UNDERGROUND RESERVOIRS
OF
SOUTH COASTAL BASIN

SCALE 2 1 0 2 4 6 8 10 12 14 16 18 20 MILES

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS

PUBLICATIONS OF THE
DIVISION OF WATER RESOURCES
EDWARD HYATT, State Engineer

Reports on State Water Plan Prepared Pursuant to Chapter 832, Statutes of 1929

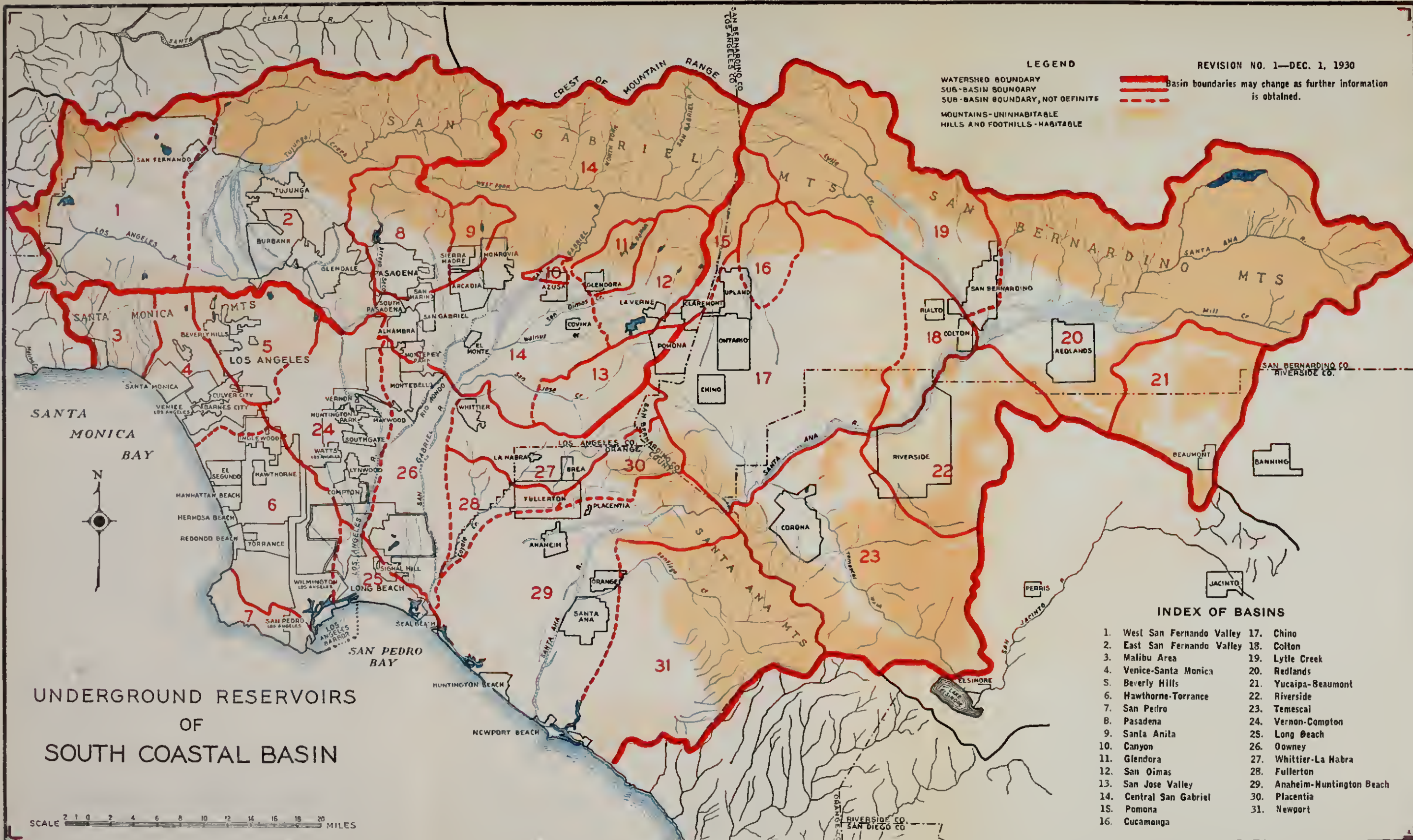
BULLETIN No. 32

SOUTH COASTAL BASIN

A Cooperative Symposium of activities and plans of public agencies in Los Angeles, Orange, San Bernardino and Riverside counties, leading to conservation of local water supplies and management of underground reservoirs.

1930

80702


UNDERGROUND RESERVOIRS
OF
SOUTH COASTAL BASIN
LEGEND
WATERSHED BOUNDARY
SUB-BASIN BOUNDARY
SUB-BASIN BOUNDARY, NOT DEFINITE
MOUNTAINS-UNINHABITABLE
HILLS AND FOOTHILLS-HABITABLE
REVISION NO. 1—DEC. 1, 1930
Basin boundaries may change as further information is obtained.
INDEX OF BASINS
1. West San Fernando Valley
2. East San Fernando Valley
3. Malibu Area
4. Venice-Santa Monica
5. Beverly Hills
6. Hawthorne-Torrance
7. San Pedro
8. Pasadena
9. Santa Anita
10. Canyon
11. Glendora
12. San Dimas
13. San Jose Valley
14. Central San Gabriel
15. Pomona
16. Cucamonga
17. Chino
18. Colton
19. Lytle Creek
20. Redlands
21. Yucaipa-Beaumont
22. Riverside
23. Temescal
24. Vernon-Compton
25. Long Beach
26. Downey
27. Whittier-La Habra
28. Fullerton
29. Anaheim-Huntington Beach
30. Placentia
31. Newport
CREST OF MOUNTAIN RANGE
SAN GABRIEL MTS
SAN BERNARDINO MTS
SANTA MONICA MTS
SANTA ANA MTS
SANTA MONICA BAY
SAN PEDRO BAY
SAN BERNARDINO CO.
LOS ANGELES CO.
RIVERSIDE CO.
ORANGE CO.
SAN DIEGO CO.
SCALE MILES

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ORGANIZATION

B. B. Meek ---------------------------- *Director of Public Works*
Edward Hyatt ---------------------------- *State Engineer*

This bulletin was planned and the introductory chapter written by
Harold Conkling, *Deputy State Engineer*

CHAPTER 832, STATUTES OF 1929

An act making an appropriation for work of exploration, investigation and preliminary plans in furtherance of a coordinated plan for the conservation, development, and utilization of the water resources of California including the Santa Ana river, Mojave river and all water resources of southern California.

[I object to the item of $450,000.00 in section 1 and reduce the amount to $390,000.00. With this reduction I approve the bill. Dated June 17, 1929. C. C. YOUNG, Governor.]

The people of the State of California do enact as follows:

SECTION 1. Out of any money in the state treasury not otherwise appropriated, the sum of four hundred fifty thousand dollars, or so much thereof as may be necessary, is hereby appropriated to be expended by the state department of public works in accordance with law in conducting work of exploration, investigation and preliminary plans in furtherance of a coordinated plan for the conservation, development and utilization of the water resources of California including the Santa Ana river and its tributaries, the Mojave river and its tributaries, and all other water resources of southern California.

SEC. 2. The department of public works, subject to the other provisions of this act, is empowered to expend any portion of the appropriation herein provided for the purposes of this act, in cooperation with the government of the United States of America or in cooperation with political subdivisions of the State of California; and for the purpose of such cooperation is hereby authorized to draw its claim upon said appropriation in favor of the United States of America or the appropriate agency thereof for the payment of the cost of such portion of said cooperative work as may be determined by the department of public works.

SEC. 3. Upon the sale of any bonds of this state hereafter authorized to be issued to be expended for any one or more of the purposes for which any part of the appropriation herein provided may have been expended, the amount so expended from the appropriation herein provided shall be returned into the general fund of the state treasury out of the proceeds first derived from the sale of said bonds.

FOREWORD

This report is one of a series of bulletins on the State Water Plan issued by the Division of Water Resources pursuant to the provisions of Chapter 832, Statutes of 1929, directing further investigations of the water resources of California. The series includes Bulletins Nos. 25 to 36, inclusive. Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," is a summary report of the entire investigation.

Prior to the studies carried out under this act, the water resources investigation had been in progress more or less continuously since 1921 under several statutory enactments. The results of the earlier work have been published as Bulletins Nos. 3, 4, 5, 6, 9, 11, 12, 13, 14, 19 and 20 of the former Division of Engineering and Irrigation, Nos. 5, 6 and 7 of the former Division of Water Rights and Nos. 22 and 24 of the Division of Water Resources.

This bulletin consists of articles by the technical head of each public construction and research agency which is doing work leading to conservation or utilization of the waters of South Coastal Basin or by a member of the staff of such agency. It is not designed to furnish answers to any questions and, except in those few cases where work has proceeded to the point where conclusions are definite, none are set out. Needless to say, a conclusion by one writer does not imply that the others agree, nor does it necessarily represent the views of the Division of Water Resources. The bulletin is a progress report written by each man concerning his own work and does not pretend to be more.

CHAPTER I

GENERAL STATEMENT

Projects planned in detail or actually under way for additional water supplies for South Coastal Basin will cost in the aggregate close to $350,000,000. Distribution systems will add much more to this cost, but plans for these have not yet been studied in detail and await more comprehensive knowledge than now exists.

Additional supplies may come from the following:

1. Salvage of local flood wastes.
2. Salvage of local evapo-transpiration losses.
3. Salvage of sewage waste.
4. Importation of water from Mono Basin and from Colorado River.

South Coastal Basin consists of the Santa Ana, San Gabriel and Los Angeles River valleys, and the West and South Coastal Plains. It is 90 miles long at its greatest length, 50 miles wide at its greatest width, contains 2200 square miles of irrigable or habitable land and has a population of 2,500,000. The total of all water it is proposed to import and the total of all local water it may be possible to salvage gives a quantity which, spread over the entire 2200 square miles, would cover it a foot deep. Of this, slightly more than 20 per cent may be furnished by salvage of local waters. With proper distribution this quantity of water is probably sufficient for ultimate needs so far as the future may be visualized.

The increase in use of water has been rapid for some time back, but the past, especially in the territory to the east of the Metropolitan Area, is not necessarily indicative of future rate of growth. More than half of the present annual increase is in the Metropolitan Area, comprising the western 40 per cent of the basin. In the Agricultural Area, which term may be applied to the eastern 60 per cent, total annual increase in use is less than in the Metropolitan Area.

If importations for Los Angeles city from Owens Valley be neglected, about 90 per cent of all water supplies are derived from underground reservoirs underlying the valley floors on which the major part of the cities and towns and agriculture have been developed. These underground reservoirs or basins in turn get their supply by retaining a part of the wild and sudden floods of the region and a part of the rainfall which comes upon the valley floors overlying them. They regulate by natural processes the surplus waters of the wet for use in the dry years and have made the present economic development of the region possible. All plans for additional water supply propose further utilization of the underground reservoirs and control, in so far as possible, of the supplies placed in them.

If the entire South Coastal Basin were a single underground reservoir the matter of further utilization would be comparatively simple from the physical standpoint. Preliminary estimates indicate for the basin as a whole that the long time average replenishment, including present importations from Owens Valley to Los Angeles, is about equal to the present draft, but a statement to the effect that replenishment equals demand would be misleading and in fact in some basins, even if long time supply does equal demand, the situation is precarious for other reasons. Preliminary studies indicate that instead of one simple basin there are twenty-nine separate units or underground reservoirs and that each one is a problem which must be studied separately. A few of these basins apparently have a surplus, considering the long time average replenishment. The others are overdrawn in varying degrees. But legal, financial and physical barriers to general transfer of supplies from one to the other are almost insuperable, so that any estimate of present shortage must disregard the surpluses and combine the shortages in individual basins. On this basis, preliminary estimates place the aggregate present shortages in the Agricultural Area, or eastern two-thirds, at between 200,000 and 250,000 acre-feet. That is, when estimated long time average annual recharge is compared to present annual draft it is found that the draft is greater than the recharge by the above amounts and that the basins in which this condition exists are drawing on water stored in past ages. In the Metropolitan Area, or western third, there is a present surplus, small as compared to rate of increase in demand, belonging to the city of Los Angeles and due to importation of water from Owens Valley.

Many agencies are at work on varied activities directed toward conservation of local wastes and to a better understanding of the local situation. Two agencies are directing their activities toward importing additional supplies. The city of Los Angeles is bringing additional water from Mono Basin and this of course belongs exclusively to the city and cannot be used outside. The Metropolitan Water District is organized to bring in water from Colorado River and is actively proceeding toward that end. Its legal setup is broader in scope than that of Los Angeles city and its plans are especially important to the people of South Coastal Basin.

This bulletin, however, deals exclusively with activities directed toward salvage of local waters or toward a better understanding of the local situation as to water supply. It is a symposium of those activities. Each article is written or has been reviewed by the technical head of the public construction or research agency under whose charge work is going on, with the exception of the article describing spreading works which are functioning, and investigations along lines which may lead to more efficient spreading. In that case it was thought best that, since the Division of Agricultural Engineering. U. S. Department of Agriculture, is doing certain research work on spreading, it could deal more concisely with all than would be the case were separate articles written about each particular item. The articles describe the object of the various lines of research work now in progress and the general plans of the construction agencies in so far as they are now formulated. They were written and the bulletin is published to assemble, in convenient form, a statement as to the very considerable activities under way.

These have many phases. It is not intended here to describe the work of the organizations contributing, since these are fully covered in the various articles, but it may be said that the work now going on divides readily into three groups:

1. Construction for salvage of flood waters.
2. Research to assist efficient planning of construction work or to assist general plans. This is particularly directed toward rain or flood waters.
3. Research on sewage disposal and reclamation.

Specifically the subjects discussed herein are:

Plans for flood control and salvage of flood waste.
Plans for sewage disposal.
Research in sewage reclamation.
Research on penetration of rainfall on valley floors.
Research on use of water by noneconomic plant life or by seeped lands.
Research on use of water by cultivated plants.
Research on effect of forest cover on run-off.
Investigation of spreading works and description thereof.

The bulletin is the first effort to bring together information useful in the entire South Coastal Basin. All agencies working in the basin are gathering vast amounts of information. This work will go on indefinitely. It is planned that at appropriate intervals, probably once each year, the State Division of Water Resources, in cooperation with the local organizations represented in these pages and others as found desirable, will bring out a bulletin giving the salient data on run-off, rainfall, change in water plane and such other features as are important. This will be for the use of engineers and others and, if plans are successful, will be in effect a manual of the hydrology of South Coastal Basin.

The technical heads represented in this bulletin have consented to form a committee to act in conjunction with the State Engineer's office. Others may be added as occasion arises. Little can be accomplished without the active help not only of this committee but of the many water companies and associations of the basin. It is hoped that, through this cooperation and the vast mass of data made available, there will come an ordered analysis and presentation of the whole matter which will prove to be the basis for planning developments in the basin. It is not intended to convey the idea, however, that any construction which can be done should not proceed at once. The results which may be achieved will point to more intelligent management, once the water is placed under control, but it is necessary first to construct the reservoirs and other works needed for control.

All students of the matter agree that any attempt to conserve water in South Coastal Basin must rest on better utilization of the underground reservoirs. Little has been done toward studying control and utilization of underground reservoirs in any part of the world so far as known. Probably more has been done here than in any other place, but information is not great even here, although a start has been made. In any approach to the matter of water supply in South Coastal Basin it is found that the basins (of which there are twenty-nine) are the units which must be studied. Political boundaries are not important.

The boundaries of the basins are tentatively outlined in the frontispiece, but further study may show that these must be revised and, in fact, some may be eliminated and others added. The present study and the final analysis which will be made resolve principally into the most accurate estimates possible of the following for each of the twenty-nine basins:

1. Its capacity in acre-feet down to a level beyond which pumping is infeasible.
2. Its present water supply and the sources thereof.
3. The draft on it, whether by pumping, by overflow as rising water or by underflow over or through its boundaries.
4. Surplus or shortage of supply with present draft, probable future drafts and probable future water levels.
5. Effect on overflow from one reservoir to another caused by changes in the water supply to the first.
6. The accretions to supply of each basin which may be brought about by salvage of flood waste and of waste by evaporation from seeped land.
7. The elevation of water plane necessary to shut out intrusion of salt water from the ocean. (For basins in the Coastal Plain.)
8. The amount of water necessary to drain into the ocean to keep alkali content of the underground water within the limit of tolerance by plant life.

During the course of the investigation many other matters will be studied. The reader is referred to the Appendix (page 61) for a complete program. The program presents many difficulties, but the situation demands and justifies extraordinary refinement of study.

These matters can be determined with more or less accuracy, depending on the data available. With reasonably good estimates there will be set up the physical foundation for the most intelligent approach to the matter of water supply and management. If a plan for a complete water supply to any basin or to groups of basins or to the entire South Coastal Basin is desired it will utilize this information. Intelligent distribution and utilization of water from Colorado River, if it is to be used for agriculture at all, can proceed from this as a basis. Accuracy of results depends on consistent accumulation and analysis of data.

CHAPTER II

LOS ANGELES COUNTY FLOOD CONTROL DISTRICT

PRELIMINARY OUTLINE OF ULTIMATE PLAN

By E. C. EATON, Chief Engineer

Anyone who has lived in Los Angeles County fifteen years or more can testify regarding the liability to floods and the tremendous damage that would be occasioned by recurrence of such a one as happened in 1914, which was by no means a record inundation.

A similar or entirely possible flood, 50 per cent greater than that of 1914, would cause, in the present extensively developed state of the county, damages to property easily running into many millions.

In the relatively brief period of the past fifteen years the county valuation has risen from 700 millions to a present value of about three billion dollars.

While a great majority of present residents have not experienced destructive floods in California, every one has been well informed of the danger of water shortage. Fortunately the existing natural underground storage reservoirs are of tremendous capacity and are cut by cross dikes acting as natural submerged dams that prevent them from functioning merely as underground streams. Considering the tremendous draft that has been made upon these natural basins, the relatively little that has been done toward replenishing them and the extremely dry cycle of recent years, it is remarkable how well they have held up.

The rapid development of streets, roads and buildings has deprived these underground basins of much of the normal percolation that occurred in the past and has permitted rainfall that formerly penetrated directly into the ground to run off in heavily increasing percentages. There is no doubt that valley rainfall contributes much to the underground basins.

There has been lacking a coordinated ultimate flood control and conservation plan to make progressive construction work fit into some definite program. While construction work within financial limits has been carried on, there has been building up a coordinated ultimate plan during the past two years. To develop such a plan, however, has entailed a great deal of work.

The ground work of such a plan must of course be the expected normal water supply and the possible peak floods. A general idea of the work involved in procuring basic data may be had from the following:

Measurements at 250 rainfall stations.
Measurements at 150 stream gaging stations.

Measurements at 2500 wells.
Measurements at 40 evaporation and snow stations.
Five thousand current meter measurements.
Four debris stations.
Seven run-off and precipitation stations.

Conclusions are not based on any broad assumptions, but are the result of intensive studies by a well organized hydrographic department which has devoted much time and study to the problem while carrying on its regular duties of maintaining and operating permanent structures.

The district area is 2800 square miles approximately evenly divided between mountain and valley areas. There are over 150 separate watersheds debouching in as many separate stream channels onto the valley areas. The largest of these is the San Gabriel, with 200 square miles, and the second largest the Big Tujunga, with 100 square miles.

At the mouths of all of these canyons, years of erosion by storm waters have built up and deposited deltas of material, some of them of great depth and forming tremendous underground storage basins overlain with gravel deposits through which these basins are replenished. The depths of some are known from records to be 1000 feet. The extent to which these basins are now capable of receiving water is evidenced by computations showing an available underground space throughout the country today of 2,300,000 acre-feet below the level of 1914. As an indication of this capacity, it is equal to twelve times the quantity of water brought in by the Owens River aqueduct last year.

It is indeed fortunate that these natural storages of much greater capacity than it would be feasible to develop in surface storages exist with freedom from the wasteful evaporation and other losses attendant on long term holdover storages. These underground basins form the keynote to the harmonization of the requirements for flood control and conservation within reasonable costs and flood control is an essential, even though its protection may be needed only occasionally.

To provide for full flood control by means of merely building large channels to carry flood waters to the ocean would be expensive and wasteful.

In any layout for flood control and conservation it must not be forgotten that present and future conditions of development are not only tending toward prevention of percolation and absorption by the ground surface, but run-off is now caused to drain into channels at greatly increased rates of flow and greatly increased quantities. The average valley rainfall of 14 inches falling upon the natural absorptive surface would probably not give an average run-off greater than 20 per cent, while the same rainfall upon a pavement would produce more nearly 80 per cent in run-off. The paved and improved street surfaces in the county aggregate something over 50 square miles and it is probable that loss of penetration from this and roof surfaces of buildings aggregates at least 25,000 acre-feet annually.

There are, also, salt water encroachment problems within an area of the Coastal Plain aggregating over 40 square miles already having a salt content of 15 grains per gallon, or over, and a further area of 120 square miles back of this whose wells draw from main strata below sea level. At the present rate of pumping and present lack of replenishment in sufficient amounts to create pressure to crowd out the heavier salt water, further encroachments are certain.

There is the debris problem, not a serious one, if brush and forest cover can be maintained, but it is only due to the efficient and untiring efforts of County and Federal officials charged with fire prevention measures that more disastrous and much more frequent fires do not occur in the mountain and foothill areas. Even a rain of relatively moderate intensity following a fire on a small watershed has been known to produce as much as 30,000 yards of debris from one square mile of mountain watershed.

Comprehensive Plan.

The fundamental principle of studies made has been an endeavor to put flood control, as far as possible, on a paying basis by making the value of waters conserved pay as great a proportion as possible for essential flood control.

All possible conservation works should be among the earlier units of the construction program. The basic features of the plan have been:

1. The regulation of mountain flood waters down to a rate of flow where they may be caused to percolate through spreading basins into the underground reservoirs. It will not be sufficient merely to provide regulation to retard these flows to a rate which can be absorbed, but there should also be provided sufficient regulation to permit a time interval to allow the valley rainfall and the run-off of the smaller unregulated streams to be absorbed. This can be accomplished by not super-imposing concurrently the regulated mountain flows.

2. The development to the fullest extent of the natural spreading areas into spreading basins to permit the absorption of all possible amounts of flood waters. Studies and measurements have shown that, on a conservative and practical basis, it is possible to absorb four cubic feet per second per wetted acre of spreading grounds in some cases and wet with spreading ditches and other means up to 25 per cent of the gross area, giving an absorption capacity of spreading grounds of one cubic foot per second per gross acre.

Absorption by spreading grounds is more nearly a function of the area wetted than of the depth of water and if it were possible to spread out flood flows in a thin sheet over the entire available absorption surface, a maximum of percolation would be obtained. As a practical matter also it is advisable to maintain a flowing stream over the spreading area with sufficient velocity to scour the top few inches of the percolation area and keep it free from fine silt deposits which so rapidly seal up and retard percolation.

As an indication of the value of spreading grounds the following example is of interest: A channel 100 feet wide and 10 feet deep in a 1000-foot length would percolate about two and one-quarter second-feet. If this same volume of water were spread out over a percolation area in a sheet six inches deep the absorption in the same length would be 20 to 30 times this amount.

There are many areas, each small in themselves but aggregating large amounts, where to construct spreading ditches will not be feasible. In such areas open bottom channels of as great width as practicable should be maintained and the surface areas should be scarified to depths of six inches or more at frequent intervals just before periods of flow. Measurements made indicate that the percolation may be increased in such areas by 25 to 100 per cent.

The foregoing applies to a general scheme for treatment of the larger mountain watersheds. There are over 80 smaller watersheds of up to two square miles in individual area which, however, aggregate over 10 per cent of the total mountain region.

For the treatment of such and for the treatment of the headwaters of the larger watersheds, check dams appear to be the best and logical solution. Piles of stone and brush are inadequate and even may be dangerous. Check dams should be built to moderate heights, not to exceed 10 feet, and be constructed of flexible wire-bound rock mattress. The retardation of water produced by them tends toward building up a brush and small tree growth in the channel materially aiding in retarding flood flows. They should not be used in the steeper rocky slopes, but in the looser pervious watersheds and should be spaced to act as drops in canals to break up the stream velocities.

Debris basins at the mouths of the smaller canyons will be found to be economical and many can be constructed in conjunction with gravel pits.

In the treatment of the mountain areas the ground work to the amount of storage required is the availability of ground water storage space. Figures show that there is today in excess of 2,225,000 acre-feet of space below the 1914 water level. The medium through which these storages must be filled is the natural percolation areas. While development during the dry cycle has encroached upon much of the natural percolation areas there is still available in the county today in excess of 10,000 acres of spreading areas which may be acquired at costs entirely within reason. One difficulty will be to deal with the rock plants, but this should not be insurmountable. With a cooperative attitude on the part of the rock companies their operations can be combined with those of spreading requirements by the cutting of channels instead of deep holes, to the advantage of both. The acquisition of these potential spreading grounds and their development to an efficient spreading system easily capable of increasing the rate of percolation from 20 to 30 times that obtaining in the natural state will not be expensive, in fact the limiting expense will be the practical one of acquisition. Having the area suitable for spreading, the results of tests in the particular location will determine the practical rate of percolation which may be allowed. The areas have been grouped into various types ranging from one second-foot per acre gross to one-quarter second-foot per acre gross, the lower values applying to some of the areas cut by dikes and cross seams of impervious materials to the point where percolation is retarded.

The percolation rate applied to the practical area available sets a figure to which possible mountain flood flows must be regulated to permit the absorption of the full amount of these possible flows.

Computations of the amount of regulation required to reduce possible flashy flood peaks down to a rate at which the flows may be absorbed is not a difficult matter. The computation of such possible flood peaks is somewhat more difficult, involving certain assumptions, and fortunately good basic data for long periods on a number of major streams in the county are available, which supplies invaluable ground work for peak flows on the larger streams.

The data collected by the State Division of Water Rights is extremely helpful. When the hydrographic department was started a little over three years ago there was a lack of data on the smaller watersheds, which, while individually small, aggregate a large percentage of the total, and also a lack of correlated rainfall and run-off figures on the valley floor.

The installation of recording and staff gages, together with results of rain gage stations, has given, during the past three years, some valuable data and has emphasized the importance of fullest consideration of the large number of smaller watersheds, and the importance of capturing the valley run-off which annually runs to waste in increasing quantities with increased development.

It is true the last three years have been of abnormally light rainfall, particularly abnormally light mountain rainfall, but this has merely had the effect of making the summation of amounts of run-off which may be conserved possibly ultra conservative, and any present figures may be substantially increased by perhaps as much as 50 per cent after obtaining the necessary basic data from a single year of moderate flood. Resuming the discussion of mountain regulation, as previously stated, the regulating storage necessary should be that required to iron out the peak flows from the mountains to rates at which they may be absorbed and placed under ground.

With the large underground storages available in this county there is no economy in providing heavy holdover storage in mountain reservoirs. The remaining storage sites are not cheap and surface holdover storage is wasteful. Under the flashy conditions of floods in Los Angeles County, with large annual variations, it would be necessary to provide storage in the amount of six times the mean annual run-off to get a practical water crop 60 per cent of normal. This is about the situation in parts of San Diego County where they are not fortunate enough to have advantages in the way of underground reservoirs.

In the matter of mountain reservoirs a series of small dams will prove more economical than a fewer number of higher structures. These mountains and valleys are cut by minor fault lines in all directions and the soundest rock conditions are in the blocks between these lines. These fault lines, where definitely known, are in reality an advantage, constituting planes of weaknesses on which earth movements, if and when they occur, will take place. The selection of blocks not intersected by fault lines gives the safest possible location. These blocks are large enough to permit safe construction of adequately designed dams. Rock conditions in general improve in progressing up the canyons where rocks are fresher and sounder.

This combination tends toward greater economy through construction of a number of smaller structures, rather than a few larger dams.

Having laid out the required capacity of regulating structures, for example a group of dams suitably proportioned to control the watershed above each of them, there must be provided not only sufficient regulatory storage to cut a peak flow to a rate permitting its absorption, but also a retardation period sufficient to prevent the superimposing of mountain flows upon direct valley rainfall and also permit the smaller streams to have time for percolation.

The debris problem above these main dams must also be considered. In the loose erosional material, with moderate stream slopes, check dams, suitably constructed and properly spaced and located, form an ideal solution. They have the additional advantage of rapidity of construction, which is an important factor should prompt action be desirable following a fire. In some of the steeper and more rocky canyons small arch dams, acting as debris restrainers, will be found most effective and of cheap construction.

Summarizing the treatment of typical large mountain watersheds, proceeding from the crest downstream, the following would be the procedure:

1. Check dams in the upper reaches where conditions are suitable.
2. Small restraining dams.
3. Larger regulatory dams.
4. Spreading grounds.

Flexible types of dams should undoubtedly be given preference. Among the flexible types are the various arch and structural types, whose stability depends solely upon arch action, and the rockfill and earthfill types. All of these are capable of considerable movement without danger to their stability. The future will see many rockfill types of conservative design built in this county.

In every case it is not possible to find suitably located spreading grounds tributary to, and upon the same watershed with, the mountain streams to be regulated. There are various reasons for this, one being that areas superficially appearing possible for percolation in reality function poorly in this manner. One example of this is the delta at the mouth of San Dimas Wash. The difficulty in this location is that the strata just below the surface are intersected with many dikes and lenses of impermeable material which retard the vertical percolation to water-bearing strata, which in this location are at great depths.

Fortunately in this locality an excellent surface storage, Puddingstone Reservoir at moderate cost ($40 per acre-foot), was available and by construction of a flood channel about two and a half miles long the Puddingstone Reservoir may be filled from the regulated San Dimas Wash. In this case the Puddingstone Reservior acts in effect similar to underground storages, except that it has the disadvantage of greater evaporation losses than occur in the underground basins. The combination, however, of San Dimas Regulatory Dam, Puddingstone Diversion Dam, Puddingstone Channel and Puddingstone Reservoir is one of the most, if not the most complete and effective flood control and conservation project which has yet been constructed.

For convenience of studies in connection with the Comprehensive Plan, the county was divided into 26 physical projects, the most important being the San Gabriel Project No. 1.

With the disclosure of conditions on the west abutment of San Gabriel Dam which led to the prohibition of construction of the original rigid type of structure, immediate steps were taken to evolve a constructive program capable of affording flood protection and maximum conservation of flood flows. such as have occurred and will occur again.

San Gabriel Studies.

By the use of airplane survey methods the entire San Gabriel watershed was mapped and studies made of over twenty dam sites.

By process of elimination of the most expensive of these, the number was reduced to ten for more intensive study. The necessity for sites capable of being developed to storage capacities in proportion to the producing quantities of watershed above them and studies of physical conditions, have resulted in three of these being tentatively selected for the initial development.

While surface conditions appear favorable, any definite and absolute selection of these sites and adoption of the type of dam to be built must await the thorough exploration and detailed geological studies which will be the next step prior to adoption of a definite plan. Should one or more of these three sites prove infeasible for any reason, one or more of the other sites may be selected and examined.

Preliminary studies are based upon the rockfill type dam, with flat upstream and downstream slopes, slightly flatter than the angle of repose of rock with an ample grouted cut-off on the upstream toe and a flexible concrete face. Other flexible types, such as a modification of the multiple arch or other structural type, may prove cheaper and the final selection must await exploration and geological reports, detailed designs and estimates or bids on different designs to insure maximum economy.

One of the three sites tentatively selected is about two miles below the present Forks site and, should it prove as good as all indications point to, its construction will permit the use of the present railroad. the present camp, the lands already acquired and, should a rockfill dam prove most economical, even the use of some of the excavated rock which was dumped about midway between the Forks and this site. The two other sites are nine miles and four miles up the west and east forks, respectively, and the site up the west fork may admit of arch dam construction.

The three sites are physically capable of being constructed to in excess of 250,000 acre-feet combined capacity. However, studies show that, without providing surface holdover, 130,000 acre-feet will provide for regulation and full conservation of a flood flow 50 per cent greater than occurred in 1914.

The height of the three dams would not be great as dams go nowadays, No. 1, or the one below the Forks site, being 310 feet, No. 2. or the West Fork, being 320 feet. and No. 3, or the East Fork, being 355 feet.

The upper portion of the West and East Forks tributaries show favorable conditions for a combination of check dams and low concrete dams for debris protection and increasing natural vegetation.

Spreading.

Having provided regulatory storage in the San Gabriel mountains, the next important items are the spreading areas at the mouth of the canyon. Here it is found that even with serious encroachment of improvements there still remains nearly 6000 acres that may be acquired for spreading purposes, and which is capable of spreading an average of nearly 6000 second-feet, if suitably developed.

The first of these areas consists of an upper basin above the Foothill boulevard, which, while relatively small, is of great importance since it has been developed and used for many years. One of the very few spreading grounds in the county today is located upon this area and has annually conserved several thousand acre-feet of water of which the developments in this vicinity would otherwise have been deprived. This spreading area may, however, be extended about 25 per cent or 30 per cent to advantage.

The second and largest basin extends from just below Foothill boulevard to El Monte. Present plans include, after the regulation has been provided, a combined headgate and regulating structure at the point where the Rio Hondo and San Gabriel split is located.

It is entirely possible, under certain conditions of lodging of debris, for the entire flow of the San Gabriel or any proportion to go down either the San Gabriel or Rio Hondo rivers.

The regulation of this condition is essential in order to split the flow down either channel into any predetermined quantity, the amount depending upon the relative rights on each stream. A 50 per cent divisions would about meet the present demands. From this same structure, which would be a low ogee dam about 1600 feet long, branch laterals and canals would lead to smaller canals and spreading works. The system would permit not only the percolation of an increased amount of water over that which now naturally percolates in years of major floods, but the putting of the water into the ground higher up on the spreading areas, thus lengthening the time before the water reaches the lower, or rising water area, at the constriction near El Monte.

Rising Water.

The matter of use and filling of underground basins is not the simple matter of merely filling up a basin and pumping it out, for the water in these basins is not a level area as in a reservoir, but has a slow flow through the gravels ranging from one foot to fifty feet per day. Particularly in the San Gabriel underground basin is this rising water evident, ranging over a strip about four miles, measured up and down stream, the upper rising water limit being just below the city of El Monte. Advantage has been taken of this natural condition as is shown by numerous gravity irrigation canals which take out at this point. The water which percolates into the overlying gravels of the upper basin will, if not pumped out and used, eventually emerge at this rising water area; and while a portion of it will, if left alone, percolate again in the channels of the Rio Hondo and San Gabriel rivers into the lower coastal basin, the areas and rate of percolation is relatively too small to absorb the full amount of rising water. It is inevitable that filling the upper ground water basins to the fullest extent will increase the amounts of rising water in this vicinity.

In addition to this the problem of taking care of the surplus waters from such streams as Sawpit, Santa Anita, Eaton and Rubio Wash, all of which enter the San Gabriel below the spreading areas and on each of which there are insufficient percolating areas to absorb their regulated flows, presents itself. In addition there are very substantial valley areas contributing flows in increasing amounts each year as additional buildings are constructed and more and wider paving programs are built.

Valley Run-off.

Studies of waste waters, even in such years as the past two, show the economy of taking care of these waste valley flows, the aggregate amounts of which are much greater than is ordinarily appreciated. The advisability of conserving these valley flows and the knowledge that many off stream storage reservoirs, similar to Puddingstone and capable of development at low cost probably existed, was the incentive for the search for all possible sites, using airplane maps and topographic maps. In all over 30 were found, many of which, while cheap for construction purposes, were not suitably located to catch the run-off by diversion from streams. Use may, however, be found eventually for some of them.

A site has been located just below the junction of the Alhambra Wash, on the west, and the San Jose Wash, on the east, with San Gabriel and Rio Hondo rivers. This site is physically capable of development with a dam 100 feet in height to a capacity of nearly one-half million acre-feet. Limitation of improvements, however, has resulted in tentatively adopting a maximum height of 45 feet, with a storage capacity of 33,000 acre-feet, as entirely feasible from the cost standpoint. From a storage capacity standpoint its development up to 60,000 acre-feet at least would be advisable, but probably prohibitive in cost of improvements for this or greater capacities.

This reservoir would function for various purposes. First, it would take care of the unregulated foothill, mountain and valley flows of the group of streams—Alhambra, Rubio, Eaton, Walnut, Dalton and San Jose creeks. Second, as a seasonal regulatory storage for the increased rising waters which will result from increased percolation above, it would allow the more efficient use of the gravity diversions now taking out from this area, permitting regulation in accordance with their seasonal needs. Third, it would regulate the rising waters, permitting greater amounts to be absorbed in the shoestring basins on the San Gabriel and Rio Hondo rivers, which areas are largely the feeders for much of the Coastal Plain supplies. Fourth, it would make possible circulation of rising waters by pumping from this lower reservoir into the upper portion of the basin.

The fullest development of any such conservation scheme requires a coordinated and regulated scheme of pumping. Fortunately the San Gabriel Valley area is well organized in its water users association for such purposes. A general scheme of coordinated pumping should be instituted and much of the pumping and gravity diversion done from this lower basin.

Going to the Los Angeles River, while the main tributary, the Tujunga, can be developed along similar lines, namely, mountain regulation and spreading grounds, many of the tributaries are individually small, but aggregate large amounts, and these can not be economically regulated. In addition a large part of the valley areas are drained by the Los Angeles River.

A search for suitable off stream reservoirs capable of catching these flows indicated that Nigger Slough was best situated for this purpose and capable of having by-passed into it not only the Los Angeles River, but the important tributary, Compton Creek.

While physically a dam 19 feet high would store nearly 60,000 acre-feet and use could be found for this storage without requiring the acquisition of too many improvements, it is believed that about 20,000 acre-feet would be the limit. This storage could be developed by a dam with a maximum height of nine feet.

The underground basin of the Coastal Plain, the wells of which are now showing salt water, and a large area now pumping from strata below sea level appear to have their source of supply from underground streams passing through the dikes known to exist from Baldwin to Dominguez Hills and thence southeasterly to the coast.

The disposition of the waters stored in Nigger Slough Reservoir could be accomplished by means of a string of deep shafts run parallel to and between this dike and the sea, the shafts tapping the lower strata.

Water can be run by gravity or pumped with low lifts from this reservoir into the shafts, replenishing these lower strata and creating the necessary pressure head to prevent encroachments of the heavier salt waters that is now taking place.

Summary of Present Conditions.

Summarizing the present conditions we have:

Six per cent of the total mountain area now regulated by dams.

Thirteen per cent of the spreading basins now developed.

Eleven per cent of the total channel lengths now permanently protected.

Three-fourths of 1 per cent of valley area run-off now controlled.

It is entirely feasible to regulate the mountain areas by dams, develop spreading grounds, construct valley storages to the fullest extent and thus have:

Thirty-five per cent of total mountain area regulated by dams.

One hundred per cent of spreading basins developed.

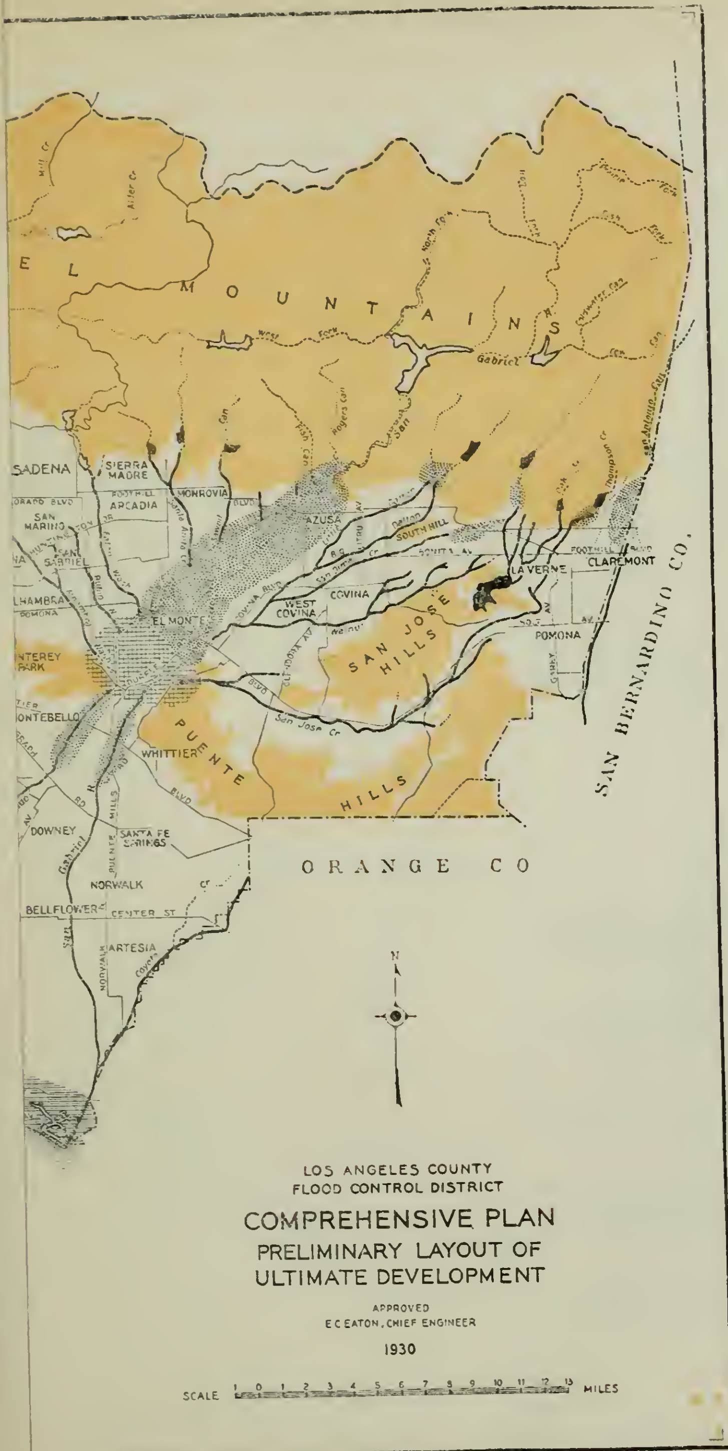
One hundred per cent of total channel lengths permanently protected.

Seventy per cent of valley area controlled by off stream storages.

It is estimated that on a conservative basis the full development will yield an average annual water crop, now wasted, of over 100,000 acre-feet per year and it is probable, with the advantage of measurements during a single flood year, that there can be supported an estimate that the average annual water crop now running to waste is greater than this by possibly as much as 50 per cent.

For purposes of visualization, this amount which may be conserved is equivalent to an average of about one inch of run-off over the entire mountain and valley areas.

The average mountain rainfall is 23 inches and the average valley rainfall 14 inches. Using another index of the quantity of water conserved which this will represent, the aqueduct in 1929 brought in to the county about 191,000 acre-feet. The ultimate development will



LOS ANGELES COUNTY
FLOOD CONTROL DISTRICT

COMPREHENSIVE PLAN
PRELIMINARY LAYOUT OF
ULTIMATE DEVELOPMENT

APPROVED
E C EATON, CHIEF ENGINEER

1930

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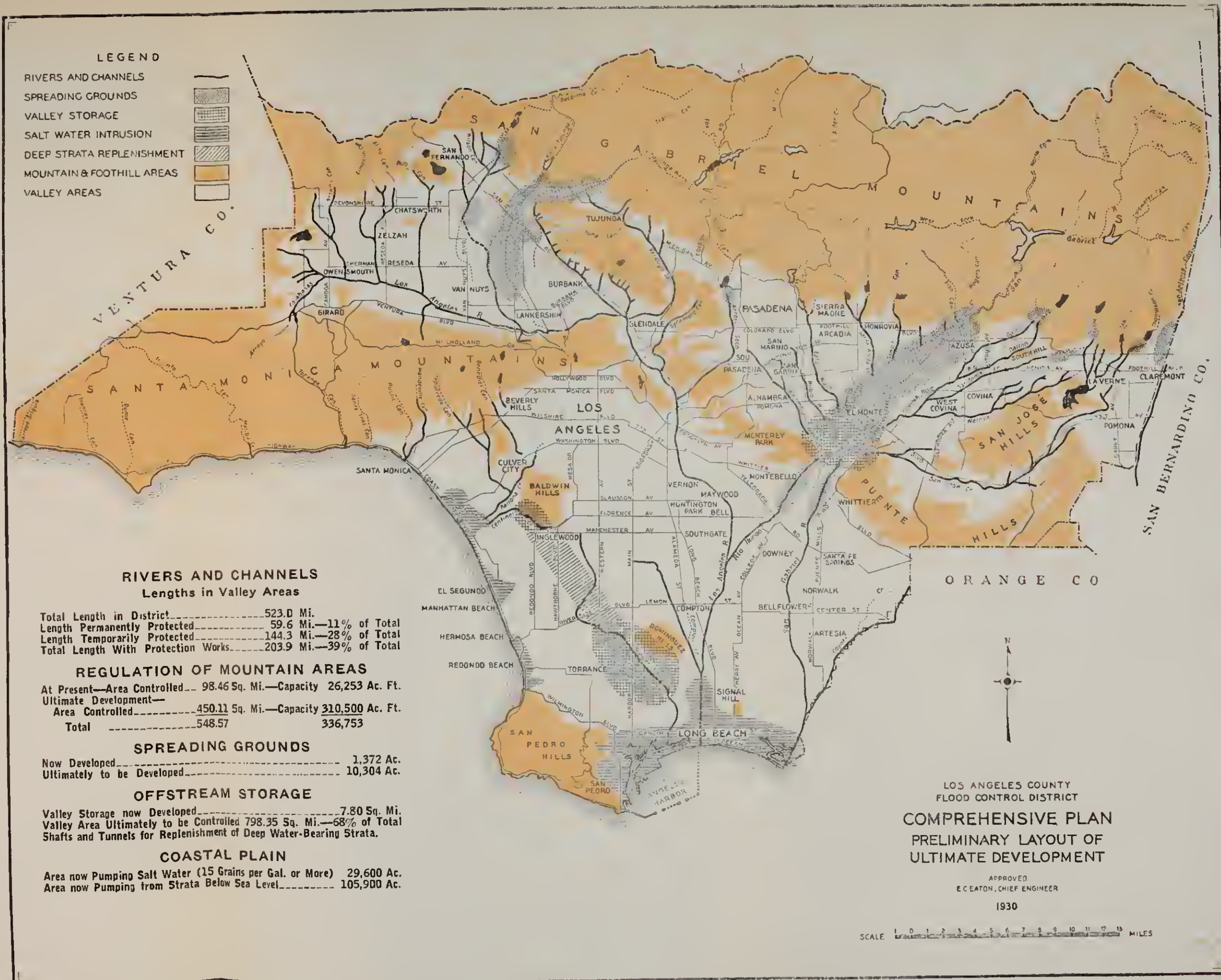
LEGEND
RIVERS AND CHANNELS
SPREADING GROUNDS
VALLEY STORAGE
SALT WATER INTRUSION
DEEP STRATA REPLENISHMENT
MOUNTAIN & FOOTHILL AREAS
VALLEY AREAS
RIVERS AND CHANNELS
Lengths in Valley Areas
Total Length in District 523.0 Mi.
Length Permanently Protected 59.6 Mi.—11% of Total
Length Temporarily Protected 144.3 Mi.—28% of Total
Total Length With Protection Works 203.9 Mi.—39% of Total
REGULATION OF MOUNTAIN AREAS
At Present—Area Controlled 98.46 Sq. Mi.—Capacity 26,253 Ac. Ft.
Ultimate Development—
Area Controlled 450.11 Sq. Mi.—Capacity 310,500 Ac. Ft.
Total 548.57 336,753
SPREADING GROUNDS
Now Developed 1,372 Ac.
Ultimately to be Developed 10,304 Ac.
OFFSTREAM STORAGE
Valley Storage now Developed 7.80 Sq. Mi.
Valley Area Ultimately to be Controlled 798.35 Sq. Mi.—68% of Total
Shafts and Tunnels for Replenishment of Deep Water-Bearing Strata.
COASTAL PLAIN
Area now Pumping Salt Water (15 Grains per Gal. or More) 29,600 Ac.
Area now Pumping from Strata Below Sea Level 105,900 Ac.
VENTURA CO.
SAN GABRIEL MOUNTAINS
SANTA MONICA MOUNTAINS
SAN FERNANDO
CHATSWORTH
ZELZAH
OWENSMOUTH
RESEDA
VAN NUYS
GIRARD
LANKERSHIM
BURBANK
TUJUNGA
GLENDALE
PASADENA
SIERRA MADRE
ARCADIA
MONROVIA
AZUSA
SAN MARINO
ALHAMBRA
MONTEREY PARK
EL MONTE
WEST COVINA
COVINA
LAVERNE
CLAREMONT
POMONA
SAN JOSE HILLS
BEVERLY HILLS
LOS ANGELES
CULVER CITY
BALDWIN HILLS
SANTA MONICA
VERNON
MAYWOOD
HUNTINGTON PARK
BELL
MONTEBELLO
WHITTIER
PUENTE HILLS
SAN BERNARDINO CO.
INGLEWOOD
SOUTHGATE
DOWNEY
SANTA FE SPRINGS
NORWALK
ORANGE CO
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
COMPTON
BELLFLOWER
ARTESIA
DOMINGUEZ HILLS
SIGNAL HILL
LONG BEACH
SAN PEDRO HILLS
SAN PEDRO
N
LOS ANGELES COUNTY
FLOOD CONTROL DISTRICT
COMPREHENSIVE PLAN
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yield from 100,000 to 150,000 acre-feet of water annually for use, or at the least over 50 per cent of this amount. It is obvious that the full development should not be attempted for many years. There are, however, many of the units vitally needed for flood protection and all possible spreading grounds, in conjunction with mountain regulation, should be among the earliest units to be built.

The benefits from increased water conserved will pay a portion of the cost of the necessary flood control.

CHAPTER III

ORANGE COUNTY FLOOD CONTROL DISTRICT

SUMMARY OF ENGINEERING INVESTIGATION FOR FLOOD CONTROL AND WATER CONSERVATION

By M. N. Thompson, Acting Engineer in Charge

Operating under the Orange County Flood Control District Act, Statutes of 1927, the board of supervisors of Orange County on August 16, 1927, appointed Mr. Paul Bailey as chief engineer to conduct an engineering study and submit a report for the purpose of a bond election to provide funds for the construction of works to control excessive floods and conserve flood waters.

The investigation conducted covered the study of all of the watersheds of Orange County and the Lower Santa Ana River Canyon for the location of possible dam and reservoir sites, the necessary geological study, the storage possibilities for flood control and temporary storage, the amount of run-off, the distribution of the temporary storage and the amount of conservation.

The report was filed April 30, 1929, and recommended the issuance of bonds in the amount of $16,500,000 for the construction of nine dams, three diversions and the acquisition of river channel for spreading purposes, stating that should these works be constructed approximately complete conservation of all waters now wasted would be had and the damage from floods would be greatly reduced.

The report was submitted to the people in June, 1929, for consideration, and was rejected by a small margin.

The question was again brought before the board of supervisors and a new board of consulting engineers was appointed for a restudy and revised report.

The details of the present study are not available except that additional dam and reservoir sites are being investigated.

Other data being collected covers the installation of rainfall stations in the various watersheds of Orange County, the establishment of stream gaging stations and the installation of continuous recorders on the principal contributing streams.

The former organization was cooperating with the State in observing certain wells for information on the underground water plane. The break in these records is unfortunate, but there has been added some 200 wells to this list for a study on the amount of depletion and recharge. Continuous recorders have been installed on wells in several areas to determine, if possible, the relation of certain areas or sub-basins.

Test wells in the perched water table are being read periodically and a continuous recorder installed in a typical well for a relation between the pumping zone and the surface zone.

The areas of nonproductive growths are being obtained for a study of the useless wastes.

Areas are being investigated in the stream bed of the Santa Ana River and other county streams for the purpose of determining percolation losses during the season of stream flows.

Periodically tests are being made to determine the salinity in wells in the lower part of the basin for a check on salt encroachment.

The penetration of rainfall in the valley floor is being studied by the U. S. Department of Agriculture under the direction of H. F. Blaney, with some cooperation by the district, to learn its effect upon the replenishment of the underground basin water.

The equipment which is being installed for the collection of data on stream flow, rainfall and the fluctuations of the water table, is a part of a permanent program as a break in such records leads to an uncertain determination of results.

CHAPTER IV

INFLUENCE OF FOREST COVER ON WATER SUPPLY

INVESTIGATIONS RELATING TO SOUTH COASTAL BASIN, CONDUCTED OR PROPOSED BY THE CALIFORNIA FOREST EXPERIMENT STATION

By E. I. Kotok, Director

The United States Forest Service is concerned in the water problems of the Los Angeles Basin because the national forests form the backbone of that basin and, by reason of their elevation, receive the major portion of the precipitation and contribute the bulk of the waters derived from local sources. The amount and character of the water crop received from these brush and forest covered areas is directly influenced, not only by precipitation, topography and character of rock and soil, but by the amount and character of the vegetation covering them. The form of management and protection given to the cover on these lands is therefore an important factor in their water yield.

The California Forest Experiment Station was established in 1926 as the representative in this region of the Research Branch of the U. S. Forest Service. It is located at and in cooperation with the University of California. The members of its staff engaged in forest influences and erosion studies are W. C. Lowdermilk, C. J. Kraebel, H. L. Sundling, A. E. Wieslander, Roscoe Weaver, H. C. Clar (State Division of Forestry).

In southern California, where water is the most important product of wild land, the investigations of the California station are directed primarily toward the determination of the relation of forest and brush cover to water production, and the measures of protection and management of such lands required for the production of maximum water crops. These studies are of direct and fundamental importance to the development of a water resource plan for this region and can not safely be omitted from its consideration.

So far, engineering studies have been largely devoted to determining the amount of rainfall falling within a given watershed and to streamflow measurements, which gage the amount of available water. This gives what is commonly accepted as the run-off coefficient of a watershed. Vegetation, however, plays a very significant role in this relationship. It consumes water through its own transpiration, but this must be regarded as the price to be paid for its service in modifying evaporation, in slowing up run-off and in building a beneficial soil profile. The problem here is, then, the definite determination of whether, and how far, the beneficial action of the brush cover increases available water over and above its cost in water consumed by the vegetation. In this problem three factors often lost sight of are of major importance—the vegetation has already been proved to be completely determinative in the building up and maintenance of maximum water absorptive and retentive capacity in uncultivated soils; its presence is the major condition of minimum silt load in run-off waters from wild lands; and the water transpired to the air by vegetation may not necessarily be lost, but is probably returned in whole or in part by subsequent precipitation.

Major studies dealing with the influence of forests and vegetation on stream-flow have hitherto attacked the problem from the aspect of the entire watershed. Under such methods of study, the many interrelated factors operating within a watershed to produce the resultant stream-flow are masked and deductions are necessarily incomplete or even erroneous. In order to avoid these fallacies the attack of this station has been made by isolating and breaking up the factors into their component parts.

These studies have been grouped into three principal divisions, namely:

I. The isolation and measurement of the variable factors which influence erosion and run-off. These are:

(a) types of vegetation;
(b) kind and character of ground litter from such vegetation;
(c) types of soil;
(d) structural characteristics of soils as affected by flora and fauna;
(e) rain intensities and their duration, under experimental control.

II. The tracing of the operation of such variables by studies of run-off plots in place, and then of entire watersheds, starting with small and ending with large areas.

These variables are studied as they affect:

(a) the amount and regularity of stream flow;
(b) silt content;
(c) silting of reservoirs;
(d) sinking of water on alluvial fans;
(e) water use by vegetation.

III. Another series of studies deal with fire control and methods of water conservation and erosion control.

I. Under the first series of studies, the progress to date in isolating variables influencing erosion and run-off will be briefly summarized.

1. The Function of Forest Litter.

A series of tanks were designed, having a surface of 10 square feet and a depth of 2.5 feet, in which typical forest soils were placed, duplicating field occurrence, layer for layer, including the forest litter. The instrumentation permits application and measurement of both natural and artificial rain. Surface run-off, seepage and eroded material can be directly measured and correlated with precipitation intensities for the smallest time intervals. Three soil types have been studied in these tanks, which have been subjected to natural and artificial rains. Eight tanks were used in the experiment, two for each of the three soil types studied, with one pair in duplicate. The litter on each alternate tank was burned. The study then compared differences in run-off, seepage and erosion for bare and forest litter covered soils.

These studies show that the forest litter has little effect on surface run-off or erosion through its own absorption of water, its principal function being to maintain the soil profile at its maximum capacity for percolation. Briefly, the removal of the forest litter may increase immediate surface run-off three to 30 times, depending on the character of soil and intensity of precipitation. Erosion from the contrasted surfaces differs in much greater ratios, varying from 50 to 6000 times as much on bare as on litter covered surfaces.

PLATE III

BARRANCO WATERSHED NEAR MOUTH OF DEVIL CANYON

Large-scale forest influence experimentation is being carried on in this watershed. White circles denote rain gages. Light rectangular area at bottom is reservoir of one and a half acre-feet capacity.

2. The Function of Grass Cover, in Contrast to Forest Litter, on Surface Run-off and Erosion.

Five tanks, each having a surface of 20 square feet and a soil depth of three feet, have been installed. The same technique as was applied to the forest litter studies is employed in measuring precipitation on, and surface run-off and erosion from, these grass covered tanks. The first phase of this study is in progress and the results are not yet available.

3. Function of Different Gradients on Surface Run-off and Erosion.

Five tanks having surfaces of 20 square feet and a soil depth of three feet are being used with varying gradients for each soil type studied.

Artificial and natural rains have been applied, as in the other tank studies, to bare soils of the Aiken series. The results indicate that for bare soils of this type, gradients varying from 5 to 25 per cent show no correlation to surface run-off, the percolating capacity of bare soils being independent of gradient. Soil texture is more important than gradient in determining run-off. Gradient, however, has a very direct influence on amount of eroded material, which increases markedly with gradients over 15 per cent.

4. The Function of Chaparral Forest Cover on Surface Run-off and Erosion.

Three series of run-off plots, each of approximately one-fortieth acre in area, have been set out in the upper chamisal type and in the oak-*Ceanothus* type. In these experiments precipitation is automatically registered at one minute intervals, and the surface run-off is simultaneously recorded. Eroded material is measured at the end of each storm. Thus the correlation of surface run-off with the intensities and amounts of rain can be directly compared. Each series has four plots, two exemplifying an undisturbed cover of vegetation and two burned clean of vegetation and litter.

The results of the experiments on the run-off plots indicate conclusively that a mantle of vegetation produces conditions of maximum absorption of water and a minimum immediate surface run-off. Surface run-off from bare soils exceeded that from similar covered soils in ratios up to 66 to 1. Erosion increased about 400 fold.

Where intensities of rain are below 0.5 inch per hour, the condition of the surface has very little effect on surface run-off and erosion, but when intensities of rain reach 1.0 inch or over per hour, even for very short intervals, the denudation of the vegetative cover produces enormous increases in surface run-off, by making the water flow muddy, which in turn seals the soil surface and thus progressively reduces percolation and seepage into the soil mass. In this process, the rapid accumulation of surface flow increases the development of erosion and frequently produces the destructive mud flows, characteristic of the region.

The results of these studies partially explain the so-called cloudbursts in southern California, which are confined to canyons burned over within a one to three year period. For example, the Burbank flood of 1928 followed a fire of 1927 which burned over a 704-acre watershed of the canyon above this town. With only 1.07 inches of rain in three hours, but with a maximum intensity of 1.70 inches per hour for about ten minutes, surface run-off was increased three fold, as compared to unburned adjacent canyons, and between 25,000 and 50,000 cubic yards of eroded material were swept off the watershed, while none moved from adjacent canyons.

5. Consumptive Use of Water by Brush, Chaparral and Forest Vegetation and Its Effects on Yield of Water from Watersheds.

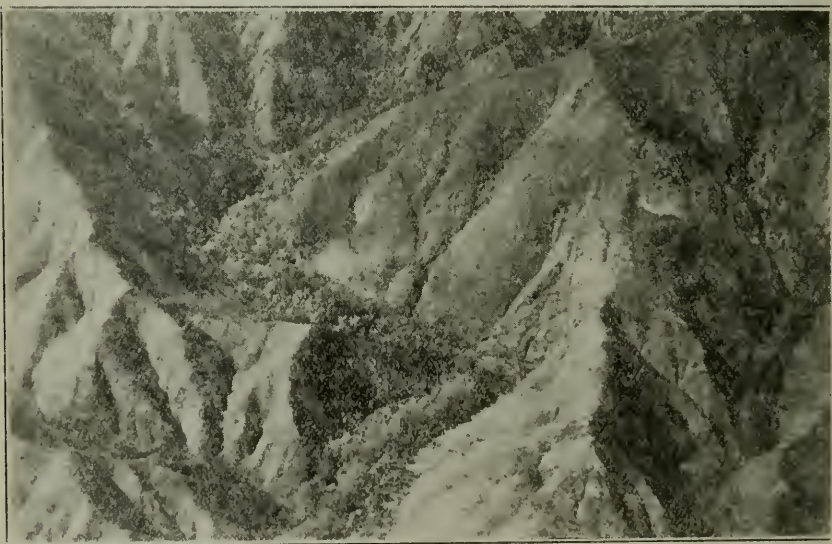
Special instruments have been designed and installed under field conditions to measure water loss from soil through evaporation and transpiration, the effect of penetration of rain into soil and the remainder used by plant life itself. These studies are correlated to the growing season and the fluctuations in moisture content in the soil for varying types of vegetation.

II. The second main series of studies must necessarily await results from the first series. Work has thus far been confined to:

1. Development of Technique in the Measurement of Run-off Charged with Silt and Debris and of Erosion from Small Watersheds.

A 40-acre watershed on the south front of the San Bernardino Mountains, denuded by fire in 1925, was surveyed in 1927 and equipped with rain gages, meteorological instruments and weirs. The weir first installed was found unsatisfactory and was replaced with a Parshall

PLATE IV



PORTION OF SAN GABRIEL WATERSHED

Cover type demarcation is particularily distinct for canyon bottom vegetation.

flume, which gives promise of being a satisfactory method of measuring and automatically recording sediment-laden run-off from watersheds. A permeable earth reservoir has proved satisfactory for trapping and measuring eroded material in fairly large quantities. This experiment will also determine the period necessary for vegetation to become reestablished and completely arrest excessive erosion processes.

2. Plant Succession Following Fires.

No vegetation is static; constant change is the order of Nature. But in every land area there exists a comparatively stable "climax" type of vegetation which is the result of the combined forces of the climate and soil of the area through a long period of time. The settlement of the white man in California has brought with it use and abuse of the vegetative cover, in which the natural process of succession has been greatly disturbed and the original vegetation over vast areas altered. These changes have been due in part to grazing animals, in part to lumbering, but in far greater part to fire. Spectacular changes in the vegetative cover have been wrought in southern California where fire has frequently been followed by floods swelled with eroded soil from denuded mountain slopes. The loss of top soil has reduced the water absorption and water holding capacity of the soil mass and likewise reduced vegetation, both as to amount and kind. Evidence of this is found upon the hills where remnants of woodland or spruce types have escaped many fires and now stand isolated within extensive areas of vegetation of a lower order.

Detailed information on the manner and rate of these vegetative changes and the correlation of results with their causes is required for the development of effective management of southern California's mountain lands. The Experiment Station has begun this study at its Devil Canyon Branch in the San Bernardino Mountains by the establishment of thirty-six milacre quadrats in an area burned in 1925, and the more extensive observation of other burned areas. The records already indicate the peculiar characteristics of individual species which control their reproduction and fate in the vegetative complex following fire.

The study must be extended to various cover types representing the seasonal fluctuations in plant activity which must be subjected to fire at different times of the year to learn their degree of susceptibility to fire damage.

3. Cover-type Map.

The nature and extent of vegetative cover constitutes the basic knowledge on which to begin investigations of betterment. A cover-type map of all the forest and brush lands of Los Angeles County, showing the major types and subtypes of vegetation, has been completed. The parts of San Bernardino and Ventura counties lying within the Los Angeles basin have also been mapped. This cover-type map will be of indispensable value later in estimating the water productive capacity of this basin. An individual plant is of little significance in a watershed, but the association of plants in large numbers governs the relationship of vegetation to soil and water. The major types and subtypes of vegetation, their age and condition and their height and density, affect soil development, run-off, seepage and transpiration.

This map has another important use, for the forest protective agencies in the region. By showing the amount, density and nature of fuel upon the land, the map makes possible the preparation of appropriate fire prevention and suppression plans in advance of the occurrence of fires.

III. In the third series work has been confined to:

1. Testing of Native and Exotic Vegetation for the Possible Replacement of Native Highly Inflammable Vegetation.

A series of tests are being made with succulent species of low water requirements, but effective in the control of erosion.

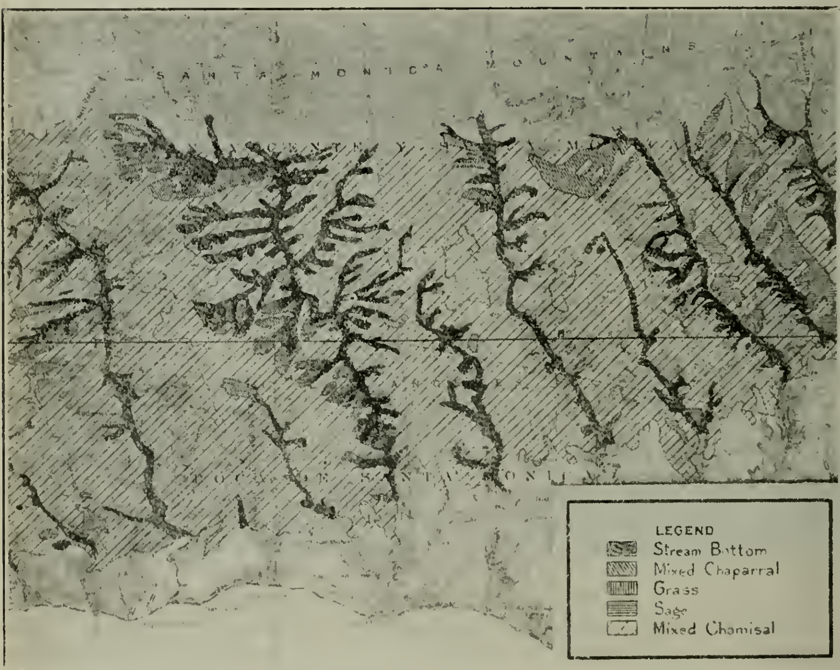
2. Experimentation on Methods of Erosion Control by Planting.

A series of experiments is under way to test various forms of coniferous and hardwood trees, shrubs and secondary vegetation as a means of checking erosion already in progress. These experiments are closely correlated with successional studies on burned-over plots where the natural processes of vegetative recovery are under observation.

3. Determination of Adequate Fire Control.

All the evidence is thus far conclusive that complete fire exclusion is essential for watershed preservation. Baring of soils to erosion,

PLATE V



MAP INDICATING DISTINCT TYPES OF FOREST COVER

sealing of soils to water absorption and undesirable changes in the returning vegetation are always brought about by fire on the brush covered wild lands of southern California. Problems in the protection of watersheds from fire require solution, both in prevention of fires themselves and in their control when started. A group of intensive studies dealing separately with this subject is on the program of the California Forest Experiment Station. Its results will find direct application to the southern California problem.

Summary.

These initial studies have been concentrated to break up a very complex problem into its component parts. They have been valuable in indicating, in both a qualitative and a quantitative way, the importance of the soil profile, the vegetative cover and its resultant litter on run-off, seepage and erosion. From these simple tank, surface-plot and quadrat studies, the next step is the development of technique enabling the study of watersheds themselves. Such watershed studies, which will involve two or more small comparable watersheds, a complete network of precipitation stations to measure intensities as well as total fall of rain, a series of run-off plots representing all types of soil and vegetation, and detailed studies of water use by vegetative types, are planned.

The results of our completed studies, it is hoped, will form a basis for a sound and effective management of wild lands which, in correlation with the studies of other interested agencies, will assure the maximum yield of water for human use and will command the approval of engineers and foresters alike.

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CHAPTER V

SEWAGE RECLAMATION

By Dr. Carl Wilson, Director of Sanitation, Department of Water and Power, City of Los Angeles

Because all the water which naturally belongs to semiarid southern California, together with the supply which has been imported from other basins and that which is still available for importation, will not suffice for the ultimate needs of this rapidly developing area, it is necessary that intensive conservation of all waters be immediately inaugurated. In a general way conservation in industry has meant the transformation of wastes into by-products, and the industry of purveying water is not an exception to this rule. The first by-product which the water works engineer turned to advantage was hydro-electric power, but there remains a waste from his enterprise which has thus far been neglected, even though its disposal has cost in the aggregate untold millions of dollars. This burdensome waste is sewage, and its principal by-product is reclaimed water which may be given many useful applications. Realization of the impending need caused the officials of the Department of Water and Power of the City of Los Angeles several years ago to undertake an investigation of the possibilities. It was realized from the outset that successful reclamation, if used to replenish underground storage, either directly or through return water from irrigation, offered the possibility of serious consequences. One part of phenol in 500 million parts of water may cause annoying taste troubles, while half that amount of salicyl compounds may be even worse. Because of the complicated reactions which might be anticipated and also because the earlier studies were so promising, it was decided in the latter part of 1929 to place the investigation upon an experimental basis so that authoritative data applicable to southern California conditions might be made available. The program adopted is ambitious, but to have made it less comprehensive would have been to defeat the purpose.

Any scheme of sewage reclamation must necessarily begin with sewage reduction, a subject around which there has been developed a voluminous literature during recent years, but valuable as this fund of information is, it stops far short of the present goal. It concerns itself with sewage disposal, and carries treatment to the minimum degree which will insure freedom from nuisance.

Our problem in southern California compels us to make sewage treatment a special business, for we must produce an effluent which is useful and attractive, although we can easily conceive that here, as in other industries, we may turn out products of various grades, implying different costs and different selling values, which shall be applicable for different uses. At present the activated sludge process is in the ascendency, perhaps because it is based upon the utilization of natural forces, which are accelerated and controlled by scientific adaptation of environment to obtain the most efficient operation of biological processes. Therefore it was decided to construct an activated sludge plant to treat 200,000 gallons per day, and this plant has been in uninterrupted service since May 12, 1930. It is located on the edge of Griffith Park, upon property belonging to the department of water and power, adjacent to a playground camp, the municipal golf course and close to a well traveled highway, so that no odor nuisance could be tolerated.

Sharp criticism from some quarters has been directed at the activated sludge process as being unable to handle industrial wastes, but it is believed by those conducting the present experiments that careful attention to the fundamentals underlying the process will bring about success with all types of organic wastes. We are utilizing the activities of bacteria, fungi and protozoans, and we know they are very sensitive to acids and alkalies—therefore we must carefully control the hydrogen ion concentration or pH. in our plant. They function best at their optimum temperature, hence we must preserve temperatures within certain limits. We know that up to a certain point in our process aerobic action is preferable to anaerobic reduction, although this condition is reversed in the case of separate sludge digestion, especially if gas collection is a part of the scheme. Therefore we must constantly provide air to inhibit anaerobic action and promote aerobic processes in the aerators and clarifiers. Lastly, we know that certain inorganic salts interfere with the treatment.

Inorganic salts in excess of certain concentrations, must therefore be kept out of the sewers, and that seems an entirely feasible thing to accomplish. By satisfying these conditions, it is practicable to treat all organic wastes, and peach cannery wastes have already been successfully treated at the experimental plant.

An important feature of the study now being conducted is a determination of the maximum concentration of certain inorganic compounds, such as salt and alkalis, which may be permitted in industrial wastes which are allowed to enter the sewers. Of equal moment is an investigation of the degree of purification necessary in effluents destined for different purposes. Reclaimed water intended for irrigation need not be so highly purified (consequently the cost may be less) as for some other use. Therefore a correlation between treatment costs and proposed uses is of great importance.

The complete program of the department's reclamation studies is published herewith to show the extent of the enterprise, and also in the hope that it may save some unnecessary duplication of effort, with its accompanying expense.

A completely equipped laboratory has been provided at Crystal Springs for the exclusive study of sewage treatment and its allied problems, including the feasibility of introducing sewage effluents into the ground water by infiltration through the sand and gravel deposits overlying or tributary to the underground basins.

The work thus far accomplished sounds a warning, which seems unavoidable, that, if disaster is to be averted, the disposition of sewage effluents, where they may reach waters used for domestic supply, must be under the control of the authorities responsible for the quality and safety of the water. The potential possibility of seriously affecting present and future supplies destined for human consumption is such that constant control of the quality of the effluent must be exercised, and the effect of the effluent upon underground waters must be continuously studied if the quality of our domestic supplies is not to be jeopardized. It would seem that only those officials who are held responsible for the safety and quality of public water supplies are likely to appreciate the importance of such studies, or the many conditions which must be guarded against. Moreover, the technology of water quality has become so complex that only the water works laboratories are likely to be equipped for the conduct of the necessary control, or to adequately interpret the laboratory findings.

PROGRAM OF WASTE WATER RECLAMATION STUDIES

The following outline covers items under investigation by the Los Angeles Department of Water and Power on the subject of "reclamation."

1. Volume of Municipal Waste Water Available.

(a) Location of all sewers 24 inches in diameter and larger.
(b) Average, maximum and minimum daily and seasonal flows, both for the present and the future, determined at the principal gathering points of intercepting sewers.
(c) Elevations at which adequate volumes can be obtained.
(d) Possible rerouting of existing or proposed intercepting sewers to favor the various projects under consideration.

2. Character of Waste Waters.

(a) Strength of waste waters at different points.
(b) Checking mineral contents from each intercepting sewer and if any exceed working limits continue studies to either find means of control or separate disposition.
(c) Study of industrial loads for different areas.
(d) Effect of future industrial loads on character of combined wastes.
(e) Selection of those intercepting sewers which, from the standpoint of the character of their wastes, offers the best combination for each scheme under consideration.

3. Treatment of Municipal Waste Waters.

(a) Complete knowledge on the most up-to-date developments in sewage treatment, including that for industrial wastes.
(b) Research into the proper methods of treatment as adapted to our type of sewage and climatic influences.
(c) Determination of installation and operation costs for that degree of treatment required by each project under consideration and industrial wastes to be handled.
(d) Selection of suitable treatment plant sites or pumping plants and force mains to known sites best fitting in with each project.
(e) Cost of sewerage works to ocean versus reclamation.

(f) Cost of additional treatment required at the ocean end, which may be avoided if some scheme of reclamation is adopted.
(g) Determination of what part of the additional treatment required for reclamation is chargeable to sewage disposal.
(h) Analysis of so-called aesthetic and social objections.

4. Types of Reclamation Under Consideration and Research Involved.

(a) Augmentation of domestic supplies.
  1. Addition to large reservoirs in times of extreme emergency, involving studies on the sufficiency of complete treatment and the effect on the biological balance in the reservoirs.
  2. Replenishment of underground water supplies above wells and galleries, involving studies as to where this can best be accomplished; experiments in spreading of such waters in galleries or on the surface; percolation experiments; purification effected by filtration resultant from spreading; travel of underground pollution; study of chemical transformations during its period of underground travel; and the percentage recoverable in different basins.
(b) Exchange with large irrigation companies using their water for domestic purposes.
(c) Sale to irrigation companies in Los Angeles and other counties, involving study as to location of such companies; acres under cultivation; types of crops grown; what safe return value could be obtained from the water; extent to which their systems might have to be modified to ensure safe drinking water for them; and, the cost of transportation, storage and distribution.
(d) Development of new acreage in Los Angeles and other counties and the determination of treatment necessary for such projects.
(e) Irrigation of golf courses, large estates, parks, etc., involving studies of location, acreage and water duty.
(f) Industrial and commercial use of reclaimed water, involving study of present and future requirements of such industries that might be able to use reclaimed water.

5. Resources Available in Reclamation.

(a) Value of water for domestic use, both direct and indirect.
(b) Value of water for irrigation of various crops or purposes.
(c) Value and demand of water for industrial use.
(d) Value of reclaimed water in underground reservoirs in stopping inroads of salt water from the ocean, lowering pumping costs by raising water table, and guaranteeing water for valuable crops.
(e) Value of gas reclaimed from treatment works or sold to consumers.
(f) Value of fertilizer in sludge from the treatment works and in the water used for irrigation.
(g) Efficiency of various projects comparing production costs with reclaimed values.
(h) Comparison of reclaimed costs with existing and future aqueduct supplies.

6. Cooperation with Agencies Outside the City of Los Angeles.

(a) Collection of sewage from other districts.
(b) Utilization of flood control, spreading and storage works if practical.
(c) Joint use of private pipe lines, storage, or distribution works.

7 Definite Recommendations.

(a) Reduction of all projects to a comparable basis, including first cost, labor, power, chemicals, depreciation and maintenance, for additional treatment works over that needed for present disposal, pumping plants, pipe lines, storage reservoirs and distribution facilities.
(b) Whether reclamation is warranted.
(c) What constitutes the most efficient method of reclamation, who should do it, and how it should be financed.

CHAPTER VI

RECLAMATION OF SEWAGE OF LOS ANGELES CITY

By W. T. Knowlton, Sanitary Engineer, Bureau of Engineering, Department of Public Works, City of Los Angeles

The City of Los Angeles is located, to a large extent, in the valley of the Los Angeles River and on the flood plain westerly thereof, so that the control and use of storm water run-off from the highly improved areas of this city should be one of the principal factors in the study of conservation of water supplies. Another factor or source of supply is the reclamation of sewage, which, at the present, is discharged into the Pacific Ocean. The amount of sewage collected from that portion of this city north of 120th street and discharged into the Pacific Ocean at Hyperion amounts to about 100,000,000 gallons per day. As the sewage from several adjoining cities and some county sanitation districts is also collected and discharged into the city system, the total sewage flow going into the ocean at Hyperion is about 110,000,000 gallons per day.

In the Harbor District of this city the sewage flow averages about 6,000,000 gallons per day, this flow being discharged into the inner harbor for most of the district. A portion of the Wilmington sewage, together with the sewage of East San Pedro, is discharged into the ocean on the south side of Terminal Island. Following the plan, which has been proposed, that the sewage from the Harbor District be combined with the sewage from the Los Angeles County Sanitation District at the treatment plant now in use by the county, there would be at least 16,000,000 gallons per day of sewage flow, which would probably increase to 30,000,000 gallons per day within the next five years.

At the Hyperion plant, reclamation of sewage to a limited extent by the Standard Oil Company at its El Segundo refinery has been proposed and a contract prepared, to give this oil company 6,000,000 gallons of sewage per day for treatment and use for industrial purposes. At the present time this company has made studies of this treatment by the activated sludge process and will probably arrange to build such a plant as soon as it has closed a contract with the city for this purpose.

In the proposed treatment of sewage from the Los Angeles system by the Standard Oil Company, it was realized that the amount of salt content would have a vital bearing on the reclamation of sewage for industrial use. Analyses of the Hyperion sewage show an average content of approximately eighteen grains per gallon or 300 parts per million. The treatment of sewage where the salt content is over 500 parts per million is rendered difficult. It has been proposed that legislation be enacted to prevent industries from discharging waste water into the sewers where the salt content in the industrial waste is over 300 parts per million. To overcome the effect of this amount of salt, the Standard Oil company has proposed to pump the sewage from the Hyperion outfall during those hours when the salt content is low.

The use of reclaimed sewage to supplement underground waters has been considered by others than the Standard Oil Company, and there is a possibility that the sewage of the Harbor District of this city, as well as that from the county sanitation districts, may be treated to advantage and used by the oil companies in that district, rather than discharged into the ocean.

Although past experience has indicated that ocean disposal of treated sewage is positive, while the proposed use of reclaimed sewage by industries is somewhat undetermined, it is considered that proposals could be received for the purchase and use of this reclaimed sewage and thereby determine the practicability of this plan. Should no proposals be received for the use of such reclaimed water in the Harbor District steps could then be taken to provide for ocean disposal.

In the disposal of waste of all kinds, it is important that only such waste be permitted to be discharged into the sewerage system as can readily be handled thereby. In other words, there are many trade wastes which should properly be kept out of the sewers and treated at the plant of the industry. The prevailing ordinances of this city prohibit the discharge into sewers of solids or liquid wastes of any kind containing chemicals, grease or oil, which shall tend to clog, obstruct or interfere with the effective use of the sewer. Quite frequently it has been found that many industries are inclined to discharge into the sewer such materials as are prohibited by the existing ordinances. An examination of this situation in other cities of the country indicates that there is a growing tendency for the industry to be required to treat its trade waste sufficiently to prevent injurious material from being discharged into the sewers.

It is realized that there may be considerable opposition to the use of reclaimed sewage to supplement the underground water supply. However, many cities obtain their supply from rivers that have been polluted, to a more or less extent, by sewage and industrial waste. By treating the sewage and industrial waste before disposal into rivers, the purification of the water supply from such streams can be had at a minimum cost of treatment.

The amount of run-off during the rainy season from the built up portions of the City of Los Angeles is unknown. During the summer season it is possible that there will be a certain amount of dry weather flow coming from the use of water for sprinkling purposes and containing some of the industrial wastes.

A comprehensive plan for the conservation of water and use of reclaimed sewage will require that a certain body be organized to make studies required for such reclamation.

The bureau of engineering of the board of public works has the duty of providing for the collection and disposal of sewage from the City of Los Angeles. Contracts which have been made by Los Angeles with several adjacent cities and county sanitation districts will increase the flow of sewage in the outfall sewers of this city.

The department of water and power has the duty of providing for the water needs of this city. As, however, it is possible and probable that the sewage from this city could be reclaimed and used by interests outside of the city, the subject is one that is of vital interest to the entire Metropolitan District.

In the event that an organization is formed for the reclamation of sewage from the Metropolitan District, the following problems must be determined:

1. Where shall the reclaimed sewage be taken?
2. How much sewage would such a location use?
3. How shall payment be provided for the required treatment and disposal of the reclaimed sewage?
4. After disposal into the underground basins, will the riparian water rights of the owners be affected and to what extent?

The area to be benefited by the use of reclaimed water may either apply to only the City of Los Angeles, or it may apply to several cities in the county, or to the City and County of Los Angeles, or to other cities and counties outside of the County of Los Angeles. It would therefore appear that the State of California should properly have charge of the study and survey to be made for the proposed reclamation. By so doing the organization to be appointed by the State would be free from local influences.

It is suggested that the following items be given attention in the proposed survey and study:

1. A survey of industries to determine (a) the amount of water consumed; (b) the possibility of local treatment of industrial waste for reuse; (c) the feasibility of separating harmless liquid waste from sewage and polluted waste.
2. A survey of sewage treatment plants to determine what treatment is necessary for the proposed reclamation.
3. Studies to determine what industries could use the reclaimed sewage.
4. Studies to determine the amount of storm water run-off and methods and cost of reclaiming such run-off.
5. A study of the organization and legislation required to place a comprehensive plan for this reclamation in effect.

In connection with instructions which the writer has received to submit a report relative to the treatment and disposal of sewage from the Harbor District of this city, arrangements are being made to prepare a preliminary report on the "Reclamation of the City Sewage," which, after treatment, could be discharged into the selected places in the San Fernando Valley, San Gabriel Valley, or elsewhere. This report should accordingly give alternate costs of reclamation for these different locations.

CHAPTER VII

RESEARCH ACTIVITIES IN SOUTHERN CALIFORNIA

BY THE DIVISION OF AGRICULTURAL ENGINEERING, U. S. DEPARTMENT OF AGRICULTURE

By W. W. McLaughlin, Associate Chief

The Division of Agricultural Engineering of the U. S. Department of Agriculture is that branch of the federal government dealing with all agricultural engineering problems of the department, excepting those pertaining to public roads and some of the activities of the forest service. It undertakes research investigations involving agricultural and rural problems relating to mechanics, hydraulics, electricity, sanitation, water supply, buildings, structures, erosion, irrigation, drainage and other phases in which engineering is involved.

In California, most of this research work is conducted cooperatively with the State Department of Public Works, the Agricultural Experiment Station of the University of California, the City of Los Angeles, and with Riverside, San Bernardino and Orange counties.

Consumptive Use of Water.

Studies of the consumptive use of water and the water requirements of crop plants and native vegetation form by far the larger part of the activities of the division in this state.

Studies of the consumptive use of water by citrus and walnut groves in certain areas are conducted by Prof. S. H. Beckett of the University, who will present a discussion of this phase of the work. These investigations are cooperative with the State Department of Public Works and with the State Agricultural Experiment Station. The results of the work in San Diego County have been published as Bulletin No. 489 of the Experiment Station.

The work of this division, under immediate supervision of H. F. Blaney, irrigation engineer, and C. A. Taylor, assistant irrigation engineer, and its cooperating associates, has been confined, and will probably continue to be confined, to the valley floor in so far as native vegetation is concerned. At the present time these studies of native vegetation are carried on only in the Santa Ana Basin. The methods for determination of the consumptive use of water by native vegetation do not differ from the methods employed for citrus crops. Studies of the consumptive use of water by citrus and deciduous groves and by alfalfa are being conducted in the Ontario, Upland, San Dimas and San Fernando areas.

There has been determined the use of water by citrus trees for each of the 12 months, as shown below:

Monthly Transpiration of Water by Citrus Trees
(Near San Dimas)

Date	*Acre-inches*
1928—July	3.01
August	2.86
September	2.25
October	1.74
November	1.43
December	0.95
1929—January	0.82
February	0.72
March	1.05
April	1.36
May	1.63
June	1.92
Total	19.74

Preliminary investigations were begun in 1929 at San Dimas under informal cooperation with the U. S. Bureau of Plant Industry to determine:

I. The effect of soil moisture conditions upon the yield, storage and shipping qualities of lemons.
II. The irrigation methods that are permissible from a crop yield standpoint to conserve the water supply.

Supplementing field work, there is being conducted at Santa Ana by A. A. Young, assistant irrigation engineer of this division, a series of tank experiments primarily for the three-fold purpose of determining:

A. The evaporation rate from uncropped areas with the water table maintained at different definite distances below the surface.
B. The consumptive use of water on cropped areas with the water table maintained at various definite depths below the surface.
C. The transpiration rate of various water-loving plants, such as tules, cat-tails, willows, etc.

The method of operation in tank experiments is to maintain a water level at a constant elevation by employing the principle of the Mariotte bottle, the loss of water from the bottle giving a measure of the amount evaporated or transpired or both.

Investigations are also being carried on to show the hourly rate of use of water by various plants throughout their growth. In this case an automatic recording device is used in place of the Mariotte bottle. Our present information is that the minimum use of water by the plants occurs about 7 o'clock in the morning, while the maximum use occurs shortly after midday.

Supplementing the tank experiments to determine the use of water by water-loving plants, there have been installed in Temescal Canyon automatic water recording devices at the upper and lower ends of a geologically water-tight section of the canyon. At the bottom of this canyon there are growing various native plants, and we have been able to measure the amount of water lost in this area of the canyon by transpiration and evaporation.

One of the surprising findings has been the enormous use of water by tules and river bed growths, as shown in the following tables:

Loss of Water by Transpiration and Evaporation Through River Bed Vegetation, Temescal Creek (Natural Conditions)

For the week ending (1929)	*Loss for week in acre-inches*
April 22	0.354
April 29	1.038
May 6	1.932
May 13	2.617
May 20	3.735
May 27	4.258

Evaporation-Transpiration Loss by Tules at Santa Ana, Planted in Tanks Two Feet in Diameter and Fully Exposed

1929	*Acre-inches*
August	23.46
September	23.75
October	28.38
November	23.35
December	11.30
1930	
January	1.86
February	3.61
March	6.02
April	17.59
May	22.57
June	23.07
July	28.60
Total	213.56
	or 17.80 acre-feet.

Rainfall Penetration.

The rainfall penetration investigations have been carried out under the immediate supervision of H. F. Blaney and C. A. Taylor of the U. S. Department of Agriculture.

The question has arisen many times as to what becomes of rain falling upon valley floors:

To what extent does it contribute to the underground water supply?

What portion of it runs off into the natural drainage channels?

What portion is stored in the soil for immediate use by plants?

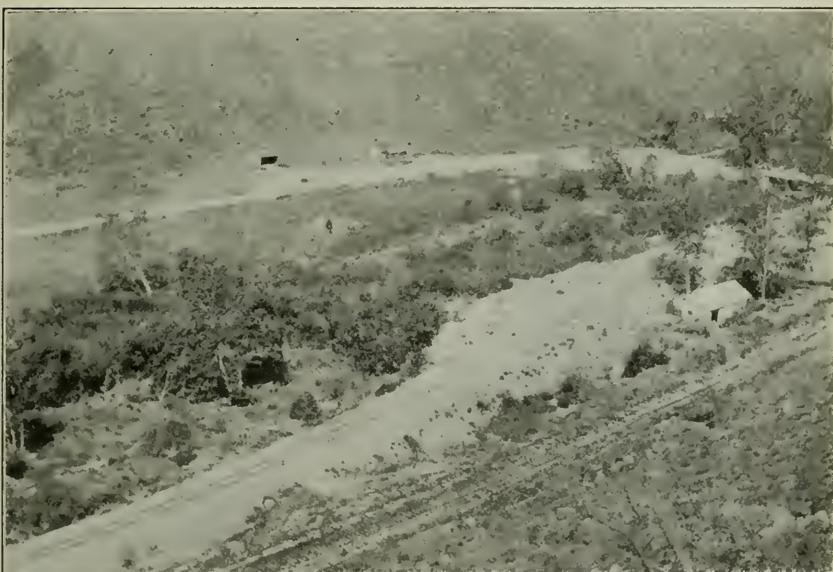
What is the disposition of rainfall of different intensities and extending over periods of different lengths?

These are some of the questions that we are attempting to answer in our cooperative study of the disposal of rainfall in the Santa Ana River Basin. This is a cooperative study with the State Department of Public Works, the three counties, the Agricultural Experiment Station of the University of California and this Division.

The results of the first season investigations were published in part in Bulletin 19 of the State Department of Public Works and a report covering all results up to date has been prepared by this office and is to be published by the State Engineer.

The four factors that combine in disposing of rainfall are (1) surface run-off, (2) evaporation, (3) transpiration, and (4) percolation. Under ordinary topographic and soil conditions a part of the precipitation runs off from the surface of the land and eventually reaches the main drainage channels. That portion retained temporarily in the top layer of the soil or intercepted by plants is returned to the atmosphere

PLATE VI



VEGETATION GROWTH IN MOIST LAND ALONG TEMESCAL CREEK

by evaporation. Of the water which percolates into the ground, a portion is stored in the soil within the root zone and subsequently is transpired by plants, while the remainder penetrates below the root zone and joins the ground water. The amount penetrating to ground water may be determined indirectly if values are established for the other three factors entering into the disposition of rainfall, since all water penetrating below the root zone beyond capillary reach of plant rootlets and evaporation must ultimately reach ground water, excepting only moisture lost in the form of vapor resulting from the circulation of air in the soil below the root zone. This loss is very small and is disregarded herein.

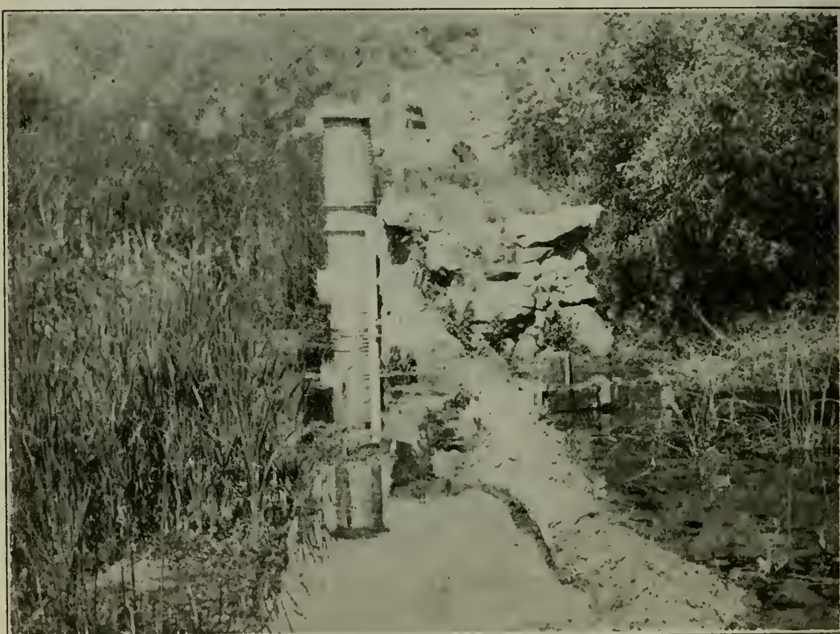
In many sections of the western states underground reservoirs, having an aggregate storage capacity vastly greater than that of all artificially constructed reservoirs combined, have been created through the deposition of alluvial material in water-bearing fans, lenses and strata, constituting more or less valuable aquifers. Such natural reservoirs serve to regulate the erratic supplies resulting from rainfall by storing the surpluses of seasons of high precipitation until drier periods occur. They are replenished by the deep percolation of rain falling directly upon the valley floors, seepage from streams traversing or intersecting the valleys, flood waters discharging over the alluvial aquifers, losses incidental to irrigation and other sources.

The details of procedure for our studies are set forth in Bulletin 19 above referred to.

Water Spreading.

This activity is being presented by A. T. Mitchelson, senior irrigation engineer of this division.

PLATE VII



WATER STAGE RECORDER AND SIX-INCH VENTURI FLUME, TEMESCAL CREEK

Canal Lining and Cleaning.

This division is conducting, without formal cooperation, investigations of methods of cleaning and lining canals, not only in southern California but throughout the west. The object of this study is to determine the best methods in practice and to develop new or improve existing methods.

Canal Operation and Maintenance.

This division likewise is conducting a general study of methods of operating and maintaining canal and ditch systems, including methods of water delivery. There has recently been published by this division Technical Bulletin 47, Delivery of Water to Irrigators.

Cost of Water.

At the present time we are conducting an investigation of the cost of water to irrigators in California. This study is in cooperation with the Department of Public Works and the University of California. It is expected that the results will be published as a bulletin of the State Department of Public Works and will supplement Bulletin 8 of the same department.

Drainage Investigations.

Incidental to other work, we are conducting certain drainage studies in the vicinity of Santa Ana, to determine:

A. The effect of various storms upon the run-off from drainage areas.
B. The effect of such storms on the water level in drained and undrained areas.

This study is conducted in cooperation with the Orange County Flood Control Board.

Evaporation from Free Water Surfaces.

There has been carried on in many parts of this and other countries studies of the evaporation losses occurring from free water surfaces. Usually these studies have involved the use of pans of various depths and areas. A few years ago the U. S. Weather Bureau adopted a standard weather bureau evaporation pan and prescribed how it should be set up. Many agencies have made more or less disconnected investigations of the evaporation losses occurring on large bodies of water and from floating pans. In some instances elaborate set-ups have been made, but there has always arisen the difficulty of adapting results obtained at one place to other places where conditions of climate, altitude and the like are much different.

Three or four years ago this division inaugurated a series of investigations to determine the effect of meteorological factors, as well as altitude, upon evaporation losses from standard weather bureau pans. There was inaugurated at the same time a series of investigations to adapt results obtained from standard weather bureau pans to larger bodies of water.

These investigations have been conducted in various parts of California and during the past summer evaporation losses were determined from the surface of East Park reservoir and the results coordinated with standard weather bureau pan determinations, as well as floating pan observations. It is expected the results of this investigation will be published this winter.

Other Investigations.

In connection with its general studies, this division is conducting occasional studies along the various lines of hydraulics, irrigation, drainage and allied subjects.

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CHAPTER VIII

STORAGE OF WATER UNDERGROUND BY SPREADING OVER ABSORPTIVE AREAS

By A. T. Mitchelson, Senior Irrigation Engineer, Division of Agricultural Engineering, U. S. Department of Agriculture

This discussion is not intended as a technical contribution to the subject of spreading water, but merely as a resume of projects carried on under this subject, enumerating the agencies, giving a brief outline of their methods and, where possible, results obtained either in going projects or research studies. Its purpose is to inform the reader of what is being done by the varions activities working for a solution of this important problem.

According to authentic records, the first actual spreading of water in this basin for the purpose of storage was done by the Irvine Ranch Company from Santiago Creek in 1896. At the present time water is being spread from this stream by the Serrano and Carpenter Irrigation District. While, of course, some improvements have been made in the manner of spreading, the general procedure is as described in Bulletin 19, Department of Public Works of California.

The Tri-county Water Conservation Association spreads water from the Santa Ana River at Mentone and at Barton flat (see Plate VIII), but there are no authentic data showing either the amount of water diverted to the spreading grounds or the area over which it is spread. There is an opportunity to develop some worth-while information from a study of conditions on this project and it is the intention of the Division of Agricultural Engineering, U. S. Department of Agriculture, to attempt such a study this winter.

From the Mill Creek run-off, the city of Redlands and the Lugonio Water Company are spreading water when it is available, but they have not made any attempt to produce data on the rates of percolation, ratio of gross area to wetted area or any of the other factors entering into this study.

The city of Pasadena operates a spreading area at the mouth of the Arroyo Seco Canyon, where that stream leaves the mountains and enters its entrenched channel. The grounds are located about 1500 feet upstream from the maximum high water line of the Devil's Gate Reservoir.

The works consist of a diversion flume five feet eight inches wide by two feet deep, constructed of two by twelve inch planks with the cracks covered by one by three inch battens. A short distance below the head of the flume there is a swing gate which closes the flume downstream and returns to the channel water that is too muddy to be spread. For some years a staff gage in the flume gave records from which the quantity spread was computed. In recent years a Watson and later a Stevens recorder have been installed. The gross area of the spreading ground is about 35 acres. Within this area there is laid out about 15,400 feet of ditch from one and a half to two feet wide and about two acres in pools. In the last few years use has been made of an abandoned gravel pit at the lower margin of the spreading grounds.

During a large flow water enters the flume directly, but in order to divert low flows a brush and rock dam is built in the channel. The attendance of one man is required to regulate the flow between ditches and pools. The flume has a capacity of about 50 second-feet, but the spreading grounds can not absorb that quantity of water. Prior to the use of the gravel pit the maximum quantity spread at one time was at the initial rate of 28 second-feet, eleven second-feet per acre. This rate is usually quickly reduced to an average of about four and four-tenths second-feet per acre. From time to time, at the end of the season, a tractor pulling a slip scraper cleans out the pools.

The quantity spread is given in the following table:

1914–15	2,420 acre-feet
1915–16	3,120 acre-feet
1916–17	2,330 acre-feet
1917–18	900 acre-feet
1918–19	290 acre-feet
1919–20	1,180 acre-feet
1920–21	300 acre-feet
1921–22	4,220 acre-feet
1922–23	0 acre-feet
1923–24	0 acre-feet
1924–25	0 acre-feet
1925–26	440 acre-feet
1926–27	1,290 acre-feet
1927–28	0 acre-feet

The amount of water spread during the last two years has not been worked up to date, a new rating curve being necessary because of change of location of the gage.

No detailed research work has been done concerning the factors governing rates of percolation.

The Bureau of Water Works and Supply of the City of Los Angeles is also making studies of water spreading and during the seasons of 1928–29 conducted some percolation tests on city-owned property at the northeast corner of Vanowen street and Whitsett avenue. This site is approximately two and a half miles north of North Hollywood (formerly Lankershim) and one mile east of Lankershim boulevard. The property adjoins the flood control channel of what is now termed the "east channel" of the Big Tejunga Wash, the entire property having been covered by the floods of 1922.

At the north end of this property the surface soil consists of a fine silt, making it necessary to excavate four or five feet in order to reach a good sand which would facilitate percolation. Twenty-two rectangular basins were therefore excavated for the purpose of impounding the spreading water, fifteen of which were 20 feet wide with a depth of from four to five feet below the natural ground surface and side slopes of approximately one to one. By the time the fifteenth of this series of basins was completed, the first one had been filled and it was found that the steep side slopes resulted in sloughing of the side and end walls, thereby washing the silt to the bottom and sealing off percolation. The remaining seven basins were therefore made 40 feet wide and the side slopes trimmed to a two to one slope. All of the basins were approximately 300 feet long.

The soils of the area in which the tests were made are classified by the Bureau of Chemistry and Soils of the U. S. Department of Agriculture as "Tujunga sand" and "River Wash." As referred to before, however, the upper, or north portion, of the property contained an abundance of colloidal matter which necessitated the deep excavation and which afterwards gave considerable trouble by sealing up the bottoms of the trenches. By digging a narrow trench about six inches deep around the basin at the toe of the side slopes, this silty material was encouraged to deposit there and the sealing off greatly reduced.

Water was measured into Basin Nos. 1 to 15; inclusive, through two six-inch Neptune irrigation meters, the water being delivered to Basin No. 1, then spilled in rotation to each of the others of the group through an overflow pipe connecting each pair.

Basins 16–21, inclusive, were fed independently by four-inch Neptune irrigation meters. The delivery pipes from the meters to the basins were placed in the bottoms of the respective basins and after the pipes were perforated for their entire length within the basins, the ends were sealed so as to cause a diffusion of the water instead of a concentrated stream which would encourage erosion and consequently silt deposit.

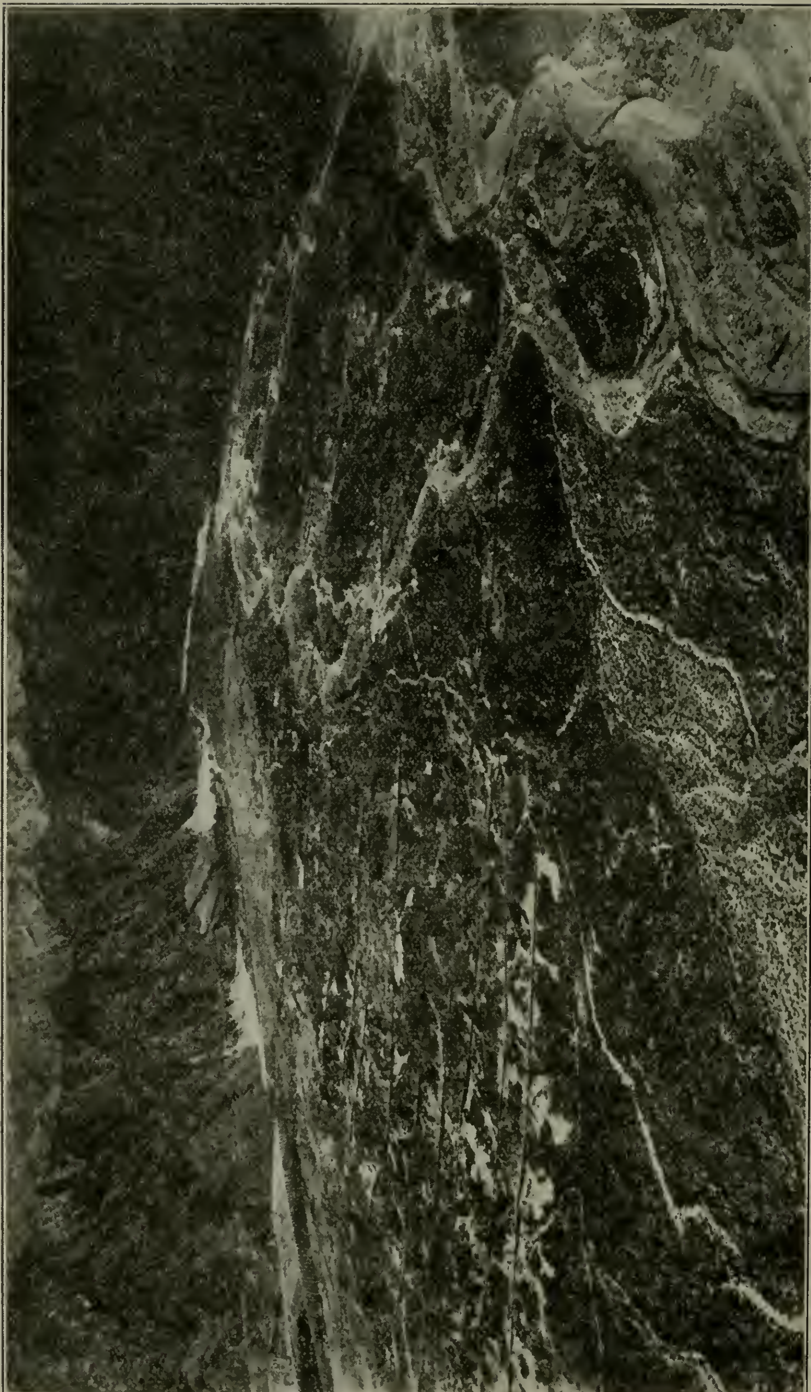
Basin No. 22 was served by allowing Basin No. 21 to spill over through its overflow pipe. An evaporation pan was maintained adjacent to the basins during the spreading operation. Rainfall records, temperature of air and water and readings on numerous wells were taken during the tests.

The purpose of the tests was to determine the feasibility of spreading a part of the winter flow of the Owens River aqueduct on the gravels of the San Fernando Valley, utilizing the underground basin as a storage reservoir. Scientific studies were made as to the rates of absorption by gravels, the effect on the water table, the direction and rate of movement of underground water, and the effect of temperature and silt on rates of percolation.

It is proposed by the city officials in charge of this work to continue these studies and it is also proposed to extend the spreading area during the coming spreading season, provided certain conditions prevail at that time.

The United States Department of Agriculture, Division of Agricultural Engineering, operated an experimental plot at the mouth of San Gabriel Canyon during the past spreading season. The site selected was in a sandy soil in the San Gabriel Wash, but above the river bed and at a point where there is a luxuriant growth of clover, grass and willows. It was particularly adaptable because it was desired to obtain a plot where complete wetting of the surface could be accomplished without resorting to leveling, thereby disturbing the vegetation. It

PLATE VIII



SANTA ANA RIVER DEBRIS CONE AND SPREADING WORKS was the thought of the promoters of the study that, by maintaining a natural and healthy growth on the surface, the root action of the plants would tend to keep the soil open, prevent sealing-off by silt deposits and accordingly facilitate percolation. The plot is .38 of an acre, being approximately 80 feet wide by 200 feet long.

Water is supplied from a stand pipe of the San Gabriel River Water Committee, from whence it is conveyed to a weir box at the head of the plot. A twelve-inch rectangular weir, a continuous water stage recorder, a check hook gage and thermometers for taking air and water temperature are parts of the equipment mentioned.

After discharging through the weir, the water is caught in an over-pour box and delivered to a system of three six by eight inch redwood flumes connected in the form of the letter H, and in which are fixed two-inch metal irrigation gates spaced five feet apart throughout the length of each flume.

These outlets are intended to give an even distribution of water over the entire area, thereby making it unnecessary to correct for wetted area as compared to gross area in computing for rate of percolation.

Ground water levels were taken during the past season from a well about 1000 feet south of the plot.

The project was started in order to gather information on the rate of percolation on other than streambed soils; the effect of vegetation on the rate of percolation; the effect of the roots of vegetation on the sealing-off of spreading areas by the application of silt-laden water; the effect of temperature on rate of percolation; and the effect of a rising water table on the percolation rate.

No satisfactory deductions were drawn as to the last of the above items of study, but it is felt that some worth while data were obtained on the others.

The following is a summary of the results for the period February 24 to June 9, 1930.

Total area of plot=0.38 acre.

Gross season February 24 to June 9=105 days.

Total number of days unaffected by shutdown=87.5.

Maximum percolation rate=5.33 acre-feet per acre per day occurring a total of six days during the season.

Minimum percolation rate=3.03 acre-feet per acre per day occurring seven times in the entire season. Lesser rates were recorded, but occurring at those times not advisable to be considered as true minimum rates.

Average daily percolation rate per acre per day (over the gross period of 105 days)=3.78. This is the average of the entire season disregarding the fact that the plot was shut down several days during this period due to rains which caused silty water unfit for percolation.

Average daily rate of those days of percolation without shutdown= 3.98 acre-feet per acre per day. This may be termed the average daily percolation rate per day since it includes only those days ($87\frac{1}{2}$ in number) during which percolation continued without halt.

Gross amount of water applied for the entire season (per acre basis)=$(151.10 \div 0.38) \times 1 = 398.0$ acre-feet per acre.

It is planned to extend the spreading area on this same site next season—running as checks a plot with vegetation removed, but with level surface, and a plot with vegetation removed and furrowed.

The San Antonio Water Company in cooperation with the State Department of Public Works, Division of Water Resources, ran a brief series of tests on seven plots of seven different soil types on the Cucamonga Cone.

In this study efforts were made to determine the absorptive capacities or the transmission coefficient of the different soils, with and without vegetation, and in an undisturbed state. The plots were ten by ten feet

PLATE IX

STILLING BASIN AND MAIN DISTRIBUTION DITCH

City of San Bernardino spreading project near mouth of Waterman and East Twin Creek canyons.

or 100 square feet and walled in to confine the applied water. Water was carefully measured to the plots, and accurate time intervals recorded. Both water and air temperature were taken during the duration of the tests. These tests were productive of some interesting development and it is understood they may be extended during the coming season.

With the exception of some research studies now being made in California School of Technology, seeking to determine the effect of varying water table on rates of percolation, the above are the only research projects on spreading now operating in this area and known to the writer.

Active spreading grounds for the recharging of the underground supplies, but without research studies, are maintained and operated by City Creek Water Company on City Creek. The city of San Bernardino is spreading over grounds maintained by the city in Devil's Canyon and they have also started some recent work on approximately 200 acres just east of Sierra way and extending from the mouth of Waterman and East Twin Creek canyons. They have constructed a weir and diversion works and a main distribution canal at the upper end of this property (see Plate IX), feeding water to the lower lying cone across which they have constructed a series of low contour dams.

These dams are from three to five feet in height and are run uphill to grade on the ends. They are intended to form settling basins and, at intervals of their length, are provided with outlet gates through which water is delivered to the next lower basin.

From the last basin of the series water is fed to a number of furrows ploughed down the slope of the spreading area and varying from about 800 to 1300 feet in length. The furrows are spaced five feet apart and each one is fed separately by a four-inch pipe running under the dike which forms the final barrier in the series of settling basins. There is a possibility of obtaining some information on the efficiency of running water in furrows in order to facilitate percolation.

Beside functioning as a percolating area, the project serves to dissipate the force of flood waters formerly allowed to flow down into some of the main streets of the city.

The San Gabriel River Water Committee is spreading on approximately 122 acres of land on the upper San Gabriel cone. The net area or the actual wetted area is estimated at about fifteen acres, however, or about 12 per cent of the gross spreading grounds. Considering the crude manner of making a check on the rate of percolation in the area actually wetted, the writer found a remarkable similarity in the figures representing rates of percolation and apparent effect of temperature on this rate, as compared to the results on the experimental plot operated by the U. S. Department of Agriculture on the same cone. It is in informal cooperation with this organization that the spreading work of the U. S. Department of Agriculture is being done near Azusa.

On Lytle Creek and Lower Lytle Creek, the Lytle Creek Conservation Association has been spreading since about 1912 and has made extensive improvements in its works and methods since about 1926.

The U. S. Department of Agriculture hopes to study the possibilities of doing some research work in the area during the coming year in order to determine the feasibility of sinking water through tunnels or shafts.

The Etiwanda Water Company is operating spreading works from Day Canyon, the Cucamonga Water Company and others from Cucamonga Creek, the San Antonio Water Company on Cucamonga Cone, the Pomona Valley Protective Association from San Antonio Creek and the Beaumont Irrigation District from Edgar Canyon (Beaumont).

The Temescal Water Company also is spreading on about 80 acres at the mouth of Gold Water Canyon in the Temescal basin. Water from the canyon is measured over a fifteen-foot weir. The spreading area has an estimated capacity of from 12,000 to 15,000 miner's inches, or the equivalent of about six to seven and a half acre-feet per acre per day.

It is understood that the chief engineer of the Los Angeles County Flood Control District will contribute a report embracing the spreading activities of that agency, therefore no mention has been made in this paper of the splendid work being done by them.

In conclusion, the writer wishes to acknowledge with thanks the data contributed by Mr. C. W. Sopp on the spreading projects of the city of Pasadena and Mr. D. A. Lane on the Los Angeles city work.

CHAPTER IX

IRRIGATION REQUIREMENT STUDIES IN SOUTHERN CALIFORNIA

By S. H. BECKETT, Division of Irrigation Investigations and Practice, University of California College of Agriculture

In the outline of the original project approved by the Dean of the College of Agriculture in 1926, the purpose of the present investigation of irrigation requirements in southern California was stated to be "to determine, for the various agricultural areas of southern California, the least quantities of water needed for profitable crop production, as well as to ascertain the safe economic water requirement under which irrigation districts and mutual water companies may be organized."

In starting these investigations, it was decided that the work should be centered at several points in southern California, these to be so located that the results obtained would have a general application to the more extensive areas under similar conditions of topography, climate and water supply.

Active field work was started in the Escondido, Vista and Fallbrook areas of northern San Diego County in the spring of 1926, and during the next two years an intensive study was made of the water requirements of citrus and avocados. The results of this work were recently published as Bulletin 489 of the College of Agriculture.

In the spring of 1928 the work was transferred to the Anaheim, Santa Ana and Tustin sections of Orange County and during the seasons of 1928 and 1929 investigations with oranges and walnuts as the principal crops were continued. In the spring of 1930 the work was centered at Riverside and studies begun in the San Bernardino and Redlands areas of San Bernardino County, and in the Riverside, Arlington and Corona areas of Riverside County.

Methods.

Thus far, all investigations have been conducted on field plots in commercial groves, located on the predominating soil types of the area, and in groves and orchards which represent good practice in cultivation and in the application of irrigation water.

Measurements are made of the water applied to these groves and by means of intensive soil sampling throughout each season, continuous records are obtained of soil moisture conditions and depth of moisture penetration resulting from the applications of water. These soil moisture records are then used as a basis for computing the per cent of water applied and which is being put to useful purpose in crop production, the soil depths from which this water is being taken, and, finally, the monthly rate of water extraction from the soil. Knowing this rate of water extraction or use, a dependable estimate can be made of the monthly and seasonal irrigation requirement under reasonably efficient irrigation practice, and of the desirable frequency of irrigation on the various soil types.

Correlation of climatic conditions in the different localities is determined from black and white atmometer bulbs placed in each experimental area. These bulbs furnish a simple means of obtaining a comparative measure of the evaporating power of the atmosphere and, when properly set up and maintained, furnish results comparable with those obtained from standard evaporation pans.

Principal Conclusions to Date.

The conclusions reached in the northern San Diego County investigations were that, under conditions of normal rainfall and reasonable efficiency in the application of water, mature citrus groves in the Fallbrook and Escondido areas have a net seasonal summer irrigation requirement of eighteen acre-inches per acre, as compared to fifteen acre-inches per acre in the Vista area.

In the Santa Ana, Anaheim and Tustin areas of Orange County, mature citrus and walnut groves have a summer irrigation requirement of eighteen acre-inches per acre, while groves 12 to 14 years old have a summer requirement of twelve acre-inches per acre.

Investigations with mature groves in the citrus areas of Riverside and San Bernardino counties from April to September of 1930 indicate that the use of water in these localities will be about one-third greater than that found in the Santa Ana area.

Table 1 below shows the average use of water by citrus and walnut trees from April to October, inclusive, in Orange County during 1928 and 1929, and in Table 2 an estimate is made of the maximum probable irrigation need by months for citrus in this same area.

It will be noted that the average seasonal irrigation requirement as given in Table 1 does not exactly agree with the maximum irrigation requirement as given in Table 2. The values given in Table 1 are based on exact figures obtained from the experimental plots, while those in Table 2 represent an estimated requirement under conditions of a full soil moisture supply being available for the trees throughout the season, with a reasonable allowance for waste in application.

It will also be observed that no estimate has been made of the winter irrigation requirement, which may vary widely from year to year, depending upon the amount and distribution of the rainfall. During the winter of 1928–29 determinations of use of water by trees were made on a covered plot in a mature citrus grove at Tustin. From November to March, inclusive, this plot showed an average use of water of less than one and a half acre-inches per acre per month. The normal rainfall of the area in which this grove is located, when normally distributed, should furnish sufficient moisture to meet the needs of the trees through April, and at least until the middle of May.

No estimate other than the total seasonal irrigation requirement has been included for walnuts. This is due to the limited observations thus far made, as well as to the wide variation in opinion as to the necessity

TABLE 1

Average Use of Water by Citrus and Walnut Trees in Orange County, Seasons of 1928 and 1929, Acre-inches per Acre

Year	Location	Crop	April	May	June	July	August	September	October	Total	Carry-over from winter rainfall	Seasonal irrigation require-ment*
1928	Anaheim, Tustin and Santa Ana areas.	Mature citrus	1.48	2.00	2.90	3.32	2.98	2.38	1.65	16.71	4.19	16.6
1929	Anaheim, Tustin and Santa Ana areas.	Mature citrus	1.28	1.74	2.19	2.48	2.60	2.33	1.70	14.32	3.65	14.2
		Average	1.38	1.87	2.54	2.90	2.80	2.35	1.68	15.50	3.92	15.4
1928	Anaheim, Tustin and Santa Ana areas.	12 to 14-year-old citrus	1.35	1.50	1.82	1.85	1.72	1.52	1.27	11.02	2.32	12.00
1929	Anaheim, Tustin and Santa Ana areas.	12 to 14-year-old citrus	1.15	1.57	1.52	1.50	1.85	1.60	1.25	10.44	2.70	10.00
		Average	1.25	1.53	1.67	1.67	1.79	1.56	1.26	10.73	2.51	11.00
1928	Tustin area	Mature walnuts	------	4.00	3.20	6.30	5.20	3.60	1.60	23.90	10.00	18.00
1929	Tustin area	Mature walnuts	1.00	4.15	4.45	6.45	5.50	2.85	1.75	26.15	10.50	18.00
		Average	.50	4.07	3.82	6.38	5.35	3.22	1.68	25.02	10.25	18.00

* On a basis of 75 per cent efficiency in irrigation; that is that 75 per cent of the water delivered to the area irrigated reaches the soil zone occupied by the main portion of the rooting system of the trees.

or desirability of irrigation following harvest. However, with the trees starting new growth in the spring under conditions of a full moisture supply, it is estimated that eighteen acre-inches per acre, if efficiently applied, will meet the normal needs of mature orchards during the summer irrigation period.

TABLE 2

Estimated Maximum Summer Irrigation Requirement for Citrus Groves in Orange County, Acre-inch per Acre

Crop	May	June	July	August	September	October	Total
For mature trees	1.00	3.50	4.00	4.00	3.50	2.50	18.50
For trees 12 to 14 years old	.75	2.25	2.50	2.50	2.25	1.75	12.00
Approximate distribution by months in per cent	5	19	22	22	19	13	100

After several years observations in the irrigated areas of the South Coastal Basin, the writer is of the opinion that the greatest waste of irrigation water in the south comes from a lack of storage facilities. In this area, most of the gravity water is distributed through mutual water companies, many of which operate under a fixed rotation schedule. Diversions are made and water placed in the canals at the disposal of the user in the early spring, often long before the soil shows a need for moisture replenishment. Although an appreciable percentage of this water may be applied to the land, but little of it is put to useful purpose and practically none of it is carried over as stored-up moisture for summer use when the water demand of the crops is at a maximum.

Future Irrigation Requirement Studies in Southern California.

Thus far the investigations have been limited to the use of water by, and irrigation needs of citrus fruits, avocados and walnuts under conditions that may be considered a full soil moisture supply throughout the year. The next step in the study lies in a determination of the least quantities of water needed to maintain normal growth and profitable production under varying conditions of soil and climate and to ascertain the effects on growth and production when the crops are subject to periods of drought and soil moisture deficiencies.

In the meantime, the present investigations should continue with citrus and walnut trees and should be extended to include deciduous and other subtropical fruits and the various field and truck crops being produced in the southern California areas, including Imperial and Coachella valleys.

Cooperation.

The investigations here described are conducted cooperatively by the Division of Irrigation Investigations and Practice and the Citrus Experiment Station of the College of Agriculture, the Division of Agricultural Engineering, Bureau of Public Roads, United States Department of Agriculture, and the Division of Water Resources, State Department of Public Works.

APPENDIX

OUTLINE FOR INVESTIGATIONAL AND RESEARCH WORK IN SOUTH COASTAL BASIN OF CALIFORNIA

By

HAROLD CONKLING

Deputy State Engineer

June 1, 1930

NOTE.—Some statements made in this appendix are repeated in Chapter I, but in spite of this it is deemed advisable to publish the Outline as originally prepared.

OUTLINE FOR
INVESTIGATIONAL AND RESEARCH WORK
SOUTH COASTAL BASIN

The following report is the result of a request by Los Angeles County Conservation Association that a preliminary survey, which would set out briefly the work being done by public bodies and by investigators along lines which will give added water supply to the South Coastal Basin, be made by the office of the State Engineer. It was also requested by the association that the report contain information as to what supplementary or additional lines of investigation should be initiated to bring about most complete and economic salvage of local supplies now wasting and to coordinate activities.

During the preparation of the report it was found desirable to broaden the scope and to outline work, which should be done so that all problems which are now apparent, not only in connection with conservation of local wastes but utilization of imported waters, should be encompassed.

It was found that there are eighteen different lines of investigation which are either in progress or which should be initiated, and that many agencies are now at work on these matters. The report gives a brief statement of the situation which makes each line of investigation necessary in order to achieve the ultimate conservation, together with a statement of what is being done or has been done along that particular line; the agency doing the work, if any; and additional work considered necessary. In outlining this, question arose as to the adequacy of present organizations to handle all the problems confronting the various communities. These matters of organization and financing are briefly touched on as one of the eighteen lines for investigation.

SUMMARY STATEMENT

Before discussing in any detail the various lines of investigation considered necessary in the South Coastal Basin, it appears desirable to give a brief summary of the general situation, which summary contains many things well known to all students of the situation but which are here noted in order to provide a background against which the matters discussed can be more readily seen.

Only that portion of Los Angeles, San Bernardino, Riverside and Orange counties lying in the Coastal Basin of Los Angeles, San Gabriel and Santa Ana rivers and the minor streams west of Los Angeles are considered in this report.

The South Coastal Basin, or Los Angeles Basin as it is variously called, occupies an area 90 miles from east to west at its greatest length and 50 miles north and south at its greatest width. It contains 57 incorporated cities, numerous urban communities not incorporated and 2200 square miles of irrigable land or land suitable for residential development. About 2,500,000 people, or nearly 50 per cent of the population of the state, live in this basin, although the area is less than one and four-tenths per cent of the total area of the state and only seven-tenths of one per cent of the water supply is found here. Population and irrigated area are rapidly increasing.

It should be noted that only seven-tenths of one per cent of the water supplies of the state are found in this region. From this it may be inferred that water supply will be the limiting factor in development of the section. It is isolated and remote from other sources and to bring water to it is an engineering undertaking of the first magnitude. To amplify the local supply, the city of Los Angeles has constructed its 250-mile aqueduct to bring in Owens Valley water from the north and now proposes to extend this to Mono Basin still further north in order to reach additional supplies. The Metropolitan Water District is actively proceeding with its Colorado River Project to bring in 1500 second-feet. Despite the fact that it has been necessary to bring in these supplements from outside, local waters still go to waste in time of flood. There is also a constantly increasing discharge of sewage water into the ocean.

Many organizations are working to the end of saving local wastes. Los Angeles County Flood Control District is active in the San Gabriel and Los Angeles River watersheds with the dual purpose of salvage of waste and protection from floods. Orange County Flood Control District has laid out a similar program for Orange County. The Tri-Counties Conservation Association is actively engaged in conservation in the upper Santa Ana watershed. Many water companies, both singly and in groups, have made or are making their contribution to this end. But the matter is complex and the object costly to achieve. Many agencies for research and investigation have been busy on the matter for several years past, obtaining data useful and necessary to final consumption of the salvage of local wastes. The U. S. Geological Survey is measuring stream flow from mountains and waste into the ocean. The U. S. Division of Agricultural Engineering is determining wastes of water by uneconomic plant life and contributions to the supply from rainfall on the valley floors. It is also beginning work looking toward increasing the efficiency of spreading water on gravel cones. The U. S. Forest Service is organized to protect the watershed and is doing experimental work looking toward increasing the efficiency of watershed cover. The city of Los Angeles is investigating the use of sewage water in industry and agriculture. The State Division of Water Resources has done a great deal of investigational work in gathering and analyzing data to determine amounts of waste, possibility of salvage and utilization of the underground reservoirs to better advantage.

Recitation of these very considerable activities draws attention to the important place which the matter of water supply has reached. It is stated by students of the subject that increasing demand will make it imperative to save all local supplies, as well as to import all water under consideration at the present time, the principal difference in views being as to when this will be necessary and as to the most economic solution. It is also stated that overdraft of local supplies exists now, that Colorado River water will not be available for eight years at the earliest, that local wastes would be available sooner than that if they can be saved and that salvage of local waste should proceed to the fullest extent possible concurrently with development of outside supplies.

On studying the problem which was presented by the request for this survey, it became apparent that, while many agencies are at work, the task of providing this area with water is a single problem. The region is too closely bound, both in a physical and an economic sense, to make it otherwise. It is a single problem, but it has many facets. The same information which will lead to intelligent conservation of the various local wastes will also be necessary for intelligent distribution and utilization of Colorado River water. It is commonly stated that the shortage in available local supplies is even now widespread and almost universal over the region. Yet even if this is true, the waters which can be salvaged may not be used by all areas in which shortage exists, for the situation is complex in the extreme, both physically and legally.

Still another phase of the matter which should receive study concurrently with the physical situation, presents itself. Utilization for supplies, whether local or foreign, will require organization for the purpose of financing on the part of those whose needs become so great that they must undergo the expense of supplementing their supply. How best can the communities and areas which wish to do so proceed with their plans, and in what way will these costs be met? Not only is the problem a many sided one from the physical or engineering approach, but the social, economic, legal, organization and administrative aspects must be considered. This report points out the lines of investigation which are being carried forward, the agencies making such investigation and notes added lines of research necessary to establish a sound basis of physical facts and analysis.

The physical situation may be briefly reviewed: The region is supplied by three stream systems—Los Angeles, San Gabriel and Santa Ana rivers. About 90 per cent of the water supply is drawn from underground reservoirs which have captured and held a part of the wild and sudden floods of the region. The area separates into 29 more or less definitely delimited underground reservoirs, each one of which is tied in with others so that what is done toward water supply in one affects perhaps several others. Each one of these is an individual study which must be combined with the whole to reach an answer. Any attempts at salvage resolve themselves finally into attempts at adding to the natural supply of one or more of these underground reservoirs and utilizing them to better advantage. The water plane in practically all of these has been falling for many years past. Into some, salt water is penetrating from the ocean. Water is being pumped from below sea level in 162 square miles of the Coastal Plain, according to recent surveys. Salvage of local waste will be available to some and not to others. An important step in investigation will be the determination of shortage in each basin, if such exists, source of water available for it and the effect of development in one basin on the supply to another.

Local wastes occur by floods, by outflow of sewage into the ocean and by evaporation from a high water plane. Only those flood wastes originating above a reservoir site can be salvaged unless spreading works, which will function in flood times, can be developed. Salvage of flood waste and of sewage is a matter of public effort, but salvage of water evaporated from seeped lands may not be. It depends on the particular situation. In most cases reclamation of seeped lands will merely result in their cultivation. In other words a useful draft will be substituted for a waste, but on the same land. This may not affect the general situation.

Only those wastes which it is believed possible to salvage in whole or in part are listed below. Estimates are as follows:

Average Annual Waste

Estimated flood waste possible to salvage—		
Los Angeles River	10,000 acre-feet	
San Gabriel River	62,000 acre-feet	
Santa Ana River	33,000 acre-feet	
	105,000 acre-feet	33%
Measured sewage waste—		
Los Angeles and south and west	155,000 acre-feet	
Santa Ana outfall	6,000 acre-feet	
	161,000 acre-feet	50%
Estimated waste from seeped lands—		
Los Angeles River	Small	
San Gabriel River	10,000 acre-feet	
Santa Ana River	45,000 acre-feet	
	55,000 acre-feet	17%
Grand total	321,000 acre-feet	100%

There is also a possibility of salvaging water originating from rain on the valley floor. Present information is not sufficient to determine whether this can be done, or to estimate the amount which can be salvaged in this way.

As before stated, plans for salvage of waste flood water are made and actual construction is being actively prosecuted by the Los Angeles County Flood Control District. Plans for salvage have also been made by Orange County Flood Control District. Utilization of other wastes is a matter of study.

The several lines of investigation which are thought to be necessary are outlined in the following statement. It should not be inferred from the fact that a particular line of investigation is mentioned, that nothing is being done in that line. In fact much work may be in progress. It is merely desired in this memorandum to outline all lines of endeavor, which at present appear desirable, in order that the matter may be fully presented. In the following paragraphs will be found a brief summary of the situation leading to the conclusion that investigation in these different lines is desirable, together with a statement of what is being done along that line by the several agencies now operating. The recommended investigations are:

1. Determination of erosion and silting rates, and survey of methods and areas for disposition of such materials.
2. Survey of additional reservoir sites, both in mountain and valley
3. Survey of check dam possibilities and benefits.
4. Investigations to increase efficiency of watershed vegetation.
5. Investigation and survey of spreading works.

6. Investigation of penetration of rainfall on valley floor to water plane.
7. Investigation of noneconomic use of water by plant life.
8. Determination of flood waste into ocean, its quantity and origin.
9. Stream gaging—additional program.
10. Investigation of underground waste into ocean.
11. Investigation of sewage waste into ocean and its utilization.
12. Investigation of intrusion of salt water from ocean and other sources into underground basins.
13. Investigation of shortages in each underground basin of the 29 in the region.
14. Investigation looking toward increased efficiency of operation of underground reservoirs.
15. Investigation of quality of water, both local and imported.
16. Investigation of locations for best utilization of water imported by Metropolitan Water District.
17. Study of organization for financing and distributing benefits.
18. Study of legal phases.

It will be seen that the work which is being done, or which may be done, toward salvage resolves itself into two general phases. In one, actual construction is the main feature and the result will be immediate salvage of waste. In the other, research for a term of years is necessary to arrive at the more elusive wastes and the best methods of utilizing all wastes and imported waters.

DETAIL

It is the intention to outline, in as much detail as seems warranted, for each phase of the subject and for each area, what information is necessary, what is being done in each phase by different agencies and what is necessary for the future.

The matter has been approached as though the region were a virgin territory so far as investigation is concerned, and the question asked, "What lines of investigation would be necessary here if it were desired to determine what must be done to assure the basin a complete water supply?" This resulted in setting out the eighteen lines of investigation heretofore mentioned. Next the field was surveyed to determine what work is already under way in each of these lines. In all lines work is being done by able men and in some lines the entire field is fairly well covered. In others, due to limitations of organization scope, the field is not being completely covered. For instance, no attempt has been made to bring together, in one whole, the analyses of original data and reach conclusions as to the steps necessary to assure the region a complete supply as its development proceeds.

Erosion.

Erosion from mountains has filled the valleys. Hitherto the streams have followed different courses across the valleys and deposition of material has been uniform. Now, in order to prevent destruction, the stream must be confined so deposition will occur along a single line. The problem which is presented is to determine rate of erosion so that the area in which the material is deposited shall be sufficient to dispose of it.

Rates of erosion have been studied by the U. S. Forest Service and by many organizations under somewhat different conditions than those which exist here. Future studies should concern themselves more definitely with movements of and disposal of material after it has reached the valleys.

Reservoirs.

Reservoirs are a prerequisite to salvage of the sudden flashy floods of the region. On some streams they are necessary for flood control and on all streams they are an aid. By reducing peaks they aid spreading of water on gravel cones to cause it to percolate into the underground basins. They are necessary also in the operation of conduits such as that from Owens Valley and that proposed from Colorado River.

The City of Los Angeles has made extensive surveys for reservoir sites in Santa Monica Mountains, in the Saugus area and in the lower lying foothills of San Gabriel Mountains north of San Fernando Valley. Many of these have been constructed. Los Angeles County Flood Control District has made extensive surveys in Santa Monica Mountains to the west of the area covered by the city of Los Angeles and at higher elevations in San Gabriel Mountains north of San Fernando Valley than covered by the city. The district has covered extensively San Gabriel Mountains north of San Gabriel Valley, the hills in the valley and the valley floor. Metropolitan Water District has surveyed reservoir sites suitable for its distribution needs. Orange County Flood Control District has covered possibilities in Orange County. The state has covered quite intensively the entire Santa Ana watershed. In all of these areas some reservoirs have been constructed.

This information should all be brought together on a map showing locations, with lists of pertinent data for each reservoir site. Wherever it appears that sufficient reconnaissance has not been made, this should be done. The final result should show a complete inventory with preliminary estimates of cost and feasibility.

This work can be undertaken and completed at an early date.

Check Dams and Barriers.

Check dams and debris barriers in the bottom of small mountain canyons have been built to hold back small quantities of water for the dry season, to prevent erosion and as an aid to flood control.

Various organizations have undertaken this work in a great many of the smaller canyons. In some, heavy floods have washed the dams out and in others they have withstood the flood waters and appear to be functioning successfully.

This subject should be studied to arrive at the principles which make for success and to determine the effect on salvage of waters. The possibility of such dams at favorable locations, built to heights as yet unattempted, should also be studied and the possibilities should be mapped.

This study might occupy a period of two or three years, depending on whether rainfall conditions give opportunity for observations.

Forest Cover.

Forest cover retards erosion, aids penetration of rainfall into the soils of the watershed and reduces the peak of floods. Unprotected mountain sides would erode so much faster than the geologic norm that any reservoirs constructed in the mountains would fill with silt very rapidly. Without this protection the floods would be more violent, productive valley lands would be subject to great hazard and the greater load of silt carried by the stream would impair the efficiency of spreading grounds at the mouths of canyons and decrease the natural percolation into the underground reservoirs.

Any natural resource, when made useful to man, gives only a small percentage of its theoretical efficiency. Coal burned in even the most efficient steam engine gives hardly more than 20 per cent of its possibilities. A stream will rarely give more than 50 per cent of its possible power when transformed into electricity. In ordinary irrigation practice hardly more than 30 per cent of the water diverted by gravity becomes useful. Much research and investigation has been done to reach even the efficiencies noted. Likewise in performing its work of reducing floods so that part of the water is made available for use by man, the forest uses a large percentage of the water and hardly more than 20 to 25 per cent becomes available for direct use.

The United States Forest Service is studying this problem in southern California to determine whether steps can be taken to give a greater yield of useful water, or, in other words, to see if the efficiency of nature can be improved on, both in flood prevention and water yield. A great deal of work is being done also by the U. S. Forest Service, Los Angeles County Forest Service, Los Angeles County Conservation Association, Tri-Counties Conservation Association and various other bodies, looking toward prevention of fires in the mountains which destroy the vegetation and leave the mountain sides unprotected, with the evil results before noted. Improvement in efficiency of forest cover, if it can be accomplished at all, will come only after a long period of research. Maintenance of protection is well organized and through experience is being perfected.

Spreading.

The underground reservoirs from which about 90 per cent of the water supplies of the region are drawn are supplied in part by percolation in the stream beds themselves. The porous material of the valley fills absorbs water readily, so that the smaller streams are generally absorbed on their own cones. When the stream beds are in favorable condition several hundred second-feet may be thus taken up. It is often desirable, however, even when all of the stream naturally percolates, that the absorption take place as near the mountains as possible, instead of over a considerable length of stream bed. The only way to cause this to happen is by artificial means—that is by increasing the area which the streams will cover at the point where it is desired to induce it to percolate. This process is called "spreading." Spreading, except in the streambed itself, has not been successfully accomplished when water is muddy, as the silt clogs the pores and seals against percolation.

Spreading is greatly aided by reservoirs which will reduce the peak of the floods. Where the streams are flowing in an unstable channel on top of a cone, diversion for spreading outside of the channel is dangerous, particularly in the case of the larger streams, as it may cause the stream to cut a new channel through a populous community and leave a trail of death and destruction. The art of spreading is in its infancy and much remains to be learned.

The largest spreading works are at the mouth of Santa Ana Canyon and have been constructed by the Tri-Counties Conservation Association. Excellent works have been constructed on Lytle Creek, Cucamonga Creek, San Antonio Creek, Mill Creek and at the mouth of San Gabriel Canyon. Los Angeles County Flood Control District is planning large spreading works for San Gabriel River and other streams in San Gabriel Valley and San Fernando Valley. The Division of Water Resources, in cooperation with water users on the streams in Santa Ana Valley, is investigating the feasibility of enlarging and increasing the efficiency of spreading works on practically all streams in that valley. The city of Los Angeles is doing experimental work on spreading on Tujunga Wash in San Fernando Valley. The U. S. Division of Agricultural Engineering is also doing experimental research work on the subject and is making the first test on the San Gabriel Cone.

Apparently rates of percolation are governed by obscure conditions not apparent on casual examination. The rates on the various cones are different and the physical situations have marked divergencies. The layout of spreading works for each stream must be from an original study of that stream.

Spreading is one of the most important features of conservation in southern California and is worthy of much study, but enough is known of its benefits so that construction of spreading works need not wait on research. Construction and observation of results is the most effective means of finding the facts. A careful study and survey of each stream should be made before expensive construction is undertaken.

The program of installation of spreading works will go ahead as fast as funds are available, but the most effective use of such works and their type waits on experimentation.

Rainfall Penetration—Valley Floor.

While it has long been recognized that part of the rainfall on the valley floor, even in a semiarid region such as this, penetrates the subsoil, if sufficient in quantity, and eventually reaches the water plane when subsurface conditions permit, it has been only in the past few years that the extent of this contribution to the water supply has been appreciated in southern California. The rainfall in this basin varies from ten to 30 inches on the valley floor and naturally the increment to ground water is much larger in the areas of higher rainfall. Inasmuch as the general basin under discussion is divided into 29 minor basins or underground reservoirs, this difference in penetration, other things being equal, makes substantial differences in the water supply to each basin. Intelligent analysis of the supply for any basin demands that knowledge of the percolation which may be expected should be at hand.

The Division of Water Resources has made general determinations of penetration in San Gabriel Valley and Santa Ana Valley. More than this is needed. The U. S. Division of Agricultural Engineering, in cooperation with this Division, started an investigation in the winter of 1927–28 in an endeavor to determine the penetration in different soils and for different amounts of rain. This investigation still is in progress and should be extended and amplified in scope if results warrant. It will take several years to reach satisfactory results.

Noneconomic Consumption of Water.

By this is meant water which is consumed by brush and other native vegetation on the valley floor without benefit to man. In areas where the water plane is high, the heavy growth of water-loving trees and other vegetation along streams, the use by salt grass and other grasses of this nature and evaporation from moist lands not covered by vegetation are all wastes of water without benefit to man.

Experimental work to determine the amounts of such losses is being carried on by San Gabriel Protective Association in San Gabriel Valley and Central Coastal Plain and by the U. S. Division of Agricultural Engineering, in cooperation with the Division of Water Resources, in the Eastern Coastal Plain and in the neighborhood of San Bernardino. Drainage works have been installed in southwestern Orange County to remove surplus water. These drains prevent such losses and make available for use water which would otherwise be lost.

Experimental work should be continued. It is to be expected that drains will be built where such losses are expected to continue and in that way these areas will, in part at least, supply themselves with water. For the general investigation, knowledge is needed as to what the development of these areas will demand from the general water supply and this requires as accurate evaluation as possible of the present use.

Flood Waste Into Ocean.

After any rain of magnitude, water flows into the ocean. In general the smaller rains flow into the ocean only from the hills and valley floor and the urban areas where the rainfall has less chance for percolation, due to paving and buildings. Opportunities to salvage directly the waste originating in places other than the mountains are limited because of lack of reservoir sites or difficulty of diverting to them if they do exist. The tendency is for this waste to increase because of extension of urban areas and paving of channels into which it concentrates and in which, in a state of nature, considerable percolation takes place. Construction of drains should be such that, so far as practical, the bottom of the channel is left open so that percolation can take place to the fullest extent. Los Angeles County Flood Control District is investigating valley reservoir sites which may be utilized for storage of water originating below the mountains.

Waste of water from the mountains occurs after the heavier rains. That from San Gabriel River and from Santa Ana River has been estimated after extensive investigation by the Division of Water Resources. Investigation into that from Los Angeles River and from

Santa Monica Mountains is now under way by Los Angeles County Flood Control District.

Stream Gaging.

This subject naturally follows the preceding. It is only from the results of such gaging, extended over a term of years, that the amount of wastes which may be salvaged can be obtained. Gaging stations are maintained on every tributary of any importance in Los Angeles, San Gabriel and Santa Ana drainages by the U. S. Geological Survey. Gaging stations also exist at strategic points on San Gabriel River below the mountains and are being maintained by Los Angeles County Flood Control District and San Gabriel Protective Association. At similar points on Santa Ana River stations are being maintained by the Geological Survey. In Santa Monica Mountains gaging stations are maintained by Los Angeles County Flood Control District.

The situation should be carefully surveyed to determine the necessity for additional stations to better determine run-off available to reservoir sites and waste into ocean from the various sources above noted. The amount of waste which may be salvaged is extremely important and it is also important to know the rate of increase of waste from urban areas. This increase will measure the decrease in available supplies, inasmuch as part of it would have percolated to underground basins whence it might be utilized.

Underground Water Into Ocean.

It is not unreasonable to assume that there is a possibility that water from the underground basins escapes into the ocean through underground channels at such openings in the barrier range bordering the south coast as Dominguez Pass, west of Long Beach, and through the similar opening to the east of Long Beach. The formation on the west coast is believed favorable to such escape. No work on such a study has been made and no direct way of evaluating such waste, if it does occur, is known. The importance of determining whether such wastes occur and their location, is the aid such knowledge will give toward determination of future saline intrusion. It is probable, if such waste is occurring and if the water plane is lowered in the future to a point below sea level, that salt water will flow into the underground basins and destroy valuable water resources.

Sewage Waste.

About half the water used in the residential section is for domestic purposes and become sewage. So long as outfall sewage systems are not constructed, this water finds its way from cesspools, unpurified, back to the water plane and is again used. When outfall systems, which merely carry the sewage to some waste area where it is more or less purified by treatment, are built, it goes back into the ground water in the same way. When the amount of sewage becomes large its discharge into the ocean becomes the most convenient way to dispose of it. At times and in some places, it is perhaps the only way. Thus a source of supply formerly available to the ground water is cut off.

Of the notable sewage disposal plants in the region, only those of the city of Los Angeles (including west coast cities), the Santa Ana joint outfall, the city of Long Beach and San Pedro District discharge into the ocean. The outlet of Los Angeles, which is by far the largest, is at Hyperion. Los Angeles County Sanitation District is seeking an outlet under San Pedro hills. There are direct wastes from oil refineries which, however, are small in the aggregate as compared to municipal sewage. The city of Los Angeles is now experimenting to see what can be done toward making the sewage useful. No other work of that nature is being done locally. The problem is a large one, involving social and economic factors which must have fullest consideration. There is little agriculture practiced in the immediate neighborhood of the Los Angeles plant and investigation should determine where the sewage, if reclaimed, may be used. Investigation for the future should direct itself toward a determination of the character of this water for use in agriculture and in industrial plants, cost of reclamation, areas which can use it, cost of transportation, replenishment of ground water, layout of systems so that most economic reuse may be made and the general social aspects of the entire matter.

Salvage of this waste, although expensive, is one of the definite possibilities of supply from local sources for the region.

Saline Intrusion.

If there is a connection between the underground water bearing strata and the ocean, and if the water plane recedes sufficiently, salt water will flow from the ocean to the wells and new sources of supply must be found. This has occurred along the west coast and seems imminent on the south coast. In 1929 some of the wells of the Standard Oil Company at El Segundo were rendered unfit for use. Since then other wells have become similarly affected, until now in 45 square miles of west coast territory wells are becoming saline. In an additional 117 square miles water is being drawn from below sea level and the water plane over the South Coastal Basin is receding. Salt water is being found in a small area along Santa Ana River over a mile from the coast.

Saline intrusion may also occur from oil wells in which the salt water is forced from deep strata into the pumping horizon. It may occur inland, away from the sea and away from oil wells, where the fresh water supplies have been greatly depleted and infiltration from deep lying salt water beds takes place.

Los Angeles County Flood Control District and the city of Los Angeles are both studying this matter on the south and west coasts. The State Division of Mines also is studying it in connection with infiltration from oil wells. Once wells are thus ruined it is not certain that they can be brought back to productivity.

Study should be along the lines of prevention by determining threat of such intrusion in advance and guarding against it.

Shortages in Each Basin.

There are 29 basins in the region, each one of which consists of an underground reservoir more or less definitely delimited from all other basins. Some of these 29 basins can be further separated into still more minor basins. The separation is dictated by geology, physiography or by different sources of supply. While it is often stated generally that the region is short of water when the demands are compared to the long time average supplies, neglecting entirely a period of extremely deficient supply such as is current at this time, this is not true of every basin. A few have a supply which, when the long time average is considered, makes it probable that no shortage in local supplies will ever occur if the basin is sufficiently large so that the demand on it will not overtax the supply stored up during a period of wet years or if the basin does not have such complex geological conditions that exploration for new sources is so extremely difficult as to be prohibitive. The different basins separate into the following classes:

Class 1. Those in which the average supply is greater than the average draft and which are of sufficient capacity to tide over any conceivable series of dry years and which also are of such simple geologic conditions that no extraordinary difficulties are encountered when the water plane recedes and wells must be deepened.

Class 2. Those in which the average supply is greater than the average draft, but which, because of limitations of size even though the geology be simple, do not have sufficient holdover capacity to tide over a series of dry years.

Class 3. Those in which the average supply is greater than the average draft, but in which, because of complexities of underground structure, discovery of new supplies as the water plane recedes becomes extremely difficult.

Class 4. Those that have demands at present greater than average supplies and are thus overdrawn, regardless of limitations of underground capacity or geology. These may again separate into two subclasses, depending on the size of the underground reservoir. Some have large capacity and the fossil water may tide over a long period of overdraft. Others have small capacity and the fossil water will endure for only a short period.

The demand in some basins is increasing rapidly; in others it is increasing slowly due to practically complete development. Each basin is a study in itself in which the available stream flow and rainfall must be considered. The draft, rate of increase in draft, underground inflow and underground outflow must also be considered. Geology must be studied and capacity of the basins determined if possible. This is one of the most important of the several features for study suggested in this paper, for on such determination rests intelligent utilization not only of local supplies, but of waters brought in from the outside. In simple words there are 29 more or less separated, but more or less mutually dependent, reservoirs, in most of which the drafts are thought to exceed the supplies, but by widely differing percentages. The sources of supply and the amounts of such overdraft, both present and prospective, should be sought so that it will be possible to determine the most feasible method of replenishing the storage and distributing the imported water.

Considerable work has been done by the Division of Water Resources in San Gabriel and Santa Ana basins toward this end. The city of Los Angeles has investigated San Fernando Valley and the small basins along the west coast. San Gabriel Protective Association is continuing and amplifying the work of the State in San Gabriel Valley and Southern Coastal Plain.

It is found in the last analysis that investigation of water supply development in this area requires an independent study of each of the 29 underground basins to establish the present supply of and demand on each, possible additions to the supply of each and the relation of each to others. Therefore conclusions reached in this phase of the investigational work will be the result of the combination of all the work heretofore mentioned and discussed under subsequent headings.

Intensive research in this direction is desirable for some years to come.

Operation of Underground Reservoirs.

To a degree, the operation of the underground reservoirs can be influenced by proper works and by placing of additional supplies. Inasmuch as the water supplies of the region are drawn from this source almost entirely, it becomes important to study the extent to which the operation of these reservoirs may be improved.

The Division of Water Resources has made a beginning of this in San Gabriel Valley. The work is being carried on by San Gabriel Protective Association and by Los Angeles County Flood Control District.

This study is one that must be pursued over a long period of time.

Quality of Water.

A general investigation of the quality of underground water was made in 1904 by the U. S. Geological Survey. This should be resurveyed and investigation of the quality of imported waters should go forward.

Work along this line is being done by Los Angeles County Flood Control District and by governmental agencies, but should be amplified.

Imported Water.

Metropolitan Water District proposes to bring in 1500 second-feet from Colorado River. Regardless of the legal set up of the district, there will be surplus water available for many years to come. All the studies suggested in this paper would lend themselves to the solution of the problem of its best utilization.

Organization.

Fully half of the agricultural territory is organized into water companies. Many cities have their own organizations, while others are supplied by public utilities. In addition there are flood control districts and the Metropolitan Water District. While all of these are of beneficial intent, not one is so legally organized that it can take care of the interests of all the inhabitants of the territory. How are the costs of sewage reclamation and transportation to place of use to be borne? Who will pay for the construction of the needed reservoirs and for the spreading works? How will drainage works, if eventually found desirable, be financed? Through what agency can the agricultural interests of any area, which so desires, take advantage of surplus water brought in from the Colorado? How can costs be apportioned equably? The water supply of every basin is interdependent on the water supply of several others. If one seeks to benefit itself, all others below, but linked in the chain, receive benefits also from the increased supply. It is certain that no benefits can accrue without organization, but it is a question whether this organization should proceed by individual units or by a greater district. The problem is one of statecraft and constructive thinking on the part of those affected. Without this it is not possible that the best results will be achieved. Along with the physical studies outlined here should go studies of this phase in order that the final outcome may best fit the peculiar physical conditions of the region. Organizations will function best when they shape themselves to the physical situation.

Economic Phases.

The expense of water supplies in this region is on the increase. The cost to the individual residential water user of a city is negligible, but it may become greater than the farmer may bear. What should he do? Can he cheapen costs by better combinations of units and greater efficiency as manufacturers are doing in the face of rising wages? Opportunities undoubtedly exist for this. The University of California has special agencies to study the economic phases of farm life and these trends and possibilities should be studied here.

Legal Aspects.

Water law is designed to protect the owner of water right in his peaceful use of that right. Is the development of the law sufficient for the situation now existing or which will exist in southern California? Does the law permit the most economic development of water supplies and the most economic distribution of water? There are important legal aspects to the whole situation which can best be studied by a committee of attorneys, versed in the local situation, to act as general advisers in the public good.

PUBLICATIONS

DIVISION OF WATER RESOURCES

PUBLICATIONS OF THE

DIVISION OF WATER RESOURCES

DEPARTMENT OF PUBLIC WORKS

STATE OF CALIFORNIA

When the Department of Public Works was created in July, 1921, the State Water Commission was succeeded by the Division of Water Rights, and the Department of Engineering was succeeded by the Division of Engineering and Irrigation in all duties except those pertaining to State Architect. Both the Division of Water Rights and the Division of Engineering and Irrigation functioned until August, 1929, when they were consolidated to form the Division of Water Resources.

STATE WATER COMMISSION

First Report, State Water Commission, March 24 to November 1, 1912.
Second Report, State Water Commission, November 1, 1912, to April 1, 1914.
*Biennial Report, State Water Commission, March 1, 1915, to December 1, 1916.
Biennial Report, State Water Commission, December 1, 1916, to September 1, 1918.
Biennial Report, State Water Commission, September 1, 1918, to September 1, 1920.

DIVISION OF WATER RIGHTS

*Bulletin No. 1—Hydrographic Investigation of San Joaquin River, 1920–1923.
*Bulletin No. 2—Kings River Investigation, Water Master's Reports, 1918–1923.
*Bulletin No. 3—Proceedings First Sacramento-San Joaquin River Problems Conference, 1924.
*Bulletin No. 4—Proceedings Second Sacramento-San Joaquin River Problems Conference, and Water Supervisor's Report, 1924.
Bulletin No. 5—San Gabriel Investigation—Basic Data, 1923–1926.
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Bulletin No. 7—San Gabriel Investigation—Analysis and Conclusions, 1929.
*Biennial Report, Division of Water Rights, 1920–1922.
*Biennial Report, Division of Water Rights, 1922–1924.
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*Bulletin No. 1—Cooperative Irrigation Investigations in California, 1912–1914.
*Bulletin No. 2—Irrigation Districts in California, 1887–1915.
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*Bulletin No. 4—Preliminary Report on Conservation and Control of Flood Waters in Coachella Valley, California, 1917.
*Bulletin No. 5—Report on the Utilization of Mojave River for Irrigation in Victor Valley, California, 1918.
*Bulletin No. 6—California Irrigation District Laws, 1919 (now obsolete).
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*Bulletin No. 8—Flood Problems of the Calaveras River, 1919.
Bulletin No. 9—Water Resources of Kern River and Adjacent Streams and Their Utilization, 1920.
*Biennial Report, Department of Engineering, 1907–1908.
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*Biennial Report, Department of Engineering, 1910–1912.
*Biennial Report, Department of Engineering, 1912–1914.
*Biennial Report, Department of Engineering, 1914–1916.
*Biennial Report, Department of Engineering, 1916–1918.
*Biennial Report, Department of Engineering, 1918–1920.

* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

DIVISION OF WATER RESOURCES

Including Reports of the Former Division of Engineering and Irrigation

*Bulletin No. 1—California Irrigation District Laws, 1921 (now obsolete).
*Bulletin No. 2—Formation of Irrigation Districts, Issuance of Bonds, etc., 1922.
Bulletin No. 3—Water Resources of Tulare County and Their Utilization, 1922.
Bulletin No. 4—Water Resources of California, 1923.
Bulletin No. 5—Flow in California Streams, 1923.
Bulletin No. 6—Irrigation Requirements of California Lands, 1923.
*Bulletin No. 7—California Irrigation District Laws, 1923 (now obsolete).
*Bulletin No. 8—Cost of Water to Irrigators in California, 1925.
Bulletin No. 9—Supplemental Report on Water Resources of California, 1925.
*Bulletin No. 10—California Irrigation District Laws, 1925 (now obsolete).
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* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

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