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RAINFALL FORECASTING

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Much work performed by engineers involves forecasting—making predictions of what will occur in the future. An engineer designs and builds a bridge, and in doing so predicts that it will support certain loads without failure. He plans and constructs a water system for an irrigation or for a domestic supply, with the assurance that it will properly serve the area or the community for which it has been built.

He can do these things with confidence, because he knows—from previous experimental work—the tension or compression per square inch that steel, concrete or timber will sustain without failure. He is familiar with mathematical formulae, charts and diagrams from which he can determine the load which a beam, column or truss will support. He has formulae, charts or slide rules that tell him how much water a pipeline, ditch or flume will carry, if made of steel, concrete or wood, and these being based likewise upon mathematical formulae and laboratory experiments. He is dealing with certainties and his results—as estimated before a structure, project or facility is built—are very close to actual performance.

In his plans and designs, however, he must assume certain requirements that will be met. His bridge must be safe for a certain maximum load—his irrigation or domestic water system must have a water supply and reservoirs, pumping plants and conduits adequate to furnish water to an irrigated area containing a certain number of acres, or to a community having a certain number of inhabitants. Here again the engineer must make forecasts. How heavy will future truck loadings be over what they are today? Will legislation be enacted in the future limiting truck weights and loading? Assuming an ample source of water supply, how many acres will ultimately be irrigated from his system, what crops will be grown and how much water will they take? How fast will the community served by the domestic water system grow—what will be its ultimate population? The engineer must be careful not to overbuild or to provide too much unused capacity, upon which interest and depreciation charges will have to be paid.

In estimating these things—or forecasting them—he not alone has current information, but makes use of past trends which indicate probable rate of increase of the things whose growth he must forecast. His results are not as accurate as those which he makes pertaining to performance, structures or facilities, but nevertheless they have a reasonable degree of accuracy, and capital based upon them is invested in works and facilities.

Finally the engineer encounters matters concerning which he is sometimes called to make forecasts, where he must depend solely upon what has happened in the past, and analyze information pertaining to such past happenings in order to determine whether these past happenings follow any given laws or rules. This he must do if he attempts to forecast future rainfall.

For years it has been possible to forecast tomorrow's weather with a reasonable degree of accuracy, and within the past few years, forecasts of future weather conditions covering up to five days have been issued with comparable accuracy. From past weather records, it can safely be assumed that no rain will fall on August 1st in Southern California, except possibly thundershowers in the mountains, and that chances are five to one, or more, that it will be clear and sunny on New Years Day for the Rose Bowl Game. Furthermore, a few days before New Years day, it is now possible, with current techniques, to forecast with considerable accuracy the relative probability of clear sunny weather on New Years Day for the Tournament of Roses.

Forecasting annual rainfall involves the dealing with past rainfall records of great length. It rests upon the premise that what has happened in the past will again occur in the future, and in much the same manner. Knowledge of past occurrences must extend over a fairly long period of time—the longer the period the more dependable the forecast. We know the average amount of rain at any given location, and know that there is small probability of next year's rainfall being less than 40% or more than 200% of this amount, but just where within these limits it will occur cannot be foretold.

Recording of rainfall in California commenced some 100 years ago, and there exist records for San Francisco, Sacramento and San Diego commencing with the season 1849-50. Around 1870 the Signal Corps of the U. S. Army started to keep rainfall records, as did the railroads. By 1880 there were a considerable number of rainfall records in this state and the total number has been continually increasing. Even records of 70 to 100 years in length, however, are not sufficiently long for use as a basis of forecasting from past performance, particularly since in the case of many of the oldest records the rain gages have been moved about through various locations, and these older records are so few in number that inaccuracies at one station cannot be reduced through averaging a number of stations.

During the 1920's, Mr. Henry B. Lynch, Consulting Engineer of Los Angeles, made a study of early rainfall records in Southern California, and extended his research on the subject over the early history of the area to the founding of the San Diego Mission in 1769-70. His study included the early mission records, the writings of early settlers, explorers and historians of the area, as well as newspapers and periodicals. The results of this splendid and valuable piece of research by Mr. Lynch were published in bulletin form by the Metropolitan Water District of Southern California, covering the period from 1769-70 to 1929-30. The bulletin contains a tabulation giving a seasonal "index of rainfall" for the Los Angeles area, starting with the season 1769-70 and continuing for each season through that of 1929-30. This index of rainfall is the ratio—expressed in percent—of the rainfall for any given season to the longtime average rainfall, and covers the Los Angeles area. The rainfall used for any season is not that at any given station, but is the average of a number of stations in the area. Mr. Lynch has recently brought his tabulation of indexes down to the season 1950-51, so that there is now available a 182 year period of rainfall variation in the Los Angeles area.

Lack of information prevented the development of similar records of indexes of rainfall for other localities of Southern California, but records which are available, ranging from 70 to 100 years in length, indicate that seasonal variations of rainfall throughout Southern California westerly of the Coast Range follow a uniform pattern from year to year. For example, if during any given season the rainfall in the Los Angeles area is 70 per cent of the long time average that in the Santa Barbara, Ventura, Riverside, San Bernardino, Orange and San Diego County areas will not depart greatly from this figure. Likewise periods of wet and dry years throughout the area begin and end at about the same year, and average wetness or dryness for a period will likewise be quite uniform. This feature allows the results of any study which is made of the 182 year record for the Los Angeles area to be applied to other areas in Southern California with considerable confidence.

Before commencing upon a study of the long record of rainfall in the Los Angeles area, it was necessary to have some assurance that it reasonably represented seasonal variations of rainfall in that area with an adequate degree of accuracy. The record was divided into two sections, the first section being the 74 seasons from 1877-78 to 1950-51, during which actual rainfall records were available in the Los Angeles area, and the second being the 108 seasons from 1769-70 to 1876-77, when historical, and other data were used to develop the annual "index of rainfall." Each section was subjected to four mathematical criteria, and the results indicated, to the writer's satisfaction, that the quality of the record during the first 108 years, while its quality was naturally not quite as high as that during the latter 74 year period, was still very good, and fully acceptable for the purpose of the study. It was therefore felt that results based upon the entire 182 season period could be accepted with a reasonable degree of confidence. This fact—in the opinion of the writer—is a high tribute to Mr. Lynch's work.

A review of the 182 year record indicates that it consists of a number of groups of seasons, or periods, with the average rainfall for a period being less than that of the long-time average, or 100 per cent, followed by a period of seasons during which the average rainfall would be above the long time average. One dry and one wet period, when taken together, constitute a cycle.

For many years not alone in Southern California but throughout the country as a whole, many people have held to the idea that the length of such wet and dry periods of rainfall is controlled by the occurrence of sunspots, and that such periods are of fairly uniform length. There has been much talk of 11, 23 and 35 year periods. There is no indication from the record of the Los Angeles area that any such regularity exists as to length of wet and dry periods. The record commenced in 1769-70, with a wet period which, however, had started some years prior to 1769-70. Beginning with the season 1781-82, and ending with the season 1943-44, six cycles are encountered, each consisting of a dry and a wet period. With the season 1944-45, the Los Angeles area has entered another dry period, of which seven years have now transpired. During the 163 years over which the six complete cycles occurred, the dry periods have ranged in length from 7 to 28 years, with average rainfall during a single dry period varying from 56 to 87 per cent of the long time average. The average length of these six dry periods has been 15.2 years. Wet periods occurring in these six cycles have varied from 8 to 18 years in length, with an average length of 12 years. The average rainfall during a single wet period ranged from 111.0 to 130.7 per cent of the long time mean.

Not every year during a dry period has a rainfall of less than the long-time average. The six dry periods included a total of 91 years, of which 66 had less than average rainfall, and 25 greater than average. Wet periods included 72 years, of which 47 were wet and 25 were dry. The fact that seasonal rainfall varies in this manner in the Los Angeles area and the remainder of Southern California allows certain things pertaining to future rainfall to be forecast with a good degree of probability. Since it frequently occurs that one or more wet years will come during a dry period, and conversely that one or more dry years will occur during a wet period, it is necessary to determine when a wet and when a dry period has commenced. The 182 year record indicates that in every instance where three consecutive wet years, which have an average precipitation in excess of 120 per cent of the long time average, follow a dry year, a wet period has commenced. No such definite rule was found by which to determine the start of a dry period. While each of the six dry periods in the record has started with a series of three or four dry years following a wet year, similar series of three or even four dry years are found towards the latter end of wet periods. The only definite conclusion which may be drawn on this phase is that when such a series of dry years occurs following a wet year, it may or may not indicate the beginning of a dry period, but it does indicate that the wet period then in existence is drawing to a close, and that the beginning of a dry period can be expected within a short period of time.

A second relationship of interest was developed by the writer from this study. It was found that in five out of the six cycles, average rainfall during the first four years of a wet period never varied more than nine per cent from the *average* rainfall for the entire wet period, and averaged within 4½ percent of this average. Similarly, it was found that in five out of the six dry periods, the average rainfall for the first five years of a dry period never differed more than six per cent from the average rainfall for the entire dry period, and averaged within three per cent of the dry period average. It was also further found that—in the case of both wet and dry periods—the wetter or the dryer the period, the shorter was its duration.

With these relationships, it *was* possible, from this 182 year record, to determine when the current dry period had probably commenced, how long it would probably last, and how serious the drought occasioned by it could be expected to be. The present dry period commenced with the season 1944-45, and the average rainfall during its first five years was 77 per cent of the long-time average, which would indicate that the average rainfall for the entire dry period should be close to this percentage figure.

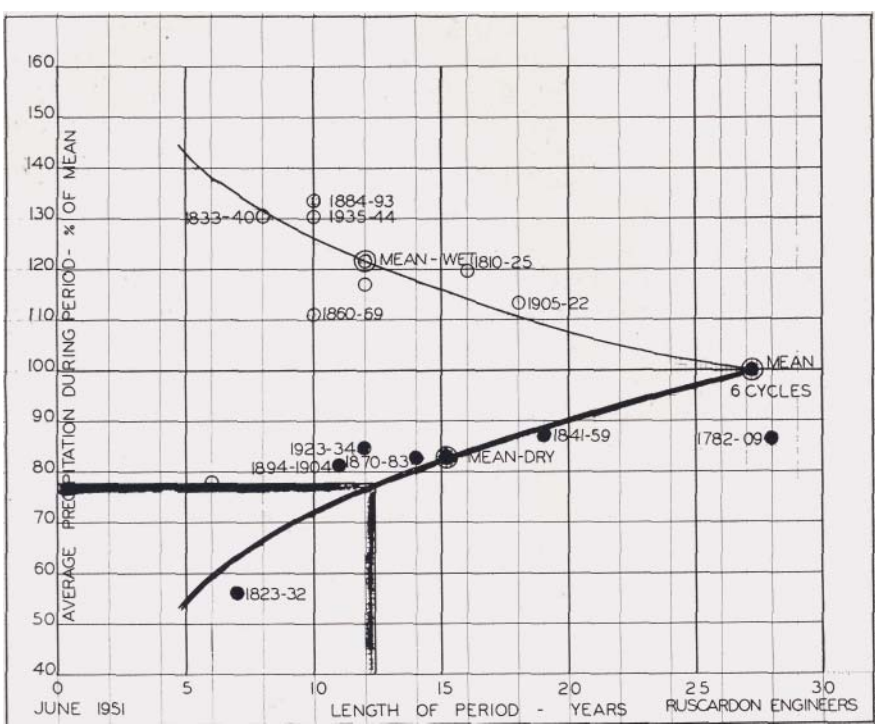
The relation between the average wetness and dryness of these periods and their length indicated that the current dry period should be of the order of 12-13 years in length, although it might be a year less or greater. This would indicate that it will continue until the latter years of the 1950-60 decade.

All facts points to its being a very serious drought. The most serious dry period in the 182 years of record occurred from 1825-26, through 1831-32, when the average rainfall for such seven year period was 56 per cent of the long-time average. The average for the first five of these seven years was 59 per cent of the long-time *average.* The second most serious complete dry period, 13 years in length, commenced with the season

1893-94 and continued through the season 1903-04, with average rainfall during the period being 81 per cent of the long-time average. The rainfall for the first five years of this 11 year period was 80 per cent of the long-time average. This latter dry period is within the memory of many water users in Southern California.

The dry period which commenced with the season 1923-24 and continued until the middle of the 1930-40 decade had an average rainfall which was 85 per cent of the long-time average. During the dry period occurring around the turn of the century, users who depended upon surface sources for their water supply were seriously affected. There was, however, little development of underground water at that time. In the dry years following 1923-24, use of underground sources of supply had increased very markedly, and by the middle 1930's *water* levels in ground-water basins in Southern California had reached unprecedented low elevations. This was not, however, a serious dry period, in fact it was the "third wettest" dry period of the six which have occurred during the past 182 years.

The current dry period, with a probable average rainfall of 77 per cent of the long-time average, should without question be the second driest period encountered since the original Spanish settlement of Southern California. Already water levels in Southern California groundwater basins have dropped during the past seven years in many areas to elevations well below those attained at the end of the dry period which commenced in 1923-24, and the current period is probably only about half finished. This lowering of the groundwater has been occasioned not only by the series of dry years, but has been accentuated by the greatly increased rate of production of water which has occurred in recent years from such basins. Were it not for the availability of imported supplies from the Colorado River and of the possibility of further conservation of local sources in some areas, the situation would have developed an extremely serious aspect by the latter end of the 1950-60 decade.



A further fact might be developed from the 182 year record—the character of rainfall which is to be expected during the coming 1951-52 season. There have been two periods during the past 182 years when seven consecutive years have occurred, during each of which rainfall has been less than the long-time average. The first of these occurred from 1825-26 to 1831-32, and the second during the past seven years, commencing with the season 1944-45. At no time during the past 182 years has any period occurred with more than seven consecutive dry years, although it is entirely within the realm of possibility that an eight year period could occur, and next year might be the eighth year of such a period. The probability is very strong, however, that the coming season will have rainfall which is in excess of the average. Rainfall during the season 1831-32, which followed seven consecutive dry years, was 164 per cent of the average, but in most instances where shorter periods of from four to six years in length occurred, the wet year following such dry seasons has been of the order of 120 to 140 per cent of the average.

The probability of next season being one having a 150 per cent or more rainfall is rather remote. It is far greater that it will have rainfall of from 120 to 135 per cent of the average. In the latter event, streamflow and replenishment of groundwater basins will not be much above normal. Since the soil cover in mountain water sheds and in valley areas, where rainfall has an opportunity through deep percolation to pass downwards and replenish the groundwater, is badly depleted of moisture, much of the rainfall in excess of the average will be retained in the upper soil strata to make up the soil moisture deficiencies that have accrued during the past seven dry years.

When considering forecasts such as those made herein, it must be kept in mind that they are based upon what the gambling fraternity term "past performance". The favorite does not always win the horse race, the football game or the prize fight, but he usually does, and during a large percentage of the time. There is a good probability that these forecasts will prove to have been correct. They certainly furnish a better method of looking into the future than one based solely upon guesswork or upon "Indian Signs".