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BORON IN IRRIGATION WATERS

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INTRODUCTION

The fact that boron occurs naturally as a constituent of irrigation waters in southern California and occasionally in such concentrations as to be injurious to crop plants was discovered through investigations by Kelley and Brown (*11*) [1] in 1926 and 1927. Subsequent investigations by the Bureau of Plant Industry, herein reported, have amplified and confirmed the earlier findings, and have also shown that boron occurs in injurious concentrations in the irrigation and underground waters of other parts of California and in Nevada. The information available at the present time indicates that, aside from several areas in southern California, boron injury occurs in a small area southeast of Bakersfield, in a more extensive area along the west side of the San Joaquin Valley, in an area of Cache Creek on the west side of the Sacramento Valley, and on the Newlands reclamation project in Nevada.

[1] Italic numbers in parentheses refer to Literature Cited, p. 64.

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The present report deals only with the boron areas in southern California. These may be enumerated as follows: (1) The Valley of the Santa Clara River, in Ventura County, where the boron is brought in chiefly by Piru and Sespe Creeks; (2) the Simi Valley, also in Ventura County, where the boron occurs in underground waters that are pumped for irrigation; (3) the San Fernando Valley in Los Angeles County, where the boron occurs in the water brought in through the Los Angeles Aqueduct from Owens River; (4) the vicinity of San Bernardino, where boron occurs in the waters of Arrowhead Hot Springs and in certain wells; and (5) the coastal plain in southern Orange County, where boron occurs in some of the underground waters pumped for irrigation. In addition to these areas, boron injury has been observed in a number of other localities, often involving only a few trees or at most a few acres. Some of these are irrigated from small springs containing toxic quantities of boron. There have been a few cases of injury through the use in irrigation of waste waters containing borax and also a few cases where the source of the boron has not been definitely established.

By way of summarizing the boron situation in southern California, it may be said that in the aggregate the areas where boron injury occurs constitute only a small part of the total irrigated area, and, furthermore, that within these areas the extent of the injury definitely attributable to boron is often not large. For the whole of the territory under consideration, the extent of crop injury due to salts other than those of boron contained in irrigation water is much greater than may be charged to boron alone. In other words, boron is one of the constituents of the salts that occur in the irrigation waters of southern California, and in a few instances this element is found in such concentrations as to be the dominant cause of crop injury. In many other cases crops are injured or the physical condition of the soil is impaired through the accumulation in the soil solution of toxic concentrations of other elements or salts.

Boron has not been generally recognized heretofore as an important element in the complex of salts that occur in irrigation water or in the soil solution. It has not usually been determined in the analyses of irrigation water. It has long been known that the salts of boron are highly toxic to many plants; but only recently has it been recognized that, in low concentrations, boron is beneficial, if not essential, to the growth of certain plants. In connection with the present investigations it has become apparent that, although boron at relatively low concentrations is toxic to plants, at still lower or subtoxic concentrations it is stimulating to many plants. This may be true also for other elements that occur commonly in the salts of irrigation water, but it is not so evident with chlorine, for example, as with boron.

In the present report the point is emphasized that boron injury is directly traceable to the boron carried in irrigation water. It is probably equally true that most of the crop injury caused by salts on irrigated lands is similarly due to the salts carried in the irrigation water. Where the conditions of irrigation are such that the salts, whether of boron or of any other element, carried in solution in the irrigation water, accumulate and remain in the soil solution of the root zone, ultimate crop injury appears to be inevitable. The concentration of salts in irrigation water is seldom, if ever, so high as to be immediately injurious to crop plants. But when irrigation water containing salts is applied to the soil the water is absorbed by the plants or dissipated by evaporation, while the salts remain in the soil solution (*14*).

If ultimate injury is to be avoided, the methods of irrigation and the conditions of drainage must be such that the salts brought to the root zone by the irrigation water can be removed by leaching. This is true for the salts of boron as well as for those of other elements. It is pointed out in the following pages that while for irrigation water the critical concentration with respect to boron may be as low as 0.5 p. p. m.,[2] the critical concentration for the soil solution is probably above 4.0 p. p. m., even for the more sensitive crops. This difference between what is referred to as the critical concentration of irrigation water and of the soil solution implies recognition of the fact that in irrigated lands the concentration of salts in the soil solution of the root zone is much higher than in the water used for irrigation. The magnitude of this difference depends upon the methods of irrigation and the conditions of drainage. Where the natural drainage is good and the quantity of water applied, together with the rainfall, is sufficient to displace occasionally a part of the more concentrated soil solution of the root zone, this difference in concentration may be controlled and crop injury avoided. But if leaching of the root zone does not take place, then the concentration of the soil solution must increase with each successive irrigation until it reaches the limit of solubility of each salt. The soubility of the borate and chloride salts is beyond the limit of tolerance of crop plants, as is also that of the sulphates of sodium and magnesium. Calcium sulphate and calcium carbonate are precipitated from the soil solution before the limit of plant tolerance is reached.

BORON INJURY IN PLANTS

EVIDENCES OF BORON INJURY

The occurrence of boron in the soil solution in concentrations injurious to crops is manifested by specific and characteristic reactions in a number of plants. Two such "indicator" plants are the lemon and the Persian or English walnut. Both these plants are extensively grown in southern California and have been useful in the survey work here reported, in which it has been the aim to distinguish between crop injury caused by boron and that due to other salts in the soil solution or to other adverse conditions. Other species of Citrus, such as the orange and the grapefruit, are only slightly less sensitive to boron than the lemon, but their symptoms of injury are sometimes less definite.

A lemon tree suffering from an increasing concentration of boron in the soil solution shows a characteristic type of yellowing of the leaves. This appears first on the more mature leaves, whose tissue along the margins and between the veins loses its normal green color and becomes yellow, sometimes pale but more often a bright golden yellow. As the symptoms progress, the marginal leaf tissue may die and turn brown, but frequently the leaf falls off before that stage is reached. Typical examples of boron injury to citrus leaves are illustrated in Plate 1. It is frequently observed that the leaves

[2] Parts per million.

falling from boron-injured lemon trees are detached from the petiole, leaving the petiole attached to the stem, but this is not always true.

Normally healthy lemon leaves often remain attached to the tree for 20 to 30 months or longer, so that leaves representing five or six successive cycles of growth are found on the longer branches. When boron injury occurs, the leaves often fall when only 8 to 10 months old, so that it may be hard to find leaves of the fourth or even of the third growth cycle from the tip of the branch. This premature leaf shedding of boron-injured trees results in a marked contrast between them and normal trees with their dense foliage. An example of the thin foliage resulting from boron injury in a lemon tree is shown in Figure 1, in which also may be seen the characteristic discoloration of the leaves and the absence of fruit. This is a 23-

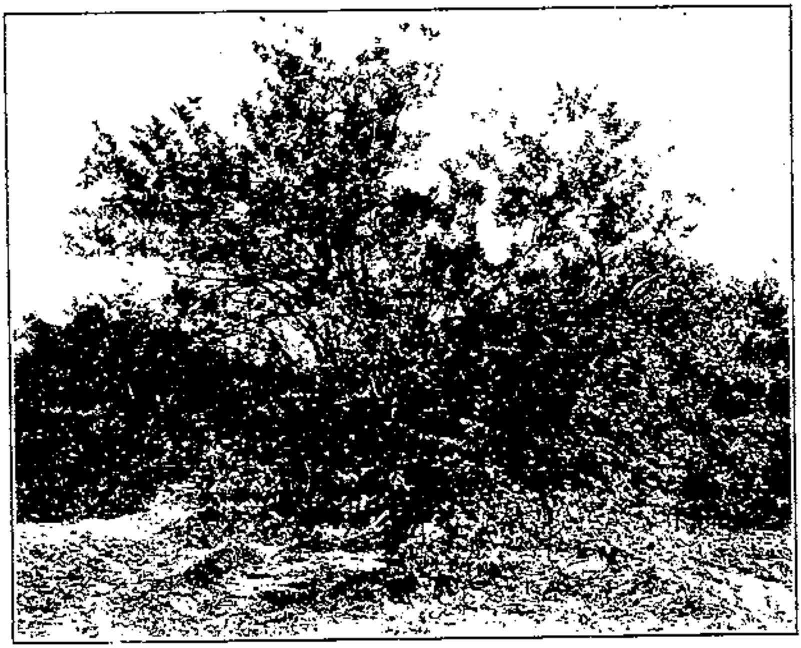
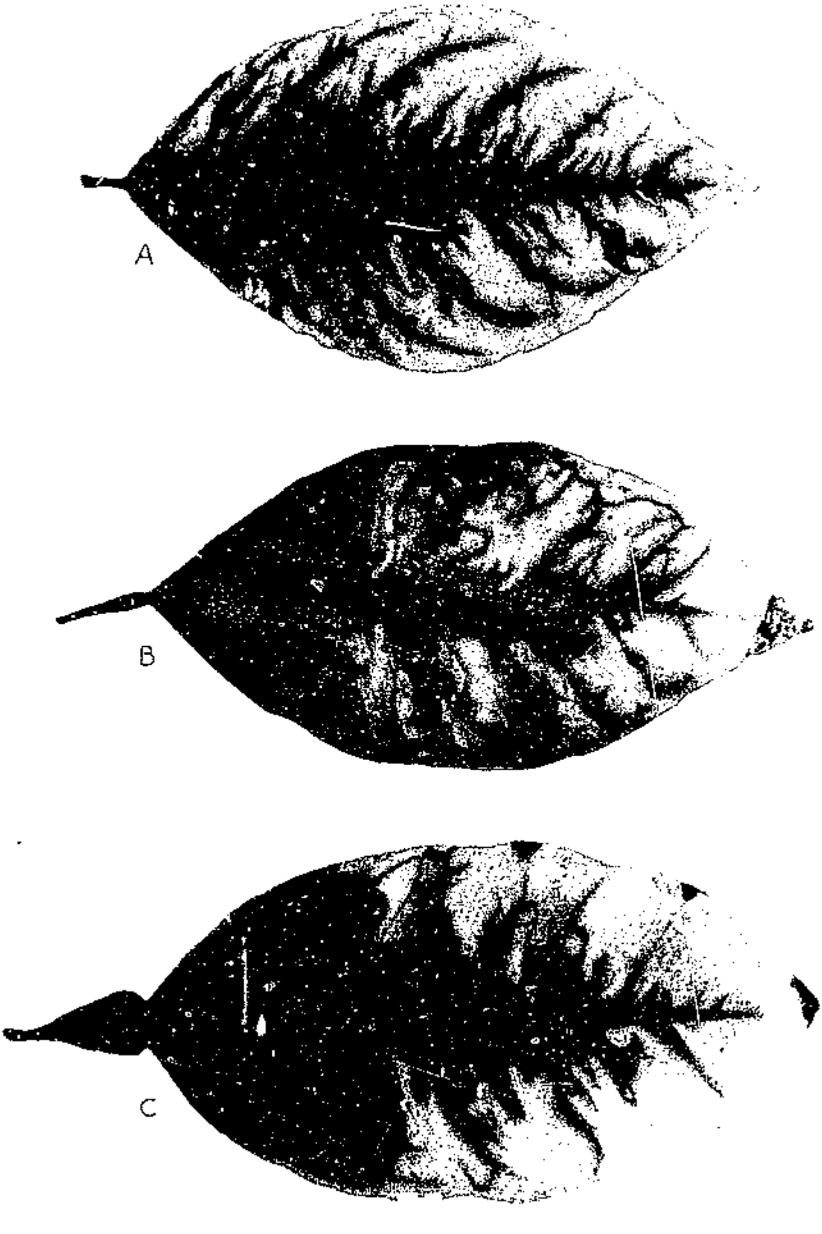


FIGURE 1.—Lemon tree showing typical boron injury characterized by absence of fruit, thin foliage, and yellowing leaves. Photographed by Field in February, 1929

year-old tree in the grove at Rubidoux, near Riverside, Calif. It was making vigorous normal growth prior to 1926, when the first applications of borax were made. In March, 1926, a basin was made around the tree, and with each of the next 10 irrigations 50 grams of borax was dissolved in the irrigation water. These treatments were concluded in May, 1927, when the tree showed symptoms of severe injury. These symptoms were still pronounced when the photograph was made, in February, 1929.

It should be emphasized that the new lemon leaves do not ordinarily show the symptoms of boron injury. It is only after the leaf reaches full size that the discoloration appears. Consequently, a lemon tree may have nearly every remaining leaf discolored in January or February, and have an entirely different appearance a few months



Citrus leaves showing typical severe boron injury. (Natural size. Photographed by Field.) Collected at Fillmore, Calif. A—Lemon leaf, sample L 67, boron content 810 p. p. m. (Collected October 19, 1928, by [illegible] Scofield.) B and C—Leaves of orange and grapefruit from groves irrigated with Sespe Creek water. (Collected March, [illegible], by L. V. Wilcox.)

later when these old leaves have fallen and the tree is covered with new leaves not yet discolored.

It is not uncommon for lemon trees to continue to bear fruit, sometimes abundantly, for several years after the first leaf symptoms of boron injury appear. This is true, of course, only where conditions are such that the boron concentration of the soil solution is increasing very slowly. If the onset of the injury is rapid, the young fruit is dropped as well as the older leaves. This shedding of the young fruit also occurs in the more advanced stages of injury that follow the gradual increase in the concentration of boron in the soil solution.

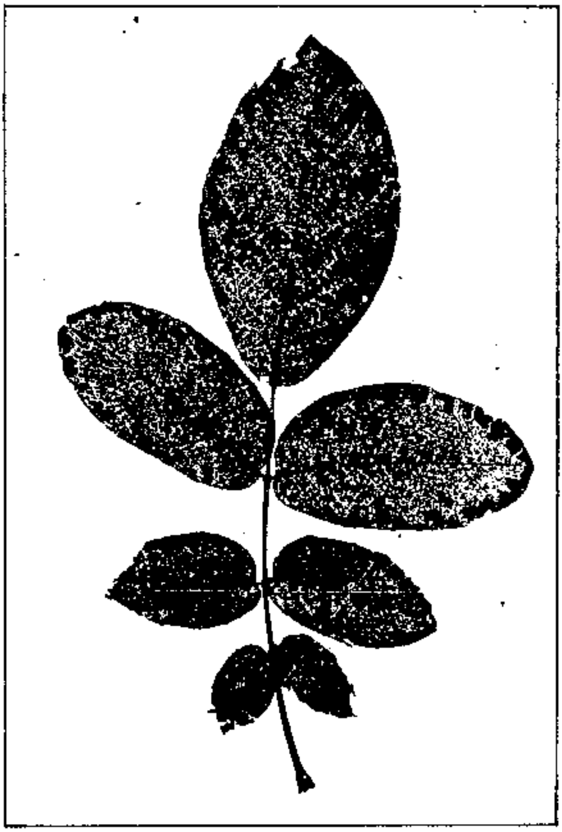


FIGURE 2.—Walnut leaf showing typical severe boron injury. Collected at Santa Susana, Calif.

The Persian walnut develops leaf symptoms of boron injury, that, while very different from those of the lemon tree, are no less unmistakable. As an "indicator" plant the walnut is less useful than the lemon because it is deciduous and consequently leafless for five or six months of the year. Furthermore, its boron symptoms, like those of the lemon, appear only when the leaves approach maturity. Thus it is only during two or three months of the late summer that the walnut serves to indicate the occurrence of excessive concentrations of boron in the soil solution. When such concentration is very high and the consequent injury severe, the characteristic leaf symptoms may appear in mid-July, or earlier, but generally they do not develop until mid-August. These symptoms in the walnut leaf appear at first at the margin of the leaflets, where the leaf tissue dies and turns brown. Then spots of dead brown tissue appear between the veins near the margin. Similar spots develop later between the veins in the direction of the midrib. An example of typical boron injury of a walnut leaf is shown in Figure 2.

These symptoms of boron injury in the leaves of citrus and of walnut are so characteristic and so distinct that they can be distinguished from other leaf abnormalities, such, for example, as result from excessive concentrations of salts other than those of boron in the soil solution. On lemon trees injured by the high salt content of the soil solution the leaves may become chlorotic, or, if the onset of the injury is acute, the marginal leaf tissue may die and turn brown and the leaves fall prematurely. In the walnut, salt injury, particularly that caused by chloride, may be shown by a breaking down of the marginal leaf tissue without the occurrence of the spots of dead tissue between the veins.

The diagnosis of boron injury in the lemon and in the walnut has been confirmed in three ways: (1) It has been shown that the symptoms of boron injury can be induced by adding borax to the soil in contact with the roots of normal healthy trees; (2) it has been demonstrated repeatedly that when these symptoms occur naturally the soil solution contains more than the normal proportion of boron; and (3) the diagnosis is supported by the results of chemical analysis of the leaf material. Normal mature leaves of the lemon and of the walnut contain about 100 p. p. m. of boron based on the dry weight of the material. The proportion is about the same when the leaves show injury from such causes as drought or an excess of salts other than those of boron in the soil solution. In leaf samples showing the characteristic boron injury the boron content is much higher, ranging up to 1,000 or 1,200 p. p. m., and is seldom less than 600 p. p. m.

Many plants other than lemon and walnut show definite and characteristic symptoms of leaf injury when grown in situations where the boron content of the soil solution is above normal. The grapefruit under certain conditions shows leaf symptoms very similar to those described for the lemon, but in other situations the symptoms may be different and due probably to other causes. In the orange it is sometimes difficult to distinguish between slight boron injury and other leaf abnormalities, such as mottle leaf.

Grapes of the European type show characteristic leaf abnormalities as a result of boron injury. Such abnormalities may appear in the young leaves, which become cup shaped because their marginal growth is restricted while the growth of the inner tissue continues, and which remain smaller than normal, with some spotting or breaking down of the marginal tissue. In other plants an excess of boron may produce in the leaves marginal injury, the development of pale or dead spots in the tissue between the veins, reduced size, or premature fading and abscission.

BORON INJURY DUE TO IRRIGATION WATER

In attempting to arrive at a correct understanding of the boron problem in southern California, it became necessary to decide whether the injury was due chiefly to boron as an original constituent of the soil of certain areas or as a constituent received in the fertilizer or the irrigation water. The present indications are that by far the larger part of the injury is due to boron carried in the irrigation water. Such injury was first identified (*11*) as the result of the use for irrigation of waste water from a citrus packing house where borax was used in the wash water for cleaning the fruit. The investigation of the conditions in a number of localities where boron injury has been found has led to the conclusion that, while some cases of injury may be traced to the use of fertilizer containing boron and while others may be due to the occurrence of boron in the soil as the result of natural causes, the great majority of cases are the result of the use of irrigation water in which salts of boron are carried in solution.

Only a few places have been found where the evidence indicated that the natural boron content of the soil was of the character and quantity to be injurious to crops. In these places the area of injury was irregular in outline within the field, with the limits sharply defined, and the boron content of the irrigation water in use was too low to be injurious. These boron localities so far discovered have been small, seldom more than an acre in extent, and it is assumed that they represent the outlets of ancient springs or fumaroles through which boron waters or gases reached the surface and were precipitated in the soil. A number of boron minerals occur in the rocks of southern California which have doubtless contributed to the formation of the soil, but many of these yield so slowly to the processes of decomposition by weathering that the proportion of water-soluble boron from this source must be very small.

In view of certain experiences reported from the Eastern States, during 1917 and 1918, where crop injury was traced to the use of chemical fertilizers containing boron as an impurity, it was to be expected that similar instances would be found in California. It is believed that a few examples of such injury have been found, but the evidence is not very clear. In a few orchards where boron injury has been found in certain rows and where this injury could not be traced to the irrigation water, it has seemed probable that the trouble may have been due to contaminated fertilizer. This belief has been supported by the knowledge that borax is a constituent of some of the compounds used to kill the larvae of flies that breed in compost heaps and as a disinfectant in dairy barns or corrals from which organic fertilizers are obtained for orchards. It is possible also that boron, carried as an impurity in chemical fertilizers, may have contributed to or accentuated the injury ascribed to the boron of irrigation water in some orchards; but the present conclusion is that boron contained in fertilizers, either organic or chemical, has been a very small factor in the boron problem of southern California.

With few exceptions it has been found that boron injury in fields or orchards could be traced to the irrigation supply and that the area of injury is conterminous with the use of that water. The contrast in the appearance of adjacent groves of citrus fruits irrigated with different water supplies is often very striking. And the high correlation that is found between the boron content of a water supply and that of the leaves of the trees irrigated with the water is further convincing evidence.

SOURCES OF BORON CONTAMINATION

Prior to the discovery that boron was causing injury to certain crops in southern California, very few boron determinations had been made on the irrigation waters of that region, and there was very little information with respect to their boron content. It was known that boron compounds and minerals occurred in several localities and that borax and boric acid had been produced in commercial quantities from these deposits for more than half a century. Borate salts had been reported as occurring in Clear Lake, Mono Lake, and Lake Elsinore; numerous borax springs had been reported; the brines of such desert lake beds as Owens Lake, Searles Lake, and the flats of Death Valley were recognized as sources of boron; extensive deposits of boron minerals, such as colemanite and kernite, had been exploited; and boron had been identified in a number of geysers, hot springs, and mud volcanoes in the State. But until 1925 no direct connection had been established between these boron deposits and crop injury.

In the investigations that have followed the discovery of this connection it has been found that boron is present in measurable quantities in all of the natural waters that have been examined, except in waters coming directly from high mountains and derived chiefly from melting snow. In other words, boron appears to be a normal constituent of the salts found in the percolating waters of southern California. It occurs usually in low concentrations of the order of 0.1 to 0.3 p. p. m., which is equivalent approximately to a solution of 2.5 to 7.5 pounds of borax in an acre-foot of water. In situations where crops showed boron injury the boron content of the irrigation water was found to be much higher, frequently more than 1 p. p. m. and occasionally as much as 7 or 8 p. p. m.

Where injurious quantities of boron have been found in an irrigation supply an attempt has been made to determine its source. It has been assumed that, when the concentration is as low as 0.3 p. p. m. or less, it may represent the gradual dissolution, through weathering, of highly resistant boron minerals widely distributed through the soil. The higher concentrations were thought to indicate the existence within the drainage basin of deposits of more soluble boron minerals or of springs or other outlets through which boron in solution was derived. A number of such investigations, reported in more detail in later sections of this bulletin, have shown that this is true. If the water of a stream is found to contain an excessive proportion of boron, it is usually possible to trace this excess to its source or sources by testing samples of each tributary. It is ordinarily found that one or more of these contributes most of the boron. Similarly, when an irrigation supply is drawn from a number of wells, if the boron content of a composite sample is high, the well or wells at fault may be identified. These surveys of a number of drainage basins have made it evident that the sources of boron contamination are localized and usually of small extent.

These sources appear to fall into three groups: (1) Those in which the boron is derived by the erosion and dissolution of exposed outcrops of soluble boron minerals, such as the colemanite deposits of Lockwood Valley on the headwaters of Piru Creek; (2) those in which the boron is derived from subterranean deposits of soluble boron minerals from which it reaches the surface, either through springs or wells; and (3) those in which the boron, in the form of a gas usually mixed with superheated steam, reaches the surface through fumaroles or, coming in contact with percolating water, emerges as hot springs or geysers.

This classification of sources, while convenient for certain purposes, is probably not fundamentally important. Boric acid is known to occur commonly along with superheated steam in magmatic gases. When such hot gases come in contact with surface or percolating waters and are condensed, the boric acid, reacting with dissolved mineral salts, may remain in solution or may be precipitated. Whether the borate salts remain in solution or are first precipitated and later redissolved, or whether these reactions take place at the surface of the ground or at some point below the surface is not a matter of concern in the present connection. Nor is it of material importance whether these emanations and reactions are going on now or took place long ago. The point to be emphasized is that the borates now found in irrigation water probably originated in magmatic vapors resulting from volcanic activity. Experience in tracing these salts as they occur in stream and well waters leads the writers to conclude that their sources are usually localized in small areas and that it is often possible to segregate these waters from the main supply. Fortunately, many of the larger sources of boron, including the principal deposits of the more soluble boron minerals, occur in the desert regions of southern California and southern Nevada and not in the drainage basis from which the more important irrigation supplies are drawn.

CRITICAL CONCENTRATION OF BORON IN WATER AND IN THE SOIL SOLUTION

In the survey of conditions where boron injury has been found in orchards of lemons and walnuts in southern California, an attempt has been made to determine the critical concentration of boron in irrigation water and in the soil solution. By critical concentration is meant that concentration below which injury has not resulted in reduced yield and above which it has. It will be evident that several difficulties lie in the way of determining this critical concentration with respect to either the irrigation water used on a particular orchard or the soil solution in the root zone of that orchard. First, as regards the irrigation water, the fact that its boron content may change from time to time must be recognized. Samples taken once a week for a year or more from certain streams show that the boron content of a stream may range in a year from 0.6 to 3.6 p. p. m. Since the past irrigation history of an orchard or the past conditions of the stream are not known accurately, the average boron content of the water applied can not be very closely determined. Even when it is found that in the case of a certain grove irrigated from a certain well the boron content of that well has continued approximately constant for the past year, there may still be uncertainty as to the influence of other factors. For example, the boron content of the well may have been different in past years, or other water may have been used in the past, or in one situation the soil may have been leached occasionally by winter rains and not so leached in another case, or the quantity of irrigation water applied may have resulted in leaching the root zone in one orchard and not in another. These points are brought out to indicate the nature of the uncertainties that attend the present attempt to establish the critical concentration of boron in irrigation water and in the soil solution.

In the course of the present survey, the writers have examined many orchards of lemons and walnuts; they have determined the boron content of more than 1,000 samples of water used to irrigate these orchards and the boron content of more than 100 leaf samples; and in addition they have observed the results of growing lemon seedlings in water cultures containing known quantities of boron and the results of applying definite quantities of boron as borax to normal lemon trees growing in soil. From these observations it has been concluded that for lemons and walnuts the critical concentration of irrigation water lies between 0.5 and 1.0 p. p. m. of boron. With respect to the soil solution, it is believed that the critical concentration is between 4 and 8 p. p. m. of the solution, not of the soil.

It may be helpful to an understanding of the quantitative relations involved to give some other expressions of the proportions indicated. The ratio of the weight of elemental boron to that of boric acid (crystalline H_3BO_3) is as 1 to 5.72 and to that of borax ($Na_2B_4O_7.10H_2O$) 1 to 8.81. The weight of an acre-foot of water is approximately 2,720,000 pounds. Thus, if a sample of water contains 0.5 p. p. m. of boron, it is equivalent to 7.78 pounds of boric acid, or 11.98 pounds of borax, per acre-foot. From this it will be seen that when it is customary to apply 2 acre-feet of irrigation water to an acre of land each year, the corresponding application of borax is approximately 24 pounds per acre when the water contains 0.5 p. p. m. of boron.

It has been reported in connection with experiments in the eastern part of the United States that where borax has been applied in fertilizer mixtures its use at the rate of 20 pounds[3] per acre or more has caused measurable injury and reduced yields with a number of crops (*5, 16*). It is apparent that a given quantity of boron when applied in solution in irrigation water and thus distributed uniformly through the soil solution of the root zone is likely to cause less injury than when applied in a chemical fertilizer from which it might be dissolved by the moisture of the surface soil to form a solution of much higher concentration in the upper part of the root zone.

It is to be assumed that the boron concentration of the soil solution in an orchard would become much higher than that of the water with which the orchard is irrigated. It is not easy to obtain definite information as to these relative concentrations because of the difficulty of obtaining representative samples of the soil solution in sufficient quantity for boron determinations. Furthermore, the concentration of the soil solution is probably extremely variable, even if that of the irrigation water continues uniform. The soil solution is diluted by each irrigation or by rainfall, and becomes more concentrated as water is absorbed by the plant roots or lost by evaporation. With certain soils and certain irrigation programs there is doubtless some leaching of the root zone with the consequent removal of boron, while in other situations, where the subsoil conditions are such that no leaching occurs or where the quantity of irrigation water applied is merely sufficient to replenish the capacity of the root zone, it is probable that the boron concentration of the soil solution increases progressively with each irrigation. Kelley and Brown (*11, p. 455*) reported on two samples of soil solution, obtained by the displacement method, in which they found 6.0 and 6.5 p. p. m. of boron. These soils were from lemon groves where the trees showed definite injury and where the investigators found 1 p. p. m. of boron in the irrigation water.

In giving the present opinion as to the critical boron concentration in irrigation water and soil solution the writers have assumed a ratio between them of 1 to 8. In other words, with respect to boron the soil solution may be expected to contain eight times as much as the irrigation supply. It will be understood that in setting these limits for critical concentration the writers have taken into account various factors of the environment, so that the limits may appear to be some-

[3] In these fertilizer experiments the quantities of borax applied were usually expressed as anhydrous borax, of which 20 pounds is equivalent to 37.8 pounds of crystalline borax.

times too high and sometimes too low. Of these factors, time is, of course, an important one. If, for example, irrigation water containing 0.6 p. p. m. of boron be applied to a tract of new land, it might take 10 years of irrigation to accumulate enough boron in the soil solution to be injurious to the more sensitive crops. Indeed, if the soil conditions were favorable and enough water were applied occasionally to leach the root zone, crop injury might be postponed indefinitely. Wherever it is possible to replace the more concentrated soil solution with a more dilute solution such as irrigation water or, better still, rain water, there should be an improvement in conditions.

In presenting their views as to these critical concentrations of boron the writers have indicated merely what conditions they have found in orchards of lemons and walnuts in southern California where evidences of boron injury were apparent. They do not wish to condemn as unfit for use every water supply that contains more than 0.5 p. p. m. of boron, any more than they would condemn as too salty any supply that contained more than 175 p. p. m. of chloride. But they do believe that when irrigation water contains more than these proportions of either element it should be regarded as possibly injurious to such sensitive crops as lemons and walnuts in situations where the root zone can not be leached occasionally.

In this connection it is desirable to emphasize two points. The first is that, in both lemons and walnuts, the writers find that definite symptoms of leaf injury, including high boron content and premature leaf shedding, often appear well in advance of measurable reduction of crop yields. This appears to be particularly true where conditions are such that the boron concentration of the soil solution is increasing very gradually from year to year. In fact, there is some evidence to support the view that, with a slowly increasing boron concentration, the first evidences of leaf injury may be accompanied by increased yields. On the other hand, there appears to be little doubt that, in the more advanced stages of injury, yields are severely depressed. Trees of both species may survive for a long time after boron injury has become so severe that crop production has practically ceased. The second point is that the critical boron concentrations given by the writers for lemons and walnuts should not be taken as applying to other crops. It has been noted that the orange and possibly the grapefruit are less sensitive than the lemon, and it has been found that a number of the deciduous fruit trees appear to be less sensitive than the walnut. Wide differences of tolerance have been observed among the field and garden crops. In fact, some of these appear to thrive on boron concentrations that are injurious or even fatal to others.

IRRIGATION METHODS AND CONDITIONS INFLUENCING BORON INJURY

In view of the findings that boron injury to crops in southern California is due chiefly to boron compounds dissolved in certain irrigation waters, it seems proper to discuss the relation of irrigation methods and of soil and climatic conditions to the onset of injury. It has been found, for example, that one lemon grove irrigated from a certain water supply may show severe injury throughout, whereas an adjacent grove irrigated from another water supply may show no evidence of injury. On the other hand, differences in degree of injury have been found in the same grove that are apparently due to differences in the character of the soil. In some groves the injury, as evidenced by leaf discoloration and premature shedding, is limited to certain areas, although the analyses of leaf samples from trees that are apparently uninjured show that the boron content is abnormally high. On the other hand, there are adjacent groves of approximately the same age and of the same variety of lemon, apparently on the same rootstock, and known to have been irrigated with the same water supply, in one of which the symptoms of boron injury may be very pronounced and scarcely apparent in the other, although leaf analyses may show that the boron content is above normal in the uninjured trees. Such observations lead to the conclusion that differences of soil type or differences in the methods of irrigation or of orchard management, including fertilization, may influence the degree of injury from the same quantity of boron in the irrigation water, particularly if that quantity is near the critical concentration.

With respect to soil type, it is manifestly essential to consider not only the texture of the surface soil but also that of the subsoil, even below the root zone. The texture of the horizons of the subsoil influences the downward movement of irrigation water and consequently the possibility of leaching the root zone. When the subsoil conditions are such that the root zone may be leached occasionally, either by rainfall or by heavy irrigation, it should be possible to prevent the accumulation of harmful concentrations of boron in the soil solution of that zone. On the other hand, where subsoil conditions are such that it is not possible to leach the root zone it seems inevitable that the boron dissolved in the irrigation water should accumulate in the soil solution until harmful concentrations are reached.

In one lemon orchard, where there were severe symptoms of boron injury and where the surface soil was of sandy loam, it was found that the subsoil at 4 to 6 feet below the surface was of compact silt, practically impervious to the movement of water. This thick layer of silt appeared to prevent or at least to retard the downward movement of water so effectively that the progressive concentration of boron in the soil solution could not be prevented by leaching the root zone. In other situations where the irrigation water contained substantially the same quantity of boron but where more permeable subsoils permitted root-zone leaching, the boron injury has been found to be much less severe. It should be emphasized in this connection that if root-zone leaching is to be accomplished, the quantity of water applied to the soil must be somewhat in excess of that required for the crop and for the unavoidable losses by surface evaporation. If the total quantity of water applied is less than may be used by the plants or evaporated from the soil, leaching may not occur even where the subsoil conditions are favorable.

There is some evidence to support the view that, with a given concentration of boron in the irrigation water and no root-zone leaching, the symptoms of boron injury will develop more rapidly in plants grown on a sandy soil than in those grown on very heavy soil. A given mass of sandy soil holds less water than the same mass of a finer soil, such as loam or clay, and consequently a given quantity of boron added to the lighter soil would result in a higher concentration of the soil solution. Also, there may be some absorption of boron by the soil from the soil solution, and this absorption may be greater where the clay content of the soil is higher. It has been found by experiment that, when a given quantity of boron is added to the soil solution and the solution is subsequently displaced by leaching, a smaller proportion of the boron is recovered from the clay soil than from the sandy soil. The nature of the reactions involved in this apparent absorption of boron has not been investigated.

While it is here indicated that a method of irrigation that results in some leaching of the root zone may be expected to diminish the intensity or retard the onset of boron injury resulting from the use of contaminated irrigation water, it is not intended to imply that orchards should be irrigated more frequently or more copiously throughout the year. The proper control of the supply of soil moisture during the season of active plant growth is closely related to the more general problem of orchard management and to the health and productivity of the trees. If conditions make it desirable to leach the root zone from time to time, in order to diminish the concentration of borates or other salts in the soil solution, it would seem advisable that this leaching be done during the dormant period rather than by more frequent or more copious irrigations during the growing season.

It is a matter of common observation that the evidences of boron injury are more striking in lemon and walnut trees that are not well cared for than in those groves where good cultural methods are followed. It is possible that such differences may be due partly to the more vigorous growth of the trees that are better cared for and partly to the specific effect of some constituent of the fertilizer. It is frequently suggested that some substance may be found in a fertilizer to counteract the injurious effect of boron, either by precipitating it from the soil solution, retarding its absorption by the plant roots, or neutralizing its effect in the plant itself. The evidence at present available does not warrant the hope of such a discovery. There can be no doubt that where the boron content of the water supply is at or near the critical concentration, trees that are well fertilized and cared for show less evidence of boron injury and produce very much better yields than trees that are neglected. But these differences can not be traced definitely to any one factor, either of cultivation, irrigation, pest control, or fertilization. It might be added that no practical method has yet been found to remove from irrigation water the small quantity of boron that is sufficient to cause crop injury.

SEGREGATION OF BORON CONTAMINATION

It has been pointed out in a previous section on the sources of boron contamination that where the boron content of an irrigation supply is injurious it is usually found to be derived from a single source. This makes it possible, in some cases at least, to avoid further crop injury by cutting the source off from the general supply. This course is indicated where the boron content of the water from a spring or a well is so high as to contaminate seriously the water with which it is mixed. In order to deal intelligently with the boron problem in any given water supply it is necessary to learn the facts by a series of analyses. Where the water is obtained from a natural stream each tributary must be sampled to determine those that contribute the boron. A series of samples along such tributaries should then reveal the source or sources of the boron. When the source is found, the problem is one of withholding or diverting the contaminated water from the main supply. Fortunately these primary sources of the excess boron in natural streams often contribute only small quantites of water with a high content of boron. This is illustrated by the O'Banion Spring on Parida Creek (Table 12), which contained 17.3 p. p. m. of boron; the hot springs on Sespe Creek (Table 8) with 7.0 p. p. m., and an artesian well near the heading of the Los Angeles Aqueduct (Table 16) that contained 9.3 p. p. m. of boron. The elimination from the main supply of such contributions as these should reduce correspondingly the boron content of that supply.

When the irrigation supply is obtained from wells, either of two sets of conditions may exist. In one case the water from several wells may be blended into one supply. If it is found that the boron content of this supply is at or above the critical concentration, the well or wells contributing the high boron water can be eliminated.

On the other hand, there are situations in which the water from each well is used to irrigate one or more contiguous orchards. If it is found that boron injury is produced by water from one of the wells in such a group and not by that from others it may be possible to overcome the difficulty by blending the waters from several wells and thus diluting the boron content of the whole supply to a point below the critical concentration.

DIVERSITY OF BORON TOLERANCE OF CROP PLANTS

The earlier observations on the effects of boron in southern California indicated that the cultivated species of Citrus and the Persian walnut were more susceptible to injury than any other of the more common crop species. In fact it was thought for some time that citrus and walnut were the only crops injured by the concentrations of boron found in California soils. It was found that many of the field and truck crops showed no symptoms of leaf injury or evidence of reduced growth when they were planted on land where the injury to citrus was severe. Notwithstanding these observations in California, it was known that in the eastern United States there had been reports of injury to a number of field and truck crops from the use of chemical fertilizers containing small quantities of boron.

With the progress of the survey of the boron areas it has become evident that there are (1) a number of species of crop plants only slightly more tolerant than citrus and walnut to boron, (2) numerous species that are apparently not seriously injured by concentrations of boron in the soil solution two or three times as high as the concentrations known to be injurious to citrus, and (3) other species that seem not only to tolerate relatively high concentrations of boron, but actually to thrive better on concentrations that are fatal to citrus and other less tolerant crops and injurious to crops of the second group.

It has been shown by several investigators (*1, 4, 10, 17*), working with different plants, that boron is essential to plant growth. The quantity required is small, often much less than 1 p. p. m. of the culture solution. In fact, the minimum requirement of boron with many plants is so low that it may be met by the boron contained as impurities in the chemicals used in the culture solutions or in the containers used for the culture experiments. In order to demonstrate that boron is essential to plant growth it has been necessary for plant physiologists to use for their control cultures chemicals that have been carefully purified and containers that would not yield boron to the culture solutions.

In their investigation of the boron problem the writers have accepted as a fact the hypothesis that boron is essential to plant growth and have not sought to determine the minimum quantities necessary to support normal growth in the various species. They have been concerned rather with the upper limits of tolerance to boron of crop species generally grown in the boron areas. Such information has been sought partly by field observations and partly by controlled experiments with culture solutions containing known concentrations of boron. These investigations are as yet incomplete and can not now be reported. It is possible, however, to say, as has been indicated above, that some species have a much higher critical concentration than others.

As stated in an earlier section of this bulletin, the writers believe that the critical concentration of boron in the soil solution lies between 4 and 8 p. p. m. for citrus and walnuts. They find that European varieties of grapes, while slightly more tolerant than citrus, are measurably injured in this same range. Such fruit trees as apples, apricots, avocados, peaches, pears, plums, and persimmons make better growth in low boron concentration than do grapes. The olive, on the other hand, appears to tolerate high concentrations.

Of the garden or truck crops that have been under observation it has been found that navy beans and sweetpotatoes have a low tolerance. Lima beans and pumpkins are somewhat more tolerant, and peppers still more so. Asparagus, cabbage, and tomato, while showing some growth depression, are not seriously injured by concentrations up to 20 p. p. m. in culture solution, and there is some evidence that both cabbage and tomato are stimulated by concentrations of about 5 p. p. m.

The cereal crops corn, milo, barley, and wheat show very slight depression of growth in concentrations up to 15 or 20 p. p. m. Corn appears to be the most sensitive of those named and develops symptoms of leaf injury in the higher concentrations. Cotton of both the upland and Egyptian types seems somewhat more tolerant than the cereals named and is apparently stimulated by quantities of boron that would be injurious to grapes and a number of deciduous fruit trees.

Fortunately, from the standpoint of utilizing boron waters, alfalfa is highly tolerant. Its critical concentration of boron is not yet known. So far no example has been found in the field of boron injury to alfalfa. The character and diversity of the vegetation that is supported around boron springs and along streams of high boron content confirm the impression that, while some species are very sensitive, many others are not. It seems highly probable that, as our knowledge of the critical concentrations of species is extended, it will be possible to utilize effectively, by the choice of resistant crops, most of the water that now causes trouble because of its high boron content.

OCCURRENCE OF BORON IN PLANTS

BORON AS A NATURAL CONSTITUENT OF PLANTS

In connection with this survey of boron conditions in southern California, it has been found that boron occurs in measurable quantities in the leaves of all the plants that have been examined; but it was found also that boron is a constituent of the salts in all the irrigation waters and that irrigation water is used on most of the cultivated plants. In view of these findings it became a matter of interest to learn the boron content of similar plants grown in the eastern part of the United States under rainfall conditions. For this purpose a number of leaf samples of Citrus species were obtained through the courtesy of T. Ralph Robinson, from several places in Florida, from Silverhill, Ala., and from Weslaco, Tex. In addition, Mr. Robinson collected the fruits of string beans, eggplants, peppers, and tomatoes from Terra Ceia, Fla. Leaves of the post oak, of sassafras, and of wild grape were collected at the end of August in Maryland. The boron content of these samples was determined at Washington, D. C., by the same analytical methods as are used at the laboratory in California.

The Florida leaf samples, of which there were 17, included sweet orange, sour orange, sweet lemon, rough lemon, grapefruit, and lime. The mean boron content was 89 p. p. m., ranging from 31 to 161. The samples from Silverhill, Ala., three Satsumas and one citrangequat, had a mean boron content of 80 p. p. m., and ranged from 55 to 132. There were six samples from Weslaco, Tex., in the valley of the lower Rio Grande. Their mean boron content was 124 p. p. m., ranging from 61 to 177. These included orange, grapefruit, and lemon. Some of the trees from which the Weslaco samples were taken were said to show symptoms of salt injury, and these trees had been irrigated, whereas those in Florida and Alabama had not.

In addition to leaf samples from Florida, reported above, there were eight samples of leaves from trees of sour orange and rough lemon that had been treated some four or five months previously with borax or borate minerals. When these leaf samples were taken they showed the characteristic symptoms of boron injury. For these eight samples the mean boron content was 712 p. p. m., ranging from 325 to 1,162.

The samples of vegetables from Terra Ceia, Fla., had a mean boron content of 20 p. p. m., ranging from 16 to 25. The leaves of post oak from Maryland contained 35 p. p. m., the sassafras leaves, 59 p. p. m. and the wild-grape leaves, 51 p. p. m.

These analyses show that the leaves of citrus trees from Florida, Alabama, and Texas contain practically as much boron as is found in citrus leaves in those areas of California where the boron content of the irrigation water is well below the critical concentration. Furthermore, the samples of vegetables from Florida and the leaves of native trees in Maryland showed measurable quantities of boron. From these results it may be assumed that boron is absorbed normally by plants even when it occurs in very small quantities in the soil solution.

The fact that boron is a normal constituent of plant material was established by Agulhon (*1*), on the basis of the analyses of samples of 27 species, representing 18 plant families. These ranged from algae, collected in the English Channel, to olives, from Corsica.

Agulhon made his boron determinations on the ashed plant material and reported his results as boric acid, as percentage both of the ash and of the original dry weight of the sample. His material was various, including the leaves, stems, and bark of trees, the seeds of cereals, and parts of whole plants of seaweeds. He found the boron content as low as 7 p. p. m. in the young stems of fir trees and as high as 168 p. p. m. in Fucus from the English Channel.

The boron content of a number of plant products, such as dried fruits, cacao beans, and coffee, has also been reported quantitatively by Dodd (*6, 7*), who found this element occurring as a normal constituent in measurable quantities in a wide variety of food materials from many sources.

BORON CONTENT OF CITRUS AND WALNUT LEAVES

It has been noted that the leaves of citrus and walnut trees show characteristic symptoms when the boron content of the soil solution is above a certain limit, referred to as the critical concentration. While these symptoms are fairly distinct, it must be recognized that other types of leaf injury, due to other causes, also occur. It is not always possible to distinguish definitely by appearance alone between the type of leaf injury caused by excessive concentrations of boron and those due to other causes. The fact that high boron content of the soil solution is accompanied by a corresponding increase in the boron content of the leaves of citrus and walnut trees makes it possible to confirm by leaf analysis the evidence of boron injury.

In the course of the present survey the writers have collected and analyzed a number of leaf samples of lemon, orange, grapefruit, and walnut trees, from areas where the boron content of the soil solution was known to be high and from other areas where it was known to be low. The characteristic leaf symptoms have been noted in each case. With very few exceptions the analytical results have confirmed the field diagnosis. It should be noted that there have been exceptions. In all four species the symptoms were sometimes rather doubtful, and the boron content either lower or higher than the apparent degree of injury would indicate.

One cause of these differences in boron content may lie in the age of the leaves collected. It has been observed that the symptoms of boron injury rarely occur on young leaves of citrus and walnut but become evident as the leaves approach maturity. In collecting leaf samples of citrus it has been customary to select leaves representing the third or if possible the fourth cycle of growth back of the growing point. This is not always possible, because, when boron injury is severe the leaves of the older growth cycles may fall, leaving only the older leaves of the second cycle available. It has been noted also that in citrus the symptoms of boron injury are sometimes more pronounced on the south or southwest side of the tree than on the north side. It has been assumed that this difference is due to the greater intensity of light and consequently to greater transpiration. Such a condition was observed in a lemon grove near Santa Paula. A sample of leaves from the south side of a row of trees collected February 20, 1929, contained 330 p. p. m. of boron based on dry weight, while a similar sample collected at the same time from the north side of the trees contained 178 p. p. m.

The walnut tree sheds all its leaves each autumn. The leaves during the growing season usually show the first symptoms of boron injury about the middle of August. As the season advances the symptoms become more pronounced, and in cases of severe boron injury the leaves begin to fall prematurely. The analytical results

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given in Table 1 show that in walnut leaves the boron content increases as the leaves approach maturity. Three sets of leaf samples were collected late in August and again from the same trees in mid-October. The boron content of the more mature leaves was nearly 50 per cent higher than that of the leaves collected late in August, soon after the boron symptoms first appeared.

TABLE 1.—*Increase in boron content of walnut leaves with advance of season*

Sample No.	Date	Locality	Boron content	Increase
	1928		*P. p. m.*[1]	*P. p. m.*[1]
56	Aug. 29	Near Simi	432	
45	Oct. 9	do	682	250
67	Aug. 30	Near Santa Susana	555	
71	Oct. 22	do	810	255
32	Aug. 29	Near Fillmore	755	
42	Oct. 6	do	1,088	333

[1] Parts per million.

In the course of the survey of boron areas in southern California, 127 leaf samples of lemon, orange, grapefruit, and walnut trees have been collected and analyzed for boron. As each sample was taken it was classified as uninjured, doubtful, or injured, with respect to boron symptoms. The analytical results are given in Table 2. From these results it may be seen that, while the boron content of leaves classed as uninjured may range up to 300 p. p. m., the lowest boron content of leaves classed as injured was 460 p. p. m. Of the whole series, 15 samples were classed as doubtful, and in these the boron content ranged from 302 to 522 p. p. m.

TABLE 2.—*Boron content of citrus and walnut leaves in southern California classified with reference to injurious effect, expressed as parts per million based on the dry weight of the material*

Condition of leaves and kind of tree	Samples	Boron content		
		Lowest	Highest	Mean
	Number	*P. p. m.*	*P. p. m.*	*P. p. m.*
Uninjured:				
Lemon	30	38	285	157
Orange	5	35	162	92
Grapefruit	7	128	295	231
Walnut	19	108	292	198
Doubtful:				
Lemon	6	302	380	340
Orange	3	433	522	490
Grapefruit	1			468
Walnut	5	305	378	336
Injured:				
Lemon	20	460	892	646
Orange	9	568	1,062	708
Grapefruit	6	717	1,522	974
Walnut	16	432	1,088	686

In these field studies it has not been possible to establish a close correlation between the boron content of the leaves and that of the irrigation supply if the latter has been within or above the limits of critical concentration. In other words, the boron content of leaves may be quite as high when the boron content of the irrigation water is between 0.5 and 1.0 p. p. m. as when it ranges from 1 to 2 p. p. m.

Such difficulties rarely occur in comparisons between leaves produced with waters the boron content of which is well below the critical concentration on the one hand and those produced with waters the boron content of which is within or above those limits on the other. It has been possible in several localities to obtain leaf samples both from adjacent citrus and from adjacent walnut groves one of which had been irrigated with water having a boron content below the critical concentration and the other with water having a boron content above 0.5 p. p. m. In one such case the boron content of the leaves of lemon trees was 68 p. p. m. in the uninjured grove and 638 p. p. m. in the injured grove. In another case the leaves of walnut trees from the uninjured grove contained 110 p. p. m. of boron, while those from the injured grove contained 678 p. p. m.

While the evidence obtained from these field studies overwhelmingly supports the view that boron injury is due to boron carried in the irrigation water, certain exceptions must be noted. In two places—one in the Coachella Valley and one on the Yuma Mesa—severe boron injury was found in restricted areas in grapefruit groves that were being irrigated with water containing very little boron. In both these cases the injury appeared to be due to local boron contamination. It was found that within each area the boron content of the soil solution was high. In neither case was it possible to determine the source of the boron, but it was manifestly not derived from the present irrigation supply.

Several other cases have been found where trees in limited areas showed symptoms of boron injury but where the evidence indicated that the boron had been applied with manure or fertilizer. Another exceptional case was that of a lemon grove in Santa Barbara County, irrigated with water containing 0.8 p. p. m. of boron, in which the boron content of the leaves was abnormally low. The trees in this grove, although well cared for, were not thrifty or highly productive. The leaf symptoms were abnormal, and the boron content of three leaf samples was 68, 70, and 88 p. p. m., respectively. This is the only example so far found where the excessive boron content of irrigation water was not accompanied by excessive boron content in lemon leaves. This water had been used on the grove for three years, and it is possible that the boron content of the soil solution had not yet reached the critical concentration.

ANALYSIS OF IRRIGATION WATERS

ANALYTICAL METHODS

DETERMINATION OF CONDUCTANCE

The writers used the conventional set-up for the determination of conductance. Resistance was measured with a Wheatstone bridge supplied with a 1,000-cycle alternating current from a 6-volt dry battery through a microphone hummer. The writers have found that for the waters encountered in this work an electrode vessel having a cell constant of about 1.3 is most useful. The cell constant for each series of readings was determined by noting the resistance at 25° C. of a 0.01-normal solution of sodium chloride. The value 0.00119 reciprocal ohms (mhos) has been used as the specific conductance (*12, v. 6, p. 233*) of this solution.[1] The determinations have been

[1] The value given is 0.0011863.

made at 25° ±0.1°, so that no temperature correction was necessary. Two aliquots of each sample are placed in large test tubes and brought to this temperature in a water bath. The electrode vessel is rinsed several times in one of the tubes, then placed in the other. An immersion electrode vessel has been used chiefly, though the pipette type also was found very satisfactory. In using the immersion type it is essential that the sample tubes be of uniform size and that they contain a uniform quantity of the sample.

Conductance is calculated from the ratio:

$$K=\frac{C}{R}$$

where K=conductance at 25° C. expressed as reciprocal ohms; C=cell constant; and R=the resistance in ohms at 25°.

DETERMINATION OF CARBONATE AND BICARBONATE

The carbonate and bicarbonate ions were titrated with 0.05-normal sulphuric acid, phenolphthalein indicator being used for the carbonate and methyl orange for the bicarbonate. The official method (*2, p. 93*) was followed.

DETERMINATION OF CHLORIDE

Chloride was determined by adding 1 c. c. potassium chromate indicator to the neutral solution resulting from the carbonate-bicarbonate titration, and then titrating with 0.05 normal silver nitrate solution. The official method was followed in this also.

DETERMINATION OF SULPHATE

Sulphate was determined gravimetrically as barium sulphate. The official method was followed, except that silica was not removed prior to the precipitation of the barium sulphate. The relatively small quantity of silica does not appear to interfere so long as the volume does not evaporate below 75 to 100 c. c.

DETERMINATION OF CALCIUM AND MAGNESIUM

The soap method (*15, v. 2, p. 1439*) was used to determine total alkaline-earth bases, chiefly calcium and magnesium, in samples Nos. 1 to 160.

Samples Nos. 161 to 500 were analyzed by the official "total hardness" method (*2, p. 107, 108*). An aliquot of the sample was treated with a known volume of a sodium hydroxide-sodium carbonate reagent, which precipitated the alkaline-earth bases. The precipitate was filtered off and the excess reagent titrated in the filtrate. The quantity of reagent used was assumed to be equivalent to the total alkaline-earth bases present.

Starting with No. 501 and continuing through No. 767, calcium and magnesium were determined separately by the Clarke soap method (*9*) as modified by Winkler (*20*). This method is described in detail by Schreiner and Failyer (*13, p. 56*). Calcium is determined by titration with a standard soap solution. Alkaline sodium potassium tartrate solution is added before the titration. Magnesium is titrated with soap in a separate aliquot. In this case, alkaline ammonium chloride solution was added before the titration.

For all samples after No. 767 calcium has been precipitated as the oxalate and titrated with permanganate, following the method described by Blasdale (*3*).

The writers continued to determine magnesium by the soap method of Winkler, through sample No. 2300. After No. 2300, magnesium was precipitated as magnesium ammonium phosphate, which was ignited and weighed as the pyrophosphate.

As may be inferred from the changes enumerated, the writers were not entirely satisfied with the soap methods. In most cases the agreement between the soap methods and the official methods was reasonably satisfactory, but occasionally, when magnesium was high, difficulty was encountered.

DETERMINATION OF ALKALINE BASES

No determination was made for the alkaline bases, but the quantity present was estimated by difference. From the sum of the milligram equivalents of acid radicals the writers subtracted the milligram equivalents of calcium and magnesium. The difference, expressed as milligram equivalents, is reported as alkaline bases.

DETERMINATION OF BORON

A modification of the Chapin method (*18*) as described by the junior writer (*19*) was used for the determination of boron. The boron compound was separated from the other salts by treating the evaporated residue with methyl alcohol and distilling it. The boron thus separated was converted into orthoboric acid and titrated with sodium hydroxide in the presence of mannite.

In some cases, noted in the text, a turmeric method (*8*) was used. This is primarily qualitative, but approximately quantitative results are obtainable.

INTERPRETATION OF ANALYTICAL RESULTS

CONDUCTANCE

In these investigations the writers have used the specific conductance (K) of the water samples as the measure of the total salinity, or total dissolved electrolytes. This is regarded as a measurement of a definite physical property of the water, quite as significant and probably more accurate than the gravimetric determination of total dissolved solids. The specific conductance is the reciprocal (mhos) of the electrical resistance of the solution as measured in ohms. For convenience of expression the decimal point is moved five places to the right; thus, $K = 0.00129$ is the same as $K \times 10^5 = 129$.

The specific conductance of a solution varies directly with its concentration, although the ratio of conductance to total dissolved salts is not a constant. Variations from a constant ratio are due partly to differences in the degree of dissociation of the salts at different solution concentrations and partly to differences in the atomic weight and the motility of the ions in solutions of mixed salts such as occur in irrigation water.

Where desirable, the total salt content may be estimated as parts per million from a conductance determination by the use of suitable conversion factors. For approximate estimates with irrigation waters having a conductance of 100 or more, in which sulphates predominate, the conductance multiplied by 7 will give a figure fairly close to the total salt content in parts per million. If the conductance is much below 100 or if chlorides predominate in the salt complex, then the conductance multiplied by 6 will be nearer the true value for total salt content. If it is desired to estimate the salt content of water in terms of tons of salt per acre-foot of water it may be assumed that a conductance of 100 is approximately equivalent to 1 ton of salt per acre-foot. The writers prefer, however, to use the conductance for comparative purposes, as an accurate measure of a significant and definite physical property of irrigation water.

BORON

The boron content is expressed as parts per million of elemental boron in the solution. Although the writers have reported in their tables values carried to the second decimal place they do not mean to imply full confidence in the last figure. The aliquots and the titrating solution are of such proportions that 0.05 c. c. of the latter is equivalent to 0.01 p. p. m. of boron, and, while the error of such burette reading is not great, there are other sources of possible error in the process of analysis.

MILLIGRAM EQUIVALENTS

The writers have elected to express the salt constituents other than boron in terms of milligram equivalents, or reacting units, rather than in parts per million, because they believe that the relative concentrations are better shown in this way. In the following paragraphs is given the atomic or combining weight of each constituent, so that if it is desired to compute the writers' results as parts per million, it may be done by multiplying the number of milligram equivalents by the weight given.

CARBONATE AND BICARBONATE

The carbonate and bicarbonate ions have been grouped together because relatively few irrigation waters contain appreciable quantities of normal carbonates. Furthermore, the carbonate-bicarbonate balance in a water sample is influenced by the conditions of temperature and aeration to which it has been subjected, through the absorption or liberation of carbon dioxide. In the titrations 50 c. c. aliquots and 0.05-normal acid were used, so that a burette reading of 0.05 c. c. corresponds to 0.05 milligram equivalent. The combining weight of the bicarbonate ion is 61, and this factor should be used in converting milligram equivalents of CO_3+HCO_3 to parts per million.

CHLORIDE

In the chloride titration the same aliquot is used as in the bicarbonate titration, and the silver nitrate is also 0.05 normal. The combining weight of the chloride ion is 35.5. If it is desired to compute the equivalent sodium chloride, the factor 58.5 should be used.

SULPHATE

In the sulphate determination an aliquot of 200 c. c. is used and the precipitate as barium sulphate is weighed to 0.1 milligram. This corresponds to 0.0043 milligram equivalent per liter. The combining weight of the hydrogen equivalent of sulphate ion is 48, or the sulphate content may be computed as calcium sulphate by multiplying the milligram equivalents by 68.

CALCIUM AND MAGNESIUM

Calcium and magnesium have been determined sometimes together and sometimes separately. Taken together, they may be referred to as the alkaline-earth bases. The combining weight of calcium is 20 and that of magnesium 12.15. Where they are reported together, the factor 20 should be used to obtain the corresponding parts per million.

ALKALINE BASES

The alkaline bases include the sodium and potassium contained in the water. These constituents have not been determined except for a few samples. The figures reported in the tables are obtained by adding together the milligram equivalents of bicarbonate, chloride, and sulphate, and from that sum subtracting the sum of the calcium and magnesium. Since it is known that sodium is the predominant element in this group, it is customary to use its combining weight, 23, as the factor for computing parts per million.

TOTAL SALTS

One of the methods sometimes used as a basis for estimating the total salts in irrigation water is to add together the products of the milligram equivalents by their combining weights. When this is done it is customary to include for the bicarbonate only half its product because of the loss of carbon dioxide that occurs when the alkaline-earth carbonates are precipitated by evaporation.

HARDNESS

The total hardness of water, as this term is used in relation to domestic or industrial waters, implies the quantity of the alkaline-earth bases computed as calcium carbonate in parts per million. Thus the sum of the milligram equivalents of calcium and magnesium multiplied by 50 gives the total hardness.

In water for domestic or industrial use a high degree of hardness is not desirable, but for irrigation hardness is no disadvantage. In fact, hard water is definitely beneficial in its effect on the physical condition of the soil. This is because of the reactions of base exchange that take place between the soil and the salts of the soil solution. As the sodium salts of the soil solution become more concentrated through the application of soft water the reactions of base exchange tend to unite the sodium with the soil and to release equivalent quantities of calcium from soil compounds into the solution. Such reactions impair the physical condition of the soil, making it impermeable to water. On the other hand, if the soil solution contains more calcium than sodium, the results of reactions of base exchange are not likely to be injurious to the physical condition of the soil, and may be beneficial. For this reason the degree of hardness in irrigation water can not properly be judged except in reference to the quantity of the alkaline bases with which it is associated. Thus, if the quantity of alkaline-earth bases, expressed as milligram equivalents of calcium and magnesium, is much in excess of the alkaline bases, expressed as milligram equivalents of sodium, the water would be described as hard and desirable for irrigation. But if these proportions are reversed so that the alkaline bases are in excess, the water would be referred to as soft, even though it contained so much calcium and magnesium as to be unsatisfactory for domestic or industrial use.

SURFACE WATERS OF THE SANTA CLARA VALLEY

The Santa Clara River rises near Acton, Calif., at the head of Soledad Canyon, north of the San Gabriel Mountains. It flows westward about 75 miles into the Pacific Ocean near Ventura. Its chief tributaries enter from the north. (Fig. 3.) From Soledad Canyon to its delta, the flood plain is generally broad and composed of sand and gravel. The downstream movement of water through the porous material of the flood plain is impeded by several subsurface dikes of rock or other impermeable material, so that while the surface of the stream bed is usually dry in long sections, except at flood time, there are several sections in which there are pools or sluggish streams throughout the year. Practically all the surface flow except that from occasional floods is diverted for irrigation.

The quality of the surface water of the main stream and of some of its tributaries is shown in Table 3. The locations in this table are to be found on the map, Figure 3, being the numbers inclosed in circles. The first five locations listed in the table represent conditions above the junction of Piru Creek, where analyses show that very little boron is contributed to the main stream. The effect of boron contributed by Piru Creek is shown by the increase in the mean boron content of the samples collected at location 8, the highway bridge between Fillmore and Bardsdale (0.99 p. p. m.), as compared with the mean of those collected at location 5, Newhall ranch bridge (0.49 p. p. m.), an increase of 0.50 p. p. m. Piru Creek (location 6), with an annual mean boron content of 1.56 p. p. m., and Sespe Creek (location 9), with an annual mean of 2.01 p. p. m., appear to be the chief sources of boron in the Santa Clara drainage system. The waters of Hopper Creek (location 7) and of Santa Paula Creek (location 12), though represented in the table by only one sample in each case, appear to carry very little boron.

TABLE 3.—*Quality of surface waters of the Santa Clara River and its tributaries*

Location No.	Samples	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
					$CO_3 + HCO_3$	Cl	SO_4	Ca+Mg	Alkaline bases
	Number	*C. f. s.*[1]		*P. p. m.*					
1	1	1.50	90	0.10	6.50	1.51	2.33	6.70	3.69
2	1	1.00	206	.16	7.10	1.11	17.10	17.80	8.13
3	1	1.00	70	.16	3.02	.72	1.66	7.13	------
4	1	1.00	80	.20	5.08	.57	3.19	9.02	.07
5	20	7.10	157.3	.49	4.89	1.66	11.23	12.12	5.66
6	56	6.01	191.7	1.56	5.00	1.90	16.57	15.88	7.66
7	1	5	185.0	.23	8.28	.98	12.11	15.28	6.12
8	13	7.8	122.0	.99	4.20	1.02	8.55	10.73	3.01
9	56	8.23	90.8	2.01	2.99	2.60	4.36	5.99	3.96
10	13	20.5	120.0	.75	4.11	1.04	8.19	10.19	3.15
11	8	16.0	138.1	.81	4.26	1.75	9.86	12.19	3.68
12	1		63	.10	3.15	.20	4.20	7.20	.65

[1] Cubic feet per second.

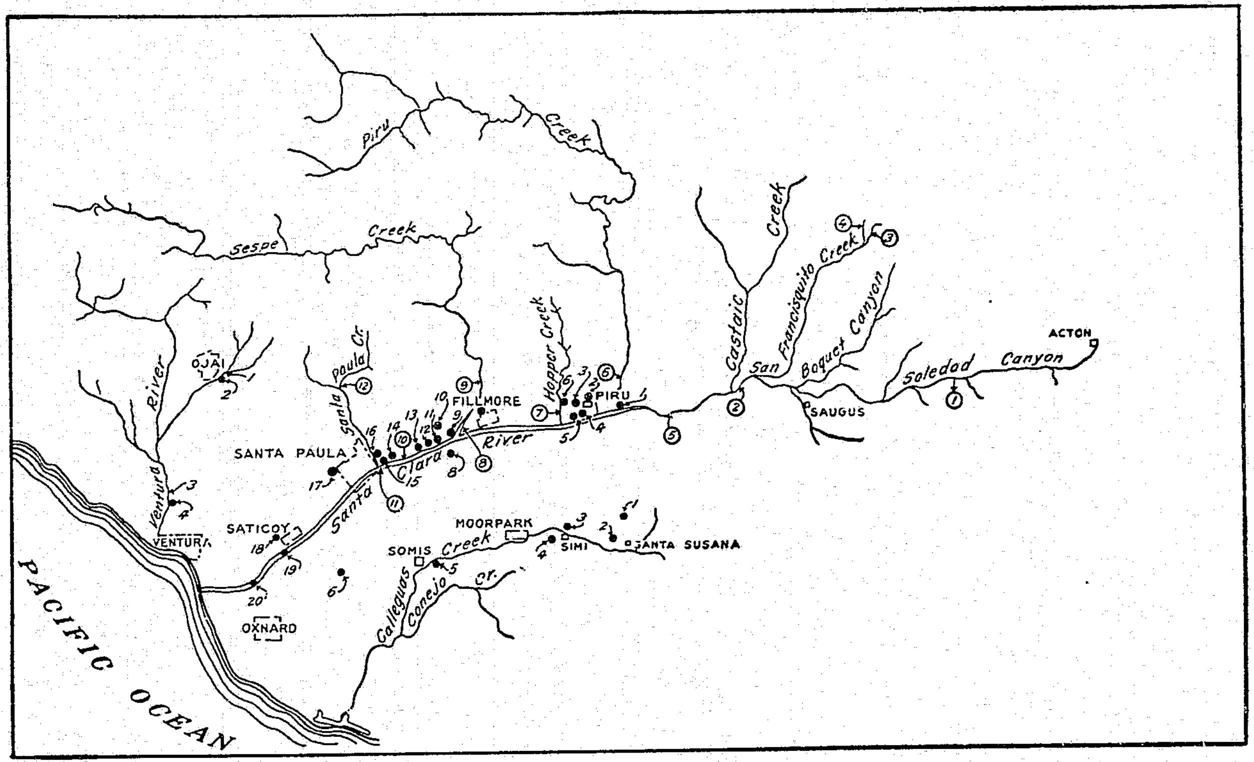

FIGURE 3.—Map of the Santa Clara Valley and vicinity in Ventura County, Calif., showing locations of water samples taken during boron survey in 1928–29. The numbers in circles along the Santa Clara River refer to Table 3; those on the same stream but not in circles refer to Table 4; the numbers along the Ventura River refer to Table 11; and those along Calleguas Creek refer to Table 15

Locations 10 and 11 are on the main stream below the junction of Sespe Creek. While the mean boron content reported for these two locations is somewhat lower than that reported for location 8, it seems probable that the differences are due to variations in discharge at the time of sampling. It is to be noted that the waters of the Santa Clara River are relatively low in chlorides and high in bicarbonates, sulphates, and alkaline-earth bases. The water of Sespe Creek is exceptional in having less bicarbonates and sulphates and more chlorides than the other sources.

With respect to the values for discharge given in Table 3, and in the descriptions of locations it should be said that these are based on estimates made when the samples were taken. It should not be assumed that they may be used as a basis for estimating the total discharge or the mean annual discharge of the stream. The subject of the stream flow of this drainage basin has been under investigation since 1927 by Richard H. Jamison, of the division of water resources of the California Department of Public Works, and two reports have been issued.[5]

LOCATIONS LISTED IN TABLE 3

(See fig. 3)

1. The Santa Clara River, near its headwaters, in the Soledad Canyon east of Lang; sampled July 15, 1928.
2. The Santa Clara River, near the junction of San Francisquito Creek, 2 miles west of Saugus; sampled July 15, 1928.
3. San Francisquito Creek, above the junction with Clearwater Creek; sampled April 18, 1929.
4. Clearwater Creek, above its junction with San Francisquito Creek; sampled April 18, 1929.
5. The Santa Clara River at Newhall Ranch Bridge, 4 miles above Piru; sampled for 20 consecutive weeks from February 19 to July 16, 1929. During that period the discharge ranged from 20 to 0.25 cubic feet per second, and the boron content from 0.34 to 0.84 p. p. m.
6. Piru Creek, at the diversion dam, 1.2 miles above Piru; sampled weekly from July 18, 1928, to August 6, 1929. During that period the discharge ranged from 20 to 1 cubic foot per second and the boron content from 0.92 to 2.35 p. p. m.
7. Hopper Creek, at the crossing of the State highway, 2.5 miles west of Piru and 1 mile above its junction with the Santa Clara River. The creek is ordinarily dry at this point, but carried some water following the spring rains. Sampled April 8, 1929.
8. The Santa Clara River, at the highway bridge between Fillmore and Bardsdale. This is below the junction of Piru and Hopper Creeks, but 2 miles above the junction of Sespe Creek. The river is usually dry at this point except during the spring. Sampled weekly from February 5 to May 7, 1929. The discharge during that period ranged from 15 to 2 cubic feet per second and the boron content from 0.64 to 1.31 p. p. m.
9. Sespe Creek, at the diversion dam, 4.5 miles above the junction with the Santa Clara River, and above the town of Fillmore. The discharge as reported in the table is the mean of weekly estimates made at the diversion dam. During the same period the discharge of the stream was measured 17 times by Richard H. Jamison of the division of water resources of the State of California. These measurements were made both at the diversion dam and at the highway bridge west of Fillmore. The mean of the Jamison measurements—total discharge, including diversion—is 13.73 cubic feet per second. The samples here reported were taken weekly from July 18, 1928, to August 6, 1929. The range of discharge was from 25 to 2 cubic feet per second, and the range of boron content was from 0.45 to 3.66 p. p. m.

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[5] JAMISON, R. H. VENTURA COUNTY INVESTIGATION. REPORT FOR THE PERIOD AUGUST 20, 1927, TO JULY 31, 1928. Calif. Dept. Pub. Works, Div. Water Rights. 228 p., illus. Sacramento, Calif. 1928. [Mimeographed.]

——— VENTURA COUNTY INVESTIGATION. REPORT FOR THE PERIOD AUGUST 1, 1928, TO JULY 31, 1929. Calif. Dept. Pub. Works, Div. Water Resources Rpts. 165 p., illus. Sacramento, Calif. 1929. [Mimeographed.]

10. The Santa Clara River, above Dent's Slough, the point of diversion for the ditch of the Farmers' Irrigation Co. located about 3 miles upstream from the highway bridge across the river at Santa Paula. The samples were taken during the period January 3 to June 11, 1929. The estimated discharge ranged from 50 to 16 cubic feet per second and the boron content from 0.58 to 1.12 p. p. m.

11. The Santa Clara River, at the point of diversion for the ditch of the South Mountain Lemon Co. located about three-fourths of a mile upstream from the highway bridge across the river at Santa Paula. Of the eight samples included in the table, seven were taken weekly from December 26, 1928, to February 12, 1929, and one on August 6, 1929. The estimated discharge ranged from 25 to 10 cubic feet per second, and the boron content from 0.52 to 0.96 p. p. m.

12. Santa Paula Creek, above its junction with Sisar Creek; sampled December 29, 1928.

UNDERGROUND WATERS OF THE SANTA CLARA VALLEY

The irrigation agriculture of the Santa Clara Valley is supported partly by the surface waters diverted from that stream and its tributaries, and partly by waters drawn from the underground supplies of the valley. It is to be assumed that these underground water supplies are replenished both by percolation from the stream channels and by the uncollected run-off from the hills on either side of the valley. Since these well waters constitute an important part of the local irrigation supply, it seemed desirable to undertake a detailed survey of them, not only to obtain evidence as to what concentration of boron in irrigation water causes injury to the various crop plants, but also to learn what variations occur in boron concentration in what appears to be a connected body of underground water.

In this survey samples were taken from 20 wells, all of which are used for irrigation. These wells represent an area extending from a short distance east of Piru to Montalvo on the delta plain of the Santa Clara River, a distance of approximately 30 miles. (See fig. 3, in which the numbers along the Santa Clara River, not in circles, correspond to the locations in Table 4.) Altogether, 173 samples were analyzed in connection with this survey. (Table 4.) With one exception the results for each well are based on the analyses of four or more samples. These samples were taken usually during the irrigation season, with intervals of four weeks between the dates of sampling.

TABLE 4.—*Quality of underground water as obtained from irrigation wells in the valley of the Santa Clara River*

Location No.	Samples	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
				CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number		*P. p. m.*					
1	7	148	0.51	5.22	1.48	10.35	11.81	5.24
2	49	137	1.24	3.95	1.14	11.03	12.12	4.02
3	5	147	1.09	4.57	.77	12.08	14.60	2.82
4	5	152	1.28	5.01	1.15	11.57	15.01	2.72
5	6	114	.60	3.60	.74	8.46	11.20	1.69
6	4	258	.72	6.50	1.54	25.25	31.87	1.72
7	4	131	.48	4.66	1.25	8.79	10.89	3.81
8	5	120	.43	4.44	1.17	7.96	10.04	3.53
9	18	105	.97	4.16	1.44	6.13	7.72	4.01
10	4	82.4	.42	3.91	1.36	3.43	7.00	1.70
11	11	101	.89	4.05	1.43	5.32	7.28	3.52
12	11	116	.57	4.42	.09	7.42	9.34	3.49
13	6	120	.56	4.47	1.10	8.19	7.92	5.84
14	5	109	.40	4.85	.80	6.41	9.94	2.12
15	7	118	.47	4.36	1.06	7.84	9.72	3.61
16	2	94	.44	4.90	.63	7.02	7.74	2.81
17	4	116	.28	5.21	1.02	6.75	8.61	4.37
18	6	141	.51	5.50	1.84	8.72	11.31	4.75
19	7	156	.53	5.27	1.96	10.61	11.61	6.23
20	7	136	.54	4.27	1.49	9.51	10.50	4.77

An inspection of Table 4 shows at once that there is a very low correlation between the total salt content and the boron concentration. Nor is there high correlation between the boron and the chloride concentrations, such as is noted later in the description of the Owens River area. These results appear to warrant the inference that the boron contained in these underground waters is not derived locally by solution from material in the water-bearing strata but is brought in by the percolating waters from sources outside the valley.

It was noted in the section dealing with the surface waters of this valley that the boron content was low in the waters above the junction of Piru Creek. In the present series the water from location 1, which is 2 miles above this junction, has a boron content of 0.51 p. p. m., while that from location 2, just below Piru Creek, contains 1.24 p. p. m. With respect to the other constituents, these two waters are not very different. Locations 2, 3, and 4 are in the valley below the junction of Piru Creek, and all three contain more than 1 p. p. m. of boron. Locations 5 and 6, although in the same area, are more to the west and nearer Hopper Creek, the effect of which may be to reduce the boron content by dilution, though the water at location 6 is very high in total salts.

The well at location 7 is close to the bed of Pole Creek. Here the water is low in boron though not essentially different from many other wells in the valley with respect to the other salt constituents. The well at location 8 is south of the Santa Clara River, near the mouth of Grimes Canyon. The boron content of this is low as compared with that of either the surface or subsurface waters of the main stream above this point. It is known that some of the ground waters of Grimes Canyon, as at Dryden Spring, are very low in boron and in other salts also. Individual samples from other wells in the Bardsdale area indicate that not all the underground water south of the river at this point is low in boron. This area is opposite the delta of Sespe Creek, the boron content of which is high, and there is a possibility that some of the wells on the south side of the river tap strata that are replenished in part from this creek.

The well at location 9 is west of Sespe Creek but close to the flood plain of the Santa Clara River. It was installed to provide an irrigation supply in place of surface water from Sespe Creek that was believed to have caused injury to citrus and walnut trees. The water from this well when compared with that of Sespe Creek (location 9, Table 3) is seen to contain much less boron. Its average is 0.97 p. p. m., while Sespe Creek averaged 2.01 p. p. m. The other constituents are slightly different also. The bicarbonate and sulphate content of the well water is higher and the chloride content is lower than that of the creek water, indicating that the well draws on some of the percolating waters of the Santa Clara River, which are characteristically high in bicarbonates and sulphates. The well at location 11 yields water very similar to that at location 9. The wells are only 1 mile apart, and both are at the edge of the flood plain of the river.

The well at location 10 is one that merits special consideration. It is in the same general area as locations 9 and 11, but is about one-fourth mile north of the river bed and near the foothills. The water supply is not large, about 0.4 cubic foot per second, and is used to irrigate a small citrus orchard. The trees on either side of this orchard have been irrigated either with Sespe Creek water or water from the well at location 9. In these the evidences of boron injury are very plain, while the trees irrigated from this well show no symptoms of boron injury. It seems probable that this well taps a supply of underground water that is largely replenished by run-off from the adjacent hills containing much less boron than the underground waters of the center of the valley. The conditions surrounding the well tend to support the view that if irrigation water contains less than one-half p. p. m. of boron its use on citrus and walnut trees is not likely to cause serious boron injury.

The wells at locations 12 and 13 are both situated close to the flood plain of the Santa Clara River, some distance downstream from the well at location 11. The water from these two wells is of the same quality, but differs from that at location 11 in having slightly more salt and slightly less boron. The next three wells listed in the table, those at locations 14, 15, and 16, are located still farther downstream toward the delta of Santa Paula Creek. The run-off of this stream and of Timber Canyon doubtless contributes water of low boron content that tends to dilute the underground supply of this area with respect to that element. The well at location 17 is situated west of the delta of Santa Paula Creek and close to the north edge of the valley at the mouth of Fagan Canyon. The boron content of its water is the lowest of any in this series. The surface water of Santa Paula Creek (location 12, Table 3) is very low in boron and may contribute to the supply drawn upon by this well.

The last two wells, those at locations 19 and 20, reported in Table 4 are located in the flood plain near the mouth of the Santa Clara River, and these waters should represent a composite sample of what may be referred to as the "underflow" of that stream. With respect to total salts as measured by conductance, these waters are very little above the average of the upstream samples. The boron content is less than that found at several points above, which indicates that the effect of the run-off below Sespe Creek is to dilute the underflow with respect to that element.

LOCATIONS OF WELLS LISTED IN TABLE 4

(See fig. 3)

1. Camulos ranch, domestic well, 2¼ miles east of Piru, one-quarter mile south of highway; depth, 154 feet; discharge, 0.4 cubic feet per second.
2. Warring well, 0.1 mile north of the packing house of the Piru Citrus Association, Piru, depth, 275 feet; discharge, 1.6 cubic feet per second.
3. Padelford well No. 1, 2 miles west of Piru, 0.3 mile north of highway, NE. ¼ sec. 25, T. 4 N., R. 19 W.; depth, 223 feet, perforated below 173 feet; discharge, 0.5 cubic feet per second.
4. Citrola ranch well, 2 miles west of Piru, 100 feet south of highway, SE. ¼ sec. 25, T. 4 N., R. 19 W.; depth, 220 feet; discharge, 1.5 cubic feet per second.
5. Carter ranch well, 2.1 miles west of Piru; 0.2 mile south of highway, SE. ¼ sec. 25, T. 4 N., R. 19 W.; depth, 200 feet; discharge, 2.5 cubic feet per second.
6. Padelford well No. 2, 2.4 miles west of Piru; 0.2 mile north of highway on east bank of Hopper Creek; depth, 215 feet; discharge, 2 cubic feet per second.
7. Texas Refinery well No. 3, one-half mile east of Fillmore; 50 feet north of highway, on the east bank of Pole Creek; depth, 750 feet; discharge, 2.4 cubic feet per second.
8. King ranch well, west of Bardsdale, one-fourth mile west on first road from south end of bridge between Fillmore and Bardsdale; depth, 263 feet; discharge, 1.5 cubic feet per second.
9. Brownstone well, on the west bank of Sespe Creek, 1½ miles west of Fillmore and 0.2 mile south of highway; depth, 260 feet; discharge, 3 cubic feet per second.

10. Lombard ranch well, 2¼ miles west of Fillmore; 400 yards north of highway on Oak Road; depth, 150 feet; discharge, 0.4 cubic feet per second.

11. Sespe ranch well No. 3, 2.5 miles west of Fillmore on the north bank of Sespe Creek; depth, 404 feet; discharge, 3.8 cubic feet per second.

12. Sespe ranch well No. 2, 4.5 miles west of Fillmore-Bardsdale bridge on the north side of the Santa Clara River at the edge of the flood plain; depth, 375 feet; discharge, 2.2 cubic feet per second.

13. Sespe ranch well No. 1, 3 miles west of Fillmore-Bardsdale bridge on the north side of the Santa Clara River near ranch headquarters, at the edge of the flood plain of the river; depth, 320 feet; discharge, 4 cubic feet per second.

14. Hardscrabble Water Co. well, on delta cone of Timber Canyon, 1.65 miles east of Highway Bridge across Santa Paula Creek, 0.3 mile south of highway; depth, 360 feet; discharge, 3 cubic feet per second. The static level is at the ground surface; the draw down is 12 feet for 3 cubic feet per second discharge.

15. Farmers' Irrigation Co. well No. 7, NE. ¼ sec. 12, T. 3 N., R. 21 W., 0.6 mile east of highway bridge across Santa Paula Creek and 0.3 mile south of highway. Depth, 260 feet; discharge, 5 cubic feet per second.

16. Teague-McKevett well, 0.55 mile east of Highway Bridge across Santa Paula Creek and 0.2 mile north of highway; depth, 381 feet; discharge, 3 cubic feet per second.

17. Blanchard well, Santa Paula, 0.6 mile north of Main Street at Palm Street on the east bank of Fagan Canyon; depth, 394 feet; discharge, 1.2 cubic feet per second.

18. Ventura County Country Club well, 0.3 mile northwest of Saticoy; depth, 100 feet; discharge, 0.9 cubic feet per second.

19. Alta mutual wells, Saticoy, in flood plain of the Santa Clara River, 0.35 mile southeast of highway crossing of railroad; depth, 665 feet; discharge, 5.4 cubic feet per second for four wells.

20. Montalvo mutual wells, 1 mile southwest of Montalvo, in the flood plain of the Santa Clara River; depth, 586 feet; discharge, 9 cubic feet per second for two wells.

SUCCESSIVE HORIZONS OF UNDERGROUND WATER

In making a survey of the underground waters of the Santa Clara Valley it was found that the valley fill is composed of irregular strata of gravel, sand, and clay. Some of these strata yield water readily and abundantly, others are impermeable, or "dry." When wells are drilled it is customary to keep a record of strata encountered and subsequently to perforate the casing opposite the sections of water-bearing gravel. When the pump is finally installed, the water may be drawn in part from all these strata and thus represent a composite of all.

In view of the possible localization of boron contamination, it seemed desirable to determine whether there were differences in the quality of the water from the successive horizons encountered in drilling deep wells. An opportunity for making this investigation was afforded during the spring of 1929 when five wells were being drilled in the vicinity of Santa Paula. As each well was drilled, samples of water were taken from time to time for analysis. The results of these analyses from two of the wells are reported in Tables 5 and 6. The conditions found in the other three wells were not essentially different from those in these two. In the case of the well known as Citrus No. 1 (Table 5) the successive samples were essentially the same with respect to their salts, including the boron. In the other well, Church No. 2 (Table 6), the first water encountered was higher in salts and in boron than the deeper water. The third sample, taken at 270 feet, was also higher in boron than the deeper water, but the total salt content, as measured by conductance, was only slightly higher. In this well the casing was perforated only at the lower strata.

TABLE 5.—*Quality of water from successive horizons encountered in drilling a well, Citrus No. 1, in Santa Paula in February, 1929*

[Depth, 394 feet; discharge, 4 cubic feet per second]

Sample No.	Date	Depth	K × 10⁵ at 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	1929	*Feet*		*P. p. m.*					
621	Feb. 2	106	106	0.29	4.65	1.18	5.31	7.23	3.91
622	Feb. 5	132	114	.32	5.00	1.30	5.76	9.96	2.10
646	Feb. 14	[1] 190	109	.32	4.80	1.25	5.78	10.50	1.33
666	Feb. 23	232	109	.34	5.10	1.15	5.73	7.71	4.27
667	Feb. 25	255	112	.31	5.10	1.10	5.75	8.27	3.68
672	Feb. 26	287	111	.32	5.20	1.20	5.76	8.40	3.78
704	Mar. 2	318	105	.33	5.00	1.20	5.81	8.52	3.49
705	Mar. 2	328	108	.29	5.20	1.20	5.81	8.87	3.34
712	Mar. 9	392	113	.30	5.25	1.25	6.28	10.03	2.75
800	Apr. 2	[2] 394	112	.37	5.25	1.24	5.86	10.02	2.33

[1] In clay below 172 feet.

[2] Pump installed and started.

TABLE 6.—*Quality of water from successive horizons encountered in drilling a well, Church No. 2, in Santa Paula*

[Depth, 411 feet; discharge, 4 cubic feet per second]

Sample No.	Date	Depth	K × 10⁵ at 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	1929	*Feet*		*P. p. m.*					
824	Apr. 9	120	176	0.83	7.39	1.49	9.79	11.19	7.48
840	Apr. 12	230	119	.50	5.70	.94	6.42	9.47	3.59
847	Apr. 13	270	122	.09	5.54	1.12	6.30	8.99	3.97
888	Apr. 16	312	114	.39	5.50	1.02	5.82	9.43	2.91
891	Apr. 18	326	112	.40	5.35	.92	6.01	9.67	2.61
898	Apr. 22	364	114	.46	5.34	.94	6.15	8.33	4.10
916	Apr. 24	378	110	.42	5.10	.87	5.76	7.80	3.87
981	Apr. 27	[1] 411	114	.36	5.34	1.02	6.00	8.11	4.25

[1] After 2 hours' pumping.

These observations indicate that, in this area at least, the differences in the quality of the water in the successive strata are not very pronounced. It is to be assumed that there is ample communication vertically as well as laterally to permit approximate equilibrium with respect to its dissolved salts to be established in time throughout the whole body of underground water.

WATERS OF SESPE CREEK

Sespe Creek joins the Santa Clara River near Fillmore, Calif. It is a perennial stream, but the flow is usually not more than 4 or 5 cubic feet per second except during the rainy season. There is no storage on the stream at present, but there is a small diversion dam about 5 miles above its mouth. The samples reported in Table 7 were taken at this dam. There is little if any irrigated land above this dam, where the water is diverted into a distribution system for irrigating lands near Fillmore.

TABLE 7.—*Quality of the water of Sespe Creek, as sampled at the diversion dam 4.5 miles above its mouth*

[Monthly means of weekly analyses]

Year and month	Analyses	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
1928	*Number*	*C. f. s.*		*P. p. m.*					
August	5	4	98.1	2.48	2.70	3.60	3.27	5.05	4.52
September	4	4	101.1	2.61	2.64	4.07	3.43	4.77	5.37
October	5	4	106.6	3.19	2.92	4.52	3.32	5.05	5.71
November	4	6	116.7	3.29	3.30	4.20	4.22	5.40	6.32
December	4	11	105.0	2.04	3.24	2.77	5.40	5.04	5.77
1929									
January	5	12	114.3	2.09	3.33	2.53	6.38	8.06	4.18
February	4	15	89.0	.98	3.14	1.12	5.27	7.60	1.93
March	4	17	84.5	.91	3.11	.93	4.77	6.91	1.90
April	5	12	84.3	.81	3.03	.97	4.81	6.90	1.91
May	4	8	87.6	1.53	2.75	1.25	4.62	6.21	2.41
June	4	7	91.0	1.88	2.84	1.95	4.46	5.81	3.44
July	5	3	85.9	1.98	2.93	2.55	3.38	5.15	3.71
Mean		8.6	97.0	1.98	2.99	2.54	4.44	6.05	3.92

The analyses reported in Table 7 represent water samples taken each week from August 1, 1928, to July 30, 1929. The discharge of the stream was estimated, not measured, at the time each sample was taken, and these discharge figures are not to be considered as more than approximately correct. It will be observed that in the course of the year the salt content, as measured by electrical conductance, ranged from 84.3 to 116.7 for the monthly means. For the individual determinations the range was from a minimum of 60.1 to a maximum of 127. There is not a close correlation, either direct or inverse, between the total salt content and the volume of discharge. It is probable that the heavier and more general rains, such as contributed to the high discharge volumes of January, February, and March, caused enough direct run-off to reduce the salt content appreciably. However, the winter season is characterized by irregularity in the salt content, probably because some of the run-off from the lighter showers found its way gradually into the stream as seepage of higher salt content. The mean of the conductances, 97×10^{-5} at 25° C., indicates a salt content of approximately 700 parts per million. With an average discharge of 8.6 cubic feet per second, this is equivalent to 16.25 tons of salt per day.

The boron content of this stream, taking the average of 53 determinations for the year, was 2.01 p. p. m., ranging from a minimum of 0.45 to a maximum of 3.66. For the monthly means the average was 1.98, ranging from 0.81 to 3.29. There was an upward trend in the boron content from midsummer to the end of November, when a break occurred following the first autumn rains. Through the winter and well into the spring the boron content was well below the mean. This is taken as confirming the opinion, supported also by other evidence, that most of the boron carried by this stream is contributed by springs having fairly uniform flow and high boron content. During periods when the discharge of the stream is low these springs contribute a larger proportion of the total than when the discharge is increased as a result of rains. If it may be assumed that 8.6 cubic feet per second is the mean discharge for this stream and that the boron content of the water is 2.01 p. p. m., and if this boron be computed to its equivalent of borax, then the average daily discharge of borax is 824 pounds.

The composition of the salts other than those of boron carried by the water of Sespe Creek is shown in the last five columns of Table 7, expressed as reaction values, or milligram equivalents.

The carbonates and bicarbonates, though determined separately, are here reported together. The mean for the year is 2.99 milligram equivalents, which is equivalent to 182 p. p. m. of HCO_3. It may be observed that the figures for the CO_3+HCO_3 show much less variation for the year than is shown, for example, by the boron on one hand or by the chlorides on the other. It is generally true that with respect to any given water supply the carbonate-bicarbonate content is less variable than that of the other ions.

The chloride content averaged for the year 2.54 milligram equivalents, or 90 p. p. m. It will be observed that there is a close correlation between the chloride content and the boron content, which probably indicates that the same sources that contribute the boron also contribute the chlorides. In proportion to its total salt content the water of Sespe Creek contains more chlorides than any of the other waters of the Santa Clara Valley.

The sulphate content averaged for the year 4.44 milligram equivalents, or 213 p. p. m. The range during the year was greater than that of the carbonates but less than that of the chlorides. During the winter, or rainy season, the proportion of sulphates to chlorides was much greater than during the summer, indicating that the salts contributed by leaching the surface soils of the drainage area are largely sulphates.

The alkaline-earth bases, calcium and magnesium, averaged for the year 6.05 milligram equivalents, equivalent to 121 p. p. m. of calcium. Like the sulphates, the calcium and magnesium ran somewhat above the mean during the winter months and probably for the same reason. For the period during which the calcium and magnesium were separately determined, the mean for the calcium was 4.38 and for the magnesium 2.29 milligram equivalents, or nearly twice as much calcium as magnesium.

The alkaline bases, shown in the last column of Table 4, are assumed to include both sodium and potassium but to consist chiefly of sodium. These elements were not determined by analysis, but the figures given in the table are computed by subtracting the sum of the milligram equivalents for the alkaline-earth bases, calcium and magnesium, from the sum of the milligram equivalents of the acid ions, carbonates, bicarbonates, chlorides, and sulphates. The mean of the alkaline bases for the year is 3.92 milligram equivalents, equivalent to 90 p. p. m. when computed as sodium. The ratio of alkaline-earth bases to alkaline bases is approximately 6 to 4, which indicates that this water should not impair the physical condition of the soil through reactions of base exchange.

The analytical results for the water of Sespe Creek show that, except for its high boron content, this water might be regarded as of good quality and quite safe to use for irrigation. During the winter and early spring the boron content is relatively low; and if conditions as observed during the past year are typical of the regimen of the stream, it might be possible to utilize the flood waters during the spring with less danger of boron injury than would follow the use of the summer flow.

In view of the fact that the water of Sespe Creek, except for its high boron content, would be of excellent quality for irrigation, it seemed desirable to attempt to locate the source of boron contamination. The stream drains an area of rough topography north of the Santa Clara Valley, and its upper basin is somewhat difficult of access. Through the cooperation of Walter F. Emerick, of Santa Paula, and Guerdon Ellis, district forest ranger at Ojai, arrangements were made in the autumn of 1928 for the collection of samples of water from the upper stream and some of its tributaries. Samples from the headwaters down to Bear Canyon were collected on October 18 and 26, 1928, by Ralph Walton, a forest guard, while samples from Hot Springs Creek to Timber Canyon Creek were collected on October 25 and 26, 1928, by J. N. Johns, also a forest guard. Owing to the difficulty of transport, the samples obtained at this time were only 250 c. c. each, a quantity too small to utilize for quantitative determinations of boron and sufficient only for an estimate of the boron concentration by the turmeric method.

The results of this preliminary survey indicated that the boron contamination came from two hot springs tributary to the stream north of Topatopa Mountain and only a few miles above the diversion dam. If this should prove to be true it would apparently be possible to prevent contamination by storing the flood waters of the stream above these springs, which would thus be segregated from the main supply.

In the spring of 1930, from March 31 to April 3, V. M. Freeman, managing engineer of the Santa Clara water conservation district, went into the upper basin and collected a series of 5-gallon samples from the headwaters to the mouth, measuring accurately the discharge at each sampling point. These samples were analyzed at the Limoneira laboratory, the boron determinations being made in duplicate by the quantitative method. The results of the analyses of the samples obtained in the autumn of 1928 and in the spring of 1930 are given in Table 8.

TABLE 8.—*Quality of the water of Sespe Creek and its tributaries, as sampled in October, 1928, and in March and April, 1930*

Location No.	Sample No.	Date	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
						CO_3 + HCO_3	Cl	SO_4	Ca + Mg	Alkaline bases
			C. f. s.		*P. p. m.*					
1	2509	March, 1930	11.40	102	0.18	3.00	0.80	6.98	9.38	2.00
1	2510	do	11.40	101	.10	4.00	.75	7.00	9.45	2.30
2	313	October, 1928	.06	63	[1] .10	4.20	.10	1.20	3.30	2.20
2	2508	March, 1930	3.13	41	.11	2.05	.05	1.46	3.95	.51
3	2511	April, 1930	.60	153	.25	3.85	.25	11.33	14.83	3.60
4	314	October, 1928	.08	69	[1] .10	4.40	.30	2.80	1.90	5.60
4		April, 1930	15.96	(2)						
5	315	October, 1928	.01	74	[1] 2.00	5.80	.60	1.80	3.50	4.70
5	2512	April, 1930	4.51	48	.19	3.75	.10	3.11	5.92	1.04
6	316	October, 1928	.10	70	[1] .40	5.10	.60	2.00	4.20	3.50
7	317	do	.02	121	[1] .20	6.70	.30	7.00	8.40	5.60
7	2513	April, 1930	5.58	35	.03	1.45	.10	1.99	3.14	.40
8	318	October, 1928	.04	103	[1] .30	4.10	.40	8.00	6.90	5.60
9	2515	April, 1930		66	.11	2.45	.40	4.28	5.84	1.29
10	319	October, 1928	.02	71	[1] .40	3.70	.10	3.60	5.30	2.10

[1] Boron estimated by the turmeric method. [2] No sample.

TABLE 8.—*Quality of the water of Sespe Creek and its tributaries, as sampled in October, 1928, and in March and April, 1930*—Continued

Location No.	Sample No.	Date	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
						CO_3+HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
			C. f. s.		*P. p. m.*					
10	2514	April, 1930	5.01	47	.24	2.25	.10	2.69	4.37	.67
11	350	October, 1928	.01	84	[1] .20	4.00	.10	5.50	6.70	2.00
12	353	do	.04	106	[1] .30	5.40	.20	6.50	8.20	3.70
12	2516	April, 1930	1.73	49	.11	1.95	.10	3.20	4.62	.63
13	354	October, 1928		100	[1] .40	1.50	.60	10.00	7.80	4.30
14	2517	April, 1930	.40	84	.09	4.15	.10	5.50	8.76	.09
15	355	October, 1928	.05	137	[1] 8.50	10.30	2.70	1.00	1.20	12.80
15	2518	April, 1930	.01	132	6.83	0.90	2.50	1.88	2.14	12.14
16	356	October, 1928		112	[1] 7.00	8.70	2.30	5.00	3.80	12.00
16	2519	April, 1930	30.92	71	.22	3.10	.30	4.61	6.64	1.37
17	351	October, 1928	.16	170	[1] 12.50	2.00	7.90	6.00	2.90	13.00
17	2520	April, 1930	2.20	150	6.69	2.95	3.90	9.47	8.18	8.14
18	352	October, 1928	.32	171	[1] 12.50	2.30	7.00	6.50	2.90	12.90
19	2521	April, 1930	1.06	67	.70	3.00	.25	3.94	5.27	1.92
20	2522	do	.41	45	.15	2.10	.05	2.68	4.22	.61
21	2523	do	3.49	39	.11	1.40	.05	2.20	3.05	.60
22	2524	do	1.50	28	.13	2.15	.05	.60	2.49	.31
23	2525	do	3.27	120	.22	4.50	.35	8.87	11.37	2.35
24	2526	do	.53	77	.21	3.80	.10	4.59	7.55	.94
25	2527	do	.99	81	.52	3.50	.20	5.35	6.14	2.91
26	2528	do	.54	225	.33	4.70	.65	23.93	10.52	9.56
27	2529	do	61.15	83	.70	3.00	.80	5.00	5.76	3.01

[1] Boron estimated by the turmeric method.

It should be kept in mind that the samples of 1928 were taken in the autumn, when the discharge of the stream was near its lowest point, while those of 1930 were taken in the spring, when the discharge was high. Furthermore, the values for the boron concentration of the 1928 samples are at best only approximate, while those of the 1930 samples are probably very close to the truth.

The results given in Table 8 show that above Willett Hot Springs (location 15), the boron content of the water is below the critical concentration. Even at this point the quantity of water contributed to the main stream is so small, 0.01 c. f. s., that the boron contamination is not serious. The major contribution of boron appears to come from the Sespe Hot Springs Creek (location 17) which on April 2 was discharging 2.2 c. f. s., containing 6.69 p. p. m. boron. This is equivalent to 700 pounds of borax per day, which may be compared with the 824 pounds computed as the average daily quantity carried by Sespe Creek at the diversion dam. In other words, it seems clear that if it is found practicable to segregate or by-pass the high-boron water coming from Sespe Hot Springs, the water of Sespe Creek could be used for irrigation without danger of injury.

LOCATIONS ON SESPE CREEK LISTED IN TABLE 8

1. Sespe Creek, at Cold Springs about 1¼ miles above the junction of Howard Creek and near northwest corner T. 5 N., R. 22 W., San Bernardino base and meridian.
2. Howard Creek, about 200 yards above its junction with Sespe Creek.
3. Rock Creek, above its junction with Sespe Creek.
4. Sespe Creek, below the junctions of Howard Creek and Rock Creek.
5. Lion Canyon Creek, above its junction with Sespe Creek.
6. Sespe Creek, about 300 yards below the junction of Lion Canyon Creek.
7. Piedra Blanca Creek, above its junction with Sespe Creek near southeast corner sec. 36, T. 6 N., R. 22 W.
8. Sespe Creek, about 300 yards below the junction of Piedra Blanca Creek.
9. Sespe Creek, above junction of Bear Canyon Creek.

10. Bear Canyon Creek, above its junction with Sespe Creek.
11. Sespe Creek, 100 yards below the junction of Bear Canyon Creek.
12. Timber Canyon Creek, above its junction with Sespe Creek.
13. Sespe Creek, one-fourth mile below the junction of Timber Canyon Creek.
14. Red Reef Canyon Creek, above its junction with Sespe Creek near the southeast corner sec. 36, T. 6 N., R. 21 W.
15. Willett Hot Springs Creek, above its junction with Sespe Creek, about 1 mile below the junction of Red Reef Canyon Creek.
16. Sespe Creek at Hartman's, about 1 mile below the junction of Willett Hot Springs Creek.
17. Sespe Hot Springs Creek, above its junction with Sespe Creek, near southeast corner sec. 27, T. 6 N., R. 20 W.
18. Sespe Creek, 100 yards below the junction of Sespe Hot Springs Creek.
19. Alder Creek, above its junction with Sespe Creek, near the center of sec. 36, T. 6. N., R. 20 W.
20. Sidewalk Creek, above its junction with Sespe Creek, about 2 miles below that of Alder Creek.
21. West Fork of Sespe Creek, above its junction with Sespe Creek. This creek drains the southern slope of Topatopa Mountains, while the drainage of the northern slopes reaches Sespe Creek through Timber Canyon Creek and Red Reef Canyon.
22. Heaven Springs Creek, above its junction with Sespe Creek.
23. Tar Creek, above its junction with Sespe Creek. This is a tributary from the east and drains the area north of Little Sespe Creek.
24. Coldwater Canyon Creek, above its junction with Sespe Creek.
25. Pine Creek, above its junction with Sespe Creek. This and Coldwater Canyon Creek drain the rugged eastern slope of San Cayetano Mountain, just above the diversion dam of Sespe Creek.
26. Little Sespe Creek, above its junction with Sespe Creek, which is a half-mile below the diversion dam.
27. Sespe Creek at the highway bridge, 3½ miles below the diversion dam, and 1½ miles above its junction with the Santa Clara River.

WATERS OF PIRU CREEK

Piru Creek is, like Sespe Creek, an important tributary of the Santa Clara River. Its water is not stored but is diverted for the irrigation of land west of the town of Piru, where the surface flow is supplemented by wells. The quality of this surface flow is shown in Table 9, which is based on samples taken each week from August 1, 1928, to July 30, 1929.

TABLE 9.—*Quality of the water of Piru Creek, as sampled at the diversion dam above Piru, Calif.*

[Monthly means of weekly analyses]

Year and month	Analyses	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
1928	*Number*	*C. f. s.*		*P. p. m.*					
August	5	2	275	1.52	6.18	2.63	26.40	22.70	12.51
September	4	2	260	1.40	5.62	2.52	26.21	19.45	14.90
October	5	2	228	1.65	5.07	2.39	21.13	16.83	11.76
November	4	5	201	1.50	5.44	2.15	16.52	13.40	10.71
December	4	11	153	1.35	4.64	1.86	11.51	10.68	7.33
1929									
January	5	12	150	1.56	4.94	1.60	10.90	14.13	3.31
February	4	10	136	1.38	4.22	1.17	10.09	13.68	1.80
March	4	10	127	1.10	4.17	1.06	9.28	10.98	3.53
April	5	10	133	1.39	4.42	1.07	9.51	11.40	3.60
May	4	6	160	1.39	4.87	1.35	11.84	12.90	5.16
June	4	4	173	1.68	5.05	1.67	13.37	13.86	6.23
July	5	2	265	2.21	5.64	2.72	21.08	23.03	9.41
Mean		6.4	189	1.51	5.02	1.85	15.89	15.25	7.72

The salt content of this water, as measured by electrical conductance, is much higher than that of Sespé Creek, ranging for the individual observations from 98 to 312 and for the monthly means from 127 to 275, with an annual mean of 189×10^{-5} at 25° C., which indicates approximately 1,500 p. p. m. of total salts. With a mean annual discharge estimated at 6.3 c. f. s., this is equivalent to 25.5 tons of salt per day.

The boron content of the stream is less than that of Sespe Creek. The range for the individual observations was from 0.92 to 2.35 p. p. m. For the monthly means the range was from 1.35 to 2.21 p. p. m., with an average for the year of 1.54 p. p. m. There appears to be a slight correlation between the boron and the total salt content.

If the boron be computed as borax, then the daily discharge as borax is 233 pounds.

The composition of the salts other than those of boron shows a preponderance of sulphates, with a high proportion of alkaline-earth bases. For the latter part of the year, when the calcium and magnesium were determined separately, the proportions were approximately 8 milligram equivalents of calcium to 7 of magnesium. The ratio of alkaline-earth bases to alkaline bases is almost 2 to 1, indicating that this water, though salty, should not impair the physical condition of the soil.

The drainage basin of Piru Creek lies north and east of that of Sespe Creek. Its headwaters drain the eastern foothills of Pine Mountain, the southern slopes of which are drained by Sespe Creek and the northern slopes by Cuyama River. About 12 miles northeast of Pine Mountain is Lockwood Valley, on the northern side of which occur outcroppings of a borate mineral known as colemanite. These deposits were formerly mined on a commercial scale as a source of borax. The drainage of Lockwood Valley is collected in Lockwood Creek, which is an important tributary of Piru Creek.

A series of water samples from Piru Creek and its more important tributaries was obtained in the spring of 1930 by V. M. Freeman, managing engineer of the Santa Clara water conservation district, and discharge measurements were made at the places where the samples were taken. These samples were analyzed in duplicate at the Limoneira laboratory, and the results are given in Table 10. The analyses show that the stream waters above the junction of Lockwood Creek contain very little boron. This was found to be the case also with the headwaters of Sespe Creek and may be taken to indicate that the soils and rocks of Pine Mountain do not yield much boron.

Table 10.—*Quality of the water of Piru Creek and its tributaries as sampled in April, 1930*

[Samples taken by V. M. Freeman]

Location No.	Sample No.	Location	K × 10⁵ at 25° C.	Discharge	Boron	Milligram equivalents					
						CO_3+ HCO_3	Cl	SO_4	Ca	Mg	Alkaline bases
				C. f. s.	*P. p. m.*						
1	2591	Piru	136.0	2.03	0.18	2.50	0.10	13.58	9.55	5.51	1.32
2	2590	Mutau	60.4	.00	.09	2.20	.25	3.70	2.50	2.32	1.33
3	2592	Lockwood	72.3	1.56	4.95	2.20	.15	4.99	2.02	2.26	2.10
4	2589	Snowy	32.8	1.18	.09	2.30	.10	.83	1.51	1.33	.30
5	2587	Buck	49.8	1.06	.20	4.00	.25	1.27	2.83	1.63	1.00
6	2586	South	91.3	.10	.55	5.25	.55	4.55	3.69	2.72	3.94
7	2588	Alamos	83.2	2.32	.82	4.55	1.40	2.57	2.82	1.42	4.28
8	2585	Liebre Gulch	315.0	.05	2.26	9.05	3.05	21.58	7.27	11.40	17.01
9		French Flats		13.99							
10	2584	Piru	104.0	13.93	1.67	3.70	.60	6.73	4.59	3.66	2.78
11	2583	Fish	48.2	1.95	1.17	2.75	.05	2.10	1.88	2.71	.21
12	2582	West	81.5	.09	2.05	4.15	.25	3.46	4.66	2.68	.54
13	2581	East	168.0	.08	.32	4.20	.25	15.92	10.05	5.51	4.81
14	2541	Piru	98.2	15.40	1.05	3.70	.60	7.15	4.73	3.40	3.32
15	2540	Agua Blanca	152.0	2.91	1.28	4.50	.55	12.92	7.37	5.96	4.64
16	2539	Canton	160.0	.40	1.27	4.90	1.10	12.74	8.50	5.83	4.41
17	2538	James ranch	174.0	.14	1.49	4.95	.70	14.20	8.03	6.87	4.95
18	2537	Reasoner	292.0	.02	.27	4.55	1.10	35.20	17.94	14.20	8.71
19	2536	Lime	199.0	.02	.30	5.70	.25	17.28	8.37	8.21	6.65
20	2535	Modelo	402.0	.02	1.72	6.45	.60	43.50	11.02	13.07	25.56
21	2534	Piru	110.0	23.43	1.65	4.10	.95	9.16	5.77	4.24	4.20

Lockwood Creek, on the other hand, carries a large quantity of boron, doubtless obtained from the gradual solution of the borate minerals, chiefly calcium borate, exposed along the northern side of the valley. On April 12, 1930, when Lockwood Creek was sampled near its junction with Piru Creek its discharge was 1.56 c. f. s. and its boron content was 4.95 p. p. m. This discharge and boron content are equivalent to 367 pounds of borax per day. It is highly probable that the discharge and daily boron contribution of this stream is much less during the summer.

The tributaries immediately below Lockwood Creek do not contain much boron but lower down the waters of Fish Creek and Agua Blanca Creek bring substantial contributions. These streams drain broken country immediately east of Sespe Hot Springs, and there may be similar springs in their drainage basins.

Several of the smaller tributaries, notably Liebre Gulch and Reasoner and Modelo Creeks, are very salty, as is indicated by the high electrical conductance. These contributions may account for the high salt content of Piru Creek during the low-water period.

It seems probable that in addition to the surface flow of Piru Creek a substantial quantity of water is contributed to the underlying gravels of its delta through deep percolation. The quality of this underground water is shown in Table 4, locations 2 to 6, inclusive. These wells are so situated as to draw largely from the underflow of Piru Creek, though probably some water is drawn by them from the Santa Clara River or from Hopper Creek.

LOCATIONS ON PIRU CREEK LISTED IN TABLE 10 AND DATES OF SAMPLING

1. Piru Creek, 25 yards above the junction of Mutau Creek, sec. 20, T. 7 N., R. 20 W., San Bernardino base and meridian; April 12, 1930.
2. Mutau Creek, above its junction with Piru Creek; April 11, 1930.

3. Lockwood Creek, above its junction with Piru Creek, at east center sec. 16, T. 7 N., R. 20 W.; April 12, 1930.
4. Snowy Creek, above its junction with Piru Creek, at north center sec. 23, T. 7 N., R. 19 W.; April 11, 1930.
5. Buck Creek, above its junction with Piru Creek, at north center sec. 31, T. 7 N., R. 18 W.; April 10, 1930.
6. A small creek entering Piru Creek from the south, 2 miles east of Buck Creek; April 10, 1930.
7. Canada de Los Alamos Creek, above its junction with Piru Creek near center sec. 34, T. 7 N., R. 18 W.; April 10, 1930.
8. Liebre Gulch Creek, above its junction with Piru Creek, northeast corner sec. 2, T. 6 N., R. 18 W.; April 10, 1930.
9. Piru Creek, at French Flats, sec. 13, T. 6 N., R. 18 W. Stream measurement but no sample, April 10, 1930.
10. Piru Creek, above the junction of Fish Creek, 3 miles below location 9; April 9, 1930.
11. Fish Creek, above its junction with Piru Creek; April 9, 1930.
12. A small stream, joining Piru Creek from the west, 1 mile below Fish Creek; April 9, 1930.
13. A small stream, joining Piru Creek from the east, 3 miles below Fish Creek; April 9, 1930.
14. Piru Creek, above the junction of Agua Blanca Creek; April 8, 1930.
15. Agua Blanca Creek, above its junction with Piru Creek, near southeast corner sec. 4, T. 5 N., R. 18 W.; April 8, 1930.
16. Canton Creek, above its junction with Piru Creek, 2 miles below the junction of Agua Blanca Creek; April 8, 1930.
17. A small creek, joining Piru Creek from the west, near the James ranch, sec. 26, T. 5 N., R. 18 W.; April 8, 1930.
18. Reasoner Creek, above its junction with Piru Creek; April 8, 1930.
19. Lime Creek, above its junction with Piru Creek; April 8, 1930.
20. Modelo Creek, above its junction with Piru Creek; April 8, 1930.
21. Piru Creek, at railroad bridge near Piru; April 8, 1930.

OJAI VALLEY AND VENTURA RIVER

Ojai Valley is a small valley located about 12 miles northwest of the Santa Clara Valley on the north side of Sulphur Mountain. Its drainage outlet is through San Antonio Creek, which is a tributary of Ventura River. There are a number of citrus plantings in the Ojai Valley, and these trees are free from the symptoms of boron injury that occur so commonly in the Santa Clara Valley.

Water samples were obtained from two sources near the upper or east end of Ojai Valley. (Table 11 and fig. 3.) One of these (from location 1) represents surface and spring water draining from the hills into Horn Canyon, and the other (from location 2) is from a deep well on the delta cone of that canyon. In both these waters the boron content is very low.

TABLE 11.—*Quality of the water of the Ojai Valley and of Ventura River*

Location No.	Samples	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
				CO_3+HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number		*P. p. m.*					
1	1	79.8	0.12	3.76	0.26	4.57	8.51	0.08
2	1	75.2	.10	3.77	.28	3.96	7.67	.34
3	1	100.1	.17	4.19	1.51	5.37	8.95	2.12
4	2	126.0	.14	5.78	1.46	6.90	12.89	1.25

The other sources sampled for this area represent the combined drainage of the Ventura River. The water from location 3 represents the surface flow of that stream at a point about 5 miles above its mouth. That at location 4 represents underground water close to the stream bed. The water from both these locations contains somewhat more salt and more boron than the water from the upper Ojai Valley. It may be noted that the chloride content also is higher. This higher content of boron and of chloride may be due to the effect of a number of hot springs that occur in the foothills along the Ventura River above the point where the samples were taken.

LOCATIONS LISTED IN TABLE 11

(See fig. 3)

1. Outlet of pipe line from Horn Canyon on Topatopa ranch at east end of Ojai Valley, near southwest corner sec. 34, T. 5 N., R. 22 W., Mount Diablo base and meridian. These samples represent surface and spring waters.
2. Topatopa ranch well, near northeast corner sec. 4, T. 4 N., R. 22 W.; depth, 407 feet; discharge, 0.33 cubic foot per second.
3. Ventura River, at Foster Park, about 5 miles north of the city of Ventura.
4. Berger's well near the bed of the Ventura River, at Foster Park. An open pit, 8 feet square and 30 feet deep; static level of water, about 12 feet below surface.

PARIDA CREEK AND VICINITY

On the coastal plain between Carpinteria and Summerland, northwest of Ventura, there are a number of groves of citrus trees irrigated partly by surface waters from the slopes of the Santa Ynez Mountains and partly by water from wells. It was found that in an area located about 2 miles northwest of Carpinteria a number of citrus trees showed pronounced symptoms of boron injury. An investigation of this area resulted in finding a spring, known locally as the O'Banion Spring, in which the water contained the highest proportion of boron so far found in any water in southern California—17.3 p. p. m. This spring is located at the eastern end of a hill that lies between Santa Monica Canyon and Toro Canyon. The hill is separated from the main foothills by a narrow valley which follows a fault line known as the Parida fault. (Fig. 4.) Through this valley flows Parida Creek, whose discharge is absorbed in its gravel delta close to the hills.

Parida Creek has one important tributary that drains Oil Canyon and joins the main stream just above the fault line. Samples of water obtained on February 15, 1929, from the upper section of Parida Creek, showed low boron content. (Table 12.) No. 642, taken from the stream in Oil Canyon above its junction with Parida Creek, contained 0.23 p. p. m. of boron, while No. 641, taken from the stream near the fault line, contained 0.48 p. p. m.

TABLE 12.—*Quality of the water of Parida Creek area above Carpinteria, Calif.*

Sample No.	Location	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
				CO_3 + HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
			P. p. m.					
642	Oil Canyon	116	0.23	6.05	1.10	6.03	7.38+4.90	0.90
641	Parida Creek	98	.48	6.10	2.05	1.80	4.90+3.23	1.91
422	O'Banion Spring	487	17.30	11.85	38.70	(1)	1.45	47.10
420	Parida Creek	256	6.60	8.20	16.40	.82	4.60	20.82
421	do	235	5.84	8.70	14.20	.86	4.70	19.06
311	do	278	7.74	7.45	10.75	.37	5.05	22.52
206	Lewis well	167	1.80	5.15	8.75	2.00	15.20	.79

[1] Trace.

The sample from O'Banion Spring, No. 422, taken on November 20, 1928, had a high specific conductance and, in addition to a boron content of 17.3 p. p. m., only a trace of sulphate, the salts being chiefly sodium chloride and sodium bicarbonate. Again it is to be observed that high boron content appears to be associated with high chloride content. It seems probable that the boron appearing in this

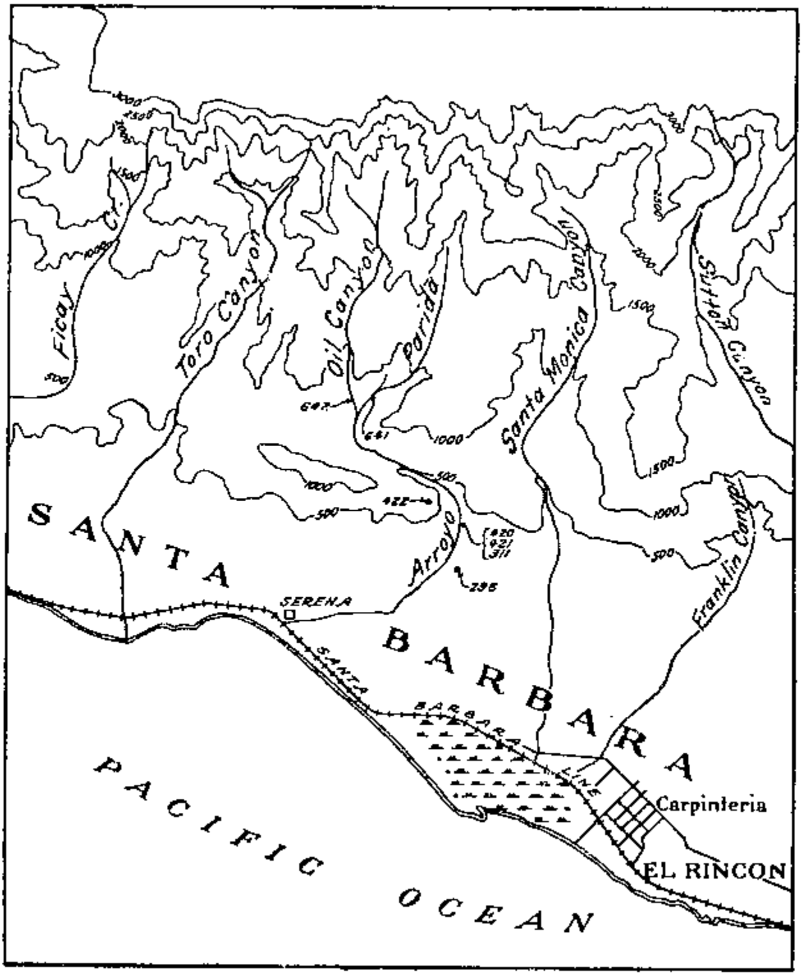

FIGURE 4.—Map of a portion of the Santa Barbara area on the coast of southern California, showing by number the location of Parida Creek and of the water samples reported in Table 12

spring water is derived from some form of volcanic activity connected with the formation of the adjacent fault.

Three samples of water taken from Parida Creek below the location of the O'Banion Spring showed high boron content. No. 420, taken on November 20, 1928, from the main stream as piped to a dairy ranch, contained 6.6 p. p. m., while No. 421, taken on the same date from the main stream at the 250-foot contour line, contained 5.84 p. p. m. The third sample, No. 311, was taken on October 24, 1928, farther downstream where the water is diverted for irrigation. This sample contained 7.74 p. p. m. This water, which is available only during the winter months following rains, is said to have been very injurious to the orchard trees on which it was used.

The last sample of this series, No. 296, is from a well located on the delta cone of Parida Creek, from which water is taken for irrigation during the summer when the creek supply is low. This well water, while much less salty than the creek water and containing much less boron, 1.89 p. p. m., shows the influence of the creek water in both its boron and chloride content, which are much higher than is usual in the wells of the Ventura area. The lemon and walnut trees that had been irrigated partly with the creek water and partly with water from this well showed pronounced symptoms of injury not only in their leaves but also in general growth conditions.

The conditions that have resulted in the occurrence of the high content of boron in the waters of Parida Creek appear to be local. No evidence of boron injury has been found in groves on either side of those watered by it. Furthermore, a sample of water from Santa Monica Creek, the next stream east of Parida Creek, showed only 0.14 p. p. m. of boron, while a sample from Rincon Creek, still farther east, contained only 0.27 p. p. m.

The influence of the salts contributed by Parida Creek to the underground waters below its delta cone is to be seen in a series of samples obtained from another well in that area. These samples (Table 13) are from a well located within a few hundred feet of the beach at Serena, about 1 mile from the delta of Parida Creek. The table shows in detail the analyses of six samples taken on successive dates. These analyses show how slight are the variations that occur in such a series and the consequent probability that a single sample from a well will give dependable information as to the quality of the water.

TABLE 13.—*Quality of the water of the Serena well of the Toro Canyon ranch, located near the beach of the Pacific at the delta of Parida Creek*

[Discharge, 0.21 cubic feet per second]

Date	Sample No.	K × 10⁵ at 25° C.	Boron	Milligram equivalents				
				CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
1928			*P. p. m.*					
Oct. 20	294	99	0.84	5.00	2.60	2.58	5.10	5.38
Oct. 24	310	95	.86	5.05	2.70	2.79	5.60	4.94
Nov. 1	337	91	.82	4.50	2.40	2.80	5.00	4.70
Nov. 6	357	91	.88	4.90	2.40	2.70	5.20	4.80
Nov. 14	402	96	.78	4.85	2.25	2.75	5.35	4.50
1929								
Feb. 15	643	97	.63	4.65	2.30	2.36	6.69	2.62
Mean		95	.79	4.82	2.44	2.71	5.49	4.48

The water of the Serena well contains much less salt than that of Parida Creek and also much less boron; yet in both boron and chloride its content is higher than that of waters from outside the area immediately influenced by Parida Creek. The samples from Santa Monica and Rincon Creeks to the eastward have been referred to in a foregoing paragraph. Waters to the westward were likewise found to be free from injurious boron contamination. A series of samples was obtained from the supply line of the Montecito water district, the analyses of which are given in Table 14. The water supply for this district has been developed in the course of driving a tunnel through the Santa Ynez Mountains, by which it is intended ultimately to conduct surplus flood waters stored by a reservoir on the Santa Ynez River, which drains the region north of these mountains. The samples reported in the table represent water developed in the tunnel and not the water of the Santa Ynez River. This water is not only low in total salts (conductance 66×10^{-5}) but is also low in boron, 0.20 p. p. m. A sample (No. 295) obtained from a well used for irrigation in the vicinity of Goleta, still farther west beyond Santa Barbara, was found to have a conductance of 187×10^{-5} and a boron content of 0.26 p. p. m.

TABLE 14. *Quality of the water of the Montecito water district, as sampled at the pipe line from the tunnel leading to the Santa Ynez River*

Date	Sample No.	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
				CO_3 + HCO_3	Cl	SO_4	Ca + Mg	Alkaline bases
1928			*P. p. m.*					
Oct. 23	309	68	0.17	4.35	0.30	3.03	4.05	3.63
Oct. 30	336	62	.22	3.30	.45	3.07	4.50	2.32
Nov. 6	358	65	.21	4.10	.25	2.90	4.50	2.75
Nov. 14	401	70	.20	4.50	.30	3.06	4.90	2.96
Mean		66	.20	4.06	.32	3.01	4.49	2.90

It should not be inferred from the foregoing statements that there are no other occurrences of injurious quantities of boron in waters to the west and northwest along the coast above Santa Barbara. That region has not yet been examined critically. The point it is desired to emphasize is that the occurrence of boron in a stream such as Parida Creek may be due to local conditions and may be confined to a small area.

SIMI AND LAS POSAS VALLEYS

Simi and Las Posas Valleys, which are connected end to end, lie to the south of the Santa Clara Valley and are separated from it by hills known as Oak Ridge and South Mountain. The valleys include the towns of Santa Susana, Simi, Moorpark, and Somis. The drainage is not sufficient to maintain a perennial surface flow from the valleys, and there is no defined stream channel at the western end, which is the natural outlet.

The irrigation supply of the two valleys is largely obtained from wells located in the valley trough or near the deltas of the tributary valleys. The salt constituents of the underground waters taken from some of these wells are shown in Table 15. (Fig. 3.) The wells are so selected as to be representative of most of the irrigation waters in this section. All the waters sampled are relatively high in total salt content as measured by specific conductance, and the boron content is close to or above the critical limit of 0.5 p. p. m. The supply at location 2 is well above that limit, and it was noted that the leaves of the walnut trees irrigated with that water showed the characteristic type of injury and the high boron content that have been observed in other areas where the boron content of the irrigation water is much above 0.5 p. p. m. These waters are also characterized by relatively high proportions of sulphates and alkaline-earth bases, in which they resemble the waters of the Santa Clara Valley.

TABLE 15.—*Quality of the underground water of the Simi Valley*

Location No.	Samples	$K \times 10^6$ at 25° C.	Boron	Milligram equivalents				
				CO_3+HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number		*P. p. m.*					
1	3	153	0.68	5.17	2.06	10.57	13.15	4.65
2	6	204	.98	4.62	2.93	16.63	18.01	6.17
3	3	190	.71	4.80	3.12	14.21	14.63	7.50
4	4	139	.48	4.13	2.22	9.17	10.63	4.89
5	5	155	.55	3.96	3.16	10.00	11.87	5.25
6	4	171	.60	5.30	2.28	11.15	13.75	5.04

LOCATIONS OF WELLS LISTED IN TABLE 15

1. Wells of the Tapo Mutual Water Co., on the north side of the Simi Valley near the outlet of Tapo Canyon, about 2.5 miles northwest of Santa Susana. These samples represent a number of different wells and possibly some gravity water.
2. Wolff ranch well, 0.25 mile north of the highway, 1 mile west of Santa Susana; depth, 433 feet; discharge, 1.8 cubic feet per second.
3. Simi ranch well, 0.2 mile north of Simi, near the bed of the arroyo; depth, 227 feet; discharge, 0.8 cubic foot per second.
4. Hacienda Sinaloa wells, 0.5 mile southwest of Simi; depth of three wells, 200 to 222 feet; combined discharge, 3.5 cubic feet per second.
5. Zone Mutual Water Co. wells, 1 mile east of Somis, and 0.1 mile south of highway near channel of Arroyo Las Posas; approximate depth, 790 feet; discharge, 4.5 cubic feet per second.
6. Del Norte Water Co. well, 2.5 miles southeast of Saticoy, near the junction of Las Posas Valley with the Santa Clara Valley.

LOS ANGELES AQUEDUCT

In view of the fact that symptoms of boron injury on citrus and walnut trees had been observed in the San Fernando Valley, it seemed advisable to investigate the water supplies used for irrigation in that valley. These irrigation waters are obtained partly by pumping from the underground waters of the valley, but mostly from the Los Angeles Aqueduct. Water from the aqueduct became available for irrigation in the San Fernando Valley in 1916, and since that time its distribution and use have been extended until at present it forms by far the chief supply.

The Los Angeles or Owens River Aqueduct draws its water supply chiefly from Owens River. The aqueduct heading is located in Owens Valley near the southwest corner of sec. 13, T. 11 S., R. 34 E., Mount Diablo base and meridian. From this diversion point the water of Owens River is carried south through the valley in an open, unlined canal for 24 miles to a point known as Alabama Gates. Some creeks and springs discharge into the canal along this section, and the natural flow is supplemented by a number of wells (about 60) that are drawn upon during the summer as additional water is needed.

From Alabama Gates the water is carried in an open, concrete-lined canal along the eastern base of Alabama Hills and the Sierras, in a southerly direction for 25 miles, where it is discharged into the north end of Haiwee Reservoir. A few streams from the mountains, notably Cottonwood Creek, contribute some water to the canal in this section. Throughout this section the canal is carried above the level of the valley floor and the dry bed that was formerly Owens Lake.

Haiwee Reservoir is located on a low ridge that separates Owens Valley from the Mohave Desert and drainage basin. It occupies a narrow trough across this ridge with a dam at the north end as well as at the south end. Its capacity is 63,000 acre-feet, and it serves to equalize the variable discharge of the upper canal.

At the south end of Haiwee Reservoir the water is carried through a penstock and power house, from which it passes into the main section of the aqueduct, a lined and covered section that discharges finally, through a power house, into a reservoir in the San Fernando Valley just north of the city of Los Angeles.

For the examination of the water of the aqueduct here reported, samples were taken each week for one year at five points as follows:

(1) At the heading near Aberdeen, where the samples represent the surface waters reaching the Owens River above that point.

(2) At Alabama Gates, north of Lone Pine, where the samples represent not only the surface waters diverted from the river at the heading but also the additions contributed by springs and by seepage along the unlined section of the canal and by the wells located in the valley on both sides of the canal.

(3) At North Haiwee, near Olancha, where the water is discharged from the lined section of the canal into the Haiwee Reservoir. Samples taken at this point were expected to serve as checks on the samples taken at Alabama Gates, except as influenced by the small or occasional contributions from the creeks that drain the eastern slopes of the Sierras in this section.

(4) At South Haiwee, where the mixed waters of the reservoir are discharged into the covered section of the aqueduct.

(5) At the San Fernando power house, where the water from the aqueduct is discharged into a reservoir from which it passes into conduits, partly for domestic and industrial uses in Los Angeles and partly for irrigation in the San Fernando Valley.

It was thought that by means of this series of samples taken each week throughout the year it would be possible to determine whether the boron in this supply was contributed largely from the drainage area above the heading or from the area below that point, and, furthermore, that these samples would afford an opportunity to check the accuracy of the analytical determinations.

In addition, it was decided to obtain samples from the underground supply in the San Fernando Valley. It had been observed that the symptoms of boron injury were not to be found everywhere throughout the valley and that some of this underground water was used for irrigation. For purposes of comparison with the aqueduct supply, a series of weekly samples was obtained from one of the wells supplying the city of San Fernando, and samples were also obtained for short periods from one of the mission wells and from one of the Lankershim wells.

OWENS RIVER ABOVE THE AQUEDUCT HEADING

Owens River is formed by the union of its upper tributaries in Long Valley, about 20 miles southeast of Mono Lake. This valley is about 12 miles long by 7 miles wide, sloping to the southeast. Its swampy floor is 7,000 feet above sea level. The more important tributaries drain the high Sierras that bound the valley on the south and west.

(Fig. 5.) In the valley there are a number of hot springs and small geysers, which yield only small quantities of water; but these waters are relatively rich in boron salts.

The waters collecting in Long Valley to form Owens River are discharged through a narrow gorge at the southeast corner of the valley, emerging into the northwest corner of the upper Owens or Bishop Valley at an elevation of 4,500 feet. In Bishop Valley numerous other creeks contribute to Owens River, notably Rock Creek and Bishop Creek. The waters of these creeks and of Owens River are extensively diverted for irrigation in the Bishop Valley, the floor of which is

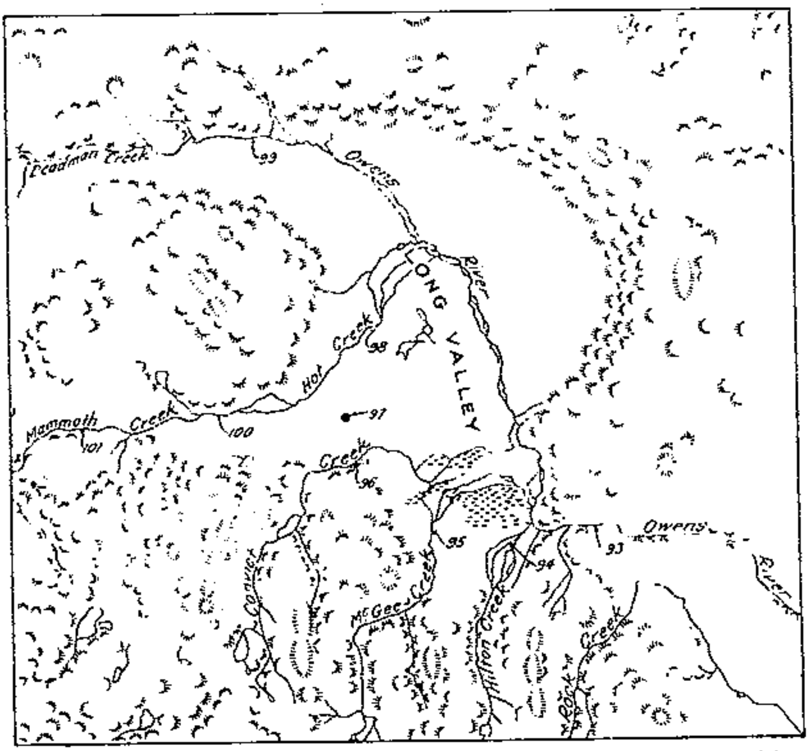

FIGURE 5.—Map of Long Valley, Calif., showing tributaries of Owens River at its head and locations of water samples collected in August, 1928. The numbers refer to those listed in Table 16

flat and poorly drained. The surplus waters not used in crop production or dissipated by evaporation from the valley swamps find their way into the main channel of Owens River and pass from Bishop Valley into the main or lower Owens Valley to be diverted into the aqueduct.

In the summer of 1928 numerous samples of water were collected from streams and springs tributary to Owens River above the aqueduct heading. The first series of samples collected in July was tested qualitatively for boron. It was found that in the mountain streams and in many of the springs the boron content was very low but that the water of the main stream as it leaves Long Valley gave a strong boron reaction. It was found also that the waters from the hot springs and geysers in Long Valley were rich in boron, and the indications were that these were the chief source of the boron carried in Owens River.

In August of the same year, 1928, a series of larger samples of water was collected from this area for the quantitative determination of the boron content. The results of the analyses of these samples are given in Table 16.[5] The first five samples listed in the table represent creeks that discharge into Long Valley from the mountains. These waters are all very pure and contain very little boron. They may be taken as typical of most of the water contributed to Owens River.

TABLE 16.—*Quality of the water of Owens River and its tributaries above the heading of the Los Angeles Aqueduct, as sampled in August, 1928*

Sample No.	Temperature	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
					CO_3+HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	°C.	C. f. s.		P. p. m.					
94	18	3.0	4.27	0.13	0.46	0.48	0.18	0.20	0.52
95	13	10.0	10.3	.05	.90	(1)	.51	.90	.41
96	20.5	5.0	11.9	.03	1.00	(1)	.53	1.10	.43
101	16.5	15.0	9.78	.02	.90	(1)	.14	.80	.24
100	19	30.0	8.76	.08	.90	(1)	.64	.50	.94
98	34.5	35.0	59.1	2.32	3.60	1.58	.68	1.00	4.86
97	36	1.0	69.1	2.31	4.30	2.03	.70	1.05	5.98
99	21	100.0	21.1	.41	1.60	.29	.15	.85	1.19
93	17.5		37.1	1.00	2.70	.70	.38	1.35	2.43
92	24		31.3	.92	2.20	.57	.49	1.05	2.21
91	22	11.3	40.0	.28	2.70	.30	1.16	2.25	1.91
102	19	23.0	31.9	.38	2.60	.37	.44	1.85	1.56
90	25	.6	489.0	9.28	50.40	14.37	1.06	43.50	22.33

[1] Trace.

Of these five samples the last two, Nos. 101 and 100, were taken from the upper section of Mammoth Creek. This creek was given special attention because it had been found in the earlier survey that the water near its lower end gave a strong reaction for boron. The difference in the quality of the waters of this creek has been recognized locally, the same stream that is known as Mammoth Creek along its upper section being called Hot Creek along its lower section. When the samples were taken on August 17, 1928, the temperature of the water at the town of Mammoth was 16.5° C. (62° F.); at the highway crossing it was 19° C. (66° F.); while in the lower section, below the hot springs (sample No. 98), it was 34.5° C. (94° F.). The hot springs and geysers that appear to be largely responsible for the higher temperature and the increased boron content of the water are located along the creek in a canyon in sec. 25, T. 3 S., R. 28 E. The quantity of water contributed by these geysers appears to be small, but its salt and boron content must be high, since the conductance of the water above them is 9×10^{-5}, while below them it is 59×10^{-5}. The boron content of the whole stream, which had an estimated discharge of 30 cubic feet per second above the geysers, is increased from less than 0.1 to 2.32 p. p. m.

The water of Owens River as sampled near the Ford ranch above the junction of Hot Creek (sample No. 99), had a conductance of

[5] The last four samples listed in this table are from the Bishop Valley, and the locations are not shown on the map, Figure 5.

21×10^{-5} and a boron content of 0.41 p. p. m. The same stream, as sampled at the head of the gorge where it leaves Long Valley (sample No. 93), had a conductance of 37×10^{-5} and a boron content of 1 p. p. m. At the lower end of the gorge (sample No. 92), the conductance was 31×10^{-5}, and the boron content 0.92 p. p. m., indicating that there was some dilution in that section of the stream.

The foregoing observations as to conditions in Long Valley indicate that the boron carried out of the valley by Owens River is derived largely from the hot springs that occur at several places on the valley floor. Among these, the ones located along the channel of Mammoth Creek appear to be the most important. But there are known to be others, as at Casa Diablo and at Whitmore's Tub. A sample of water obtained at the latter place (sample No. 97), had a conductance of 69×10^{-5} and a boron content of 2.94 p. p. m.

In view of the fact that the quantities of water delivered by these high-boron hot springs are relatively small, it might be possible to isolate some or all of them from the main drainage system and thereby reduce materially the quantity of boron carried by the main stream.

The surveys of the summer of 1928 did not disclose any important source of boron contamination in the Owens River drainage below Long Valley. A sample of water from Fish Slough, north of Bishop (sample No. 91), contained only 0.28 p. p. m., while a sample of water from a drainage canal south of Bishop and below the delta of Bishop Creek (sample No. 102) contained only 0.38 p. p. m. of boron. The latter sample is significant in that it represents in part drainage from lands irrigated by diversion from Owens River, and its composition shows that the boron content of the underground water is lower than that of Owens River, probably because of dilution by the relatively pure water from Bishop Creek.

The last sample listed in Table 16 (sample No. 90) is from an artesian well just south of the aqueduct heading in Owens Valley. The water from this well is warm and very salty, with a conductance of 489×10^{-5}; and the boron content of 9.28 p. p. m. is very high. The discharge of 0.6 cubic feet per second is so small, however, that the total quantity of boron contributed to the aqueduct supply from this source is small as compared with the quantities derived from the hot springs in Long Valley. Thus, if the boron content of the water from this artesian well be computed as borax, on the basis of the analysis and discharge reported from sample No. 90 in the table, the daily output of borax from this well would be 265 pounds. By a similar computation for Hot Creek (sample No. 98), a discharge of 35 cubic feet per second, with a boron content of 2.32 p. p. m., is equivalent to 3,859 pounds of borax per day.

These surveys of the tributaries of Owens River above the aqueduct heading indicate that the boron entering the aqueduct water supply is largely contributed by the hot springs and geysers in Long Valley. These geysers and hot springs yield a relatively small part of the total water supply obtained from that valley, and in so far as it may be feasible to isolate them and withhold their waters there should result a corresponding decrease in the boron content of the aqueduct water.

LOCATIONS LISTED BY LABORATORY NUMBERS IN TABLE 16

94. Hilton Creek, in Long Valley, about 1 mile above its junction with Owens River; sec. 23, T. 4 S., R. 29 E., Mount Diablo base and meridian; sample taken August 17, 1928; temperature, 18° C.

95. McGee Creek, in Long Valley, about 3 miles above its junction with Owens River; sec. 21, T. 4 S., R. 29 E.; sample taken August 17, 1928; temperature, 13° C.

96. Convict Creek, in Long Valley, about 5 miles above its junction with Owens River; sec. 6, T. 4 S., R. 29 E.; sample taken August 17, 1928; temperature, 20.5° C.

101. Mammoth Creek (Hot Creek), in Long Valley, at Mammoth, about 13 miles above its junction with Owens River; sec. 2, T. 4 S., R. 27 E.; sample taken August 17, 1928; temperature, 16.5° C.

100. Mammoth Creek (Hot Creek), in Long Valley at highway crossing, about 9 miles above its junction with Owens River; sec. 32, T. 3 S., R. 28 E.; sample taken August 17, 1928; temperature, 19° C.

98. Hot Creek (Mammoth Creek), in Long Valley at bridge, about 3 miles above its junction with Owens River; sec. 19, T. 3 S., R. 29 E.; sample taken August 17, 1928; temperature, 34.5° C.

97. Whitmore Tub Springs, in Long Valley; sec. 6, T. 4 S., R. 29 E.; sample taken August 17, 1928; temperature, 36° C.

99. Owens River, in Long Valley, at Ford ranch, 6 miles above junction of Hot Creek, sec. 25, T. 2 S., R. 28 E.; sample taken August 17, 1928; temperature, 21° C.

93. Owens River, at outlet of Long Valley, one-fourth mile below the junction of Crooked Creek; sec. 19, T. 4 S., R. 30 E.; sample taken August 17, 1928; temperature, 17.5° C.

92. Owens River, at mouth of gorge into Round Valley, one-half mile above junction of Rock Creek; sec. 10, T. 6 S., R. 31 E.; sample taken August 16, 1928; temperature, 21° C.

91. Fish Slough, Bishop Valley, about 2 miles above its junction with Owens River; sec. 13, T. 6 S., R. 33 E.; sample taken August 16, 1928; temperature, 22° C.

102. Drainage ditch, Owens Valley, 4 miles south of Bishop; sample taken August 17, 1928; temperature, 19° C.

90. Artesian well, Aberdeen; one-fourth mile south of the heading of the Los Angeles Aqueduct; sample taken August 16, 1928; temperature, 25° C.

QUALITY OF THE AQUEDUCT WATER

The general features of the Owens River Aqueduct and the locations of the places where its waters were sampled have been described above. It remains to report and discuss the results of the analyses of these samples. The samples from the heading, Alabama Gates, North Haiwee, and South Haiwee were taken each week throughout the year by local employees of the bureau of water and power of the city of Los Angeles.[6] The samples were taken in 1-gallon glass bottles. These were labeled as to date, location, and volume of discharge, and were shipped by parcel post to the Limoneira laboratory at Santa Paula. The samples from the San Fernando power house were taken by persons connected with the Limoneira laboratory until April 9, 1929, after which date they were taken by R. L. Rich, a power-house employee, and sent to the laboratory by mail.

The quality of the water at the aqueduct heading for the year ended August 2, 1929, is shown in Table 17. At this point the volume of discharge is more variable from month to month than it is at the other points where samples were taken. It was at its lowest in August, 1928, increasing rapidly in October with the advent of winter rains and

[6] The samples from the aqueduct heading were taken by John I. Jones; those from Alabama Gates by Frank Laskey; those from North Haiwee by William Carter; and those from South Haiwee by J. L. McCullough.

the end of the irrigation season in Bishop Valley. It should be noted with respect to these discharge records that the figures reported in this and the following tables for the aqueduct are the means of reports made each week at the time of sampling. These figures should not be taken as representing the actual mean daily discharge of the aqueduct at the points named, because of fluctuations that may have occurred between the times of sampling. The peak of the discharge at the heading for the year occurred during the winter months, December to February. The total salt content as measured by specific electrical conductance (at 25° C.) was always low as compared with many of the irrigation supplies of southern California.

TABLE 17.—*Quality of the water of the Los Angeles Aqueduct as sampled at the heading near Aberdeen, Calif., August, 1928, to July, 1929*

[Monthly means of weekly analyses]

Year and month	Samples	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
					CO_3+HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number	*C. f. s.*		*P. p. m.*					
1928									
August	5	62	41.5	0.47	3.26	0.62	0.64	2.16	2.36
September	4	90	44.0	.56	3.45	.59	.75	2.02	2.76
October	4	218	37.2	.77	2.71	.67	.68	1.51	2.55
November	5	291	37.5	.87	2.59	.58	.59	1.23	2.53
December	4	328	37.3	.68	2.60	.69	.63	1.54	2.38
1929									
January	5	338	38.8	.80	2.66	.71	.58	1.74	2.21
February	4	323	45.6	.78	2.85	.75	.86	2.11	2.34
March	4	274	55.5	1.26	3.63	1.12	.73	1.95	3.53
April	4	187	48.7	.96	3.27	.87	.78	2.25	2.67
May	5	163	45.7	.78	3.18	.63	.68	2.25	2.24
June	4	159	39.5	.72	2.74	.60	.52	1.86	2.00
July	5	126	35.3	.55	2.59	.49	.58	1.98	1.64
Mean		213	42.2	.77	2.96	.69	.67	1.88	2.43

The mean monthly boron content at the aqueduct heading ranged from a low point of 0.47 p. p. m. in August, 1928, to 1.26 p. p. m. in March, 1929, with a mean of 0.77 for the year. The discharge of Owens River as sampled at the aqueduct heading shows a condition with respect to the relation of salt content to discharge that is different from that of some of the other streams in southern California. The salt content of Owens River tends to increase with the discharge, particularly toward the end of the flood season. The salt content of the Colorado River, on the other hand, is much lower during the flood season than during the period of low discharge. It will be observed also that there is an apparent relationship between the boron content and the chloride content of the water entering the aqueduct. A similar relationship is to be seen in Table 16, which includes the analyses of waters from Long Valley and from an artesian well in Owens Valley. The boron content of the water at the aqueduct heading when computed as borax is equivalent to an average of 3.89 tons per day.

The conditions at Alabama Gates are shown in Table 18. It may be recalled that the aqueduct water is conducted from the heading to Alabama Gates in an open, unlined canal into which springs, streams, and wells discharge. There is somewhat less variation in the discharge from month to month at Alabama Gates than at the heading. Both the salt content, as measured by conductance, and the boron content are lower. This fact indicates that the water contributed along this section, a daily average for the year of 63 c. f. s., adds very little salt or boron to the system. The computed borax content of the aqueduct at this point is equivalent to 4.06 tons per day.

TABLE 18.—*Quality of the water of the Los Angeles Aqueduct as sampled at Alabama Gates, near Lone Pine, Calif., August, 1928, to July, 1929*

[Monthly means of weekly analyses]

Year and month	Samples	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number	*C. f. s.*		*P. p. m.*					
1928									
August	4	153	32.0	0.30	2.32	0.51	0.62	1.50	1.87
September	4	173	31.0	.46	2.46	.44	.55	1.39	2.06
October	4	205	33.3	.64	2.32	.55	.88	1.54	2.24
November	4	364	35.0	.66	2.47	.50	.55	1.20	2.42
December	5	382	34.6	.63	2.38	.59	.68	1.51	2.12
1929									
January	4	382	38.1	.71	2.26	.64	.56	1.67	1.79
February	4	376	40.6	.67	2.58	.66	.63	1.74	2.11
March	4	338	44.3	.90	2.07	.79	.69	1.71	2.74
April	4	203	44.1	.76	3.01	.82	.64	2.13	2.35
May	4	233	39.6	.65	2.50	.61	.52	2.01	1.71
June	5	217	33.8	.56	2.30	.49	.48	1.82	1.45
July	5	200	31.6	.40	2.25	.50	.46	1.84	1.33
Mean		276	36.7	.62	2.49	.60	.60	1.68	2.01

The samples taken at North Haiwee (Table 19) should show conditions closely similar to those found at Alabama Gates. The canal between these two points is concrete lined, and the total contribution from the creeks discharging into this section is not large. In view of the fact that the samples were taken at the two points on different days of the week and might represent different conditions of discharge, it is not to be expected that there would be exact agreement in the analytical results. There is, however, a close agreement between the two stations in the annual means. The discharge at North Haiwee is slightly higher, by a daily average of 7 c. f. s. The total salt content as measured by conductance is slightly lower, indicating that a measurable quantity of salt is not contributed to this section of the canal. The mean boron content is slightly higher, but a critical examination of the detailed analytical results leads to the conclusion that this higher mean is due to the chance irregularities of sampling rather than to uniformly higher boron content at North Haiwee. Differences of similar magnitude occur in the results for the other constituents reported in the tables.

TABLE 19.—*Quality of the water of the Los Angeles Aqueduct as sampled at North Haiwee, near Olancha, Calif., August, 1928, to July, 1929*

[Monthly means of weekly analyses]

Year and month	Samples	Discharge	K × 10⁵ at 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number	*C. f. s.*		*P. p. m.*					
1928									
August	5	143	31.3	0.39	2.15	0.51	0.54	1.49	1.67
September	4	176	34.5	.59	2.42	.61	.82	1.35	2.51
October	4	300	33.4	.64	2.39	.59	.50	1.24	2.32
November	5	368	34.6	.86	2.42	.62	.53	1.19	2.38
December	4	402	34.3	.60	2.34	.61	.61	1.41	2.15
1929									
January	5	394	37.4	.74	2.57	.60	.53	1.70	2.09
February	4	381	39.8	.74	2.66	.72	.55	1.71	2.23
March	4	336	40.2	1.20	3.24	1.01	.70	1.67	3.28
April	4	204	40.1	.80	2.78	.69	.49	2.03	1.93
May	5	246	35.4	.62	2.48	.59	.66	1.95	1.78
June	4	234	33.2	.52	2.23	.48	.47	1.71	1.47
July	5	215	30.2	.40	2.08	.46	.53	1.72	1.36
Mean		283	36.1	.67	2.48	.63	.58	1.60	2.10

The analytical results for the samples taken at South Haiwee are given in Table 20. The samples taken at this station represent water that has been mixed in the Haiwee Reservoir and consequently should be, as shown in the table, less variable from month to month than samples taken from stations above the reservoir. The discharge for the year at South Haiwee averaged very close to that at North Haiwee, and the average boron content was the same, which affords a basis for confidence in the accuracy of these determinations.

TABLE 20.—*Quality of the water of the Los Angeles Aqueduct as sampled at South Haiwee, near Olancha, Calif., August, 1928, to July, 1929*

[Monthly means of weekly analyses]

Year and month	Samples	Discharge	K × 10⁵ at 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number	*C. f. s.*		*P. p. m.*					
1928									
August	4	375	33.2	0.64	2.40	0.52	0.65	1.27	2.28
September	5	300	36.9	.66	2.62	.62	.79	1.34	2.76
October	4	254	36.0	.58	2.47	.64	.79	1.39	2.54
November	5	267	36.0	.61	2.68	.56	.72	1.23	2.71
December	4	275	35.2	.56	2.49	.61	.66	1.62	2.14
1929									
January	5	232	36.0	.67	2.47	.66	.54	1.78	1.89
February	4	220	37.0	.68	2.56	.65	.53	1.69	2.05
March	4	220	39.3	.74	2.58	.62	.64	1.70	2.10
April	4	221	41.0	.73	2.78	.60	.64	1.76	2.36
May	5	334	43.0	.81	2.93	.82	.66	1.93	2.25
June	4	350	44.3	.73	2.85	.77	.87	2.10	2.38
July	5	374	39.7	.68	2.73	.67	.65	1.87	2.17
Mean		285	38.2	.67	2.63	.65	.68	1.64	2.30

The fifth series of samples of aqueduct water came from the outfall of the closed section of the aqueduct at the San Fernando power house about 1 mile north of San Fernando, Calif. The results of the analyses of these samples are shown in Table 21. The mean discharge as reported for the San Fernando power house is somewhat lower than that reported for three of the upper stations, but this may be due to accidental differences in discharge conditions at the time of sampling rather than to actual losses of water from the system. The salt content as measured by conductance is slightly higher than at the other three stations below the heading, but the boron content is approximately the same as at North Haiwee and South Haiwee. The discharge and salt-content conditions of the aqueduct are summarized in Table 22. The results brought together in that table appear to indicate that the water supply brought into the Los Angeles district by the Owens River Aqueduct carries the boron equivalent of approximately 4 tons of borax per day and that practically all of this boron is contributed to the system above the heading at Aberdeen. In view of the close agreement of the mean results of the boron determination for the stations of North Haiwee, South Haiwee, and the San Fernando power house, involving a total of 162 quantitative analyses, it is believed that the boron content of the aqueduct water for 1928–29 was approximately 0.68 p. p. m.

TABLE 21.—*Quality of the water of the Los Angeles Aqueduct as sampled at the San Fernando power house, near San Fernando, Calif., July, 1928, to July, 1929*

[Monthly means of weekly analyses]

Year and month	Samples	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number	*C. f. s.*		*P. p. m.*					
1928									
July	4	356	37.4	0.68	2.80	0.56	0.60	1.52	2.44
August	5	356	34.5	.65	2.56	.58	.70	1.49	2.34
September	4	261	39.6	.57	2.37	.52	.82	1.42	2.30
October	5	223	39.7	.66	2.56	.64	.90	1.66	2.44
November	4	211	38.1	.62	2.51	.59	.80	1.31	2.59
December	4	255	36.9	.66	2.50	.62	.82	1.58	2.36
1929									
January	5	163	39.9	.64	2.50	.63	.70	1.94	1.89
February	4	164	39.8	.67	2.56	.62	.67	1.95	1.91
March	4	190	41.4	.71	2.62	.61	.75	1.86	2.12
April	5	185	40.6	.73	2.67	.68	.68	1.96	2.07
May	4	329	45.4	.80	2.91	.82	.63	2.04	2.33
June	4	332	44.8	.78	2.80	.75	.70	1.91	2.53
July	5	317	41.8	.66	2.87	.76	.66	2.05	2.22
Mean		257	40.0	.68	2.64	.64	.73	1.74	2.27

TABLE 22.—*Quality of the water of the Los Angeles Aqueduct from August, 1928, to July, 1929*

[Means of monthly means at five points]

Location	Discharge	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
				CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	C. f. s.		*P. p. m.*					
Heading	214	42.2	0.77	2.96	0.69	0.67	1.88	2.43
Alabama Gates	276	36.7	.62	2.40	.60	.60	1.68	2.01
North Haiwee	283	36.1	.67	2.48	.63	.58	1.60	2.10
South Haiwee	285	38.2	.67	2.63	.65	.68	1.64	2.30
San Fernando	257	40.0	.68	2.64	.64	.73	1.74	2.27

UNDERGROUND WATERS OF THE SAN FERNANDO VALLEY

The San Fernando Valley, which lies north of the city of Los Angeles, is almost entirely surrounded by low mountains. From the San Gabriel Mountains on the northeast, it receives flood waters through the Tujunga and Pacoima washes. These flood waters, together with the drainage from the Santa Monica Mountains to the south of the valley, unite to form the Los Angeles River, which drains the valley at its southeast corner.

Under present conditions there is seldom any surface flow in the streams mentioned. The underground waters are drawn upon for use by the city of Los Angeles by means of wells, of which some are located in or near the bed of the Los Angeles River, some in the center of the valley near Lankershim, and some at the north edge of the valley near the San Fernando Mission. The water supply for San Fernando is drawn from wells on the north side of the town, a short distance east of the mission wells.

In view of the fact that water from the San Fernando city wells and the mission wells is used to some extent for irrigation, these wells were sampled and analyzed for comparison with the water of the Owens River Aqueduct. Samples were obtained also from one of the Lankershim wells, but the wells farther south along the bed of the Los Angeles River were not sampled.

The results of the observations on the water from well No. 1 of the city of San Fernando are shown in Table 23. To facilitate direct comparison with the aqueduct water, as sampled at the San Fernando power house (Table 21), these results are given as monthly means and summarized for the year. The San Fernando city water is slightly higher in total salt content, as measured by conductance (52.7), than the aqueduct water (40). The boron content is 0.31 p. p. m., as compared with 0.68 for the aqueduct. The bicarbonate, sulphate, and calcium-magnesium content is higher, but the chloride and sodium-potassium content is lower.

TABLE 23.—*Quality of the water from well No. 1 of the city of San Fernando, Calif.*

[Discharge, 1.25 cubic feet per second]

Year and month	Samples	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
				CO_3+ HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
1928	*Number*		*P. p. m.*					
July	1	52.7	0.31	3.95	0.40	1.23	4.21	1.39
August	5	51.1	.28	3.94	.47	1.46	4.28	1.59
September	4	53.4	.30	3.95	.40	1.29	4.07	1.57
October	5	53.5	.34	3.81	.48	1.49	3.92	1.86
November	4	53.0	.33	3.72	.45	1.30	3.50	1.98
December	3	52.6	.34	3.80	.48	1.22	4.16	1.34
1929								
January	5	53.5	.33	3.82	.47	1.26	4.76	.79
February	3	52.6	.39	3.75	.43	1.15	4.67	.68
March	4	53.3	.29	3.72	.44	1.24	4.21	1.19
April	4	51.9	.29	3.71	.44	1.24	4.33	1.09
May	3	52.0	.29	3.84	.45	1.48	4.39	1.39
June	4	52.7	.26	3.67	.43	1.28	4.06	1.31
July	4	52.9	.26	3.70	.44	1.28	4.48	.93
Mean		52.7	.31	3.80	.44	1.30	4.23	1.31

In view of the fact, discussed in more detail in another section, that symptoms of boron injury were not found on plants irrigated with water from the San Fernando city supply but generally on lemons irrigated with aqueduct water, it might be inferred that the critical limit for boron in irrigation water lies between 0.31 and 0.68 p. p. m., but the evidence is not conclusive. The results here reported deal with conditions for only one year. It is possible that in previous years the boron content of the aqueduct water may have been higher. It is also possible that conditions with respect to the soil, methods of irrigation, or quantities of water applied may be essentially different in the city of San Fernando from the corresponding factors in the valley outside the city.

The quality of the water used in San Fernando is compared in Table 24 with that of water from the mission and Lankershim wells. The water of the mission well is slightly higher in conductance, in sulphate, and in alkaline bases (sodium and potassium) than that of the San Fernando city well. The boron content is approximately the same. The water of the Lankershim wells is much lower in conductance and somewhat lower in all the salt constituents, including boron. These Lankershim wells are located in the delta of the Tujunga wash, and the indications are that the flood waters from the San Gabriel Mountains and the Verdugo Hills that contribute largely to the underground supply of the San Fernando Valley contain very little boron. It seems highly probable that whatever boron injury occurs to the orchard crops in the San Fernando Valley is due to the use of water brought in through the Owens River Aqueduct and that this boron is contributed to that supply by the fumaroles and hot springs in Long Valley.

TABLE 24.—*Quality of underground water of the San Fernando Valley, as sampled at three points during 1928 and 1929*

Location and well No.	Samples	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents				
				CO_3+HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
	Number		*P. p. m.*					
San Fernando City, No. 1	52	52.7	0.31	3.80	0.44	1.30	4.23	1.31
Mission, No. 2	18	63.0	.32	3.82	.83	2.17	4.26	2.56
Lankershim, No. 5	4	36.3	.12	3.03	.26	.59	2.63	1.25

ARROWHEAD HOT SPRINGS

Evidences of boron injury discovered in a limited area northeast of San Bernardino, Calif., led to an investigation of the irrigation waters originating in the adjacent foothills of the San Bernardino Mountains. The San Andreas fault line here makes the dividing line between the San Bernardino Plain and the massive uplift to the north. The local run-off from the mountains is collected in a number of small streams whose delta cones cross the faulted zone at right angles and whose flood waters join the Santa Ana River. The surface waters of these streams and of the cold-water springs above the fault line contain very little boron, as may be seen in the first four entries in Table 25. The hot springs of the Arrowhead area yield more boron as well as much more chloride and sulphate than the surface waters. These hot waters discharge into Waterman Creek to the west and into East Twin Creek to the east. The latter is joined by Strawberry Creek from the northeast at a point just above the hot-springs area.

TABLE 25.—*Quality of the water in the vicinity of Arrowhead Hot Springs*

Sample No.	Location or source	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents					
				CO_3+ HCO_3	Cl	SO_4	Ca	Mg	Alkaline bases
			P. p. m.						
2437	Waterman Creek	34.0	(1)	2.80	0.25	0.41	1.94	0.45	1.07
2439	East Twin Creek	27.4	(1)	2.45	.20	.40	1.49	1.22	.34
2440	Strawberry Creek	22.5	0.04	2.05	.20	.49	1.20	.52	.72
2442	Cold springs	43.1	.06	3.55	.30	1.10	2.33	.75	1.87
2436	Hot spring	125.0	2.06	1.70	1.45	8.73	1.95	.53	9.40
2443	do	140.0	2.35	1.50	1.85	9.42	1.73	.18	10.86
2444	do	152.0	2.04	1.30	1.95	10.37	1.30	.33	11.99
2445	do	149.0	2.64	1.35	2.05	10.24	1.47	.33	11.84
2438	Irrigation water	60.5	.52	2.70	.55	2.76	2.05	.94	3.02
2441	do	45.5	.40	2.20	.35	.79	1.36	.06	1.00
547	do	70.1	.70	2.40	1.00	4.22	2.00	1.16	4.46
548	do	76.1	.81	2.25	1.10	3.83	1.66	.48	5.04
549	Harrison wells	32.4	.33	2.10	.40	.51	1.32	.26	1.43
2496	Highland well	61.2	.92	2.35	.45	1.81	.45	.26	3.90

[1] Trace.

The waters of both Waterman Creek and East Twin Creek are diverted for irrigation below where the hot springs discharge into them. The boron concentration of the diverted waters depends upon the relative proportions of surface water and of hot-spring water at the time of sampling. The discharge from the hot springs is said to be fairly constant throughout the year, while the surface run-off is greater during the winter and spring. The two samples of irrigation water, Nos. 2438 and 2441, were taken on March 12, 1930, while the corresponding samples, Nos. 548 and 547, were taken early in January, 1929.

Two other creeks east of the Arrowhead area have their deltas across the fault zone. These are Harrison Creek and City Creek. There are a number of shallow flowing wells at the apex of the delta cone of Harrison Creek. A sample of water from these (No. 549) shows some boron contamination. A number of samples from cold springs adjacent to these wells, when tested qualitatively, showed approximately the same boron content. Water from a deep well in the delta of City Creek, northeast of Highland (No. 2496) contained 0.92 p. p. m. of boron.

The conditions along the line of the San Andreas fault in the vicinity of San Bernardino appear to support the view that the boron found in these waters comes up through the fractured zone, probably as volatilized boric acid. It seems probable that as it emanates from its deep source it is associated with other gases, including steam and hydrochloric and sulphuric acids. These gases at high temperature may come in contact with percolating water, dissolve in it, raise its temperature, and react with its mineral constituents to form salts. It will be observed in Table 25 that while the hot-spring waters contain more boron, chloride, and sulphate than the waters from above, the content of calcium and magnesium is substantially the same, while the content of bicarbonate (HCO_3) is somewhat less. Fortunately, the quantity of boron-contaminated water in the Arrowhead area is not large, and under present conditions comparatively little of it is carried into the general drainage of the Santa Ana River.

LOCATIONS LISTED BY LABORATORY NUMBERS IN TABLE 25 AND DATES OF SAMPLING

No. 2437, Waterman Creek, about 100 yards above Steam Caves Spring; discharge 1.25 cubic feet per second; collected March 12, 1930.

No. 2439, East Twin Creek, about 300 yards above the junction of Strawberry Creek and above the hot-spring area; discharge, 2 cubic feet per second; collected March 14, 1930.

No. 2440, Strawberry Creek, about 300 yards above its junction with East Twin Creek and above the hot-spring area; discharge, 3 cubic feet per second; collected March 14, 1930.

No. 2442, Arrowhead cold-spring water from pipe line leading from springs above the hot-spring area; collected March 12, 1930.

No. 2436, Steam Caves Hot Springs; discharge, 0.02 cubic foot per second; collected March 12, 1930.

No. 2443, Arrowhead Hotel Hot Spring; discharge, 0.07 cubic foot per second; collected March 12, 1930.

No. 2444, Granite Hot Spring; discharge, 0.06 cubic foot per second; collected March 12, 1930.

No. 2445, Penyugual Hot Spring; discharge, 0.02 cubic foot per second; collected March 12, 1930.

No. 2438, irrigation water from Waterman Creek, below the hot springs; collected March 12, 1930.

No. 2441, irrigation water from East Twin Creek, below the hot springs; collected March 12, 1930.

No. 547, irrigation water from Waterman Creek, below the hot springs; discharge, 1 cubic foot per second; collected January 9, 1929.

No. 548, irrigation water from East Twin Creek below the hot springs; collected January 12, 1929.

No. 549, shallow flowing wells at the mouth of Harrison Canyon; discharge, 0.2 cubic foot per second; collected January 12, 1929.

No. 2496, deep well in the delta of City Creek, northeast of Highland, used for domestic purposes; depth, 308 feet; discharge, 0.7 cubic foot per second; collected March 23, 1930.

COLORADO RIVER

From the standpoint of the extent of acreage served, the Colorado River is the most important source of irrigation water in southern California. In view of this fact and also because its water may be carried in the future outside of its basin to be used in areas where citrus crops are extensively grown, it has seemed desirable to make a series of analyses of it in the present survey. These analyses, which cover a period of 12 months, are reported in detail in Table 26.

TABLE 26. *Quality of the water of the Colorado River as sampled at Yuma, Ariz.*

Date	Sample No.	Discharge	K × 10⁵ at 25° C.	Boron	Milligram equivalents				
					CO_3 + HCO_3	Cl	SO_4	Ca+Mg	Alkaline bases
1928		*C. f. s.*		*P. p. m.*					
Aug. 30	157	4,600	129	0.31	2.80	3.21	7.38	8.55	4.84
Sept. 6	176	4,460	136	.15	2.90	3.95	8.30	8.45	6.70
Sept. 13	187	4,300	170	.18	2.80	4.10	11.68	11.35	7.23
Sept. 20	205	2,530	166	.33	3.30	6.00	11.49	10.55	10.24
Sept. 27	223	2,800	152	.17	3.25	4.20	10.20	8.95	8.70
Mean		3,738	151	.23	3.01	4.29	9.81	9.57	7.51
Oct. 4	248	2,620	161		3.15	4.50	9.66	8.80	8.51
Oct. 12	263	3,200	145	.21	2.50	5.20	10.84	8.75	9.79
Oct. 18	293	3,380	186	.20	3.30	4.80	11.93	8.40	11.63
Oct. 25	320	10,300	172	.21	3.10	3.10	13.42	8.80	10.82
Mean		4,875	166	.22	3.09	4.40	11.46	8.69	10.26

TABLE 26.—*Quality of the water of the Colorado River as sampled at Yuma, Ariz.*—Continued

Date	Sample No.	Discharge	K × 10⁵ at 25° C.	Boron	Milligram equivalents: CO_3 + HCO_3	Cl	SO_4	Ca+Mg		Alkaline bases
1928		*C. f. s.*		*P. p. m.*						
Nov. 1	341	7,080	190	.21	1.55	3.55	16.08	8.80		12.38
Nov. 8	385	14,000	160	.18	3.20	2.80	11.94	7.50		10.44
Nov. 15	405	6,400	156	.30	3.15	3.40	9.87	7.50		8.92
Nov. 23	430	6,700	167	------	3.10	4.00	11.17	6.60		11.67
Nov. 29	443	6,200	158	.24	3.40	3.60	9.80	6.80		10.00
Mean	------	8,076	167	.23	2.88	3.47	11.77	7.44		10.68
Dec. 6	468	6,640	157	.25	3.60	3.95	9.55	6.75		10.35
Dec. 13	485	6,000	151	.21	3.50	4.00	9.33	8.95		9.88
Dec. 20	500	3,300	161	.20	4.30	4.65	9.72	6.16	3.34	9.17
Dec. 27	511	3,430	162	.17	3.70	4.80	9.58	6.44	3.78	7.86
Mean		4,842	158	.21	3.77	4.35	9.51	8.35		9.31
1929										
Jan. 1	532	1,900	173	.25	4.10	5.40	10.18	6.41	3.48	9.79
Jan. 10	546	4,000	182	.29	4.00	6.50	11.08	7.72	4.67	9.19
Jan. 17	571	3,230	181	.27	3.95	5.40	10.90	6.75	5.56	7.91
Jan. 31	612	5,000	180	.24	4.20	5.60	9.77	6.31	5.72	7.54
Mean		3,532	179	.26	4.06	5.72	10.48	6.80	4.80	8.61
Feb. 7	632	4,460	180	.29	3.95	5.60	9.11	6.12	2.00	9.04
Feb. 14	648	6,400	170	.12	3.85	5.35	8.71	5.25	4.76	7.90
Feb. 21	670	3,850	154	.20	3.55	4.40	8.64	5.33	4.88	6.38
Feb. 28	686	4,200	167	.20	3.70	5.20	8.85	5.62	4.48	7.65
Mean		4,727	168	.20	3.76	5.14	8.83	5.58	4.25	7.89
Mar. 7	713	4,980	163	.30	3.65	4.75	9.26	5.89	4.96	6.81
Mar. 15	735	11,600	168	.20	3.60	4.95	9.19	6.00	3.81	7.93
Mar. 21	770	16,000	127	.19	3.00	2.22	8.20	4.60	3.15	5.67
Mar. 28	788	10,500	109	.28	2.75	1.98	7.04	4.29	3.33	4.15
Mean		10,770	142	.24	3.25	3.47	8.42	5.19	3.81	6.14
Apr. 4	821	10,000	133	.19	3.10	3.07	6.94	4.50	4.51	4.10
Apr. 11	882	35,000	118	.06	2.90	2.69	6.07	3.91	2.39	5.56
Apr. 19	900	16,800	95	.15	2.88	1.81	5.18	3.52	2.33	4.02
Apr. 28	980	32,000	88	.33	2.50	1.70	4.70	3.41	1.40	4.09
Mean		23,450	108	.18	2.84	2.37	5.72	3.83	2.66	4.44
May 2	1042	28,000	70.3	.19	2.50	1.14	3.52	2.86	1.15	3.15
May 10	1077	27,500	83.6	.13	2.57	1.44	4.04	3.18	2.05	2.82
May 16	1093	13,900	68.0	.17	2.42	.98	2.90	2.62	1.44	2.21
May 23	1121	56,000	52.8	.06	2.28	.73	2.04	2.27	1.25	1.53
May 30	1201	71,000	50.5	.22	2.21	.67	1.41	2.11	.99	1.19
Mean	------	45,280	65.0	.15	2.40	.99	2.78	2.61	1.38	2.19
June 6	1223	88,000	47.0	------	2.10	.72	1.80	1.14	1.86	2.02
June 27	1406	72,000	41.5	.08	1.82	.56	1.50	1.52	1.15	.91
Mean	------	80,000	44.2	.08	1.96	.64	1.65	1.48	1.50	1.46
July 4	1457	55,100	41.6	.08	1.80	.58	1.71	1.85	.99	1.25
July 11	1477	40,000	46.8	.06	1.76	.74	1.97	1.96	1.13	1.42
July 18	1524	25,000	60.7	.18	1.99	1.80	3.09	2.66	1.60	2.62
July 25	1561	20,000	70.8	(1)	2.15	1.48	3.32	2.84	1.60	2.51
Mean		35,100	55.0	.08	1.92	1.16	2.52	2.33	1.33	1.95
Aug. 2	1613	36,000	91.8	.13	2.80	2.00	5.15	3.60	2.12	4.23
Aug. 10	1658	16,000	154.0	.19	2.65	1.70	13.27	9.17	4.28	4.17
Aug. 15	1713	37,000	137.0	.16	2.50	1.45	11.58	7.43	3.63	4.48
Aug. 22	1733	20,000	116.0	.10	2.55	1.45	8.33	4.68	1.92	5.73
Aug. 29	1773		95.0	.12	2.65	1.80	5.41	3.97	1.92	3.07
Mean		31,750	119.3	.14	2.63	1.68	8.75	5.77	2.77	4.52
Mean of individual observations		19,054	130.0	.19	2.99	3.20	7.94	7.69 4.00	2.86	6.14
Mean of monthly means		21,595	126.8	.19	2.98	3.14	7.64	7.52 4.20	2.82	6.25

[1] Trace.

The Colorado River has a large drainage area, about 242,000 square miles, but much of this is arid land having little rainfall, and that of irregular distribution, so that a large part of the total run-off comes from the melting snows from the high mountains of the upper part of the basin. Local torrential rains, falling now in one part of the basin and now in another, contribute irregularly. The melting of the snow causes an increase in the discharge of the river during May, June, and July. Local rains may cause a temporary increase or "flash flood" at any time of the year. These conditions make for great variation, not only in the volume of the discharge throughout the year but also in the quantity and character of the salts in the water. In general, the salt content varies inversely with the discharge. That is to say, the salt concentration is much less when the river is in flood than when it is low. This is due to the fact that the summer flood waters come chiefly direct from the melting snow. The flash floods that come from rains falling on the desert may carry a large proportion of salt dissolved from the desert soil. Much of the salt carried by the river at its low stages represents the drainage from irrigated lands upstream, together with return flow by seepage from lowlands adjacent to the river that are overflowed at flood times.

The detailed values in Table 26 show that while the average discharge of the river at Yuma for the dates sampled was 19,054 c. f. s., the discharge ranged from a low point of 1,900 c. f. s. on January 4 to a high point of 88,000 c. f. s. on June 6, 1929. It should be noted in this connection that the discharge values apply only to the days on which the water samples were taken, and they should not be considered as representing the full range of variation or the true mean discharge for the year. The results given as the means of the individual observations are also slightly distorted because there were only two samples taken in June, when the river was in flood. For this reason it is believed that the means of the monthly means give a truer expression of the salt conditions of the river for the year.

The total salt content as measured by electrical conductance ranges from a low point of 41.5×10^{-5} on June 27 to a high point of 190×10^{-5} reciprocal ohms a 25° C. on November 1. The mean of the monthly means is 126×10^{-5}, which is approximately equivalent to 840 p. p. m. of total dissolved electrolytes.

The boron content is relatively low, averaging only 0.19 p. p. m. This is probably below the limit of possible danger even to the more sensitive crop plants and even when concentrated in the soil solution through evaporation losses. The proportion of other salts in this water is such that if concentration were to increase to a point at which boron became injurious, then there would probably be even greater injury from the other salts.

It should be remarked that in the water of the Colorado River the ratio of chlorides to sulphates is as 0.4 to 1.0, which is a much lower ratio than that which characterizes the waters of some of the more important irrigation supplies of Arizona and southern California.

MISCELLANEOUS WATERS

In addition to the analyses reported in the preceding tables a number of samples of water from various sources in southern California and Arizona have been analyzed, and are reported in Table 27. The areas represented are: (1) Riverside, Calif., and vicinity; (2) southern Orange

County, Calif.; (3) the Salton Sink area, Calif.; and (4) the Salt River Valley, Ariz.

TABLE 27.—*Quality of miscellaneous water samples collected in southern California and in Arizona*

Location No.	Laboratory No.	Samples	K × 10⁵ 25° C.	Boron	Milligram equivalents				
					CO_3+ HCO_3	Cl	SO_4	Ca+ Mg	Alkaline bases
RIVERSIDE, CALIF., AND VICINITY									
		Number		*P. p. m.*					
1	650	1	43.5	0.36	2.40	1.10	0.71	1.62	2.59
2	407	1	44.6	.19	3.20	.40	.83	2.15	2.33
3	408	1	35.5	.19	2.70	.35	.65	2.25	1.30
4	375	1	53.0	.80	.60	2.05	1.50	.05	4.15
5	376	1	354.0	1.44	9.10	17.25	3.59	.10	29.84
6	649	1	54.0	.10	1.95	2.10	.08	2.00	2.04
7	1,199	1	13.8	.26	.65	.15	(¹)	.55	.25
8	479	1	59.5	.54	.90	2.85	1.60	(¹)	5.55
9	--	3	46.7	.19	3.25	.38	.92	3.61	1.03
10		3	65.3	.15	4.12	1.50	.70	3.60	2.72
SOUTHERN ORANGE COUNTY, CALIF.									
11	1,000	1	110.6	0.55	3.61	4.36	2.70	7.95	2.78
12	1,015	1	78.6	.81	3.82	3.52	.10	.42	7.02
13		3	97.0	.99	3.72	5.32	.20	.43	8.81
14		3	133.0	.52	3.72	8.11	.77	2.75	9.85
15		3	88.3	.75	3.49	4.07	.28	.20	8.18
16		3	63.8	.41	3.08	2.59	.44	.15	5.96
17		3	106.6	.47	5.44	6.50	3.07	8.39	6.62
18		3	235.6	.71	4.96	10.65	5.45	11.29	9.78
SALTON SINK AREA, CALIF.									
19	432	1	40.3	0.20	1.85	0.95	1.00	0.10	3.70
20	591	1	810.0	1.88	4.35	65.00	11.96	21.45	59.86
21	592	1	220.0	2.34	10.90	8.25	2.61	.85	20.91
22	593	1	369.0	3.86	4.85	27.90	2.69	1.36	34.08
23	2,386	1	454.0	3.48	10.00	26.40	2.46	2.12	42.74
SALT RIVER VALLEY, ARIZ.									
24	737	1	178.0	0.33	3.55	7.65	7.02	8.65	9.57
25	738	1	28.9	.13	2.15	.35	.49	2.51	.48
26	739	1	142.0	.44	4.15	6.55	2.54	8.34	4.90
27	740	1	140.5	.35	2.95	8.20	2.44	5.89	7.70

¹ Trace.

Of the samples from the Riverside area, only three show high boron content. The water of Lake Elsinore (location 5) has long been known to be unsuited for irrigation use. Not only is its boron content high, 1.44 p. p. m., but its total salt content is high and the water is alkaline and very soft, that is, it has a very low proportion of calcium and magnesium. The water supply of Elsinore city (location 4) is drawn from wells not far from the lake shore. While the total salt content is low, the boron content is relatively high, and this water also is very soft. The well at location 6, south of Lake Elsinore, is used for irrigation. Its salt content is approximately the same as that of the Elsinore city supply, but the boron content is low, and the calcium-magnesium content is much higher. Beulah

Spring (location 8) is south of Riverside. It is a small spring and is of interest chiefly in that its overflow has been used on part of a near-by walnut orchard and that the trees on which it has been used have shown definite symptoms of boron injury.

The last two waters of the group (locations 9 and 10) represent Warm Creek near San Bernardino, above and below the outfall of the sewage plant. It might be expected that city sewage water would contribute appreciable quantities of boron, resulting from the domestic use of borax washing powders, but these results indicate that such contamination is very slight.

The irrigation wells in southern Orange County (locations 11 to 18) were sampled after a preliminary survey had shown evidence of some boron injury in citrus and walnut trees in this area. This preliminary survey indicated that while most of the wells in the area were giving water of low boron content, a few of them were causing trouble. The evidence of injury was not definite except for locations 13 and 15, because some of these wells were used to irrigate crops less sensitive to boron injury than citrus and walnut, and in other cases the waters of several wells were blended and the boron content of the mixture was below the critical concentration for citrus.

Of the samples from the Salton Sink area, one (location 19) is from an irrigation well north of Salton Sea in the lower end of the Coachella Valley. Some of the grapefruit on which this water was used showed symptoms of boron injury, confirmed by leaf analysis; but, as other trees in the grove were not injured, it is assumed that the boron occurred in spots in the soil. The other four samples in this group (from locations 20 to 23) are from artesian wells in the vicinity of Holtville, south of Salton Sea. These waters are not used for irrigation. The irrigation supply of the Imperial Valley is drawn from the Colorado River, of which the boron content is low (Table 26), and no definite evidence of boron injury has been seen in the valley. All artesian wells are in an area on the east side of the valley from Holtville north. In addition to the wells here reported, 10 others have been tested qualitatively for boron with positive results. It seems probable that all the deep water in this artesian belt is contaminated with boron from some subterranean source. The wells at locations 20, 21, and 22 are in the city of Holtville. No. 20 is 363 feet deep and contains 1.88 p. p. m. of boron. No. 21 is located only a few feet from No. 20, but is 811 feet deep and contains 2.34 p. p. m. of boron. No. 22 is about one-fourth mile from the first two wells and is 1,100 feet deep and contains 3.86 p. p. m. of boron. The waters from the deeper wells are very soft, while that of the first well is not only more salty but also contains so much calcium and magnesium as to indicate the possibility of the influence of deep percolation from the surrounding irrigated land. Location 23 is about 5 miles north of Holtville.

The four samples from the Salt River Valley in Arizona (locations 24 to 27) do not include a representation of Salt River water as stored in the Roosevelt Reservoir and used chiefly on the Salt River project. No. 24 is water of the Gila River as diverted from that stream above Florence, Ariz., No. 25, although taken from one of the canals of the Salt River project, represents flood water of the Verde River following a local torrential rain. No. 26 represents an irrigation supply obtained chiefly by pumping from that part of the Salt River project west of Phoenix, Ariz. No. 27 is from the Gila River at Gillespie

Dam below the Salt River project and represents partly return flow from the irrigated lands above this point and partly surface run-off from the Verde flood just mentioned. It should be noted that no definite evidences of boron injury have been observed in the Salt River Valley.

LOCATIONS LISTED IN TABLE 27 AND DATES OF SAMPLING

1. Riverside city water; February 17, 1929.
2. Riverside Canal, irrigation water; November 19, 1928.
3. Gage Canal, irrigation water; November 19, 1928.
4. Elsinore city water; November 4, 1928.
5. Lake Elsinore; November 4, 1928.
6. Irrigation well south of Lake Elsinore; February 13, 1929.
7. Irrigation water, Hemet Lake; May 25, 1929.
8. Beulah Spring water, south of Riverside; December 5, 1929.
9. Warm Creek, near San Bernardino, above the sewage outfall; January and February, 1929.
10. Warm Creek, near San Bernardino, below the sewage outfall; January and February, 1929.
11. Irrigation well, Browning ranch, Tustin; April 24, 1929.
12. Irrigation well; Townsend ranch, Costa Mesa; May 3, 1929.
13. Irrigation well, Irvine ranch No. 10, Tustin; May to July, 1929.
14. Irrigation well, Irvine ranch, No. 11, Tustin; May to July, 1929.
15. Irrigation well, Irvine ranch, No. 25, Tustin; May to July, 1929.
16. Irrigation well, Irvine ranch, No. 44, Tustin; May to July, 1929.
17. Irrigation well, Irvine ranch, No. 46, Tustin; May to July, 1929.
18. Irrigation well, Irvine ranch, No. 65, Tustin; May to July, 1929.
19. Irrigation well, Slater ranch, Oasis; November 30, 1928.
20. Artesian well, Holtville Natatorium; 363 feet deep; January 23, 1929.
21. Artesian well, Holtville Natatorium; 811 feet deep; January 23, 1929.
22. Artesian well, Holtville Ice Co.; 1,100 feet deep; January 23, 1929.
23. Artesian well, Robinson ranch; 620 feet deep; February 26, 1930.
24. Gila River water, from an irrigation canal near Florence, Ariz.; March 13, 1929
25. Verde River, flood water, from an irrigation canal near Phoenix, Ariz.; March 13, 1929.
26. Irrigation water, Roosevelt irrigation district canal near Litchfield Park, Ariz.; March 14, 1929.
27. Gila River, at Gillespie Dam, near Gila Bend, Ariz.; March 14, 1929.

SUMMARY

It has been demonstrated that boron as a natural constituent of the salts of irrigation water is the cause of injury to crops in certain areas in southern California. While the aggregate of the areas involved is not large, the injury in some of them is serious. This bulletin deals with boron conditions in southern California, but it has been found that similar troubles occur also in the San Joaquin and Sacramento Valleys and in western Nevada.

The effect of boron injury is manifested in citrus and walnut trees by characteristic discolorations of the leaf tissue and by the excessive accumulation of boron in the leaves. Somewhat similar but often less definite symptoms develop in other species.

With only one or two exceptions, it has been found that boron injury in southern California is the result of the use of irrigation water containing borate salts.

The boron that occurs in injurious concentrations in irrigation water may be derived either from the solution of exposed outcrops of soluble boron minerals, from subterranean deposits of such minerals in contact with underground waters, or directly from volcanic gases dissolved in percolating waters.

It has been found that if the boron content of irrigation water is more than 0.5 p. p. m. its use may cause injury to such crops as lemons or walnuts, although under certain conditions, with concentrations ranging up to 1 p. p. m., the injury may not be very serious. If the boron content is more than 1 p. p. m., injury to the more sensitive crops is likely to result.

The severity of crop injury resulting from boron may be influenced by local soil conditions, by climatic conditions, by the method or quantity of irrigation, or by the program of fertilization.

In some situations it is possible to segregate from an irrigation supply the chief source of boron contamination. It may also be possible to blend a contaminated supply with a larger quantity of water from other sources and thus reduce the concentration to a point below the danger limit.

There are pronounced differences among crop plants with respect to boron tolerance. When the basic facts as to these differences have been ascertained, it may be possible to utilize for certain groups of crops waters that would be injurious to more sensitive crops.

Boron occurs in plants probably as a normal constituent. It has been found in small but measurable quantities in a wide variety of plants not only in California but elsewhere in the United States and in Europe.

In many plants the boron appears to accumulate in the leaves rather than in the stems or fruit. The normal mature leaves of citrus or walnut trees may contain as much as 100 p. p. m. of boron, based on the dry weight of the leaf material. Leaves of the same species, injured by boron, frequently contain more than 1,000 p. p. m. The boron accumulates gradually, reaching its maximum as the leaves mature.

The samples of water collected for boron determination were also analyzed for the other ions or elements commonly reported for irrigation waters, and the conductance, as a measure of total salinity, was determined.

A survey of the surface waters of the Santa Clara Valley shows that most of the boron carried in Santa Clara River is derived from Piru and Sespe Creeks.

The underground waters of the Santa Clara Valley as developed by irrigation wells show that boron contamination is localized and is derived from percolation from Piru and Sespe Creeks.

In connection with the drilling of two irrigation wells in the Santa Clara Valley, analyses were made of the successive horizons of underground water, and it was found that while these differed slightly in quality the differences were not pronounced.

A detailed study was made of the water discharged by Sespe Creek in one year. This shows that the concentration of boron is not constant but varies inversely with the volume of discharge. A survey of the stream throughout its course showed that the boron is contributed chiefly from two groups of hot springs that discharge into the creek.

A similar detailed study of Piru Creek showed that its water has a higher salinity but a lower boron content than that of Sespe Creek. It is also somewhat less variable in quality. The survey of the upper stream of Piru Creek showed that the boron is derived largely from

Lockwood Valley, in which there are outcrops of colemanite, a boron mineral.

The waters of Ojai Valley contain very little boron, and the boron content of Ventura River appears to be below the critical concentration. There is no evidence of boron injury in these valleys, which lie northwest of the Santa Clara Valley.

The waters of Parida Creek near Carpinteria are contaminated with boron by a spring located near an earthquake fault. This contamination of the irrigation water has resulted in severe local injury to citrus and walnut trees.

In the Simi Valley, south of the Santa Clara Valley, there is some evidence of boron injury, chiefly to walnut trees. A survey of the irrigation wells of that valley showed that some of them yield water containing critical concentrations of boron.

The Los Angeles Aqueduct carries water from Owens River to the San Fernando Valley, where it is used partly for irrigation but chiefly as a municipal water supply. There is some evidence of boron injury in citrus and walnut groves in the San Fernando Valley, apparently resulting from the use of aqueduct water.

A survey of the tributaries of Owens River above the aqueduct heading showed that one artesian well near the heading and one stream in Long Valley were contributing most of the boron found in the aqueduct supply.

A detailed study of the waters of the Los Angeles Aqueduct carried on for a year shows that the average boron content is 0.68 p. p. m. and that there is not much seasonal variation in the quality of the water as delivered at San Fernando.

Conditions in the San Fernando Valley indicate that there is less danger of boron injury from the use of local underground water for irrigation than from the use of aqueduct water. Analyses of these underground waters show that their boron content is much less than that of the aqueduct water.

Certain hot springs located near the San Andreas fault near San Bernardino contribute boron to creeks flowing across the fault zone. Where these contaminated creek waters are used for irrigation, injury has resulted to citrus trees, and to certain other crops.

The Colorado River, as sampled at Yuma each week for a year, shows a marked seasonal variation in total salts, but the boron content is low, averaging 0.19 p. p. m.

A series of samples of irrigation waters from several other areas in southern California and in Arizona show that boron contamination occurs to a limited extent in a number of places, but in none of those listed is it a matter of serious economic concern.

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