. He concludes that, owing to the apparent lack of an erosion period between the two, the Trabuco is part of the Chico formation. Therefore, it is possible that the 3,200-foot section northeast of San Juan Capistrano includes the Trabuco formation and is of Chico age rather than entirely of the Chico formation. This is apparently Woodford's (1925, p. 173) conclusion for he states:

"Near the top of the conglomerate member and perhaps at the base of the true Chico are beds with a strikingly different matrix."

In another section of Chico near the south fork of San Onofre Creek, Woodford (1925) found the conglomerate to be missing and only grit, sandstone, and shale present. Accordingly, the section on the reservation is much thinner than that northeast of San Juan Capistrano, and is believed to be approximately 1,500 to 2,000 feet thick.

In exposures studied during the investigation, the Chico formation was found to consist mainly of massive coarse brown sandstone with gray siltstone and shale. Some boulder and cobble conglomerates were found near the base. These beds are well cemented and compacted and are resistant to weathering. Accordingly, owing to its induration and compactness, the Chico formation as exposed on the Camp is considered to be essentially non-water-bearing.

Basement Complex

(Cretaceous (?) to Triassic)

Extent and character.--The northeastern part of Camp Pendleton is underlain by the western edge of the batholith of southern California and the older rocks that it has intruded. It is in this area that the oldest rocks on the Camp are found, and for the purposes of this report they are collectively called the basement complex. Owing to their inaccessibility and to artillery firing, the rocks were noted but detailed studies were not made. Larsen (1948) made a detailed study of the basement complex in this area, and the information used herein is principally from his work.

The pre-batholith rocks are of probable Triassic and Jurassic (?) age and are along and within the western border of the batholith. The Bedford Canyon formation of Triassic age, which contains the oldest rocks of the area, is mildly metamorphosed slate, argillite, and quartzite. These rocks underlie a fairly large area east of De Luz Creek, a smaller area just to the west, and another area along the southern foothills of the Santa Margarita Mountains.

The Santiago Peak volcanics of Jurassic age are alternating tuffs, breccias, and flows composed principally of andesite, quartz latite, rhyolite, and possibly some basalt. They overlie unconformably the Bedford Canyon formation and are exposed in De Luz Creek and along the south flank of the Santa Margarita Mountains in a strip about 8 miles long and 3 miles wide. It is believed by Larsen (1948) that these volcanic rocks were intruded by the batholith when they formed the western flank of a late Jurassic or an early Cretaceous mountain range.

The rocks intruding the Santiago Peak volcanics are largely fine-grained granodiorite. In texture the granodiorite resembles material found in volcanic plugs and other near-surface intrusive rocks. The backbone of Santa Margarita Mountains and an area north of the De Luz dam site is composed of this fine-grained granodiorite. The rock is resistant to weathering which results in the high ridges and steep slopes of the Santa Margarita Mountains.

Larsen believed that the general emplacement of the batholith occurred early in late Cretaceous time, but that it was formed by many separate injections involving a variety of rock types. Of the different rock types, six are found on the reservation but most are rather restricted in surface area. Patches of the San Marcos gabbro, the oldest rock of the batholith, are found at the head of Las Pulgas Canyon and along the Santa Margarita River canyon just east of the town of Fallbrook. The Green Valley tonalite is next to oldest and flanks the western border of the Santiago Peak volcanics between the north and the south forks of San Onofre Creek. Within the reservation the bulk of the batholith is composed of the Bonsall tonalite which is exposed in two major areas (1) between Las Pulgas Canyon and the southeastern border of the reservation, interrupted only by the Santa Margarita River and (2) along the boundary line between Morro Hill and the town of Fallbrook. The Woodson Mountain granodiorites, and some other granodiorites, which were not correlated with any of the named formations and referred to as miscellaneous granodiorites by Larsen, occupy small areas in De Luz Creek. The Roblar leucogranite, youngest unit of the batholith occurring in the area, locally underlies the backbone of the Santa Margarita Mountains.

Also included with the rocks of the basement complex are the Tertiary volcanics which are represented by a small andesite or quartz latite stock located at the head of the south fork of San Onofre Creek and by the tridymite dacite volcanic neck which forms Morro Hill along the east edge of the reservation (pl. 1).

Upon weathering the slates yield a clayey soil, the schists and quartzites a soil with more sand, the andesitic rocks a dark clayey soil, the gabbro a scant red soil, and the tonalites and granodiorites usually a thin soil underlain by disintegrated or decomposed rock. Except for the decomposed rocks, next discussed, the basement complex is considered to be essentially non-water-bearing.

Decomposed granitic rocks.--Underlying the ancient erosional surfaces, such as the Fallbrook plain, the granitic rocks have become decomposed to known depths of from several to more than 100 feet. The process of decomposition or disintegration is brought about by the decay or transformation of the feldspar crystals to kaolin-type clay. Under conditions of long exposure to rainfall, these soft clays are partially leached out leaving a residuum much like that from a clayey to slightly clayey, angular, soft arkosic sandstone.

Rainfall and runoff from minor streams seeps downward and fills the voids in the decomposed granitic rocks to various levels depending upon local topography, structure, and subsurface drainage. Ellis and Lee (1919, pp. 191-195) state that in the highland areas of southern San Diego County, wells tapping these deposits have minor to small yields occasionally of sufficient size to irrigate several tens of acres of crops requiring a low duty of water.

Several wells have been drilled in the decomposed granitic rocks on the Fallbrook Naval Ammunition Depot. Specifically, wells 9/4-26F1 and 9/4-26M1 penetrated 18 and 68 feet respectively of decomposed granitic rock. Well 26M1 supplied a part of the needs of the Depot, and reportedly had a yield of 1,000 gpm for a period of less than 30 minutes before breaking suction. In the course of its erratic performance, it eventually dewatered the surrounding deposits to the point where no dependable yield could be obtained.

Owing to their unfavorably high topographic position, the decomposed granitic rocks form poor ground-water storage reservoirs. The water collected therein during a series of wet years either drains downslope to points of natural discharge or is depleted rapidly during prolonged dry years by pumping. Thus, it is not considered dependable for a permanent supply for the Fallbrook Naval Ammunition Depot.

GEOLOGIC STRUCTURE

Structure of the Consolidated Rocks

General regional uplift along the northwest-trending batholith of southern California has produced a relatively gentle monoclinal structure in the sediments coastward from the batholith. The Chico and La Jolla formations and the San Onofre breccia reflect the uplift in that the strike of the beds is between N. 30° W. and N. 45° W. and the dips are between 8° and 40° southwest.

Faults and a few minor folds are evident in several areas shown on the geologic map (pl. 1). In the lower Santa Margarita River valley, a series of small northwest-trending block faults occur in the La Jolla formation and San Onofre breccia along the west sides of Chappo and Ysidora Basins. Along the west side of Upper Basin a north-trending fault has raised the rocks forming the basement complex. Geologic section J-J' (pl. 5) suggests that beneath the basin the basement complex is in fault contact with the La Jolla formation.

A major northeast-trending fault with a well developed scarp occurs along the west side of Las Pulgas Canyon north of Tent Camp 1. Here the Chico formation has been uplifted on the west side and is in fault contact with the La Jolla formation. In San Mateo Creek valley, the Cristianitos fault enters the reservation near Tent Camp 3 and trends southeast to the Pacific Ocean. In Cristianitos Creek it splits into several branches, but the main trace can be observed in outcrops across the mountains and is clearly exposed in the beach cliff in sec. 30, T. 9 S., R. 6 W. The relative movement along the main trace is up on the east side and down on the west; along its eastern branch, the movement is the converse.

Faults are believed to occur in other areas that could not be examined owing to military operation and training. For the most part, light weapons firing ranges and artillery impact areas were not examined. Along the north side of the San Onofre Hills south of San Onofre Creek, numerous sag ponds and springs suggest that a west-northwest-trending fault may exist. Here the effect of seaward tilting or compressing of the sedimentary rocks may have produced minor thrust faulting along the inland contact of the competent San Onofre breccia or in the less competent La Jolla formation underlying it. None of the general structural features of the consolidated rocks affects directly the ground-water basins on the Camp.

Structure of the Unconsolidated Deposits

The San Mateo formation is the only unconsolidated water-bearing deposit that has undergone substantial structural deformation. In general the structure of the formation conforms to that of the older rocks in that it reflects the regional seaward tilting of the coastal sedimentary block. The strike of the beds is about northwest or parallel to the coast, and the dips range from 5 to 10 degrees southwest. Locally, the strike and dip of the formation reflects minor warping and does not conform to the regional trend (pl. 1).

Faulting of the formation has occurred in several places, principally on the seaward side of the San Onofre Hills in Las Pulgas and Piedra de Lumbre Creeks and along the Cristianitos fault in San Onofre and San Mateo Creeks. Geologic sections L-L', N-N', and O-O' (pls. 6 to 8) show that the San Mateo formation beneath these valleys is in fault contact with the San Onofre breccia or other non-water-bearing formations. Because these faults are along the contact between water-bearing and non-water-bearing units, they do not affect the occurrence of ground water in the several basins. The reason for the spring zone near the mouth of Las Flores Creek valley is not known, but may be due to structural deformation of the San Mateo formation. The hydrologic evidence for the postulated structural feature is discussed in the section on ground-water outflow and overflow in Las Flores Creek basin.

The higher terrace deposits along the seaward flank of the San Onofre Hills show evidence of tilting. Uplift of the main body of the hills near San Onofre Mountain has resulted in a rise in altitude of the terrace-deposit remnants from southeast to northwest along the hills. So far as could be determined there has been no uplift, deformation, or faulting of the main coastal terrace or of the lower stream terraces in the principal valleys; and further, there has been no uplift, deformation, or faulting of the alluvium.

GEOLOGIC HISTORY

Early History

The oldest known rocks in the region belong to the Bedford Canyon formation of Triassic age and the overlying Santiago Peak volcanics of Jurassic age. Larsen (1948, p. 23) believes that the Santiago Peak volcanics formed the western flank of an early Cretaceous mountain range into which the batholith of southern California was intruded. Accompanying the intrusion, which Larsen (1948, p. 136) has concluded to be of Cretaceous age, was a general elevation of the region. As the elevation increased, erosion became more active and ultimately reduced the region to a peneplain (a relatively featureless plain). The material removed by this erosion resulted in the deposition of the Chico formation of late Cretaceous age.

Near the close of the Cretaceous or at the beginning of the Tertiary the area was uplifted again and was subject to erosion and subsequent submergence. Hanna (1926, pp. 228-229) states that the character of the Delmar sand of the early Eocene indicates that estuarine conditions existed at the time of their deposition, which was followed in turn by the deposition of the Torrey sand and Rose Canyon shale--the three units comprising the La Jolla formation.

The source of the Chico formation and the unnamed conglomerate of Cretaceous (?) age and the La Jolla formation was a land mass to the east and northeast. Woodford (1925, p. 2[illegible]) states that sine analyses of the Eocene material suggest deposition possibly occurred close to the strand line.

The next period of deposition in the area did not occur until the Miocene. During the middle part of the Miocene a land mass to the west of the present shore line apparently came into evidence. This area was the contributor of the San Onofre breccia. In discussing the conditions of deposition for the earthy phase of the breccia, Woodford (1925, p. 235) concludes that it is probable the San Onofre earthy breccia is a fanglomerate, deposited under conditions more arid than those prevailing in the same region today, by streams that approached mud flows in thickness of the transporting medium. The sandy phase is considered to be of marine origin. The conclusion of a western land-mass origin for the breccia is attributed mainly to the similarity of its mineral composition to the Catalina facies of the Franciscan of Santa Catalina Island and to the lack of any such minerals in the land area to the east.

Toward the end of the Miocene there began a period of general subsidence which continued on into the Pliocene. During this time the Capistrano formation was deposited. Later in the Pliocene there occurred enough general subsidence to allow deposition of the San Mateo formation. Hertlein and Grant (1944, p. 29) suggest that the Pliocene sediments in the vicinity of San Diego were deposited in a rather still-standing sea that may have been as much as 800 feet above its present level, and that it is also possible the Poway terrace was developed during this time by subaerial erosion. The general fine-grained nature of the San Diego formation (middle Pliocene) may also be attributed to the low inland relief and the low carrying power of the rivers. This sequence could very well be similar to what occurred on the Camp Pendleton area. The present surface of the Eocene and Cretaceous rocks give some indication of having been an extensive peneplain at one time. However, the San Mateo formation has some material in it that is too coarse to have been supplied from an extensive peneplain of low relief. This would suggest that general uplift occurred to the east or north to supply the coarse phase of the San Mateo formation.

Miller (1935, p. 1,559) states that general uplift in the highland region and movement on the Elsinore fault started in the early Quaternary. But Hertlein and Grant (1944, pp. 29-30) suggest that some time after the deposition of the San Diego formation there began a slow uplift and westward tilting of the region. Accompanying this uplift was a regression of the sea and exposure to erosion of the previously deposited San Mateo formation. There are no exposures or indications of this formation inland from the San Onofre Hills. However, its surface may have been related to the fossil surface now exposed on the Murrieta plateau.

Regional uplift of the basement complex and consequent seaward tilting of the coastal sediments probably continued to mid-Pleistocene time. It is possible that at this time the San Onofre Hills were formed. The seaward-tilting process was probably slow and intermittent and gave the sea a chance to form the terraces on the southwestern slope of the hills and inland areas. That these high terraces, extending from altitudes of 200 to 300 feet to 1,300 feet, are more favorably attributed to tectonic action rather than eustatic changes in sea level is shown by Upson (1951a, p. 445).

During this period of uplift the streams in the area were adjusting themselves to their present drainage pattern. It is believed that only the ancestral Santa Margarita River antedates the regional uplift. The other major streams presumably were consequent upon the rising land mass. The terrace deposits that remain as step-like benches along the north sides of San Mateo and San Onofre Creeks are striking indications of the intermittently active regional tilting to the south and southwest. It is believed that the main period of uplift terminated about at the end of mid-Pleistocene time.

The prominent faults discussed in the preceding section were formed or reactivated during the period of regional tilting, but it is believed that little or no faulting has occurred since mid-Pleistocene time. This is indicated by the fact that none of the coastal terrace deposits show evidence of faulting. The coastal end of the Cristianitos fault exposed in the sea cliff has not displaced the overlying coastal terrace deposits. These terrace deposits are considerably older than the so-called 40-foot terrace deposit and the alluvium, but considerably younger than the high terrace deposits along the seaward side of the San Onofre Hills which have been tilted.

The old dune sand was probably deposited on the terrace deposits by wind and wave action during mid-Pleistocene time. These deposits are younger than the terrace deposits upon which they rest but are doubtlessly older than the terrace deposits that occur at considerably lower altitudes.

History of the Ground-Water Basins

It is believed that the San Mateo formation, which is the oldest water-bearing deposit on the Camp, has not undergone any major deformation or faulting since mid-Pleistocene time as was pointed out in the preceding paragraphs. A minor and local depression of the coastal block may have occurred near the end of mid-Pleistocene time with the consequent deposition of the unnamed deposit of Pleistocene (?) age.

Since mid-Pleistocene time most of the erosion and deposition has been governed by eustatic changes in sea level, which means that sea level has risen and fallen, whereas the land mass has remained relatively stable. The fluctuations of sea level possibly are correlative with some of the later glacial epochs. During periods when large masses of snow and ice were formed in the polar regions and extended laterally toward and into the temperate zones of the earth, the oceans were depleted substantially in supplying the necessary water. Consequently, the streams became entrenched in trying to grade their channels to the lower base levels created by the lowered sea level. Conversely, during interglacial periods as the snow and ice melted and the glaciers receded, the stored water so released caused a substantial rise in sea level. The streams then began backfilling their trenches as their base levels were raised by the rising level of the sea. The several cycles of alternately raised and lowered sea level are believed to have left behind at least the 40-foot and the 60- to 80-foot terrace deposits.

Prior to the deposition of the 40-foot terrace deposit the streams were graded to an ancient sea level at least 80 feet lower than at present. This minimum depth is suggested at the mouth of San Onofre Creek valley where the base of the 40-foot terrace deposit was encountered in test well 9/7-24Ml at about this depth (pl. 7, section N-N'). Subsequently, as sea level rose, the streams backfilled their trenches or canyons to an altitude of about 40 feet above present sea level--an over-all net rise of about 120 feet.

Following the deposition of the 40-foot terrace deposit, it is believed that sea level began to lower again in response to the formation of another glacial ice sheet. It has been suggested by Upson (1951a, table 1), Upson (1951b, pp. 29-30), Upson and Thomasson (1951, p. 54), and Worts (1951, pp. 46-47) that the decline accompanied the advance of the Wisconsin glacial sheet. The decline of sea level reached a level at least 200 feet below the present. This minimum depth is indicated by the base of the alluvium at the mouths of most major river valleys along the California coast, as is mentioned in the above references and as is shown in the lower Santa Margarita River valley by cross-section E-E' (pl. 4).

San Mateo, San Onofre, Las Flores, and other smaller creek valleys do not appear to have been graded to an ancient sea level 200 feet or more below the present level. (See sections L-L', N-N', and O-O'; pls. 6 to 8.) Although this appears to be the case, it is believed that the streams were graded to sea level but probably either at a point considerably farther seaward than the present coastline or else their gradients were very steep at or near the ancient seashore.

It is probable that the ancient sea level reached its maximum low coincident with the maximum volume and advance of the Wisconsin ice sheet. This point in geologic time marks the end of the Pleistocene epoch. It has been suggested by Schuchert and Dunbar (1933, p. 479) that this may have been approximately 27,000 years ago. However, more recent data obtained from studies of carbon 14 found in organic material in the alluvium suggest that the time may be considerably less. With the retreat of the ice sheet, the melting of the snow and ice returned water to the oceans and the rise in sea level started. This was the dawn of the Recent epoch.

The first deposits laid down by the streams were coarse-grained and in the lower Santa Margarita River valley they now form the lower member of the alluvium. The coarseness of the lower part of the alluvium in the coastal basins can be attributed to vigorous erosional activity in the headwater areas caused by exceedingly wet climatic conditions and large stream discharge and carrying power on initial gradients steeper than those now existing.

Following the deposition of the coarser material, drier climatic conditions apparently developed and finer-grained materials were deposited. In the lower Santa Margarita River valley, the fine-grained deposits form the upper member of the alluvium. Fine-grained materials also are found near the coast in the other valleys. The presence of marine sand and clay containing fossil shells and seaweed (?) indicates that at times the rate of rise in sea level was more rapid than alluvial deposition with the result that the sea intermittently invaded the lower courses of the present valleys.

O'Neill Lake, prior to the construction of the low earth dam to increase its volume, and the several small ponds at the mouths of minor tributary valleys in the lower Santa Margarita River valley owe their existence to the more rapid deposition of alluvium by the river than by the minor tributaries. As a result, the river has built natural dams of alluvium across the mouths of the minor tributaries thereby creating the ponds.

SURFACE-WATER RESOURCES

By H. C. Troxell and Walter Hofmann

CLIMATE

Climate is the result of the world-wide circulation of the earth's atmosphere, and is governed by a complex interrelationship among such meteorological phenomena as precipitation, temperature, humidity, sunshine, cloudiness, and wind. This complex interrelationship governs the types and character of the vegetative cover and creates an environment which may, or may not, be suitable for human occupation. Historically, the coastal plains and valleys of southern California have been classified as "Mediterranean" because of the mild winters of limited precipitation and the dry warm summers.

The monthly precipitation distribution for a few key stations along a cross-section extending from Oceanside on the coast through the Palomar Mountains to a point about 100 miles inland is shown graphically on plate 9. The precipitation distribution shown here for Oceanside and Fallbrook is typical of the entire Camp Pendleton area. The first part of February is generally the middle of the rainy season with the period of October through April containing about 95 percent of the annual precipitation. On numerous occasions the total precipitation during the entire summer period of May through September will be less than half of an inch.

In the mountainous headwater areas of the Santa Margarita River system the annual precipitation increases considerably although the monthly distribution remains about the same, as indicated by the record obtained at Nellie. At Aguanga, in the upper valley of the Santa Margarita River system north of the Palomar Mountains, there is a considerable decrease in precipitation, as indicated on plate 9. There is also some change in monthly distribution, with more than 10 percent of it occurring in the summer period of May through September, due to convectional storms moving from inland areas.

The monthly temperature distribution is also given along this same cross-section on plate 10. As indicated by the Oceanside and Escondido records, the temperature in the Camp Pendleton area is continuously warm, becoming slightly hot in mid-summer. The complete range in monthly temperature of about 15° to 20°F reflects the modifying influence of the Pacific Ocean. In the coastal mountain and plateau areas the temperatures are somewhat cooler, as indicated by the record obtained at Nellie in the Palomar Mountains.

Another extremely important climatic factor affecting both the comfort of the human body and the water requirements of the vegetative cover is the relative humidity. Plant life, like the human body, transpires to reduce the adjacent air temperatures. Consequently the opportunity for evapotranspiration is largely controlled by the amount of moisture in the air. Plate 11 gives the monthly relative humidity along the same cross-section as shown on plates 9 and 10. The records obtained at San Diego indicate that the average monthly relative humidity would range from about 68 to 78 percent in the Camp Pendleton area. In the tributary mountain area the relative humidity is considerably less, probably on the order of 32 to 60 percent shown for Mt. Wilson. The relative humidity in the inland valley of Temecula Creek at Aguanga is about of the same order. As a result, the water losses in the mountain and inland valleys are greater than in the coastal area for identical temperatures.

PRECIPITATION

Cyclic Distribution

The only source of recharge to the local water supplies of the Santa Margarita River basins and Camp Pendleton is the precipitation that falls on the area. Consequently, its magnitude and variability are of paramount importance in the effective utilization of these water reserves. The annual precipitation distribution is distinguished by extended sequences in which most of the years are wet and other equally long sequences in which most of the years are dry.

The longest authentic record of these sequences of wet or dry years is to be found in the growth of the annual tree rings of carefully selected trees. Schulman (1947) in his research in the San Gabriel, San Bernardino, San Jacinto, and Palomar Mountains was able to develop a record of annual tree-ring growth for the last 560 years. In this 560 years of record, beginning in 1385, there were 19 dry periods ranging in length from 6 to 43 years. On the basis of this record, the most probable length of the dry periods will range from 9 to 20 years for 50 percent of the periods, with a median value of about 14 years. The wet periods were generally somewhat shorter, ranging from 7 to 18 years for 50 percent of the periods, with a median value of about 12 years. These two median values indicate an average "cyclic" period of about 27 years.

This cyclic-like trend can be demonstrated by plotting the mean annual precipitation[1/] for each 10-year period, such as shown on plate 12. Each plotted point on this graph represents the mean annual precipitation

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1/ As used throughout this discussion, the annual precipitation is for the Weather Bureau's climatic year, July 1 to June 30.

for a 10-year period at the Los Angeles, Santa Barbara, and San Diego stations. The vertical scale gives the ratio of the mean annual precipitation for the 10-year period to the mean annual precipitation for the entire period of record.

These graphs show three extended wet periods centered around the 10-year means of 1883-93, 1904-14, and 1934-44, indicating cyclic-like periods of 21 and 30 years. The graphs also show two completed dry periods centered around the 10-year means of 1893-1903 and 1923-33, and one still uncompleted sequence of dry years centered around the 10-year period 1941-51.

This demonstration of cyclic tendencies shown on plate 12, although enlightening, does not offer the opportunity to select the actual beginning and ending of these extended wet and dry periods. This more exacting segregation is generally developed by plotting the cumulative departures of the individual annual values from the mean for the period of record.

Of the key weather stations in or near the Santa Margarita River basin or Camp Pendleton, the one located at Fallbrook seems to be the most representative. For that reason, the cumulative departures from the mean annual precipitation for the 75-year period 1876 to 1951 is shown in graphical form on plate 13. From the records beginning in 1876 through the climatological year 1882-83, the annual precipitation was largely below the mean. In fact, only 2 of the 7 years in this sequence of years had an annual precipitation in excess of the 75-year mean. At the end of this rather short period, the cumulative departures amounted to minus 147 percent of the mean. During this sequence of dry years, the 7-year mean annual precipitation amounted to 14.39 inches or 21 percent less than the 75-year mean.

With the advent of the wet year 1883-84 this negative trend was completely reversed for reasons at present unknown. This new trend, caused by a sequence of wet years, continued until the climatological year 1890-91. During this 8-year period, the average annual precipitation was 24 percent greater than the 75-year mean, with only 2 years having less than this mean. The cumulative departures in this 8-year sequence amounted to plus 194 percent which considerably more than offsets the minus 147 percent accumulation of the preceding 7 years.

The combination of the above wet and dry sequences tends to give the appearance of a complete 15-year cyclic period. The mean annual precipitation of 18.76 inches for this cyclic period differs by only plus 3 percent from the 75-year mean.

The record continues with alternate wet and dry sequences, all of which are indicated on plate 13. In every instance there are well or fairly well defined changes in trend at the beginning and end of these periods. This combination of wet and dry sequences produces cyclic-like periods of 17 to 31 years. The average precipitation for each of these cyclic periods ranges from 1 percent below, to 9 percent above, the 75-year mean annual precipitation, all of which is shown on plate 13.

Diagrams similar to that prepared for the Fallbrook record indicate that there were five such overlapping cyclic periods in the coastal parts of southern California since 1883. These overlapping cyclic periods occurred during 1883-1904, 1893-1922, 1904-1934, 1922-1944 and 1934-1951. Table 2 gives the average annual precipitation for each of these periods at Riverside, Fallbrook, Escondido, Tustin, Julian, and Valley Center. The departure of each of these cyclic periods from the long-term mean to 1951 at each station is also included in this table. The table concludes by giving the weighted departures of the entire group based upon distance from Fallbrook.

Table 2.- Mean annual precipitation for certain cyclic periods in the Santa Margarita River basin and vicinity

Station	1883-1904		1893-1922		1904-1934		1922-1944		1934-1951	
	Average Precip-itation In inches	Departure from mean a/ in percent	Average Precip-itation in inches	Departure from mean a/ in percent	Average Precip-itation in inches	Departure from mean a/ in percent	Average Precip-itation in inches	Departure from mean a/ in percent	Average Precip-itation in inches	Departure from mean a/ in percent
Riverside	10.46	-6	11.10	-1	11.68	+4	12.38	+11	11.98	+7
Fallbrook	17.95	-1	18.65	+3	19.32	+6	19.66	+8	17.95	-1
Escondido	14.52	-10	15.92	-1	17.30	+7	17.90	+11	17.07	+6
Tustin	13.40	+3	12.29	-5	12.49	-4	13.70	+6	13.95	+8
Julian	29.54	-5	29.39	-5	32.42	+4	32.57	+5	30.38	-2
Valley Center	20.17	+5	18.23	-5	19.00	-1	20.40	+6	19.38	+1
Average	-	-2	-	-2	-	+3	-	+8	-	+3

a/ Mean annual precipitation for the period of record.

Areal Distribution

Because of its extreme variability, the precipitation data must be adjusted to a common basic time period before developing its areal distribution. It is also essential that this basic time period contain equal numbers of wet and dry sequences; otherwise the results will be biased. This can be accomplished by the use of table 2, where each cyclic period represents a combination of one wet and one dry sequence. Consequently any one of these five cyclic-like periods or certain combinations of these cyclic periods could be used in selecting the base period. The combination of the three consecutive cyclic-like periods 1883-1904, 1904-1934, and 1934-1951 has been selected to give the basic period 1883-1951.

Upon the selection of this 68-year base period, all the available precipitation data for shorter periods of time were adjusted to give a mean for this time period on the basis of indices of wetness. The individual records are summarized in table 3 which contains the location, altitude, period of record, and the mean annual precipitation for the 1883-51 base period. Most of these precipitation data were collected between 1943 and 1946 (Troxell, 1948) and little effort has been made to bring these records up to date.

It is always a most difficult task to develop accurately the areal distribution of the mean annual precipitation over such irregular and rugged topography as exists in the Camp Pendleton area and the Santa Margarita River system. The task is made even more difficult, owing to the lack of an organized network of meteorological stations in the region.

[illegible]	[illegible]	[illegible]	1,290	1934-40	9.9
Cajalco No 2 /f	[illegible]°50'	117°22'	490	[illegible]-46	10
Gavilan Valley - Buck	33°47'	117°24'	2,050	1939-46	11.6
Smith, H. J.	33°50'	117°21'	1,650	1919-36	11.6
Perris Valley					
Ethanae	33°45'	117°10'	1,475	1905-16	10.5
March Field	33°55'	117°15'	1,528	1929-51	10.1
Paloma Valley, Zeider	33°38'	117°10'	1,520	1939-45	14.2
Perris, Hendricks	33°47'	117°14'	1,456	1911-39	11.8
Winchester, Houser	33°42'	117°05'	1,470	1940-45	11.1
Long Valley					
"A" Gage, Pauba Ranch /e	33°32'	117°03'	1,410	1919-21	13.3
Greenwood, W. R.	33°34'	117°05'	1,400	1912-26	12.5
Palomar Mountains					
Amago	33°17'	116°52'	2,715	1912-43	26.5
Aqua Tibia	33°21'	117°01'	1,025	1931-43	17.4
Aquanga No 1	33°27'	116°51'	1,986	1908-27	13.3
Aquanga No 2	33°30'	116°49'	3,100	1928-46	12.9
Deadman's Hole	33°20'	116°44'	3,200	1911-24	21.2
Mendenhall Valley	33°20'	116°51'	4,500	1911-16	33.9
Mount Palomar	33°21'	116°52'	5,550	1938-51	25.5
Nellie	33°19'	116°53'	5,000	1901-23	44.4
Nigger Canyon /e	33°30'	116°58'	1,450	1919-46	11.9
Oak Grove	33°23'	116°47'	2,751	1910-21	16.8
Pauba Ranch /e	33°29'	117°06'	1,080	1919-44	15.8
Pauma	33°19'	117°00'	800	1932-40	19.3
Rincon, Mansur	33°17'	116°57'	1,080	1923-43	16.6

/a Orange County Flood Control District
/b Irvine Ranch Company
/c Temescal Water Company
/d Department of Agriculture
/e Vail Cattle Company
/f Metropolitan Water District

Ranch House /e	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Re[illegible] unt [illegible] Rar[illegible]	33°2[illegible]'	117°1[illegible]'	940	1924-46	17.8
Santa Margarita Ranch	33°19'	117°20'	90	1893-1941	14.[illegible]
Tenaja, Santa Rosa Ranch /e	33°31'	117°22'	2,050	1922-41	19.9
Wight	33°21	117°08'	300	1929-43	14.7
Elsinore Valley					
Elsinore	33°40'	117°20'	1,272	1886-1951	13.3
Sherman, Edwin M.	33°41'	117°23'	1,300	1916-46	17.0
Wilomar	33°36'	117°17'	1,242	1913-27	13.1
Temescal Plateau					
Cajalco No 1 /f	33°51'	117°27'	1,290	1934-46	9.9
Cajalco No 2 /f	33°50'	117°22'	1,490	1934-46	10.3
Gavilin Valley - Buck	33°47'	117°24'	2,050	1939-46	11.6
Smith, H. J.	33°50'	117°21'	1,650	1919-36	11.6
Perris Valley					
Ethanac	33°45'	117°10'	1,475	1905-16	10.5
March Field	33°55'	117°15'	1,528	1929-51	10.1
Paloma Valley, Zeider	33°38'	117°10'	1,520	1939-45	14.2
Perris, Hendricks	33°47'	117°14'	1,456	1911-39	11.8
Winchester, Houser	33°42'	117°05'	1,470	1940-45	11.1
Long Valley					
"A" Gage, Pauba Ranch /e	33°32'	117°03'	1,410	1919-21	13.3
Greenwood, W. R.	33°34'	117°05'	1,400	1912-26	12.5
Palomar Mountains					
Amago	33°17'	116°52'	2,715	1912-43	26.5
Aqua Tibia	33°21'	117°01'	1,025	1931-43	17.4
Aquanga No 1	33°27'	116°51'	1,986	1908-27	13.3
Aquanga No 2	33°30'	116°49'	3,100	1928-46	12.9
Deadman's Hole	33°20'	116°44'	3,200	1911-24	21.2
Mendenhall Valley	33°20'	116°51'	4,500	1911-16	33.9
Mount Palomar	33°21'	116°52'	5,550	1938-51	25.5
Nellie	33°19'	116°53'	5,000	1901-23	44.4
Nigger Canyon /e	33°30'	116°58'	1,450	1919-46	11.9
Oak Grove	33°23'	116°47'	2,751	1910-21	16.8
Pauba Ranch /e	33°29'	117°06'	1,080	1919-44	15.8
Pauma	33°19'	117°00'	800	1932-40	19.3
Rincon, Mansur	33°17'	116°57'	1,080	1923-43	16.6

/a Orange County Flood Control District
/b Irvine Ranch Company
/c Temescal Water Company
/d Department of Agriculture
/e Vail Cattle Company

Table 3.- Mean annual precipitation in inches for the period 1883 to 1951

Station	Latitude	Longitude	Altitude	Period of record	Mean annual precipitation 1883-1951
Santa Ana Mountains					
Dawson, J. W. /a	33°41'	117°30'	2,000	1930-32	26.6
Hare & Star Ranch /a	33°39'	117°34'	1,250	1930-43	19.3
Harris, George /a	33°41'	117°37'	1,200	1930-32	17.7
Holtz Ranch	33°45'	117°38'	1,500	1918-43	20.8
Limestone Ranch /b	33°46'	117°44'	1,000	1917-43	16.9
Pember, E. J. /a	33°45'	117°35'	2,000	1930-43	25.5
Pleasants' Ranch	33°43'	117°39'	1,200	1894-1933	19.1
Redman	33°44'	117°39'	1,100	1920-32	19.9
Robinson, Louis	33°40'	117°35'	1,100	1925-43	19.6
San Juan Hot Springs	33°36'	117°31'	800	1930-35	17.8
Temescal Canyon /c	33°46'	117°29'	1,014	1905-46	16.1
Trabuco Oaks /a	33°40'	117°35'	1,050	1930-39	20.0
Turner, Wyman /d	33°53'	117°40'	500	1928-33	14.2
Murrieta Plateau					
Cienega, Santa Rosa Ranch /e	33°30'	117°20'	2,000	1925-41	23.5
De Luz	33°27'	117°19'	450	1902-40	19.1
Gate, Santa Rosa Ranch /e	33°33'	117°14'	1,200	1922-41	17.1
Fallbrook, White, H.E.	33°23'	117°12'	750	1875-1951	18.8
Mesa, Santa Rosa Ranch /e	33°31'	117°17'	1,980	1923-41	23.4
Ranch House /e	33°31'	117°16'	1,720	1922-41	24.9
Red Mountain Ranch	33°23'	117°12'	940	1924-46	17.8
Santa Margarita Ranch	33°19'	117°20'	90	1893-1941	14.6
Tenaja, Santa Rosa Ranch /e	33°31'	117°22'	2,050	1922-41	19.9
Wight	33°21	117°08'	300	1929-43	14.7
Elsinore Valley					
Elsinore	33°40'	117°20'	1,272	1886-1951	13.3
Sherman, Edwin M.	33°41'	117°23'	1,300	1916-46	17.0
Wilomar	33°36'	117°17'	1,242	1913-27	13.1

The major part of this precipitation has its origin in the Pacific maritime air masses which generally cross the region in an easterly or north-easterly direction. All of the mountains in the path of these air masses act as barriers. Consequently the moisture-laden air masses are forced upward to cross the barriers. The lifting of this moisture into altitudes of lower temperature generally causes an intensification of the precipitation on the windward slopes of the hills or mountains.

On the leeward sides of the mountains the process is reversed. Here the air masses are descending and warming, which results in a rapid decrease in the amount of the precipitation. The leeward sides are generally the northern and eastern slopes and are said to be in a "rain shadow."

In the report on the "Hydrology of Western Riverside County," Troxell (1948) proposes a method whereby all the precipitation data are adjusted to a common plane or datum in order to eliminate insofar as possible, the orographic influences. These data are then plotted on a map to develop the areal distribution at this datum. Then, by superimposing this map over a topographic map, it is possible to obtain the areal distribution of precipitation at ground surface.

By using the above methods, it has been possible to develop the isohyetal map given on plate 14. This map shows that a mean annual precipitation of less than 14 inches along the coastline increases to 18 inches in the coastal foothill and mountain areas of Camp Pendleton. On the broad Murrieta or Santa Rosa Plateau inland from the mountain and foothill areas the mean annual precipitation increases to 30 inches. In the inland valleys on the leeward side of the Murrieta Plateau the mean annual precipitation decreases to less than 12 inches. However, on the leeward side of the Palomar Mountains and tributary to one of these inland valleys, the mean annual precipitation increases to 30 inches. On the basis of this map, the mean annual precipitation for the entire Santa Margarita River system above the Railroad Canyon Gorge through the Murrieta Plateau amounts to 16.9 inches.

RUNOFF

Drainage Systems and Location of Gaging Stations

The Santa Margarita River is by far the largest stream discharging into the ocean within the confines of Camp Pendleton. The stream system of this 750-square-mile basin originates on the leeward or north and east slopes of the Palomar Mountains and the south and west slopes of the Coahuila Mountains, has cut a deep gorge-like channel through the Murrieta Plateau, and discharges into the Pacific Ocean about 3 miles northwest of Oceanside in the southeast part of Camp Pendleton. The outline of the basin, together with the principal land forms and the stream systems, is shown on plate 15. The two principal tributaries are Temecula and Murrieta Creeks which unite to form the Santa Margarita River just upstream from Temecula (Railroad) Canyon at the entrance to the gorge through the Murrieta Plateau.

As early as 1888, Hall (1888), the State Engineer, stated:

> "...this river is no exception to the rule of light summer flow and winter torrents which is applicable to all Southern California streams. In July or August, one unfamiliar with these water-courses could not suspect it of the extreme violence displayed in such winters as 1884-85, when it destroyed the California Southern railroad for nearly twenty miles. Several thousand cubic feet per second (possibly five thousand) must have been the volume of its flow at that time, sustained for several weeks. The ordinary winter flow, however, does not exceed six or eight hundred cubic feet per second, and that immediately following protracted storms, only. In summer it is never dry in the long cañon, and maintains a discharge of two to four cubic feet per second throughout the driest month."

However, it was not until January 1906 that systematic efforts were made to obtain a record of daily discharge. At that time a temporary staff gage was established on Temecula Creek above its junction with

Pechanga Creek on the Temecula-Fallbrook highway bridge. This gage was read once a day until the middle of July and again during the month of December. After that the station was abandoned.

No further observations were obtained until the spring of 1923. At that time the pending litigation over water rights to the flow of the Santa Margarita River caused the owners of the Pauba and Santa Margarita ranches to establish a network of stream-flow gaging stations which were installed under the direction of the Geological Survey. These stations are listed in table 4 together with the location, altitude, and period of record. The locations of these stations are also shown on plate 15.

The second most important stream system discharging into the ocean within the confines of Camp Pendleton is San Mateo Creek, also known as Arroyo San Mateo. This stream system has cut deep V-shaped gorges, often more than 2,000 feet below the rolling lands of the Murrieta Plateau on which it originates. These plateau lands form the most important part of the basin, with the precipitation falling on this area contributing about 80 percent of the runoff.

About one-third of this 137-square-mile drainage area is within the boundaries of Camp Pendleton. In an effort to obtain a measure of the magnitude and distribution of runoff from this area, the Department of the Navy established, in 1946, a gaging station just upstream from the ocean. In 1950 two additional stations were located some distance upstream to measure the inflow into the alluvial valleys that extend about 10 miles upstream from the ocean.

Table 4.- Location and altitude of gaging stations, and periods of record

Stream and location of gaging station	Latitude	Longitude	Altitude of station	Period of record
Santa Margarita River				
Temecula Creek at Nigger Canyon, near Temecula	33°29'40"	116°59'00"	1,350	1923-52
Temecula Creek near Temecula	33°28'30"	117°07'30"	1,000	1906
Temecula Creek at Railroad Canyon, near Temecula	33°28'25"	117°08'35"	950	1923-52
Santa Margarita River near Fallbrook	33°24'50"	117°14'50"	290	1924-52
Santa Margarita River at Ysidora	33°14'40"	117°22'50"	15	1923-52
Murrieta Creek at Temecula	33°29'00"	117°08'50"	1,050	1930-52
De Luz Creek near Fallbrook	33°22'40"	117°19'20"	170	1951-52
San Mateo Creek				
San Mateo Creek near San Clemente	33°28'15"	117°28'20"	420	1952
San Mateo Creek near San Onofre	33°25'10"	117°31'50"	160	1950-52
San Mateo Creek at San Onofre	33°23'15"	117°35'32"	20	1946-52
Cristianitos Creek near San Clemente	33°26'55"	117°34'15"	170	1950-52
San Onofre Creek				
San Onofre Creek near San Onofre	33°23'25"	117°30'50"	170	1950-52
San Onofre Creek at San Onofre	33°22'31"	117°34'31"	15	1946-52
Piedra de Lumbre and Las Pulgas Creeks				
Las Flores Creek near Oceanside	33°17'25"	117°27'25"	20	1951-52

About a mile east of the mouth of San Mateo Creek, the runoff from San Onofre Creek, also known as Arroyo San Onofre, discharges into the ocean. This 43-square-mile basin, all within the confines of Camp Pendleton, drains the coastal and foothill areas as well as the coastal slopes of the Santa Margarita Mountains. In 1946 the Department of the Navy established a gaging station near the ocean to measure this discharge. Four years later, in 1950, a second station was established at the upper end of the alluvial valley, near Tent Camp 2, that extends some distance inland from the ocean (pl. 28).

Also completely within the confines of Camp Pendleton are the Piedra de Lumbre and Las Pulgas Creeks drainage areas located immediately southeast of the San Onofre Creek basin. These streams originate on the frontal slopes of the Santa Margarita Mountains and in the coastal mountain and foothill areas to discharge into the ocean through the Las Flores Creek channel. During 1951 the Department of the Navy, in cooperation with the Geological Survey, established a station on Las Flores Creek to obtain a measure of the waste to the ocean.

Between Las Pulgas Creek and the Santa Margarita River is the small Aliso Creek drainage area. This stream also originates on the frontal slopes of the Santa Margarita Mountains and discharges into the ocean about 2.5 miles north of the Santa Margarita River. Currently, no effort is being made to measure the runoff from this 8-square-mile drainage area.

Runoff, a Residual

Records of runoff obtained in southern California indicate that the scrubby, dwarfed, drought-resistant native vegetation of the mountains, together with the more luxurious vegetation in the cienega (spring) areas or along the water courses, consume the major part of the precipitation in such semiarid areas as Camp Pendleton and the Santa Margarita River system. As a rule, it is only in the higher and cooler parts of these areas that the precipitation consistently exceeds the water requirements of this native vegetation. Thus, runoff is the precipitation residual left after the water requirements of the soil and native vegetation have been met.

The degree to which the precipitation is consumed by this native plant life is given in table 5 for the Santa Margarita River basin and similar regions. This table gives the basin-wide average annual precipitation, natural water losses, and runoff in several stream basins of southern California.

As indicated in this table, 84 percent of the precipitation falling in the Santa Ysabel Creek drainage area is consumed by the water requirements of the native vegetation, leaving a residual of 4.7 inches available for runoff. This residual is also a rough measure of the recoverable water.

Table 5.- Average annual precipitation, natural water losses, and runoff, in inches, for selected drainage areas in southern California

Drainage area	Basin-wide average annual mean		
	Precipitation	Natural water losses	Runoff
San Dieguito River Basin			
Santa Ysabel Creek near Mesa Grande	29.8	25.1	4.7
San Luis Rey River basin			
San Luis Rey River at Lake Henshaw	21.9	19.3	2.6
Santa Margarita River basin			
Temecula Creek at Nigger Canyon, near Temecula	18.2	17.5	.7
Murrieta Creek at Temecula	14.9	14.1	.8
Temecula Creek at Railroad Canyon, near Temecula	16.9	16.2	.7
San Juan Creek basin			
San Juan Creek near San Juan Capistrano	21.9	19.8	2.1
Trabuco Creek near San Juan Capistrano	22.8	20.0	2.8
Aliso Creek basin			
Aliso Creek at El Toro	18.1	16.5	1.6
Santa Ana River basin			
Santiago Creek near Villa Park	23.7	21.8	1.9

In the headwater areas of the Santa Margarita River, only 0.7 inch is recovered in the Temecula Creek drainage area above Nigger Canyon out of a basin-wide precipitation of 18.2 inches. In this case the recoverable water amounts to only 4 percent of the basin-wide precipitation. This recoverable water, or runoff, increases to about 5 percent of the precipitation in the Murrieta Creek drainage area. As a result of these natural water losses, the recoverable water available for use in the Santa Margarita River basin and Camp Pendleton areas are only a small portion of the precipitation falling on the area.

Currently, very little effort is being made to reduce these natural losses even though a small decrease in these losses could make a substantial increase in the available water. This lack of effort is attributable to the small amount of intensive research on the subject which thus far has failed to produce a feasible or practical method for the salvage of a portion of these waters.

Runoff Characteristics

The runoff residual, being only a small part of the basin-wide precipitation, is subject to considerable variability. This is due largely to the complex interrelationship between rates of precipitation, the absorptive and retentive characteristics of the mantle rock, the soil moisture deficiencies in the mantle rock prior to each storm, and many other less easily identified factors. The integrated effect of all these factors in the semiarid regions of southern California tends to produce a large runoff concentration in short intervals of time. Few fully appreciate the fact that since 1923, 40 percent of the total runoff in the mountainous Temecula Creek drainage area above Nigger Canyon occurred in 1 percent of the time.

The distribution of runoff of Temecula Creek at Nigger Canyon is shown on plate 16 and is typical of the entire Santa Margarita River system and the Camp Pendleton area. The data on this diagram indicates that 11 percent of the runoff occurred in 0.01 percent of the time or on 1 day in 10,000 and that 23 percent of the runoff occurred in 0.1 percent of the time or 1 day in 1,000. Probably the most significant feature of this diagram is that 50 percent of all the runoff occurred in 2.6 percent of the time or 2.6 days in 100. Consequently, the remaining 50 percent of the runoff was distributed over the remaining 97.4 days out of each 100. It becomes readily apparent from this analysis that the major part of the runoff cannot be effectively utilized without the aid of surface reservoirs.

The duration curve of daily discharge of Temecula Creek at Nigger Canyon shown on plate 17 offers a further demonstration of the concentrated nature of the runoff. The diagram gives the percent of time in which the daily discharge is equal to or greater than any indicated discharge.

Frequently, unusual significance is attached to the mean value, in this case the mean daily discharge; yet this curve shows that the mean daily discharge was equalled or exceeded for only 16 percent of the time or 16 days out of 100. Probably the most important feature of this relationship is that for 84 percent of the time or 84 days out of 100, the daily discharge will be less than the mean daily discharge. A far better measure of the unregulated runoff is the median. In this case the median discharge amounts to 0.31 of the mean. Being the median, the daily discharge will equal or exceed this value for half the time and will be less than this value for the remaining half of the time.

Also, undue significance is often attached to the mean annual runoff of a stream. As plate 18 shows, for Temecula Creek at Nigger Canyon, 32 percent of the years has a runoff equal to or greater than the mean annual runoff and 68 percent of the years has less runoff. This distribution is believed to be more or less typical of the entire Santa Margarita River basin. A somewhat better index of annual runoff is the median which amounts to only 58 percent of the mean annual value.

Cyclic Distribution

In the preceding analysis, the runoff items are assumed to occur in a purely random sequence. Actually this is seldom the case. As already indicated in the case of precipitation and annual tree-ring growth, there are often long sequences of dry years followed by long sequences of wet years. Being a residual of the precipitation, the annual runoff will have this same cyclic-like distribution.

The alternating sequences of wet and dry years are shown on plate 19, which gives the annual runoff in the San Gabriel and Santa Ana Rivers since 1896 and 1897 respectively. These records are among the longest and most reliable obtained in southern California and should be typical of the annual runoff distribution in the Santa Margarita River basin and the Camp Pendleton area.

As shown on plate 19, the record resolves itself into three dry periods and two wet periods, all of which have been indicated on the diagram. Not all the years within the wet period are wet, but they predominate, and not all the years within the dry period are dry, but they predominate. The net result is that the average annual runoff for each of the wet and dry sequences varies greatly, as shown by the cross-hatched areas on this diagram. In addition to the mean and the median annual runoff for the period of record, the diagram indicates the 10 driest years in order of dryness.

Because of this cyclic-like characteristic, the runoff data must also be analyzed on the basis of this wet and dry distribution. In order to eliminate a bias, each basic time period should contain equal numbers of wet and dry sequences similar to that used in table 2 which gives the mean annual precipitation. In fact, the beginning and end of these runoff sequences are in very close agreement with similar segregation of precipitation data, except for the occasional time lag in the runoff. For that reason the same time periods used in developing table 2 also have been used in preparing table 6. This table gives the average annual runoff in five southern California streams and its departure from the 1893 to 1951 mean annual runoff for the three cyclic periods 1904-1934, 1922-1944 and 1934-51.

Each of these three cyclic-like periods could be used as a suitable base period of runoff analysis in the Santa Margarita River basin and Camp Pendleton area. However, in the analysis that follows, the base time periods have been confined to the two periods 1922-1944 and 1934-1951.

Table 6.- Mean annual runoff, in acre-feet, for certain cyclic periods

	1904 - 1934		1922 - 1944		1934 - 1951	
	Average runoff	Departure from mean in percent a/	Average runoff	Departure from mean in percent a/	Average runoff	Departure from mean in percent a/
Santa Ana River near Mentone	74,100	+14	59,300	- 8	59,500	- 8
San Gabriel River near Azusa	128,300	+11	111,900	- 4	124,700	+ 8
Santa Ysabel Creek near Mesa Grande	15,900 b/	+ 9	14,600 b/	0	12,700	-13
San Luis Rey River at Lake Henshaw	31,500 b/	+ 7	28,600	- 2	27,100	- 8
Temecula Creek at Nigger Canyon	12,800 b/	+10	11,400	- 2	10,000	-14
Average	-	+10	-	- 3	-	- 8

a/ Mean annual runoff 1893 to 1951.
b/ Partly or completely estimated.

Computed Runoff

In order to obtain the annual runoff in many of the Camp Pendleton streams for the two base periods 1922-44 and 1934-1951, it has been necessary to determine the magnitude of this runoff from correlative data. These correlative data must include an estimate of the basin-wide precipitation, an appraisal of the absorptive and retentive qualities of the mantle rock, and an estimate of the natural water losses. On the basis of these factors, a correlation was developed, such as that shown on plate 20, between the unmeasured monthly discharge of San Onofre Creek and the observed monthly discharge of Santa Ysabel Creek near Mesa Grande, Temecula Creek at Nigger Canyon near Temecula, and Murrieta Creek near Temecula after a pattern described by Troxell (1948). By the use of each of these observed records, three independent determinations of discharge of San Onofre Creek for the period October 1922 through September 1951 were obtained. The average of these determinations was assumed to represent the computed monthly discharge, unless otherwise indicated. This method was repeated for each of the basins treated in this report.

Santa Margarita River

The Santa Margarita River is the largest and most important of the streams discharging into the ocean within the confines of Camp Pendleton. The lower portion of the Santa Margarita River system consists of an alluvial valley extending upstream for a distance of about 10 miles from the ocean, which has been designated the lower Santa Margarita River valley. The ground water stored in these deposits is one of the principal sources of water for Camp Pendleton. These ground-water reserves are largely sustained by the runoff originating above the De Luz dam site at the head of the valley. Accordingly, the following analysis develops the annual surface-water inflow to this alluvial valley at De Luz dam site for the two time periods 1922-44 and 1934-51. This is followed by the annual surface-water outflow or waste from this valley for the same time periods.

Inflow

The inflow to the lower Santa Margarita River valley and potential source of ground-water recharge in that valley has not, and is not now, being measured at De Luz dam site. However, since November 1924 a gaging station has been maintained on the Santa Margarita River about 8 miles upstream from De Luz dam site. This station, known as "Santa Margarita River near Fallbrook," measures the runoff from 645 square miles, which represents about 87 percent of the entire basin.

Table 7 gives the monthly discharge, in cubic feet per second, and annual runoff, in acre-feet, as recorded at the Fallbrook gage. These data are summarized by giving the minimum, quartile, median, maximum, and mean monthly and annual values at the bottom of the table. The extreme range in these monthly and annual values illustrates the variability of the runoff in this stream system.

Table 7.- Monthly discharge, in cubic feet per second, and annual runoff, in acre-feet, of Santa Margarita River near Fallbrook, Calif., for the period 1924-52

Drainage area, 645 square miles

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1924-25	-	-	13.0	12.3	7.86	6.79	8.98	2.78	2.94	1.85	1.02	1.69	-
-26	4.85	7.59	9.89	8.34	18.2	8.37	13.7	8.45	4.51	1.61	.78	.98	12,500
-27	3.38	7.08	14.6	11.3	1,380	53.5	23.6	11.8	7.19	2.67	1.40	3.37	85,100
-28	7.25	11.8	14.5	13.9	14.1	13.8	5.47	3.61	2.69	1.05	.93	1.70	5,480
-29	6.07	8.60	11.5	13.3	12.6	10.8	7.94	2.77	2.06	.43	1.04	3.30	4,830
-30	2.81	2.65	4.53	45.0	13.7	26.6	7.90	23.0	5.68	4.05	3.43	3.68	8,680
-31	5.39	7.83	7.87	9.52	25.6	6.53	6.11	5.25	3.26	1.35	1.64	2.77	4,920
-32	4.82	7.59	27.4	15.5	496	41.7	12.6	9.11	6.73	4.45	3.75	4.70	36,900
-33	7.74	8.03	12.5	29.7	14.9	10.6	9.53	7.92	4.47	2.87	2.80	4.09	6,940
-34	5.01	6.65	10.3	16.8	12.8	9.03	5.73	3.41	4.18	2.69	2.07	2.45	4,870
-35	4.99	6.50	16.8	17.4	28.6	25.5	11.5	6.81	4.05	2.52	2.47	2.95	7,780
-36	4.36	6.43	7.37	8.24	58.8	12.3	11.1	4.38	2.37	1.10	1.22	1.82	7,070
-37	7.36	6.73	75.6	63.3	591	430	98.5	27.5	14.4	8.39	6.42	5.77	78,310
-38	7.65	10.2	14.5	15.1	53.7	1,249	64.4	29.4	14.8	11.8	9.84	9.32	91,090
-39	11.8	12.7	44.5	37.2	92.4	37.4	23.8	13.4	9.12	7.44	6.21	21.4	18,850
-40	10.9	12.2	13.5	77.2	83.5	19.5	26.9	11.4	8.00	4.35	4.81	6.88	16,720
-41	9.61	11.5	113	22.4	183	582	334	66.0	23.8	12.7	12.1	11.2	83,100
-42	18.0	19.7	30.2	38.6	38.1	42.5	29.7	14.0	10.8	7.21	6.12	7.27	15,760
-43	8.52	10.2	13.0	416	151	260	50.4	16.6	11.8	7.79	6.09	6.52	57,890
-44	10.0	11.3	32.3	22.9	165	58.4	20.8	14.5	11.3	7.79	6.34	6.74	21,850
-45	8.09	51.9	16.5	17.0	27.3	74.8	22.0	11.3	8.38	5.14	8.07	7.79	15,560
-46	8.02	10.6	48.5	14.1	16.2	33.5	22.0	9.47	6.17	8.35	3.54	3.87	11,150
-47	7.99	25.4	25.4	16.9	14.5	12.8	10.2	7.81	7.72	5.44	4.47	5.87	8,700
-48	7.23	8.80	14.6	11.7	17.5	13.3	11.5	7.94	6.33	4.23	3.56	3.21	6,640
-49	5.30	6.60	9.86	16.3	14.5	12.1	9.37	7.24	5.18	4.14	3.66	3.67	5,880
-50	4.24	5.66	8.32	9.75	9.76	8.13	6.43	4.96	2.86	1.71	1.19	2.02	3,910
-51	2.76	5.29	5.73	7.38	7.00	6.18	4.00	3.45	1.13	.33	1.37	1.17	2,750
-52	1.46	2.61	44.8	351	11.8	301	41.0	8.29	2.82	.54	.25	1.47	47,010
Minimum	1.46	2.61	4.53	7.38	7.00	6.18	4.00	2.77	1.13	.33	.25	.98	2,750
Quartile	4.71	6.59	9.98	11.8	13.6	10.8	8.19	4.89	3.00	1.57	1.25	2.08	5,970
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.40	5.87	3.91	3.38	3.66	10,880

Year	Oct.	Nov.	Dec.	Jan.	Feb.		Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1924-25	-	-	13.0	12.3	7.86		6.79	8.98	2.78	2.94	1.85	1.02	1.69	-
-26	4.85	7.59	9.89	8.34	18.2		8.37	13.7	8.45	4.51	1.61	.78	.98	12,500
-27	3.38	7.08	14.6	11.3	1,380		53.5	23.6	11.8	7.19	2.67	1.40	3.37	85,100
-28	7.25	11.8	14.5	13.9	14.1		13.8	5.47	3.61	2.69	1.05	.93	1.70	5,480
-29	6.07	8.60	11.5	13.3	12.6		10.8	7.94	2.77	2.06	.43	1.04	3.30	4,830
-30	2.81	2.65	4.53	45.0	13.7		26.6	7.90	23.0	5.68	4.05	3.43	3.68	8,680
-31	5.39	7.83	7.87	9.52	25.6		6.53	6.11	5.25	3.26	1.35	1.64	2.77	4,920
-32	4.82	7.59	27.4	15.5	496		41.7	12.6	9.11	6.73	4.45	3.75	4.70	36,900
-33	7.74	8.03	12.5	29.7	14.9		10.6	9.53	7.92	4.47	2.87	2.80	4.09	6,940
-34	5.01	6.65	10.3	16.8	12.8		9.03	5.73	3.41	4.18	2.69	2.07	2.45	4,870
-35	4.99	6.50	16.8	17.4	28.6		25.5	11.5	6.81	4.05	2.52	2.47	2.95	7,780
-36	4.36	6.43	7.37	8.24	58.8		12.3	11.1	4.38	2.37	1.10	1.22	1.82	7,070
-37	7.36	6.73	75.6	63.3	591		430	98.5	27.5	14.4	8.39	6.42	5.77	78,310
-38	7.65	10.2	14.5	15.1	53.7		1,249	64.4	29.4	14.8	11.8	9.84	9.32	91,090
-39	11.8	12.7	44.5	37.2	92.4		37.4	23.8	13.4	9.12	7.44	6.21	21.4	18,850
-40	10.9	12.2	13.5	77.2	83.5		19.5	26.9	11.4	8.00	4.35	4.81	6.88	16,720
-41	9.61	11.5	113	22.4	183		582	334	66.0	23.8	12.7	12.1	11.2	83,100
-42	18.0	19.7	30.2	38.6	38.1		42.5	29.7	14.0	10.8	7.21	6.12	7.27	15,760
-43	8.52	10.2	13.0	416	151		260	50.4	16.6	11.8	7.79	6.09	6.52	57,890
-44	10.0	11.3	32.3	22.9	165		58.4	20.8	14.5	11.3	7.79	6.34	6.74	21,850
-45	8.09	51.9	16.5	17.0	27.3		74.8	22.0	11.3	8.38	5.14	8.07	7.79	15,560
-46	8.02	10.6	48.5	14.1	16.2		33.5	22.0	9.47	6.17	8.35	3.54	3.87	11,150
-47	7.99	25.4	25.4	16.9	14.5		12.8	10.2	7.81	7.72	5.44	4.47	5.87	8,700
-48	7.23	8.80	14.6	11.7	17.5		13.3	11.5	7.94	6.33	4.23	3.56	3.21	6,640
-49	5.30	6.60	9.86	16.3	14.5		12.1	9.37	7.24	5.18	4.14	3.66	3.67	5,880
-50	4.24	5.66	8.32	9.75	9.76		8.13	6.43	4.96	2.86	1.71	1.19	2.02	3,910
-51	2.76	5.29	5.73	7.38	7.00		6.18	4.00	3.45	1.13	.33	1.37	1.17	2,750
-52	1.46	2.61	44.8	351	11.8		301	41.0	8.29	2.82	.54	.25	1.47	47,010
Minimum	1.46	2.61	4.53	7.38	7.00		6.18	4.00	2.77	1.13	.33	.25	.98	2,750
Quartile	4.71	6.59	9.98	11.8	13.6		10.8	8.19	4.89	3.00	1.57	1.25	2.08	5,970
Median	6.94	8.12	14.4	16.4	22.1		17.6	12.2	8.42	5.87	3.91	3.38	3.66	10,880
Quartile	8.18	11.5	27.6	29.9	79.6		45.0	24.5	13.2	8.47	6.82	5.80	6.41	35,660
Maximum	18.0	51.9	113	416	1,380		1,249	334	66.0	23.8	12.7	12.1	21.4	91,090
Mean	6.87	10.8	23.6	47.8	127		120	32.1	12.2	6.96	4.43	3.81	4.65	24,820

Between the Fallbrook station and De Luz dam site the main tributary is De Luz Creek. The importance of the contribution from this area was recognized in March 1951 by the establishment of a gaging station by the Department of the Navy and the Geological Survey. The monthly discharge and annual runoff for this very short period of record is given in table 8.

Table 8.- Monthly discharge, in cubic feet per second, and annual runoff, in acre-feet, of De Luz Creek near Fallbrook, Calif., for the period 1951-52

Water year	Month												Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1951	-	-	-	-	-	0.01	0.46	0	0	0	0	0	29
1952	0	0	1.04	64.5	7.46	92.4	25.7	4.00	.88	.22	0	0	11,980

In order to obtain a satisfactory estimate of the inflow to the lower Santa Margarita River valley at De Luz dam site, it has been necessary to compute the probable runoff from the 60-square-mile drainage area, including De Luz Creek, between the Fallbrook station and the dam site for the 29-year period 1922-51. This computed record was based on a correlation with the monthly runoff of Murrieta, Temecula, and Santa Ysabel Creeks along the pattern previously described. These computed values were assumed to represent 85 percent of the observed monthly inflow between the Fallbrook station and the mouth of the river plus the water losses and retention between these two points. The computed runoff from this 60-square-mile drainage area when added to the Fallbrook record as indicated in table 9 gives the runoff from the 705-square-mile basin above the De Luz dam site and the annual inflow into the lower Santa Margarita River valley.

Table 9.- Computed annual inflow, in acre-feet, to the lower Santa Margarita River valley at De Luz dam site for period 1922-52

Water year	Annual inflow		
	Santa Margarita River [a]	De Luz Creek [b]	Combined
1923	/c 7,800	4,000	11,800
1924	/c 7,000	1,800	8,800
1925	/c 4,200	1,400	5,600
1926	12,500	8,000	20,500
1927	85,100	12,000	97,100
1928	5,480	2,400	7,880
1929	4,830	1,700	6,530
1930	8,680	3,600	12,300
1931	4,920	1,900	6,820
1932	36,900	9,000	45,900
1933	6,940	3,600	10,500
1934	4,870	2,600	7,470
1935	7,780	7,000	14,800
1936	7,070	5,600	12,700
1937	78,310	38,000	116,000
1938	91,090	32,000	123,000
1939	18,850	9,800	28,600
1940	16,720	10,000	26,700
1941	83,100	37,000	120,000
1942	15,760	5,800	21,600
1943	57,890	20,000	77,900
1944	21,850	11,000	32,800
1945	15,560	9,200	24,800
1946	11,150	5,600	16,800
1947	8,700	3,300	12,000
1948	6,640	600	7,240
1949	5,880	900	6,780
1950	3,910	600	4,510
1951	2,750	200	2,950
1952	47,010	14,790	61,800

Base period	Mean annual inflow
1922-44	37,000
1934-51	38,200

/a Near Fallbrook.
/b Includes all of the tributary area between Fallbrook station and De Luz dam site.
/c Estimated.

This computed inflow ranges from 2,950 acre-feet in 1950-51 to 123,000 acre-feet in 1937-38, which is typical of the extreme variability of the runoff throughout most of southern California. The mean annual inflow for the 29-year period amounts to 30,700 acre-feet. However, this value has little significance in that the 29-year period contained two extended dry sequences and only one wet sequence of years. When the two basic time periods are used, the mean increases to 37,000 acre-feet for the 1922-44 period, and 38,200 acre-feet for the 1934-51 period, giving an average value of 37,600 acre-feet which may be subject to a possible error of about 10 percent.

Because of the extreme variability of this inflow, the annual runoff for the single year 1937-38 exceeded the mean annual inflow by 227 percent, as shown in table 10. This table gives the maximum and minimum average annual runoff for time periods ranging from 1 to 6 consecutive years. The two wettest consecutive years were from October 1936 to September 1938 with an average annual runoff of 120,000 acre-feet or 219 percent above the mean value obtained from table 9. As the time period increased to 6 consecutive years, the average annual runoff decreased to 72,600 acre-feet but still remained 93 percent above the mean value.

At the other extreme the 6 consecutive driest years occurred from October 1945 to September 1951 and had an average annual runoff of 8,400 acre-feet, which is 78 percent below the mean value. The driest single year was that of October 1950 to September 1951 and had a runoff of only 2,950 acre-feet or only 8 percent of the mean value.

Table 10.- Maximum and minimum annual inflow, in acre-feet, to the lower Santa Margarita River valley at De Luz dam site for periods of 1 to 6 consecutive years

Length of period	Period	Average annual inflow	Departure from mean annual inflow,[a] in percent
		Maximum annual inflow	
1 year	1937-38	123,000	227
2 years	1936-38	120,000	219
3 years	1936-39	89,200	137
4 years	1936-40	73,600	96
5 years	1936-41	82,900	120
6 years	1936-42	72,600	93
		Minimum annual inflow	
6 years	1945-51	8,400	-78
5 years	1946-51	6,700	-82
4 years	1947-51	5,370	-86
3 years	1948-51	4,750	-87
2 years	1949-51	3,730	-90
1 year	1950-51	2,950	-92

a. Mean annual inflow = 37,600 acre-feet (based on the averages for the 1922-44 and 1934-51 base periods).

Outflow

The surface-water outflow or waste from the lower Santa Margarita River valley has been observed since February 1923 when a station was established at Ysidora about 2 miles upstream from the ocean. Table 11 contains the monthly discharge and annual runoff at this station for the period 1923-52. As in the case of the record obtained at the Fallbrook station, this table gives the minimum, quartiles, median, maximum, and mean monthly discharges, and the annual runoff.

On the basis of these data and the estimated annual outflow for 1922-23 and 1929-30, the mean annual outflow was 33,000 acre-feet for the 1922-44 base period and 34,400 acre-feet for the 1934-51 period, with the average annual outflow amounting to 33,700 acre-feet.

Table 11.- Monthly discharge, in cubic feet per second, and annual runoff, in acre-feet, for Santa Margarita River at Ysidora, Calif., for the period 1923-52

Drainage area, 740 square miles

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1922-23	-	-	-	-	-	15.3	1.47	0.12	0	0	0	0	-
-24	0	0	7.08	9.77	4.07	8.63	9.04	.31	0	0	0	0	2,360
-25	0	0	2.68	6.42	1.33	1.18	1.33	.08	0	0	0	0	790
-26	0	0	.30	.16	20.5	3.38	239	2.41	0.38	0	0	0	15,700
-27	0	0	.71	5.71	1,470	100	38	7.0	5.0	0.7	0.05	0	91,200
-28	0	3.24	15	17	12	13.2	3.51	1.74	.42	.003	0	0	4,000
-29	0.01	.03	1.06	1.48	11.2	5.19	3.14	1.09	.05	0	0	0	1,360
-30	-	-	-	-	-	-	-	-	-	-	-	-	-
-31	.07	.61	.94	3.83	44.4	7.61	3.37	1.97	.73	.133	.124	.047	3,660
-32	.38	1.25	45.8	30.7	543	58.2	8.16	5.37	1.66	.43	.28	.47	40,600
-33	1.58	1.55	9.79	45.2	28.4	10.2	5.19	2.86	1.15	1.02	.94	1.14	6,520
-34	1.42	1.29	5.96	51.5	9.44	6.96	2.35	1.23	1.17	.52	.38	.40	5,010
-35	.82	1.58	16.1	31.7	65.9	64.6	20.7	4.89	5.04	2.69	2.30	2.30	12,990
-36	2.22	2.44	2.49	2.55	128	17.2	19.3	4.25	4.15	3.15	1.79	1.57	11,060
-37	2.29	2.40	93.5	133	1,002	586	143	34.6	11.3	.46	.39	0	117,200
-38	.64	.70	11.1	17.7	94.2	1,730	89.7	43.6	8.57	.48	0	0	122,000
-39	0	2.65	72.0	60.4	140	57.6	33.2	7.76	.06	0	0	13.5	22,900
-40	4.85	7.43	10.4	114	166	31.3	35.9	5.55	0	0	0	0	22,320
-41	0	0	141	44.2	305	871	465	101	28.7	2.54	0.08	0	117,600
-42	13.3	22.0	48.8	57.1	45.5	49.0	34.5	10.2	1.4	0	0	0	16,930
-43	0	.61	8.81	532	240	361	72.2	17.2	2.79	0	0	0	74,270
-44	0	0	53.4	28.4	248	105	24.5	7.60	2.53	0	0	0	27,800
-45	0	65.8	17.3	17.0	51.5	143	36.2	6.46	.93	0	0	0	20,270
-46	0	0	65.7	17.9	18.7	42.0	45.7	2.52	0	.57	0	0	11,680
-47	0	22.2	35.7	24.6	17.0	11.5	4.07	.07	0	0	0	0	6,930
-48	0	0	0	0	3.52	2.85	3.10	0	0	0	0	0	562
-49	0	0	0	0	3.07	5.02	0	0	0	0	0	0	479
-50	0	0	0	0	0	0	0	0	0	0	0	0	0
-51	0	0	0	0	0	0	0	0	0	0	0	0	0
-52	0	0	0	349	13.8	346	61.6	7.06	0	0	0	0	47,640
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0
Quartile	0	0	.66	2.60	8.54	5.59	2.92	.16	0	0	0	0	2,440
Median	0	.53	9.11	18.8	35.3	20.2	17.1	3.12	.49	0	0	0	12,680

1922-23	-	-	-	-	-	1[illegible].3	1.47	0.12	0	0	0	0	-
-24	0	0	7.08	9.77	4.07	8.63	9.04	.31	0	0	0	0	2,360
-25	0	0	2.68	6.42	1.33	1.18	1.33	.08	0	0	0	0	790
-26	0	0	.30	.16	20.5	3.38	239	2.41	0.38	0	0	0	15,700
-27	0	0	.71	5.71	1,470	100	38	7.0	5.0	0.7	0.05	0	91,200
-28	0	3.24	15	17	12	13.2	3.51	1.74	.42	.003	0	0	4,000
-29	0.01	.03	1.06	1.48	11.2	5.19	3.14	1.09	.05	0	0	0	1,360
-30	-	-	-	-	-	-	-	-	-	-	-	-	-
-31	.07	.61	.94	3.83	44.4	7.61	3.37	1.97	.73	.133	.124	.047	3,660
-32	.38	1.25	45.8	30.7	543	58.2	8.16	5.37	1.66	.43	.28	.47	40,600
-33	1.58	1.55	9.79	45.2	28.4	10.2	5.19	2.86	1.15	1.02	.94	1.14	6,520
-34	1.42	1.29	5.96	51.5	9.44	6.96	2.35	1.23	1.17	.52	.38	.40	5,010
-35	.82	1.58	16.1	31.7	65.9	64.6	20.7	4.89	5.04	2.69	2.30	2.30	12,990
-36	2.22	2.44	2.49	2.55	128	17.2	19.3	4.25	4.15	3.15	1.79	1.57	11,060
-37	2.29	2.40	93.5	133	1,002	586	143	34.6	11.3	.46	.39	0	117,200
-38	.64	.70	11.1	17.7	94.2	1,730	89.7	43.6	8.57	.48	0	0	122,000
-39	0	2.65	72.0	60.4	140	57.6	33.2	7.76	.06	0	0	13.5	22,900
-40	4.85	7.43	10.4	114	166	31.3	35.9	5.55	0	0	0	0	22,320
-41	0	0	141	44.2	305	871	465	101	28.7	2.54	0.08	0	117,600
-42	13.3	22.0	48.8	57.1	45.5	49.0	34.5	10.2	1.4	0	0	0	16,930
-43	0	.61	8.81	532	240	361	72.2	17.2	2.79	0	0	0	74,270
-44	0	0	53.4	28.4	248	105	24.5	7.60	2.53	0	0	0	27,800
-45	0	65.8	17.3	17.0	51.5	143	36.2	6.46	.93	0	0	0	20,270
-46	0	0	65.7	17.9	18.7	42.0	45.7	2.52	0	.57	0	0	11,680
-47	0	22.2	35.7	24.6	17.0	11.5	4.07	.07	0	0	0	0	6,930
-48	0	0	0	0	3.52	2.85	3.10	0	0	0	0	0	562
-49	0	0	0	0	3.07	5.02	0	0	0	0	0	0	479
-50	0	0	0	0	0	0	0	0	0	0	0	0	0
-51	0	0	0	0	0	0	0	0	0	0	0	0	0
-52	0	0	0	349	13.8	346	61.6	7.06	0	0	0	0	47,640
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0
Quartile	0	0	.66	2.60	8.54	5.59	2.92	.16	0	0	0	0	2,440
Median	0	.53	9.11	18.8	35.3	20.2	17.1	3.12	.49	0	0	0	12,680
Quartile	.62	2.20	33.6	46.5	144	92.4	39.5	7.18	2.38	.48	.08	.06	29,780
Maximum	13.3	65.8	141	532	1,470	1,730	465	101	28.7	3.15	2.30	13.5	122,000
Mean	.98	4.85	23.8	57.2	167	160	48.4	9.55	2.62	.44	.22	.67	28,710

The maximum and minimum annual surface-water outflow from the lower Santa Margarita River valley is given in table 12 for periods of 1 to 6 consecutive years. The maximum annual outflow occurred in 1937-38 and amounted to 122,000 acre-feet or 1,000 acre-feet less than the inflow. The average annual outflow for the wettest 6 consecutive years amounted to 69,800 acre-feet, indicating an average annual retention of 2,800 acre-feet in the lower Santa Margarita River valley.

During the 6 driest consecutive years occurring between October 1945 and September 1951 the average annual outflow amounted to 3,280 acre-feet. This represents an average annual retention of 5,120 acre-feet in the lower Santa Margarita River valley.

On the basis of the mean values of inflow to and outflow from the Santa Margarita River valley, the mean annual retention has been about 3,900 acre-feet. This retention was of course supplemented by precipitation falling on the valley floor and minor runoff from the 35-square-mile tributary area between the De Luz dam site and the Ysidora gage.

Table 12.- Maximum and minimum annual outflow, in acre-feet, from the lower Santa Margarita River valley at Ysidora for periods of 1 to 6 consecutive years

Length of period	Period	Average annual outflow	Departure from mean annual outflow[a] in percent
		Maximum annual outflow	
1 year	1937-38	122,000	262
2 years	1936-38	119,600	254
3 years	1936-39	87,300	159
4 years	1936-40	71,100	111
5 years	1936-41	80,400	139
6 years	1936-42	69,800	107
		Minimum annual outflow	
6 years	1945-51	3,280	-90
5 years	1946-51	1,590	-95
4 years	1947-51	260	-99
3 years	1948-51	160	-99
2 years	1949-51	0	-100
1 year	1950-51	0	-100

a/ Mean annual outflow = 33,700 acre-feet (based on the averages for the 1922-44 and 1934-51 base periods).

San Mateo Creek

The main purpose of this analysis is the determination of the surface-water inflow to and the outflow from the alluvial deposits that fill the main canyon from the ocean upstream to Devil Canyon, a distance of about 10 miles. The inflow represents the opportunity for the recharge of ground-water storage as well as a measure of the recoverable water available for future use; whereas the outflow represents the waste to the ocean. As in the preceding analysis, these data are segregated into two parts, inflow to and outflow from these alluvial valley areas.

Inflow

As an aid in developing the surface-water inflow quantities, the contributing area has been segregated into three parts: (a) The upper San Mateo Creek which drains the major part of the Murrieta Plateau; (b) the Cristianitos Canyon; and (c) the lower mountain and foothill areas.

Upper San Mateo Creek.--The upper San Mateo Creek drainage area includes the 83 square miles on the Murrieta Plateau above the junction with Devil Canyon Creek. In 1951 the Geological Survey and the Department of the Navy established a gaging station on San Mateo Creek about 0.3 mile above San Mateo Road ford. In September 1952 a permanent station was established half a mile below the junction of San Mateo Creek with Devil Canyon Creek to measure more accurately the runoff from the plateau area to the alluvial valley. However, the record from this station is entirely too short to be of great significance in developing the runoff characteristics of the area.

Consequently, in order to obtain the runoff from Murrieta Plateau, it was necessary to resort to analytical methods involving the precipitation, the absorptive and retentive qualities of the mantle rock, and the natural water losses. Using these items, it has been possible to develop a relationship between the unmeasured runoff from the plateau and the monthly runoff of Murrieta, Temecula, and Santa Ysabel Creeks. The data obtained for the period 1922-52 are shown in table 13.

Table 13.- Computed annual runoff, in acre-feet, of upper San Mateo Creek for the period 1922-52

Water year	Annual runoff	Water year	Annual runoff
1923	6,700	1938	30,000
1924	3,700	1939	10,000
1925	2,800	1940	8,600
1926	11,000	1941	36,000
1927	45,000	1942	8,100
1928	2,700	1943	21,000
1929	4,100	1944	11,000
1930	6,100	1945	9,500
1931	2,400	1946	6,600
1932	21,000	1947	3,300
1933	4,200	1948	1,900
1934	1,300	1949	2,800
1935	5,100	1950	1,600
1936	5,200	1951	1,100
1937	40,000	1952	23,000

Base period	Mean annual runoff
1922-44	13,000
1934-51	11,900

The 30-year period included in this table tends to produce a biased record in that it includes one wet and two dry periods. When adjusted for the cyclic time periods in an effort to reduce this bias, the mean annual runoff amounts to 13,000 acre-feet for the 22-year period 1922-44 and 11,900 acre-feet for the 17-year period 1934-51. On the basis of these quantities the mean annual runoff of the upper San Mateo Creek basin is 12,400 acre-feet, subject to a possible error of about 20 percent.

Cristianitos Creek.--On December 26, 1950, a gaging station was established on Cristianitos Creek below its junction with Talega Creek, which measures the runoff from about 24 square miles, by the Geological Survey and the Department of the Navy. The records of monthly discharge and annual runoff obtained at this site are given in table 14. This

Table 14.- Monthly discharge, in cubic feet per second, and annual runoff, in acre-feet, for Cristianitos Creek near San Clemente for the period 1950-52

Water year	Month												Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1951	-	-	-	0	0	0	0	0	0	0	0	0	-
1952	0	0	0.2	36	2.9	30	10	4.2	1.3	0.5	0.2	0.1	5,200

record of about 2 years is entirely too short to represent runoff conditions in this area. Consequently, it was necessary to resort to the same analytical methods used in developing the previous record. The computed monthly runoff from the 24 square miles upstream from this site for the 30-year period 1922-52 is summarized by years in table 15.

Table 15.- Computed annual runoff, in acre-feet, of Cristianitos Creek for the period 1922-52

Water year	Annual runoff	Water year	Annual runoff
1923	710	1938	7,500
1924	290	1939	1,600
1925	150	1940	1,300
1926	2,400	1941	8,500
1927	14,000	1942	990
1928	150	1943	4,700
1929	360	1944	1,800
1930	670	1945	1,400
1931	190	1946	820
1932	5,000	1947	260
1933	390	1948	77
1934	39	1949	200
1935	580	1950	61
1936	760	1951	a 0
1937	10,000	1952	a 5,200

Base period	Mean annual runoff
1922-44	2,800
1934-51	2,400

a/ Measured.

The data listed in table 15 indicate a mean annual runoff of 2,800 acre-feet for the 22-year base period 1922-44 and 2,400 acre-feet for the 17-year period 1934-51. On the basis of both these periods, the mean annual runoff of Cristianitos Creek is 2,600 acre-feet, subject to a possible error of about 20 percent.

Lower mountain and foothill areas.--The remaining portions of the San Mateo Creek basin tributary to the coastal alluvial valleys are in the lower mountain and foothill area below the upper San Mateo and Cristianitos Creek gages. The computed annual runoff from these mountain and foothill areas of about 30 square miles for the period 1922 to 1952 is given in table 16.

Table 16.- Computed annual runoff, in acre-feet, of the lower mountain and foothill areas of San Mateo Creek for the period 1922-52

Water year	Annual runoff	Water year	Annual runoff
1923	220	1938	3,200
1924	120	1939	520
1925	77	1940	440
1926	940	1941	3,200
1927	5,800	1942	320
1928	73	1943	1,700
1929	130	1944	610
1930	280	1945	450
1931	87	1946	260
1932	2,000	1947	100
1933	110	1948	52
1934	36	1949	81
1935	190	1950	48
1936	140	1951	35
1937	4,000	1952	2,000

Base period	Mean annual runoff
1922-44	1,100
1934-51	900

The mean annual runoff amounted to 1,100 acre-feet for the 22-year base period 1922-44 and 900 acre-feet for the 17-year base period 1934-51. On the basis of these two periods the mean annual runoff for the area is 1,000 acre-feet, subject to a possible error of about 20 percent.

Total inflow.--The entire surface-water inflow tributary to the alluvial valleys in the lower portions of the San Mateo Creek valley represents the sum of the data in tables 13, 15 and 16, which is summarized in table 17 for the 30-year period 1922 to 1952. During this period the estimated annual inflow from the 137 square miles of drainage area has ranged from 1,100 acre-feet in the 1951 water year to 65,000 acre-feet in the 1927 water year. The mean annual inflow for the unbiased base time periods amounted to 16,900 acre-feet for the 1922-44 period and to 15,100 acre-feet for the 1934-51 period, which gives a mean annual inflow of 16,000 acre-feet, subject to a possible error of about 20 percent.

Table 17.- Computed annual inflow, in acre-feet, to the alluvial valleys of San Mateo Creek for the period 1922-52

Water year	Annual inflow	Water year	Annual inflow
1923	7,600	1938	41,000
1924	4,100	1939	12,000
1925	3,000	1940	10,000
1926	14,000	1941	48,000
1927	65,000	1942	9,400
1928	2,900	1943	27,000
1929	4,600	1944	13,000
1930	7,000	1945	11,000
1931	2,700	1946	7,700
1932	28,000	1947	3,700
1933	4,700	1948	2,000
1934	1,400	1949	3,100
1935	5,900	1950	1,700
1936	6,100	1951	1,100
1937	54,000	1952	30,000

Base period	Mean annual runoff
1922-44	16,900
1934-51	15,100

The extreme variability of this inflow is demonstrated by the data given in table 18 for periods of 1 to 6 consecutive years. The estimated maximum annual inflow occurred in 1926-27 when it exceeded the mean annual value by 306 percent. As the time period lengthened to 6 consecutive years, the average maximum inflow decreased to 29,100 acre-feet for the period 1936-42, which is still 82 percent above the mean annual value.

Table 18.- Maximum and minimum computed annual inflow, in acre-feet, to the alluvial valleys of San Mateo Creek for periods of 1 to 6 consecutive years

Length of period	Period	Average annual inflow	Departure from mean annual inflow[a] (in percent)
		Maximum annual inflow	
1 year	1926-27	65,000	306
2 years	1936-38	47,500	197
3 years	1936-39	35,700	123
4 years	1936-40	29,200	82
5 years	1936-41	33,000	106
6 years	1936-42	29,100	82
		Minimum annual inflow	
6 years	1945-51	3,200	-80
5 years	1946-51	2,300	-86
4 years	1947-51	2,000	-88
3 years	1948-51	2,000	-88
2 years	1949-51	1,400	-91
1 year	1950-51	1,100	-93

a/ Mean annual inflow = 16,000 acre-feet (based on the averages for the 1922-44 and 1934-51 base periods).

During the driest 6-consecutive-year period 1945-51 the estimated average annual inflow decreased to 3,200 acre-feet or 80 percent below the mean value. In 1950-51 the inflow further decreased to 1,100 acre-feet, which was only 7 percent of the mean annual inflow.

Outflow

In an effort to determine that portion of the surface-water inflow wasted as surface-water outflow from the coastal alluvial valley areas, the Department of the Navy established a gaging station on October 22, 1946, on San Mateo Creek about half a mile from the ocean. The observed monthly outflow in cubic feet per second and the annual runoff in acre-feet, prior to October 1, 1952, are listed in table 19.

Table 19.- Monthly outflow, in cubic feet per second, and annual outflow, in acre-feet, for San Mateo Creek at San Onofre for the period 1946-52

Water year	Month												Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1947	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.03	0	0	0	50
1948	0	0	0	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0	0	0	0	0	0
1952	0	0	0	128	5.95	187	43.8	9.1	0.03	0	0	0	22,850

Because of the extreme dryness, only 50 acre-feet wasted into the ocean as surface runoff during the 5-year period 1946-51. During this period the total computed inflow amounted to 11,600 acre-feet. Consequently, this would represent an apparent average annual retention of 2,300 acre-feet. During the final period of this record, the outflow amounted to 22,850 acre-feet from a computed inflow of 30,000 acre-feet. This would leave an apparent retention of 7,150 acre-feet in the alluvial valley fill.

Prior to the installation of the outflow gage, a series of miscellaneous measurements were also made at this site by F. E. Green beginning in April 1938 and continuing through February 1941. On the basis of these frequent measurements it has been possible to develop an estimate of the monthly and annual outflow for the 2-year period 1938-40 as shown in table 20. During this 2-year period the outflow totaled 9,300 acre-feet from an estimated inflow of 22,000 acre-feet, and the residual represents an apparent annual retention of 6,350 acre-feet.

Table 20.- Estimated monthly outflow, in cubic feet per second, and annual outflow, in acre-feet, of San Mateo Creek at San Onofre for the period 1938-40

Water year	Month												Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1939	1.1	1.0	1.7	6.1	36	12.2	5.7	1.8	1.1	0.9	0.9	0.9	4,200
1940	.6	.4	.6	2.4	38	10.4	27	1.8	.9	.8	.6	.6	5,100

San Onofre Creek

The alluvial valley of San Onofre Creek extends upstream from the ocean 7 to 8 miles. The ground water stored in these deposits is an important source of water supply to the Camp Pendleton area. Consequently, one of the main purposes of this analysis was to determine the surface-water inflow to and recharge opportunity for sustaining the ground water in these alluvial deposits.

Inflow

On December 27, 1950, the Department of the Navy, in cooperation with the Geological Survey, established a gaging station on San Onofre Creek in the valley area about 4 miles from the ocean to measure the surface-water inflow or gross recharge opportunity to the main valley area downstream. It was impractical to measure the inflow at the heads of the valley not only because three stations would be required instead of one but also because the deposits are thin. The monthly and annual inflow from the 41 square miles of drainage area as observed at this single station is given in table 21.

Table 21.- Monthly inflow, in cubic feet per second, and annual inflow, in acre-feet, for San Onofre Creek near San Onofre for the period 1950-52

Water year	Month												Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1951	-	-	-	0	0	0	0	0	0	0	0	0	-
1952	0	0	1.10	44.6	2.75	54.3	13.0	4.35	2.11	1.32	.72	.48	7,620

The lack of records at the head of the alluvial valley near Tent Camp 2 made it necessary to compute the annual inflow for the 30-year period 1922-52 which is given in table 22 and derived from the comparative records of the Murrieta, Temecula, and Santa Ysabel Creeks. The computed mean annual inflow to the alluvial area from the 41 square miles of drainage area for the 22-year base period 1922-44 amounts to 4,200 acre-feet, decreasing to 3,800 acre-feet for the 17-year base period 1934-51. On the basis of these two periods, the mean annual inflow will be 4,000 acre-feet, subject to a possible error of about 20 percent.

Table 22.- Computed annual inflow, in acre-feet, to the alluvial valley of San Onofre Creek for the period 1922 to 1952

Water year	Annual inflow	Water year	Annual inflow
1923	1,700	1938	11,100
1924	930	1939	2,800
1925	650	1940	2,400
1926	3,800	1941	12,300
1927	14,800	1942	2,200
1928	630	1943	6,900
1929	1,000	1944	3,200
1930	1,600	1945	2,600
1931	420	1946	1,800
1932	7,400	1947	790
1933	1,100	1948	420
1934	290	1949	680
1935	1,100	1950	380
1936	1,400	1951	250
1937	14,300	1952	7,600

Base period	Mean annual inflow
1922-44	4,200
1934-51	3,800

The maximum and minimum annual inflow to the alluvial valley are given in table 23 for 1 to 6 consecutive years. During the wet year 1926-27 the annual inflow of 14,800 acre-feet exceeded the mean value by 270 percent. The average annual inflow for the wettest 6 consecutive years from 1936 to 1942 amounted to 7,500 acre-feet or 88 percent more than the mean value.

Table 23.- Maximum and minimum annual inflow, in acre-feet, to the alluvial valley of San Onofre Creek for periods of 1 to 6 consecutive years

Length of period	Period	Average annual inflow	Departure from mean annual inflow[a] (in percent)
		Maximum annual inflow	
1 year	1926-27	14,800	270
2 years	1936-38	12,700	218
3 years	1936-39	9,400	135
4 years	1936-40	7,650	91
5 years	1936-41	8,600	115
6 years	1936-42	7,500	88
		Minimum annual inflow	
6 years	1945-51	720	-82
5 years	1946-51	500	-88
4 years	1947-51	430	-89
3 years	1948-51	440	-89
2 years	1949-51	320	-92
1 year	1950-51	250	-94

a/ Mean annual inflow = 4,000 acre-feet (based on the averages for the 1922-44 and 1934-51 base periods).

In the driest 6 consecutive years 1945 to 1951 the average annual inflow declined to 720 acre-feet or 82 percent below the mean annual inflow of 4,000 acre-feet. The minimum inflow occurred in 1950-51 and amounted to only 6 percent of the mean value.

Outflow

On October 18, 1946, a station was established by the Department of the Navy on San Onofre Creek about 0.5 mile upstream from the ocean to measure the surface-water outflow or waste from the alluvial valley. The record of monthly and annual outflow is given in table 24 for the period of record.

Table 24.- Monthly outflow, in cubic feet per second, and annual outflow, in acre-feet, for San Onofre Creek at San Onofre for the period 1946-52

Water year	Month												Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1947	0	0	0	0	0	0	0	0	0	0	0	0	0
1948	0	0	0	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0	0	0	0	0	0
1952	0	0	0	37.1	0	41.9	2.91	0	0	0	0	0	5,030

On the basis of this outflow record, the apparent average annual retention in the alluvial valley amounted to about 500 acre-feet during the 5-year period of 1946-51. During the fairly wet year 1951-52 the apparent annual retention was 2,600 acre-feet.

Las Flores Creek Valley

Piedra de Lumbre and Las Pulgas Creeks, which together form the Las Flores Creek valley, drain about 25 square miles of coastal mountain and foothill area before discharging onto the alluvial deposits of the coastal plain. After crossing the coastal plain, these two streams join to form Las Flores Creek about 0.8 mile from the ocean.

Inflow

The computed annual surface-water inflow to the coastal plain from the 25-square-mile tributary area as derived from the same type of analytical methods used for San Mateo and San Onofre Creek valleys is given in table 25. As indicated in the table, the estimated annual inflow ranged from 26 to 8,100 acre-feet, with a mean annual value of 1,480 acre-feet for the unbiased base period 1922-44 and 1,210 acre-feet for the base period 1934-51. The average of the two base periods gives a mean of 1,340 acre-feet subject to a possible error of about 20 percent.

Table 25.- Computed annual inflow, in acre-feet, to the alluvial valleys of Piedra de Lumbre and Las Pulgas Creeks for the period 1922-52

Water year	Annual inflow	Water year	Annual inflow
1923	310	1938	4,200
1924	160	1939	710
1925	94	1940	610
1926	1,200	1941	4,200
1927	8,100	1942	460
1928	90	1943	2,300
1929	180	1944	840
1930	350	1945	620
1931	54	1946	390
1932	2,600	1947	150
1933	190	1948	69
1934	42	1949	93
1935	270	1950	49
1936	350	1951	26
1937	5,300	1952	2,600

Base period	Mean annual inflow
1922-44	1,480
1934-51	1,210

These data are supplemented by table 26 which gives the extremes of this annual inflow for periods of 1 to 6 consecutive years. The extreme variability of the inflow is shown by the periods of 6 consecutive years for which the average annual inflow ranged from 130 to 2,600 acre-feet; or the departures ranged from plus 94 to minus 90 percent from the mean annual inflow of 1,340 acre-feet.

Table 26.- Maximum and minimum annual inflow, in acre-feet, to the alluvial valleys of Piedra de Lumbre and Las Pulgas Creeks for periods of 1 to 6 consecutive years

Length of period	Period	Average annual inflow	Departure from mean annual inflow[a] (in percent)
		Maximum annual inflow	
1 year	1926-27	8,100	504
2 years	1936-38	4,750	254
3 years	1936-39	3,400	154
4 years	1936-40	2,700	101
5 years	1936-41	3,000	124
6 years	1936-42	2,600	94
		Minimum annual inflow	
6 years	1945-51	130	-90
5 years	1946-51	77	-94
4 years	1947-51	59	-96
3 years	1948-51	56	-96
2 years	1949-51	38	-97
1 year	1950-51	26	-98

a/ Mean annual inflow = 1,340 acre-feet (based on the averages for the 1922-44 and 1934-51 base periods).

Outflow

In order to measure the surface-water outflow from the valley, the Department of the Navy in cooperation with the Geological Survey established a gaging station on Las Flores Creek on April 23, 1951. The monthly and annual outflow for the two water years 1951 and 1952 are given in table 27. Miscellaneous discharge measurements made in the 1952 water year at a culvert under the railroad fill about 1,000 feet south of the gaging station indicated an additional outflow of about 60 acre-feet, which is derived from ground-water overflow. (See section on ground-water outflow and overflow.)

Table 27.- Monthly outflow, in cubic feet per second, and annual outflow, in acre-feet, for Las Flores Creek near Oceanside for the period 1950-52

Water year	Month												Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1951	-	-	-	-	-	-	-	0	0	0	0	0	-
1952	0	.09	.17	14.1	.017	12.6	2.73	.003	0	0	0	0	1,830

On the basis of this very short record, the apparent annual retention from the surface-water inflow to the alluvial deposits of this drainage area amounted to about 26 acre-feet in the 1951 water year and 710 acre-feet in the 1952 water year.

Aliso Creek

Between Las Pulgas Creek and the Santa Margarita River is the Aliso Creek drainage area. In most respects this drainage area is very similar to that for Las Flores Creek valley. About 8.1 square miles of the coastal mountain and foothill areas in the Aliso Creek drainage area are tributary to a minor alluvial plain that extends inland from the ocean about 1.8 miles (pl. 1).

Inflow

The average annual surface-water inflow from this mountain and foothill area to the alluvial plain is estimated to be 270 acre-feet subject, however, to a possible error of about 20 percent. The chronological distribution and magnitude of the annual events should vary directly with the similar data for Piedra de Lumbre and Las Pulgas Creeks.

Outflow

The surface-water outflow wasting into the ocean from this drainage area is not being measured, and no estimate has been made.

GROUND-WATER RESOURCES

By G. F. Worts, Jr.

INTRODUCTION

Camp Pendleton contains four sizable coastal stream basins all of which have been developed for ground-water supply for Camp and irrigation use. These basins are formed in the valleys of the Santa Margarita River, Las Flores Creek, San Onofre Creek, and San Mateo Creek (pl. 1). In addition, there is a very minor coastal stream valley, namely Aliso Creek, which has only one small supply well, and the coastal area between Las Flores Creek and Cockleburr Canyon, which is undeveloped. Because these areas geologically and hydrologically are largely separate, the ground-water resources of each is necessarily treated basin by basin. The order of treatment is according to size of the stream system, as follows: Santa Margarita, San Mateo, San Onofre, Las Flores, and Aliso. In addition, ground water in the coastal intervalley area is discussed.

The evaluation of the ground-water resources of each stream valley is developed through a presentation of the occurrence of ground water, source and movement of ground water, nature and quantity of recharge and discharge, water-level fluctuations and their relation to storage change and to sea-water intrusion, estimates of perennial yield insofar as possible, and the chemical quality of water in the water-yielding deposits and rocks. The quantitative treatment of the various basins is to a large degree limited by the available records of stream runoff, ground-water pumpage, and water-level records. The concepts regarding the basic principles of ground-water occurrence, movement, recharge, discharge, storage, and perennial yield are discussed in the treatment of the lower Santa Margarita River basin; but, except for critical principles, are not repeated in the presentation of the other stream valleys.

Throughout the following sections of the report, references are made to the four basic data appendixes that have been assembled in a separate volume. Data pertaining to wells, their depth, casing size, measuring point for obtaining water-level measurements, etc., are contained in appendix 1, table 1A; cross-indexes of test-well, Camp-supply well, and Geological Survey well numbers are contained in tables 1B and 1C; drillers' logs, test-well logs, and shallow-well logs are presented in appendix 2, tables 2A through 2C; records of water-level measurements in wells are compiled in appendix 3, table 3A; and chemical analyses of stream, well, and ocean waters are contained in appendix 4, tables 4A through 4E.

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THE LOWER SANTA MARGARITA RIVER BASIN

Areal Extent

The areal extent of the lower Santa Margarita River basin is limited principally by the surface extent of the alluvium, channel deposits, and terrace deposits. The upstream end of the basin has been set arbitrarily at De Luz dam site because the design for the proposed dam specifies a clay cutoff wall or dike which would effectively truncate the alluvial deposits at this point. From the dam site the basin extends downstream to the coast--a distance of 11.4 miles. In width, the basin varies from as little as 600 feet at De Luz dam site and Ysidora Narrows to as much as 10,000 feet in Chappo Basin about 1 mile below Basilone Road ford. In surface area the lower Santa Margarita River basin embraces a total of about 5,200 acres, excluding minor tongues of alluvium extending up the small tributary canyons, but including the lagoon area.

It has been indicated that the periods of downcutting and backfilling of the Santa Margarita River have produced wide and narrow sections of alluvial fill along its lower course. The wide sections, in downstream order, have been designated Upper (O'Neill), Chappo (Middle), and Ysidora (Lower) Basins for ease in treatment and for reference. In addition, immediately downstream from Ysidora Narrows and adjoining the Pacific Ocean is the lagoon area which forms a fourth basin. However, owing to problems of sea-water intrusion, this latter basin has never been developed as a source of ground-water supply. Nevertheless, it is a critical segment in the lower Santa Margarita River basin in that it is the connecting link between the Pacific Ocean and the developed basins upstream.

Occurrence of Ground Water

The water-bearing properties of all formations and deposits in the lower Santa Margarita River basin have been described in the section on geology. From this discussion and from the distribution of wells shown on plate 1, it is readily apparent that the alluvium is the principal source of ground-water supply. Minor amounts of water are contained in the bordering terrace deposits. The San Mateo formation, which locally is in contact with the alluvium in the lagoon area, yields water of poor quality but in fair quantity to test wells 11/5-4R1 and 11/5-9J1.

Beneath the basin floor these deposits are largely saturated and form a relatively large ground-water body. This water body extends continuously from the Pacific Ocean upstream to the canyon reaches of De Luz Creek and the Santa Margarita River where the deposits containing the water body thin rapidly upstream. The sides and bottom of the water body and basin are formed, in downstream order, by the basement complex, the La Jolla formation, and the San Onofre breccia. Relatively minor amounts of water of poor quality are contained in the La Jolla formation. Thus, that formation does not form a tight container; rather, the La Jolla can transmit small quantities of water to the basin. On the other hand, the basement complex and the San Onofre breccia form an essentially watertight seal.

It has been demonstrated that the alluvium in the lower Santa Margarita River basin in the downstream one-half of its extent is divisible vertically into two stratigraphic units whose distinction in well logs becomes progressively more apparent toward the coast. These two units have been designated the upper member, which is predominantly fine grained, and the lower member, which is predominantly coarse grained.

The hydrologic characteristics of the upper member are particularly significant in lower Chappo Basin, Ysidora Basin, Ysidora Narrows, and the lagoon area in that the member forms a semiconfining to confining blanket to water contained in the underlying highly permeable and productive lower member, is a restraining bed to seepage loss from streams and infiltration of rainfall, but locally contains a shallow semiperched water body whose water-level fluctuations are somewhat distinct from those in the lower member. This area is referred to loosely as the area of confinement, even though it is known that the confinement in most places is poor. Furthermore, the upstream edge of the area of confinement is irregular and indistinct because it is gradational from coarse upstream to fine downstream and has been established by the study of well logs and water-level fluctuations. These data indicate that the upstream edge is approximately along a line near well 10/5-13J1 (pl. 4). The total surface extent of the area of confinement above the Ysidora stream gage is roughly 2,900 acres.

Adjoining the area of confinement and extending upstream into the canyon reach, the upper member of the alluvium becomes progressively coarser until near well 10/4-7H1 it can not be distinguished from the lower member. Here the water body occurs under water-table conditions. In this area any recharge by seepage loss from the Santa Margarita River, infiltration of rainfall, and discharge from Lake O'Neill is able to percolate readily downward to the water table at any time the basins are not full. Because seepage losses have been measured from Upper Basin as far downstream as Ysidora gage, the area of confinement and the area where recharge occurs overlap considerably.

Source and Movement of Ground Water

Features Shown by Water-Level Contour Maps

Water-level contour maps, such as plates 21 and 22, are constructed by connecting points of equal head in the same ground-water body with a continuous line. The datum used is usually mean sea level and the points used for control are the altitudes of the "static" or nonpumping water levels in wells tapping the common water body. Where the control is good the contour lines of equal elevation are solid; where poor, the lines are dashed. No distinction is made between contour lines drawn on the surface of the water table and the lines connecting points of equal pressure head in the area of confinement. Where there are two water bodies, such as the shallow semiperched body and the deep main water body on the east side of Ysidora Basin, separate sets of water-level contours can then be drawn on each (pls. 21 and 22).

Water, whether it is on the surface or underground, is always in the process of seeking or moving toward the place of lowest head which for ground water may be toward a point of natural ground-water discharge, the pumping level in a single well, or a general area in which the levels have been depressed by large pumping withdrawals. It follows logically then that ground water is moving down gradient from a source or sources of recharge toward points of discharge. The direction of movement is always normal to the water-level contours, and of course, from a higher to a lower contour.

Plates 21 and 22 show water-level contours for all the stream basins on Camp Pendleton for October 1951 and the spring of 1952--the lowest and nearly the highest levels of record respectively. These contours are drawn on the main water body for each of the basins and on the shallow water body in Ysidora Basin. In addition, so that the position of the water levels may be viewed in their vertical aspect both in relation to the containing deposits and to sea level, water-level profiles on the deep water bodies for the same two periods are shown on geologic sections E-E' and L-L' through P-P' (pls. 4, 6, 7, and 8).

In the lower Santa Margarita River basin, the water-level contours for March 1952 indicate that ground water is moving downstream from above De Luz dam site to the lagoon area; for October 1951 they indicate that ground water is moving downstream to mid-Ysidora Basin, but below is moving inland from the lagoon area through Ysidora Narrows to Ysidora Basin. In accordance with the general concepts of ground-water movement presented above, the sources of ground-water replenishment or recharge are indicated to be principally from the Santa Margarita River and by underflow beneath the canyon reach of the river. During some periods, such as in October 1951 when water levels in Ysidora Basin and Ysidora Narrows were drawn down to and below sea level, a wholly undesirable form of movement and recharge takes place--sea-water intrusion.

Movement from Upper Basin to Ysidora Basin

The water-level contours show that the gradient in Upper Basin averaged about 15 feet per mile in October 1951 and about 11 feet per mile in March 1952 as compared to average gradients in the canyon upstream of 20 and 23 feet per mile, respectively. The downstream decrease in gradient is due to a substantial increase in the cross-sectional area which more than compensates for the relatively small decrease in permeability. At the lower end of Upper Basin the gradient again steepens as the cross-sectional area decreases upstream from Basilone Road. Here the gradient was 30 feet per mile in October 1951 and 15 feet per mile in March 1952.

In Chappo Basin the cross-sectional area increases substantially and the water-level gradient flattens accordingly. Between wells 10/4-18R2 and 10/5-23J3 the gradients in October 1951 and March 1952 were 7 and 10 feet per mile, respectively. The contours as drawn for October 1951 suggest that there is some seepage from the terrace deposits around the north side of the basin and a minor amount from the tributary fan in the vicinity of well 10/4-19L1.

The gradient again steepens as the cross-sectional area decreases in the restriction between Chappo and Ysidora Basins. At well 10/5-26L1 the deposits have remained saturated historically within 6 to 14 feet of the land surface. Near well 10/5-26L1 the gradients in October 1951 and March 1952 were 20 and 16 feet per mile, respectively.

Movement in Ysidora Basin, Ysidora Narrows,
and the Lagoon Area

<u>The deep water body</u>.--The water-level contour maps show two distinctly different conditions for October 1951 and March 1952 (pls. 21 and 22). In March the hydraulic gradient was through Ysidora Basin, the narrows, and the lagoon area; between wells 10/5-35K1 and 11/5-2E1 the gradient was 6.3 feet per mile, between wells 11/5-2E1 and 11/5-10B1 it was 3.2 feet per mile, and between wells 11/5-10B1 and 11/5-9J1 it was 3.0 feet per mile. Because the water levels in March 1952 were 5 to 9 feet lower than the peak water levels in March 1932 the gradient too was somewhat less. In March 1932 the gradient through the narrows was about 7 feet per mile.

On the other hand, in October 1951 the hydraulic gradient sloped inland from the coast to a residual pumping depression near the south end of Ysidora Basin. Between wells 11/5-9J1 and 11/5-10B1 the reversed or inland gradient was 1.3 feet per mile and between wells 11/5-10B1 and 11/5-2E1 it was 4.3 feet per mile. This reversed gradient was brought about by a combination of dry years of little recharge and heavy pumping withdrawals from Ysidora Basin. The hydrograph for well 11/5-2E2 (pl. 25) suggests that during the 4-year period 1948-51 and possibly earlier the "static" water levels were drawn down to and below sea level. Prior to this period, the hydrographs show that the "static" levels have consistently remained above sea level and for the greater part of the record, 1920 to 1944(?), were more than 10 feet above.

The shallow water body.--Plates 21 and 22 also show the relation between water-level contours drawn on the shallow and deep water bodies in Ysidora Basin for October 1951 and March 1952. With regard to ground-water movement in the shallow water body, a study of the contours indicates that at the end of the prolonged dry period ending in the fall of 1951, the shallow water was moving westward across Ysidora Basin toward the river. This movement indicates that on the west side of the basin near the river the shallow water is able to percolate downward to recharge the deep water body. Also, the contour map for October 1951 shows that shallow water was moving inland through Ysidora Narrows to Ysidora Basin; it may also have been recharging the deep water body in Ysidora Narrows.

Following the winter recharge in 1952, the shallow water contours for March show movement eastward away from the river indicating that the shallow water body was being recharged from that source. Also, the contours show that seepage from a flooded area at the southeast end of the basin supplied considerable recharge to the shallow water body. At this same time, the normal seaward movement of the shallow water was reestablished.

Recharge to Ground Water

In the lower Santa Margarita River basin recharge to ground water takes place principally by seepage loss from the river, with lesser increments supplied by ground-water inflow moving into the basin beneath the river channel, by returned treated sewage effluent, and by infiltration of rainfall on the basin floor. The estimates of recharge from these four sources are discussed separately in the following sections of the report. Also discussed are the diversions from the river to O'Neill Lake which bear a direct relation to the data on surface-water inflow and outflow as well as to the estimated recharge to ground water.

Seepage Loss from the River

Between De Luz dam site and the Ysidora stream gage the Santa Margarita River flows across the ground-water basins for a distance of 9 miles. Within this reach seepage loss from the river percolates downward through the zone of aeration in the channel deposits and alluvium to the water table or zone of saturation. The deposits in Upper Basin and the upper part of Chappo Basin are coarse and are capable of transmitting water from the stream most readily. Downstream as the deposits become finer, their ability to transmit water decreases.

The magnitude of the seepage losses is limited by the time distribution and amount of runoff, by the ability of the deposits to transmit water away from the river bed, and by the storage space available in the channel deposits and alluvium at times when runoff occurs.

The records of water-level fluctuations in wells show that there is a rapid rise in water levels accompanying runoff in the river. Substantial runoff has almost always been of long enough duration so that the water levels have risen to about their highest stage in such years. This has been possible because, as the historical records show, the water levels have never been depressed more than 12 feet in Upper Basin, 20 feet in the upper part of Chappo Basin, nor more than 29 feet in Ysidora Basin (pl. 4). Thus, the high water levels in the basins have been a limiting factor to recharge rather than the ability of the deposits to transmit recharge from the river. However, should storage ever be depleted to the point where water levels are several tens of feet below the land surface, then during a period of runoff, the permeability of the deposits might become a limiting factor in that short-term runoff could not be absorbed into the deposits before it reached the sea.

Except for minor gains from small intervening tributaries and to losses due to diversion and storage in O'Neill Lake, the seepage loss is essentially the mathematical difference between the discharge at De Luz dam site and the discharge at Ysidora gaging station. The contribution from the minor intervening tributaries is small and occurs only during years of above-average rainfall. During the period of Camp tenure, runoff from the tributaries probably occurred only in the 2 water years 1943 and 1952. The amount contributed probably falls within the limits of error of computed discharge at De Luz dam site and measured discharge at Ysidora gaging station, and therefore it is not estimated.

O'Neill Lake--diversions and losses.--The diversions to O'Neill Lake take place through O'Neill Ditch, which has its intake about 1 mile below De Luz dam site. A gage on the ditch measures the diversions, which are either discharged into the lake or are allowed to bypass the lake and return through a ditch to the river near well 10/4-7R1 (pl. 28). Table 28 shows the diversions through O'Neill Ditch for the period 1925-52.

Table 28.- Measured diversions, in acre-feet, from the Santa Margarita River to O'Neill Ditch in the water years 1925-52

[From published records of U. S. Geological Survey, except as noted]

Year ending Sept. 30	Diversion	Year ending Sept. 30	Diversion	Year ending Sept. 30	Diversion
1925	a 1,526	1935	1,270	1945	2,280
26	a 1,204	36	2,340	46	3,020
27	a 2,275	37	2,470	47	2,100
28	a 1,617	38	3,340	48	4,940
29	a 2,564	39	2,100	49	4,340
1930	a 3,902	1940	1,080	1950	b 1,950
31	2,540	41	1,800	51	ab 1,480
32	3,050	42	1,640	52	ab 185
33	2,200	43	1,160		
34	2,490	44	4,940		
Total					65,803
28-year average					2,350

a/ From Public Works Office records.

b/ An additional 187, 901, and 997 acre-feet discharged in 1950, 1951, and 1952, respectively, into the lake from sewage treatment plant 1.

O'Neill Lake occupies a natural depression, the lower end of which has been dammed with an earthen structure; when full, it has an area of about 135 acres and a capacity of 1,440 acre-feet. This structure was built by the Rancho Santa Margarita largely for the purpose of temporary storage to irrigate farm lands in Chappo Basin. Since the period of Camp tenure, the lake has been used as a recreation area for boating.

The bottom of the lake is silted so there probably is very little loss by seepage through the sides or bottom. The water-level contours suggest no appreciable recharge from this source. However, the Camp has kept the lake essentially full, so there is some loss by evaporation from the lake surface. The evaporation loss is equal to the seasonal evaporation minus the seasonal rainfall. The U. S. Army Engineers (1949, appendix 6, p.22) have estimated the average yearly net loss from the proposed De Luz dam reservoir to be 3 feet annually by estimating the average evaporation to be 4 feet and the average rainfall to be 1 foot. This annual net-loss estimate can be applied to O'Neill Lake. The average annual loss, then, is the area of 135 acres times the net loss of 3 feet or about 400 acre-feet per year.

Estimated seepage loss.--Thus, by subtracting the annual outflow recorded at Ysidora gage and the evaporation loss from O'Neill Lake from the computed annual inflow at De Luz dam site, the yearly recharge by seepage loss from the river can be estimated. Table 29 shows the yearly recharge to ground water in the lower Santa Margarita River basin in the years of Camp tenure 1941-42 through 1951-52.

Table 29.- Estimated seepage loss, in acre-feet, from the Santa Margarita River in the water years 1942-52

Year ending Sept. 30	Computed inflow a/	Measured outflow b/	Difference	Estimated evaporation loss from O'Neill Lake c/	Estimated seepage loss d/
1942	21,600	16,930	4,670	420	4,250
43	77,900	74,270	3,630	340	3,300 - 40%
44	32,800	27,800	5,000	390	4,600
45	24,800	20,270	4,530	410	4,100
1946	16,800	11,680	5,120	440	4,700
47	12,000	6,930	5,070	440	4,650
48	7,240	562	6,678	470	6,200
49	6,780	479	6,301	450	5,850
50	4,510	0	4,510	460	4,050
1951	2,950	0	2,950	450	2,500 - 90%
52	61,800	47,640	14,160	e 185	14,000 f (10,000)
Total	269,180	206,561	62,619	4,455	58,200
11-year average	24,200	18,700	5,700	450	5,300

a. From table 9.
b. From table 11.
c. By diversion and storage in O'Neill Lake. Annual evaporation loss estimated to be 4 feet less annual rainfall times area of 135 acres.
d. Rounded to nearest 50 acre-feet.
e. Total diverted during year.
f. Possible seepage loss for 1952 as suggested by data in table 39 and following pages.

Table 29 shows that under conditions during Camp tenure the seepage losses range from 90 percent of the inflow during dry years, such as 1949-50, to as little as 4 percent of the inflow during wet years, such as 1942-43, at the end of a wet period; but may be as much as 16 percent (if seepage loss 10,000 acre-feet) to 23 percent (if seepage loss 14,000 acre-feet) of the inflow during a wet year, such as 1951-52, following relatively heavy pumpage and ground-water depletion during a dry period. Except for the dry years, the table does not indicate what the maximum seepage losses from the river would be under similar conditions of runoff if the water levels in the basins were depressed several tens of feet below the riverbed to permit larger losses to occur. The seepage loss in 1951-52, which is more than twice that of any previous year, suggests what the magnitude might be if water levels were depressed appreciably as they were in the fall of 1951 prior to a year of large and well-distributed runoff (pl. 21). The water levels in the basins were drawn down 10 to 25 feet prior to the runoff in 1951-52, and were nearly fully restored by March 1952. Thus, the bulk of the recharge occurred between Dec. 30, 1951, and March 1952.

The daily discharge rates in 1951-52 for the Fallbrook and Ysidora gages, which will be published in the series of U. S. Geological Survey Water-Supply Papers entitled, "Surface water supply of the United States [1952] Part 11: Pacific Slope basins in California," show no runoff at Ysidora gage until January 13, 1952. At the Fallbrook gage, which does not measure all the inflow at De Luz dam site, the daily discharge on December 30 was 800 second-feet, and on December 31 was 400 second-feet indicating that the alluvium downstream from the gage absorbed all the runoff at this high rate and none reached Ysidora gage. Of course, some of this recharge took place in the 7.5-mile narrow canyon reach above De Luz dam site.

With regard to measured seepage losses between De Luz dam site and the Ysidora gage during periods of low flow, sets of miscellaneous measurements made within a few hours of each other on the same day show the magnitude of the losses. The measurements in the period February to June 1952 were made following periods of substantial runoff when the basins were nearly full and therefore do not indicate the maximum rates, but those in December 1952 were made before any substantial runoff occurred. Selected measurements at the various sites are shown in table 30.

Table 30.- Miscellaneous low-flow measurements, in second-feet, on the Santa Margarita River in 1952 and 1953

(Measurements by Office of Ground Water Resources, Camp Pendleton)

Date 1952	De Luz dam site	Basilone Road	Ysidora gage[a]	Date 1952	De Luz dam site	Basilone Road	Ysidora gage[a]
Feb. 5	36.8	--	29.8	May 16	21.8	--	7.2
11	30.5	31.7	24.6	27	11.2	--	1.8
13	24.4	21.6	15.6	June 3	9.2	--	2.2
21	17.6	14.9	7.3	10	5.3	--	1.4
28	12.3	7.6	5.4	Dec. 3	45.6	0	0
Mar. 10	159.6	--	172.2	5	18.4	1.0	0
21	196.2	--	207.2	12	9.1	0	0
27	106.7	--	95.0	19	14.0	4.8	0
Apr. 3	47.9	--	48.9	22	36.9	47.0	0
17	60.0	--	54.3	31	14.7	17.1	0
29	39.9	--	42.2	1953			
				Jan. 7	247.0	220.3	0

a. Measuring station about 3,000 feet downstream from gage.

Low-flow seepage losses measured in the winter and spring of 1952 by the Office of Ground Water Resources indicate that as much as 10 second-feet was lost between De Luz dam site and near the Ysidora gage. Some gains are also shown during this period, probably ground-water discharge from Upper Basin, are indicated by the few measurements at Basilone Road crossing.

In December 1952 the maximum loss of 47 second-feet is indicated between Basilone Road and the Ysidora gage. The one measurement for January shows over 240 second-feet of seepage loss between De Luz dam site and near the Ysidora gage. However, it is not known whether the measurements were made during a rising river stage. Nevertheless, the measurements indicate that relatively large losses can and do take place.

One set of measurements made by the Geological Survey on Jan. 24, 1952, showed the following discharges in second-feet on the river: Near Navy Hospital, 66.8; Basilone Road, 71.3; near well 10/5-26L1, 67.9; and Ysidora gage, 56.7. These measurements, in addition to showing an over-all net loss, show that a loss of 11 second-feet took place in Ysidora Basin. Thus, all the miscellaneous measurement data show that seepage losses may occur at least as far downstream as Ysidora gage.

Deep Penetration of Rain

Rain falling on Upper, Chappo, and Ysidora Basins, which have a total area of about 4,500 acres, is consumed by the native vegetation, is evaporated directly into the atmosphere, satisfies the soil-moisture requirement, and the residual seeps downward to ground-water storage. Blaney (1933) in his work in Ventura County, which is a coastal area similar in climate to Camp Pendleton, determined by field studies that in general when the yearly precipitation is less than 18 inches on brushlands, less than 15 inches on grasslands, or less than 12 inches on bare or irrigated lands, there is essentially no deep penetration of rain to ground water. It is essentially all utilized by evapotranspiration and in making up the soil-moisture deficiency.

Since the Navy acquired the Camp properties in 1942, the surface of the basin has been largely grass covered except for about 500 acres of phreatophytes which thrive on rainfall and ground water. In addition, about 500 acres on the east side of Ysidora Basin, underlain by relatively impervious deposits, would probably provide little effective rainfall infiltration to the deep-water body. Thus it is suggested that for years in which the precipitation was less than 15 inches no surplus penetrated to ground water beneath the grasslands, which cover 3,500 acres. In the area of phreatophytes, it is assumed that all rainfall is consumed by the plants. For years 1931-1942, the Rancho records show that a total of about 1,000 acres in Chappo and Ysidora Basins was irrigated. Also, it is estimated about 1,000 acres of land was occupied by phreatophytes which consumed essentially all the rainfall. It is suggested that the yearly precipitation in excess of 12 inches on the irrigated lands penetrated to ground-water storage and that the precipitation in excess of 15 inches on the remaining 2,000 acres of grasslands penetrated to ground water.

The rainfall records used are those at San Clemente and Oceanside which are probably on the correct order of magnitude for the lower segments of all the coastal valleys on the Camp. Because of the proximity to the bordering hills, it is probable that the precipitation at the upper ends of the valleys would be somewhat greater than along the coast, but probably not enough to change materially the rough estimates of infiltration derived below.

Table 31 shows the composite record by water years of the precipitation at San Clemente, 1930-31 through 1944-45; and Oceanside, 1945-46 through 1951-52; and the estimated deep penetration over the 4,000 acres of the basin from De Luz dam site to Ysidora gaging station, excluding the 500 acres in the eastern part of Ysidora Basin underlain by impermeable deposits.

Table 31.- Estimated yearly recharge to ground water, in acre-feet, by deep infiltration of rain in the lower Santa Margarita River basin in the water years 1931-52

Year ending Sept. 30	Rainfall [a] (inches)	Recharge to ground water [b] (acre-feet)	Year ending Sept. 30	Rainfall [a] (inches)	Recharge to ground water [b] (acre-feet)
1931	12.33	30	1942	10.59	0
1932	16.29	600	1943	17.93	900
1933	10.23	0	1944	12.90	0
1934	8.15	0	1945	11.16	0
1935	17.93	1,000	1946	9.40	0
1936	10.63	0	1947	8.83	0
1937	17.76	900	1948	6.30	0
1938	15.92	500	1949	8.27	0
1939	13.80	100	1950	7.50	0
1940	11.42	0	1951	7.08	0
1941	26.17	3,000	1952	19.32	1,300
Total				279.91	8,300
22-year average, 1931-52				12.73	375
17-year base period 1935-51				12.56	375
11-year average, 1942-52				10.84	200

a. Composite record from San Clemente and Oceanside.
b. Period 1931-41, on 1,000 acres of irrigated land and estimated 2,000 acres of grassland; 1942-52, on 3,500 acres of grassland; estimate rounded to nearest 100 acre-feet, except when less than 100.

During the period 1942-52, the total estimated recharge was about 2,200 acre-feet and occurred in the two wet years 1943 and 1952. Because of the numerous dry years in the period, the average of about 200 acre-feet per year is lower than it would be for a representative or average base period. If the rainfall data are applied to the existing acreages of grasslands, 3,500 acres, for the base period 1935-51, such as was used in the section on runoff, the average annual expectable recharge would be on the order of 400 acre-feet. However, the average rainfall for the period was only 12.56 inches and no deep penetration would have occurred except in the years when the rainfall was at least 2.5 inches greater than the average for the period.

Underflow at De Luz Dam Site

The quantity of water moving as underflow through the alluvium at De Luz dam site is roughly computed herewith to show the magnitude of the continuous recharge moving into the Upper Basin during the year. However, if the proposed dam and cutoff wall are constructed to bedrock, then this underflow will be eliminated. The amount of underflow is determined by use of Darcy's law, which may be expressed by the formula:

$$Q = PIA$$

in which $\underline{Q}$ is the quantity of water in gallons per day, $\underline{P}$ is the permeability coefficient in gallons per day per square foot, $\underline{I}$ is the hydraulic gradient in feet per mile, and $\underline{A}$ is the cross-sectional area in square feet (Wenzel, 1942, p. 3-4). The permeability coefficient used is 4,500 gallons per day per square foot, obtained from the aquifer-performance test run on well 10/4-7H1 and from data on well 10/5-5H1 (p. 64). The deposits have been saturated to the land surface at the dam site and immediately upstream and downstream during this investigation, and reportedly have always been saturated. Thus, the hydraulic gradient has remained constant and essentially the same as the surface gradient of the channel or 20 feet per mile. The cross-sectional area, which is shown in geologic section K-K' (pl. 5), is well controlled by data obtained from the core holes drilled at the dam site by the U. S. Army Engineers, and is about 40,000 square feet.

The underflow moving downstream by the De Luz dam site, then, is computed as follows:

$$Q = \frac{4,500 \times 20 \times 40,000}{5,280}$$

$$Q = 680,000 \text{ gallons per day}$$

This is equivalent to a constant underflow of about 1 second-foot or about 700 acre-feet per year. Thus, each year this quantity is estimated to be the continuous recharge moving through the alluvium by the De Luz dam site to Upper Basin.

Treated Sewage Effluent

The supply wells in the lower Santa Margarita River valley supply the Camp areas along the river, on the hills to the east, and on the coastal terrace west of the river. A large part of the pumpage eventually reaches six sewage-treatment plants. Treated sewage effluent from three of the plants is returned to the valley in as many different places--into O'Neill Lake, into the river at the lower end of Chappo Basin in the SW¼SE¼ sec. 23, T. 10 S., R. 5 W., and into a small creek in the SW¼SE¼ sec. 36, T. 10 S., R. 5 W. Plant 1 has been returning effluent to O'Neill Lake since August 1950, Plant 2 has been returning effluent to Ysidora Basin only since July 1952, and Plant 3 has been returning effluent to lower Chappo Basin since December 1943. Plants 1 and 2 formerly discharged the effluent into the San Luis Rey River drainage. Plants 4 to 6 at Camp Del Mar along the coast discharge partially treated effluent into the sea through outfall sewers. Table 32 shows the amount of treated-sewage effluent that has been returned to the lower Santa Margarita River valley.

Table 32.- Treated sewage effluent, in acre-feet, returned to the lower Santa Margarita River valley in the water years 1944-52

Year ending Sept. 30	Effluent in acre-feet												
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Plant 1 (discharge to O'Neill Lake)													
1950	-	-	-	-	-	-	-	-	-	-	101	86	187
51	82	81	62	62	56	76	68	85	85	86	91	67	901
52	85	81	80	85	72	63	68	89	92	89	91	102	997
Total													2,085
Plant 2 (discharge to Ysidora Basin)													
1952	-	-	-	-	-	-	-	-	-	48	62	63	173
Plant 3 (discharge to Chappo Basin)													
1944	-	-	25	20	16	20	19	21	24	27	26	28	226
45	30	30	31	29	28	35	34	34	34	-	-	-	a 370
46	-	-	-	-	-	29	28	30	33	34	25	22	a 340
47	25	28	24	27	25	28	26	27	32	36	33	34	345
48	36	38	37	39	39	44	38	44	43	43	40	37	478
1949	37	38	39	39	37	41	42	38	42	41	42	39	475
50	36	36	38	40	37	40	38	42	41	42	44	37	471
51	39	37	40	42	41	46	47	49	51	53	50	43	538
52	50	43	46	51	46	54	53	54	59	58	58	60	632
Total													3,875
Grand total													6,133

a. Includes estimates for missing record.

Thus, the total effluent since December 1943 has been slightly more than 6,000 acre-feet. With all three plants returning effluent to the lower Santa Margarita River valley during the latter part of 1952, and with the discharge of Plant 2 based on its rate for the entire year, the annual return is now on the order of 2,000 acre-feet per year.

The percentage of the effluent that returns to ground-water storage from all three plants can not be accurately determined. Plant 1 discharges into a small pond, then into a creek that drains into O'Neill Lake where a part is consumed by evaporation. Because this evaporation has already been deducted from the seepage-loss estimates, most of the effluent discharged in 1950-52, or its equivalent volume in the lake, was returned to ground water by spill into Upper Basin and is included in the estimate of total recharge. Plant 2 discharges into the head of a small creek, and relatively large evaporation and transpiration losses occur along the stream bed and in aeration ponds, so the return to ground water is negligible. Plant 3 discharges directly into the bed of the Santa Margarita River where most of the effluent returns to ground-water storage. Thus, during the years of Camp tenure, about 5,900 acre-feet, or the discharge from Plant 3 plus most of that from Plant 1 in the years 1951-52, has been returned to ground-water storage. That part which is lost through evapotranspiration is included in the section on discharge.

The Navy has shown good foresight and planning by returning at considerable expense the treated sewage effluent to the valley from which it is pumped. From the present points of discharge, it would take little extra construction to extend the facilities of Plants 1 and 2 to permit direct spreading in or near the riverbed. In this connection, it is understood that plans are now under consideration to return treated sewage from Camp Del Mar to the Santa Margarita River at a point about 3,000 feet downstream from the Ysidora gage. In 1951, the discharge of Plants 4, 5, and 6 totaled 600 acre-feet. Thus, there is a potential yearly return at the 1951-52 rate of about 2,900 acre-feet, or roughly 50 percent of the pumpage for Camp use.

It should be pointed out that if the effluent from all the plants is returned as recharge, there is some possibility of causing a gradual deterioration in the chemical quality of the ground waters in the basins. Constituents such as nitrate and boron and total solids are likely to increase steadily by this means of "recirculating" ground water.

Total Recharge

The total recharge to ground water in the lower Santa Margarita River valley is estimated for the 11-year period 1942-52 of Camp tenure. It is the sum of the estimated forms of recharge by seepage loss, rainfall infiltration, ground-water underflow at De Luz dam site, and returned treated sewage effluent from Plants 1 and 3. The estimated total yearly recharge is shown in table 33.

Table 33.- Estimated total recharge, in acre-feet, to the lower Santa Margarita River basin in the water years 1942-52

Year ending Sept. 30	Total a/ recharge	Year ending Sept. 30	Total a/ recharge
1942	5,000	1948	7,400
1943	4,900	1949	7,000
1944	5,500	1950	5,400
1945	5,200	1951	4,600
1946	5,700	1952	17,500 b(13,500)
1947	5,700		
Total			73,900
11-year average			6,700

a. Rounded to nearest 100 acre-feet.

b. Assuming seepage loss in 1952 to be 10,000 instead of 14,000 acre-feet. See data in table 39 and following pages.

Table 33 shows that the estimated recharge remained fairly constant between 5,000 and 6,000 acre-feet in the years 1942-47, increased somewhat in 1948, then declined to only about 4,600 acre-feet in 1951, and finally in 1952, the first wet year in 9, the estimated recharge was more than 17,000 acre-feet (if seepage loss 14,000 acre-feet) or more than 13,000 acre-feet (if seepage loss 10,000 acre-feet). The progressive depletion of ground-water storage during the years 1944-51 provided space for the recharge made available by the large runoff. The comparison of the recharge by seepage loss from streams with the total recharge suggests that for the period 1942-52, seepage loss has been about 80 percent of the total. Because of the several estimates involved in the computations for runoff at De Luz dam site, for deep infiltration of rain, and for evaporation losses from O'Neill Lake, errors in which may tend to balance one against the other, the average yearly recharge for the 11-year period is believed to have been between 6,000 and 7,000 acre-feet. This is the actual estimated recharge under the physical conditions prevailing in 1942-52; it is not the maximum potential recharge. With cyclic storage operation in the basin, the recharge can be increased substantially by providing storage space to accommodate larger seepage losses from the river.

Ground-Water Discharge

Discharge of ground water in all the principal stream valleys on the Camp takes place by artificial and natural means. The artificial discharge is man made and is hereinafter referred to as ground-water withdrawals by pumping or simply as pumpage. The natural discharge includes evapotranspiration by native phreatophytes (water-loving plants) and by ground-water overflow and outflow to the sea. These two principal forms of discharge are treated separately below.

Pumpage

Rancho Santa Margarita.--The records of well logs in the lower Santa Margarita River basin indicate that the first irrigation wells on the Rancho Santa Margarita were drilled in 1912 and 1913 in Ysidora Basin (table 1A). It is believed that additional wells were first drilled in Chappo Basin in the early twenties although some may have been drilled earlier. Most of these old wells were destroyed during periods of flood either by sanding in or principally by being washed out. Records of pumpage for these early years are not available. However, shortly after litigation started between the Rancho Santa Margarita and Vail Ranch, records of pumpage and all records of stream diversion of the Santa Margarita River were maintained. Most of these records were started in 1924.

Notes found in the Public Works Office indicate that from 1924 to 1936 a yearly average of about 1,000 acres, 500 each in Ysidora and Chappo Basins, was irrigated from wells, and about an additional 500 acres was irrigated in Chappo Basin by gravity flow from O'Neill Lake. For the lands irrigated from wells, it was estimated by the ranch that an average of about 1,700 acre-feet was pumped for application on various crops. Records are available showing the combined total river diversions to O'Neill Lake and estimated pumpage for the period 1924 to February 1942 when the U. S. Navy acquired the Rancho. An estimate of the pumpage can be obtained by subtracting the river diversions (table 28) from this total. Table 34 shows the yearly pumpage by water years for the period 1925-41. The period October 1941 to February 1942 is shown with the Camp pumpage (table 35).

Table 34.- Total pumpage, in acre-feet, for irrigation use by the Rancho Santa Margarita in the water years 1925-41

[From records at the Public Works Office]

Year ending Sept. 30		Year ending Sept. 30		Year ending Sept. 30	
1925	1,900	1931	1,920	1937	1,250
1926	1,730	1932	1,750	1938	2,080
1927	1,550	1933	1,900	1939	2,550
1928	1,960	1934	1,890	1940	2,450
1929	2,000	1935	1,730	1941	2,840
1930	1,550	1936	1,900		

Total	32,950
17-year average	1,940

For the period 1925-37 the table shows a range in pumpage for irrigation of from 1,250 to 2,000 acre-feet, which averages slightly more than 1,700 acre-feet per year. For the period 1938-41 the range is from 2,080 to 2,840 acre-feet, which averages over 2,400 acre-feet per year. This increase was due to the additional 1,000 acres of land on Stuart Mesa placed under irrigation in 1938 and to an additional 600 acres of land on the coastal terrace south of the river placed under irrigation in 1939.

No estimates of pumpage are available for the cattle, which was the primary business of the Rancho. However, at the present time some 15,000 to 20,000 animal units of sheep and over 1,000 animal units of cattle are grazed on the Camp. Stock water is obtained from several windmill wells, from the streams during periods of flow, and occasionally from irrigation or Camp supply wells. The total pumpage for stock use on the Camp, however, probably does not exceed 100 acre-feet per year.

Camp Pendleton.--Records of pumpage in the lower Santa Margarita River basin that were maintained by the Rancho Santa Margarita have been continued by Camp Pendleton. These records include pumpage for Camp use, for irrigation use on Stuart Mesa and the terrace to the south, for the U. S. Navy Hospital, for Camp De Luz, and for the Fallbrook Naval Ammunition Depot. The latter two are upstream from the lower Santa Margarita River basin.

Wells that are or have been used for Camp supply are: 10/4-7R1, 10/4-18E1, 10/4-18M1, 10/5-13K1, 10/5-14P1, 10/5-23J1, 10/5-24H1, 11/5-2A1, 11/5-2F1 (in small part), and 11/5-2K1. Wells that are or have been used for irrigation are: 10/5-35K1, 11/5-2D1, 11/5-2E1, and 11/5-2F1 (largely). One well, 10/4-5D1, and its predecessor, well 5D2 (destroyed), supplies the U. S. Navy Hospital. Well 9/4-14H1 supplies the Naval Ammunition Depot (pl. 1) and is an infiltration tunnel or gallery constructed beneath the Santa Margarita River channel. The records of pumpage obtained from the Public Works Office are shown in table 35 by well, basin, and use for the water years 1942-52.

Table 35.- Ground-water pumpage, in acre-feet, from the lower Santa Margarita River basin for Camp and Irrigation use in the water years 1942-52

(Partial subtotals or totals enclosed by parentheses)

Basin and well	1941-42	1942-43	1943-44	1944-45	1945-46	1946-47
Camp use						
Upper Basin						
10/4-5M1, 2	81	(a)	72	402	423	410
7M1	(a)	(a)	164	684	553	411
Subtotal	(81)	(a)	(235)	1,086	976	821
Chappo Basin						
10/4-18[illegible]1	(a)	(a)	291	1,139	501	441
18N1	(a)	(a)	86	287	599	522
10/5-13M1	(a)	(a)	171	514	739	612
14F1	(a)	(a)	(a)	(a)	2	3
23J1	-	-	-	-	-	-
24H1	-	-	-	-	-	-
Subtotal	(a)	(a)	(548)	(1,940)	1,841	1,578
Ysidora Basin						
11/5- 2A1	151	(a)	221	773	612	732
2E1	(a)	71	39	13	0	0
Subtotal	(151)	(71)	(260)	786	612	732
Total Camp use	b 800	b 3,000	b 3,493	3,792	3,429	3,131
Irrigation use						
Ysidora Basin						
10/5-35M1	9	(a)	(a)	(a)	(a)	(a)
11/5- 2M1	542	592	645	742	1,071	1,097
2L1	536	731	686	669	1,090	873
2N1[c]	994	819	528	145	142	173
Total irr. use	2,081	b 2,359	(1,859)	(1,556)	(2,303)	(2,143)
Subtotal for Ysidora Basin	(2,232)	(2,430)	(2,119)	(2,342)	(2,915)	(2,875)
Grand total	b 2,881	b 5,359	b 5,352	(5,348)	(5,732)	(5,274)
Fallbrook Naval Ammunition Depot						
9/4-14[illegible]1	(a)	12	119	60	68	42
Camp De Luz						
9/4-[illegible]	(a)	(a)	(a)	21	14	6

a. Pumpage records not available.
b. From records at Public Works Office.
c. Supplies some water for Camp Del Mar, but mostly for irrigation.

Table 35.- Continued

Basin and well	1947-48	1948-49	1949-50	1950-51	1951-52	Total
Camp use						
Upper Basin						
10/4- 5E1	394	334	316	316	296	(3,044)
7R1	552	742	852	817	851	(5,606)
Subtotal	946	1,076	1,168	1,133	1,147	(8,650)
Chappo Basin						
10/4-18E1	971	1,094	1,153	1,406	1,647	(8,643)
18D1	345	392	4	0	-	(2,235)
10/5-13N1	558	491	663	178	-	(3,926)
14P1	3	5	11	8	10	(42)
23J1	-	-	-	9	519	528
24N1	-	-	-	222	286	508
Subtotal	1,877	1,982	1,831	1,823	2,462	(15,882)
Ysidora Basin						
11/5- 2A1	881	1,045	863	791	673	6,742
2H1	22	3	-	-	-	148
Subtotal	903	1,048	863	791	673	(6,890)
Total Camp use	3,725	4,106	3,862	3,747	4,282	(37,368)
Irrigation use						
Ysidora Basin						
10/5-35R1	(a)	302	351	170	324	(1,156)
11/5- 2D1	1,206	849	1,295	714	825	9,579
2E1	869	700	0	291	0	6,445
2F1 c/	711	519	623	447	304	5,405
Total irr. use	(2,786)	2,370	2,270	1,622	1,453	(22,802)
Subtotal for Ysidora Basin	(3,689)	3,418	3,133	2,413	2,126	(29,692)
Grand total	(6,512)	6,476	6,132	5,369	5,735	(60,170)

Fallbrook Naval Ammunition Depot						
9/4-18[illegible]	[illegible]	90	66	63	66	672
Camp De Luz						
9/4-2[illegible]	17	16	17	6	5	102

a. Pumpage records not available.
b. From records at Public Works Office
c. Supplies some water for Camp Del Mar, but mostly for irrigation.

Because the pumpage for the Fallbrook Naval Ammunition Depot and Camp De Luz is extracted from the alluvium above the De Luz dam site, it is not included with the grand total shown in the table.

Records of pumpage for the years 1941-42 through 1943-44 are available as estimates of total pumpage for Camp and irrigation use. However, there are numerous incomplete records of pumpage by wells. Accordingly, the subtotals by basins for this period do not add up to total Camp or irrigation uses. Starting in 1947-48 the records for most wells are available and the subtotals do add up to and equal the total pumpage figures.

The table shows that the total pumpage was about 5,300 acre-feet from 1942-43 through 1946-47, increased to about 6,500 acre-feet in the two following years, and then decreased to about 5,500 acre-feet in the last two years. The reason for the decrease in the last two years is largely due to water-rationing for irrigation on Stuart Mesa and the terrace to the south.

Of the total pumpage of more than 60,000 acre-feet for the 11-year period, essentially one-half or about 30,000 acre-feet has been supplied from Ysidora Basin, more than 16,000 acre-feet (probably about 20,000 acre-feet or about one-third) has been pumped from Chappo Basin, and more than 8,600 acre-feet (probably about 10,000 acre-feet or about one-sixth) has been extracted from Upper Basin. The pumpage for irrigation, all from Ysidora Basin, has been at least 23,000 acre-feet or 38 percent of the total. The average pumpage for the 10-year period 1943-52, which excludes the low pumpage in 1941-42, has probably been about 6,000 acre-feet per year.

The pumpage for irrigation is transported by pipeline to the coastal mesas and thus is applied to lands outside the lower Santa Margarita River basin. The water for Camp use is chiefly for domestic purposes and so is discharged into sewer systems after use. Little, if any, of the water is used in such a way that a part can return to the ground-water reservoir. Therefore, it is concluded that the ground-water pumpage is all utilized, and that no part returns to the reservoir directly, except after treatment of the sewage and reconveyance to the basins, as already discussed.

Natural Discharge

Prior to the advent of man on the Rancho Santa Margarita, natural discharge of ground water was the only form of discharge. In all the principal stream valleys ground water either was consumed by the natural vegetation or moved downstream through the water-bearing deposits to discharge into the Pacific Ocean. Also, in the lower reaches of the valleys, some of the ground water probably seeped back into the stream beds to form a perennial low flow, which is termed ground-water overflow in this report. For the lower Santa Margarita River basin, the character and extent of the natural discharge is described below.

Evapotranspiration.--Originally the alluvial plain of the Santa Margarita River basin was in all probability choked with dense growths of cottonwoods, willows, tules, and other water-loving plants in a manner similar to that now found in the Santa Margarita River above De Luz Creek or in the lower reach of nearby San Luis Rey River valley. These plants consumed considerable quantities of both surface and ground waters by the process of evapotranspiration. As is shown in the following section, the ground-water outflow is small. Therefore, under natural conditions evapotranspiration formed the bulk of the natural discharge.

Subsequently the plain has been successively cleared for irrigation, for flood control, and for ground-water conservation. The areas of phreatophytes were determined from aerial photographs flown in 1951, and the total area supporting phreatophytes between De Luz dam site and the Ysidora stream gage was only about 500 acres at that time.

With regard to the consumptive use of phreatophytes, studies made in the South Coastal Basin of southern California (Gleason, 1947) indicate that where the water level is within 2 to 5 feet of the land surface, growths of typical assemblages of phreatophytes found in coastal stream valleys will consume between 3 and 5 acre-feet per acre per year of ground water less the yearly rainfall. In the areas of phreatophytes in the lower Santa Margarita River basin in the period 1942-52, the water levels have been from 0 to 10 feet below land surface and have averaged about 5 feet below. Thus, for the purposes of this report it is assumed that the average use is 3 feet per year. Accordingly, the ground water consumed by these plants may be computed as follows:

$$Q = 500(3 - R)$$

where Q is the quantity consumed in acre-feet, the figure 500 is the area of phreatophytes in acres, the figure 3 is the consumptive use in feet, and R is the rainfall in feet. For example, in 1952 the amount of ground water discharged by phreatophytes is estimated to have been 500(3 - 1.5) - or 750 acre-feet.

If it is assumed that the area of phreatophytes has been on the order of 500 acres since 1942 when the Navy acquired the Rancho, then it can be estimated roughly that the evapotranspiration losses have totaled about 11,500 acre-feet or average about 1,000 acre-feet per year. Because this form of discharge is 15 percent of the total, errors in the two assumptions made would affect appreciably the magnitude of the total discharge.

<u>Ground-water outflow</u>.--Ground-water outflow to the sea takes place by the movement of ground water principally through the lower member of the alluvium, but probably in small part through the upper member, whenever the hydraulic gradient is toward the coast. Under this favorable gradient, discharge takes place through permeable beds directly into the Pacific Ocean offshore from the mouth of the river and/or by seepage into the lagoon. The hydrographs of wells in Ysidora Basin together with the record of stream runoff suggest that the "static" water levels remained above sea level until about 1945 indicating the continued existence of a coastward hydraulic gradient and hence ground-water outflow.

From the mid-forties through the fall of 1951, the combined effects of dry years and heavy pumpage in Ysidora Basin caused water levels to decline. From 1948 through 1951 the hydrographs show that the "static" levels were mostly below sea level (pl. 23). When the levels were below, the normal seaward gradient was reversed and ground water was moving inland from the coast to Ysidora Basin. Permeable beds in the alluvium, which formerly had discharged ground water into the Pacific Ocean and/or into the lagoon, were then serving as conduits for the inland movement of sea water of modified character. This water moved inland far enough to render wells 11/5-2M1 and 11/5-2M1 unfit for use. Finally, following the wet winter of 1951-52, the water levels in Ysidora Basin rose to within about 5 feet of the high levels of the 1930's. (See pl. 4.) A seaward hydraulic gradient and ground-water outflow to the sea were reestablished.

Estimates of the amount of ground water moving either coastward or inland through the lower member of the alluvium are made for Ysidora Narrows at the Ysidora gaging station. The formula used is Darcy's law in a manner similar to that used to estimate the underflow at De Luz dam site.

Specifically, three periods have been selected: March 1932 and March 1952 to show the underflow moving seaward, and October 1951 to show the underflow moving inland. For all periods the permeability and the cross-sectional area remained constant.

In the section on water-bearing properties of the alluvium, the permeability of the lower member in Ysidora Basin was estimated to be about 2,500 gallons per day per square foot, which is probably applicable to Ysidora Narrows. The cross-sectional area of the lower member as shown in section F-F' (pl. 5) is about 40,000 square feet. In March 1932 the seaward hydraulic gradient as determined from "static" levels was about 7.0 feet per mile (pl. 4). Thus, the ground-water outflow is estimated to have been:

$$Q = \frac{2,500 \times 7.0 \times 40,000}{5,280}$$

$$Q = 130,000 \text{ gallons per day}$$

This is equivalent to about 0.2 second-foot and, theoretically, a rate of nearly 150 acre-feet per year. Because the gradient in 1932 decreased through late spring, summer, and early fall to about 4 feet per mile, the estimated yearly outflow to the sea was about 120 acre-feet.

In March 1952 the seaward hydraulic gradient was 3.2 feet per mile. By substituting in the above formula, the outflow is estimated to have been about 0.09 second-foot or theoretically about 70 acre-feet per year. However the gradient decreased substantially during the summer so that the yearly outflow was probably more nearly 50 acre-feet.

In October 1951 the inland hydraulic gradient was about 4.3 feet per mile. By substituting in the above formula the inflow is estimated to have been about 0.12 second-foot and theoretically equivalent to a rate of about 90 acre-feet per year. However, during prolonged periods of heavy pumping withdrawals, the gradient and hence the inland underflow would be greater. Taking into account the steeper inland gradients created by pumping and, on the other hand, the less steep inland gradient during the winter of 1950-51, the total inflow for the year was probably at least 100 acre-feet.

Owing to the complexity of the relative movements of the salt and fresh water when the normal seaward hydraulic gradient approaches zero, the amount of water moving inland or seaward can not be easily ascertained. For example, as the seaward hydraulic gradient decreases to 2 feet per mile, fresh water is still moving seaward above the fresh-water salt-water interface at the same time that the salt-water wedge beneath is moving inland. Under these conditions the underground waters can be moving in opposite directions at the same time. No estimate of the net result has been made.

Accordingly, it can only be concluded that prior to the decline of water levels, which started in about 1944, the ground-water outflow to the sea was on the order of 100 to 120 acre-feet per year. During 1951, when levels reached the lowest of record, the inflow was on the order of 100 acre-feet. In 1952, after the water levels had recovered substantially, the outflow was on the order of 50 acre-feet. In order to derive the outflow or inflow in the years 1944 through 1951 the water-level and chemical data were used. Plate 30 shows that sea-water had invaded well 11/5-2H1 in the fall of 1947 and well 11/5-2M1 in the summer of 1948. Thus, the intrusion from Ysidora Narrows probably started several years prior to 1947, possibly in 1945.

Accordingly, it is believed that the outflow decreased from about 100 acre-feet in 1942 to essentially none in 1945 and that intrusion, which may have started in the fall of 1945, increased in the subsequent years through the fall of 1951. On this basis it is estimated that the amount of intrusion past Ysidora gage from the mid-forties to the fall of 1951 was on the order of 400 acre-feet. The outflow in 1952 probably decreased the amount intruded by roughly 50 acre-feet.

Total Discharge

The total ground-water discharge from the lower Santa Margarita River basin is the sum of the pumpage, the evapotranspiration, and the ground-water outflow. For years when there was an inland hydraulic gradient, the inflow was subtracted from the total discharge. The estimated total yearly discharge is shown in table 36.

Table 36.- Estimated total discharge, in acre-feet, from the lower Santa Margarita River basin in the water years 1942-52[1]

Year ending Sept. 30	Total discharge	Year ending Sept. 30	Total discharge
1942	4,000	1948	7,700
1943	6,200	1949	7,500
1944	6,400	1950	7,200
1945	6,400	1951	6,500
1946	6,800	1952	6,500
1947	6,400		
Total			71,600
11-year average			6,500

1. Pumpage totals for years 1945-46 are incomplete (table 35).

The total yearly discharge was between 6,200 and 6,800 acre-feet for the period 1943-47, then increased to over 7,000 acre-feet for the next 3 years, and decreased to about 6,500 acre-feet in the 2 years 1951-52, which also was about the average for the 11-year period. Principal weaknesses in the estimate of total discharge are in the evapotranspiration loss figures and the pumpage figures for 1945 through 1948. Because the pumpage has been metered and is 84 percent of the estimated total discharge for the period, however, it is believed that the average annual discharge of 6,500 acre-feet is reasonably accurate.

Water-Level Fluctuations in Wells

Intermittent records of water-level fluctuations in wells in the lower Santa Margarita River basin are available for the 33-year period 1920-52. These measurements were made by F. E. Green, hydrographic engineer, by the Camp, and starting in 1950, by the U. S. Geological Survey. Records of both deep and shallow wells are included as table 3A in the appendixes. In addition, selected records for the Upper, Chappo, and Ysidora Basins are shown in hydrograph form on plates 23 through 27. The locations of these wells are shown on plate 1. Because the position of water levels in relation to sea level is critical, they have been plotted with respect to mean sea-level datum rather than with respect to land-surface datum, which has been used in table 3A. On the hydrograph of each well is shown the depth of the well and the altitude of land-surface datum.

In addition to the hydrographs, which show water-level changes at wells or at specific points, the water-level contour maps show the conditions in October 1951, the lowest levels of record, and in the spring of 1952, the most recent high levels, for the lower Santa Margarita River basin (pls. 21 and 22). A comparison of these two maps reveals the magnitude of the change at all places in the basin. In addition, the water-level profiles on plate 4 show the range in fluctuations along the line of section longitudinally from the coast to De Luz Creek. The fluctuations of water levels are discussed by basins in downstream order in the following sections.

Upper Basin

The composite record for wells 10/4-8M1 and 10/4-7J1 is used to show the water-level fluctuations in Upper Basin on plate 23. Because of the differential of 6 feet in altitude between the two wells, it appears that the level has declined in the basin since the end of the record for well 10/4-8M1. By adding 6 feet to the altitude of the levels in well 10/4-7J1 to place both at a comparative altitude, it is apparent that no over-all net decline has occurred in the basin from January 1921 to March 1952.

The hydrograph shows that the principal type of fluctuation is a seasonal rise and decline--late in the autumn the levels begin to rise in response to the combined effects of decreased evapotranspiration and pumpage and increased recharge from the river and reach a peak sometime between January and May. In the spring and summer the levels decline in response to the increased evapotranspiration and pumpage and to the decrease or cessation of recharge from the river and reach a low sometime between October and December. From peak to low in any one year the decline was on the order of only 2 to 6 feet.

The rapidity with which Upper Basin is recharged is indicated by the record from the automatic water-level recorder on well 10/4-7J1 (plot not shown in this report). During November and December 1951 the water level was slowly declining at a rate of about 0.2 foot per month. Large runoff occurred in the river on December 30, causing the water level in well 7J1 to start rising on the same day; by January 1 the level had risen one foot, and by January 14 had risen a total of 2.5 feet. Large runoff accompanying a second storm on January 16, produced an additional rise starting on the same day; two days later the level had risen an additional foot. The total rise for the two storms was 4.5 feet, and the water level was only 2 feet below land surface. Furthermore, had the levels in the fall of 1951 been substantially lower, a considerably larger rise in levels and hence an increased recharge to ground water would have occurred from runoff later in the winter and spring.

The depths to water below land surface in Upper Basin, as exemplified by the two hydrographs on plate 23, have ranged from a minimum of 2 to 3 feet during wet years such as 1921 and 1952 to a maximum of about 9 feet in December 1931 in well 10/4-8E1 and to a maximum of about 6.5 feet below in December 1951 in well 10/4-7J1. It is pertinent that the water levels have remained so close to land surface irrespective of relatively prolonged dry periods such as that from 1944-51. Because ground water in Upper Basin occurs under water-table conditions, the maximum indicated range in water-level fluctuations shows that only small changes in ground-water storage have taken place. In other words, the basin has remained essentially full of water. Therefore, the basin offers an excellent opportunity for further ground-water development.

Chappo Basin

For Chappo Basin, the water-level record for well 10/5-24M1, near the lower end of the basin, and the composite record for wells 10/5-24G1 and 10/5-24H1, near the middle of the basin, are used to show the character of fluctuations (pl. 23). Well 10/5-24M1, which is within the area of confinement, flowed during several winters of the 1920's and 1930's, and in March 1952 was within 0.6 foot of the land surface. Before 1936, the hydrograph shows a seasonal range of from less than 1 to nearly 4 feet. The graph also shows that there was no cyclic trend comparable with periods of consecutive dry and wet years. For the period 1945-52, the hydrograph suggests no significant change until 1950 at which time a gentle progressive decline started. This decline continued until December 1951 when the level reached a record low of about 6.5 feet below land surface. Following the winter storms, the level recovered rapidly to a maximum of 0.6 foot below--a rise of about 6 feet. Thus, for the 32-year period of record the range in fluctuations has been only from flowing to 6.5 feet below land surface.

The composite hydrograph for wells 10/5-24G1 and 24H1, which shows conditions near the indefinite edge of the area of confinement, indicates essentially the same type of fluctuations as well 10/5-24M1. In order to place the composite graph of the two wells on a comparative basis, the difference in their altitudes of 5 feet must be considered. For the years prior to 1938, the graph for well 10/5-24G1 shows a maximum seasonal variation in water level of as much as 5 feet, but usually more nearly 2 to 3 feet. No cyclic trend is indicated. For well 10/5-24H1 the record is short, but the graph shows a decline that reached a low in December 1951 of nearly 14.5 feet below land surface. However, winter recharge caused the level to rise rapidly to a high of only 5 feet below land surface in March 1952--a net rise of nearly 10 feet. Thus, taking into account the 5-foot disparity in altitude the net decline from the flowing in November 1920 to the level in March 1952 has been somewhat more than 5 feet.

An automatic water-level recorder operated at the upstream edge of the confined area of Chappo Basin on test well 10/5-13J1 (plot not shown in this report) shows a good response to recharge from the river. Starting on December 3, 1952, when there was low flow in the river, the level rose about 1 foot in 2 days; on December 20, the level again rose about 1 foot in 2 days. The over-all rise in a period of 3 weeks was from 9.3 feet below land surface to 6.8 feet below. This well also shows about the largest range in water-level fluctuations for the basin. The level reached 15.7 feet below land surface in December 1951 and rose to 2.2 feet below in March 1952--a net rise in response to river recharge of about 13.5 feet.

Recorder charts for test wells 10/5-23J3 and 10/5-23L1, 600 feet and 2,000 feet respectively from new Camp supply well 10/5-23J1 which yields about 1,500 gpm, show fluctuations characteristic of confined water when the supply well is operated. Daily fluctuations in well 23J3 were on the order of 4 feet in July 1952 and in well 23L1 were on the order of 2 to 2.5 feet in December 1951. On the other hand, well 10/5-13J1, which is 1,500 feet from new Camp supply well 10/4-18E2 which yields about 1,100 gpm, shows only a 0.2-foot daily fluctuation to pumping in the supply well. Even this small response in the test well indicates that some minor confinement exists, but a comparison of the fluctuations in test well 13J1 with those in test wells 23J3 and 23L1 shows definitely that the degree of confinement is increasing downstream.

Recorder graphs for test well 10/5-23Q1, which taps water only in the La Jolla formation, show daily fluctuations of 0.05 to 0.07 foot that can be readily correlated with the pumping schedule for supply well 10/5-23J1 some 2,200 feet away. This indicates that water in the alluvium is in hydraulic continuity with that in the La Jolla formation, but the small range in fluctuation suggests that the interconnection is poor and possibly that the coefficient of transmissibility of the La Jolla is also poor.

A shallow well, 10/5-23J4, was drilled to a depth of 11.2 feet at a point 18.3 feet southwest of supply well 10/5-23J1 for the purpose of determining the effect of pumping in the deep water on the shallow water. The measurements made in the shallow well showed no effect when the supply well was pumping. However, slow downward percolation is suggested by the steady decline of water level in the shallow well. In October 1951 the depth to water was 7.06 feet; in November it was 7.65 feet. Following the winter storms, the level rose to a high in March 1952 of only 3.44 feet below land surface. Thus, the shallow water in Chappo Basin is recharged during wet years and does supply some recharge to deep ground water in the coarse-grained lower member of the alluvium by slow downward percolation.

Ysidora Basin

Records of water levels for several wells in Ysidora Basin are available from 1920 to date. The composite records for deep wells 11/5-2B2 and 2E1 and deep wells 11/5-35K3, 35J1, and 35K1 have been plotted on plate 23 to show the character of the long-term fluctuations. The deep wells tap confined water in the coarse-grained lower member of the alluvium. In order to determine the nature of the fluctuations in the shallow water, which is contained in the fine-grained upper member of the alluvium, the Geological Survey constructed six shallow 1½-inch wells near existing deep wells. The distinction between the fluctuations in shallow and deep water bodies is shown by the paired hydrographs for wells 10/5-26L1 and 26L2, and 10/5-35K1 and 35K4 (pl. 24); 10/5-35R1 and 35R3, and 11/5-2A1 and 2A5 (pl. 25); and 11/5-2E1 and 2E4, and 11/5-2F3 and 2K1 (pl. 26). Also, on plates 21 and 22 the water-level contours have been drawn on both the shallow and deep water bodies to show the difference not only in direction of movement but also in levels at various places in the basin.

Long-term fluctuations.--Prior to 1939 the two composite hydrographs on plate 23 show principally only seasonal fluctuations related to recharge and discharge, and show no cyclic trend comparable to dry and wet periods. In 1938, which was a wet year marked by high floods in March, the levels rose above the general spring peaks for the preceding years. In general, the seasonal change averaged between 3 and 9 feet. During the period 1920-38 the level in well 11/5-2B2 ranged from 4 to 11 feet below land surface and in wells 10/5-35K3 and 35J1 ranged from 5 to nearly 10 feet below. Thus, both records show that through the thirties Ysidora Basin remained full and undepleted.

For the period 1945-52, the hydrographs show a progressive decline starting at levels slightly below those in the preceding period. The "static" levels in wells 11/5-2D1 and 2D2 went below sea level for the first known time in 1948. However, they may have gone below during the summers in prior years, but no data are available. In 1950 and 1951 the "static" levels remained below sea level for nearly the entire time; the hydrograph suggests the average level may have been 4 to 5 feet below. From October 1951 to March 1952 and in response to recharge, the level recovered rapidly from 5 feet below sea level to 11 feet above sea level--a rise of 16 feet. Even so, the level was still about 5 to 9 feet below the spring peaks of the twenties and thirties.

The graph for well 10/5-35K1 shows the same general features for the period 1945-52. The level progressively declined to a record low in August 1951 of 0.3 foot below sea level. In March the level had recovered to 17.1 feet above sea level--a rise of 17.4 feet, but still some 6 to 8 feet below the peak levels in the late thirties. Thus, in Yeldora Basin the average net decline of water levels in wells from the spring peaks in the late thirties to those in 1952 was on the order of 5 to 9 feet.

In the central part of the basin plate 4 shows that the "static" levels in October 1951 were about 7 feet below sea level and as much as 27 feet below land surface. The levels in pumping wells during 1950 and 1951 were as much as 40 feet below sea level.

<u>Fluctuations in shallow and deep water bodies</u>.--The paired hydrographs for shallow and deep wells show that generally east of Vandegrift Boulevard the levels in the two water bodies are separate and distinct; whereas on the west side the levels are more nearly correlative. These features are also shown by the water-level contours drawn on the shallow and deep water bodies.

Paired wells 10/5-35R1 and 35R3 and 11/5-2A1 and 2A5, east of Vandegrift Boulevard, show very poor correlation to the effects of pumping and recharge (pl. 25). During the 1951 summer pumping season the shallow water stood 5 to 10 feet higher than the deep and declined slowly; during the 1952 winter season of recharge the shallow water rose slowly but the deep levels rose rapidly some 15 feet to an average level about 5 to 8 feet above the shallow levels; and during the 1952 summer pumping season, the shallow water level showed a very small steady rise, whereas the deep water again declined some 10 feet to a level 3 to 5 feet below the shallow water.

Paired wells 11/5-2F3 and 2K1, which are in a pond area, show a better correlation in fluctuations (pl. 26). However, the two wells are about 600 feet apart, and accordingly the levels are not strictly correlative. Thus, on the basis of water-level fluctuations and the well logs it is concluded that on the east side of Ysidora Basin the upper member of the alluvium forms an effective barrier to the vertical movement of ground water between the shallow and deep water bodies, and thus that the deep water is well confined.

On the other hand, paired hydrographs for wells 10/5-26L1 and 26L2, and 10/5-35K1 and 35K4 (pl. 24), at the upper end and on the west side of the basin near the river, and 11/5-2E1 and 2E4 (pl. 26), at the lower end of the basin, show that the levels in the shallow and deep water bodies in general are closely correlative. In fact, most of the measurements made in 1950 and 1951 in wells 26L1 and 26L2 plot within the same circle (pl. 24), and no distinction in fluctuations can be made. For paired wells 10/5-35K1 and 35K4 and 11/5-2E1 and 2E4 (pls. 24 and 26), during the 1951 and 1952 summer pumping seasons, the shallow levels were 1 to 4 feet higher than the deep levels; and during the 1952 winter recharge season, the shallow water rose some 15 to 19 feet to levels about 1 to 2 feet higher than the deep levels. Both the deep and shallow water bodies responded with about the same facility to the seasonal effects of recharge and pumping. Thus, on the west side of Ysidora Basin the water-level fluctuations in the shallow water body indicate that the two water bodies are in fair hydraulic continuity and that recharge from the river is able to percolate downward to the deep water body.

The response of water levels in the shallow wells to pumping in the adjacent deep wells is not so closely correlative. When well 10/5-35K1 is pumped the level in the shallow well 35K4, only 25 feet to the west, declines between 1 and 3 feet, depending on the length of the pumping period; whereas recorder graphs for deep well 10/5-26L1, about 4,500 feet away, 10/5-35R1, about 2,400 feet away, and 11/5-2K1, about 5,600 feet away, have showed declines of about 0.4, 5.5, and 1.4 feet, respectively. Thus, although the levels in the shallow and deep water bodies closely parallel each other during seasonal periods of recharge and pumping, the shallow water does not respond readily to daily pumping effects as does the deep water body.

<u>Fluctuations in the La Jolla formation.</u>--A recorder was operated on test well 11/5-2K2, which had been drilled to a depth of 300 feet entirely in the La Jolla formation, to determine the character of the fluctuations in the sandstone beds. Although this test well yields little water when pumped, it responds actively to the effects of pumping and recharge in the confined deep water body in the alluvium nearby. Daily pumping effects amounting to 0.1 to 0.4 foot were recorded. At the end of the heavy pumping season in October 1951, when the pressure head in the deep water body in the alluvium had declined below sea level, the level in well 11/5-2K2 was

about 1 foot above sea level. Following the winter recharge, the level in March 1952 was about 11.5 feet above sea level--a rise of 10.5 feet. However, owing to the low yield of the well and to the quick response of nearby pumping, it is believed that the water-level fluctuations represent pressure-head changes induced through sandstone beds or through fractures and joints in the La Jolla formation that are in contact with the lower confined member of the alluvium and do not suggest significant storage changes in the La Jolla formation.

Ysidora Narrows and the Lagoon Area

Three pairs of shallow and deep test wells were drilled to ascertain the character and correlation of fluctuations of the shallow and deep water bodies in the alluvium in Ysidora Narrows and in the lagoon area. Paired hydrographs for wells 11/5-2N4 and 2N5, 11/5-10E1 and 10G1, and 11/5-9J1 and 9J2 (pl. 27) show the principal features. The deep and shallow water levels respond very similarly to the seasonal effects of recharge and pumping as was described for paired wells on the west side of Ysidora Basin, but the magnitude of the fluctuations decreases toward the coast. The levels in wells 11/5-2N4 and 2N5 rose about 14 feet from 2 to 5 feet below sea level in October 1951 to 10 to 11 feet above in March 1952, levels in 11/5-10E1 and 10G1 rose about 8 feet from about sea level or slightly below to nearly 8 feet above, and wells 11/5-9J1 and 9J2 rose more than 4 feet from about sea level to 4.5 feet above.

Daily pumping in Ysidora Basin during 1951 produced declines and recoveries on recorder charts on deep test well 11/5-2N4 of as much as 8 feet, and on deep test well 11/5-10E1 of as much as 1 foot, but on deep test well 11/5-9J1 there was no effect. The shallow wells paired with the deep showed no daily effects from pumping.

Recorder charts obtained from the three deep wells show the effects of pressure head changes induced by the normal rise and fall of the ocean tides. The tidal effects are caused by the changes in pressure head on the confined lower member of the alluvium where it is exposed on the ocean floor and by the tidal loading or changing weight of the great mass of sea water on the confining beds in the upper member of the alluvium. In well 11/5-9J1 the maximum tides produce changes in water level of about 2 feet in a 24-hour period, and the minimum tides produce changes of only 0.6 foot in a 24-hour period. In well 11/5-10E1 the maximum and minimum tides produce changes of 1 foot and 0.3 foot respectively, and in well 11/5-2M4 produce changes difficult to distinguish from changes caused by barometric and pumping effects, but may be as much as 0.1 foot. The shallow wells paired with the deep did not respond to changes in the tide.

Ground-Water Storage Capacity

Ground-water storage capacity may be defined as the reservoir space contained in a given volume of deposits. Under optimum conditions of use the volume of water that can be alternately extracted and replaced in the deposit is the usable ground-water storage capacity; it may range from a small part of total ground-water storage capacity to essentially all of it, depending on the physical conditions in the reservoir.

The preliminary estimates of ground-water storage capacity of the alluvium and terrace deposits in the lower Santa Margarita River basin were presented in an interim report (Worts, Boss, and Riley, 1952). At that time it was believed that aquifer-rating tests, also called pumping tests, would provide the necessary data to revise the specific-yield values assigned to the deposits in the interim report. However, as was pointed out in the section on water-bearing properties of the alluvium, usable values for coefficient of transmissibility were obtained from the tests, but usable values for coefficient of storage or specific yield could not be derived.

Further study and work with the well logs and the water-level data indicate that essentially no changes in the original estimates are warranted. Accordingly, the following treatment summarizes the material contained in the interim report.

Storage Units and Depth Zones

The lower Santa Margarita River basin was divided into three major storage units as follows: (1) Upper Basin storage unit, which extends from De Luz dam site to the upper end of the Chappo Basin and which has a surface area of 850 acres; (2) Chappo Basin storage unit, which extends from the lower end of Upper Basin to Ysidora Basin and which has a surface area of 2,640 acres; and (3) Ysidora Basin storage unit, which extends from the lower end of Chappo Basin to the Ysidora stream gage and which covers an area of 1,080 acres. These units, which have a total area of about 4,500 acres, are shown on plate 28.

Plate 28 shows that the storage-unit boundaries exclude the tongues of alluvium extending up minor tributary valleys, but include some 460 acres of terrace deposits along the north side of Chappo Basin. The establishment of the north boundary at De Luz dam site was considered the most logical in view of the plans for a cutoff wall to be constructed to bedrock in conjunction with the construction of the dam. Similarly, the boundary at the Ysidora stream gage was selected because some consideration has been given to establishing a hydrologic barrier about at this point in the Narrows to halt sea-water intrusion.

The depth zones used in the storage computations for the alluvium are 5 to 50 feet and 50 to 100 feet below land surface; for the terrace deposits along the north side of Chappo Basin the zone used is that between the projected surface of the alluvium and bedrock. The zone in the terrace deposits averages only about 20 feet in thickness.

The volumes of deposits in each storage unit to depths between 5 and 50 feet and 50 and 100 feet and for the terrace deposits were determined from a subsurface contour or isopach map. This map was prepared by using well logs to establish control points on bedrock, and contours were then drawn connecting points of equal thickness of the deposits. By planimetering the tops and bottoms of each of the storage-unit depth zones, average areas were obtained. These average areas when multiplied by the thicknesses of the depth zones gave the volumes of deposits in each storage unit.

Specific-Yield Values

The specific yield of a deposit may be defined as the percentage obtained by dividing the volume of water which the deposit, after being saturated, will yield by gravity by the volume of the deposit. In California, two intensive investigations have been made to determine the specific yield of water-bearing deposits--one was made by Eckis (1934) in the South Coastal Basin and the other was made by Piper and others (1939) in the Mokelumne area. From these two sources together with data from less detailed studies, specific-yield values have been selected for the principal types of materials composing the alluvium and terrace deposits in the basins.

There are 86 logs available in the storage-unit areas and some 80 different types of material were reported by drillers. On the basis of the logs obtained by the Geological Survey during the drilling of the test wells, these numerous drillers' terms have been grouped into five general classes of materials which have similar hydrologic properties. The specific-yield values assigned to the five classes of materials are shown in table 37.

Table 37.- Specific-yield values assigned to the materials comprising the alluvium

Material	Assigned specific yield (percent)
Sand, including sand and some gravel, very clean and fairly well sorted	30
Gravel, including gravel and sand, fairly clean and loosely packed	25
Sand and silt, including fine sand and tight sand	15
Sand and "clay," including gravel and "clay"	10
"Clay," including silt, silty "clay," and clayey silt	5

The specific yield of a pure clay is much less than 5 percent; however, very little pure clay was encountered in drilling the test wells and it is concluded that the driller's term "clay" is largely silt to clayey silt. Accordingly, a value of 5 percent for this class of material is believed warranted.

Estimate of Storage Capacity

The estimate of ground-water storage capacity for the two depth zones, 5 to 50 and 50 to 100 feet below land surface, in each of the three storage basin units was derived by the following steps: (1) The average specific yield was derived for each depth zone in each storage unit by multiplying the percentage of each type of material times the appropriate assigned value of specific yield for that material and then totaling the products; (2) the average specific yield was then multiplied by the total volume of deposits to obtain the storage capacity for each depth zone; (3) the storage capacity of each storage unit is the sum of the storage capacities of the several depth zones; and (4) the total ground-water storage capacity for the area considered is the sum of the storage in the three storage units. The following table shows the estimated ground-water storage capacity in Upper, Chappo, and Ysidora basin storage units.

Table 38.- Estimated ground-water storage capacity of the lower Santa Margarita River Basin

Storage unit	Depth zone									
	5 - 50 feet			50 - 100 feet			Both zones (5 - 100 feet)			
	Average area (acres)	Specific yield (percent)	Storage (acre-feet)	Average area (acres)	Specific yield (percent)	Storage (acre-feet)	Average area (acres)	Specific yield (percent)	Storage (acre-feet)	Percent of total storage
Upper Basin	775	21.6	7,500	570	17.5	5,000	667	19.7	12,500	26
Chappo Basin	2,260	13.0	13,200	1,610	17.1	13,800	1,918	14.8	27,000	56
Ysidora Basin	995	9.0	4,000	830	11.1	4,600	908	10.0	8,600	18
Totals	4,030	13.6	24,700	3,010	15.5	23,400	3,493	14.5	48,100	100

Table 38 shows that the estimate of storage capacity for the three storage units totals about 48,000 acre-feet. Owing to the threat of sea-water intrusion, it is not feasible to utilize the storage in the Ysidora Basin storage unit until such time as an effective barrier is established. Thus, the sum of the storage capacity in the Upper and Chappo Basin storage units, or about 40,000 acre-feet, is available for use under optimum conditions of withdrawal. The historic records of water-level fluctuations indicate that essentially this total amount of stored water was available in Chappo and Upper Basins until the period 1945-51 when the level and hence stored water was drawn down somewhat.

Plate 29 shows the relation between water-level change and storage change within the depth zone computed, between 5 and 100 feet below land surface, for the Upper, Chappo, and Ysidora Basin storage units. For late October 1951, when the average water levels in each basin were the lowest of record, the graphs show that there was about 11,500 acre-feet of storage in Upper Basin, or about 92 percent of the total capacity; about 24,000 acre-feet of storage in Chappo Basin, or about 89 percent of the total capacity; and about 6,500 acre-feet of storage in Ysidora Basin, or about 75 percent of the total capacity. For the three basins, then, there was a total storage of about 42,000 acre-feet, or nearly 90 percent of the amount when the three basins are full. Thus, for a depth of 100 feet below land surface the graphs can be used to determine the amount of water in storage or available for pumpage at any given average depth to water in the basins.

Relation of Storage Capacity to Sea-Water Intrusion

Because the depth zone 5 to 100 feet extends to average depths of 75 feet below sea level in Ysidora Basin, 45 feet below sea level in Chappo Basin, and about to sea level in Upper Basin, it is also desirable to know the storage capacity for the zone above sea level that would not create the problem of sea-water intrusion. For Ysidora Basin the zone from 5 feet below land surface to 10 feet above sea level is selected to provide for a sufficient head above sea level to prevent sea-water intrusion. The average depth below land surface to the base of this zone is 14 feet. If this point is picked on the graph (pl. 29) it indicates a storage of 7,400 acre-feet which, when subtracted from the total storage of 8,600 acre-feet, suggests a storage for the zone 5 feet below land surface down to 10 feet above sea level of only 1,200 acre-feet.

For Chappo and Upper Basins the zone from 5 feet below land surface down to sea level is used. In Chappo Basin the average depth below land surface to the base of this zone is 55 feet. If this point is picked on the graph (pl. 29) it indicates a storage of 12,500 acre-feet, which, when subtracted from the total storage of 27,000 acre-feet, suggests a storage for the zone 5 feet below land surface down to sea level of 14,500 acre-feet. In Upper Basin, the average depth below land surface to the base of this zone is about 100 feet, which is the same as that computed for the depth zone shown in table 38. The storage, then, would be essentially the same or about 12,500 acre-feet.

Because the base of these depth zones is parallel to sea level rather than parallel to the sloping land surface from which storage zones were computed, the storage in the affected depth zones was recomputed and the following estimates of storage were derived: Ysidora Basin, for the depth zone 5 feet below land surface down to 10 feet above sea level, 1,300 acre-feet; and Chappo and Upper Basins, for the depth zone 5 feet below land surface down to sea level, 15,000 and 12,000 acre-feet, respectively. These estimates of storage agree closely with those obtained from the graph (pl. 29).

Thus, the estimated total ground-water storage for the three basins that would be available for use and, with cyclic water and dewatering, would present no problem with respect to sea-water intrusion is on the order of 28,000 acre-feet. In October 1951, when water levels and hence stored water were the lowest of record, the stored water in Ysidora Basin was depleted by some 800 acre-feet more than the amount considered feasible to prevent sea-water intrusion, Chappo Basin had a surplus in storage above sea level of about 12,000 acre-feet, and Upper Basin had a surplus in storage above sea level of about 11,000 acre-feet. This is a net total of about 22,000 acre-feet, or 80 percent of the total when the basins are full.

It is apparent that the amount of storage capacity available for use is directly related to the problem of sea-water intrusion. It has been demonstrated that in the depth zone 5 to 100 feet below land surface, the storage capacity is about 48,000 acre-feet (table 38), but in the zone above sea level is only about 28,000 acre-feet or 60 percent of the former. However, under practical conditions of operation with no pumpage from Ysidora Basin and with sewage treatment plant 3 discharging into the river bed at the lower end of Chappo Basin and recharging ground water, it probably would be possible to utilize nearly the full 40,000 acre-feet of storage in Chappo and Upper Basins for relatively short periods of time without causing serious intrusion of sea water into Ysidora Basin. Under normal operations it is assumed that storage would be drawn down to this extent only near the end of prolonged dry periods.

Usable Ground-Water Storage Capacity

Usable ground-water storage capacity may be defined as the amount of water that can be withdrawn and replenished within a specified depth zone in a basin under optimum conditions of operation and without causing chemical deterioration of the supply. In the lower Santa Margarita River basin the principal threats to the supply are sea-water intrusion and possible local contamination by movement of water of poor quality from the La Jolla formation into the basins. The limits placed on the optimum conditions of operation involve principally the rate and magnitude of withdrawal. If withdrawals are made at a rate too rapid to allow the finer materials to drain, then the usable storage would be less than the estimated storage capacity.

Relation of storage to pumpage.--The total pumpage from the three basins for all uses for the 5 years 1947-48 through 1951-52 has averaged about 6,000 acre-feet per year--4,000 for Camp use and 2,000 for irrigation use (table 34). This rate of withdrawal exceeded the rate of drainage of the finer materials only in the eastern part of Ysidora Basin where in 1951 the paired hydrographs of deep and shallow wells show that the shallow water was standing above the deep water (pl. 25). Elsewhere, however, the water-level records indicate that the rate of depletion did not exceed the drainage rate of the deposits.

The length of time that it would take to dewater Upper and Chappo Basins to a depth of 100 feet and to extract the 40,000 acre-feet of estimated storage can be computed with certain theoretical criteria. It is assumed that the basins are full, that there is no recharge by seepage from streams or from rainfall, that the pumpage and returned sewage effluent are at the 1952 rates of 6,000 and 1,500 acre-feet, respectively, that ground-water underflow at De Luz dam site is stopped, and that the evapotranspiration losses are reduced to zero. With these assumptions, the number of years of supply would be the storage (40,000 acre-feet) divided by the difference of the pumpage less the returned effluent (4,500 acre-feet) or a period of 9 years. Except locally, it is believed that this rate of depletion would not exceed the natural drainage rate of the deposits.

Relation of storage to recharge.--The surface-water outflow of the Santa Margarita River at Ysidora Narrows has ranged from zero in 1949 and 1950 to 122,000 acre-feet in 1937-38, and the mean for the two base periods was 33,700 acre-feet per year (table 12). These data indicate that a substantial amount of potential recharge wastes to the ocean. An examination of the water-level records, profiles, and hydrographs shows why the waste has been so large. During the dry period 1945-51 when pumpage was the highest of record, storage at the end of the period was only about 6,000 acre-feet less than the estimated maximum storage capacity. Accordingly, during the wet winter of 1951-52, the basins were replenished and 47,640 acre-feet wasted to the ocean.

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Under conditions of natural stream runoff, the most effective means by which the available recharge can be utilized is to deplete ground-water storage in the lower Santa Margarita River basin to provide storage space for river recharge during wet years. This could be accomplished as follows.

First, an examination of the distribution of the average total pumpage by basins during the past five years, 1947-48 through 1951-52 shows: Ysidora Basin, about 2,900 acre-feet; Chappo Basin, about 2,000 acre-feet; and Upper Basin, about 1,100 acre-feet. In terms of percent of the average about 48 percent was pumped from Ysidora Basin, about 34 percent from Chappo Basin, and about 18 percent from Upper Basin.

Second, an examination of the physical conditions and storage capacities of the basins for the 100-foot depth zone shows that Ysidora Basin, if sea-water intrusion is to be remedied and avoided, should not be pumped; and that Chappo and Upper Basins contain about 27,000 and 12,500 acre-feet, respectively, of usable storage. In terms of percent of the total, Ysidora Basin contains none, Chappo Basin about 68 percent, and Upper Basin about 32 percent of usable storage.

Finally, a study of the geology and hydrology of the alluvium shows that recharge from the river takes place most readily in Upper Basin, but that because the upper member of the alluvium becomes progressively finer downstream, the recharge potential decreases toward the coast.

Thus, a comparison of the distribution of pumpage, usable storage capacity, and best areas of recharge shows that for fuller utilization of storage capacity a redistribution of the Camp supply and irrigation wells would be desirable. On the basis of the criteria presented above, the available storage capacity could be utilized most effectively by having the distribution of pumpage arranged roughly in proportion to the storage capacity of the basins. This would involve a decrease in pumpage in Ysidora Basin from 48 percent of the total to essentially nothing (emergency use only); in Chappo Basin it would involve an increase from 34 percent of the total pumpage to about 68 percent of the total or to about 4,000 acre-feet per year; and in Upper Basin it would involve an increase of from 18 percent of the total pumpage to about 32 percent of the total or to about 2,000 acre-feet per year. This would be essentially double the average pumpage from each during the past 5 years.

During a series of dry years, the result of redistributing the pumpage would cause an appreciable decline in water levels and hence storage in Chappo and Upper Basins. Then during a subsequent period of wet years, recharge from the river not only would have a considerable volume of storage space to fill but also would take place in the area of greatest recharge opportunity.

Finally, under conditions of natural stream runoff, the benefits derived from the redistribution of pumpage would be three-fold: (1) It would reduce if not entirely end the threat of sea-water intrusion into the ground-water basins; (2) it would induce greater recharge by providing better recharge opportunity in the most receptive recharge areas of the river basin; and (3) it would salvage a substantial part of the surface-water outflow now wasting to the ocean.

Toward the realization of this program, the Public Works Office, Camp Pendleton, in 1950-52 constructed new wells in Chappo Basin. No new wells as yet have been drilled in Upper Basin. The wells being used in Ysidora Basin were drilled by the former owners of Rancho Santa Margarita. The four new wells drilled in Chappo Basin are large-capacity wells (up to 1,500 gpm) capable of supplying 6,000 acre-feet per year if pumped about 75 percent of the time. However, in Upper Basin, there are only two wells, one of which supplies the Navy Hospital. Thus, if it is desired to utilize the available storage capacity, it would be advisable to drill several large supply wells in Upper Basin. If this were done, then the total Camp and irrigation supply could be pumped from these two basins which would allow Ysidora Basin to act as a natural barrier to sea-water intrusion until such time as a physical barrier might be constructed in the narrows.

Storage in the La Jolla Formation

It was indicated that the yields of test wells drilled in the La Jolla formation were very low, and that the transmissibility of the formation also is quite low. However, because the formation locally contains water of high chloride content (up to 600 ppm) and because of the gradual increase in chloride content of waters in the alluvium from Upper Basin downstream to mid-Ysidora Basin, there is good evidence to consider the relatively few soft sandstones or fracture and joint systems of this formation as a possible storage unit. If the alluvium were to be dewatered appreciably as a result of heavy pumping during dry years, the adjacent La Jolla formation eventually might also be dewatered to the same depth. The resultant movement of water from the formation into the alluvium would be unavoidable.

A study of the surface exposures, samples, cores, and drilling rates of test wells 10/5-23Q1 and 11/5-2P2 suggests that only about 6 percent of the sandstones could be classed as any better than poorly water bearing (p. 96). The relatively high percentage of decomposed feldspar, the degree of compaction of the rocks, and the lack of openings between grains of harder minerals, when examined microscopically, all suggest that the specific yield of these soft sandstones on the whole would be very low.

The numerous minor faults and the joints and fractures in the deposit not only may provide access for leaching of contained chloride by downward seepage of rain water and subsequent concentration in the zone of ground-water saturation below but also might provide numerous small channelways for the movement of water out of the La Jolla formation into the adjacent alluvium. Thus, owing to the complexity of the occurrence and movement of water in the formation, there is no valid means by which a storage estimate can be made nor is there any known method to predict the areas where the movement might be critical with respect to the quantity and quality of water injected into the alluvium when water levels in the latter are depressed. No known critical lateral invasion has occurred. Vertically, however, supply well 10/5-14P1 taps sufficient fractures and/or water-yielding sandstone beds to produce a blend of water from the La Jolla formation and the alluvium containing about 250 ppm of chloride. This would not appear to be a practical example of what might be expected by lateral movement of water from the formation under conditions of gentler hydraulic gradient and longer periods of time.

Repeated flushing of the La Jolla formation has apparently occurred locally around the sides of Ysidora Basin as is suggested by the data obtained from test well 11/5-2K2. A recorder installed on this well showed fluctuations of as much as 0.7 foot in response to pumping in Ysidora Basin indicating a hydraulic connection with the alluvium. The chloride content of the water from the well is only 160 ppm, and is low possibly owing to repeated movement of water back and forth from the alluvium into the La Jolla formation. This example is presented to show that there would probably be a general improvement in the quality of water in the La Jolla formation after several cycles of depletion and replenishment of the alluvium had occurred. There is reason to believe that the quality of water in the La Jolla formation would improve with time.

Finally, as has been stated the drawing down of water levels in the basins is likely to cause the higher-chloride waters of the La Jolla formation to invade the alluvium. The invading waters would blend with the low-chloride waters in the alluvium thereby producing, at least locally, a water fairly high in chloride. However, even with basin levels drawn down substantially, not only would the bulk of the water still be taken from the alluvium, but also it is believed that the blend would vary considerably from place to place and probably would not exceed 250 ppm.

Hydrologic Equation for the Period 1942-52

The years of large runoff in the late 1930's and early 1940's fully recharged the lower Santa Margarita River basin so that by 1943, the last year of large runoff for this period, water levels and hence storage were very close to the land surface. In the following dry years, particularly the period 1948-51, water levels and storage declined to the historic low in the fall of 1951. During the winter and spring of 1952, the large runoff and recharge replenished the basins, except for Ysidora Basin, to levels essentially as high as those in 1943. The levels and storage in Ysidora Basin recovered substantially, but not to the pre-drought levels.

It has been shown that total recharge and total discharge have been derived by estimating, computing, or measuring the various elements that make up the totals. Thus, a comparison of the two totals for the period 1942 through 1951 should show the magnitude of the depletion in storage, totals for the year 1952 should show the magnitude of the replenishment, and the difference between recharge and discharge or the net change from 1942 to 1952, which the water-level records indicate to be a period of little net change, should be small.

In the section on ground-water storage capacity the magnitude of the storage depletion in 1951 was shown. The storage increase in 1952 (October 1, 1951 to September 30, 1952) was computed and is shown in table 39. Thus, a comparison of the total recharge and total discharge with the storage-change data provides two independent methods of determining the hydrologic equation for the period 1942-52 and also provides a means of checking the accuracy of the estimates. Table 39 shows these data for the period 1942-52.

Table 39.- Comparison of recharge and discharge with storage changes, in acre-feet, in the water years 1942-52

	Period (year ending Sept. 30)		
	1942-51	1952	1942-52
Recharge:			
Seepage loss from Santa Margarita River ----	44,200	a14,000	58,200
Rainfall infiltration on basin -------------	900	1,300	2,200
Ground-water inflow, De Luz dam site -------	7,000	700	7,700
Returned sewage effluent -------------------	4,300	1,500	5,800
(1) Total (table 33)	56,400	17,500	73,900
Discharge:			
Pumpage:			
Upper Basin, in part -------------------	6,500+	1,147	8,650+
Chappo Basin, do -------------------	13,400+	2,462	15,900+
Ysidora Basin, do -------------------	27,600+	2,126	29,700+
Total pumpage (table 35)	54,500+	5,735	60,200+
Evapotranspiration by phreatophytes --------	10,800	700	11,500
Ground-water outflow, Ysidora Narrows ------	-175	+50	-125
(2) Total (table 36)	65,100+	6,500	71,600+
(3) Difference: (1) - (2)	-8,700+	+11,000	+2,300-
Ground-water storage change [net increase (+) or decrease (-)]:			
Upper Basin ----------------------------	-1,000	+900	-100
Chappo Basin ---------------------------	-3,000	+2,000	-1,000
Ysidora Basin --------------------------	-2,100	+700	-1,400
(4) Total	-6,100	+3,600	-2,500
(5) Difference between methods: (3) - (4)	-2,600+	+7,400	+4,800-

a. See following pages for possible reduction of computed seepage loss for 1952 to 10,000 acre-feet.

The table shows that substantial discrepancies exist between the recharge and discharge differences compared to storage change (5). For the 11-year period 1942-52, the water-level data for wells in the lower S nta Margarita River basin clearly indicate that levels in 1952 were below those in 1942. Hence, there must have been a net depletion for the period. Obviously, the indicated surplus or increase of 2,300 acre-feet derived by the use of recharge and discharge is in error.

For the 10-year period of storage depletion 1942-51, the difference between methods (5) of 2,600 acre-feet, although suggesting an error of between 30 and 45 percent of the two storage depletions derived, (3) and (4), is actually only 4 to 5 percent of the recharge and discharge totals for the period. However, the error might be more if it is considered that the pumpage totals are incomplete (table 36).

Therefore, the principal error appears to be in the estimates for the water year 1952 for which the difference between methods (5) was 7,400 acre-feet. An examination of the elements making up the recharge and discharge shows that the pumpage for 1952 was metered so the error is not in this figure, and, except for the seepage loss estimate, the other estimates are too small to change materially the end result. Thus, most of the error must be in the seepage-loss estimate of 14,000 acre-feet for 1952, which is about 80 percent of the total recharge. A reduction of 4,000 acre-feet for this one year would reduce the discrepancies considerably. There would still remain a considerable discrepancy between methods for the 1952 water year, but the discrepancy for the 11-year period 1942-52 would be essentially eliminated. Although a decrease of 4,000 acre-feet in the seepage-loss estimate suggests an error of 30 percent in the estimate, the decrease is only 6 percent of the computed inflow and 8 percent of the gaged outflow from which the seepage-loss estimate was made.

Thus, assuming that essentially all the error in the hydrologic equation is in the seepage loss for the 1952 water year, the seepage loss is reduced from 14,000 to 10,000 acre-feet--4,000 acre-feet less than the estimated seepage loss obtained by difference between inflow and outflow. This would reduce the difference between methods (5) for the 1952 water year from 7,400 to 3,400 acre-feet. Actually, this reduction for 1952 also would reduce the difference between methods for the 11-year period 1942-52 from 4,800 to 800 acre-feet. This revised seepage loss of 10,000 acre-feet in the 1952 water year is shown in parentheses in tables 29 and 33 and has been used in the following sections of the report.

Perennial Yield of the Lower Santa Margarita River Basin

General Considerations

The perennial yield of a ground-water basin is the rate at which water can be pumped from wells year after year without decreasing the storage to the point where the rate (1) becomes physically impossible to maintain, (2) causes chemical deterioration of the ground waters, or (3) becomes economically infeasible. In the lower Santa Margarita River basin, the rate has not and in all probability would not become economically infeasible because the deepest possible pumping lift would be limited by the maximum thickness of the alluvium or only about 200 feet. However, the rate could become physically impossible to maintain by locally depleting storage to a depth where supply wells would become dry. Except for Upper Basin this is not likely to occur in view of the 100-foot depth zone for which the usable storage has been computed. In Upper Basin it is possible that new supply wells might encounter bedrock at depths above that established as the base of the usable storage depth zone with the result that such wells would not be able to utilize the full computed storage. In turn, this condition would reduce somewhat the estimated yield.

With regard to the rate of yearly pumpage that would cause chemical deterioration of the ground water, it might be argued that the perennial yield has been exceeded because of sea-water intrusion into Ysidora Basin. However, it has been demonstrated that essentially 50 percent of the total pumpage has been from Ysidora Basin, and hence conditions of local overdraft rather than over-all basin-wide overdraft have developed. Thus, had the distribution of pumpage been more in line with the distribution of usable storage in the three basins, sea-water intrusion would not have occurred, nor could it have been construed that the perennial yield had been exceeded.

Basically, the perennial yield is the amount of water that is available for pumping--it is the maximum long-term recharge less any unrecoverable natural water losses. The natural water losses are the ground-water outflow through Ysidora Narrows, evapotranspiration from areas of phreatophytes, and evaporation from O'Neill Lake by diversion from the river. With cyclic storage depletion and replenishment under conditions of optimum basin operation, a large part of these natural water losses would be greatly reduced by lowering the water levels below the reach of plant roots or by periodically removing the phreatophytes as was done by the Navy for a part of the basin, and in time the losses might average only a few hundred acre-feet per year; ground-water outflow would range from zero for short periods to as much as 100 acre-feet per year, and evaporation from O'Neill Lake would remain the same or average about 400 acre-feet per year. It is estimated that under optimum conditions the total unrecoverable natural losses would be on the order of 600 acre-feet per year.

The maximum recharge under conditions of optimum basin operation would be the sum of the ground-water underflow at De Luz dam site of about 700 acre-feet per year, the average rainfall infiltration of about 400 acre-feet per year, the sewage effluent returned to points of recharge in the basin, and the seepage loss from the Santa Margarita River. The sum of the first two elements is 1,100 acre-feet a year. This amount less the estimated unrecoverable natural water losses would be on the order of 500 acre-feet per year. Thus, the perennial yield is the sum of the seepage loss, the returned sewage effluent, and the constant of about 500 acre-feet.

The amount of effluent returned to ground water in the future will vary almost proportionately with the pumpage for Camp use but also will depend in large part upon the point of discharge into the basin. With adequate treatment and aeration, Plant 1 could keep O'Neill Lake full for use as a recreation area with a surplus to spill for recharge directly into Upper Basin. By extending the discharge line, Plant 2 could discharge directly into the river bed in Ysidora Basin. Plant 3 discharges into the river bed near the downstream end of Chappo Basin.

Finally, the amount of seepage loss that historically has taken place in the lower Santa Margarita River basin is no measure of the potential seepage loss, even in the 1951-52 water year when the river supplied 10,000 to 14,000 acre-feet of recharge. In the section on surface-water resources, it was shown that the average seepage loss during two base periods, 1922-44 and 1934-51, was only about 4,000 acre-feet per year or a little over 10 percent of the average surface-water inflow for the base periods; the remaining 90 percent has wasted to the ocean. Thus, with no surface storage the perennial yield can be increased by the amount of salvagable surface water that would be wasting to the ocean.

Four elements limit the amount of seepage loss that can take place from the river: (1) The distribution and amount of runoff with respect to time; (2) the permeability of the channel deposits and alluvium or their ability to transmit water downward and laterally away from the river; (3) the maximum area of the channel deposits that can be wetted in a flood; and (4) the depth to water or the amount of storage space available in the basin during periods of runoff; if the levels are high there is room for little recharge, and if depressed substantially there is room for considerable recharge. Until the dry period 1945-51 the water-level records indicate that there has been little storage space available for recharge. Accordingly, item (4) has been the limiting factor to any substantial recharge from the river. In 1951-52, the seepage loss would have been greater had the water levels in Upper and Chappo Basins been lower before runoff began.

With regard to limiting elements (1) and (2) above, studies of runoff in addition to seepage made elsewhere provide some empirical data on the amount of seepage loss possible under natural conditions of runoff and with due consideration given to the permeability of the channel deposits and alluvium. These elements are discussed in the following section of the report.

Theoretical Seepage Losses with Basin Depletion

In order to determine the perennial yield of the lower Santa Margarita River basin, it is necessary to know the magnitude of seepage losses from the river under conditions of substantial storage depletion. However, there are few data available to show the magnitude of the losses for a basin that has been historically nearly saturated with ground water. An empirical method was suggested by Gleason (1947, p. 73 and pl. 23) in the

South Coastal Basin investigation and is based on the Manning formula for flow in open channels. Plate 23 of Gleason's report shows a sample percolation diagram for a channel reach 25,000 feet in length and beneath which seepage water could escape freely downward to the water table some distance below. Flows up to 40 second-feet would be absorbed, but for flows greater than 40 second-feet an ever-increasing amount would waste in proportion to the seepage loss until with a daily discharge of 15,000 second-feet only about 370 second-feet or 740 acre-feet a day would be seepage loss.

This sample percolation diagram is used in conjunction with the daily flow at the Fallbrook gaging station to develop estimates of annual seepage loss for the lower Santa Margarita River basin. It is here emphasized that the estimates are completely theoretical and would probably differ considerably from measured losses under conditions of substantial storage depletion. However, where possible the theoretical losses are compared with computed losses to show the probable degree of error in their derivation and application. The theoretical seepage losses derived are used in the next section of the report to develop the projected perennial yield of the basin.

The 25,000-foot reach of absorptive channel mentioned above is a conservative length compared to that between De Luz dam site and Ysidora gaging station, which is about 50,000 feet and along which low-flow seepage losses have been measured. Accordingly, from the standpoint of absorptive channel length, the use of the 25,000-foot reach shown on the sample diagram is conservative for the lower Santa Margarita River basin.

To show the frequency and magnitude of the theoretical seepage losses as derived from the sample percolation diagram, the daily discharges at the Fallbrook gage have been used for the 27-year period 1926-52, and the results are shown in table 40.

Table 40.- Frequency and magnitude of theoretical seepage loss with respect to time in the water years 1926-52

(Data from daily discharge records at the Fallbrook gage)

Daily flow (second-feet)	Theoretical daily seepage loss (second-feet)	(acre-feet)	percent of flow	Number of days	Percent of time
10,000-15,000	310-370	615-734	3 to 2	2	0.02
5,000-10,000	240-310	476-615	5 to 3	3	.03
1,000-5,000	130-240	258-476	13 to 5	32	.3
500-1,000	100-130	198-258	20 to 13	37	.4
100-500	56-100	111-198	56 to 20	271	2.6
40-100	40-56	79-111	100 to 56	376	3.7
25-40	25-40	50-79	100	450	4.4
0-25	0-25	0-50	100	9,056	88.5
Total				10,227	99.95

The table shows that for 93 percent of the time the flow at the Fallbrook stream gage was less than 40 second-feet which in turn suggests that for 93 percent of the time all flow would have been theoretical seepage loss. For the remaining 7 percent of the time when the daily flows were greater than 40 second-feet, the sample percolation diagram suggests that the theoretical daily seepage loss rate would have been between 40 and 370 second-feet. The errors introduced by use of this method would probably be proportional to the magnitude of the daily flow--particularly the flows in excess of 500 second-feet. However, these larger flows occurred only on 74 days out of 10,227.

The data obtained from the daily records at the Fallbrook gage and the sample percolation diagram were compiled to show the magnitude of the theoretical seepage losses that might occur in a 25,000-foot reach of channel for the period 1923-52, which are shown in table 41. The discharge at the Fallbrook gage is about one-third less than that computed at the De Luz dam site (table 9). Accordingly, the theoretical seepage loss below the dam site would be somewhat greater than that computed from the records for the Fallbrook gage, but certainly would not be one-third greater. Taking into account the dry years when essentially all the runoff might be seepage loss and the extremely wet years when the theoretical seepage loss might be a small percentage of the runoff, the theoretical seepage losses computed for the Fallbrook gage were increased conservatively by only about 10 percent to allow for the increased runoff at the dam site. The theoretical seepage losses so derived are also shown in table 41.

Table 41.- Annual runoff at and theoretical seepage loss below the Fallbrook stream gage and De Luz dam site, in acre-feet, in the water years 1923-52

Year ending Sept. 30	Fallbrook gage		De Luz dam site	
	Gaged runoff	Theoretical seepage loss	Computed runoff	Theoretical seepage loss
1923	a 4,560	4,560	11,800	5,000
24	a 6,180	6,180	8,800	6,800
1925	4,200	4,200	5,600	4,600
26	12,500	6,500	20,500	7,200
27	85,100	11,700	97,100	13,000
28	5,480	5,480	7,880	6,000
29	4,830	4,830	6,530	5,300
1930	8,680	7,100	12,300	7,800
31	4,920	4,600	6,820	5,100
32	36,900	11,600	45,900	13,000
33	6,940	6,500	10,500	7,200
34	4,870	4,700	7,470	5,200
1935	7,780	7,200	14,800	7,900
36	7,070	5,400	12,700	5,900
37	78,310	21,100	116,000	23,000
38	91,090	18,600	123,000	20,000
39	18,850	14,700	28,600	16,000
1940	16,720	11,100	25,700	12,000
41	83,100	24,600	120,000	27,000
42	15,760	14,300	21,600	16,000
43	57,890	16,600	77,900	18,000
44	21,850	13,500	32,800	15,000
1945	15,550	12,400	24,800	14,000
46	11,150	8,500	16,800	9,400
47	8,700	8,200	12,000	9,000
48	6,640	6,600	7,240	7,200
49	5,880	5,880	6,780	6,500
1950	3,910	3,910	4,510	4,400
51	2,750	2,750	2,950	3,000
52	47,010	10,000	61,800	11,000

Base period,	1923-44,	theoretical average seepage loss	11,200	acre-feet
Do. ,	1935-51,	do.	12,600	do.
	Average		12,000	do.
Dry period,	1929-36,	do.	7,200	do.
Do. ,	1946-51,	do.	6,400	do.
	Average		6,800	do.
Wet period,	1937-45,	do.	18,000	do.

a. Runoff at Railroad Canyon, Santa Margarita River.

De Luz Dam site (6,800 AF/YR) (Table)

The table suggests that the theoretical seepage losses below De Luz dam site range from essentially all the computed runoff during dry years, such as 1950 and 1951, to as much as 27,000 acre-feet in 1941. The theoretical losses of 4,400 acre-feet for 1950 and 3,000 acre-feet for 1951 agree very closely to the computed losses for the two years, which were 4,510 and 2,950 acre-feet respectively (table 29). A comparison of the theoretical seepage loss of 11,000 acre-feet in 1952 to the computed seepage loss of 14,000 acre-feet (table 29) or to the revised seepage loss of 10,000 acre-feet (table 39 and following pages) suggests that there may be fairly close agreement. However, because considerable potential recharge in 1952 was rejected and wasted to the sea, about 47,600 acre-feet (table 29), it is reasonable to expect that, if the stored water in the basins had been depleted substantially below that prior to the 1952 runoff, the seepage losses would have been larger. Thus, the possibility of the theoretical seepage losses approaching actual seepage losses under optimum conditions of basin operation appear to range from good in years of low runoff to fair in years of large runoff with the probability of increasing error as runoff increases. Based on the 1952 runoff data, it would appear that the theoretical seepage losses for years of large runoff might be conservative.

It has been shown that losses of 40 second-feet and more have been measured between De Luz dam site and Ysidora gage, so the theoretical seepage losses at this rate are known to be possible. A hypothetical sustained flow of 40 second-feet and sustained ground-water depletion would provide a recharge of about 2,400 acre-feet per month or about 29,000 acre-feet per year.

Table 41 suggests that theoretical average seepage loss was 6,800 acre-feet during the two dry periods 1923-36 and 1946-51. Based on the comparison in the above paragraphs, the theoretical average might approach closely the actual seepage losses in similar dry periods under conditions of basin depletion. However, the theoretical average seepage loss of 18,000 acre-feet for the one wet period 1937-45 is subject to considerable error not only because there is just one wet period to use, but also because of the probability of increased error in the method of estimating the theoretical seepage losses under conditions of large runoff.

Finally, the table shows that for the two base periods, 1923-44 and 1935-51, the average theoretical maximum seepage losses estimated for the reach below De Luz dam site would have been 11,200 and 12,600 acre-feet respectively and averaged about 12,000 acre-feet per year. This seepage loss is about 30 percent of the computed average annual inflow for the same base period. Based on the actual seepage losses measured along other large stream valleys in southern California, which have relatively long permeable channel reaches, substantial runoff, and depressed water levels beneath the channels, a seepage loss of 30 percent of the surface-water inflow appears quite reasonable.

Thus, under conditions of continued substantial storage depletion in the lower Santa Margarita River basin and with a long-term average runoff of nearly 38,000 acre-feet, it is believed that the estimated theoretical maximum seepage loss of nearly 12,000 acre-feet might be reasonably close to the actual losses under optimum conditions of basin operation.

Projected Perennial Yield

The term projected as applied to perennial yield, previously defined, is used in this report to suggest the order of magnitude of the yield of lower Santa Margarita River basin under optimum conditions of cyclic storage depletion and replenishment and with increased recharge by seepage loss and decreased natural discharge under those conditions. The increased recharge would be supplied from the river by salvage of a part of the rejected runoff, or potential recharge, which has wasted to the ocean.

The preceding estimates of the theoretical long-term average seepage loss of 12,000 acre-feet per year and the 500 acre-feet per year of other forms of recharge in excess of natural discharge occurring under conditions of optimum basin development and cyclic-storage operation, suggest that the average maximum pumpage for all uses from Chappo and Upper Basins could be 12,500 acre-feet per year plus the sewage effluent returned to ground water in the two basins.

Most critical, perhaps, would be the effect of a sustained pumpage of 12,500 acre-feet per year during a protracted dry period. For example, starting with a full basin in the 1922 water year and with an average annual theoretical seepage loss of 6,800 acre-feet during the 14-year period 1923-36 plus 500 acre-feet per year from other forms of recharge, by 1936 there would have been a storage depletion of: 14 x (12,500 - 7,300) or 73,000 acre-feet. This is 33,000 acre-feet more than the combined estimated storage capacities of Chappo and Upper Basins to a depth of 100 feet. However, this depletion does not take into account any sewage effluent returned to ground water, which in 1952 was on the order of 1,500 acre-feet. The suggested depletion would vary inversely with the amount of sewage effluent returned. If this return is used, and in all probability the return would be much larger with a pumpage of 12,500 acre-feet, the depletion would be reduced for the period 1923-36 to about 52,000 acre-feet, or about 12,000 acre-feet more than the usable storage capacity.

Thus, because the storage capacity of the basins is only 40,000 acre-feet, it is apparent that the projected perennial yield under conditions of no surface storage would be limited to a short-term yield during protracted dry periods. As is shown on plate 12, the protracted dry periods average about 15 years in length. Accordingly, if the returned sewage effluent is neglected, the projected perennial yield may be expressed as the average annual theoretical seepage loss during dry periods, plus the usable storage capacity divided by the number of years comprising an expectable dry period, plus the amount contributed annually by other forms of recharge in excess of the natural discharge; or:

$$\text{Projected perennial yield} = 6{,}800 + \frac{40{,}000}{15} + 500$$
$$= 10{,}000 \text{ acre-feet}$$

Thus, based principally on the theoretical average seepage loss, the projected perennial yield of the lower Santa Margarita River basin is about 10,000 acre-feet. It was indicated that the theoretical seepage loss figures were more accurate for dry periods than for wet periods. Accordingly, this estimate of yield, which is based principally on the seepage loss during the dry periods, is more accurate than an estimated long-term yield, which involves not only the estimates of theoretical seepage loss in periods of low runoff but also the less accurate estimates of theoretical seepage loss during periods of large runoff.

Ellis and Lee (1919, table 41) indicate that the yield of the basin is 4,570 acre-feet. However, this figure is based on an estimated storage capacity of only 13,700 acre-feet and was obtained by dividing the storage by a three-year period of no recharge. Because the method does not consider the recharge and discharge in conjunction with storage and because the estimated storage capacity is small, the result obtained is not a measure of the perennial yield.

Green (1943, typewritten report) estimated the yield during the acute 7-year dry period 1898-1904 to be 10,395 acre-feet. To derive this yield, Green estimated the surface-water inflow and assumed there would be no outflow. He also used an estimated storage capacity of 38,325 acre-feet for the upper 50 feet of the alluvium, which is considerably greater than that estimated in this report for the same zone (table 38). However, the figure is close to the 40,000 acre-feet used in this report for the full depth zone 5 to 100 feet below land surface. As a result the yield derived by Green for a dry period happens to agree very closely with the 10,000 acre-feet derived above.

In order to show the effect of a draft of 10,000 acre-feet, exclusive of returned sewage effluent, the theoretical seepage losses for the period of record (table 41) plus the 500 acre-feet supplied by other forms of recharge in excess of natural discharge have been used in conjunction with a pumpage of 10,000 acre-feet per year to obtain an accumulated net change in storage for the dry period 1923-36, and the results are shown in table 42. It is assumed that the basins are fully recharged at the beginning of the period in 1922.

Table 42.- Theoretical accumulated net changes in storage, in acre-feet, with a pumpage of 10,000 acre-feet per year in the water years 1923-52

Year ending Sept. 30	Theoretical recharge[1]	Theoretical recharge less pumpage of 10,000 acre-feet	Accumulated net change in storage	Amount remaining in storage
1922	--	--	--	40,000
23	5,500	-4,500	-4,500	35,500
24	7,300	-2,700	-7,200	32,800
1925	5,100	-4,900	-12,100	27,900
26	7,700	-2,300	-14,400	25,600
27	13,500	+3,500	-10,900	29,100
28	6,500	-3,500	-14,400	25,600
29	5,800	-4,200	-18,600	21,400
1930	8,300	-1,700	-20,300	19,700
31	5,600	-4,400	-24,700	15,300
32	13,500	+3,500	-21,200	18,800
33	7,700	-2,300	-23,500	16,500
34	5,700	-4,300	-27,800	12,200
1935	8,400	-1,600	-29,400	10,600
36	6,400	-3,600	-33,000	7,000
37	23,500	+13,500	-19,500	20,500
38	20,500	+10,500	-9,000	31,000
39	16,500	+6,500	-2,500	37,500
1940	12,500	+2,500	0	40,000
41	27,500	+17,500	a +17,500	40,000
42	16,500	+6,500	a +24,000	40,000
43	18,500	+8,500	a +32,500	40,000
44	15,500	+5,500	a +38,000	40,000
1945	14,500	+4,500	a +42,500	40,000
46	9,900	-100	-100	39,900
47	9,500	-500	-600	39,400
48	7,700	-2,300	-2,900	37,100
49	7,000	-3,000	-5,900	34,100
1950	4,900	-5,100	-11,000	29,000
51	3,500	-6,500	-17,500	22,500
52	11,500	+1,500	-16,000	24,000

1. Sum of theoretical seepage loss below De Luz dam site (table 41) and average estimated recharge from other sources of 500 acre-feet per year, not including any returned sewage effluent.

a. Theoretical waste to ocean.

Accumulated net change in storage. (Table 42)

The table shows that if the pumpage had been 10,000 acre-feet during the 14-year dry period 1923-36, storage might have been depleted by about 33,000 acre-feet, which is less than the 40,000 acre-feet of storage capacity estimated for Chappo and Upper Basins to a depth of 100 feet. Had the dry period continued another 3 years at the suggested average annual depletion rate of about 2,400 acre-feet, the storage capacity would have been equaled.

The table also suggests that in 1940 the basins would have been fully recharged--4 years after the end of the dry period. For the years 1941-45 an accumulated excess of about 42,000 acre-feet of rejected recharge would have wasted to the ocean. Thus, the usable storage capacity is a limiting factor to the amount of the projected perennial yield. For the following dry period, 1946-51, the depletion would have started again in the year 1946 which was the first year of deficient recharge since 1936. In 1951 the suggested accumulated net depletion would have been nearly 18,000 acre-feet.

The projected perennial yield of 10,000 acre-feet could be increased in two ways, as follows: (1) It could be increased by the establishment of a barrier to sea-water intrusion across Ysidora Narrows after the contaminated saline water had been expelled. This would permit the use of a larger range in usable storage capacity to at least the estimated 48,000 acre-feet in the three basins. The increased storage would permit greater storage depletion during a prolonged dry period and the yield could be increased accordingly; and (2) it could be increased directly by the amount of sewage effluent returned to ground water. In 1952 the return was about 1,500 acre-feet so the yield including sewage return at the 1952 rate was about 11,500 acre-feet per year. However, it has been indicated that the return of a substantial amount of sewage effluent year after year may have a deleterious effect on the quality of water. Accordingly, continued sampling of effluent and ground water should be made to determine the status of ground-water deterioration, if any.

Finally, the construction of a dam at De Luz dam site or elsewhere upstream would completely change the concept of perennial yield of the lower Santa Margarita River basin. The Nigger Canyon dam upstream on the Temecula River was completed in 1948, but there was no water in the reservoir until 1952. The preceding treatment of runoff, seepage loss, and perennial yield has been based on the actual measured or computed flow of the river without taking into account the operation of Nigger Canyon Dam. It is not known to what extent the operation of the dam will reduce the flow at De Luz dam site. Obviously, the perennial yield will be affected accordingly.

If the De Luz dam is constructed and the cut-off wall installed to bedrock, the projected perennial yield of the basin as estimated on previous pages will become meaningless. The yield then becomes a composite function of the coordinated operation of the ground-water basin and the surface-water reservoir.

Chemical Quality of Water

For the lower Santa Margarita River basin, chemical analyses of waters made by the Sanitation Division Laboratory, Eleventh Naval District, San Diego, are shown in tables 4C, 4D, and 4E; and those made by the Geological Survey are shown in tables 4A and 4B (in appendixes). The analyses include those taken from the river and the ocean, but chiefly are for samples taken from wells. Complete analyses are available for essentially all the supply wells, all the test wells, from the ocean, and from the river. Partial analyses, for which determinations for chloride, hardness, and specific conductance were made, have been obtained periodically from selected wells and are shown in table 4B.

Analyses of well waters include those taken from the alluvium, the San Mateo formation, the La Jolla formation, and the terrace deposits. The quality of water in these various formations is discussed below. Also, the principles of sea-water intrusion are discussed.

The Alluvium

The ground waters in the alluvium are from three sources: Native water derived from stream runoff and underflow, native water modified by seepage from the La Jolla formation into the alluvium, and sea water of modified character that has moved inland into the lower end of Ysidora Basin, discussed in a separate section.

The quality of surface and ground waters entering the basins is best shown by analyses from the river and from wells 10/4-5E1, 7E1, and 7H1 in Upper Basin (appendix 4). These waters are generally the sodium-bicarbonate type.[1/] A study of the analyses shows that the waters contain certain

1. In this report the type of water is based on the anions and cations whose percentage equivalents are predominant.

constituents in about the following concentration: Sodium, 125 ppm; bicarbonate, 250 ppm; chloride, 125 ppm; hardness, 250 ppm; and total dissolved solids, 650 ppm.

In moving downstream, the ground waters retain essentially the same character as far as the lower end of Chappo Basin. Below this point to about the middle of Ysidora Basin there is an increase in concentration of certain constituents. The analyses from wells 10/5-23J1, 23L1, 26L1, 35K1, and 35K5, and 11/5-2A1 and 2D1 show the progressive increase as follows: Sodium, 125 to 209 ppm; bicarbonate, 250 to 308 ppm; chloride, 125 and 134 to 200 ppm; hardness, 250 to 293 ppm; and total dissolved solids, 650 to 927 ppm. This increase in part is believed to be caused by seepage from the La Jolla formation into the alluvium and possibly in part from returned sewage effluent.

In general the quality is fair to good for domestic purposes--the quality in Upper and Chappo Basins being better than that in the upstream part of Ysidora Basin. With regard to hardness and total dissolved solids, the quality is about the same as untreated water of the Colorado River aqueduct.

Modified Sea-Water Intrusion

Principles of sea-water intrusion.--The basic principles regarding sea-water intrusion into a coastal valley or basin are very briefly as follows: (1) Because of a difference in specific gravity between sea water and fresh water, roughly 1.025 to 1, respectively, fresh water tends to "float" on sea water; (2) in places where the density differential is 1.025 to 1, the interface will be depressed about 40 feet below sea level for each foot of fresh-water head above sea level; and (3) the salt-water-fresh-water interface is usually sharply defined provided no appreciable fluctuations in head take place. However, the normal tide change and pumping from aquifers do cause head changes with the result that the interface moves alternately inland and seaward. The magnitude of the oscillation is dependent upon the magnitude of tidal and pumping fluctuations. As a result, the interface may become a zone of diffusion.

In Ysidora Narrows, a favorable seaward hydraulic gradient, which held the fresh-water-salt-water interface out of Ysidora Basin, was maintained until about the mid-1940's. From this time through 1951 the water levels in Ysidora Basin declined, the gradient was reversed, and the interface moved inland into Ysidora Basin. The amount of fresh-water head necessary to keep the interface out of Ysidora Basin can be determined for hydrostatic equilibrium by use of principle (2) above. For example, at well 11/5-2H4 in the narrows, the thickness of the water-bearing deposits (alluvium) below sea level is about 180 feet. Thus, to hold the interface seaward of this well, it can be computed that a minimum fresh-water head of 4.5 feet above sea level is necessary. However, it has been brought out by several theorists in recent years (Todd, 1953, pp. 749-754) that the application of the density ratio directly to determine depth to interface is strictly applicable only under static conditions of no ground-water movement. Under dynamic conditions of ground-water flow, the interface will be displaced. However, the degree of displacement from the 40:1 ratio ordinarily is not great when the hydraulic gradient is low as is the case in the lower Santa Margarita River basin.

Intrusion into Ysidora Basin.--The chemical quality of the waters taken in conjunction with the hydraulic gradients indicate sea water of modified character has moved inland as far as the lower end of Ysidora Basin rendering two wells, 11/5-2H1 and 2K1, unfit for use. The deterioration in quality of waters sampled from these wells has been gradual. Plate 30 shows a progressive increase in chloride content of waters from five wells in Ysidora Basin. The graph for well 11/5-2K1 shows an increase in chloride from about 250 ppm in 1947 to a maximum of 540 ppm in 1950. The well has not been used since 1947. Similarly well 11/5-2H1 shows an increase from about 175 ppm in 1947 to 250 ppm in 1949 at which time the use of the well was discontinued. In 1950 and 1951, the well was again used and the chloride content increased rapidly in a period of about 4 months from 160 to 300 ppm before the use of the well was again discontinued.

At the outset of the investigation it appeared that the high chloride might be caused by movement of water from the older marine formations such as the San Onofre breccia and/or the La Jolla formation into the alluvium and was settling, owing to its heavier density, in the lower part of the alluvium. However, data obtained from the test-well drilling program, special sampling tests outlined below, the hydrologic studies, and geologic mapping and study all confirm that the principal source of the high chloride water is by the inland movement of sea water of modified character.

Table 4A shows a sample of ocean water taken about a mile offshore from the mouth of the Santa Margarita River in October 1951 when there was no stream discharge. The concentration of calcium is 367 ppm, magnesium is 1,260 ppm, sodium is 10,300 ppm, chloride is 18,600 ppm, sulfate is 2,580 ppm, bicarbonate is 143 ppm and bromide is only 10 ppm.[1] Also shown in table 4A are analyses taken from selected wells during pumping or immediately thereafter with a mechanical sampler or "thief" from depths where vertical traverses showed the conductance was greatest. These vertical-traverse tests were run on wells 11/5-2M1, 2M2, 2M4, 10M1, and 9J1 before sampling to select the depth where waters from each had the highest concentration. The significance of these analyses, from nearest the coast to farthest inland, is given below.

The analysis for well 11/5-9J1, sampled at 289 feet, shows the following concentration of constituents: calcium, 577 ppm; magnesium, 1,420 ppm; sodium, 11,000 ppm; chloride, 20,300 ppm; sulfate, 2,380 ppm; bicarbonate, 102 ppm; and bromide, 75 ppm. This water is derived from the San Mateo formation and is more concentrated than sea water.

Well 11/5-10M1, sampled at 194 feet, taps only the alluvium, and the analysis shows the following concentrations: calcium, 201 ppm; magnesium, 100 ppm; sodium, 550 ppm; chloride, 1,210 ppm; sulfate, 231 ppm, bicarbonate, 236 ppm; and bromide is zero. The results obtained from this well suggest that the concentrated intruded water is probably passing close to this well. A prolonged period of pumping might cause the quality to deteriorate.

Well 11/5-2M4, sampled at 195 feet, penetrates only the alluvium and the analysis shows the following concentrations: calcium, 480 ppm; magnesium, 289 ppm; sodium, 2,500 ppm, chloride, 4,910 ppm; sulfate, 602 ppm; bicarbonate, 362 ppm; and bromide, 25 ppm. The character of this water is similar

1. Bromide concentration of only 10 ppm is unusually low for ocean water. Standard analyses of ocean water taken along the California coast indicate a bromide concentration of 65 ppm (Piper, Garret, and others, 1953, p. 238).

~~in character~~ to that of ocean water and quite similar to that in the San Mateo formation (well 11/5-9J1).

Well 11/5-2H1, sampled at 185 feet, taps only the alluvium and the analysis shows the following concentrations: calcium, 109 ppm; magnesium, 62 ppm; sodium, 532 ppm; chloride, 875 ppm; sulfate, 203 ppm; bicarbonate, 303 ppm; and bromide, 0. Compared to analyses of well waters nearer the coast, this analysis shows a considerable change in the sulfate and bicarbonate content, and indicates that sulfate reduction has taken place. However, the chloride concentration is relatively large.

Well 11/5-2K2, sampled at 248 feet, taps only the La Jolla formation and the analysis shows the following concentrations: calcium, 3.2 ppm; magnesium, 2.5 ppm; sodium, 282 ppm; chloride, 155 ppm; sulfate, 30 ppm; bicarbonate, 458 ppm; and bromide, 0. The concentrations of most constituents are entirely different in character from those aforementioned. A similar test was run on another well 10/5-23Q1, sampled at 280 feet, tapping only the La Jolla formation and the analysis shows the following concentrations: calcium, 51 ppm; magnesium, 4.0 ppm; sodium, 444 ppm; chloride, 600 ppm; sulfate, 99 ppm; bicarbonate, 140 ppm; and bromide, 0.

Table 42. shows the chemical analyses expressed in percentage equivalents so that the water types and ratios between constituents can be compared. The calcium-magnesium ratio of sea water is nearly 1 to 6, in well 11/5-9J1 is about 1 to 4, in wells in Ysidora Narrows and in the lower part of Ysidora Basin is about 1 to 1, and for native fresh waters upstream is about 2 to 1. For waters in the La Jolla formation the ratio is inconsistent (wells 10/5-23Q1 and 11/5-2K2).

Table 42a.- Chemical character of Pacific Ocean water and selected well waters in the lower Santa Margarita River basin

(See appendix, table 4A, for analytical data in parts per million)

Area and well number	Dissolved solids (ppm)	Cations (percentage equivalents)			Anions (percentage equivalents)		
		Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate[1] (HCO_3)	Sulfate (SO_4)	Chloride[2] (Cl)
Upper Basin							
10/4- 7R1	605	31.4	17.5	51.0	44.7	20.8	34.3
Chappo Basin							
10/5-14P1	722	32.4	15.2	52.6	35.6	11.2	53.2
23J1	607	29.1	16.9	54.1	47.0	18.8	34.2
23Q1	1,250	7.3	1.6	90.9	10.9	8.9	80.3
Ysidora Basin							
10/5-35R1	735	28.9	17.7	53.4	43.7	17.6	38.7
11/5- 2M1	1,970	16.0	15.0	68.8	14.7	12.4	72.8
2K2	723	1.0	2.0	97.0	61.7	4.8	33.6
Ysidora Narrows							
11/5- 2L4	9,030	15.2	15.1	69.7	3.8	8.0	88.3
10M1	2,440	23.6	19.3	57.0	9.0	11.2	79.9
Lagoon area							
11/5- 9M1	36,100	4.6	18.5	76.9	0.5	7.9	91.6
Ocean water	33,700	3.1	17.8	79.1	0.5	9.2	90.3

1. Includes carbonate (CO_3), if present.
2. Includes fluoride (F) and nitrate (NO_3), if present.

The sodium-magnesium ratio of sea water and in well 11/5-9J1 is about 4 to 1, and in wells in Ysidora Narrows and in the lower part of Ysidora Basin is about 4.5 to 1, except for well 11/5-10E1 which is about 3 to 1 or the same as the native fresh waters upstream. For wells 10/5-23Q1 and 11/5-2K2, tapping the La Jolla formation, the ratio is about 50 to 1.

The comparison of these ratios and others, such as calcium-sodium and bicarbonate-sulfate ratios, and the high chloride content indicate that the poor quality water in Ysidora Basin is of sea-water origin. Furthermore, it is concluded that this sea water entering the Ysidora Basin has undergone a change in character. Accordingly, it is called sea water of modified character or simply modified sea water.

With regard to the source of the modified sea water, plate 4 shows that the San Mateo formation underlies the alluvium from the Pacific Ocean inland nearly to well 11/5-10E1. With the decline of water levels during the late 1940's through Ysidora Narrows and the lagoon area, it is possible that some of the poor quality water (connate brines) in the San Mateo formation moved upward into the lower part of the alluvium and thence moved inland through the narrows. This possibility is suggested by the bromide content of waters from wells 11/5-9J1 and 11/5-2N4. That the water from well 11/5-10E1 contains no bromide and contains lower concentrations of the critical constituents than does well 2N4, suggests that waters from the San Mateo formation may be moving into Ysidora Narrows through the slot between the knob of San Onofre breccia south of well 10E1 and Vandegrift Boulevard (pl. 1). If so, the most highly saline water would be largely bypassing well 11/5-10E1 and moving directly up Ysidora Narrows to Ysidora Basin. Thus, it is probable that a part of the intruded modified sea water has been derived from the San Mateo formation and a part from sea water moving inland from the coast entirely through the alluvium. For a more detailed treatment, Piper, Garrett, and others (1953) in their work on the quality of water in the Long Beach-Santa Ana area, California, have described in considerable detail the changes in quality of intruded sea water and connate brines.

A study of the geology, the data obtained from test well 11/5-2P1 drilled in the San Onofre breccia, and the hydraulic gradients through Ysidora Narrows precludes the possibility of the modified sea water entering Ysidora Basin by any route other than through the alluvium. The precise location of the inland front in 1951 and 1952 is not known, but the 250 ppm chloride contour is known to be between wells 11/5-2K1 and 2A1 on the east side of Ysidora Basin and between wells 11/5-2E1 and 2D1 on the west side (pl. 30). Samples taken from 2E1 since pumping stopped early in 1950 have been from the pump discharge after 30 minutes of pumping and should be representative, but do not indicate the maximum concentration of the water withdrawn but that of the over-all blend. Obviously, continued heavy draft from wells 10/5-35K1, 11/5-2A1, and 11/5-2D1 during a dry period of small recharge would cause the front to move toward them and eventually render the wells useless. An over-all general increase in chloride content of waters from these wells is indicated graphically on plate 30.

Supply and irrigation well 11/5-2F1, which is within the area of intrusion, has not become appreciably contaminated. This can probably be explained by the fact that the well is only 153 feet deep, is perforated 118 to 153 feet, and overlies the thickest part of the alluvium which at this point is 190 to 195 feet. The modified sea water has probably moved inland beneath this well and has contaminated well 11/5-2E1 which is 192 feet deep and perforated 150 to 190 feet. The vertical conductivity traverses run on well 2M1 indicate a steady increase of total dissolved solids from about 1,250 ppm at 150 feet to about 2,000 ppm at 185 feet. If the steady increase is applied to the chloride content, which during the pumping averaged 520 ppm and reached amximum at 185 feet of about 850 ppm, it can be estimated that the chloride content at 150 feet was roughly 200 to 250 ppm. Thus, because well 11/5-2M1 taps water at relatively shallow depth, it has not become contaminated; however, with continued heavy pumping the contaminated water in the lower part of the aquifer may be drawn upward into the well.

A study of the vertical conductivity traverses indicates that modified sea-water contamination occurs between depths of 130 and 300 feet (bottom of well) in well 11/5-9J1, 160 and 200 feet (base of the alluvium) in well 11/5-10E1, 160 and 197 feet (base of alluvium) in well 11/5-2M4, and about 150 and 192 feet in well 11/5-2M1. Thus, in Ysidora Narrows the modified sea water is moving inland through about the lower 40 feet of the lower member of the alluvium, which the well logs indicate is the coarsest part.

Possible remedial measures.--In order to salvage Ysidora Basin as a useful ground-water reservoir and source of supply, the following remedial measures are suggested: (1) Except for emergencies, discontinue pumping from the basin to permit water levels to recover as fully as possible. This would establish a maximum permanent seaward hydraulic gradient which in turn would cause the modified sea water to move out through Ysidora Narrows; (2) the water levels and hence the seaward hydraulic gradient could be increased artificially by spreading treated sewage effluent in the Santa Margarita River channel between wells 10/5-35K1 and 11/5-2D1; (3) with water levels recovered to the point where the hydraulic gradient is sustained at essentially the same position as in March 1932, or about

7.0 feet per mile, it has been shown that about 150 acre-feet per year would move seaward as ground-water outflow. A part of this outflow would be the modified sea water. Based on the length of time the intrusion has been occurring and on the estimated amount of intrusion in the period 1946-51, it would take roughly 5 to 10 years to force the undesirable water seaward as far as well 11/5-2N4; and (4) a physical barrier could be constructed in Ysidora Narrows. However, any attempt to construct a physical barrier prior to the flushing out of the modified sea water, whether by water spreading in the Narrows, water injection into wells, or a cut-off wall in Ysidora Narrows, would result in the entrapment of the intruded modified sea water inland. After the modified sea water had been driven downstream into the narrows, then a physical barrier could be established. The effectiveness of the barrier would determine the magnitude of the future pumpage from Ysidora Basin.

The La Jolla Formation

The analyses of waters from test wells 10/5-23Q1 and 11/5-2K2, drilled entirely in the La Jolla formation, show that the types are sodium chloride and sodium bicarbonate, respectively (table 42a). The percent sodium is over 90--too high for irrigation use. The chloride content ranges from 155 to 600 ppm, hardness from 13 to 161 ppm, and total dissolved solids from 650 to 1,334 ppm. Because of its relatively poor quality and poor water-yielding properties, the La Jolla formation should not be considered as a source of supply.

The effect of water seeping from the La Jolla formation into the alluvium on quality of water in the alluvium, also the evidence that the waters in the La Jolla formation can not be the source of the high chloride waters in the alluvium at the lower end of Ysidora Basin have been discussed in the preceding pages.

The San Mateo Formation

The analyses of water from test well 11/5-9J1, in the lagoon area, and from test well 11/5-4H1, on the terrace to the north, which in their lower parts tap the San Mateo formation, show that the types of water vary considerably (tables 42a, 4A, and 4C). Well 11/5-9J1, from which a sample was taken at a depth of 289 feet with a mechanical sampler, yielded water of a sodium-chloride type and very high in sodium, magnesium, chloride, and sulfate. In over-all character it is a concentrated sea-water type. Well 11/5-4H1, sampled at the test-pump discharge, yielded moderately saline water of a calcium-sodium chloride type with about 4,500 ppm of dissolved solids, too concentrated for domestic or irrigation use.

The Terrace Deposits

Test well 10/5-13C1, in Chappo Basin, was drilled entirely in the terrace deposits. The analysis of this water, in ppm, is as follows: sodium 70 (computed), calcium 48 (computed), chloride 120, bicarbonate 132 (computed), and total dissolved solids 350 ppm. The quality is very good, but the well is not fully developed and yields only about 5 gpm.

SAN MATEO CREEK BASIN

Areal Extent

San Mateo Creek basin embraces the valleys of Cristianitos and San Mateo Creeks, and is limited principally by the areal extent of the alluvium except that in the lower segment it includes in addition a part of the adjacent San Mateo formation (pls. 1 and 28). The upstream ends of the basin have been set arbitrarily in Cristianitos Creek just below the reservation boundary at the junction of Talega Creek and in San Mateo Creek just below the reservation boundary. These upstream parts of the basin are about 5 and 10 river miles respectively from the Pacific Ocean. The junction of Cristianitos and San Mateo Creeks is nearly 3 miles from the ocean. In width the basin ranges from as little as 400 feet in the upper reaches to as much as 6,000 feet near the coast, including the alluvium and about 1,000 feet of San Mateo formation on either side.

The surface area of the San Mateo Creek basin is about 3,000 acres of which nearly 2,500 acres is alluvium and channel deposits and 500 acres is the San Mateo formation. The alluvium in Cristianitos Creek covers about 250 acres, in San Mateo Creek above the junction covers about 1,100 acres, and in the coastal segment below the junction it also covers about 1,100 acres. In Cristianitos Creek, the area of San Mateo formation on the west side is believed to be underlain at very shallow depth by the Capistrano formation, and therefore it would supply little ground water to the basin. Accordingly, this area has been excluded from the San Mateo Creek basin, and the boundary is shown along the contact between the alluvium and the San Mateo formation (pl. 28).

Occurrence of Ground Water

In San Mateo Creek basin ground water is obtained most readily from the alluvium and locally from the San Mateo formation. Most wells are in the lower part of the basin and derive water from both the alluvium and underlying San Mateo formation. Upstream where the San Mateo formation is absent, the few wells obtain their supply wholly from the alluvium. The city of San Clemente wells, 9/7-10A1-3, obtain water wholly from the San Mateo formation.

The wells in San Mateo Creek basin tap a common ground-water body which extends from the upper end of the basin to the Pacific Ocean. Above the junction of Cristianitos Creek the sides and bottom of the basin and of the water body are formed by the essentially non-water-bearing rocks of lower Pliocene to Cretaceous age; below the junction the water-bearing beds of the San Mateo formation extend to considerable depth so the position of the bottom of the basin is not known. Possibly water of poor quality at depth in the San Mateo formation restricts the usable depth of the basin. Accordingly, because of the possibility of poor quality at depth and because of the potential threat of sea-water intrusion, the bottom of the usable portion of the basin has been set arbitrarily at sea-level datum. Laterally, the San Mateo formation extends northwest and southeast away from the pumped area for several miles. However, the effective lateral limit of the basin has been arbitrarily set at 1,000 feet beyond the sides of the alluvium (pl. 23). The fluctuation of water level in test well 9/7-11F1, drilled in the San Mateo formation about 1,000 feet west of the alluvial contact, shows responses to basin depletion and to creek recharge indicating that the basin extends laterally at least 1,000 feet away from the alluvium.

There is some evidence that a shallow water body exists at the coastal end of the basin, but it is of minor extent and consequence. Thus, it is not shown on the water-level contour maps. Observations of stream flow indicate that essentially all the basin is a recharge area and that stream losses occur from the upper end of the basin downstream to the stream gage near U. S. Highway 101. Rainfall infiltration can probably take place in the area upstream from the highway. Some clay and silt in the upper part of alluvium near the coast may cause the water to be locally semiconfined (pl. 8). This is shown by the effect that tidal loading has had on the level in test well 9/7-14M1; pumping in well 9/7-11P1 strongly and quickly affects the level in test well 9/7-11P4, some 400 feet to the south.

Source and Movement of Ground Water

The direction of ground-water movement in San Mateo Creek basin is shown by water-level contours drawn on the surface of the water body. The contours on plates 21 and 22 show respectively the movement of water in October 1951 after a considerable depletion of ground water, to historic low levels so far as is known, and in June 1952 after considerable recharge and rise in water levels to a position that may be reasonably close to the highest potential levels in the lower end of the basin and that completely filled the upper reaches of the basin.

Both sets of water-level contours show that ground water was moving from the upper end of the basin downstream to the coast. Because the direction of movement indicates not only the source of the ground water but also the areas of discharge, the contours show that Cristianitos and San Mateo Creeks form the principal source of recharge along their channels and that ground water is discharging by natural seaward movement at the coast or offshore where the water-bearing deposits are in contact with the ocean.

In October 1951 the hydraulic gradient from the upper end of San Mateo Creek to the junction of Cristianitos Creek was 300 feet in 6.1 miles, or nearly 50 feet per mile; in Cristianitos Creek the gradient was 65 feet per mile; and below the junction between the 5- and 15-foot contours was only 5.5 feet per mile. Following the large recharge in the winter of 1952, the contours on plate 22 show that the gradients in June were: 45, 50, and between the 10- and 60-foot contours, 24 feet per mile respectively.

The contours as drawn for October 1951 suggest that water was moving laterally into the alluvium from the San Mateo formation along the east side of the basin indicating recharge from that source. Along the west side, however, the contours as drawn suggest westward movement locally toward the city of San Clemente well field (9/7-10A1-3). The "static" levels in the city wells in 1951 were about at sea level and the level in test well 9/7-11F1 was about 12 feet above sea level. There is no known barrier between the basin and the city wells. Thus, it is likely that a substantial part of the supply for the city wells is from San Mateo Creek basin.

The contours as drawn for June 1952 suggest that water is moving laterally from the alluvium into the adjacent San Mateo formation along the sides of the basin. Thus, the ground water, which had been stored in the San Mateo formation prior to the dry years 1945-51 and which was depleted during the dry period, was largely replenished during the wet winter of 1952. Along the west side of the basin, a relatively steep gradient appears to have developed between the basin and the city of San Clemente wells suggesting additional recharge to the well field.

Recharge to Ground Water

Recharge to the San Mateo Creek basin is principally by seepage loss from San Mateo and Cristianitos Creeks with lesser increments supplied by infiltration of rain and by returned sewage effluent. Recharge by ground-water underflow at the upstream ends of the basin in Cristianitos and San Mateo Creeks is very minor because the deposits are very thin and are not fully saturated part of the time. Accordingly, the underflow is included in the estimates of the recharge by seepage loss from the streams. Thus, recharge is limited to estimates of seepage loss from San Mateo and Cristianitos Creeks, infiltration of rain, and returned sewage effluent.

Seepage Loss in San Mateo Creek Basin

The surface-water inflow to the San Mateo Creek basin less the surface-water outflow at the coast is the measure of the recharge by seepage loss from Cristianitos and San Mateo Creeks. As was indicated in the section on surface-water resources, stream gages installed in 1950 on the two creeks measure most of the inflow and a gage installed in 1946 near U. S. Highway 101 measures the outflow (pl. 28). In San Mateo Creek the seepage loss can take place from the upper end of the basin at least as far downstream as the lower stream gage--a distance of about 9 miles. In Cristianitos Creek the seepage loss can take place from the upper end of the basin downstream to the junction with San Mateo Creek--a distance of over 2 miles.

The magnitude of the seepage losses is limited by the time distribution and amount of runoff, by the ability of the deposits to transmit water away from the creek beds, and by the storage space available in the water-bearing deposits at times when there is runoff in the creeks. Of these limiting factors, the amount of runoff in the stream system appears to be the most critical. The records of water-level fluctuations show that the winter recharge is absorbed rapidly into the ground-water body and drains readily to the lower part of the basin where most of the pumping wells are located. Thus, with a large pumping draft and a consequent storage depletion, a relatively large seepage loss can be expected during years of substantial runoff.

The computed annual inflow to San Mateo Creek basin in the water years 1923-52 is shown in table 17, and the measured and estimated annual outflow in the water years 1939, 1940, and 1947-52 is shown in tables 19 and 20. The seepage loss indicated in these years is shown in table 43.

Table 43.- Estimated seepage loss, in acre-feet, from San Mateo Creek system in the water years 1939-53

Year ending Sept. 30	Computed inflow 1/	Outflow 2/	Estimated seepage loss
1939	12,000	4,200	7,800
1940	10,000	5,100	4,900
41	48,000	--	--
42	9,400	--	--
43	27,000	--	--
44	13,000	--	--
1945	11,000	--	a --
46	7,700	--	a --
47	3,700	50	a 3,650
48	2,000	0	2,000
49	3,100	0	3,100
1950	1,700	0	1,700
51	1,100	0	1,100
52	30,000	22,850	7,150
Total, 1947-52			18,700
6-year average, 1947-52			3,100

1. From table 17.
2. From tables 19 and 20.
a. Hydrographs suggest basin fully recharged in the spring of the year.

For the water years 1947-51, the table shows that essentially all the inflow was retained as recharge by seepage loss along the creek channels. In the years 1939, 1940, and 1952 of larger runoff, the computed seepage loss was about 65, 49, and 24 percent of the inflow. The remainder wasted to the ocean as surface-water outflow. The relatively large seepage loss in 1952 of about 7,200 acre-feet was possible because of the large inflow and because of the large storage space made available by the ground-water depletion in the preceding dry years 1948-51.

Deep Penetration of Rain

The same methods used for determining the infiltration of rain on the lower Santa Margarita River basin were applied to the San Mateo Creek basin. There is roughly 700 acres of phreatophytes in the basin which thrive on and largely consume the relatively small yearly rainfall. This leaves 2,300 acres where the deep penetration of rain takes place of which about 800 acres is irrigated, about 1,000 acres is covered by grass, and nearly 500 is covered by brush. The brush lands are largely restricted to the areas bordering the alluvium and underlain by the San Mateo formation in the lower part of the basin.

The rainfall records and assumptions used are the same as those for the lower Santa Margarita River basin (table 31). The rainfall is doubtless heavier in the upper reaches of San Mateo Creek, but probably would not change the results materially. Table 44 shows the estimated deep penetration of rain in the water years 1931-52.

Table 44.- Estimated yearly recharge, in acre-feet, by deep infiltration of rain in San Mateo Creek basin in the water years 1931-52 1/

Year ending Sept. 30	Recharge	Year ending Sept. 30	Recharge
1931	20	1942	0
32	400	43	600
33	0	44	50
34	0	45	0
35	600	46	0
1936	0	1947	0
37	600	48	0
38	300	49	0
39	100	50	0
40	0	51	0
41	2,800	52	800
Total			6,300
22-year average, 1931-52			250
17-year base period, 1935-51			300

1. Rainfall shown in table 31.

The table suggests that, based on the 17-year base period 1935-51, the long-term annual deep infiltration of rain is on the order of 300 acre-feet. During the dry periods, such as that from 1944 through 1951, there may be essentially none. On the other hand, during wet periods such as 1935-43, the data suggest that the infiltration may average as much as 550 acre-feet per year.

Returned Sewage Effluent

No records have been kept of the raw sewage discharged to the basin from the septic tanks near Tent Camp 3 in Cristianitos Creek (pl. 28). It is reported that new Camp San Mateo, now under construction, will have a sewage treatment plant and will meter the treated effluent. The Public Works Office believes that the septic-tank discharge has been in excess of 50 percent of the pumpage for Tent Camp 3. Table 46 suggests that the pumpage for the period 1944-52 has ranged from 75 to 300 acre-feet per year. Possibly as much as 50 percent of the pumpage has been returned to ground water by septic-tank discharge. Thus, it is estimated that the sewage returned to ground water has ranged from about 40 to 150 acre-feet per year.

Total Recharge

The total recharge to ground water in San Mateo Creek basin is estimated for the water years 1947-52 for which all elements of recharge are available. The estimated total yearly recharge, which is the sum of seepage loss, infiltration of rain, and the returned sewage effluent, is shown in table 45.

Table 45.- Estimated total recharge, in acre-feet, to San Mateo Creek basin in the water years 1947-52

Year ending Sept. 30	Total recharge
1947	3,700
1948	2,000
1949	3,200
1950	1,800
1951	1,200
1952	8,100
Total	20,000
6-year average	3,300

The estimated total recharge decreased from 3,700 acre-feet in 1947 to 1,200 acre-feet in 1951; in 1952 it was about 8,100 acre-feet. The progressive depletion of storage from 1948 to 1951 provided storage space for the large recharge in 1952. A comparison of the total recharge with the several elements in the 6-year period 1947-52 suggests that seepage loss was nearly 95 percent of the total for the period.

Ground-Water Discharge

Pumpage

In San Mateo Creek basin, ground water is pumped for irrigation and Camp supply. Approximately 800 acres of land are irrigated, the bulk of which is on the alluvial plain below the junction of Cristianitos Creek. Minor areas are irrigated on the terraces near the coast along the east and west sides of the valley and on the alluvium in the lower parts of Cristianitos and San Mateo Creeks.

Records of pumpage for Camp supply and irrigation are available for the 5-year period 1948 through 1952, and were obtained from the Public Works Office, Camp Pendleton. It is reported that the Camp pumpage is metered at some of the wells or storage facilities and estimated where not metered. Pumpage for irrigation is estimated by the lessees on the basis of pumping rate of well and length of time pumped.

For water years prior to 1948 the pumpage has been estimated. Pumpage for Camp use during the war years 1944 and 1945 is estimated as being about the same as in 1952 when Tent Camp 3 was essentially filled; in 1947 it is estimated at the rate of the following year; and in 1946 is estimated to be about the average of that in 1945 and 1947. Pumpage for irrigation for the dry water years 1944 through 1947 is estimated as the average of the four dry years 1948 through 1951.

It was suggested that ground-water movement from San Mateo Creek basin toward the city of San Clemente wells 9/7-10A1-3 appeared likely. The wells are probably deriving a substantial part of their supply from the basin. Accordingly, it is assumed that one-half of the supply for the city wells is from the basin and that the remainder is from other sources. The pumpage from the city wells has increased from 300 acre-feet in 1940 to 760 acre-feet in 1952. The recorded and estimated pumpage for Camp supply, irrigation, and about one-half of the city of San Clemente supply in the water years 1944-52 is shown in table 46.

Table 46.- Ground-water pumpage, in acre-feet, from San Mateo Creek basin in the water years 1944-52

Year ending Sept. 30	Pumpage		Total 1/	City of San Clemente 2/	Grand total 1/
	Camp supply	Irrigation			
1944	a 300	a 1,200	a 1,500	220	b 1,700
1945	a 300	a 1,200	a 1,500	200	b 1,700
1946	a 200	a 1,200	a 1,400	240	b 1,600
1947	a 120	a 1,200	a 1,300	250	b 1,600
1948	122	1,400	1,500	260	1,800
1949	112	1,100	1,200	300	1,500
1950	75	1,200	1,300	320	1,600
1951	144	1,200	1,300	360	1,700
1952	285	800	1,100	380	1,500
Total	1,660	10,500	12,100	2,530	14,700
9-year average	180	1,150	1,300	280	1,600

a. Estimated.
b. Estimated in part.
1. Rounded to nearest 100 acre-feet.
2. One-half the city pumpage. It is assumed that one-half the supply to city wells is from San Mateo Creek basin and one-half from other sources.

The table shows that the total pumpage has ranged from about 1,500 acre-feet in 1952 to 1,800 acre-feet in 1948 and has averaged 1,600 acre-feet for the 9-year period. Pumpage for irrigation has averaged nearly 7 times as much as that for Camp supply. The pumpage is supplied from 12 irrigation wells and 4 Camp supply wells in San Mateo Creek basin (table 1A). In the future most of the Camp supply will probably be obtained from new wells 9/7-11H2 and 9/7-11K1 (pl. 1).

The duty of water applied to about 800 acres of irrigated land ranged from about 1 foot per acre in 1952 to about 1.8 feet per acre in 1948. Because of this relatively low duty of water and because the deposits immediately underlying the main irrigated area are relatively fine grained, the percent of irrigation water that returns to ground water by deep penetration may be small. No estimate of the return is made in this report.

Natural Discharge

Evapotranspiration.--Evapotranspiration from areas of phreatophytes occurs in and along the channels of San Mateo and Cristianitos Creeks and in the area coastward from U. S. Highway 101. It is estimated from aerial photos that there is about 700 acres of phreatophytes. These plants, which depend on ground water for their principal supply, seem to have existed largely on small rainfall and runoff during the dry years even though water levels were far below the land surface (pl. 8).

By use of the same methods applied to similar areas of phreatophytes in the lower Santa Margarita River basin, estimated evapotranspiration loss was derived for the San Mateo Creek basin. The loss during the base period 1935-51 may have ranged from as little as 600 acre-feet in the wet year 1940-41 to as much as 1,600 acre-feet in some dry years. However, owing to the considerable depth to water in the upstream parts of the basin during the latter part of prolonged dry periods, the consumption of ground water probably decreases to less than 1,400 acre-feet per year. During the period 1946-51, the evapotranspiration loss may have ranged from 1,600 acre-feet in 1946 when water levels were relatively high to 1,200 acre-feet in 1951 when water levels were low.

Ground-water outflow and overflow.--So long as there is a favorable seaward hydraulic gradient, as there has been in the past, ground-water discharge takes place by underflow or outflow through the alluvium and San Mateo formation into the Pacific Ocean. The outflow takes place through a large cross-sectional area of the deposits--the width is at least 1 mile, but the depth is unknown. Thus, the amount of outflow can not be directly determined.

Ground-water overflow in San Mateo Creek basin takes place principally in the stream bed near the coast. It is caused by a combination of two physical conditions. First, the alluvium and/or the San Mateo formation become fine grained near the coast which indicates a natural decreased permeability in a downstream direction. Second, following a year when the basin has been essentially fully recharged, the hydraulic gradient is relatively steep. During the period of high levels, the amount of ground water moving down gradient exceeds the ability of the less permeable deposits near the coast to transmit the water with the result that the excess is discharged into the stream bed or into pond areas.

This condition occurred in the spring and early summer of 1952 when the creek was dry below the junction of Cristianitos Creek for a distance of a mile or more and then flow appeared in the vicinity of the stream gage. The flow increased toward the coast and discharged into the ocean.

On several occasions in the early summer of 1952 the flow at U. S. Highway 101 bridge was estimated between 0.5 and 1 second-foot. The discharge was probably greater near the beach. It is probable that a part of the overflow was recorded by the lower San Mateo Creek stream gage thereby reducing the estimated seepage loss derived by subtracting the surface-water outflow at this station from the computed inflow.

Thus, the amount of discharge by ground-water outflow and overflow can not be directly determined. However, it can be crudely estimated by subtracting all other estimates of discharge from the estimated total recharge in a period for which all other data are available. As is indicated in the section on the hydrologic equation for the period 1947-52, by the use of the recharge and discharge as compared to ground-water storage change, the ground-water outflow and overflow were determined by difference and found to average roughly 1,300 acre-feet a year for the period.

The amount of outflow and overflow in any one year would depend directly on the hydraulic gradient and the fullness of the ground-water basin. Overflow probably occurred only in the two years 1947 and 1952 when the basin was nearly full. Therefore the bulk of the discharge was by ground-water outflow to the sea. The hydraulic gradients at the coast in 1951 and 1952 were 5.5 and 24 feet per mile, respectively (pls. 21 and 22), indicating that the outflow in 1952 was over four times that in 1951.

Total Discharge

The total discharge of ground water from San Mateo Creek basin is the sum of the pumpage, the evapotranspiration, and the ground-water outflow and overflow. Of these, estimates of pumpage for Camp supply, irrigation, and one-half that for the city of San Clemente, and estimates of evapotranspiration are presented in table 47. No estimates of ground-water outflow or overflow are included in the table.

Table 47.- Estimated discharge by pumpage and evapotranspiration, in acre-feet, from the San Mateo Creek basin in the water years 1944-52

Year ending Sept. 30	Discharge	Year ending Sept. 30	Discharge
1944	3,000	1949	2,900
1945	3,200	1950	2,900
1946	3,200	1951	2,900
1947	3,200	1952	2,500
1948	3,300		
Total			27,100
9-year average			3,000

The table shows that, except for the water year 1952, the discharge by pumpage and evapotranspiration has been about 3,000 acre-feet per year. The low discharge in 1952 is attributable to the above-average rainfall and consequent low evapotranspiration loss and pumpage for irrigation.

The total discharge, which includes pumpage, evapotranspiration, and crude estimates of ground-water overflow and outflow, has been derived in the section on the hydrologic equation for the period 1947-52. The total discharge was estimated to be about 25,000 acre-feet or averaged about 4,200 acre-feet a year (table 50). Of this average about 1,300 acre-feet was computed by difference to be ground-water outflow and overflow.

Water-Level Fluctuations

The water-level fluctuations in wells in San Mateo Creek basin show a wide range between the historic low in October 1951 and the near historic high in June 1952 (pls. 8, 21, and 22). Section O-O' (pl. 8) shows that as a result of the recharge in 1952 in San Mateo Creek upstream from well 9/7-1F1, the water level rose between 25 and 40 feet, and downstream from well 1F1 the level rose as much as 45 feet to as little as 6 feet in well 9/7-14M1 near the coast. Section P-P' (pl. 8) shows that in Cristianitos Creek the level rose between 40 and 60 feet. For more detailed records of water-level fluctuations in observation wells refer to table 3A.

Long-Term Fluctuations

Records of water-level fluctuations are available from 1945 to date, and the hydrographs for 10 wells are shown on plates 31 to 33. In the upper part of San Mateo Creek above the junction of Cristianitos Creek and in Cristianitos Creek, the graphs for wells 9/6-5M1 (pl. 31) and 8/7-36M1 (pl. 32), respectively, show the character of the fluctuations. The graph for well 5M1 shows a net decline from the spring peak in 1947 to the summer low in 1951 of about 36 feet and a subsequent rise to the spring peak of 1952 amounting to about 38 feet. These levels were about 8, 44, and 6 feet, respectively, below land surface. The graph for well 8/7-36D1 showed a drawdown in 1950 that reached a maximum depth below land surface of 67 feet; the level recovered in the spring of 1952 to 8 feet below land surface, as is shown by the graph (adjusted) of well 8/7-36M1--a net recovery of about 60 feet.

The composite hydrograph for wells 9/7-1M1 and 2J1 (pl. 31), near the upper end of the main pumped area below the junction of Cristianitos Creek, shows the greatest fluctuation from 1951 into 1952, whereas that for well 9/7-14M1 (pl. 33) near the coast shows the least fluctuation for that period. The graph for wells 9/7-1M1 and 2J1 shows that a decline began in 1947 and reached a low in the fall of 1951. The level at that time was only 15 feet above sea level and about 55 feet below land surface. Following the wet winter of 1952, the level rose to more than 63 feet above sea level and the depth to water was within 11 feet of the land surface--a rise of 48 feet. The graph for well 9/7-14M1 shows that the levels rose from a low in 1951 of a little more than 3 feet above sea level to a high in the spring of 1952 of nearly 9 feet above sea level--a net rise of only about 6 feet. The level rose to more than 10 feet above in the fall of 1952 suggesting a delay in response to the winter recharge of 1952. The graphs for wells 9/7-11P3 (pl. 32) and 14F1 (pl. 33) show fluctuations that are intermediate between those in the upper and lower ends of the main pumped area.

Thus, except for seasonal changes in response to pumping and recharge, the hydrographs show that the basin was nearly full in 1945, that thereafter a general decline occurred to a maximum depletion in 1951, and that the basin was nearly fully replenished during the winter of 1952. The depletion in the upper part of San Mateo Creek where there is no pumping is due principally to natural downstream drainage of ground water and partly to evapotranspiration. There was some pumping in Cristianitos Creek valley, but it is believed that a substantial part of the depletion was due to natural drainage. In the lower part of the basin, most of the depletion was caused by pumping, but a part was due to natural seaward drainage of ground water. Therefore, the upper parts of the basin form natural reservoirs that supply by relatively slow drainage the main pumped area downstream; that part of the drainage not withdrawn by pumping or consumed by evapotranspiration moves toward the ocean.

Finally, the hydrographs show that upstream from about the middle of the lower part of the basin, recharge to ground water occurs readily and rapidly whenever there is water in the creeks. In some instances the rise in water level was at a rate of as much as 25 feet per month or nearly 1 foot per day.

Fluctuations Caused by Tides

An automatic water-level recorder was operated on test well 9/7-14M2 from March 26 to July 7, 1952. The effects of tidal loading and/or pressure on the confined aquifers caused daily fluctuations ranging from 0.15 foot to 1.8 feet. On June 8 the range was 0.16 foot to 1.08 feet and the tide range was 1.7 feet to 8.8 feet indicating a tidal efficiency of 1 to 10 and 1 to 8, respectively. The tidal fluctuations in the well are so large that they nearly mask the pumping effects caused by wells 9/7-14F1 and 14L1.

A recorder was operated from May 19 to June 16, 1952, in shallow well 9/7-14M1, which is only 25 feet deep and is about 0.6 mile from the ocean, and the graph shows that there was no effect from tidal loading or pressure effects; there was a steady decline amounting to only 0.35 foot for the period.

Fluctuations in Paired Shallow and Deep Wells

Shallow well 9/7-1412 was augered to a depth of 17 feet and $1\frac{1}{2}$-inch pipe installed by the Geological Survey. This well is 55 feet northwest of irrigation well 9/7-1411, which is 80.6 feet deep. The hydrographs for the two wells (pl. 34) show that the water level in each responds about equally to seasonal recharge and pumping. The water level in the shallow well usually lags behind that in the deep well. The recharge in 1952 caused the shallow level to rise about 2 feet above the deep level.

Only a small drawdown was observed in the shallow well when the deep well was pumping which indicates that the instantaneous effects of pumping or change in head of the deep water level does not affect the shallow level immediately, at least on the east side of the valley. However, because the seasonal changes due to pumping and recharge affect both shallow and deep levels about equally, vertical interconnection does exist.

Ground-Water Storage Capacity

Storage Units and Depth Zones

The San Mateo Creek basin was divided into four major storage units, shown on plate 25, as follows: (1) Upper San Mateo storage unit, which extends from the junction of Cristianitos Creek upstream nearly to the Camp boundary and which has a surface area of about 1,100 acres. The terrace deposits along the north side are believed to be thin and have been omitted from the unit; (2) Cristianitos storage unit, which extends from near the junction with San Mateo Creek upstream to the junction with Talega Creek and which has a surface area of about 250 acres; (3) lower San Mateo storage unit, which is delimited by the alluvium and extends from the Pacific Ocean upstream to the Cristianitos Creek unit and which has a surface area of about 1,100 acres; and (4) San Mateo lateral storage unit, which extends along both sides of the alluvium in the lower San Mateo Creek valley and which has a surface area of about 500 acres. The tongues of alluvium extending up minor tributaries have been excluded. The selection of the lateral limits for unit (4) above have already been discussed.

The depth zone used in the computations of the volumes of deposits in storage units (1) and (2) above is from 5 feet below land surface to the bottom of the alluvium; for storage unit (3) is from 5 feet below land surface down to sea level; and for storage unit (4) is between the plane formed by the top of storage unit (3) projected laterally into the San Mateo formation and sea level. Storage units (3) and (4) are wedge shaped and have zero thickness at the coast and attain maximum thicknesses at their upper ends.

Because insufficient data were available to construct an accurate isopach map, the volumes of deposits in each storage unit were determined by measuring the average lengths, widths, and thicknesses. The average cross-sectional areas of storage units (1) and (2) above were assumed to be triangular in shape, which is probably a conservative measure of the cross-sectional areas. The average cross-sectional area of storage unit (3) above was determined by assuming a triangular cross-sectional area at the upper end to about mid-way down the storage unit and a rectangular cross-sectional area from there to the ocean. The cross-sectional area of storage unit (4) was assumed to be rectangular.

Specific-Yield Values

The specific yield of the deposits in the upper and lower San Mateo storage units and in the Cristianitos storage unit, which are composed of alluvium, was determined for each unit by use of the same methods applied in the lower Santa Margarita River basin, and the same specific-yield values were assigned to the five general types of material (table 37).

For the deposits of the San Mateo formation, which comprise the San Mateo lateral storage unit, a separate set of specific-yield values were assigned to the different types of material penetrated by the wells. On the basis of the logs obtained by the Geological Survey during the drilling of the test wells, the terms applied to the numerous different types of material penetrated have been grouped into five general classes of materials which have similar hydrologic properties. The specific-yield values assigned to the five classes of material are shown in table 48.

Table 48.- Specific-yield values assigned to the materials comprising the San Mateo formation

Material	Assigned specific yield (percent)
Gravel, including gravel and sand, usually poorly sorted	20
Sand, including sand and some gravel, usually silty and poorly sorted	15
Sand and silt, including fine silty sand and tight sand	10
Sand and clay	7
Clay, including clay and some silt, and silty clay	1

In general the types of material shown in table 48 resemble those for the alluvium (table 37). However, the materials are considerably tighter than those in the alluvium and usually contain silt. The sand and the gravel types are almost always poorly sorted and frequently the feldspar mineral grains have decayed somewhat. The clay is frequently almost a shale and is very well compacted. Thus, the values assigned are somewhat less than those given by Eckis (1934, pp. 95-96), especially those for sand.

Estimate of Storage Capacity

The estimates of ground-water storage capacity for the four storage units were derived by the same method outlined for the lower Santa Margarita River basin. Table 49 shows the estimated storage capacity in upper and lower San Mateo, Cristianitos, and San Mateo lateral storage units.

Table 49.- Estimated ground-water storage capacity of San Mateo Creek basin

Storage unit	Average area (acres)	Average thickness (feet)	Total volume (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Percent of total storage
Upper San Mateo	550	47	26,000	22	5,700	39
Cristianitos	128	50	6,400	20	1,300	9
Lower San Mateo	1,030	35	36,000	18	6,500	45
San Mateo lateral	500	34	17,000	6.2	1,000	7
Totals	2,208		85,400	17.0	14,500	100

The table shows that the estimated storage capacity for the four storage units totals about 14,500 acre-feet, of which 84 percent is contained in the alluvium of San Mateo Creek. Because the storage capacity estimated for upper San Mateo and Cristianitos storage units includes all the storage space available, the amounts shown are the maximum storage capacity. However, for lower San Mateo and the San Mateo lateral storage units, more storage capacity is available below sea level, but its use would bring about a reversed inland hydraulic gradient and consequent intrusion of sea water into the basin. Storage below sea level could be utilized for short periods of time at the end of prolonged dry periods without endangering the supply.

In October 1951 the storage depletion reached the maximum of record. In the upper San Mateo storage unit there remained about 1,200 acre-feet in storage, or about 21 percent of the total capacity; in the Cristianitos storage unit there remained about 150 acre-feet, or about 12 percent of the total capacity; in the lower San Mateo storage unit there remained about 1,400 acre-feet, or about 22 percent of the total capacity; and in the San Mateo lateral storage unit there remained about 350 acre-feet, or about 35 percent of the total. Thus, in October 1951 there remained a total of about 3,100 acre-feet in storage within the limits of the defined depth zones; or the total depletion amounted to about 11,400 acre-feet.

In June 1952 the storage in Cristianitos and upper San Mateo storage units was essentially at maximum capacity; whereas the storage in the lower San Mateo and San Mateo lateral storage units were, respectively, about 1,400 and 200 acre-feet below maximum capacity. In other words, the San Mateo Creek basin was about 90 percent full as a result of the recharge supplied in the winter of 1952.

In September 1952, which is the end of the water year and the end of the period used in the development of the hydrologic equation, the storage was somewhat less than in June. In the upper San Mateo storage unit the depletion below maximum storage capacity was about 800 acre-feet; in Cristianitos, about 300 acre-feet; in lower San Mateo, about 1,900 acre-feet; and in San Mateo lateral, about 300 acre-feet; or a total depletion of 3,300 acre-feet.

Because of the relatively rapid depletion of storage in the upper San Mateo and Cristianitos storage units by the process of natural downstream drainage of ground water, it does not appear feasible to consider the construction of supply wells in these units. The supply wells drilled in 1952 in the lower San Mateo storage unit are in the proper position to receive the natural ground-water drainage from the two upstream storage units.

Hydrologic Equation for the Period 1947-52

The hydrographs for wells in the San Mateo Creek basin indicate that storage was essentially at maximum capacity in 1947, in the following years through 1951 declined to the historic low, and following the recharge in 1952, the storage was replenished to nearly the same level as in 1947. In September 1952 the storage had declined somewhat. Thus, the period 1947-52 of relatively small net change in storage provides a means of deriving a rough estimate of ground-water outflow and overflow and of checking the various elements comprising recharge, discharge, and storage change.

During the 5-year period 1947-51 of ground-water depletion, the total recharge was estimated to be about 11,900 acre-feet (table 45), and the total discharge, excluding ground-water outflow and overflow, was estimated to be about 15,200 acre-feet (table 47). The difference between the two is 3,300 acre-feet. The estimated depletion in storage for the period determined by water-level change and specific yield of the deposits was about 11,400 acre-feet. Thus, if the several estimates are reasonable, the storage depletion of 11,400 acre-feet less the difference between recharge and discharge of 3,300 acre-feet, which is 8,100 acre-feet, was discharge by ground-water outflow and overflow. This suggests that the outflow and overflow for the 5-year period averaged about 1,600 acre-feet a year.

Similarly, for the 6-year period 1947-52 of relatively small net change in water levels and hence storage, the estimated total recharge was about 20,000 acre-feet (table 45), and the discharge, excluding ground-water outflow and overflow, was about 17,700 acre-feet (table 47). The recharge in excess of discharge was 2,300 acre-feet. The estimated net depletion in storage by use of water levels and specific yield was 3,300 acre-feet. Thus, the estimated discharge by ground-water outflow and overflow was the storage depletion of about 3,300 acre-feet plus the recharge in excess of discharge of 2,300 acre-feet, or about 5,600 acre-feet. This suggests that the outflow and overflow for the 6-year period averaged nearly 1,000 acre-feet a year, which is considerably less than the 1,600 acre-feet a year estimated for the 5-year period 1947-51. The relatively large discrepancy between the two results is due to errors in estimating the recharge, discharge, and storage change. Accordingly, the outflow and overflow is assumed to be the average of the two estimates, or averaged about 1,300 acre-feet a year for the 6-year period. These data are used to form the hydrologic equation for the period 1947-52 and are shown in table 50.

Table 50.- Comparison of recharge and discharge with storage changes, in acre-feet, in San Mateo Creek basin in the water years 1947-52

	Period (year ending Sept. 30)		
	1947-51	1952	1947-52
Recharge:			
Seepage loss from streams ----------	11,600	7,200	18,800
Rainfall infiltration on basin -----	0	800	800
Returned sewage effluent -----------	300	100	400
(1) Total ----------	11,900	8,100	20,000
Discharge:			
Pumpage ---------------------------	8,200	1,500	9,700
Evapotranspiration ----------------	7,000	1,000	8,000
Ground-water outflow and overflow --	6,500	1,300	7,800
(2) Total ----------	21,700	3,800	25,500
(3) Difference: (1) - (2) --------------	-9,800	+4,300	-5,500
Ground-water storage change [net increase (+) or decrease (-)]:			
Upper San Mateo unit --------------	-4,500	+3,700	-800
Cristianitos unit -----------------	-1,150	+850	-300
Lower San Mateo unit --------------	-5,100	+3,200	-1,900
San Mateo lateral unit ------------	-650	+350	-300
(4) Total ----------	-11,400	+8,100	-3,300
(5) Difference between methods: (3) - (4)	+1,600	-3,800	-2,200

For the 6-year period 1947-52 the table shows a discrepancy between methods of 2,200 acre-feet. This discrepancy suggests that either the estimate of recharge is 11 percent too small or the estimate of discharge is 9 percent too large. Because the suggested percent of error in the estimates is reasonably small, no revisions in them have been made. The most probable sources of error in the elements of recharge and discharge shown in table 50 would be in the estimates of large magnitude, such as seepage loss, evapotranspiration, and ground-water outflow and overflow. Although the pumpage for the period was in part metered, there may be errors in the part estimated, in the assumption that there was essentially no return to ground water by deep penetration of irrigation water, and in the assumption that one-half the supply for the city of San Clemente was supplied from San Mateo Creek basin.

Perennial Yield of San Mateo Creek Basin

The perennial yield of San Mateo Creek basin is the amount of ground water that can be pumped year after year without depleting ground-water storage to the point where a damaging amount of sea-water intrusion into the basin occurs. Except for a possible local condition of overdraft created by irrigation wells 9/7-14F1 and 14L1 near the coast, the basin has not been overdrawn.

Because of the relatively small ground-water storage capacity, estimated to be nearly 15,000 acre-feet, the yield of the basin is limited to the recharge during relatively short dry periods, such as 1928-31 and 1946-51. It has been shown that during a wet year such as 1952, the basin is quickly replenished. Thus, the infrequent wet years occurring in a 14- or 15-year dry period such as 1923-36, could supply sufficient recharge to fill the basin.

The computed surface-water inflow to the San Mateo Creek valley in the years 1927, 1932, 1937, 1938, 1941, 1943, and 1952 suggests that there was sufficient runoff to essentially recharge the basin if levels were as low as those in 1951 (table 14). For the intervening dry periods, the most critical is the 6-year period 1946-51 when the runoff totaled only 19,300 acre-feet and averaged only 3,200 acre-feet a year. With regard to seepage loss during a dry period such as that of 1946-51, table 43 shows that, except for the year 1946, essentially all runoff would be recharge by seepage loss to ground water. The runoff in 1946 was computed to be 7,700 acre-feet. Water-level records show that the recharge during the preceding wet years had fully replenished the basin. Hence, the seepage loss in 1946 might be less than 50 percent of the runoff, or roughly only 3,500 acre-feet. Thus, the recharge by seepage loss from streams for a similar 6-year dry period might be on the order of 15,000 acre-feet, or an average of only 2,500 acre-feet a year. The recharge by rainfall infiltration would be negligible during the dry period.

With regard to the estimated ground-water discharge during the dry period 1946-51, the ground-water outflow and overflow averaged roughly 1,300 acre-feet a year, and evapotranspiration loss averaged about 1,400 acre-feet a year. For a similar 6-year dry period, the total natural discharge might average about 2,700 acre-feet a year, which is essentially equal to the average recharge.

Thus, because total recharge and natural discharge are about equal, the short-term perennial yield during an acute 6-year dry period, such as that in 1946-51, would be the ground-water storage capacity divided by the number of years of drought; or:

$$\text{Perennial yield} = \frac{15,000}{6} = 2,500 \text{ acre-feet}$$

This estimate would be the amount of ground water available for annual pumpage during acute dry periods. However, it was estimated that about one-half the supply to the city of San Clemente wells is obtained from San Mateo Creek basin. Accordingly, if one-half of the 1952 rate of pumpage of 760 acre-feet is deducted from the estimated yield, there would be about 2,100 acre-feet available for Camp and irrigation pumpage each year of the dry period.

Green (1945, typewritten report) estimated the maximum yield to be 1,837 acre-feet and conservatively to be only 1,000 acre-feet, based on conditions during the 10-year period 1896-1905. Green estimated the surface-water inflow and assumed there was no outflow. However, he allowed for a maximum storage depletion of only 5,438 acre-feet or an average lowering of water level of only 27.19 feet. Presumably, his yield figure would have been considerably larger had allowance been made for a greater storage depletion.

If pumpage for irrigation is continued during a future dry period at the average rate of about 1,200 acre-feet established during the dry period 1946-51, there will remain only about 1,000 acre-feet a year for Camp supply plus, of course, the amount of sewage effluent returned to ground water. Any substantial increase in the pumpage from the city of San Clemente wells, which since 1947 has been increasing at the rate of 50 acre-feet per year, and/or from irrigation wells would reduce directly the amount available for Camp supply.

On the other hand, a reduction in evapotranspiration loss would increase the yield of the basin and could be accomplished by periodic clearing of phreatophytes from the stream channels and from the area coastward from U. S. Highway 101. If the loss were reduced by one-half, the yield during a dry period could be increased to about 3,000 acre-feet a year.

With regard to increasing the water supply during periods of drought, consideration might be given to the feasibility of constructing a dam for holdover surface-water storage to supply installations in San Mateo Creek valley and possibly in San Onofre Creek valley. It has been shown that for the two base periods 1923-44 and 1935-51, the computed average annual inflow was 16,000 acre-feet. This amount is approximately the long-term average surface-water supply to San Mateo Creek valley. However, it is doubtful whether there exists a feasible dam site below the junction of Cristianitos and San Mateo Creeks. Therefore, because the computed annual inflow of San Mateo Creek is about five times that of Cristianitos Creek, or about 12,500 acre-feet, it would appear more reasonable to consider a dam site on San Mateo Creek.

Chemical Quality of Water

General Character

For San Mateo Creek basin chemical analyses of water made by the Sanitary Division Laboratory, Eleventh Naval District, San Diego, are shown in tables 4C, 4D, and 4E; and those made by the Geological Survey are shown in table 4B (in appendixes). The analyses are for waters from wells tapping the alluvium and the San Mateo formation.

The quality of the ground waters in the alluvium is best shown by the analyses for wells 9/6-5M1 in the upper part of San Mateo Creek basin, and wells 9/7-1E1 and 9/7-14M1 in the lower part of the basin (tables 4C and 4E). The latter two wells also tap the underlying San Mateo formation so the results are not indicative of the waters in the alluvium alone; rather they represent a blend. The analysis for well 9/6-5M1, in upper San Mateo Creek, shows that the water is a sodium bicarbonate type. Concentrations of the principal constituents in ppm are: Sodium 81 (computed), calcium 56 (computed), magnesium 18 (computed), bicarbonate 175 (computed), chloride 80, and sulfate 130. The total dissolved solids are shown as 340 ppm (estimated from specific conductance by the Navy Sanitation Laboratory), but have been computed to be about 450 ppm. Nevertheless, the quality is good and is considered to be satisfactory for domestic use.

For wells 9/7-1E1 and 9/7-14M1, which tap both the alluvium and San Mateo formation , the waters are the sodium bicarbonate type. Concentrations of the principal constituents in ppm average: Sodium about 85 (computed), calcium about 65 (computed), magnesium 18 (computed), bicarbonate nearly 200 (computed), sulfate about 100, and chloride 90 ppm. The total dissolved solids average about 470 ppm, which is considerably less than that in the lower Santa Margarita River basin.

Wells 9/7-11F1 and 9/7-11P4 tap water in the San Mateo formation. The analyses show that the waters are a sodium bicarbonate type, and the concentrations of the principal constituents in ppm average: Sodium about 65 (computed), calcium about 50 (computed), magnesium 19 (computed), bicarbonate about 185 (computed), sulfate nearly 90, and chloride 70. The total dissolved solids shown in table 40 appear to be somewhat low for both analyses; when computed they are about 430 ppm for well 9/7-11F1 and about 340 ppm for well 9/7-11P4.

Thus, in contrast to the highly saline water in the S n Mateo formation in the lagoon area of the lower Santa Margarita River basin, the waters in the San Mateo formation in San Mateo Creek basin are of good quality. The difference in quality is due to flushing of saline waters from the formation in San Mateo Creek basin, and its replacement by waters of good quality. The formation has been subjected to considerable elevation near the north end of the Camp so that flushing could occur; whereas near the south end of the Camp, little elevation has occurred with the result that the formation contains connate saline waters.

Sea-Water Intrusion

Periodic samples have been taken from irrigation well 9/7-14L1, which is the closest pumped well to the ocean in San Mateo Creek basin, and nearby irrigation well 9/7-14F1 (table 4B). In October 1950 the chloride content of well 14L1 was 163 ppm, the hardness 340 ppm, and the specific conductance 981; and in October 1951, they were 203 ppm, 510 ppm, and 1,320, respectively. In October 1950 the chloride content of water from nearby well 9/7-14F1 was only 79 ppm, which is about the same as the native waters in the basin. The increase in chloride content and its magnitude in relation to the native waters suggests that sea water may be encroaching toward well 9/7-14L1. If so, the encroachment has not affected as yet the chloride content of waters pumped from test well 9/7-14M1, which in August 1951 was 72 ppm.

The "static" levels in irrigation wells 9/7-14F1 and 14L1 have been above sea level throughout the period of record, but the pumping levels have ranged between 9 and 27 feet below sea level (table 3A). Thus, prolonged pumping from these wells may have caused sea water to move inland along the east side of the valley. Continued periodic sampling for chemical analysis should be made to determine the status of the intrusion into the basin.

SAN ONOFRE CREEK BASIN

Areal Extent

San Onofre Creek basin is limited principally by the areal extent of the alluvium, the 40-foot terrace deposit, and a part of the bordering San Mateo formation (pl. 1). Plate 28 shows that the upstream end of the basin has been arbitrarily set at the confluence of the north and south forks of San Onofre Creek near Tent Camp 2. From the confluence the basin extends downstream to the coast--a distance of about 4.2 miles of which the lower 1.5 miles crosses the principal area of pumped wells. In width the basin ranges from 500 feet near the upstream end to 5,000 feet near the coast, including the alluvium and about 1,000 feet of San Mateo formation on either side.

The surface area of the basin is nearly 1,200 acres of which about 750 acres is underlain by alluvium, terrace deposits, and channel deposits, and 400 acres is underlain by the San Mateo formation. The alluvium, terrace deposits, and channel deposits cover about 450 acres downstream from the trace of the Cristianitos fault and about 300 acres upstream. Actually, the alluvium extends upstream a considerable distance above the end of the basin as defined, but its thickness decreases rapidly and the contained ground water is of relatively small volume. Because the terrace deposits on the north side of the alluvium between Tent Camp 2 and San Mateo Road are believed to be relatively thin and contain a minor amount of ground water, they have been omitted from the basin area and the treatment of ground-water storage capacity (pl. 28). Similarly, the terrace deposits on the north side of the lower basin are in part omitted from the basin area.

Occurrence of Ground Water

In San Onofre Creek basin, ground water is obtained most readily from the alluvium, terrace deposits beneath the 40-foot terrace at the coast, and locally from the San Mateo formation. Most wells are in the lower part of the basin and derive water both from the alluvium and the San Mateo formation. Upstream from the Cristianitos fault trace where the San Mateo formation is absent, the few wells obtain their supply largely from the alluvium but in small part by drainage from the terrace deposits adjacent to the north side of the alluvium near well 9/6-17H1. Camp-supply well 9/7-24A1 obtains its supply wholly from the San Mateo formation. Test well 9/7-24H1 taps water only in the San Mateo formation. Test well 9/7-24D1 and well 9/7-23A1 tap water in the terrace deposits and in the San Mateo formation.

The wells tap a common ground-water body which extends from the upper end of the basin to the Pacific Ocean. Upstream from Cristianitos fault trace the sides and bottom of the basin are formed by the essentially non-water-bearing rocks of Miocene to Eocene age; downstream the water-bearing San Mateo formation extends to considerable depth so the position of the bottom is not known. Possibly water of poor quality at depth would limit the usable depth of the basin. Accordingly, because of the possibility of poor quality at depth and because of the potential threat of sea-water intrusion, the bottom has been set arbitrarily at sea-level datum. Laterally the San Mateo formation extends north and south away from the pumped area for distances up to a mile and more. However, from the standpoint of effective use, the lateral limit has been set at 1,000 feet beyond the sides of the alluvium and coastal terrace deposits except that near supply well 9/7-24A1 the edge has been moved 1,000 feet south of the well. The effects of storage change have been noted in this well and in test well 9/7-24H1 about 2,000 feet to the south. Thus, the lateral limit of 1,000 feet for the sides of the basin is believed to be conservative.

There appears to be no evidence for a shallow water body in the coastal part of the San Onofre Creek basin. However, the character of the water-level fluctuations induced by tidal loading in test well 9/7-24D1 and by pumping effects in test well 9/7-13P1 suggest that semiconfined conditions exist. However, stream losses have been observed as far downstream as test well 9/7-13P1, indicating that the semiconfining to confining clays do not form an effective barrier to ground-water recharge by seepage loss from the creek or by infiltration of rain at least as far downstream as the test well. Nearer the coast the clays may be tight and extensive enough to limit recharge from these sources.

Source and Movement of Ground Water

The direction of ground-water movement in San Onofre Creek basin is shown by water-level contours drawn on the surface of the water body. The contours on plates 21 and 22 show respectively the movement of water in October 1951, after a considerable depletion of ground water to the historic low levels so far as is known, and in May 1952 after appreciable recharge and rise of water levels to points that may be reasonably close to the historic high levels in the lower part of the basin and that completely replenished the basin upstream from irrigation well 9/6-18Q1.

Both sets of water-level contours show that ground water was moving seaward throughout the length of the basin. Because the direction of movement indicates not only the source of ground water but also the areas or points of discharge, the contours show that San Onofre Creek is the principal source of recharge along the channel reach and that ground water is discharging by natural seaward movement at the coast or offshore where the water-bearing deposits are in contact with the ocean.

In October 1951 the hydraulic gradient in the narrow canyon reach above the Cristianitos fault trace was 130 feet in 2.6 miles, or about 50 feet per mile; downstream the gradient flattened abruptly so that between the 5- and 15-foot contours the gradient was only about 12 feet per mile. In May 1952, following the winter of considerable recharge, these gradients were 50 and, between the 10- and 55-foot contours, about 30 feet per mile, respectively. The water-level profiles on plate 7 show that in the upper part of the basin in October the alluvium was nearly dewatered, whereas in May 1952 the alluvium was nearly fully recharged. Downstream the levels in October 1951 were close to sea level but had recovered substantially in May 1952.

The contours as drawn for October 1951 suggest that some recharge is moving laterally into the basin along the north side from the San Mateo formation. Along the south side, however, the contours suggest movement toward the ocean.

The contours as drawn for May 1952 suggest that water is moving laterally from the alluvium into the San Mateo formation. Thus, the storage that had been depleted during the dry period 1945-51 was in part replenished during the wet winter of 1952.

Recharge to Ground Water

Recharge to San Onofre Creek basin is principally by seepage loss from the creek with lesser amounts supplied by infiltration of rain and returned sewage effluent. Recharge by ground-water underflow at the upstream end of the basin is small not only because the deposits are relatively thin but also because they are not fully saturated during most of the time. Accordingly, the underflow is included in the estimates of recharge by seepage loss from streams.

Seepage Loss from San Onofre Creek

The surface-water inflow to the basin less the surface-water outflow at the coast is the measure of the recharge by seepage loss from San Onofre Creek. As was indicated in the section on surface-water resources, a stream gage installed in 1950 at the upper end of the basin near Tent Camp 2 measures most of the inflow and a gage installed in 1946 near U. S. Highway 101 measures the outflow (pl. 28). In San Onofre Creek seepage loss can take place in the entire channel reach between the two gages--a distance of over 4 miles.

The magnitude of the seepage loss is limited by the time distribution and amount of runoff, by the ability of the deposits to transmit water away from the creek bed, and by the storage space available in the water-bearing deposits at times when there is runoff in the creek. Of these limiting factors, the amount of runoff appears to be the most critical. The records of water-level fluctuations show that the winter recharge is absorbed rapidly into the ground-water body and drains quite readily to the lower part of the basin where the pumping wells are located. Thus, with a large pumping draft and consequent storage depletion, a relatively large seepage loss can be expected during years of substantial runoff.

The computed annual inflow to the basin in the water years 1923-52 is shown in table 22, and the outflow in the water years 1947-52 is shown in table 24. The local residents report that there was no outflow in 1946. The inflow, outflow, and seepage loss indicated by these data for the period 1946-52 are shown in table 51.

Table 51.- Estimated seepage loss, in acre-feet, from San Onofre Creek in the water years 1946-52

Year ending Sept. 30	Computed inflow[1]	Outflow[2]	Estimated seepage loss
1946	1,800	(a)	1,800
1947	790	0	790
1948	420	0	420
1949	680	0	680
1950	380	0	380
1951	250	0	250
1952	7,600	5,030	2,600
Total			6,970
7-year average			1,000

1. From table 22.
2. From table 24.
a. Local residents report no outflow.

For the water years 1946-51 the table shows that all the inflow was recharge by seepage loss along the creek channel. In 1952, about 34 percent of the inflow was seepage loss. The relatively large seepage loss in 1952 of about 2,600 acre-feet was possible because of the large inflow and because of the large storage space made available by ground-water depletion in the preceding dry years 1947-51.

Deep Penetration of Rain

The same methods used for determining the deep penetration of rain on the lower Santa Margarita River basin were applied to the San Onofre Creek basin. There is roughly 200 acres of phreatophytes which thrive on and largely consume the relatively small yearly rainfall. This leaves about 950 acres where the deep penetration of rain takes place of which about 300 acres is irrigated, about 500 acres is covered by grass, and about 150 acres is covered by brush. The brushlands are largely along the north side of the basin and are underlain chiefly by the San Mateo formation.

The rainfall records used are the same as those for the lower Santa Margarita River basin (table 31). The rainfall was probably about the same and therefore it is used without adjustment. Table 52 shows the estimated deep penetration of rain in the water years 1931-52.

Table 52.- Estimated yearly recharge, in acre-feet, by deep infiltration of rain in San Onofre Creek basin in the water years 1931-52 1/

Year ending Sept. 30	Recharge	Year ending Sept. 30	Recharge
1931	10	1942	0
32	160	43	270
33	0	44	20
34	0	45	0
35	270	46	0
1936	0	1947	0
37	250	48	0
38	140	49	0
39	50	50	0
40	0	51	0
41	900	52	380

Total	2,400
22-year average, 1931-52	100
17-year base period, 1935-51	100

1. Rainfall shown in table 31.

The table suggests that the long-term annual deep penetration of rain is on the order of 100 acre-feet. During dry periods, such as that from 1945 through 1951, there may be essentially none. On the other hand, during wet periods, such as 1935-43, the data suggest that the penetration may average as much as 200 acre-feet per year.

Returned Sewage Effluent

No records have been kept of the raw sewage discharged from the septic tanks near Tent Camp 2 in San Onofre Creek. It is reported that new Camp San Onofre under construction will have a sewage-treatment plant and will meter the treated effluent. The Public Works Office believes that the septic tank discharge has been in excess of 50 percent of the Camp pumpage. Possibly as much as 50 percent of the pumpage has been returned to ground water by septic-tank discharge. Table 54 suggests that the pumpage for the period 1944-52 has ranged from 40 to 470 acre-feet a year for Camp use. Thus, for the same period it is estimated that the sewage effluent returned to ground water has ranged from 20 to 240 acre-feet a year.

Total Recharge

The total recharge to ground water in San Onofre Creek basin is estimated for the water years 1946-52 for which all elements of recharge are available. The estimated total recharge, which is the sum of the seepage loss, infiltration of rain, and returned sewage effluent, is shown in table 53.

Table 53.- Estimated total recharge, in acre-feet, to San Onofre Creek basin in the water years 1946-52

Year ending Sept. 30	Total recharge
1946	a 2,000
1947	840
1948	440
1949	750
1950	450
1951	420
1952	3,200
Total	8,100
7-year average	1,150

a. In large part based on reported seepage-loss data.

The estimated total recharge decreased from about 2,000 acre-feet in 1946 to about 400 acre-feet in 1951; in 1952 it was about 3,200 acre-feet. The progressive depletion of storage from 1946 to 1951 provided storage space for the large recharge in 1952. A comparison of the total recharge with the several elements in the 7-year period 1946-52 suggests that seepage loss was about 85 percent of the total for the period. In 1952, it was about 80 percent of the estimated total recharge.

Ground-Water Discharge

Pumpage

In San Onofre Creek basin, ground water is pumped for both irrigation and Camp supply. Approximately 300 acres of land are or have been irrigated, the bulk of which is on the alluvial plain below the Cristianitos fault trace. Minor areas are irrigated on the terraces along the coast on both the east and west sides of the valley.

Records of pumpage for Camp supply and irrigation are available for the 5-year period 1948 through 1952 and were obtained from the Public Works Office, Camp Pendleton. It is reported that the pumpage for Camp supply is metered at some of the wells or storage facilities and estimated where not metered. Pumpage for irrigation is estimated by the lessees on the basis of pumping rate of well and length of time pumped.

For water years prior to 1948, the pumpage has been estimated. Pumpage for Camp use during the years 1944-47 is estimated as being about the same as in 1951 when Tent Camp 2 was essentially filled; and during the water year 1947 is estimated at the average rate of the following three years. Pumpage in 1952 is high owing to construction of the new Camp San Onofre. Pumpage for irrigation in the dry water years 1944 through 1947 is estimated as the average of the four dry years 1948 through 1951. The recorded and estimated pumpage for Camp supply and irrigation in the water years 1944-52 is shown in table 54.

Table 54.- Ground-water pumpage, in acre-feet, from San Onofre Creek basin in the water years 1944-52

Year ending Sept. 30	Pumpage		Total
	Camp supply	Irrigation	
1944	a 300	a 500	a 800
1945	a 300	a 500	a 800
46	a 300	a 500	a 800
47	a 100	a 500	a 600
48	39	970	1,000
49	142	420	560
1950	128	460	590
51	335	220	550
52	472	160	630
Total	2,100	4,200	6,300
9-year average	230	470	700

a. Estimated.

The table shows that the total pumpage has ranged from 550 acre-feet in 1951 to 1,000 acre-feet in 1948 and has averaged 700 acre-feet for the 9-year period. Pumpage for irrigation has averaged twice that for Camp supply. Wells 9/7-19D1 and 9/7-24A1 served as irrigation wells until the middle or late forties and thereafter have been used for Camp supply. New supply wells 9/7-19C1 and 19D4 may replace the old Camp-supply wells.

The apparent duty of water applied to about 250 acres of irrigated land ranged from less than 1 foot per acre in 1952 to 4 feet in 1948. The large duty in 1948 probably is incorrect because there was probably more than 250 acres of land irrigated. Some of the water pumped for irrigation probably returns to ground water by penetration below the root zone. However, no estimate of the return is made in this report.

Natural Discharge

Evapotranspiration.--Evapotranspiration from areas of phreatophytes occurs in and along the channel of San Onofre Creek. It is estimated from aerial photos that there is about 200 acres of phreatophytes. These plants, which depend on ground water for their principal supply, appear to have existed largely on small runoff and rainfall along the greater part of the channel reach during the dry period 1946-51 when water levels were 30 to 50 feet below land surface (pl. 7).

By use of the same methods applied to similar areas of phreatophytes in the lower Santa Margarita River basin, estimated evapotranspiration loss was derived for San Onofre Creek basin. The average estimated loss for the base period 1935-51 was roughly 400 acre-feet per year. However, owing to the considerable depth to water in the upstream part of the basin during the dry years, the average consumption of ground water was probably less than 400 acre-feet per year. During the dry period 1946-51, the evapotranspiration loss may have ranged from 500 acre-feet in 1946 when water levels were relatively high to 300 acre-feet in 1951 when water levels were low.

Ground-water outflow and overflow.--The favorable seaward hydraulic gradient that has existed at the lower end of the basin during the period of record indicates that natural discharge by ground-water outflow to the ocean has taken place through the alluvium, the so-called 40-foot terrace deposit, and the San Mateo formation. This outflow occurs through a relatively large cross-sectional area of water-bearing deposits--the width is on the order of 1¼ to 2 miles, but the depth is not known.

The manner and circumstances in which ground-water overflow occurs was explained in a similar section for San Mateo Creek basin. So far as has been observed, no ground-water overflow into the creek bed at the lower end of the valley has occurred. It is possible that minor discharge took place coastward from the U. S. Highway 101 bridge in the spring of 1952. Apparently, when the basin is essentially full the permeability and cross-sectional area of the deposits near the coast are large enough to permit the discharge of essentially all the ground water reaching the coastal end of the valley by ground-water outflow to the ocean. If so, no ground-water overflow would occur.

The amount of discharge by ground-water outflow can not be directly determined. However, it can be crudely estimated by subtracting all other estimates of discharge from the estimated total recharge in a period for which all other elements are available. As is indicated in the section on the hydrologic equation for the period 1946-52, by the use of recharge and discharge as compared to ground-water storage change, the ground-water outflow was determined by difference and found to average roughly 400 acre-feet a year for the period.

The amount of outflow in any one year would depend directly on the hydraulic gradient at the coast. The hydraulic gradients in 1951 and 1952 were 12 and 30 feet per mile, respectively (pls. 21 and 22), indicating that the outflow in 1952 was between two and three times that in 1951.

Total Discharge

The total discharge of ground water from San Onofre Creek basin is the sum of the pumpage, the evapotranspiration, and ground-water outflow. For these, estimates of pumpage for Camp supply and irrigation, and estimates of evapotranspiration are shown in table 55. No estimates of ground-water outflow are included in the table.

Table 55.- Estimated discharge by pumpage and evapotranspiration, in acre-feet, from San Onofre Creek basin in the water years 1944-52

Year ending Sept. 30	Discharge	Year ending Sept. 30	Discharge
1944	1,200	1949	1,000
1945	1,200	1950	900
1946	1,300	1951	900
1947	1,000	1952	900
1948	1,400		
Total			9,800
9-year average			1,100

The table shows that the discharge by pumpage and evapotranspiration has ranged from 900 acre-feet in the water years 1950-52 to 1,400 acre-feet in 1948 and has averaged about 1,100 acre-feet a year. In 1952 the above-average rainfall and consequent low evapotranspiration and pumpage for irrigation plus a substantial increase in pumpage for Camp supply, largely for construction work, has brought the total to the same as that for the preceding dry years. In 1948 reported pumpage for irrigation was nearly double that of any other year, possibly owing to a high duty-of-water type of crop or large irrigated area, and consequently the above-average discharge is reflected in the table.

The total discharge, which includes pumpage, evapotranspiration and crude estimates of ground-water outflow, has been derived in the section on the hydrologic equation for the 7-year period 1946-52. The total discharge was estimated to be about 10,200 acre-feet or averaged nearly 1,500 acre-feet a year (table 57). Of this average about 400 acre-feet was computed by difference to be ground-water outflow.

Water-Level Fluctuations

The water-level fluctuations in wells in San Onofre Creek basin show a wide range between the historic low levels of October 1951 and the near historic high levels of May 1952 (pls. 7, 21, and 22). Sections M-M' and N-N' (pl. 7) show that as a result of the recharge in the winter of 1952 upstream from well 9/6-18Q1, the water level rose between 39 and 45 feet, and downstream the level rose as much as 35 feet to as little as 3 feet in well 9/7-24D1 near the coast. For more detailed records of water-level fluctuations in observation wells, refer to table 3A (appendixes).

Long-Term Fluctuations

Records of water-level fluctuations are available for several wells from 1945 to date. Hydrographs for four wells are shown on plate 35. In the lower part of the basin near the coast, the composite record for well 9/7-23A1 and test well 9/7-24D1 shows that the levels have changed only slightly during the 8-year period. In 1945, the water level was nearly 14 feet above sea level--the highest of record. It may have been even higher in the spring of 1941 or 1943. From 1945 to late in the spring of 1951, the hydrograph shows a progressive decline to a little less than 7 feet above sea level, followed by a gradual rise to a maximum of a little more than 11 feet above sea level in June 1952--a rise of over 4 feet. The net decline from the spring peak of 1945 to that of 1952 was a little more than 2 feet.

In the central part of the basin and in the main pumped area, the hydrograph for irrigation well 9/6-19D2 shows that a decline was in progress at the beginning of the record in July 1945. At that time the water level was nearly 45 feet above sea level. The log for this well shows that the level in August 1934, which was near the end of a previous dry period, was about 32 feet above sea level. From July 1945 the level declined steadily to a low in November 1951 of about 13 feet above sea level--about 20 feet lower than the level in August 1934 and about 32 feet lower than the level in July 1945. In response to the winter recharge in 1952, the level rose rapidly to 46 feet above sea level in April 1952, at an average rate of about 8 feet per month and was at about the same level as in the spring of 1945. In November 1951 and April 1952, the water levels were 53 and 20 feet, respectively, below land surface.

The record on Camp supply well 9/6-17M1 was started in October 1950 by the Geological Survey and shows that a decline was in progress. From October 1950 to November 1951 the level declined from about 106 to 99 feet above sea level; from December 1951 to March 1952 the level rose 42 feet to a high of 141 feet above sea level in no more than 3 months, or at a rate of at least 14 feet per month or 0.5 foot per day. In November 1951 and March 1952 the water levels were 51 and 9 feet, respectively, below land surface.

Thus, except for seasonal changes in response to recharge and pumping, the hydrographs show that the basin was nearly full in 1945, that thereafter a general decline occurred which reached a maximum in the fall of 1951, and that the basin was nearly replenished during the winter of 1952. In the upper part of the basin above the Cristianitos fault where there is essentially no pumping (Camp supply wells 9/6-16M1 and 17M1 are used very infrequently), the depletion is due principally to natural downstream drainage of ground water and partly to evapotranspiration. In the lower part of the basin, probably most of the depletion was caused by pumping, but some was due to natural seaward discharge of ground water. Therefore, the upper part of the basin forms a natural reservoir that supplies by relatively slow drainage the main pumped area downstream; that part not withdrawn by pumping or consumed by evapotranspiration escapes to the ocean. Finally, the hydrographs show that downstream nearly to the coast, recharge to ground water occurs readily and rapidly whenever there is water in the creek.

Fluctuations Caused by Tides

Automatic water-level recorders were operated on test wells 9/7-13P1, 14R3, 24D1, and 24E1 in the spring and summer of 1952. All except well 24E1, which taps unconfined water only in the San Mateo formation, showed the effects of tidal loading or pressure. Wells 9/7-14R3 and 24D1 show fluctuations induced by tides: In well 14R3, which is about 1,500 feet from the ocean, ranging from 0.06 foot to 0.9 foot, and in well 24D1, which is about 800 feet from the ocean, ranging from 0.04 foot to 1.2 feet. Based on the records for test well 9/7-14M1 in San Mateo Creek basin, the tidal efficiency as reflected by the water levels in the two wells is probably less than 1 to 10.

Test well 9/7-13P1, which is about 3,000 feet from the ocean, shows a small fluctuation caused by the tides. The magnitude is on the order of essentially nothing to as much as 0.2 foot. The water level also is affected by pumping in irrigation well 9/7-24C1.

The record from well 9/7-24D1 shows the effect of trains and possibly heavy trucks. The well is only 75 feet from the center lines of the railroad and the highway. Heavy trains passing caused the water level to rise as much as 0.06 foot; after the train had passed, the level returned immediately to its normal trend. These fluctuations caused by a moving load on the land surface have been observed in other coastal valleys of California (Worts, 1951).

Ground-Water Storage Capacity

Storage Units and Depth Zones

The San Onofre Creek basin was divided into three major storage units as follows: (1) Upper San Onofre storage unit, which extends from the Cristianitos fault upstream to the junction of the north and south forks of San Onofre Creek and which has a surface area of about 300 acres; (2) lower San Onofre storage unit, which extends from the Cristianitos fault to the ocean and is underlain by the alluvium and 40-foot terrace deposits and which has an area of about 750 acres; and (3) the San Onofre lateral storage unit, which extends along both sides of storage unit (2) and which has an area of about 400 acres.

Plate 28 shows the extent of the storage units. It also shows that the tongues of alluvium extending up minor tributaries have been excluded. The selection of the lateral limits for storage unit (3) above have already been discussed.

The depth zone used in the computation of the volume of deposits in storage unit (1) above is from 5 feet below land surface to the bottom of the alluvium; for storage unit (2) is from 5 feet below land surface down to sea level; and for storage unit (3) is between the plane formed by the top of storage unit (2) projected laterally into the San Mateo formation and sea level. Storage units (2) and (3) are wedge shaped and have 0 thickness at the coast and attain maximum thicknesses at their upper ends.

Because insufficient data were available to construct an accurate isopach map, the volumes of deposits in each storage unit were determined by measuring the average lengths, widths, and thicknesses. The average cross-sectional area of upper San Onofre storage unit was assumed to be triangular in shape, which probably is a conservative measure of the area. The cross-sectional area of lower San Onofre storage unit at its upper end is nearly rectangular in shape and tapers coastward to zero thickness. The same applies to the San Onofre lateral storage unit.

Specific-Yield Values

The specific yield of the deposits in the upper and lower San Onofre storage units was determined by use of the same methods applied in the lower Santa Margarita River basin, and the same specific-yield values were assigned to the five general types of material (table 31). The specific-yield values were applied to the alluvium, which forms the bulk of the deposits, and to the 40-foot terrace deposit near the coast. Both have the same general lithologic and hydrologic properties.

For the deposits that comprise the San Mateo formation in the San Onofre lateral storage unit the same specific-yield values used in San Mateo Creek basin (table 48) were employed in the San Onofre Creek basin.

A total of 14 well logs were studied to derive the average specific yield for the alluvium, terrace deposits, and San Mateo formation.

Estimate of Storage Capacity

The estimates of ground-water storage capacity for the three storage units were derived by the same method outlined for the lower Santa Margarita River basin. Table 56 shows the estimated storage capacity in upper San Onofre, lower San Onofre, and San Onofre lateral storage units.

Table 56.- Estimated ground-water storage capacity of San Onofre Creek basin

Storage unit	Average area (acres)	Average thickness (feet)	Total volume (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Percent of total storage
Upper San Onofre	150	53	8,000	25	2,000	33
Lower San Onofre	450	33	14,600	16.2	2,400	40
San Onofre lateral	400	31	12,600	12.6	1,600	27
Totals	1,000	35	35,200	17.0	6,000	100

The table shows that the estimated storage capacity for the three storage units totals about 6,000 acre-feet, of which 73 percent is contained in the alluvium and terrace deposits and the remainder is contained in the San Mateo formation. Because the storage capacity estimated for upper San Onofre storage unit includes all the storage space available, the capacity of 2,000 acre-feet is the maximum. However, for the lower San Onofre and the San Onofre lateral storage units, more storage than the 4,000 acre-feet shown is available below sea level, but its use would threaten sea-water intrusion into the basin. Some storage below sea level could be utilized for short periods of time at the end of prolonged dry periods without endangering the supply. Thus, the storage capacity is somewhat greater than the estimated total of 6,000 acre-feet.

In October 1951 the storage depletion reached the maximum of record. In the upper San Onofre storage unit there remained about 400 acre-feet in storage, or about 20 percent of the total capacity; in the lower San Onofre storage unit there remained about 600 acre-feet, or 25 percent of the total capacity; and in the San Onofre lateral storage unit there remained about 400 acre-feet, or 25 percent of the total capacity. Thus, in October 1951 there remained a total of about 1,400 acre-feet in storage within limits of the defined depth zones; or the total depletion amounted to about 4,600 acre-feet.

In May 1952 the storage in the upper San Onofre storage unit was essentially filled to maximum capacity; whereas the storage in the lower San Onofre and San Onofre lateral storage units were respectively about 400 and 300 acre-feet below maximum capacity. At this time, then, the San Onofre Creek basin was about 88 percent full as a result of the recharge supplied in the winter of 1952.

In September 1952, which is the end of the water year and the end of the period used in the development of the hydrologic equation, the storage was somewhat less than in May. In the upper San Onofre storage unit the depletion below the maximum storage capacity was about 200 acre-feet; in lower San Onofre, about 900 acre-feet; and in San Onofre lateral, about 500 acre-feet; or a total depletion of 1,600 acre-feet.

Because of the relatively rapid depletion of storage in the upper San Onofre storage unit by the process of natural downstream drainage of ground water, it has not been possible to utilize effectively supply wells 9/6-16J1 and 17H1 near Tent Camp 2. Some water has been pumped from these wells in years when the storage unit was full, but they have remained idle most of the time. Thus, the lower San Onofre storage unit is the most logical unit to develop for a supply. In the fall of 1952 and the winter of 1953, new supply wells were developed immediately downstream from the Cristianitos fault.

Hydrologic Equation for the Period 1946-52

The hydrographs for wells in the San Onofre Creek basin indicate that storage was practically at maximum capacity in the spring of 1945; starting in 1946 and continuing through 1951 declined to the historic low; and following the recharge in 1952, the storage was replenished to nearly the same level as in 1945. In September 1952 the storage had declined somewhat. Thus, the period 1946-52 of relatively small net change in storage provides a means of deriving a rough estimate of ground-water outflow and of checking the various elements comprising recharge, discharge, and storage change.

During the 6-year period 1946-51 of ground-water depletion, the total recharge was estimated to be about 4,900 acre-feet, and the total discharge, excluding ground-water outflow, was estimated to be about 6,500 acre-feet. The difference between the two is 1,600 acre-feet. The estimated depletion in storage for the same period by use of water-level change and specific yield of the deposits was about 4,600 acre-feet. Thus, if the magnitude of the several estimates is reasonable, the storage depletion of 4,600 acre-feet less the difference between recharge and discharge of 1,600 acre-feet, which is 3,000 acre-feet, was discharge by ground-water outflow. This suggests that the outflow for the 6-year period averaged 500 acre-feet a year.

Similarly, for the 7-year period 1946-52 of relatively small net change in water levels and hence storage, the estimated total recharge was 8,100 acre-feet (table 53); the total discharge, excluding ground-water outflow, was about 7,400 acre-feet (table 55). The recharge in excess of discharge was about 700 acre-feet. The estimated net depletion in storage by use of water-level change and specific yield was 1,600 acre-feet.

Thus, the estimated discharge by ground-water outflow was the storage depletion of about 1,600 acre-feet plus the recharge in excess of discharge of 700 acre-feet, or about 2,300 acre-feet. This suggests that the outflow for the 7-year period averaged only 330 acre-feet a year, which is considerably less than the 500 acre-feet a year estimated for the 6-year period 1946-51. The discrepancy between the two results is due to errors in estimating the recharge, discharge, and storage change. Accordingly, the outflow is assumed to be the average of the two estimates, or averaged about 400 acre-feet a year for the 7-year period. These data are used to form the hydrologic equation for the period 1946-52 and are shown in table 57.

Table 57.- Comparison of recharge and discharge with storage changes, in acre-feet, in the San Onofre Creek basin in the water years 1946-52

	Period (year ending Sept. 30)		
	1946-51	1952	1946-52
Recharge:			
Seepage loss from streams	4,370	2,600	6,970
Rainfall infiltration on basin	0	380	380
Returned sewage effluent	530	240	770
(1) Total	4,900	3,200	8,100
Discharge:			
Pumpage	4,100	630	4,700
Evapotranspiration	2,400	300	2,700
Ground-water outflow	2,400	400	2,800
(2) Total	8,900	1,300	10,200
(3) Difference: (1) - (2)	-4,000	+1,900	-2,100
Ground-water storage change [net increase (+) or decrease (-)]:			
Upper San Onofre unit	-1,600	+1,400	-200
Lower San Onofre unit	-1,800	+900	-900
San Onofre lateral unit	-1,200	+700	-500
(4) Total	-4,600	+3,000	-1,600
(5) Difference: (3) - (4)	+600	-1,100	-500

For the 7-year period 1946-52 the table shows a discrepancy between methods of 500 acre-feet. This discrepancy suggests that either the estimate of recharge is 6 percent too small or the estimate of discharge is 5 percent too large. Because the suggested percent of error in the estimates is reasonably small, no revisions in them have been made. The most probable sources of error in the elements of recharge and discharge shown in table 57 would be in the estimates of large magnitude, such as seepage loss, evapotranspiration, and ground-water outflow. Although the pumpage for the period was in part metered, there may be error not only in the part estimated but also in the assumption that no irrigation water returned to ground water by deep penetration below the root zone.

Perennial Yield of San Onofre Creek Basin

The perennial yield of San Onofre Creek basin is the amount of ground water that can be pumped year after year without depleting ground-water storage to the point where a damaging amount of sea-water intrusion occurs. The records indicate that the basin has not been overdrawn.

Because of the relatively small ground-water storage capacity, estimated to be only 6,000 acre-feet, the yield of the basin is limited to the supply during short dry periods, such as 1928-31 and 1947-51. It has been shown that during a single wet year, such as 1952, the basin is quickly replenished. Thus, the infrequent wet years occurring in a 14- to 15-year dry period, such as 1923-36, would supply sufficient recharge to fill the basin.

The computed surface-water inflow to San Onofre Creek valley in the years 1927, possibly 1932, 1937, 1938, 1941, possibly 1943, and 1952 suggests that there was sufficient runoff to essentially recharge the basin if levels were as low as those in 1951 (table 18). For the intervening dry periods, the most critical is the 6-year period 1946-51 when runoff totaled only about 4,300 acre-feet and averaged only 700 acre-feet a year. With regard to seepage loss during a dry period, such as 1946-51, table 51 shows that essentially all the runoff would be recharge by seepage loss to ground-water storage. The recharge by rainfall infiltration would be negligible during the dry period.

With regard to the estimated ground-water discharge during the dry period 1946-51, the ground-water outflow averaged roughly 400 acre-feet a year, and the evapotranspiration loss averaged about 400 acre-feet a year. For a similar 6-year dry period, the total natural discharge might average 800 acre-feet a year, which is nearly equal to the average recharge.

Thus, because total recharge and natural discharge are about equal, the short-term perennial yield during an acute 6-year dry period, such as that in 1946-51, would be the ground-water storage capacity divided by the number of years of drought; or:

$$\text{Perennial yield} = \frac{6{,}000}{6} = 1{,}000 \text{ acre-feet}$$

This estimate would be the amount of ground water available for annual pumpage during acute dry periods.

Green (1945, typewritten report) estimated the perennial yield of the basin to be 715 acre-feet during a critical dry period. This yield was based on an estimated surface-water inflow of 2,144 acre-feet a year in the 10-year period 1896-1905, and it was assumed there was no outflow. He concluded that the yield was one-third of the surface-water inflow. The reason why Green selected one-third of the inflow as the perennial yield is not known.

If pumpage for irrigation is continued during a future dry period at the average rate of about 500 acre-feet established during the period 1946-51, there would remain only about 500 acre-feet a year for Camp supply plus a small part of the sewage effluent returned to the ground-water basin. With regard to the returned effluent, new Camp San Onofre, which is being constructed on the south fork of San Onofre Creek about 2 to 3 miles upstream from Tent Camp 2, will probably discharge its effluent some distance upstream from the basin as defined and from the pumped wells. Therefore, a substantial part of the returned effluent may be lost by evapotranspiration before it reaches the pumped basin downstream. The amount of ground water available in terms of returned sewage effluent for pumpage would be reduced accordingly.

On the other hand, a reduction in evapotranspiration loss would increase the yield of the basin and could be accomplished by periodic clearing of phreatophytes from the stream channels not only in the basin as defined but also upstream to the treated sewage outlet for new Camp San Onofre. If the loss in the basin alone were reduced by one-half, the yield during a dry period could be increased by about 20 percent or to about 1,200 acre-feet a year. The clearing of the channel upstream would provide additional yield by increasing the sewage effluent returned to the pumped basin.

With regard to increasing the water supply during periods of drought, consideration might be given to the feasibility of constructing a dam for holdover surface-water storage. It has been shown that for the two base periods, 1923-44 and 1935-51, the computed average annual inflow was 4,000 acre-feet. This amount is approximately the estimated long-term average surface-water runoff to San Onofre Creek valley. However, because the annual inflow is relatively small, it might not be economically feasible to construct a dam on San Onofre Creek for this purpose. It might be desirable to consider obtaining water from a dam on San Mateo Creek to supplement the supply during dry periods.

Chemical Quality of Water

General Character

For the San Onofre Creek basin the chemical analyses of waters made by the Sanitation Division Laboratory, Eleventh Naval District, are shown in tables 4C and 4D; and those made by the Geological Survey are shown in table 4B (appendix 4).

Most wells in the basin tap waters contained in both the alluvium and San Mateo formation. Analyses for test wells 9/7-13F1 and 9/7-14R3 show that these waters contain concentrations of principal constituents in ppm as follows: Calcium 69 and 44 (computed), magnesium 24 and 19 (computed), sodium 81 and 59 (computed), bicarbonate 190 and 193 (computed), sulfate 143 and 55, and chloride 100 and 72, respectively. The computed total dissolved solids are 500 and 350 respectively, which are higher than those shown in table 4C. The waters are a sodium-calcium bicarbonate type.

Test well 9/7-24M1, which taps water in the terrace deposits and underlying San Mateo formation, is a sodium sulfate-bicarbonate type, and the total dissolved solids are about 610 ppm. The sodium content is about 120 ppm (computed), bicarbonate 200 ppm (computed), sulfate 192 ppm, and chloride 105 ppm. The proximity of this well to the ocean may account for the higher concentrations of sodium, chloride, and sulfate.

Camp supply well 9/7-24A1 and test well 9/7-24N1 tap waters contained wholly in the San Mateo formation (tables 4C and 4D). The analysis for well 24A1 shows that the water is a sodium bicarbonate type, has a hardness of 246 (computed) ppm, chloride content of 76 ppm, and total dissolved solids of 493 ppm. The quality of water in test well 24N1 is a calcium-sodium bicarbonate type, and has a chloride content of 108 ppm-- higher than that in well 24A1. The quality of water in supply well 24A1 is more like that from wells in the main valley tapping both the alluvium and San Mateo formation; whereas the quality of water in test well 9/7-24B1, except for the sodium content, is more like that in test well 9/7-24D1 near the coast.

Thus, in general, the quality of well waters in San Onofre Creek basin are somewhat better than those in the lower Santa Margarita River basin, but are poorer than those in San Mateo Creek basin. However, the quality is satisfactory for domestic use.

Sea-Water Intrusion

Periodic samples have been taken for analysis from test wells 9/7-13P1, 9/7-14R3, and 9/7-24D1 and from well 9/7-14R2 to determine the status of sea-water intrusion into San Onofre Creek basin (tables 4B and 4C). Thus far there has been no indication of intrusion into the basin. The chloride content of test well 9/7-24D1 has remained between 100 and 108 ppm during the investigation and may represent the normal chloride content of waters in the San Mateo formation and terrace deposits.

Pumping levels in well 9/7-24C1 and 9/7-14R2 were at or slightly below sea level in the latter part of 1951, but probably not far enough below sea level to cause sea-water intrusion. Periodic samples should be obtained for chemical analysis from wells in the coastal part of the basin to determine the status of sea-water intrusion.

LAS FLORES CREEK BASIN

Areal Extent

Las Flores Creek basin is limited principally by the areal extent of the alluvium and bordering San Mateo formation in Las Flores, Piedra de Lumbre, and Las Pulgas Creeks (pl. 1). The upstream end of the basin has been arbitrarily set in Piedra de Lumbre and Las Pulgas Creeks about at the point where the two streams emerge from narrow defiles in the San Onofre breccia. Upstream the water-bearing deposits are extremely narrow, thin, and yield little water to wells. The basin as defined extends from the coast upstream a distance of 2.2 to 2.5 miles and crosses the area of pumped wells. In width the basin ranges from about 4,000 feet near the upstream end to over 6,000 feet near the central part, including the alluvium and about 1,000 feet of San Mateo formation on either side. The surface area of the basin is about 1,400 acres, of which about 850 acres is alluvium and nearly 550 acres is San Mateo formation.

Occurrence of Ground Water

In the Las Flores Creek basin, ground water is obtained largely from the San Mateo formation, although small quantities are derived from the alluvium. Camp supply wells 10/5-18E1, 18M3, 18M4, and 19E1 obtain water principally from the San Mateo formation and only minor amounts from the overlying alluvium. The supply for the two irrigation wells 10/5-18M1 and 10/6-13Q1 is from the same source.

The wells appear to tap a common ground-water body that extends from the upper ends of the basin to the Pacific Ocean, although a major anomaly occurs along a line parallel to and about one-quarter mile upstream from U. S. Highway 101. Upstream from this line a pumping depression has developed, whereas downstream the levels have remained close to the land surface, and one well has occasionally flowed. Around well 10/6-24E1 there is a spring zone that used to be the source of water for the old Mission Las Flores, now in ruins on the west side of the valley. The possible cause for the high levels in this area and coastward is discussed in the section on ground-water outflow.

The bottom of the basin is indefinite because the thickness of the San Mateo formation is not known. However, the usable depth may be limited by water of poor quality even though existing wells extend as much as 200 feet below sea level. Accordingly, because of the possibility of poor quality at depth and because of the potential threat of sea-water intrusion, the bottom has been arbitrarily set at sea level. Laterally the San Mateo formation extends away from the basin for distances of several miles up and down the coast. However, from the standpoint of effective use, the lateral limit of the basin has been set at 1,000 feet beyond the sides of the alluvium. No data are available on the effect of pumping in the basin on ground water in the adjacent areas of the San Mateo formation. The position of the water-level contours along the sides of the basin is inferred and suggests that water is able to move laterally into the basin during periods of ground-water depletion, and vice versa during periods of substantial ground-water replenishment.

Even though the alluvium is relatively fine-grained, there does not appear to be much evidence for confinement in the pumped area. However, the flowing well and spring zone indicate that confinement exists at the coastal end of the basin from the coast at least as far upstream as the spring zone. This area of confined water is about 150 acres in extent. Thus, recharge by infiltration of rain would be limited to that part of the basin upstream from the spring zone.

Source and Movement of Ground Water

The direction of ground-water movement in Las Flores Creek basin is shown by water-level contours drawn on the surface of the water body. The contours on plates 21 and 22 show respectively the movement of water in October 1951, after a considerable depletion to historic low levels so far as is known, and in June 1952, after appreciable recharge and rise in water levels, but to points considerably below the historic high levels in the pumped area.

Both sets of water-level contours show that ground water was moving seaward from the upper ends of the basin to a depression in the heavily pumped part of the basin; also, that locally water appeared to be moving inland north of an apparent ground-water divide toward the depression. The contours show that Piedra de Lumbre and Las Pulgas Creeks are sources of recharge although increments are supplied by lateral and local inland movement of water toward the center of the depression; also that coastward from U. S. Highway 101, ground water was moving toward and discharging into the Pacific Ocean. Thus, as shown on plates 6, 21, and 22 a ground-water divide or ridge existed across the valley along an east-trending line about through well 10/6-24E1.

In October 1951 at the upper ends of the basin the hydraulic gradients were about 30 feet per mile in Piedra de Lumbre Creek and about 60 feet per mile in Las Pulgas Creek valley. In Las Pulgas canyon above the basin, the gradient was roughly 50 feet per mile. The levels in the pumping depression were about 35 feet above sea level, and near U. S. Highway 101 the ground-water divide across the valley was somewhat less than 50 feet above sea level. Coastward, the hydraulic gradient was between 30 and 40 feet per mile. In June 1952 at the upper ends of the basin, the gradients were about 60 feet per mile in Piedra de Lumbre Creek and about 65 feet per mile in Las Pulgas Creek valley. In Las Pulgas canyon upstream from the basin, the gradient was roughly 40 feet per mile. The levels in the pumping depression were about 40 to 43 feet above sea level. The ground-water divide was at about the same altitude as in October 1951 and the coastward hydraulic gradient was also about the same. The gradients indicate that ground water is discharging by natural seaward movement at the coast or offshore where the water-bearing deposits are in contact with the ocean.

The water-level contours for October 1951 as drawn suggest that water was moving from the tongue of San Mateo formation between Piedra de Lumbre and Las Pulgas Creeks toward the areas of pumping, because it is inferred that some storage is supplied to the basin from this source. Following the recharge in the winter of 1952, the contours for June as drawn suggest that the tongue of San Mateo formation was being replenished.

Recharge to Ground Water

Recharge to Las Flores Creek basin is principally by seepage loss from Las Pulgas and Piedra de Lumbre Creeks upstream from the ground-water divide with lesser amounts supplied by infiltration of rain, returned sewage effluent, and ground-water underflow through the alluvium at the upstream end of the basin. Because the alluvium at the upstream end of the basin is thin, the underflow, except for one-half the sewage effluent discharged upstream, is included in the estimates of recharge by seepage loss from the streams.

Seepage Loss in Las Flores Creek Basin

The recharge by seepage loss in Las Flores Creek basin is the surface-water inflow from Piedra de Lumbre and Las Pulgas Creeks less the outflow from Las Flores Creek measured near the edge of the confined area. A stream gage has been installed near U. S. Highway 101 to measure the outflow (pl. 28). No gages are at the upper ends of the basin to measure the inflow.

The magnitude of the seepage loss is limited by the time distribution and amount of runoff, by the ability of the deposits to transmit water away from the creek bed, and by the storage space available in the water-bearing deposits at times when there is runoff in the creek. Of these, the first two elements appear to be the most critical. Unlike the larger ground-water basins on the Camp, this basin was not substantially replenished during the wet winter of 1952, and appreciable runoff wasted to the sea. There was ample storage space available, but the fine-grained poorly permeable deposits comprising the alluvium did not transmit sufficient water from the stream to ground water to refill the depleted storage.

The computed annual inflow to Las Flores Creek basin in the water years 1923-52 is shown in table 25, and the outflow in the water years 1951 and 1952 is shown in table 27. The local residents report that there was no flow upstream from U. S. Highway 101 bridge in the period 1946-51, but could supply no usable data for the years prior to 1946. The inflow, outflow, and seepage loss indicated by these data for the period 1946-52 are shown in table 58.

Table 58.- Estimated seepage loss, in acre-feet, from Las Flores Creek system in the water years 1946-52

Year ending Sept. 30	Computed inflow[1/]	Outflow[2/]	Estimated seepage loss
1946	390	(a)	390
1947	150	(a)	150
1948	69	(a)	69
1949	93	(a)	93
1950	49	(a)	49
1951	26	0	26
1952	2,600	1,830	770
Total			1,550
7-year average			220

1. From table 25.
2. From table 27.
a. Local residents report no outflow.

For the water years 1946-51 the table suggests that all the inflow was recharge by seepage loss along the creek channels. In 1952 about 30 percent of the computed inflow was seepage loss; the remainder wasted to the ocean.

Deep Penetration of Rain

The same methods used for determining the infiltration of rain on the lower Santa Margarita River basin were applied to the Las Flores Creek basin. There is roughly 100 acres of phreatophytes in the basin which thrive on and consume the relatively small yearly rainfall. In addition, the confined area of high water levels at the coastward end of the basin covers about 150 acres, most of which is farmed. This leaves about 1,150 acres where the deep penetration of rain takes place, of which about 200 acres is irrigated, about 900 acres is covered by grass, and about 50 acres is covered by brush.

The rainfall records used are those shown in table 31 for the lower Santa Margarita River basin. The rainfall was probably about the same on Las Flores Creek basin, and therefore it has been used without adjustment. Table 59 shows the estimated deep penetration of rain in the water years 1931-52.

Table 59.- Estimated yearly recharge, in acre-feet, by deep penetration of rain in Las Flores Creek basin in the water years 1931-52[1]

Year ending Sept. 30	Recharge	Year ending Sept. 30	Recharge
1931	0	1942	0
32	160	43	310
33	0	44	10
34	0	45	0
35	310	46	0
1936	0	1947	0
37	290	48	0
38	130	49	0
39	20	50	0
40	0	51	0
41	1,300	52	440

Total	2,970
22-year average, 1931-52	135
17-year base period, 1935-51	140

1. Rainfall shown in table 31.

The table suggests that the long-term annual deep penetration of rain is on the order of 140 acre-feet. During dry periods, such as that from 1945-51, there may be essentially none; but during wet periods, such as 1935-43, the table suggests that the penetration may average as much as 260 acre-feet per year.

If the high water levels in the confined area, which covers about 150 acres, are ever drawn down substantially, then the recharge by deep penetration of rain may be increased somewhat. By applying the same criteria used to derive the estimates for the rest of the area, it is estimated that an additional 20 acre-feet per year of rain infiltration might be supplied, which would make the average for the base period about 160 acre-feet per year.

Returned Sewage Effluent

There are no records of the amount of raw sewage discharged from the septic tanks near Tent Camp 1 in Las Pulgas Creek (pl. 29). It is reported that new Camp Las Pulgas, now under construction, will have a sewage treatment plant which will meter the treated effluent. The Public Works Office believes that the septic-tank discharge has been slightly in excess of 50 percent of the Camp pumpage. Table 61 shows that the pumpage for the period 1944-52 has averaged 170 acre-feet per year for Camp use. Thus, it is estimated that the sewage effluent has averaged about 90 acre-feet per year for the same period.

However, the septic-tank discharge occurs upstream in the narrow canyon of Las Pulgas Creek above the upper end of Las Flores Creek basin. Extensive growths of phreatophytes consume a part of the discharge and most of that reaching the basin downstream enters as ground-water underflow. It is assumed that only about one-half of the effluent reaches the ground water in Las Flores Creek basin.

Total Recharge

The total recharge to ground water in Las Flores Creek basin is estimated for the water years 1946-52 for which all elements of recharge are available. The estimated total recharge, which is the sum of seepage loss, infiltration of rain, and returned sewage effluent, is shown in table 60.

Table 60.- Estimated total recharge, in acre-feet, to Las Flores Creek basin in the water years 1946-52

Year ending Sept. 30	Total recharge
1946	440
1947	170
1948	90
1949	120
1950	70
1951	70
1952	1,300
Total	2,260
7-year average	320

The estimated total recharge decreased from about 440 acre-feet in 1946 to about 70 acre-feet in 1951; in 1952 it was about 1,300 acre-feet. The table shows that more than one-half the recharge for the period was supplied in 1952, or nearly 60 percent of the recharge in about 14 percent of the time. During the period, about 70 percent of the estimated recharge was supplied by seepage loss from streams. In 1952, seepage loss was about 60 percent of the estimated total recharge.

Ground-Water Discharge

Pumpage

Ground water in Las Flores Creek basin is pumped both for irrigation and Camp supply. Approximately 350 acres of land are or have been irrigated, the bulk of which is on the alluvial plains of Las Pulgas, Piedra de Lumbre, and Las Flores Creeks. Little irrigation is done on the terraces to the east and west.

Records of pumpage for Camp supply are available for the 5-year period 1948-52, and for irrigation are available for the 4-year period 1949-52. The data were obtained from the Public Works Office, Camp Pendleton. It is reported that the Camp pumpage is metered at the wells or storage facilities and estimated where not metered. Pumpage for irrigation is estimated by the lessees on the basis of pumping rate of well and length of time pumped.

For water years prior to 1948, the pumpage has been estimated. Pumpage for Camp supply during the years 1944-46 is estimated as being about the same as in 1951 when Tent Camp 1 was essentially filled; and during the water year 1947 is estimated at the average rate of the following three years. Pumpage in 1952 is high owing to construction of new Camp Las Pulgas. Pumpage for irrigation for the water years 1944 through 1948 is estimated as the average of the 3 dry years 1949 through 1951. The recorded and estimated pumpage for Camp supply and irrigation in the water years 1944-52 are shown in table 61.

Table 61.- Ground-water pumpage, in acre-feet, from Las Flores Creek basin in the water years 1944-52

Year ending Sept. 30	Pumpage		Total
	Camp supply	Irrigation	
1944	a 200	a 150	a 350
1945	a 200	a 150	a 350
46	a 200	a 150	a 350
47	a 100	a 150	a 250
48	74	a 150	a 220
49	115	110	220
1950	64	100	160
51	177	210	390
52	368	110	480
Total	1,500	1,300	2,800
9-year average	170	140	310

a. Estimated.

The table shows that the total pumpage has ranged from about 160 acre-feet in 1950 to 480 acre-feet in 1952 and has averaged a little more than 300 acre-feet per year for the 9-year period 1944-52. Pumpage for irrigation has been a little less than that for Camp supply. The pumpage is supplied by 4 supply wells and 2 irrigation wells (table 1A, appendix 1). Well 10/5-18E1 supplied Tent Camp 2 until 1952. Since then new supply wells 10/5-18M3 and 18M4 have supplied some water. Supply well 10/5-19E1 furnishes a small amount of water to a tank park on the terrace east of the valley.

The apparent duty of water applied to about 350 acres of irrigated land, largely planted in beans, ranged from 0.3 foot per acre in 1949 and 1950 to 0.6 foot per acre in 1951 as computed from lessees estimates of water use. The small duty of water, although applied to a low duty-of-water crop, may be unduly low in 1949 and 1950 owing to a smaller acreage irrigated. Some of the water pumped for irrigation probably returns to ground water by deep penetration below the root zone. However, no estimate of the return is made in this report.

Natural Discharge

Evapotranspiration.--Areas of phreatophytes are along the narrow channels of all three creeks and flourish in the spring zone area near well 10/6-24E1. The aerial photos suggest that there are nearly 100 acres of phreatophytes in the basin. Coastward from U. S. Highway 101, it is reported that the area was once overgrown with phreatophytes and was swampy. A system of tile drains was installed so that the area could be drained and farmed.

By use of the same methods applied to the areas of phreatophytes in the lower Santa Margarita River basin, estimates of evapotranspiration loss were derived for the 100 acres in Las Flores Creek basin. The average loss for the base period 1935-51 was roughly 200 acre-feet per year. During the dry years when water levels were depressed, the average consumption may have ranged from about 200 acre-feet in 1946 when water levels were relatively high to about 150 acre-feet in 1951 when water levels were low.

Ground-water outflow and overflow.--Even though a ground-water depression has existed in the central part of the basin, plates 6, 21, and 22 show that a favorable seaward hydraulic gradient has existed coastward from U. S. Highway 101 indicating that natural discharge by ground-water outflow to the ocean has occurred. The outflow takes place through the alluvium and San Mateo formation through a relatively large cross-sectional area of water-bearing deposits--the width is on the order of a mile, but the depth is unknown.

Ground-water overflow has occurred principally in and downstream from the spring zone near well 10/6-24E1 and in Las Flores Creek downstream from U. S. Highway 101. Small flows of less than 0.2 second-foot were observed in the spring of 1951 in Las Flores Creek below a drainage ditch from the spring zone. The flow stopped during the summer and fall, but resumed in 1952 and amounted to about 60 acre-feet for the 1951-52 water year (p. 161). It may have averaged about 50 acre-feet a year for the period 1946-51.

The rise in water levels along a line roughly parallel to and about $\frac{1}{4}$ mile upstream from U. S. Highway 101 may be due either to a change in lithology of the alluvium and/or the underlying San Mateo formation or to a structural feature in the San Mateo formation; or to a combination of both. A comparison of the logs of irrigation well 10/6-13Q1 and test well 10/6-24G2, about 3,000 feet apart, shows that the San Mateo formation changes in character between the two wells. The logs indicate that the upstream irrigation well penetrated a section of San Mateo formation containing 100 percent good water-bearing material to a depth of 150 feet, whereas the test well penetrated a section containing about 30 percent good water-bearing material to the same depth. Thus, the log and water-level data provide evidence for a discontinuity between the wells, but insufficient data are available to define its character.

Thus, the amount of discharge by ground-water outflow can not be directly determined. However, it can be crudely estimated by subtracting all other estimates of discharge from the estimated total recharge in a period for which all other elements are available. As is indicated in the section on the hydrologic equation for the period 1946-52, by the use of recharge and discharge as compared to ground-water storage change, the ground-water outflow was determined by difference and found to average roughly 150 acre-feet a year for the period.

The amount of outflow in any one year would depend directly on the hydraulic gradient coastward from U. S. Highway 101. The hydraulic gradients in 1951 and 1952, if interpolated between well 10/6-24G2 and the coast, were on the order of 30 to 40 feet per mile, suggesting that the outflow during the 2 years was about the same. Considering the relatively large cross-sectional area and steep hydraulic gradient, the small estimated outflow provides additional evidence for the existence of a barrier in the San Mateo formation to ground-water outflow at the coastal end of the valley.

Total Discharge

The total discharge of ground water from Las Flores Creek basin is the sum of the pumpage, evapotranspiration, ground-water underflow, and ground-water overflow. For these, estimates of pumpage for Camp supply and irrigation, evapotranspiration, and ground-water overflow have been made and are shown in table 62. No direct estimates of ground-water outflow are included in the table.

Table 62.- Estimated discharge by pumpage, evapotranspiration, and ground-water overflow in acre-feet, from Los Flores Creek basin in the water years 1944-52

Year ending Sept. 30	Discharge	Year ending Sept. 30	Discharge
1944	600	1949	450
1945	600	1950	400
1946	600	1951	600
1947	500	1952	700
1948	450		
Total			4,900
9-year average			540

The table shows that the estimated discharge by pumpage, evapotranspiration, and overflow has ranged from 400 acre-feet in 1950 to about 700 acre-feet in 1952 and has averaged more than 500 acre-feet per year for the period. The low discharge in 1950 is due to low pumpage for Camp supply and irrigation. The relatively large discharge in 1952 is attributable to a substantial increase in pumpage for Camp supply. Obviously, the relatively low pumpage for irrigation is fortunate because the recharge to the basin is small. If large duty-of-water crops had been planted and irrigated, the pumpage for irrigation would probably have been two to three times as large as it was thereby raising total discharge by several hundred acre-feet a year.

The total discharge for the period 1946-52 has been derived in the section on the hydrologic equation for the same period and was estimated to be about 4,700 acre-feet and averaged nearly 700 acre-feet a year (table 64). Of this average about 150 acre-feet was computed by difference to be ground-water outflow.

Water-Level Fluctuations

In Las Flores Creek basin the records of fluctuations of water levels in wells show the historic low was reached in about October 1951, but that unlike the other basins the peak levels in 1952 had not recovered nearly to the record high levels (table 3A, appendix 3). In general the levels recovered only 3 to 15 feet above the record low levels in the fall of 1951. Plates 6, 21, and 22 show that in the main pumped area the levels recovered only about 5 to 7 feet from 1951 to 1952 and were over 30 feet below land surface. In the main pumped area the water-level profiles for 1951 and 1952 were as much as 25 feet and 18 feet respectively lower than the profile for 1945. For a more detailed record of water-level fluctuations in observation wells, refer to table 3A.

Long-Term Fluctuations

Records for four wells, 10/5-7R1 in Piedra de Lumbre Creek, 10/5-18C1 in Las Pulgas Creek, and 10/6-13Q1 and 13Q2 in Las Flores Creek, have been plotted in hydrograph form and are shown on plate 36.

The record for windmill well 10/5-7R1 shows that a decline was in progress in 1946 which in general continued to the record low in the fall of 1951; the decline was from about 75 feet above sea level to only 57 feet above--a net decline of 18 feet. The level recovered momentarily to nearly 73 feet above sea level in April 1952 and then declined rapidly to year-end.

The record for unused well 10/5-18C1 shows a marked decline from a level possibly as high as 70 or 75 feet above sea level in the spring of 1945 to a low in December 1951 of a little more than 44 feet above sea level--a suggested net decline of roughly 30 feet. In response to winter recharge in 1952, the level rose to about 52 feet above sea level--a rise of only 8 feet.

The composite graph for windmill well 10/6-13Q2 and irrigation well 13Q1 shows a gentle steady decline from 48 feet above sea level in 1945 to about 38 feet above in the fall of 1951--a net decline of about 10 feet. The level then rose slowly and was still rising at the end of 1952 at which time it was 41 feet above sea level--a rise of nearly 3 feet. The level in December 1952 was about 7 feet below that in August 1945.

Thus, except for seasonal changes in response to recharge and pumping, the hydrographs show that the basin probably was not full in 1945, that thereafter a general decline occurred to record low levels in the fall of 1951, and that the basin was replenished only slightly during the winter of 1952. The levels projected upstream in the narrow canyon of Las Pulgas Creek suggest that the deposits there were replenished by the winter recharge of 1952. Therefore, it is believed that in the basin proper seepage loss from Las Pulgas Creek is probably restricted by the relatively low vertical permeability of the deposits. The log for test well 10/5-18M1 shows that there is considerable clay and silt in the alluvium; hence, the downward percolation of water would be restricted.

Fluctuations in Paired Shallow and Deep Wells

Shallow well 10/6-24G3 was augered to a depth of 30 feet and 2-inch pipe installed by the Geological Survey. The well is 12 feet northeast of test well 10/6-24G2, which is 150 feet deep. The hydrographs for the two wells are on plate 34 and show a general seasonal rise and decline in response to recharge and depletion. The level in the test well remained above land surface from February to December 1952. Although the graphs of the two wells are generally parallel, the level of the deep water averages about 4 feet higher than that of the shallow water, indicating the deep water is under a higher pressure head. Furthermore, there is probably slow upward leakage of ground water that recharges the shallow water. Only minor fluctuations in response to tidal loading or pressure have been observed in the test well.

The pressure head in the deep water, which is contained largely in the San Mateo formation, is probably the source of supply to the spring zone near well 10/6-24M1. The slow upward leakage also supplies the low flow in Las Flores Creek downstream from the highway and was the cause for the former swampy area on the alluvial plain coastward from the highway, now drained with tile lines.

Ground-Water Storage Capacity

Storage Units and Depth Zones

The Las Flores Creek basin was divided into two major storage units as follows: (1) The Las Flores storage unit, which extends from the upper end of the basin to the coast as previously defined, which is limited by the areal extent of the alluvium, and which has a surface area of 850 acres; and (2) the Las Flores lateral storage unit, which extends along both sides of storage unit (1) including the narrow wedge between Las Pulgas and Piedra de Lumbre Creeks, and which has an area of 550 acres.

Plate 28 shows the extent of the storage units. It also shows that the tongues of alluvium extending up minor tributaries have been excluded. The selection of the lateral limits of unit (2) above have already been defined as extending 1,000 feet beyond the sides of the alluvium.

The depth zone used in the computation of the volume for storage in unit (1) above is from 5 feet below land surface down to sea level. Cross-section L-L' (pl. 6) shows that in Las Pulgas Creek upstream from well 10/5-18E1 the base of the alluvium is above sea level. In this part, the storage unit extends from 5 feet below land surface to the base of the alluvium; it also includes the wedge of San Mateo formation below the base of the alluvium and above sea level. In Piedra de Lumbre Creek the same condition exists upstream from about Camp supply well 10/5-18E1 and is treated in the same manner. The depth zone used in the computation of volume of deposits in the Las Flores lateral storage unit is between the plane formed by the top of storage unit (1) projected laterally into the San Mateo formation and sea level.

The volumes of the deposits in each storage unit were determined by measuring the average lengths, widths, and thicknesses. The average cross-sectional area for the Las Flores storage unit in the vicinity of well 10/5-1E1 is essentially rectangular in shape; in the alluvium upstream it is approximately triangular in shape, and beneath the alluvium in the San Mateo formation, it is rectangular in shape except for the contact with the alluvium which is triangular in shape. The Las Flores lateral storage unit at its upstream ends on both sides of the valley is rectangular in shape and tapers coastward to zero thickness.

Specific-Yield Values

The specific yield of the deposits in the Las Flores storage unit, except for the underlying San Mateo formation at the upper end, was determined by the same methods used in the lower Santa Margarita River basin, and the same specific-yield values were assigned to the five general types of material comprising the alluvium (table 37).

For the deposits in the Las Flores lateral storage unit and that part of the San Mateo formation underlying the alluvium at the upper end of the basin, the same specific-yield values used in San Mateo Creek basin were employed in the Las Flores Creek basin (table 48).

The logs for 15 wells were used to derive the specific yield of the deposits in both storage units. Most of these wells tap both the alluvium and the San Mateo formation and therefore provided data for both storage units.

Estimate of Storage Capacity

The estimates of ground-water storage capacity were derived by the same method outlined for the lower Santa Margarita River basin. Table 63 shows the estimated storage capacity in the Las Flores and Las Flores lateral storage units.

Table 63.- Estimated ground-water storage capacity of Las Flores Creek basin

Storage unit	Average area (acres)	Average thickness (feet)	Total volume (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Percent of total storage
Las Flores	750	52	39,000	11.7	4,600	55
Las Flores lateral	550	48	26,300	14.5	3,800	45
Total	1,300	50	65,300	12.9	8,400	100

The table shows that the estimated storage capacity for the two storage units is about 8,400 acre-feet, of which 51 percent is contained in the alluvium and 49 percent is contained in the San Mateo formation. About 4 percent of the storage in the San Mateo formation is in the Las Flores storage unit beneath the alluvium. It is not known whether the storage in the area of confined water coastward from the spring zone and in the adjacent part of Las Flores lateral storage unit is available for cyclic storage operation in the basin. If the barrier feature near the spring zone is such that the ground waters upstream and downstream from it are separated hydraulically, the storage available for use would be less. It is estimated that coastward from Highway 101 in a depth zone 5 feet below land surface to sea level and projected laterally into the adjacent Las Flores lateral storage unit there may be 700 acre-feet of storage. The omission of this volume from the total capacity would leave about 7,700 acre-feet of storage in the upstream part of the basin.

At the end of prolonged dry periods, a limited amount of storage below sea level could be used for short periods of time. If the barrier feature effectively separates the water upstream and downstream, and thereby also proves to be an effective barrier to sea-water intrusion, then the upstream storage could be depleted below sea level without endangering the supply. However, during a period of years when storage was being depleted substantially below that in October 1951, continued water-level measurements made in the area would probably show the nature and effectiveness of the barrier although additional observation wells would be necessary to define its position with any accuracy.

In October 1951 the storage depletion reached the maximum of record. In the Las Flores storage unit about 3,300 acre-feet remained in storage, or about 70 percent of the total shown in table 63. In the Las Flores lateral storage unit about 1,800 acre-feet remained in storage, or about 50 percent of the total. Thus, a total of about 5,100 acre-feet remained in storage within the defined limits of the storage units; or the total depletion amounted to 3,300 acre-feet.

The storage in the Las Flores and Las Flores lateral storage units was increased somewhat by the recharge in the winter of 1952, but not nearly to the extent of that in the other major basins; the estimated total storage was 5,900 acre-feet in June 1952. Thus, storage at that time was about 70 percent of the maximum capacity.

In September 1952, which is the end of the water year and the end of the period used in the development of the hydrologic equation, the storage was somewhat less than in June. In the Las Flores storage unit the depletion below maximum storage capacity was about 1,000 acre-feet, and in the Las Flores lateral storage unit was about 1,700 acre-feet; or a total depletion of 2,700 acre-feet.

In October 1945, the few water-level records available suggest that there was nearly 8,000 acre-feet of ground water in storage. This is about 400 acre-feet less than the estimated maximum capacity or 95 percent of the total. Thus, the storage depletion from 1945 to 1951 was about 2,900 acre-feet, nearly 500 acre-feet a year, and the increase from October 1951 to September 1952 was about 600 acre-feet.

Hydrologic Equation for the Period 1946-52

The hydrographs for wells and the water-level profiles indicate that storage was somewhat below maximum capacity in the spring of 1945, continued a steady depletion to the historic low in 1951, and in response to moderate recharge in 1952 was replenished somewhat. However, the storage in 1952 was considerably below that in 1945. Unlike the other major basins, which were essentially replenished in 1952 and showed relatively small net change from 1946 or 1947 to 1952, the Las Flores Creek basin showed a substantial net decline or depletion for the period. Nevertheless, although a period of small net change is not available, the difference in the various elements comprising recharge and discharge can be compared to estimated storage change. In addition, a crude estimate of ground-water outflow can be made.

During the 6-year period 1946-51 of ground-water depletion, the total recharge was estimated to be nearly 1,000 acre-feet (table 60), and the total discharge, excluding ground-water outflow, was estimated to be about 3,000 acre-feet (table 62). The difference between the two is 2,000 acre-feet. The estimated depletion in storage for the same period by use of water-level change and specific yield of the deposits was about 2,900 acre-feet. Thus, if the magnitude of the several estimates is reasonable, the storage depletion of 2,900 acre-feet less the difference between recharge and discharge of 2,000 acre-feet, which is 900 acre-feet, was discharge by ground-water outflow. This suggests that the outflow for the 6-year period averaged about 150 acre-feet a year.

Similarly, for the 7-year period 1946-52 the estimated total recharge was nearly 2,300 acre-feet; and the total discharge, excluding ground-water outflow, was about 3,700 acre-feet. The discharge in excess of recharge was about 1,400 acre-feet. The estimated net depletion in storage by use of water-level change and specific yield was 2,300 acre-feet. Thus, the estimated discharge by ground-water outflow was the storage depletion of about 2,300 acre-feet less the discharge in excess of recharge of 1,400 acre-feet, or about 900 acre-feet. This suggests that there was 900 acre-feet of ground-water outflow for the 7-year period 1946-52 compared to 900 acre-feet derived above for the 6-year period 1946-51; or that the averages were 130 and 150 acre-feet a year, respectively. Because these two averages are in fairly close agreement, the estimate of annual outflow is considered to be roughly 150 acre-feet for the 7-year period. These data are used to form the hydrologic equation for 1946-52 and are shown in table 64.

Table 64.- Comparison of recharge and discharge with storage changes, in acre-feet, in Las Flores Creek basin in the water years 1946-52

	Period (year ending Sept. 30)		
	1946-51	1952	1946-52
Recharge:			
Seepage loss from streams	780	770	1,550
Rainfall infiltration on basin	0	440	440
Returned sewage effluent	180	90	270
(1) Total	960	1,300	2,260
Discharge:			
Pumpage	1,600	480	2,080
Evapotranspiration	1,100	140	1,240
Ground-water overflow	300	60	360
Ground-water outflow	900	150	1,050
(2) Total	3,900	830	4,730
(3) Difference: (1) - (2)	-2,940	+470	-2,470
Ground-water storage change [net increase (+) or decrease (-)]:			
Las Flores unit	-1,400	+300	-1,100
Las Flores lateral unit	-1,500	+300	-1,200
(4) Total	-2,900	+600	-2,300
(5) Difference: (3) - (4)	-40	-130	-170

For the 7-year period 1946-52 the table shows a discrepancy between methods of only 170 acre-feet. This discrepancy suggests that either the estimate of recharge is 8 percent too small or the estimate of discharge is 4 percent too large. Because the suggested percent of error in the estimates is small, no revisions have been made. The most probable sources of error in the elements of recharge and discharge shown in table 64 would be in the estimates of large magnitude, such as seepage loss, evapotranspiration, and ground-water outflow. Although the pumpage for the period was in part metered, there may be errors not only in the part estimated but also in the assumption that no irrigation water returned to ground water by deep penetration below the root zone.

Perennial Yield of Las Flores Creek Basin

The perennial yield of Las Flores Creek basin is the amount of ground water that can be pumped year after year without depleting ground-water storage to the point where the supply is exhausted or the quality is impaired. The records indicate that the basin has not been overdrawn. Whether the suggested barrier to ground-water movement and outflow would provide the use of a substantial volume of storage below sea level is not known, nor would it be known until water levels upstream were drawn down substantially below those of 1951. With levels in the pumped area depressed to or near sea level, the character of the suggested barrier feature might become more apparent.

Because of the relatively small ground-water storage capacity, estimated to be only 8,400 acre-feet, the yield of the basin is limited to the supply during dry periods. Furthermore, it has been shown that the basin does not become fully replenished in one wet year, such as 1952, as do the other major coastal valleys. Hence, the yield can not be based on the storage and recharge available between single wet years; rather, the yield must be based on the relatively long dry periods which are followed by wet periods of similar length. Accordingly, the yield for the 14-year dry period 1923-36 is estimated as a criterion of the probable yield in future dry periods of similar length and character.

With regard to recharge by seepage loss from streams during the 14-year dry period 1923-36, the inflow shown in table 25 taken in conjunction with the inflow and seepage loss estimates for the period 1946-52 suggest that in the years 1926, 1927, and 1932 there would have been considerable surface-water outflow to the ocean. In these 3 years the computed inflows were 1,200, 8,100, and 2,600 acre-feet respectively.

Based on the estimated seepage loss in 1952, it is assumed that seepage loss in the 3 years conservatively totaled 1,000 acre-feet. For the remaining years of low inflow, which ranged from 41 to 360 acre-feet, the inflow and seepage loss for the period 1946-51 suggest that essentially all the inflow was recharge to ground water. Thus, the seepage loss for the 14-year dry period probably totaled about 3,000 acre-feet and averaged somewhat more than 200 acre-feet a year.

Recharge by infiltration of rain probably occurred in the wet years during the dry period, but probably did not average more than 75 acre-feet a year for the period. Thus, the estimated total recharge during the dry period was roughly 4,000 acre-feet, or averaged 300 acre-feet a year.

With regard to the estimated ground-water discharge during the period 1923-36, the ground-water outflow probably averaged 150 acre-feet, which was that estimated for the period 1946-52; the ground-water overflow, which was estimated to average about 50 acre-feet for the period 1946-52, was probably about the same for the period; and evapotranspiration loss probably averaged about the same as for the period 1946-52 or between 150 and 200 acre-feet a year. The estimated total natural discharge during the 14-year dry period is the sum of the three elements, which is roughly 5,000 acre-feet or roughly 350 acre-feet a year. Thus, for a similar 14-year dry period, the natural discharge might exceed the recharge by about 1,000 acre-feet.

Because the basin may be divided by the postulated barrier near U. S. Highway 101, it appears desirable to deduct the 700 acre-feet of storage on the coastal side of the barrier from the total estimated capacity of 8,400 acre-feet. This leaves 7,700 acre-feet of storage capacity in the gorged part of the basin.

Thus, the short-term perennial yield during a similar dry period averaging 14 years in length would be the estimated storage capacity in the pumped area of 7,700 acre-feet less the discharge in excess of recharge of about 1,000 acre-feet divided by the number of years of drought; or:

$$\text{Perennial yield} = \frac{6,700}{14} = 500 \text{ acre-feet}$$

This estimate would be the amount of water available for annual pumpage in Las Flores Creek basin during a protracted dry period, such as that in 1923-36. This estimated yield is crude because of the lack of data for the elements of recharge and discharge for the 14-year dry period 1923-36.

Green (1945, typewritten report) estimated the yield during the 10-year dry period 1896-1905 to be 400 acre-feet. This yield was based on an estimated surface-water inflow of 1,200 acre-feet a year, and it was assumed there was no outflow. He concluded that the yield was one-third of the inflow. The reason why Green selected one-third of the inflow as the perennial yield is not known.

If pumpage for irrigation were continued during a future dry period at the annual rate of 150 acre-feet established during the dry years 1946-51, there would remain only about 300 to 400 acre-feet a year for Camp supply, plus a small part of the sewage effluent returned to the ground-water basin. With regard to the returned effluent, new Camp Pulgas, which is being constructed near Tent Camp 1, will probably discharge its effluent some distance upstream from Las Flores Creek basin. Accordingly, a substantial part of the effluent may be lost by evapotranspiration before it reaches the pumped basin downstream.

On the other hand, a reduction in evapotranspiration loss would increase the yield of the basin and could be accomplished by periodic clearing of phreatophytes from the stream channels not only in the basin as defined but also upstream in Las Pulgas Canyon as far as the treated sewage outlet for new Camp Pulgas. If the loss in the basin alone were reduced by one-half, the yield would be increased by about 20 percent or to about 600 acre-feet a year. The clearing of the channel upstream would provide additional yield by increasing the sewage effluent returned to the pumped basin.

It has been shown that for two base periods, 1923-44 and 1935-51, the computed average annual inflow was only 1,300 acre-feet (table 26). This amount is approximately the long-term average surface-water inflow to Las Flores Creek valley. Because this inflow is small and because there appears to be no dam site below the junction of Piedra de Lumbre and Las Pulgas Creeks, construction of a dam might not be feasible. The possibility of supplementing the supply by export from the Santa Margarita River valley might be considered. The supply could be obtained either from ground water or from the proposed De Luz dam.

Chemical Quality of Water

General Character

For Las Flores Creek basin chemical analyses of well waters made by the Sanitation Division Laboratory, Eleventh Naval District, are shown in tables 4C, 4D, and 4E; and those made by the Geological Survey are shown in table 4B (appendix 4).

Most wells in the basin tap waters in the San Mateo formation and a few domestic wells tap waters in the alluvium. In general, the alluvium is a relatively poor water-yielding deposit. Accordingly, deep wells tapping waters in both deposits derive the bulk of their supply from the San Mateo formation and therefore the analyses indicate principally the quality in this formation.

Samples analyzed for test wells 10/5-18L1, 10/5-18L2, and 10/6-24C2; Camp supply well 10/5-18M1; and irrigation wells 10/5-18M2 and 10/6-13Q1 show that the waters are a sodium chloride-bicarbonate type. In general, the chloride is close to the upper limit of 250 ppm set by the Department of Public Health for domestic use. The general range in concentrations of the principal constituents (in large part computed) for these wells in ppm are as follows: Calcium 40 to 90, magnesium 29 to 41, sodium 80 to 206, bicarbonate 298 to 378, sulfate 70 to 108, and chloride 110 to 280. The computed total dissolved solids range from 523 to 894.

The water in supply well 10/5-18M1, in Piedra de Lumbre Creek, is relatively low in chloride, 110 ppm, and in total dissolved solids, 523 ppm (computed). The water from test well 10/5-18L1, in Las Pulgas Creek, is also relatively low in chloride, 128 ppm, and in total dissolved solids, 537 ppm (computed). The quality becomes poorer toward the coast. The waters in irrigation well 10/6-13Q1 and test well 10/6-24C2 contain

280 and 260 ppm of chloride and 894 and 770 ppm (computed) of total dissolved solids respectively.

The poorer quality water toward the coast is believed to be due principally to incomplete flushing of the connate saline waters from the San Mateo formation. Thus, the degree of flushing in Las Flores Creek basin has been considerably greater than that in the lagoon area of the lower Santa Margarita River basin, but slightly less than that in San Mateo and San Onofre Creek basins.

There is some indication that the chloride content of waters in the San Mateo formation increases with depth. During the construction of supply well 10/5-1823, the chloride content increased from 230 ppm at a depth of 70 feet to 292 ppm at a depth of 280 feet and decreased to 252 ppm at 300 feet. When completed the well discharged water containing 260 ppm of chloride. During the construction of supply well 10/5-1824, the range in chloride content was only from 140 to 150 ppm. Thus, there is a considerable range in chloride content even in wells 1,000 feet apart.

Sea-Water Intrusion

Periodic samples have been obtained for analysis from supply well 10/5-19E1, windmill well 10/6-13Q2, and test well 10/6-24G2 to determine the status of sea-water intrusion into Las Flores Creek basin (tables 4B and 4C). The chloride content of the well waters has remained about the same. The water-level profiles on plate 6 show that the levels near the coast have remained considerably above sea level. Therefore, under the historic seaward hydraulic gradient there has been no tendency for sea-water intrusion to occur. Nevertheless, periodic samples should be taken for analysis to determine the status of sea-water intrusion in wells near the coastal end of the valley.

ALISO CREEK BASIN

Areal Extent

Aliso Creek basin extends from the San Onofre Hills to the Pacific Ocean--a distance of about 1.8 miles (pl. 28). One small Camp supply well, 10/5-29L1, is located on the narrow alluvial plain of Aliso Creek. The surface area of the basin is arbitrarily established as the surface extent of the alluvium which is slightly less than 200 acres.

Occurrence of Ground Water

Ground water in Aliso Creek basin is contained largely in the San Mateo formation, although some is contained in the alluvium and possibly in the lower part of the unnamed deposit of Pleistocene (?) age. So far as is known, the wells tap a common ground-water body that extends the full length of the basin and laterally is coextensive with ground water in the deposits and formations along the sides of the basin. The bottom of the basin is arbitrarily set at sea level.

Evidence of confined water at the coastward end of the basin is indicated by the water-level fluctuations in test well 10/5-31A1 which respond to the effects of tidal loading. Pumping of supply well 10/5-29L1 does not cause any observable water-level changes in the test well. However, the level in the test well responds to recharge from the creek indicating either a transmission of pressure head into the confined-water area or that recharge is able to percolate slowly downward to the ground-water body in the vicinity of the well.

Source and Movement of Ground Water

The direction of ground-water movement in Aliso Creek basin is shown by water-level contours drawn on the surface of the water body. Plates 21 and 22 show the movement in October 1951 and in June 1952--about the lowest and highest levels of record respectively. Both sets of contours show that ground water was moving seaward throughout the length of the basin, which indicates that the principal source of recharge is Aliso Creek and that discharge takes place at the coast or offshore where the water-bearing deposits are in contact with the ocean. Some recharge is contributed by infiltration of rain on the valley floor and indirectly from infiltration along the sides.

Near the central and lower part of the basin the contours for October 1951 and June 1952 show that the seaward hydraulic gradients were about 30 and 22 feet per mile respectively. The greatest rise in levels from 1951 to 1952 occurred at the lower end of the basin.

Recharge to Ground Water

Recharge to ground water in Aliso Creek basin is principally from the creek with lesser amounts supplied by rainfall infiltration and ground-water underflow at the upper end of the basin. The underflow is negligible and is included in the estimate of seepage loss from the creek. No stream gages have been established on this minor stream to measure the surface-water inflow to and outflow from the basin. However, estimates have been derived in the section on surface-water resources and show that the inflow to the upper end of Aliso Creek basin averages 270 acre-feet per year, subject to a possible error of 20 percent.

No estimate has been made of the surface-water outflow; therefore, no estimate of seepage loss is available. However, based on the average inflow-outflow relationships in other coastal valleys, the seepage loss may be on the order of 20 to 40 percent of the inflow or very roughly 100 acre-feet per year.

The amount of recharge supplied by infiltration of rain on the 200 acres of grasslands on the basin floor is small. For the base period 1934-51, the recharge may have averaged only 25 acre-feet. Thus, the total recharge is estimated as roughly 125 acre-feet a year.

Ground-Water Discharge

Ground-water discharge from Aliso Creek basin is by natural seaward movement, by minor evapotranspiration in and near the lagoon, and by pumpage from small Camp supply well 10/5-29L1. The discharge by seaward movement probably forms a large part of the discharge. Under conditions of no pumpage or storage change, the total discharge by natural processes would be equal to the total recharge or about 125 acre-feet a year.

Well 10/5-29L1 is equipped with a deep-well turbine powered by a 15-horsepower electric motor; it is used infrequently to supply one of the so-called "tank parks." The water is used principally for washing military vehicles. So far as is known, there is no complete record of pumpage from this well. However, based on reports and fragmentary records, it is believed to be very small and in the years 1950-52 probably did not average more than 20,000 gallons per day or more than 25 acre-feet per year.

Water-Level Fluctuations

Periodic water-level measurements have been made by the Geological Survey in supply well 10/5-29L1 since September 1950 and in test well 10/5-31A1 since its completion in August 1951. These records are plotted in hydrograph form on plate 37. The graph for well 29L1 shows a decline from about 43 feet above sea level in the fall of 1950 to about 35 feet above sea level in December 1951. During the wet winter of 1952, the level rose rapidly to over 47 feet above sea level; a seasonal decline in the summer months occurred followed by a recovery to 44 feet above sea level in December 1952.

The graph for test well 10/5-31A1 shows that the level was about 13.5 feet above sea level during the fall of 1951, followed by a rapid rise to over 22 feet above sea level in March 1952 and by a small seasonal decline and a subsequent recovery to about 22 feet above sea level in December 1952.

Thus, both records show either a gradual decline or essentially no decline at the end of the dry years indicating, at least in well 10/5-29L1, that natural seaward drainage plus the pumpage had depleted ground-water storage. The winter recharge in 1952 caused the levels in both wells to respond quickly by rising 9 to 12 feet in a period of 3 months.

An automatic water-level recorder was operated on test well 10/5-31A1 from March 25 to April 21, 1952. The record shows no pumping effects from supply well 10/5-29L1, which is about 0.8 mile upstream, but shows a moderate response to tidal loading and/or tidal pressure effects. The maximum tidal response was nearly 0.2 foot and the minimum was only 0.03 foot.

Perennial Yield

The perennial yield of Aliso Creek basin is essentially equal to the recharge less the unsalvagable natural dishcarge. However, because the lateral limits of the basin are indefinite, a substantial drawdown of the water levels in the basin would cause water to move in from the contiguous, so-called coastal intervalley area. This in turn would increase the potential recharge area and hence increase the perennial yield somewhat. More critical, perhaps, would be the increased storage capacity which would allow for larger yearly pumpage during prolonged dry periods. If the coastal intervalley area were to be fully developed, then the storage capacity of Aliso Creek basin would be limited. In any event, owing to the potential threat of sea-water intrusion, the storage and hence water levels should not be drawn down below sea level except possibly for short periods of time.

Under substantial development the natural discharge by ground-water outflow would be reduced. Assuming that storage would be depleted during dry periods to about sea level and would be replenished during wet periods to about maximum capacity, the ground-water outflow would be reduced to about one-half its annual rate, or to about 60 acre-feet a year. The evapotranspiration loss is believed to be small. Accordingly, it might be possible to salvage about one-half the total natural discharge by cyclic storage operation. The perennial yield, then, is estimated roughly as 50 to 75 acre-feet.

Chemical Quality of Water

The analysis of the water from test well 10/5-31A1 (table 4C) shows that the total dissolved solids are 780 ppm. The principal constituents in ppm are as follows: Sodium 133 (computed), calcium 101 (computed), magnesium 44 (computed), bicarbonate 376 (computed), and chloride 220. Thus, the water is a sodium chloride-bicarbonate type. A brief partial analysis of water from supply well 10/5-29L1 (table 4B) shows that the chloride content is 195 ppm, hardness 340 ppm, and total dissolved solids between 730 and 850 ppm (computed between 0.6 and 0.7 of the specific conductance). Thus, so far as the analysis shows, the quality is generally satisfactory for domestic use.

COASTAL INTERVALLEY AREA

Areal Extent

The coastal intervalley area in general includes the strip of broad terraces along the coast between San Onofre Creek and the San Luis Rey River. However, because of the narrowness of the area and the relatively poor yields of wells southeastward from San Onofre Creek nearly to Las Flores Creek and because of poor quality of waters in wells northwestward from the Santa Margarita River to about Cockleburr Canyon, the area of treatment is limited to the coastal mesa between Cockleburr Canyon and Las Flores Creek (pl. 28). This coastal area is about 3 miles long, and extends inland from the coast about to the edge of the exposed San Onofre breccia--a width of nearly 2 miles and an over-all area of about 3,500 acres.

Northwest of Las Flores Creek valley, test well 10/6-3P1 was drilled on the terrace near Horno Creek to determine the yield, quality of water, and relation of water level to sea level. The San Mateo formation was not encountered in the well, and the terrace deposits contained essentially no water. Wells have been drilled elsewhere along U. S. Highway 101 between Las Flores and San Onofre Creeks and reportedly had poor yields and/or poor quality of water. Thus, the part of the coastal area northwest of Las Flores Creek is not favorable to water-supply development.

Occurrence of Ground Water

Ground water in the coastal intervalley area is contained largely in the San Mateo formation but partly in the alluvium of minor streams and possibly in the lower part of the older terrace deposits. One old windmill well, 10/5-19F1, is in this area, but is now filled (pl. 1). In all probability the water body contained in the deposits is coextensive with the water bodies in Las Flores and Aliso Creek basins. This area offers possibilities for limited ground-water development, but any small supply wells drilled should be at least a mile from the coast line and about 0.5 mile from the contact of the San Onofre breccia. This leaves a narrow northwest-trending strip where it would be the most desirable to test for small supply wells.

Source and Movement of Ground Water

Too few wells exist in the coastal area to provide a basis for the construction of water-level contours on the surface of the water body. However, the position of the contours might be roughly interpreted between Aliso and Las Flores Creeks by projecting the contours from Aliso Creek northwestward parallel to the coast. Obviously, the pumping depression in Las Flores Creek basin would cause major inflections in the projected contours.

Recharge is supplied by seepage loss from the minor streams crossing the area and by infiltration of rain. Ground-water discharge occurs by natural seaward movement through the water-bearing formations and deposits directly into the ocean.

Recharge, Discharge, and Perennial Yield

In the coastal intervalley area recharge by seepage loss from the minor streams is small. If the average runoff supplied by the 8.1 square-mile drainage area of Aliso Creek to its basin is only about 270 acre-feet a year, then the amount supplied from the minor streams in the coastal area probably averages considerably less than 100 acre-feet a year. Probably less than one-half the runoff would seep downward to ground water.

Recharge by infiltration of rain is probably the principal source of supply and occurs in an area of about 3,500 acres which is largely covered with grass. Hence, the rainfall in excess of 15 inches may penetrate to ground water. For the base period 1935-51 the rainfall was probably about the same as that shown in table 31. From these rainfall data the average annual infiltration of rain can be computed to be about 400 acre-feet. Thus, the total recharge, which includes both infiltration of rain and seepage loss from minor streams, is probably on the order of 400 acre-feet per year.

Ground-water discharge from the area takes place principally by seaward movement of ground water or by ground-water outflow. Some discharge may occur by movement into the lagoons of minor creeks where minor evapotranspiration loss takes place. Because there is no pumpage, the natural discharge is essentially the same as the recharge.

The perennial yield is essentially equal to the recharge less any unsalvagable natural discharge. Under full development the natural discharge by ground-water outflow would be greatly reduced. Assuming that storage would be depleted during dry periods to about sea level and would be replenished during wet periods to about maximum capacity, the ground-water outflow would be reduced by about one-half its present annual rate of discharge or crudely to 200 acre-feet. Thus, the perennial yield would be the estimated annual average recharge of about 400 acre-feet less the unsalvagable natural discharge of possibly 200 acre-feet or would be roughly 200 acre-feet a year.

Quality of Water

The quality of water to be expected in wells drilled to moderate depths would probably be similar to that obtained from wells in Aliso and Las Flores Creek basins. If so, the waters would be a sodium chloride-bicarbonate type to a calcium chloride-bicarbonate type. The concentrations of chloride might be more than 200 ppm and the total dissolved solids more than 600 ppm. There is also a possibility of encountering water locally with a chloride concentration of more than 250 ppm.

In the area between the Santa Margarita River and Cockleburr Canyon, which is called Stuart Mesa, the water level coastward from the highway and probably inland for some distance is close to the land surface and the quality of water is very poor. Test well 11/5-4N1 was drilled to a depth of 200 feet--the upper 26 feet penetrated terrace deposits and the lower 174 feet was in the San Mateo formation. The water level in well 4N1 has fluctuated within 4 feet of the land surface (pl. 34). Stuart Mesa has been irrigated since 1938 and the high water levels may be due to returned irrigation water.

The sample from test well 11/5-4N1 shows concentrations of the principal constituents in ppm to be: Sodium plus potassium about 620(?) (computed), calcium 600 (computed), magnesium 238 (computed), bicarbonate 320 (computed), chloride 1,960(?) (shown in table 40 as 960 ppm), and sulfate 915 (table 40). The water is primarily a calcium-sodium chloride type. The high magnesium and sodium chloride suggest that it is a modified connate sea water. The water sampled was derived largely from the San Mateo formation. Thus, the poor quality at depth is probably not a result of concentrated irrigation return water.

Because of the poor quality of water in the Stuart Mesa area, it is not advisable to attempt the development of a water supply. How far northeast the poor quality water extends is not known except that the water from windmill well 10/5-33P1 is reported to be potable.

FALLBROOK NAVAL AMMUNITION DEPOT

The Fallbrook Naval Ammunition Depot is adjacent to the northeast side of Camp Pendleton and borders on the Santa Margarita River (pl. 1). The pumpage for Depot use, which is shown in table 35, has ranged from 40 to slightly more than 100 acre-feet a year. Thus, unless a substantial expansion is anticipated, it appears that a maximum of 100 to 125 acre-feet a year is ample to meet the needs of the Depot.

When the Depot was first constructed, supply well 9/4-26M1 was drilled in the decomposed granite (basement complex) to a depth of about 70 feet in an attempt to secure a supply. This well reportedly pumped 1,000 gpm for about 30 minutes and broke suction. Accordingly, after a search elsewhere for a supply, an infiltration gallery, well 9/4-14M1, was constructed in the alluvium of the Santa Margarita River (pl. 1).

Well 9/4-14M1 is about 4.5 river miles upstream from the junction of De Luz Creek. The well was constructed by excavating a trench 14 feet deep across the river bed, which is about 80 feet wide, and installing a 36-inch perforated concrete tile pipe. Cribbing and rocks were placed over the pipe and the trench was then backfilled. On the south bank a 6-foot shaft was excavated to a depth of 35 feet in granitic rock to connect with the end of the concrete pipe, and two pumps were set in the shaft. These pumps discharge into tanks where a booster pump, operating under about a 250-pound head, lifts the water to storage facilities high above the river to the south. The combined yield of the pumps, when the gallery is fully saturated, is reported to be 1,000 gpm with a drawdown of only 1/16-inch.

This installation supplied sufficient water for the Ammunition Depot until the summer of 1951 when the level in the well reportedly declined almost to the bottom of the tile pipe; and in the summer of 1952, even after a wet winter, the water level again reportedly declined below the tile pipe, and water had to be obtained from supply well 9/4-29L1 at considerable expense. The declines are probably due to the ever-increasing ground- and surface-water diversions upstream which deprive the alluvium downstream of its natural recharge. It is also possible that growths of bacteria or algae have plugged up the perforations in the concrete tile thereby greatly reducing the yield of the well.

The water level in well 9/4-29L1 at the junction of De Luz Creek was 8.3 feet below land surface in October 1951 and about 3.5 feet in March 1952. In spite of the water withdrawn from wells 9/4-14N1 and 9/4-29L1, there has been sufficient underflow moving down through the alluvium in both the Santa Margarita River and De Luz Creek to keep the deposits at De Luz dam site fully saturated.

Accordingly, because the supply from the decomposed granite appears insufficient to meet the needs of the Depot and because the supply in the alluvium of the Santa Margarita River in this reach is undependable during the late summer, it is suggested that consideration be given to supplying the Depot from the system which now supplies or will supply the main Camp area of Camp Pendleton, which is about 3 miles away.

NAVAL HOSPITAL

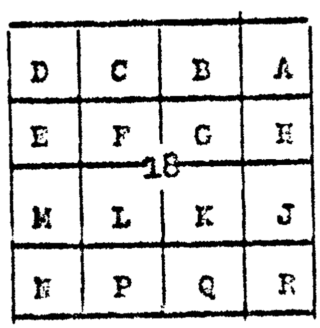
The U. S. Naval Hospital is between O'Neill Lake and the Santa Margarita River (pl. 1). The pumpage for hospital use is supplied from well 10/4-5D1 (in the early years, some water was supplied from well 10/4-5D2 now destroyed). Well 10/4-5D1 when developed pumped about 2,000 gpm with only a 9-foot drawdown, which makes it the most productive well on the Camp. Since 1945 the pumpage has ranged from about 300 to 400 acre-feet a year, which suggests that if the well were operated at a rate of 2,000 gpm it would need to operate only 45 days a year to supply 400 acre-feet. Thus, the supply from this one well is adequate.

However, should the well fail or be washed out during a flood, it would be desirable to have a standby well that could be used in such an emergency, even though it is reported that a small standby pipeline now connects the hospital with the main Camp supply. An additional well could be constructed in Upper Basin as a precautionary measure.

WELL-NUMBERING SYSTEM

The well-numbering system used in the Camp Pendleton investigation conforms to that used in essentially all ground-water investigations made by the Geological Survey in California. It has been adopted as official by the State Division of Water Resources and by the State Pollution Control Board throughout the State.

The wells are assigned numbers according to their location in the rectangular system for the subdivision of public land. For example, in the number 10/4-18M2, which was assigned to a recently completed well in Chappo Basin, the part of the number preceding the bar indicates the township (T. 10 S.), the part between the bar and the hyphen is the range (R. 4 W.), the number between the hyphen and the letter indicates the section (sec. 18), and the letter indicates the 40-acre subdivision of the section shown in the accompanying diagram.



Within each 40-acre tract the wells are numbered serially as indicated by the final digit. Thus, well 10/4-18M2 is the second well to be listed in the NW¼SW¼ sec. 18. As all of Camp Pendleton is in the southwest quadrant of the San Bernardino meridian and base lines, the foregoing abbreviation of the township and range is sufficient.

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