

SEASONAL AND ANNUAL CHANGES IN THE QUALITY OF
SOME WELL WATERS IN THE GILA RIVER VALLEY
NEAR YUMA, ARIZONA

by

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INTRODUCTION AND PURPOSE

Yuma is located in the extreme southwest corner of Arizona in one of the driest areas of the United States. The climate is warm with an average annual rainfall of 2-5 inches. The agriculture in the area consequently is dependent entirely upon irrigation. Satisfactory sources of water of good quality are essential. Because there appeared to be a threat to the quality of the well waters as a result of seepage and recharge from higher areas surrounding the Yuma Valley, a study of the quality of the waters from a series of irrigation wells in a section of the Yuma Valley, the Yuma Irrigation District, was made. The Yuma Irrigation District is located in the South Gila Valley, east of the city of Yuma, at and near the junction of the Colorado and Gila Rivers. The sample area is approximately eleven miles by three miles, parallel to Arizona Highway 95, with a strip approximately two miles wide north of the highway and approximately one mile wide south of the highway. Figure 25 is a map of the area.

The South Gila Valley is located at an extremely low elevation, only a few feet above the river bed, and is bounded by areas of higher elevation. As Colorado River water was brought into these higher surrounding areas for irrigation purposes, the high water tables in these areas apparently

caused a high water table to develop in the South Gila Valley. As a result, well water which had originally been satisfactory for irrigation began decreasing in quality, as observed by an increase in the total salt content.

The Roll-Wellton-Mohawk Valley to the north and the Yuma Mesa area to the south seem to be the immediate sources of poor quality water recharge entering the South Gila Valley and will be considered in connection with this study.

Since the decrease in quality of the water in the district might become a threat to crop production, an investigation was undertaken to determine and chart the changes in quality of water for the area, to correlate these changes with farming practices in the South Gila Valley and surrounding areas, and to identify, if possible, the sources of the poor quality water entering the South Gila Valley.

For the period 1950-1960, samples were analyzed and the quality of the water, based on total soluble salts and sodium-absorption-ratio, was plotted against time to give annual and seasonal fluctuations. During the year July 1959-June 1960, monthly analyses were made of representative samples to obtain a better concept of seasonal and monthly fluctuations. The water quality was based on the total soluble salts, sodium-absorption-ratio, percent sodium, and boron content.

Boron was determined because its concentrations were approaching limits that might be toxic to crops, and because

there are known sources of high boron waters in the Roll-Wellton-Mohawk Valley which could be used to trace the source of the incoming water.

LITERATURE REVIEW

The history of irrigation agriculture, in part, is one of once productive land which is now unproductive and abandoned because salts have accumulated in the soil until it is unsuited for plant growth. Most of these salts come from the irrigation water that is applied to the soil. Others are brought up from the sub-soil when the water level rises. High water tables with inadequate drainage facilities account for the most serious saline and alkali soil conditions. Evaporation from the soil surface and transpiration of plants cause salts to accumulate. If insufficient water is available to remove the salts, they remain to become injurious to plants and soil (8, 18, 30, 32, 62). Irrigation agriculture, then, requires an adequate supply of suitable water if it is to be a permanent part of a civilization (6, 30, 32).

Quality of Irrigation Water

The quality of irrigation water is determined by the dissolved substances, or salts, found in the water; this, in turn, provides a means of classification of the water. The classification is relative, empirical, and based on the assumption that the water will be used under normal conditions (58). It also depends on the characteristics of the soil it will be used on, climate, crops grown, management

practices, drainage, and rainfall. Some of the dissolved constituents in irrigation water are beneficial to plants and soil; some seem to have little effect on either, at least in moderate concentrations; others are definitely harmful to plants and/or soil. The usefulness and ultimate criterion of the quality of irrigation water is its effect on the plants and soil on which it is used (7, 25, 32, 46, 57).

Classification

There are three main groups of substances which determine the quality of irrigation water:

1. Total concentration. The total soluble salts correlate well with the effect of the water on plant growth.

2. Major constituents. The main cations and anions are calcium, magnesium, sodium, bicarbonate, sulfate, and chloride. These determine, for the most part, the effects of the water on the plants and soil.

3. The minor constituents, such as potassium, carbonate, nitrate, and phosphate. These are usually found in low concentrations and produce undesirable effects only if their absolute or relative concentrations become unfavorable.

Other substances, except for certain toxic elements such as boron, which may be dissolved in the water do not influence the quality for irrigation purposes and are not considered (7, 32, 39, 56, 57, 58, 60).

In determining the quality of irrigation water, the most important characteristics to be considered are:

1. Total soluble salt concentration - TSS.
2. Percent sodium.
3. Concentration of boron and other toxic substances.
4. Bicarbonate content.

The total concentration and boron content determine the quality of the water from the standpoint of the plant. The amount of sodium has a marked effect on the physical properties of the soil. For this reason, considerable attention is given to the indirect effect of sodium on plant production (10, 36, 37, 59, 60).

Salt Concentration

The total concentration of soluble salts is designated as TSS and is usually measured as electrical conductance which is given in micromhos per centimeter, $EC \times 10^6$. The inorganic salts which are dissolved in the water ionize and cause it to conduct an electric current. The amount of current indicates the amount of salts present. The total concentration may be expressed as parts per million, tons per acre foot, equivalents per liter, or milliequivalents per liter by using the proper conversion factor (51, 56, 57, 58, 60).

Thorn and Thorn (49) classify irrigation water on the basis of total concentration, as follows:

1. 0-750 EC x 10⁶ or 0-7.5 meq./l. Safe for all soil types.
2. 750-1,750 EC x 10⁶ or 7.5-17.5 meq./l. Safe for many soils but a salt problem will develop where drainage is poor or if previous leaching was insufficient.
3. 1,750-3,000 EC x 10⁶ or 17.5-30 meq./l. Crops with medium to high salt tolerance can be grown if the soil is permeable and there is some leaching.
4. 3,000-4,000 EC x 10⁶ or 30-40 meq./l. Crops with high salt tolerance can be grown if the soil is permeable, well drained, and under good management.
5. Above 5,000 EC x 10⁶ or 60 meq./l. These waters are generally undesirable; they should be used only in special situations.

Some workers prefer to use only total soluble salts as a basis for classifying irrigation water (10, 34, 46):

<u>Total Soluble Salts - TSS</u> <u>(in parts per million)</u>	<u>Classification</u>
0-500	Very good
500-1000	Good
1000-2000	Fair
above 2000	Poor

One of the most prevalent methods for classification of water quality for irrigation according to salinity is the one used by the U.S. Salinity Laboratory at Riverside,

California. These classes were determined by the relationship between the electrical conductance of the irrigation water and the electrical conductance of the corresponding saturation extract of the soil (58, 60).

C1 - Low salinity. 0-250 micromhos/cm. at 25°C. These waters can be used for most crops on most soils with little chance of developing a salinity hazard.

C2 - Medium salinity. 250-750 micromhos/cm. Plants with moderate salt tolerance can be grown if there is some leaching.

C3 - High salinity. 750-2,250 micromhos/cm. High tolerance plants can be grown if the soil drains well and has good management.

C4 - Very high salinity. 2,250-5,000 micromhos/cm. These waters are not suitable for irrigation under ordinary conditions. Very high salt-tolerant crops can be grown if the soil is very permeable, drainage adequate, and there is considerable leaching (58, 60).

There is an almost straight-line relationship between increasing amounts of salt in the irrigation water and the decrease in plant growth (39). There is no fixed concentration at which plants die, but rather, a range of concentrations where growth is gradually reduced until the plants can no longer survive (8, 39, 42). Plants grown under such high

saline conditions are stunted in growth and have smaller, darker green leaves. Characteristic leaf-burn often develops (2, 23, 51).

Actually, it is the salinity of the soil solution rather than the salinity of the original irrigation water which affects plant growth. As evapotranspiration removes water from the soil, the soil solution becomes progressively more concentrated (30, 34, 62). The resulting effects of excessive salts on plants have been attributed to two factors: the osmotic inhibition of water absorption and the specific ion effects; or the two may act simultaneously (5, 7, 32, 33, 51).

According to the classical osmotic pressure theory, the decrease in growth is due to the decrease in the diffusion pressure gradient between the soil solution and the plant root (2). That is, as the ionic concentration of the soil solution increases, due to the increase in salt content, the osmotic pressure of the soil solution becomes so great that the plant roots can no longer obtain the water necessary for growth. The types of salts present are relatively unimportant in determining the increase of the osmotic pressure. Different salts produce the same or nearly the same growth depression at equal osmotic pressures (2, 7, 32, 47, 51, 54).

For most normal soils, the osmotic pressure of the soil solution is in the range of 1-2 atmospheres, but it may

be as high as 200 atmospheres for some barren saline soils (33). Most plants exhibit poor growth at 10 atmospheres; at 15 atmospheres, most plants die; and at 47 atmospheres, no plants survive. These effects are manifested whether the increase in osmotic pressure is due to high salt content or to drying (33).

Toxicity due to specific ion effects also reduces plant growth as the salt concentration increases. Chloride, sulfate, magnesium, and boron are among the ions commonly causing toxicity to plants. These and others will be noted in the discussion of each individual ion (32, 51).

Crops vary in their tolerance to salt. The following table gives crops which are suited for different salt concentration conditions (23, 32, 42, 49, 51).

RELATIVE TOLERANCE OF SOME CROPS TO SALT

<u>Salt-Sensitive</u>	<u>Medium Tolerance</u>	<u>High Tolerance</u>
Citrus	Alfalfa	Sugar Beets
Beans, wax and navy	Carrots	Cotton
Red Clover	Wheat	Bermuda Grass

Sodium Hazard

The second most important factor in determining the quality of irrigation water is the sodium content. Most natural water contains sodium, but it does not seem to be an essential plant food element (31). Apparently, it can

substitute for K^+ in some reactions (27). Plants will accumulate it freely from the soil, but the main result is to increase the osmotic concentration of the cell sap. At high concentrations, sodium is toxic to some plants; leaf-burn and other characteristic symptoms appear (7, 17, 32, 57). This toxicity is thought to be due to the lack of Ca^{++} which is essential for plant growth (27).

Sodium is mainly injurious because of its adverse effect on soil structure. When the exchange complex of the soil becomes saturated with exchangeable sodium, undesirable physical conditions develop. The soil particles deflocculate; when wet, the soil is plastic and slowly permeable to air and water; on drying, it shrinks and cracks and is difficult to work. "Slick spots" or black alkali soil results (10, 22, 23, 32, 36, 40, 57, 59, 60). This type of soil has two effects on plant growth: air and water are less available to plant roots, and high concentrations of sodium interfere with the absorption of some essential plant nutrients, particularly calcium.

One method for indicating the sodium hazard of irrigation water is the soluble-sodium-percentage, SSP; concentrations are in milliequivalents per liter (58).

$$SSP = \frac{\text{Soluble sodium concentration} \times 100}{\text{Total cation concentration}}$$

Another expression which is frequently used is sodium percentage, %Na; concentrations are in equivalents per million (7, 52, 57).

$$\%Na = \frac{Na^+ \times 100}{Ca^{++} + Mg^{++} + Na^+ + K^+}$$

Water with a sodium percentage less than 60 and with a low bicarbonate content is probably safe for most soils. If the percentage sodium is above 60, the sodium hazard is greatly increased because at this concentration sodium begins to exchange for calcium and magnesium on the base exchange minerals and poor soil structure results (32).

A more satisfactory indicator of the sodium hazard of irrigation water is the sodium-absorption-ratio, SAR, as defined by the following equation (concentrations in milliequivalents per liter):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

There is a significant relationship between the SAR of an irrigation water and the exchangeable-sodium-percentage, ESP, that the soil will attain when the irrigation water and soil solution reach equilibrium. Therefore, by knowing the SAR of a water, it is possible to make a reasonable estimate of the resulting ESP (4, 10, 32, 36, 48, 53, 57, 58, 59, 60).

Figure 1 is a nomogram for estimating the SAR of an irrigation water and the resulting ESP of the soil. Locate the concentrations of sodium and calcium plus magnesium on the vertical scales. Connect the two points with a straight line; the point where this line crosses the diagonal will give the corresponding SAR and ESP values (58).

There are four classes of irrigation water based on sar values with divisions at 10, 18, and 26. These are based primarily on the effect of sodium on the soil (53, 58).

S1 - Low-sodium water. These can be used for most soils with little chance of a sodium hazard developing. Some sodium sensitive crops may be injured.

S2 - Medium-sodium water. This water may be used on soil with good permeability, but will present a sodium hazard on fine-textured soils with a high cation exchange capacity.

S3 - High-sodium water. Most soils will require special management if this type water is used. Crops must be selected with regard to their sodium tolerance.

S4 - Very high-sodium water. This water is generally unsatisfactory and can be used only in special cases.

If gypsum or other soluble forms of calcium are available in the soil, the sodium hazard of the irrigation water can be reduced appreciably. This should be taken into account when evaluating an irrigation water source (60).

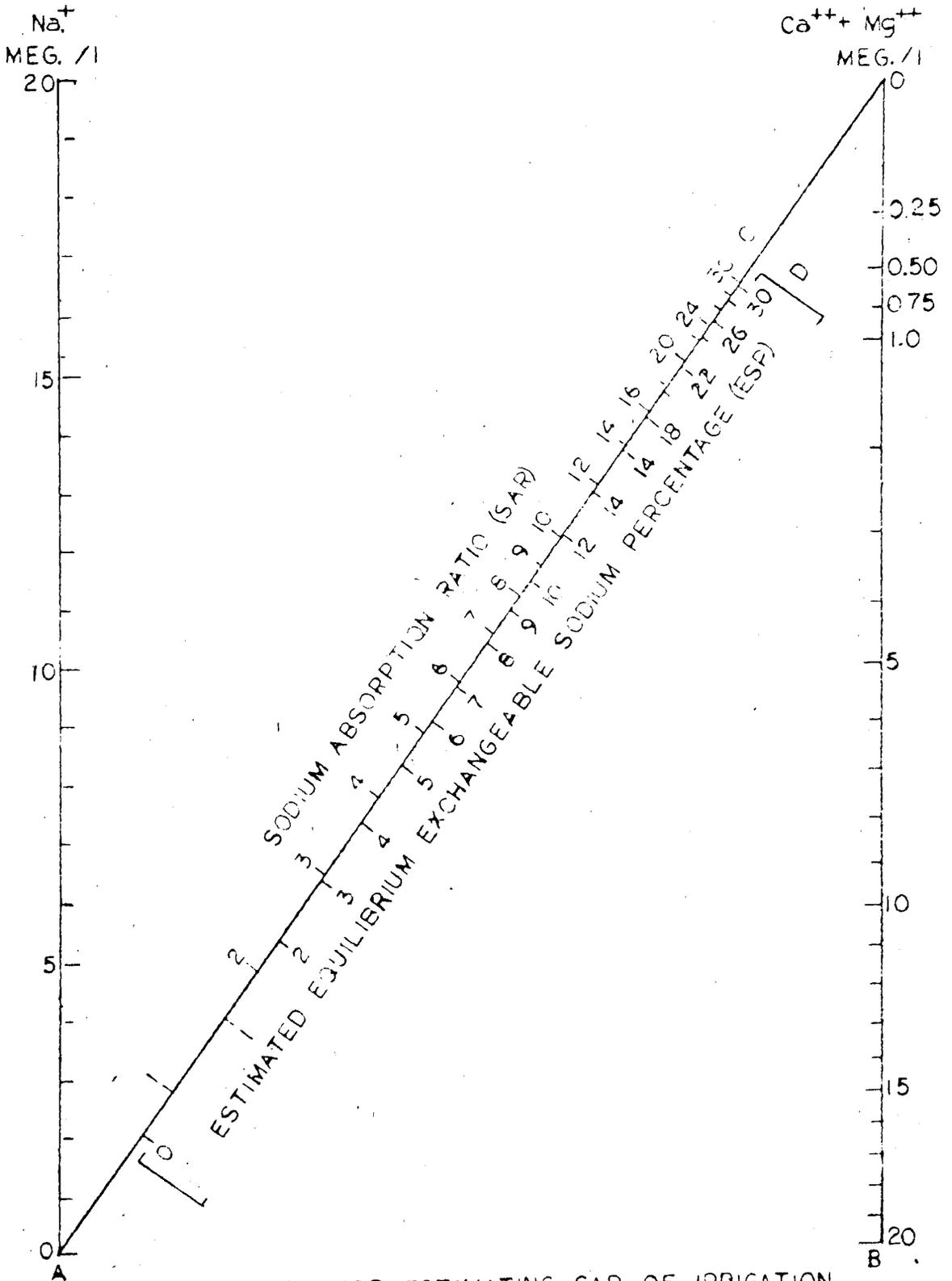


FIG.1 NOMOGRAM FOR ESTIMATING SAR OF IRRIGATION WATER AND RESULTING ESP OF SOIL

Figure 2 is a diagram for the classification of irrigation water based on the electrical conductance and the SAR. The equations describing the curves and an explanation of the calculations involved in the construction of the diagram are given in the USDA Handbook No. 60 (60).

Carbonate and Bicarbonate. An additional sodium hazard is encountered if there are large amounts of carbonate and bicarbonate ions in irrigation water. If the equivalents of $(\text{HCO}_3^- + \text{CO}_3^{2-})$ are in excess of the equivalents of $(\text{Ca}^{++} + \text{Mg}^{++})$, evaporation leaves residual Na_2CO_3 . Two undesirable effects result (3, 10, 16, 32, 36, 49, 56, 57, 58, 60, 62, 63):

1. Sodium exchanges for calcium and magnesium on the soil exchange, and calcium and magnesium precipitate as carbonates. This increases the Na:Ca ratio and the SAR.

2. The pH value of the soil increases.

Eaton (16) calculates three values when determining the quality of irrigation water according to carbonate and bicarbonate content; all concentrations are in milliequivalents per liter.

"The sodium percentage found" is the same as the percentage sodium used in the discussion of sodium.

If the sum $(\text{CO}_3^{2-} + \text{HCO}_3^-)$ is less than the sum $(\text{Ca}^{++} + \text{Mg}^{++})$, the "possible percentage sodium" is calculated.

$$\text{Possible percentage sodium} = \frac{\text{Na}^+ \times 100}{\text{Na}^+ + \text{Ca}^{++} + \text{Mg}^{++} - \text{HCO}_3^- - \text{CO}_3^{2-}}$$

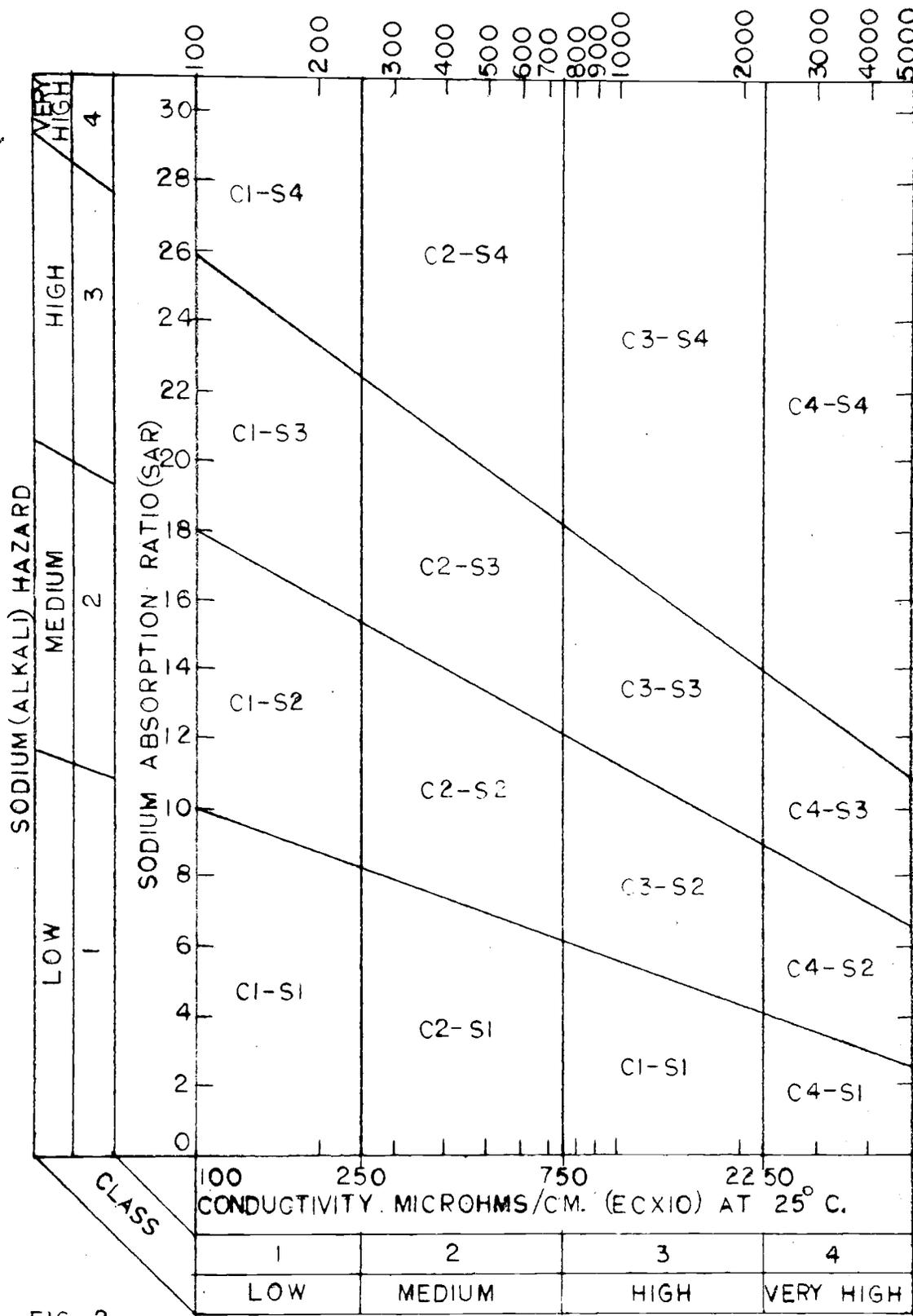


FIG. 2
 SALINITY HAZARD
 DIAGRAM FOR CLASSIFICATION OF IRRIGATION WATER
 BASED ON ELECTRICAL CONDUCTANCE AND SAR

If the quantity ($\text{CO}_3^- + \text{HCO}_3^-$) exceeds the quantity ($\text{Ca}^{++} + \text{Mg}^{++}$), the "residual sodium carbonate" is calculated.

$$\text{Residual Na}_2\text{CO}_3 = (\text{CO}_3^- - \text{HCO}_3^-) - (\text{Ca}^{++} + \text{Mg}^{++})$$

More than 2.5 meq./l residual sodium carbonate makes the water unsuited for irrigation purposes; 1.25-2.5 meq./l. is marginal; less than 1.25 meq./l. is probably safe (58, 60, 63).

Other Anions and Cations

Calcium. Calcium is an abundant element found in nearly all natural waters and its presence in irrigation water is desirable. Together with magnesium and hydrogen, it mainly controls the chemical and physical structure of the soil. A calcium soil is friable, easily worked, permeable to air and water, and does not "run together" when wet. These conditions are maintained as long as the total equivalents of Ca + Mg exceed the equivalents of sodium (2, 7, 40, 49, 57).

Calcium is one of the essential plant nutrients, but it is usually present in sufficient quantities in the soils of the west for crops. Extremely high concentrations may cause nutritional unbalance in plants. Some undesirable effects of large quantities of other ions is attributed to a lack of calcium or to an undesirable ratio of calcium to the other ions present (2, 49, 57).

The Na:Ca ratio is another factor to consider in determining the quality of irrigation water. A ratio greater than one is desirable since it indicates a high relative concentration of calcium. Only if calcium is slowly available in the soil can the Na:Ca ratio be less than one without a sodium hazard developing (46). A ratio greater than 2:1 is definitely undesirable because sodium will exchange for magnesium and calcium on the soil exchange material at concentrations above 2:1 (9, 26, 29).

The ratio of calcium and magnesium to total bases can also serve as a basis for classifying irrigation water (46).

<u>% Ca + Mg</u>	<u>% Na</u>	<u>Quality</u>
More than 50	Less than 50	Satisfactory
35 - 50	50 - 65	Doubtful
Less than 35	More than 65	Poor

Magnesium. Magnesium is a desirable constituent in irrigation water; its reactions with the soil are similar to calcium and it can replace calcium in some reactions. Magnesium is an essential plant nutrient since it is an important part of chlorophyll. However, concentrations of magnesium several times larger than the concentration of calcium are undesirable; this is thought to be a result of the lack of available calcium (7, 49, 56, 57).

Chloride. Chlorine is an essential plant nutrient; small concentrations of NaCl have been reported as stimulating

to some plants. At moderate concentrations, chlorides become toxic to most plants; at higher concentrations, they inhibit plant growth. Chlorides have no effect on the soil other than to add to the total salt concentration. In some soils, chlorides have been found to be in toxic concentrations to plants.

The amount of chloride present was formerly used as an important indication of the quality of irrigation water; the less the chloride content, the better the water (11, 34, 35, 49, 57, 59).

<u>Concentration of Chloride</u> <u>(in parts per million)</u>	<u>Quality</u>
0 - 175	Good
175 - 290	Fair
Above 290	Poor

Sulfate. A certain amount of sulfate is desirable in irrigation water since it is a readily available source of sulfur, an essential plant nutrient. High concentrations cause unfavorable salt effects in plants; sulfate is about half as toxic as chloride in equal parts per million but about as toxic in equal osmotic concentrations. Sulfate has no effect on the soil other than to increase the total salinity (11, 14, 35, 46, 49, 56, 58).

Water is rated according to sulfate content as follows:

<u>Concentration of Sulfate (in parts per million)</u>	<u>Quality</u>
0 - 350	Good
350 - 600	Fair
Over 600	Poor

Minor Constituents

Other constituents which are found in irrigation water usually occur in low concentrations and are important only in special cases.

Aluminum. Aluminum is usually found in small quantities in natural water but has no noticeable effect on soil. It is absorbed by plants although it is not thought to be essential. High concentrations in acid soils are toxic to many plants (57).

Ammonia. Ammonia is not present in well-aerated water. Ammonium salts produce unfavorable reactions in soils, causing them to deflocculate. The effect on plants is probably beneficial (57).

Fluoride. Fluoride is frequently found in natural water, but in low concentrations it has little or no effect on plants and soil. Its main importance is in human nutrition; it is not of importance in quality of irrigation waters (57).

Iron. Iron is found only in very low concentrations in the mildly alkaline waters of the west. In the soil, colloidal iron seems to cause fine particles to form larger aggregates.

Iron is an essential plant nutrient but sufficient quantities are present in most soils. Iron chlorosis in plants is thought to be due to the inability of the plant to use the available iron (57).

Sulfide. When sulfide occurs in natural waters, it is usually in the form of H_2S and is easily detected by its odor. In well-aerated soils, it has no effect on the soil or plants. It may be beneficial since it is a source of sulfur (57).

Silica. Silica occurs in natural waters, but has little effect on the chemical or physical nature of the soil. Plants absorb large quantities of silica and deposit it in the epidermis to form a protective coating (57).

Potassium. Low concentrations of potassium are usually found in irrigation water. Its reactions are similar to sodium, but it does not produce the adverse soil conditions that sodium does.

Potassium is one of the three most important plant nutrients and small amounts in irrigation water are desirable since they help keep the soil fertile (49, 57).

Phosphate. Phosphate usually occurs in low concentrations in natural waters, particularly the slightly alkaline waters of the west. It has no noticeable effect on the physical and chemical properties of the soil. Phosphate is another of the three main plant nutrients, so its presence in low concentrations in irrigation water is considered beneficial (57).

Nitrate. Low concentrations of nitrate are also found in natural waters. It has no effect on soil structure, but continued use of sodium nitrate as a fertilizer can impair soil structure. Nitrate furnishes nitrogen, the other main plant nutrient, so low concentrations in irrigation water are desirable (49, 57).

Nitrite. Nitrite is usually not found in irrigation water since its presence indicates an anaerobic condition; it is assumed to be an intermediate step in the oxidation of organic nitrogen to nitrate. Low concentrations do not affect the soil chemically, but the microbial equilibrium may be upset. Nitrites seem to be toxic to some plants, particularly citrus and avocado (57).

pH Value. The pH value indicates the hydrogen ion concentration of the water. In the west, most waters are in the mildly alkaline range, pH 7.0 - 8.5 (52, 56, 58).

The Importance of Boron in Irrigation Water

Boron is usually present in sufficient quantities in the soil. In humid regions, deficiency symptoms may occur if rainfall causes extensive leaching. Other areas, particularly the irrigated areas of the west, have toxic amounts of boron. In Arizona, the toxicity problem is not caused by excessive concentrations of boron in the soil, but rather, by excessive concentrations in the irrigation water (15, 41, 45, 61). Fifty-six minerals have been listed as sources of boron in irrigation water (38), and most of these compounds are soluble to the extent that they are toxic to plants. So far, there is no known method for removing boron from irrigation water (3, 45, 57, 58, 60, 61).

There does not seem to be a general relationship between the concentration of boron and the concentrations of other constituents in irrigation water, but there does seem to be a tendency for highly mineralized water to be high in boron, also. The quality of irrigation water from the standpoint of boron will depend on the following factors (12, 15, 24, 41):

1. Crop tolerance.
2. Type of soil. This includes such factors as organic matter and mineral content, age, and pH value.
3. Initial boron content of soil.
4. Climatic conditions.

5. Rainfall.
6. Annual quality of water.
7. Soil management, including leaching, drainage, and amendments.

Boron is essential for plant growth but it is toxic in concentrations only slightly above optimum (1, 35, 44, 45, 60). The range of concentrations which produces good plant growth is fairly limited (55). Plants vary widely in their tolerance and concentrations which are normal for one may be toxic for another. Moreover, plants show varying tolerance with age; the injury symptoms may appear in young plants, or they may not appear until the plant is mature (12). As little as 0.7 ppm. may injure sensitive crops; more than 1.5 ppm. is usually unsafe for all but very tolerant crops (32). The following table gives examples of crops with varying degrees of boron tolerance (10, 46, 59, 61):

LIMITS OF BORON IN IRRIGATION WATER FOR CROPS
OF DIFFERENT DEGREES OF BORON TOLERANCE

<u>Tolerant</u> <u>2.0-4.0 ppm.</u>	<u>Semitolerant</u> <u>1.0-2.0 ppm.</u>	<u>Sensitive</u> <u>0.3-1.0 ppm.</u>
Athel	Sunflower	Pecan
Asparagus	Cotton	Walnut
Palm	Wheat	Grapefruit
		Lemon

Injury due to toxic concentrations of boron produces distinctive symptoms and follows a regular pattern (12). In citrus and walnuts, the leaves show yellowing on tips, margins, and between veins (28, 45). There is a regular increase in concentration in the boron content of the leaf from tip to base, and the injurious effects of this increased concentration increase with the age of the leaf until it is finally shed (45).

The Ca:B ratio seems to be a significant factor in plant growth. Favorable ratios produce normal growth, but unfavorable ratios produce deficiency or toxicity symptoms. Large amounts of calcium require larger amounts of boron; higher concentrations of boron can be tolerated if larger quantities of calcium are available (1, 45).

Boron has no noticeable effect on the soil but is fixed to some extent. It has been suggested that anion exchange, chemical precipitation, molecular adsorption of boric acid, and complex formation with dihydroxy compounds in soil organic matter are possible methods for fixation (13, 19). The boron compounds in the soil are sparingly soluble and require more water for leaching than other types of salts (21, 28, 32, 57, 61). There is nothing that can be added to the soil to render the boron non-toxic (21, 28, 45, 61). Large amounts of calcium, particularly Ca(OH)_2 and CaCO_3 , in the soil seem to make boron temporarily less

available to plants; but Smith (45) found that there was no reduction of boron injury symptoms in plants when excess amounts of calcium were added to the soil.

Summary

The effects of irrigation water on soil and plants have been indicated under each topic, but they may be briefly summarized thusly:

1. The direct effects of irrigation water on soils are:
 - a. Effects on the concentration of the soil solution.
 - b. Effects on the dissolved and adsorbed constituents.
2. The indirect effects are:
 - a. Decrease in absorption of water by plants as the soil solution concentration increases.
 - b. Deterioration of soil structure due to the absorption of sodium.

The degree to which the irrigation water affects a soil will depend on the amount and type of the dissolved constituents in the water and the original characteristics of the soil (3, 7).

Plants

It is the concentration of the soil solution, not the concentration of the irrigation water itself, which affects plants. As evaporation and transpiration remove water, the

soil becomes many times more concentrated than the original irrigation water. This is the solution which produces toxic effects in plants and which attains osmotic pressures that restrict water absorption (30, 34, 39). High concentrations of salt or individually undesirable ions remain to become more concentrated in the soil solution, since relatively little salt is removed by plants.

Soil

Cations are held in the soil by cation exchange; the adsorbed cations may be replaced by other cations in the soil solution. If a soil is repeatedly irrigated with a high sodium water, the sodium will exchange for some of the calcium and magnesium; the soil will develop poor physical structure, and plants will be adversely affected (3, 4).

Soils which have been adversely affected by irrigation water fall into three classifications: saline, sodic, and saline-sodic (1, 16, 23, 51, 60).

Saline soils are soils which have a high enough concentration of soluble salts to injure plants and impair soil productivity. The accumulation of this salt depends on the concentration and composition of the irrigation water, the amount of water applied, soil and irrigation management, soil permeability and characteristics, and the depth of the water table. Most saline soils have a low relative concentration

of sodium to calcium and magnesium, have a pH value below 8.5, are flocculated and permeable, and have a white crust which forms as a result of the excess salts (1, 30, 32, 50, 51, 60).

Leaching is the only way to remove salt which has accumulated in the soil. Rainfall leaches the soil in humid regions, but in arid regions irrigation water must be used. Enough water must be allowed to flow through the soil to carry the salts past the root zone. Proper drainage is essential so that the water that has leached the soil does not raise the water table to the point where the salts are again returned to the root zone (1, 8, 20, 32, 43, 49, 51, 60).

Sodic or "black alkali" soils are the result of the chemical action of sodium on the soil. Sodium has replaced calcium and magnesium, and the soil particles have dispersed so that the soil becomes more and more impermeable to air and water. The pH value is usually above 8.5, and the organic matter is usually low (1, 16, 20, 32, 33, 50, 51, 60).

Plants which are growing in alkali soil suffer from lack of water and oxygen in the soil, unavailable plant nutrients, particularly iron and phosphorus, and high pH values (1, 16, 33, 60).

Saline-sodic soils combine the characteristics of both saline and sodic soils but are usually permeable since the excess salts keep the soil particles flocculated.

In this case, if irrigation water or rainfall removes the salts, the soils disperse and acquire the undesirable characteristics of sodic soils (1, 32, 33, 51, 60).

The control of sodium in the soil is more difficult. Leaching can help, but it cannot correct the adverse conditions alone; amendments are necessary. Some of the common ones are calcium chloride, gypsum, sulfur, sulfuric acid, iron sulfate, lime-sulfur, and ground limestone. Practices which help build soil structure are also helpful (1, 32, 49, 51, 60).

In terms of plants, irrigation water provides the moisture necessary for growth and serves as a carrier for plant nutrients. In terms of the soil, irrigation water has two uses: the control of salinity, and the control of exchangeable sodium in the soil (58).

ANALYTICAL PROCEDURES

Samples were collected by the Yuma Irrigation District and shipped to the University of Arizona where analyses were made according to the following procedures:

Anions

Bicarbonate was determined by titrating with .02 N H₂SO₄ with phenolphthalein.

Carbonate was determined by titrating with .02 N H₂SO₄ with methyl orange.

Chloride was determined by titrating with silver nitrate, using 5% potassium chromate as the indicator.

Sulfate was determined by the THQ (tetrahydroxyquinone) method.

Nitrate was determined by the phenoldisulfonic method, using filter 410 y in the Cenco photometer.

Fluoride was determined according to the method described on page 147 in the USDA Handbook No. 60.

Cations

Calcium was determined by titrating with .01 N EDTA (ethylenediamine-tetracetic acid), using Calver II indicator with 4 N NaOH.

Calcium + magnesium was determined by titrating with .01 N EDTA, using Eriochrome Black T indicator and alkaline ammonium chloride buffer. Magnesium was calculated as the difference between the two values.

Sodium was calculated as the difference between the milliequivalents of the anions chloride, sulfate, carbonate, and bicarbonate, and the milliequivalents of calcium and magnesium.

Boron

Boron was determined by titrating with standard NaOH in the presence of mannitol to pH 7.6 on the Beckman pH meter. See pages 140-141 in the USDA Handbook No. 60.

Factors

TSS, total soluble salts, were reported as parts per million, and were determined by adding the ions found.

EC x 10⁶, the conductance, was determined by the use of the Solubridge, Model RD, by Industrial Instruments. The product $EC \times 10^6 \times 700$ was used as a rough estimate of the salt content.

SAR, the sodium-absorption-ratio was calculated by the formula (concentrations in milliequivalents per liter):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

RESULTS AND DISCUSSION

Annual Changes in Water Quality--1950-1960

Two of the most important factors in determining the quality of irrigation water, total soluble salts, TSS, and sodium-absorption-ratio, SAR, were obtained for each well and plotted against time (sampling date) to show the fluctuations in the quality of the water for 1950-1960. About 31 samples were taken from each well.

The total salts are important because excessive amounts reduce plant growth and produce saline soil conditions. The U.S. Salinity Laboratory considers water with less than 1500 ppm. to be safe for most uses; water with more than this amount may require special considerations.

The alkali or sodium hazard involved in the use of an irrigation water is best defined by the sodium-absorption-ratio, SAR, of the water, since it expresses a relationship between sodium and calcium plus magnesium that can be used to interpret the effect of these ions on the physical properties of the soil. Waters with SAR values less than 15 are considered safe for most soils.

The following data are presented for ten of the 76 wells which were actually sampled. These are representative of the larger group and were chosen because they are also the

subject of a more detailed study for the year July 1959-June 1960.

Changes in Individual Wells

Well No. 2, Figure 3. The TSS showed a continuous upward trend for the ten year period. From 1950 to 1953, the values were in the range of 1100 ppm. to 1300 ppm. After this, they began to climb and reached a high value of 2800 ppm. in 1959. The changes in SAR values did not show the upward trend of the TSS. The high was 9.5 in May 1954, and lows of 3.9 were recorded in April 1951 and November 1955.

Well No. 5, Figure 4. Both the TSS and SAR showed considerable change with time for this well. High TSS values, around 3000 ppm., were recorded in the fall and summer of 1951, 1952, 1953, and 1955; low values, around 2000-2200 ppm., were recorded in January 1951, June 1952, November 1954, and in 1958-1959. Changes in SAR values followed the change trend as shown for the TSS values. Considering both values, there seems to be an improvement in the quality of the water of this well after 1955.

Well No. 14, Figure 5. There was an overall increase in TSS for this well for the test period. From 1950 through the summer of 1954, TSS values were around 1300-1500 ppm. In the fall of 1954, the values increased to 1900 ppm. and stayed in the range of 1800-2000 ppm. until the fall of 1959, when

they increased to a value of 2500. SAR values did not show the upward trend of the TSS values. High values around 9 were recorded in November 1950 and November 1954; these were contrasted by lows of 3-4 in October 1951 and December 1956.

Well No. 32, Figure 6. There was some improvement in the quality of the water for Well No. 32, except for the winter-spring of 1955-1956; TSS values reached a high of 1900 ppm. in March 1956; SAR reached a high of 12 in November 1955. For the rest of the time, TSS varied from 1200 to 1700 ppm., and SAR varied from 5 to 10.

Well No. 41, Figure 7. The TSS values also increased for this well over the ten year period. Low values were reported in the range of 1400 ppm. in 1950-1951. The values steadily increased to a high of 2300 ppm. in December 1956, after which they leveled off and remained in this range through 1959. SAR values failed to follow the upward trend of TSS. High values around 9 were recorded in March 1951 and November 1955; low values of 4-5 were recorded in December 1952 and December 1956.

Well No. 43, Figure 8. The TSS values showed some tendency to decrease with time for this well. High values of 2000-2300 ppm. were recorded in October 1950, March 1952, November 1955, and March 1957; lowest values, 1000-1300 ppm., followed in 1958 and 1959. SAR values usually followed the

changes in TSS values and were in the range of 5-9, except for a high of 13 in December 1950.

Well No. 48, Figure 9. The trends for this well were somewhat different from those of most of the wells. Highest TSS values, about 2100-2600 ppm., occurred from 1950-1953; low values of 1600-1800 ppm. were recorded in 1954-1955 and in the fall of 1956. Only a moderate increase was noted in the spring of 1956 when some wells reached peak values. There was also some increase in 1958-1959. The changes in SAR values followed the same trends as the changes in TSS values, so that the quality of water for this well improved with time.

Well No. 49A, Figure 10. The quality of the water for this well definitely decreased. From 1951 through March 1956, the TSS values were in the range of 1700-2000 ppm. In December 1956, the TSS increased to 4500 ppm. There was a slight decrease in values in 1957-1958, but TSS again increased, to 6300 ppm., in December 1959. SAR values for 1951-1955 were about 8-10. There was a sharp drop to 3.0 ppm. in March 1956, followed by a sharp increase to 15 in December 1956; after this, values were around 10-14.

Well No. 60, Figure 11. Through 1958, the TSS for this well varied from 1850-3000 ppm with lowest values recorded in 1954 and 1956. In the last half of 1959, TSS values increased to about 3800 ppm., giving some decrease in quality from the standpoint of salts. SAR values showed a

downward trend for the ten year period. The highest value, 19.2, was recorded in 1950; after this, SAR varied from 5 to 15, and generally followed the pattern of changes found in the TSS values.

Well No. 69, Figure 12. Data are incomplete for this well, but the trends seem to follow somewhat the same pattern as Well No. 40A. The TSS changed from a loss of 1500 ppm. in November 1955 to a high of 4600 ppm. in June 1957. SAR showed the same trend, increasing from 3.0 in 1955 to 20.3 in 1957.

Both this well and Well No. 49A had relatively low TSS values prior to 1956, when both increased sharply to approximately three times the original values. These high values persisted for the remainder of the test period. It seems that some factor was introduced during 1956 which had a permanent influence on the quality of the water of these two wells.

Summary of Changes in Quality for 1950-1960

The most usual trend during this ten year period of time was for relatively low salt concentrations to continue from 1950 until 1954, followed by substantial increases beginning in 1955. Wells No. 2, 14, and 41 showed a continuous increase from 1955 to 1959; Nos. 49A and 69 had a sudden, sharp increase in 1956, with later values remaining at a high

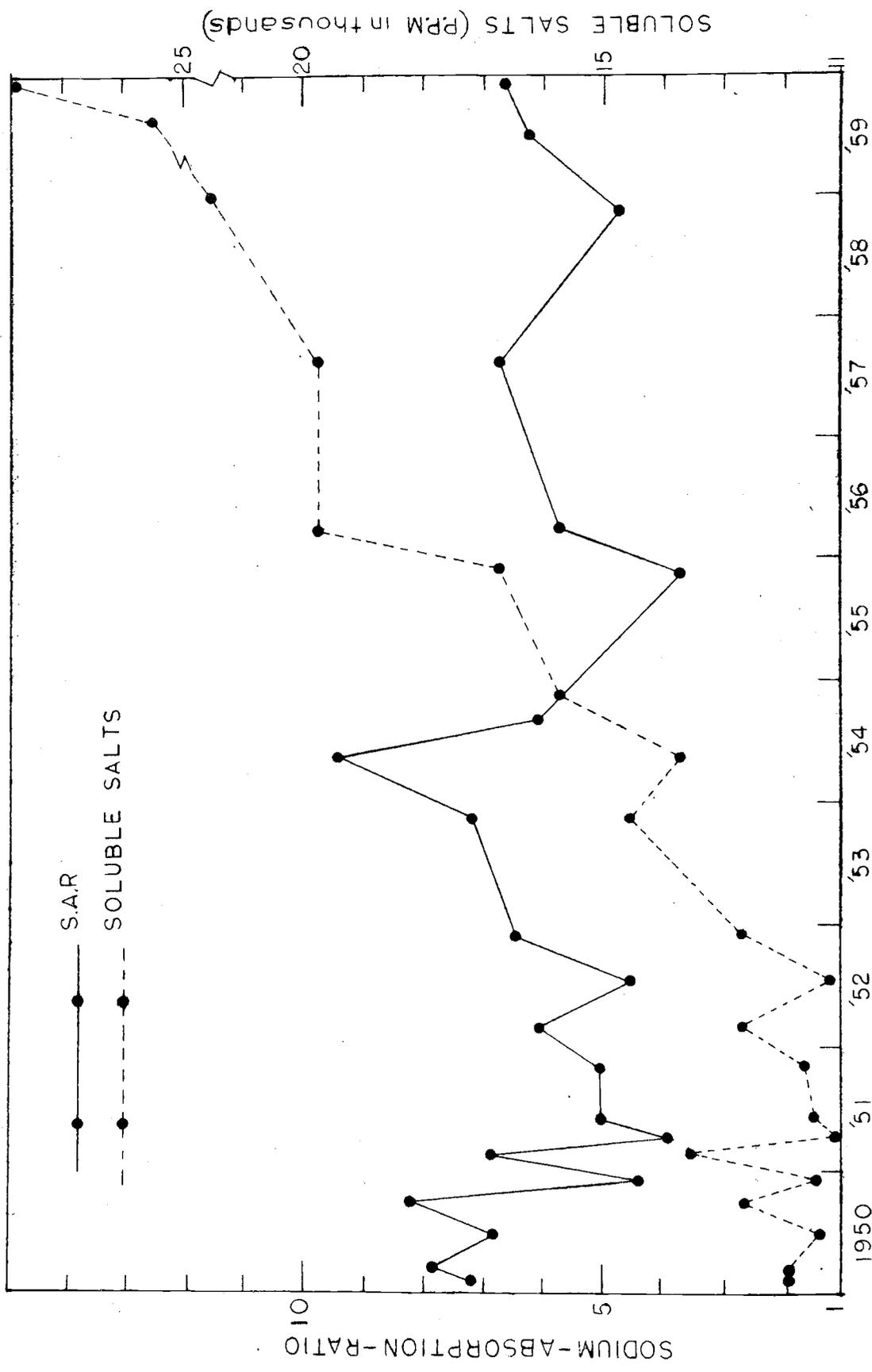


FIG. 3 ANNUAL CHANGES IN WATER QUALITY 1950 TO 1960 WELL NO. 2

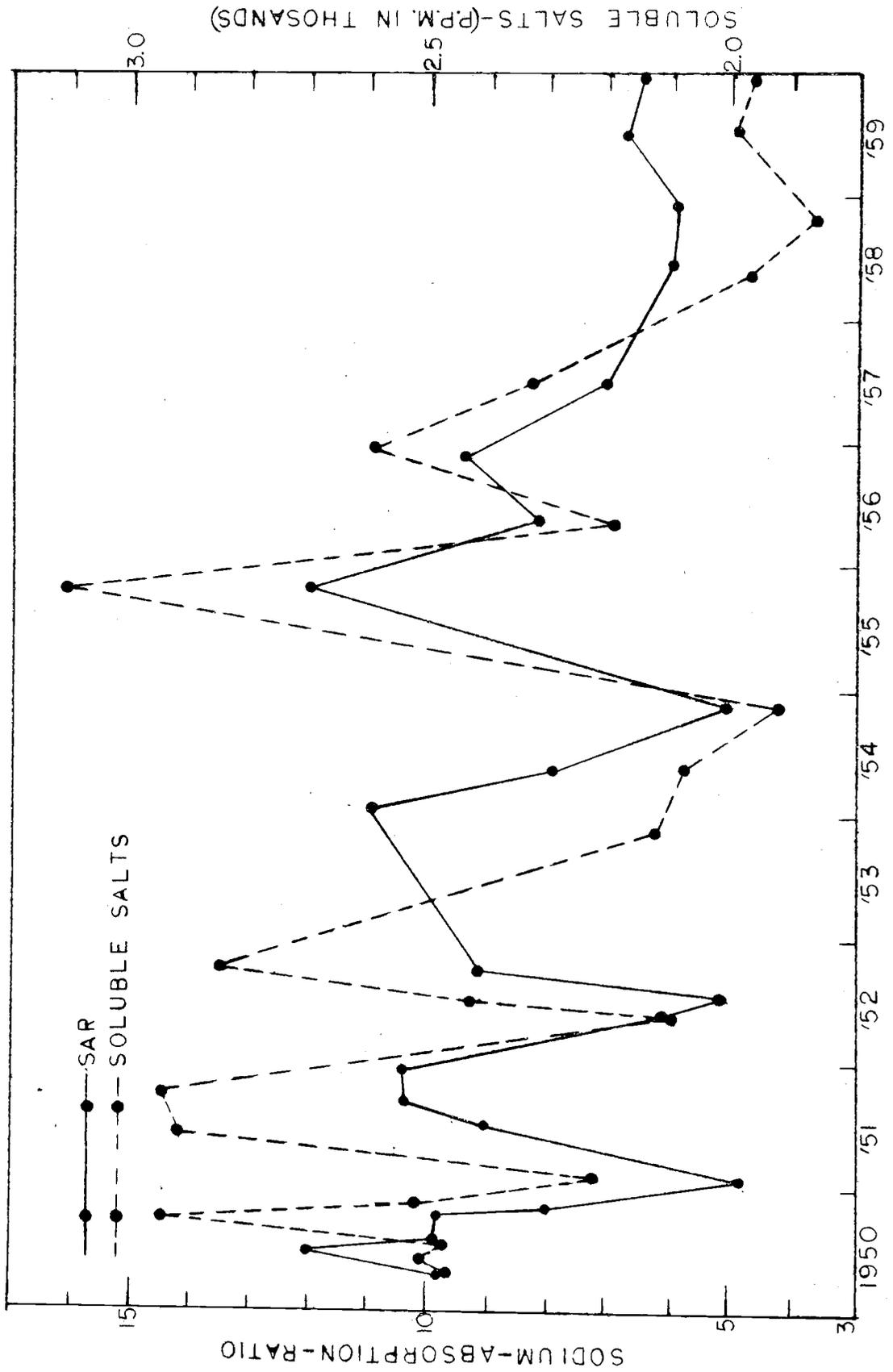


FIG. 4 ANNUAL CHANGES IN WATER QUALITY 1950 TO 1960 WELL NO. 5

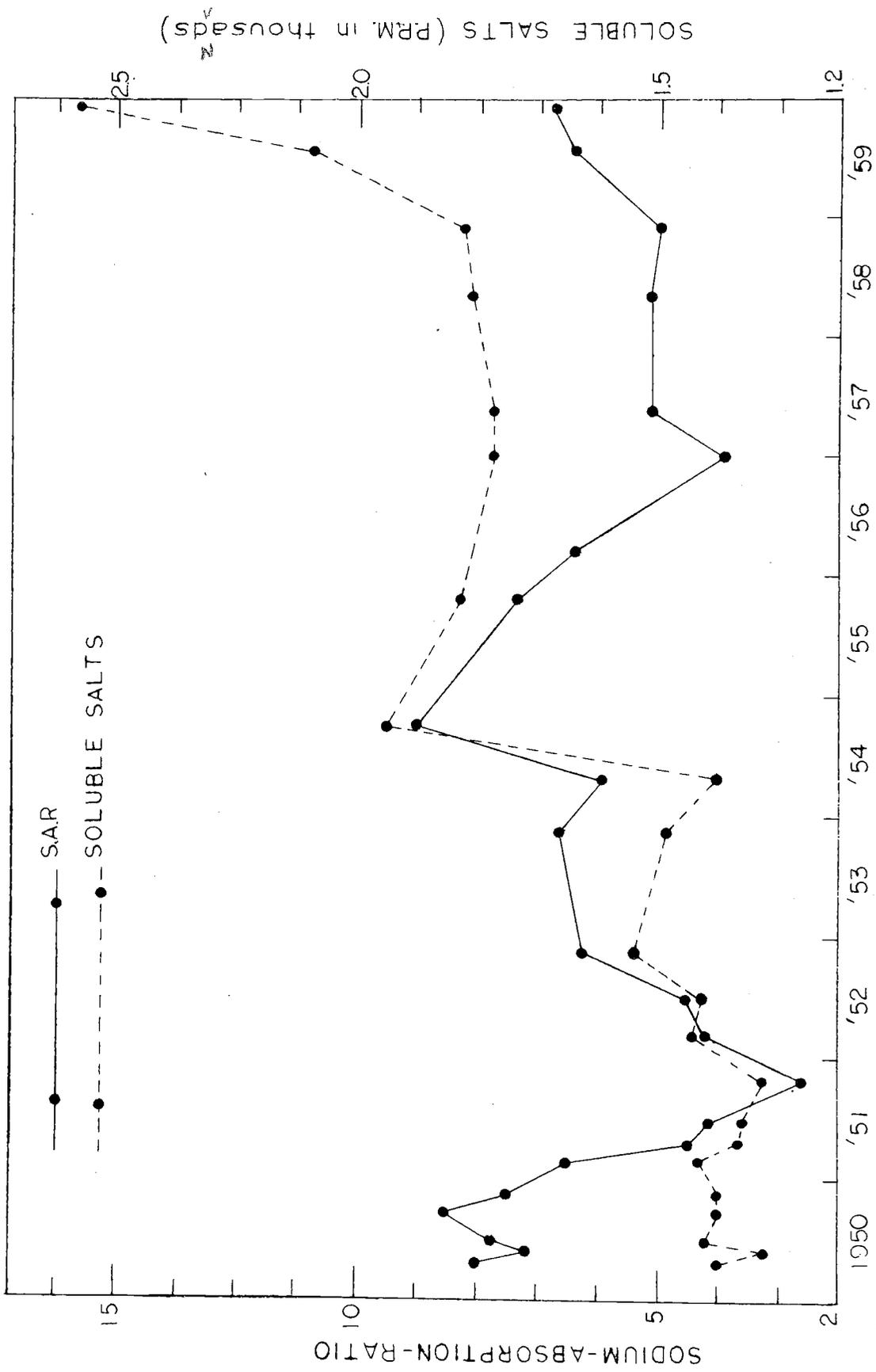


FIG. 5 ANNUAL CHANGES IN WATER QUALITY 1950 TO 1960 WELL NO. 14

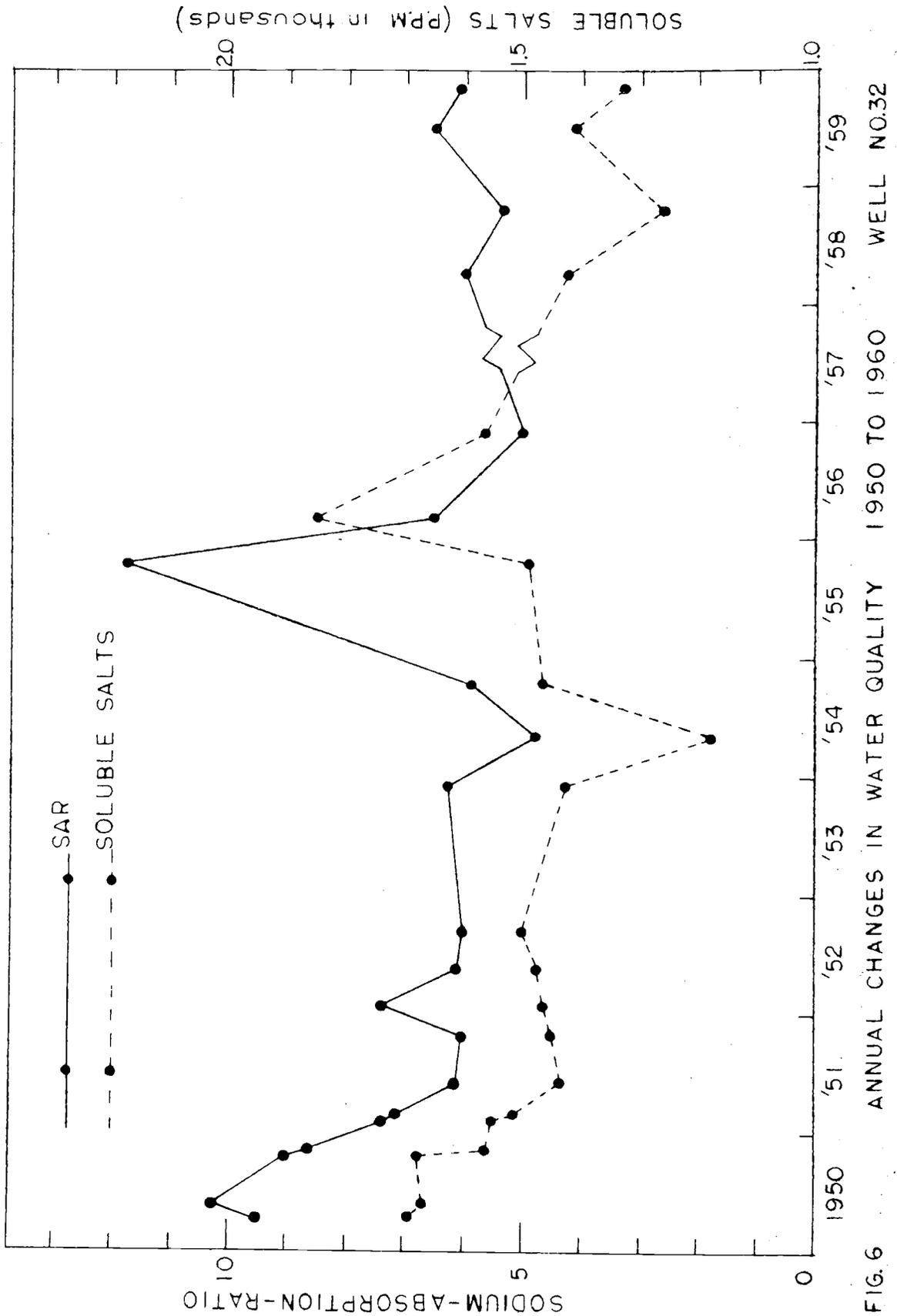


FIG. 6 ANNUAL CHANGES IN WATER QUALITY 1950 TO 1960 WELL NO.32

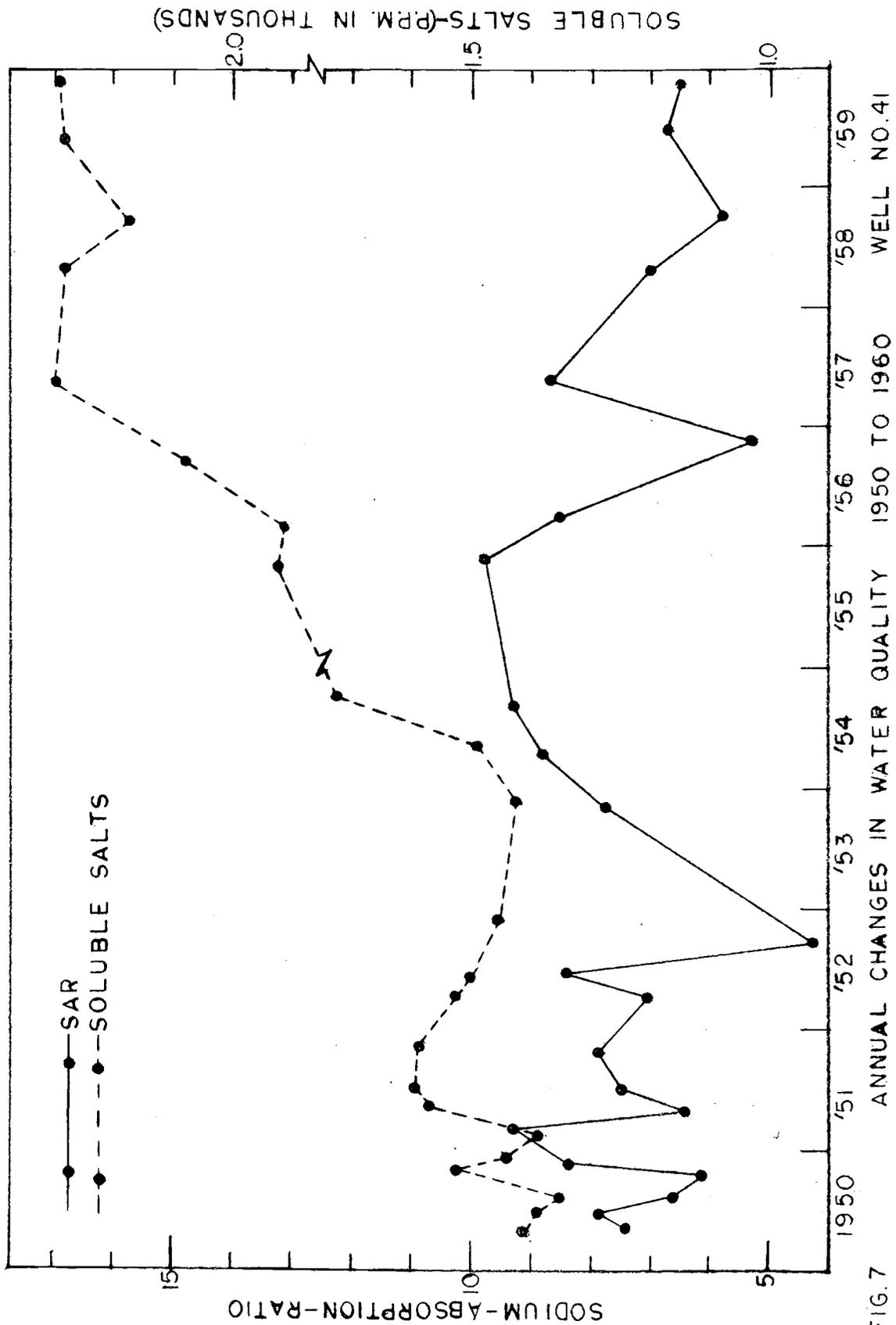


FIG. 7 ANNUAL CHANGES IN WATER QUALITY 1950 TO 1960 WELL NO. 41

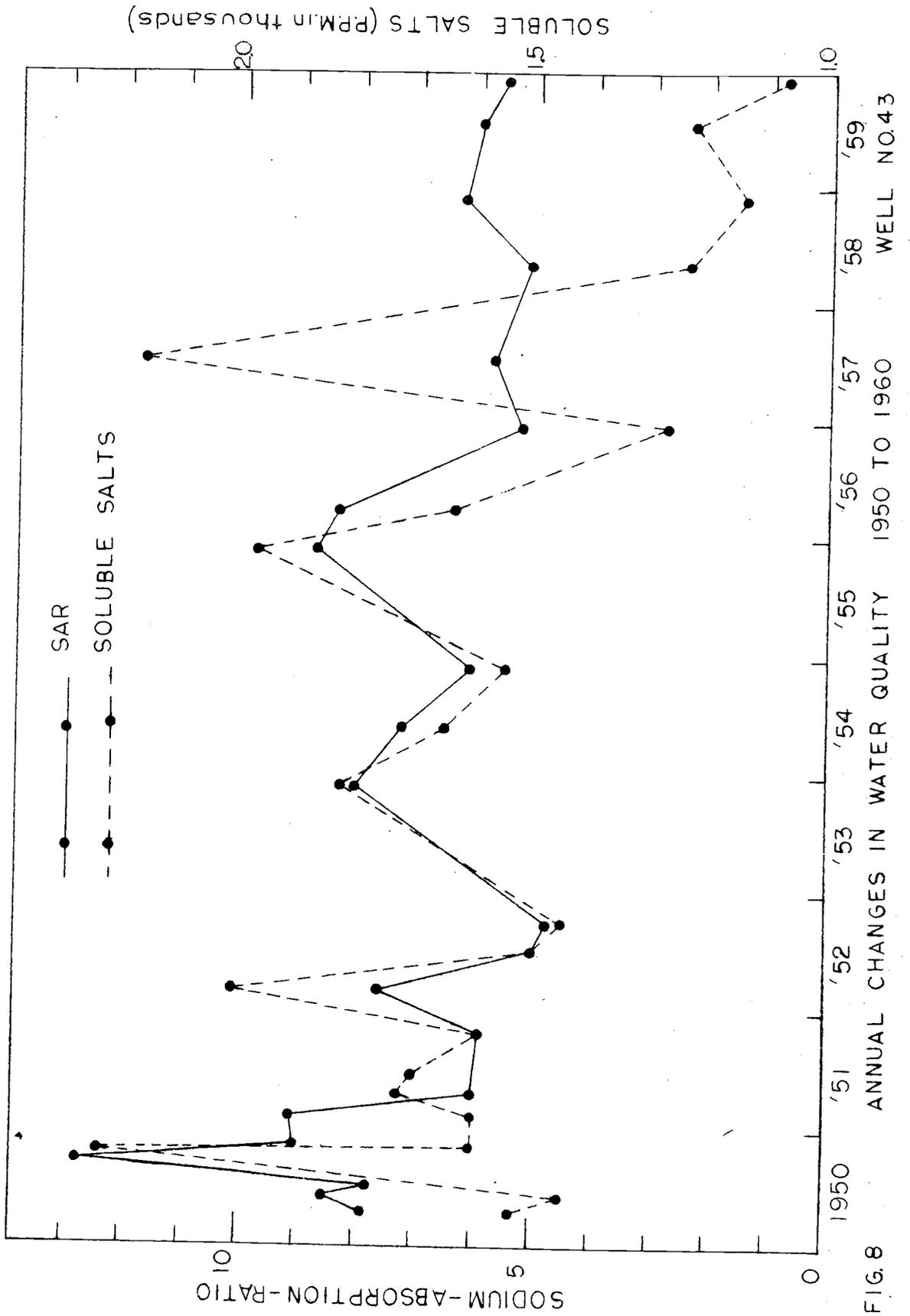


FIG. 8

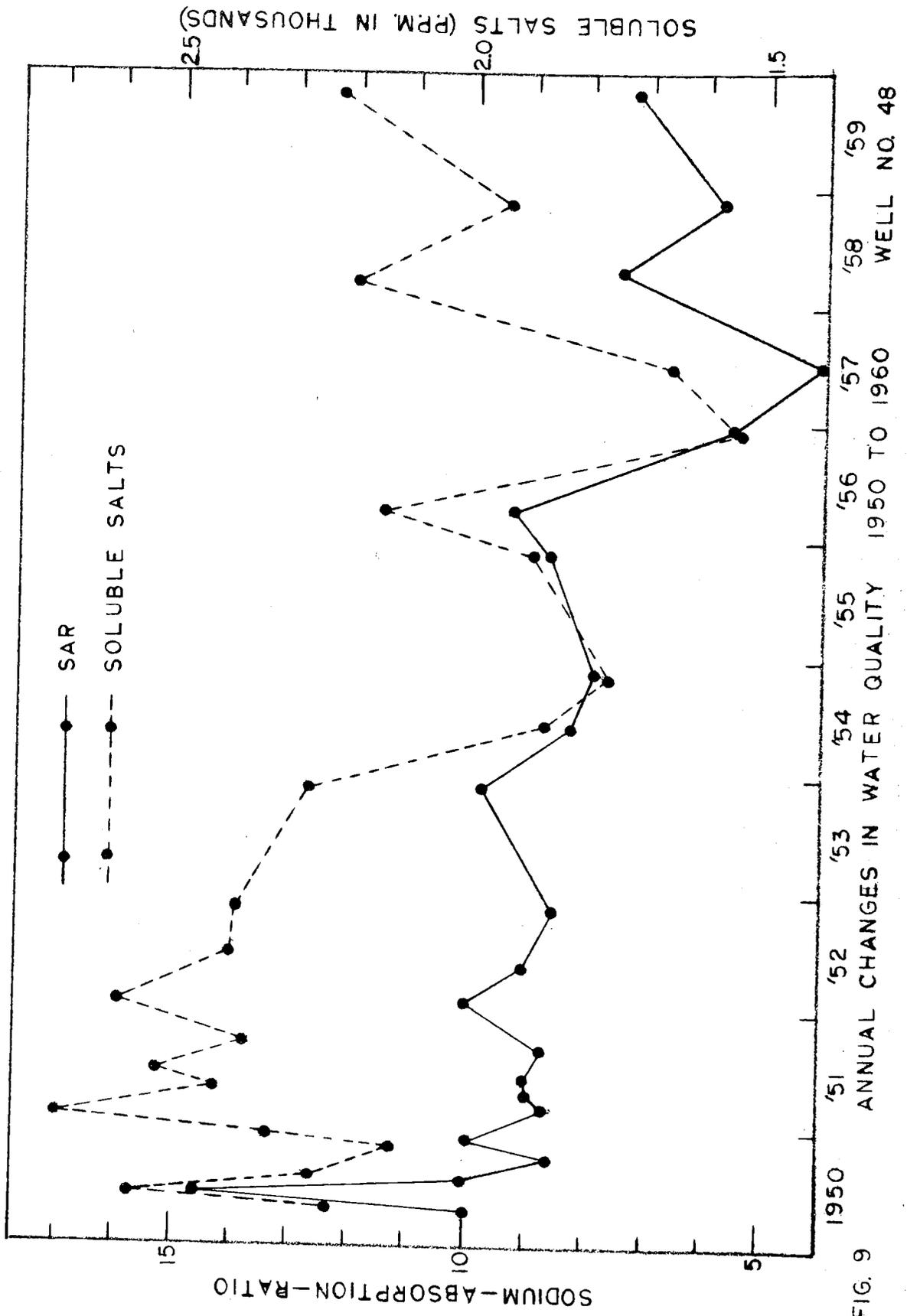


FIG. 9

WELL NO. 48

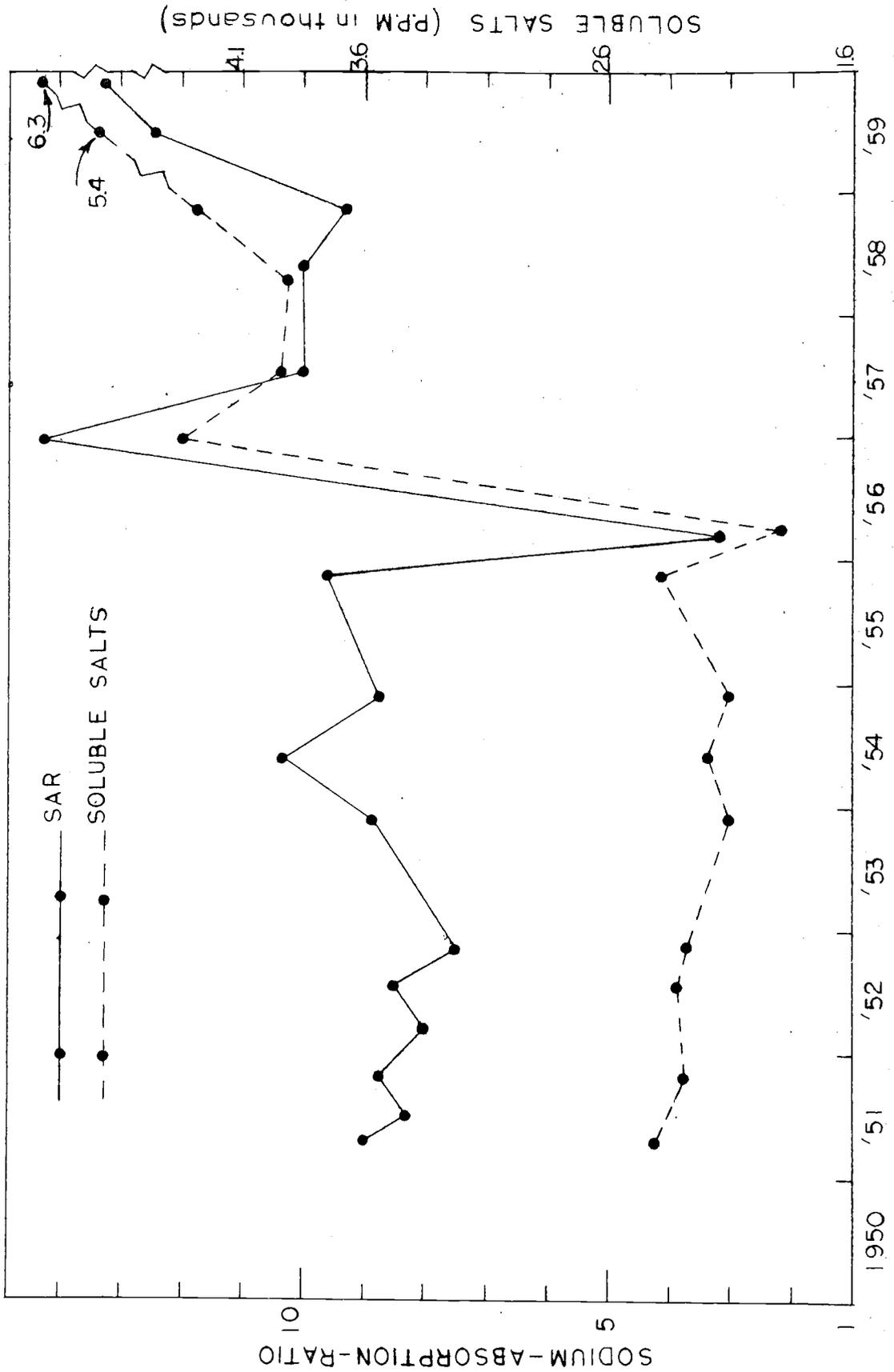


FIG. 10 ANNUAL CHANGES IN WATER QUALITY 1950 TO 1960 WELL NO. 49A

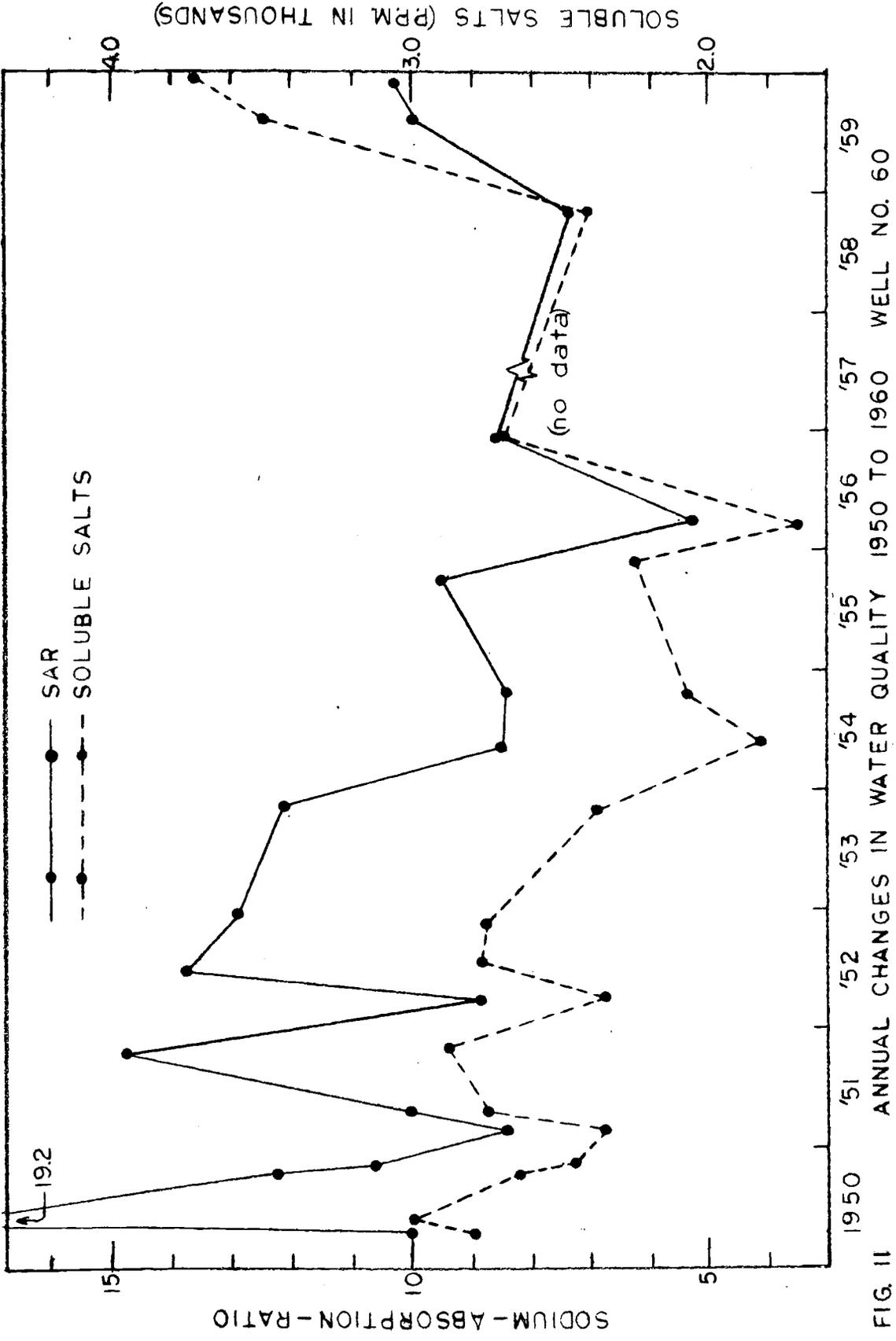


FIG. II

SOLUBLE SALTS (PPM IN THOUSANDS)

SAR
SOLUBLE SALTS

ANNUAL CHANGES IN WATER QUALITY 1950 TO 1960 WELL NO. 60

192

SODIUM-ABSORPTION-RATIO

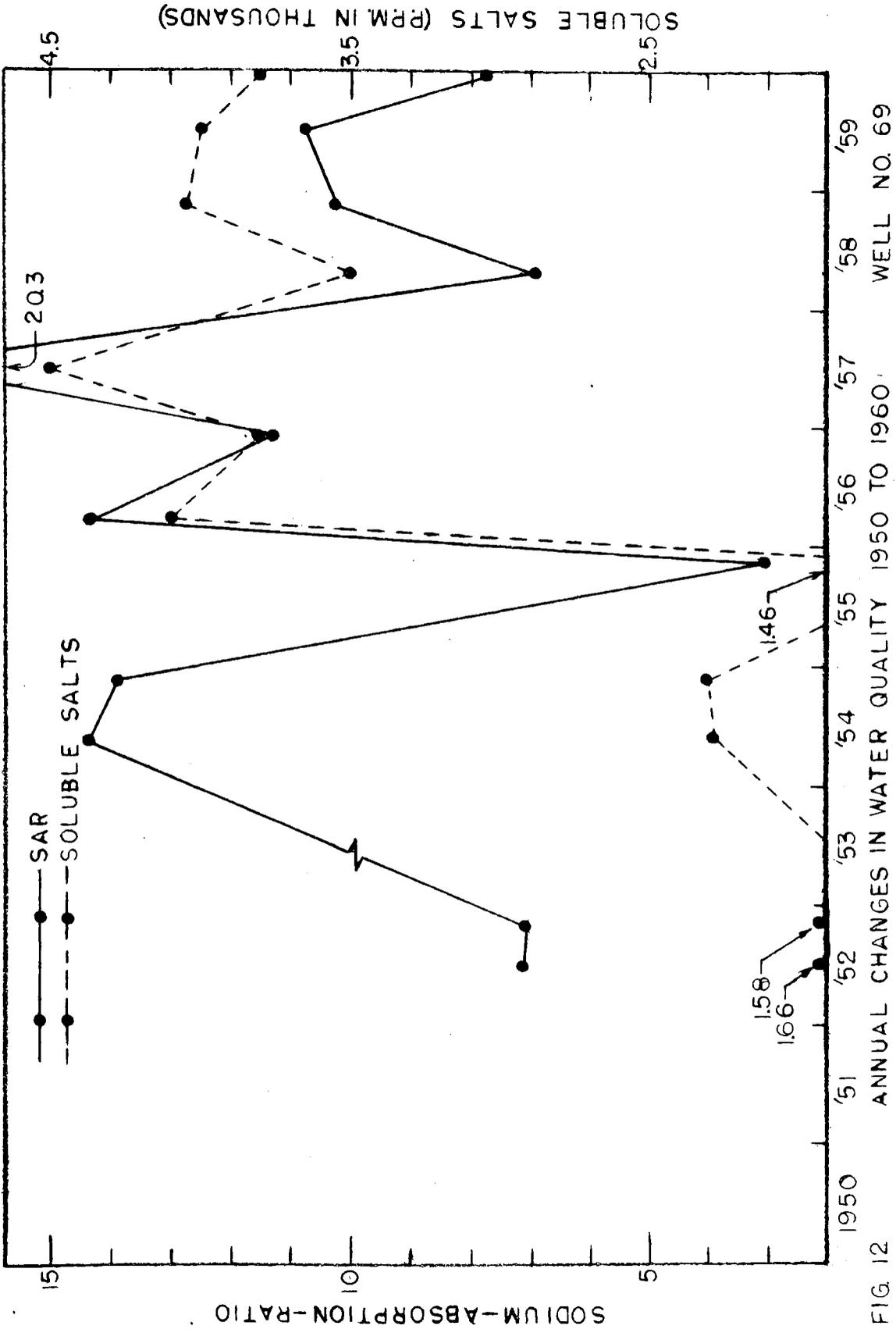


FIG. 12 ANNUAL CHANGES IN WATER QUALITY 1950 TO 1960 WELL NO. 69

level. Concentrations for the other wells tended to decrease after the 1955-1957 peaks.

Five of the wells, Nos. 2, 14, 48, 49A, and 60, had significant increases in salt content during 1959 as opposed to three other wells, Nos. 5, 32, and 43, which were decreasing in salt concentration during 1958-1959.

Wells No. 5 and 48 showed a somewhat different pattern for the first part of the test period in that their highest salt values were recorded in 1950-1953 instead of 1955-1957. Then, after low values were recorded for both in 1954, they followed the general trends of the other wells.

There were no definite general trends in the fluctuations for SAR values. Four wells, Nos. 5, 43, 48, and 60, had decreasing SAR values, or an improvement in the quality of the water from the standpoint of sodium; Nos. 49A and 69 increased in SAR for a decrease in water quality; the other wells remained approximately the same in SAR status.

Considering both values, TSS and SAR, four wells, Nos. 5, 43, 48, and 60, became better in quality over the ten year period; one well, No. 32, remained the same; and two wells, Nos. 49A and 69, became worse. The other wells, Nos. 2, 14, and 41, remained the same in SAR but increased in salt concentrations. This would lower the overall quality of the water, since an increase in salt concentration can make the sodium problem worse even though the SAR remains constant.

Relation of Water Quality to Location of Wells

Considering the ten year period as a whole, the wells with the highest values for TSS and SAR were located in the eastern third of the district and in the southern part of the central third. The best quality water was found in the western third of the district and in the northern part of the central section. In other words, the quality of the water decreases to the south and east in the valley.

There seems to be no relation between the improvement or worsening of quality for the ten year period and the location of the well. The quality pattern was somewhat heterogeneous, indicating that short-time fluctuations may be quite important for water quality evaluation. The responsible factors influencing short-time variations in quality require further intensive study.

Monthly Variations in Water Quality July 1959-June 1960

Analyses made during the year July 1959-June 1960 constitute a detailed study of the short-term or seasonal fluctuations in the quality of the irrigation water in the South Gila Valley. The object of this study was to obtain monthly changes and to determine if these could be correlated more closely with local irrigation practices and with those of the surrounding areas. The quality was determined by

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Well No. 14, Figure 15. The values for this well show less change during the year than any of the other wells. TSS values were in the range of 2000-3000 ppm. with the most significant increase in March and April. SAR values stayed in the 6-7 range until March when a peak of 8.8 was reached. The percentage sodium values were in the range of 50-55 but showed a slight downward trend during the year.

Well No. 32, Figure 16. This well was one of the lowest in salts with a low value of TSS of 1000 ppm. in May and a high of 1800 ppm. in June. The SAR was rather constant around 6-7 until March at which time it increased sharply to 9.2; this was followed by a marked drop to 3.5 in May. The abrupt fluctuation in SAR was probably due to the corresponding changes in percentage sodium which dropped from 70 in March to 49 in May.

Well No. 41, Figure 17. This well did not follow the usual trend of most of the wells, but showed highest values in September with TSS at 3150 ppm. and SAR at 9.6. There was no increase in SAR and salts during March but some increase in May and June. The changes in percentage sodium followed the changes in SAR.

Well No. 43, Figure 18. This well had the lowest salt content of all the wells. It usually ranged from 1000 to 1300 ppm. TSS. The only increase came in March and April when the values were 1700 and 2100 ppm. respectively. The SAR

followed the same general pattern but had a high of 8.5 in March which fell to 6.0 in April at which time the TSS values were highest. This was due to the sharp decrease in sodium content in April.

Well No. 48, Figure 19. This well did not show a great change in salts during the year. The high value was 3200 ppm. TSS in January followed by a low of 2100 ppm. in April without the usual increase in March. The SAR was more irregular; there was an increase to 9.8 in November which does not seem to be consistent with the values for TSS and percentage sodium. The high value for SAR was 11.8 in March which corresponded to the high value of 70 for the percentage sodium.

Well No. 49A, Figure 20. This well had the highest values of all the wells for the entire year and also showed the most fluctuation. TSS varied from 3700 ppm. to 6500 ppm. with highest values in October, December, January, and February, and lowest values in September, November, and June. The SAR also showed irregular values for the year with a low of 10 in November and highs of 14-15 in August, October, and June. The percentage sodium followed closely the SAR values.

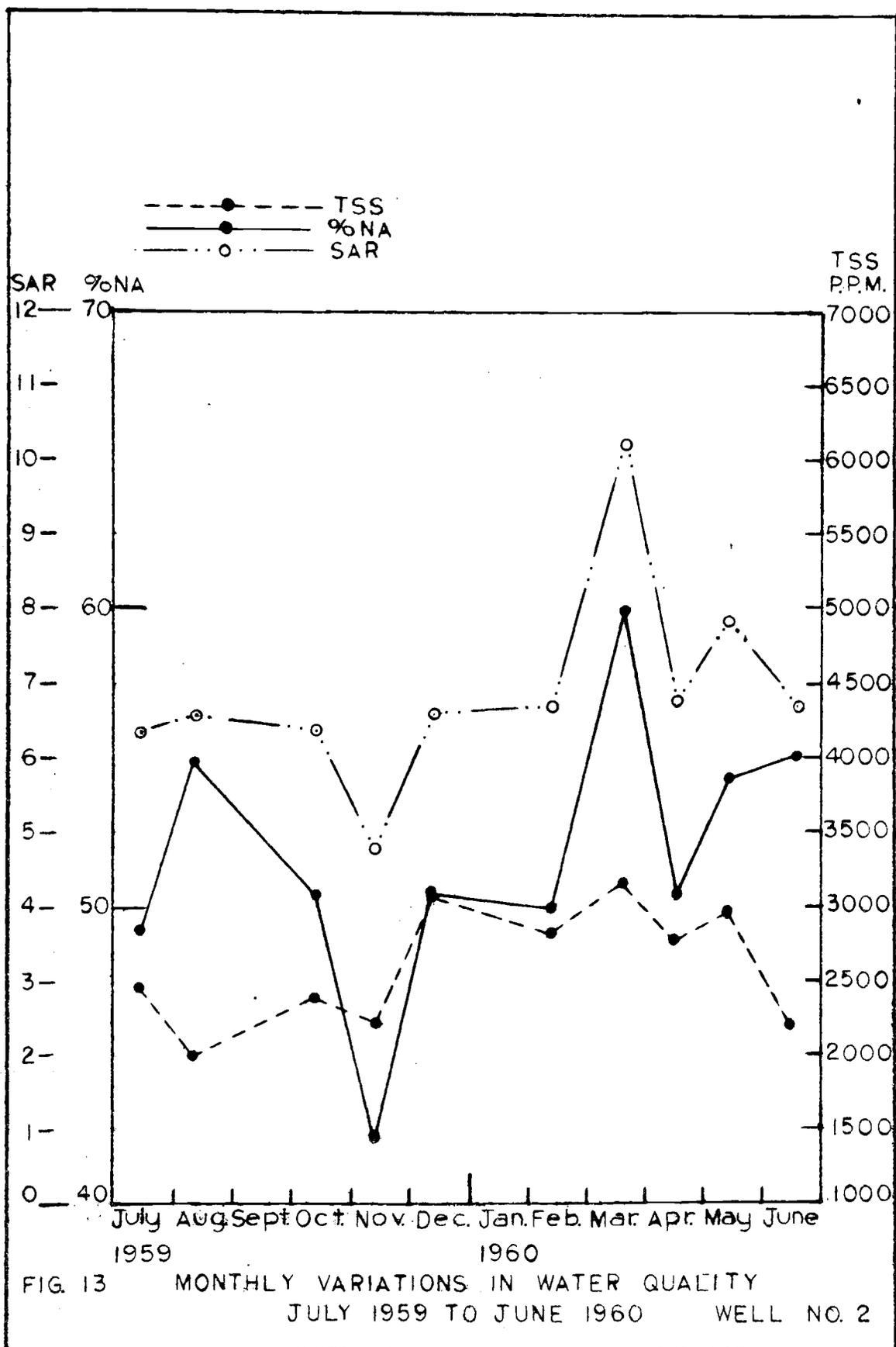
Well No. 60, Figure 21. The information for this well is incomplete but there seemed to be a tendency for all of the values to increase for the year. TSS values were in the

range of 3000 to 4000 ppm. SAR values were in the range of 10-12. The changes in the percentage sodium values followed the changes in the SAR values.

Well No. 69, Figure 22. This is the only well which showed an overall decrease in all values for the year. TSS values were high, 4100 ppm. and 4300 ppm., in July and September respectively; and were lowest, 3100 ppm., in June. There were only moderate increases in March and April. SAR values decreased from 10.9 in September to 6.0 in June. The percentage sodium followed the same pattern as the other values.

Well No. 76, Figure 23. Only four months' data are available for this well but the values seem to be rather consistent except for a sharp drop in the percentage sodium for October. The salt content ranged from 2000 to 2600 ppm. TSS, and SAR ranged from 11.5 to 13.0.

Well No. 78, Figure 24. Information is incomplete for this well but it seems to follow the general pattern of most of the wells with increased values in March and April. The TSS values were rather consistent in the range of 1800 to 2700 ppm. SAR values showed more change with a high of 16.2 in March and a low of 8.5 in June. The changes in these values were followed closely by the changes in the values for percentage sodium.



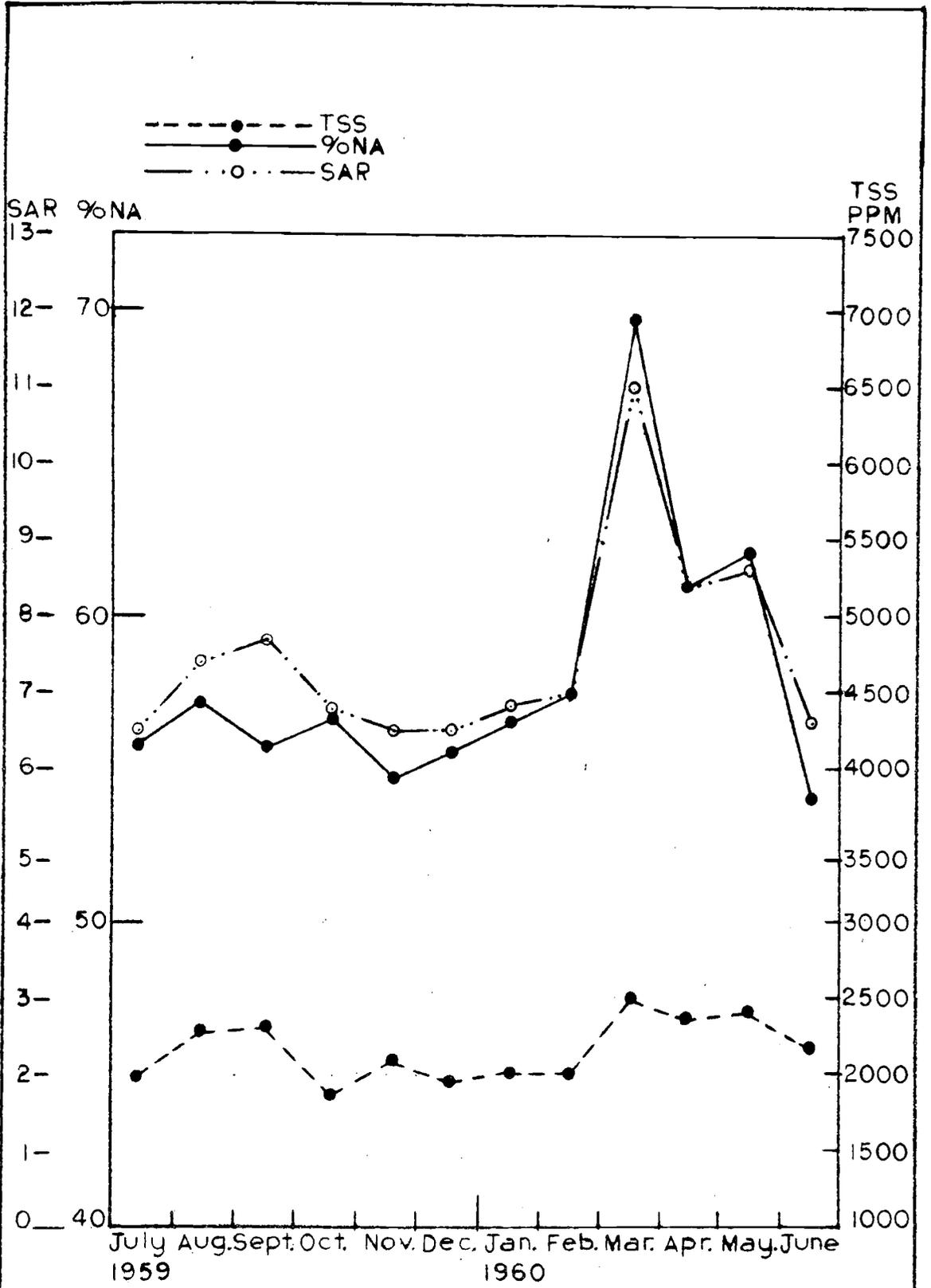


FIG. 14 MONTHLY VARIATIONS IN WATER QUALITY
 JULY 1959 TO JUNE 1960 WELL NO. 5

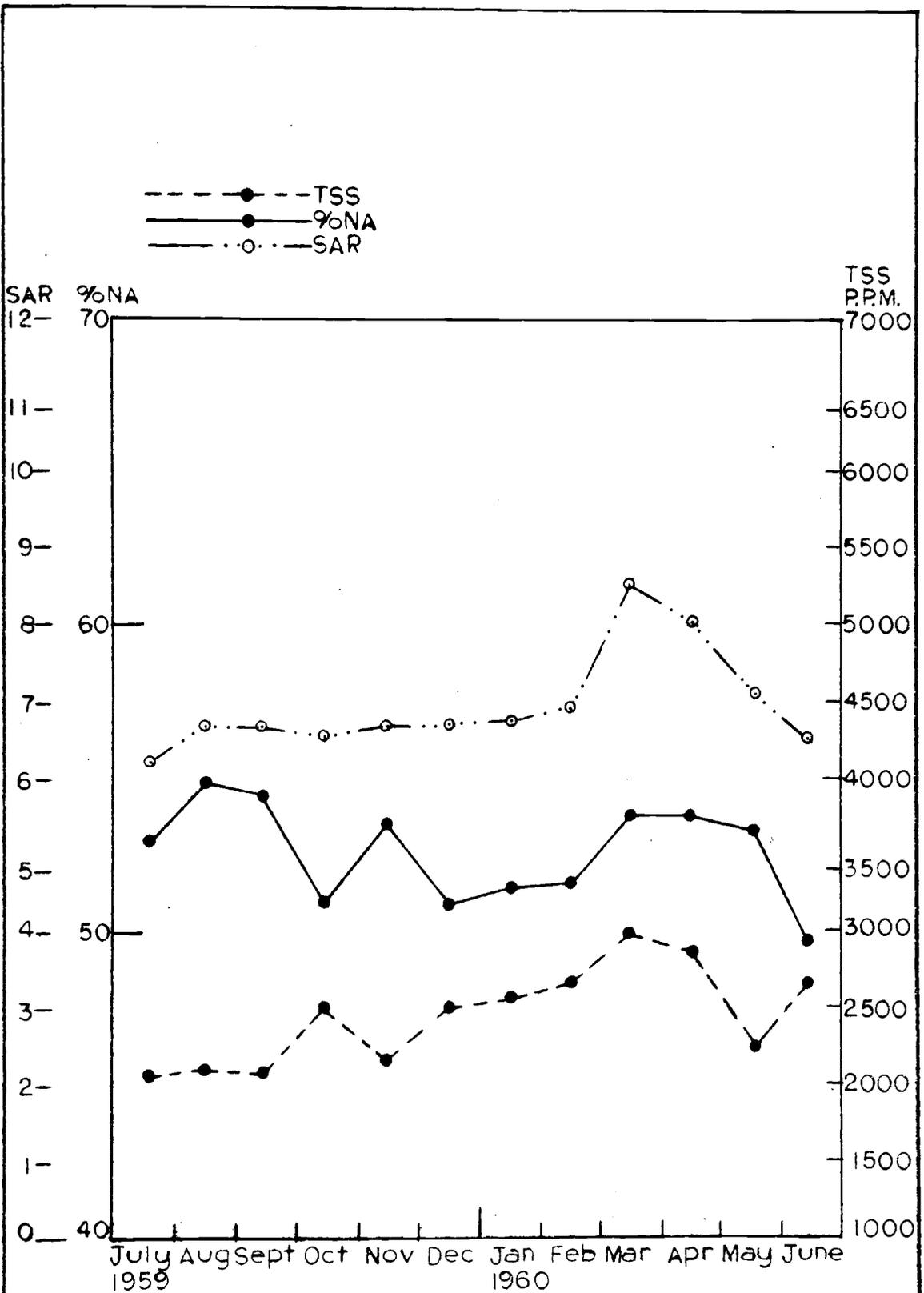


FIG. 15 MONTHLY VARIATIONS IN WATER QUALITY
 JULY 1959 TO JUNE 1960 WELL NO. 14

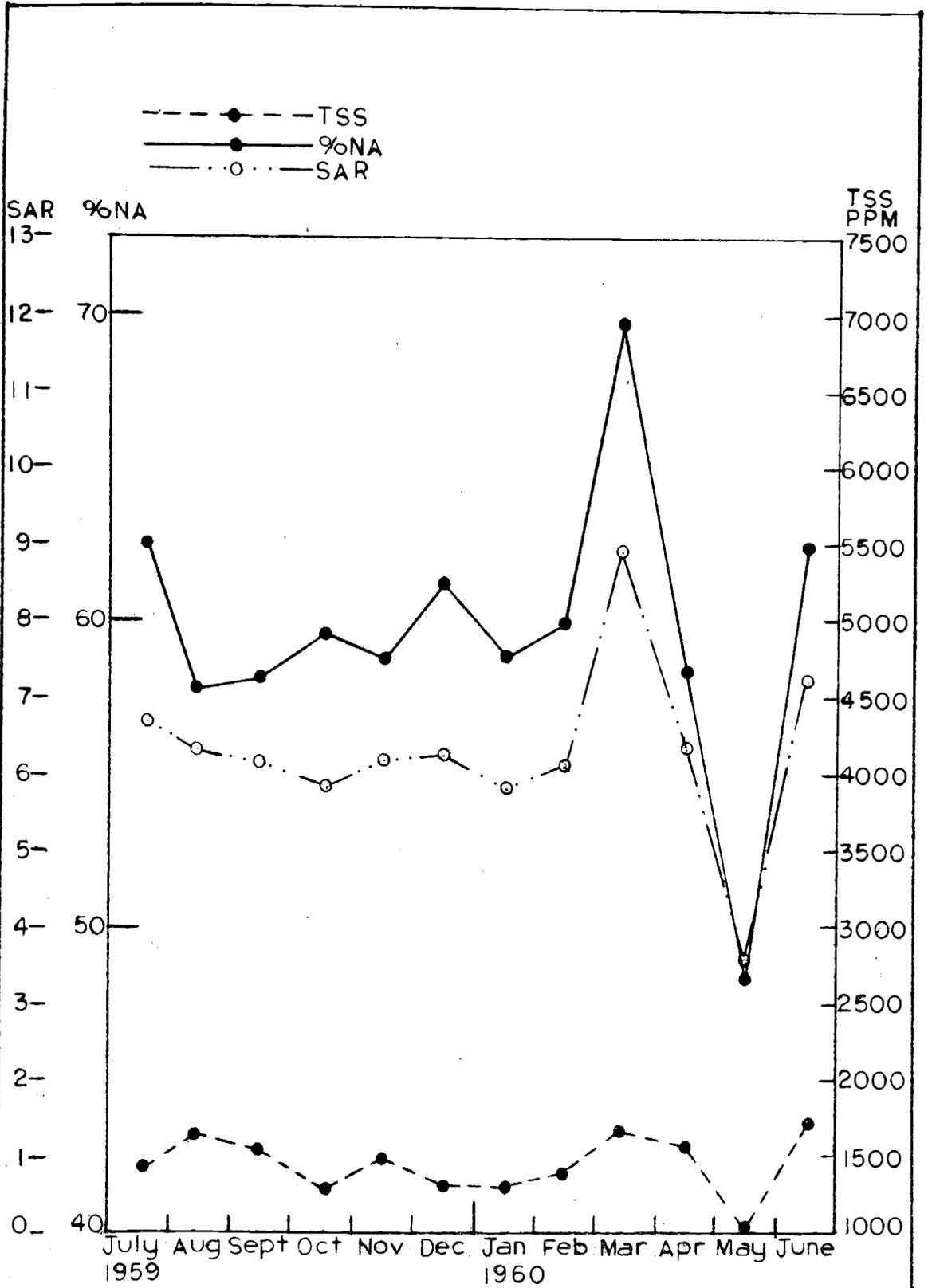


FIG. 16 MONTHLY VARIATIONS IN WATER QUALITY
 JULY 1959 TO JUNE 1960 WELL NO 32

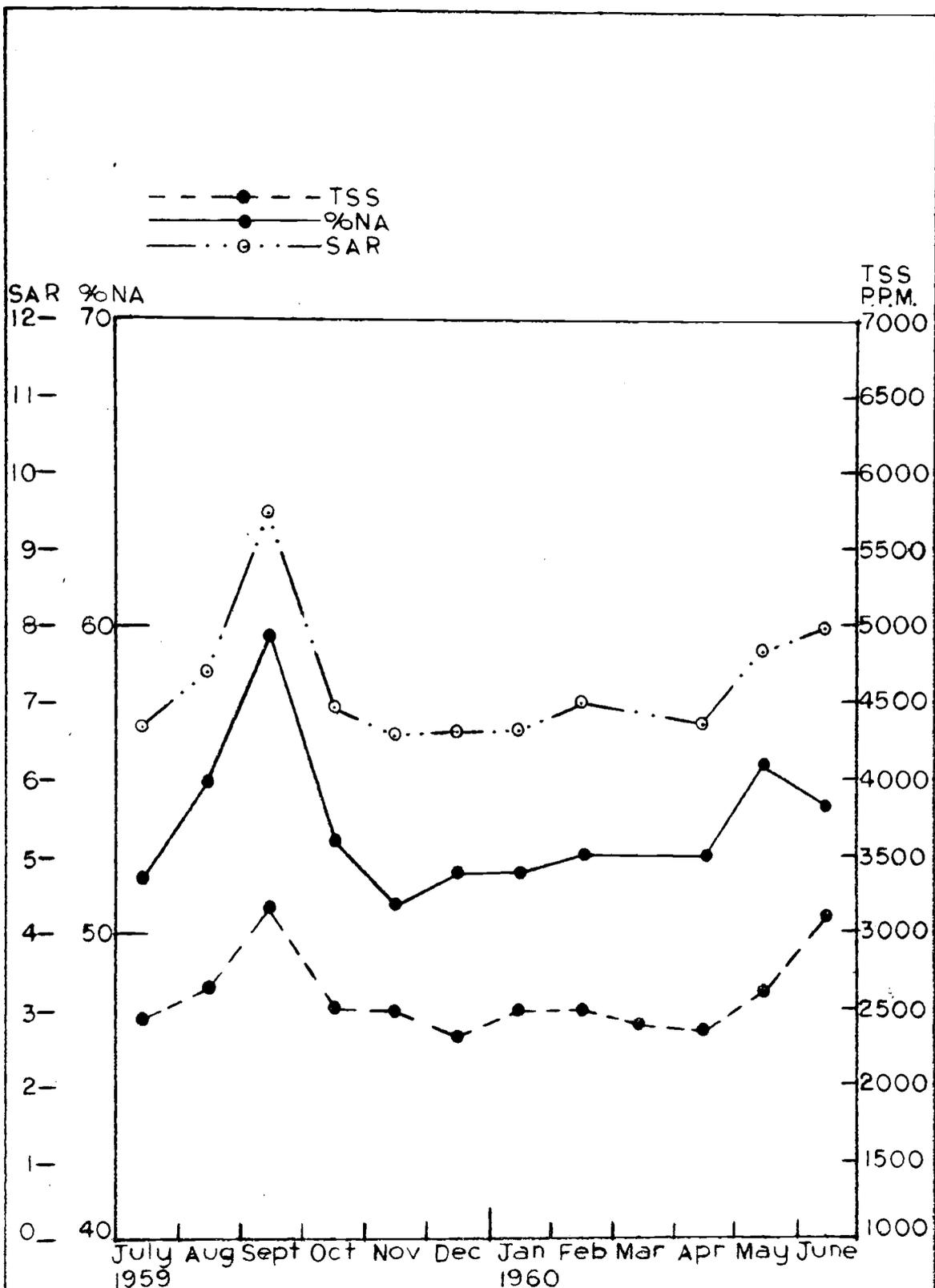


FIG. 17 MONTHLY VARIATIONS IN WATER QUALITY
 JULY 1959 TO JUNE 1960 WELL NO. 41

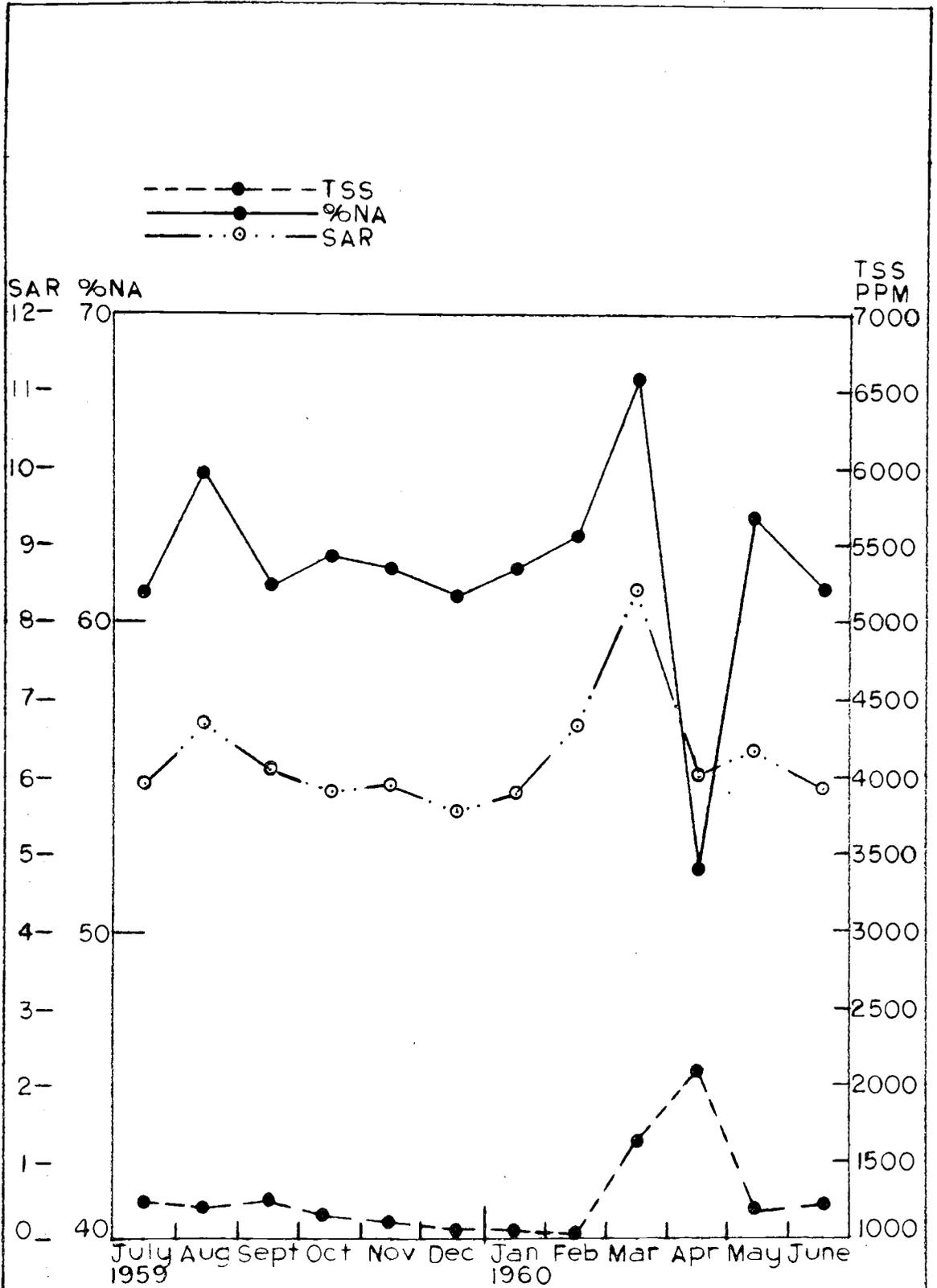


FIG. 18 MONTHLY VARIATIONS IN WATER QUALITY
 JULY 1959 TO JUNE 1960 WELL NO. 43

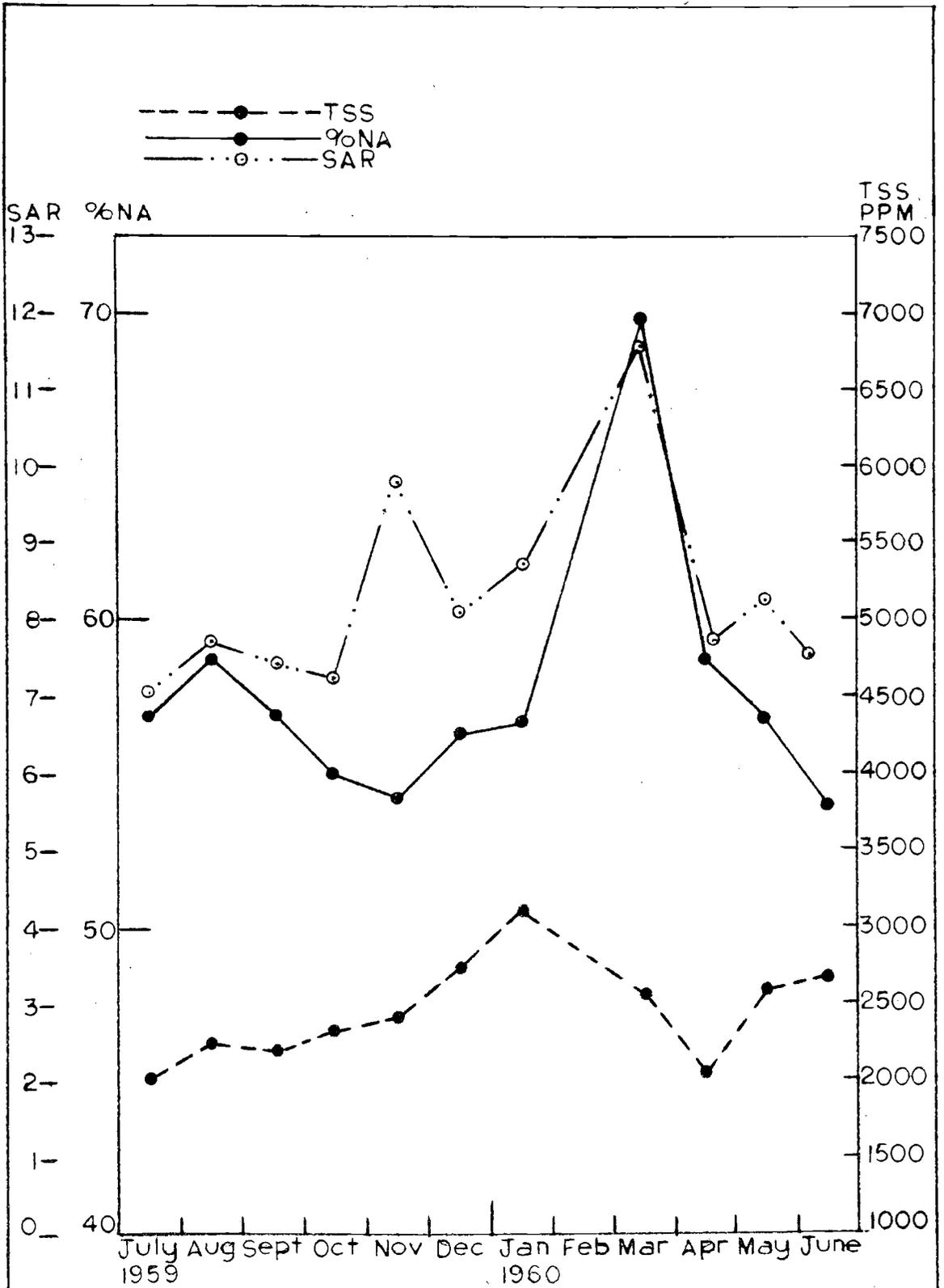


FIG. 19 MONTHLY VARIATIONS IN WATER QUALITY
 JULY 1959 TO JUNE 1960 WELL NO. 48

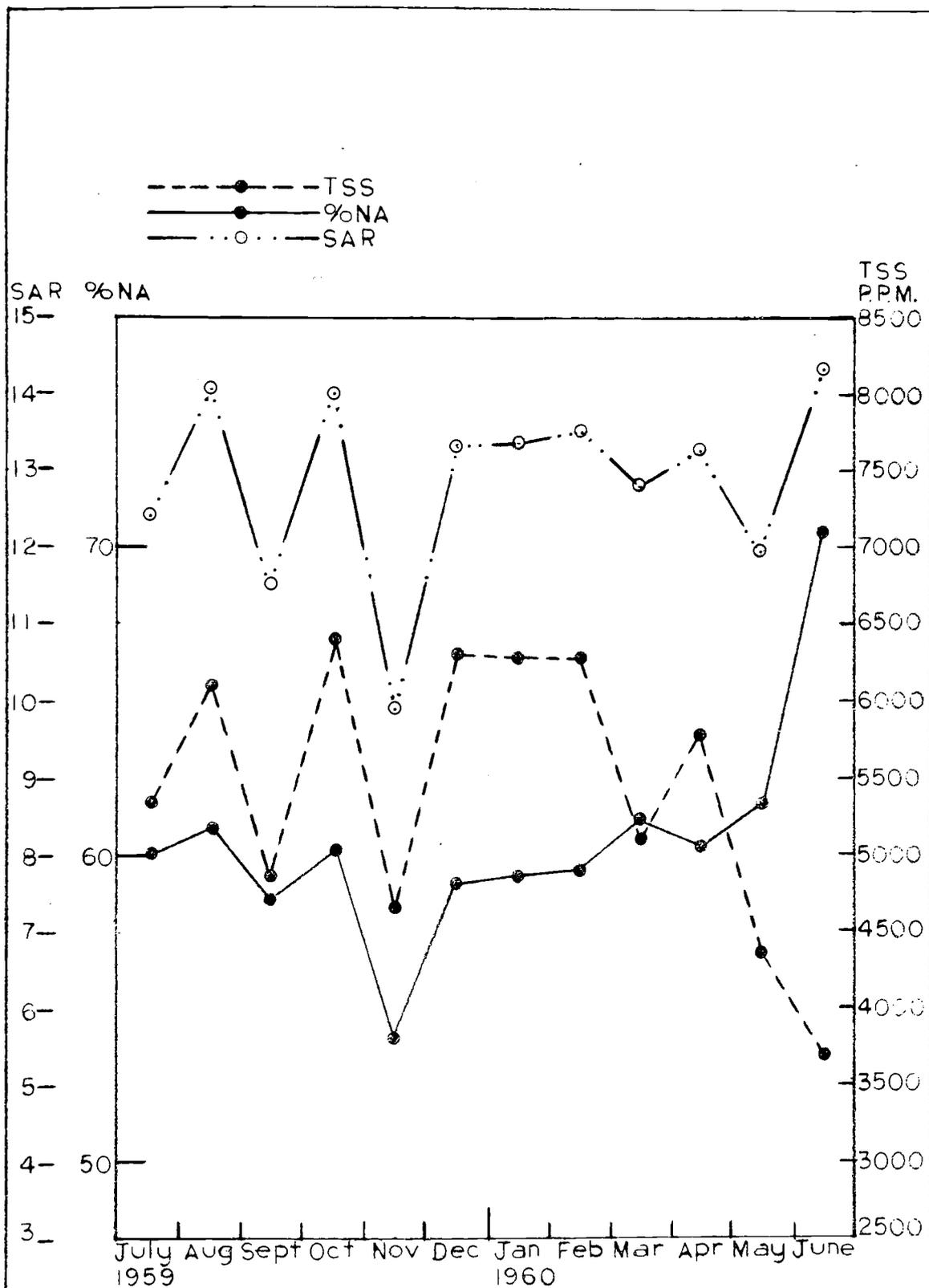


FIG. 20 MONTHLY VARIATIONS IN WATER QUALITY
JULY 1959 TO JUNE 1960 WELL NO. 49A

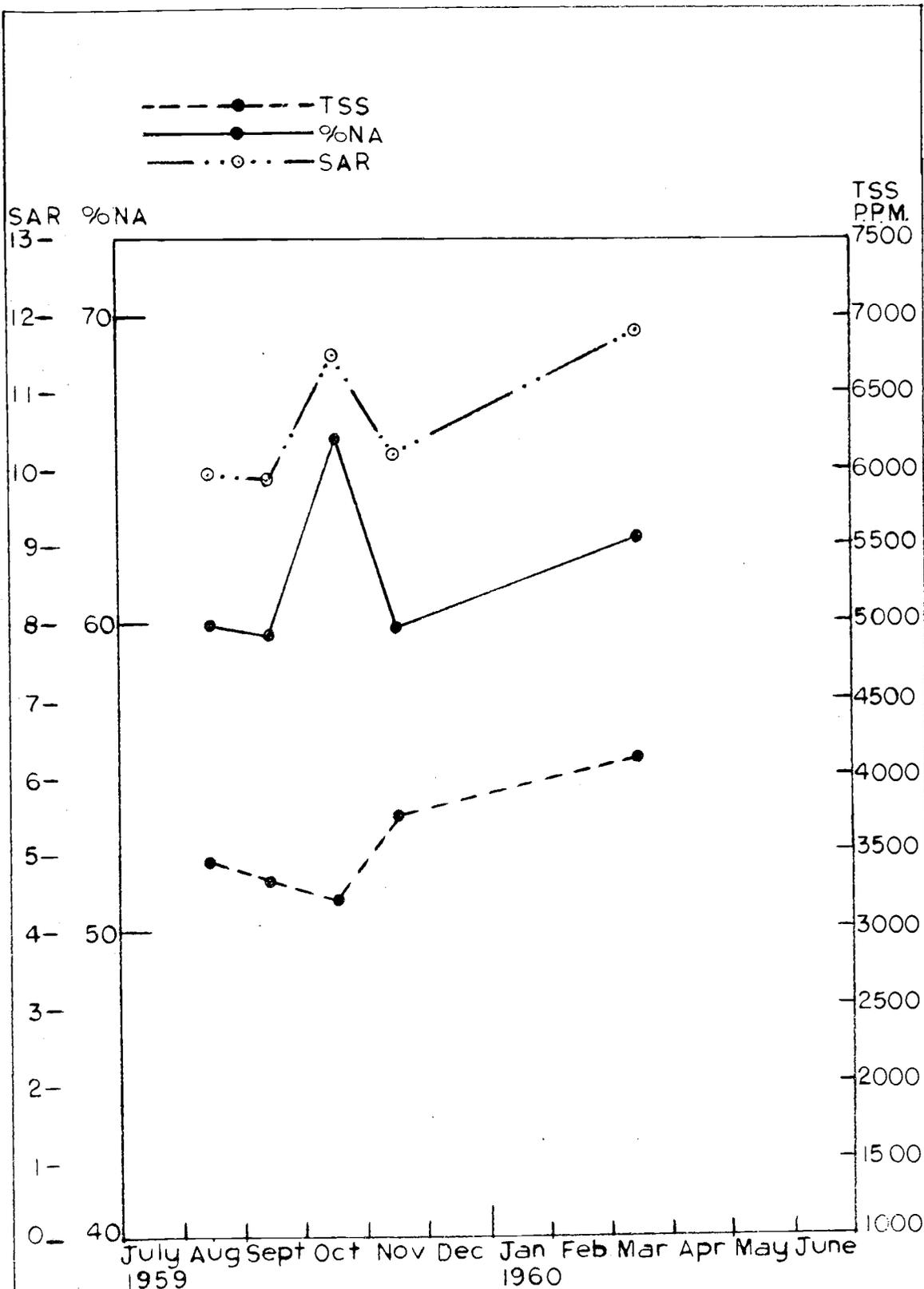


FIG. 21 MONTHLY VARIATIONS IN WATER QUALITY
 JULY 1959 TO JUNE 1960 WELL NO. 60

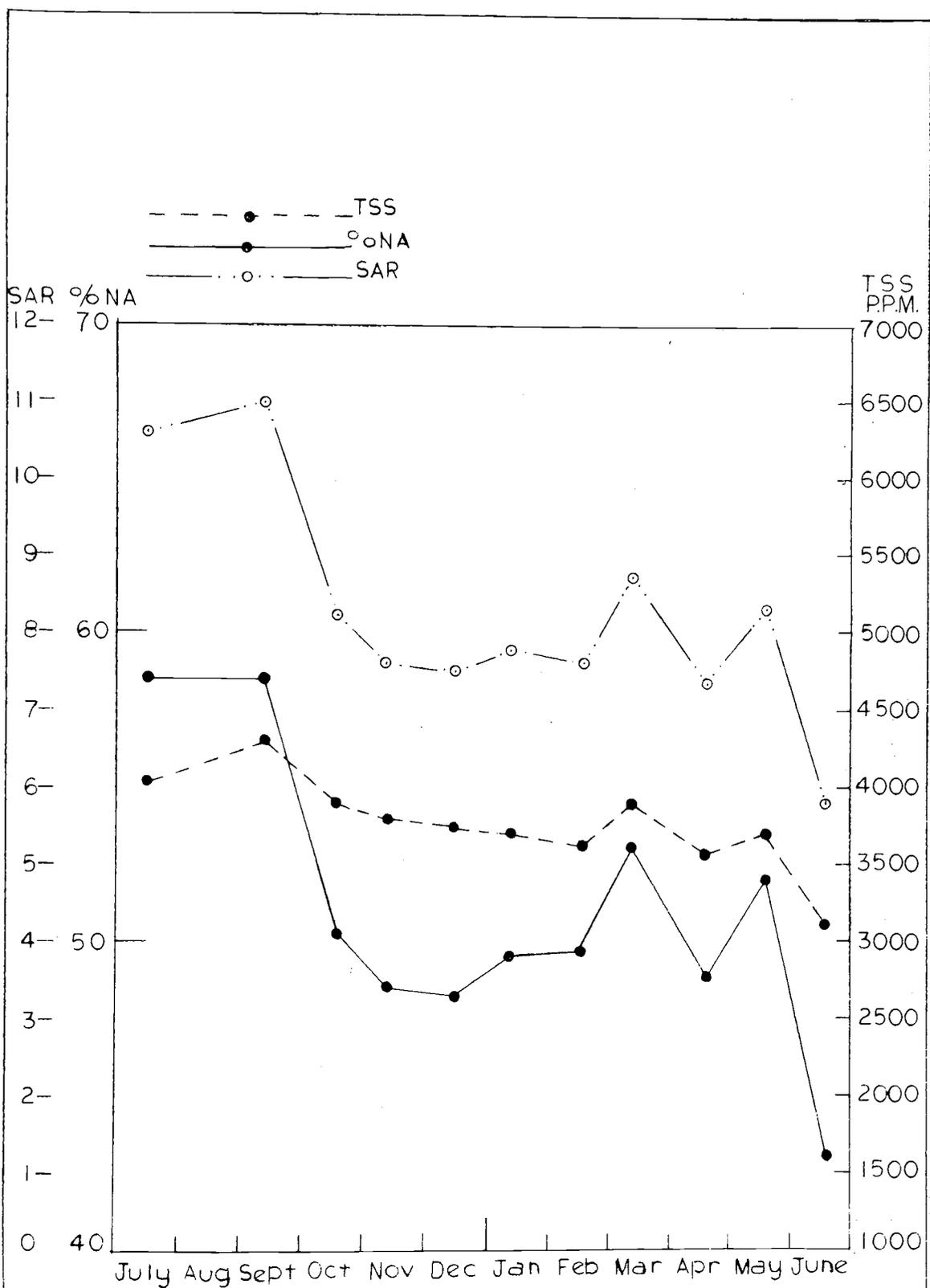
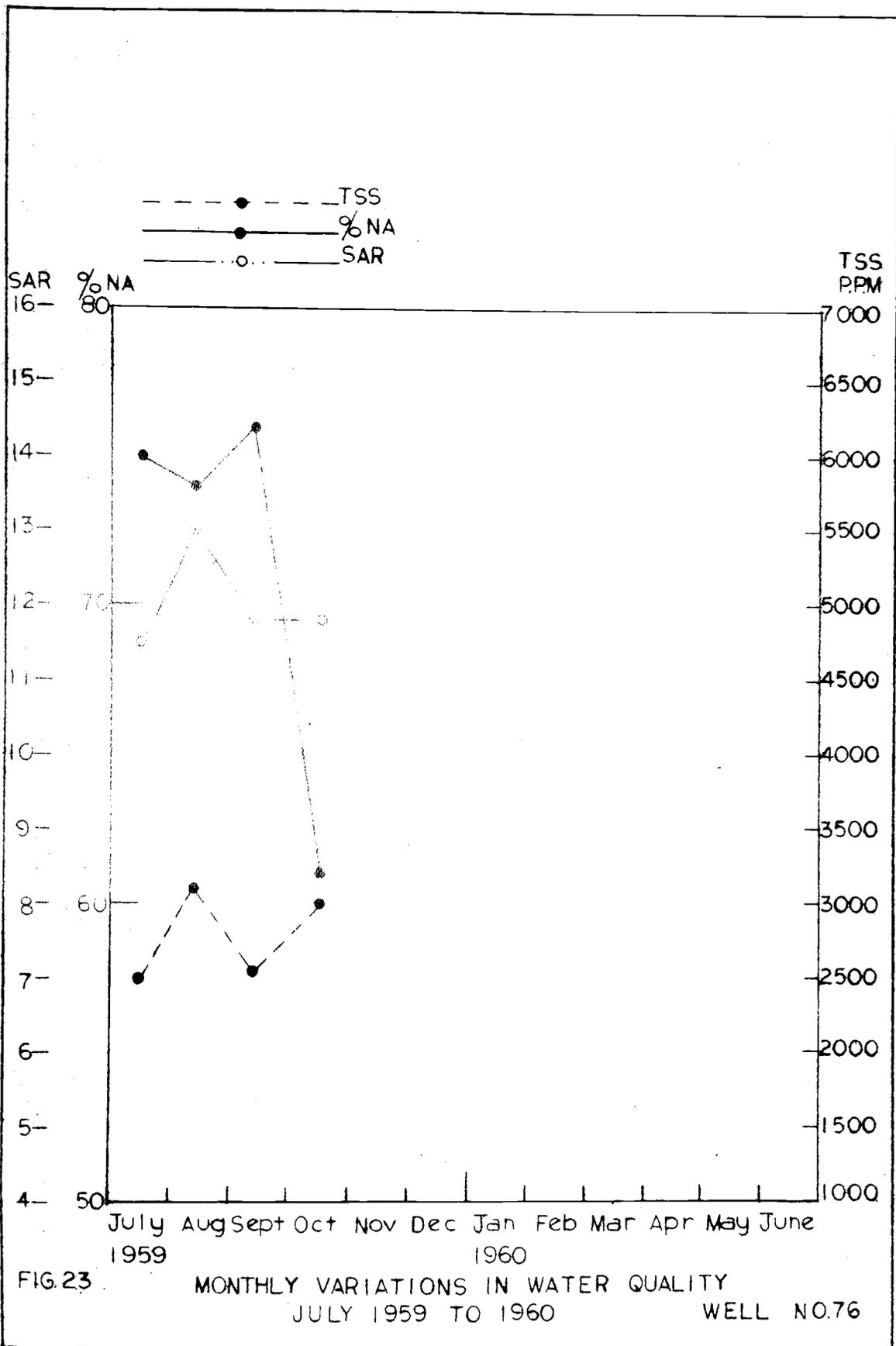


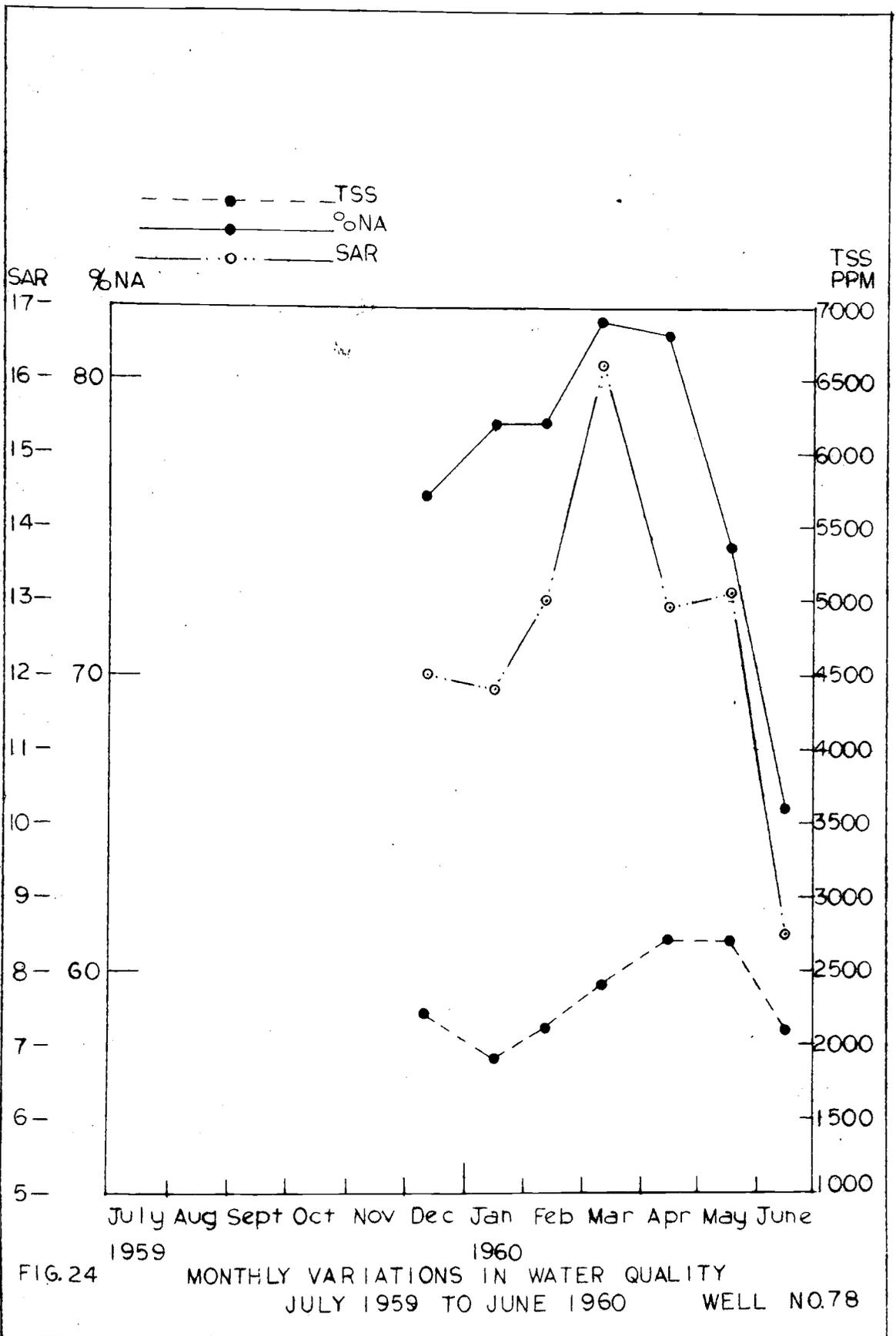
FIG.22

MONTHLY VARIATIONS IN WATER QUALITY

JULY 1959 TO JUNE 1960

WELL NO.69





General Monthly Trends

The total salt concentrations were highest for the year in the spring months with peaks usually occurring in March and April; lowest values usually occurred in the fall, most often in November. With the exception of Well No. 49A, the changes in TSS did not exceed 1000 ppm. Well No. 49A, the saltiest studied, varied approximately 3000 ppm. during the year.

Changes in the SAR values also followed the general pattern set by the changes in TSS; low values were usually found in November and high values in March. Variations were mostly in the range of 2-3 units, but some wells varied as much as six units. Percentage sodium varied directly with SAR, as would be expected.

Comparison of Monthly Variations.

Seasonal variations for TSS and SAR for the year followed the same magnitude of change as seasonal variations for the period 1950-1960. However, there were greater overall changes during the ten year period, but this is to be expected since a longer time was involved.

Boron Content

Boron was determined approximately five times during the year to provide information which might reflect changes in the quality of the water as influenced by possible recharge from surrounding areas. Bar graphs were constructed to show

the concentrations. These graphs are located geographically on a map of the area to correlate occurrence and change with location.

There were no definite patterns of change observed during the year for boron content. Some wells had slightly higher concentrations in the spring and summer of 1960; others had slightly higher concentrations in the fall of 1959. Most of the changes were small, less than 0.1 ppm.

Only two wells, 49A and 78, had concentrations over 1.00 ppm. In April No. 49A reached 1.70 ppm. and No. 78 reached 1.03 ppm. Concentrations for the others were less than 0.7 ppm., mostly in the range of 0.3-0.5 ppm.

Correlation of Boron Content and Location

The relation of boron content to position is shown on the map, Figure 25. Highest boron occurred in the eastern third of the valley and lowest content in the western third. As a general rule, the content also increased from north to south.

Correlation of Boron Content and TSS Content

There is some tendency for wells with high TSS to be high in boron also. For example, the wells with the highest TSS content for the year July 1959-June 1960 were Nos. 49A, 60, and 69; the wells with the highest boron were Nos. 49A, 60, and 78; the wells with the lowest TSS content were Nos. 5, 32, and 43; and those with the lowest boron were Nos. 2, 32,

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and 43. Furthermore, wells with high TSS and boron contents are located in the eastern and southern parts of the valley whereas those with lower salt and boron contents are found in the western and northern sections.

Conclusions

Seasonal changes seem to indicate that there are correlations between the changes in the quality of irrigation water in the South Gila Valley and water usage in the surrounding areas. This is most evident in the spring when increased salt concentration occurs at the same time that increased irrigation water is used for crop production.

The variations in water quality based on SAR indicate that different wells are being recharged with water from different sources at different times. Some of this is poorer quality water since some wells had SAR values which varied sharply. The presence of aquifers leading into and through the valley would make this possible.

As was previously pointed out, the wells with the poorest quality water were found in the eastern section of the valley and quality improves to the north and east. By inspection of the map of the area, Figure 25, it seems evident that some of the poor quality water is entering the valley at the northeast corner. Increased concentrations of boron in the water in this section also lend support to this belief

since there are high boron content waters in the lower Roll-Wellton-Mohawk Valley to the north.

There is a general trend for salinity to increase from the north to the south in the valley and it would seem that the high water table under the mesa might be blocking the normal drainage which otherwise would remove excess salts from the valley.

Well No. 49A does not seem to fit the expected pattern of change. Apparently there is some unique local factor which is causing the high salinity and boron content of this well.

SUMMARY

The Yuma Irrigation District is located in the South Gila Valley which is surrounded by regions of higher elevation. The introduction of Colorado River water into these higher areas for irrigation purposes apparently causes a high water table to develop in the South Gila Valley and a concurrent decrease in the quality of the water from wells in this lower area.

A ten year study was made of the quality of the water from the Yuma Irrigation District wells. Fluctuations in total salts and sodium relationships were studied to determine if these changes could be correlated with irrigation practices in the valley and in the surrounding areas and to determine if the sources of the poor quality water could be identified.

The quality of the water as indicated by the total soluble salts, sodium, and calcium plus magnesium relationships usually decreased for the ten year period. Increased concentrations of salts were particularly evident in 1956, 1957, and 1959. Fluctuations in TSS were usually in the range of 1000-1500 ppm. but in a few cases the changes approached the range of 3000-4000 ppm.

While the average SAR values were not found to be increasing, there were considerable variations during the

ten year period. Most changes were approximately five units, but changes up to 15 units occurred.

A more detailed study was made for the year July 1959-June 1960 to determine monthly and seasonal fluctuations and to correlate these changes more closely with local and regional irrigation practices. Boron analysis was included in this study to assist in evaluating changes in the quality of water which might be expected to come from outside sources high in boron.

The annual fluctuations showed that the quality of the water was poorest in the spring, March and April, and best in the fall, usually, November. Extremes in fluctuations were somewhat less than for the prior ten year period. Salts varied less than 1000 ppm. TSS whereas the SAR fluctuations for the year generally followed the changes in total salts. Here again, the range of variation was smaller than for the ten year period being about 2-3 units.

Boron was determined approximately five times during the year. There was no general trend of change in concentration found. Bar graphs showing concentrations were located geographically on a map of the area and it was noted that high boron content waters were found in the eastern and southern sections of the valley.

There was also a tendency for waters with high salt contents to be high in boron. This poor quality water was more prevalent in the east and south. Quality tended to improve toward the north and west.

From this information it was concluded: (a) that irrigation water in the South Gila Valley is affected by irrigation practices in the surrounding regions; (b) that poorer quality water probably is entering the valley from outside sources; (c) that some of this water is entering at the northeastern corner; (d) that a high water table under the Yuma Mesa is blocking the normal drainage of salty water from the valley causing wells along the southern boundary of the district to increase in salinity.

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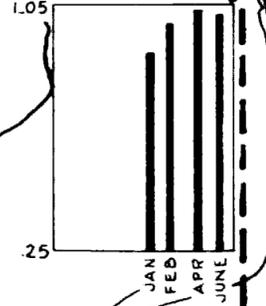
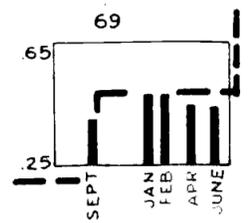
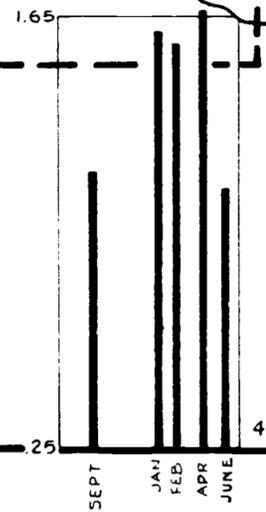
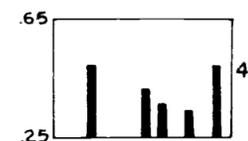
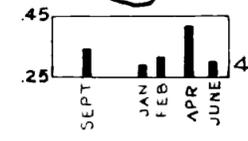
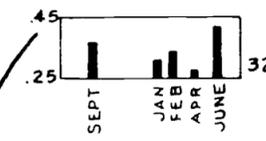
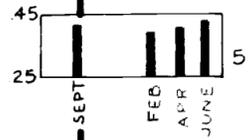
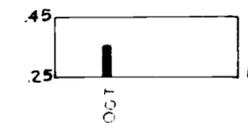
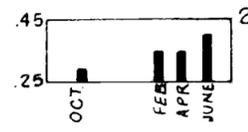
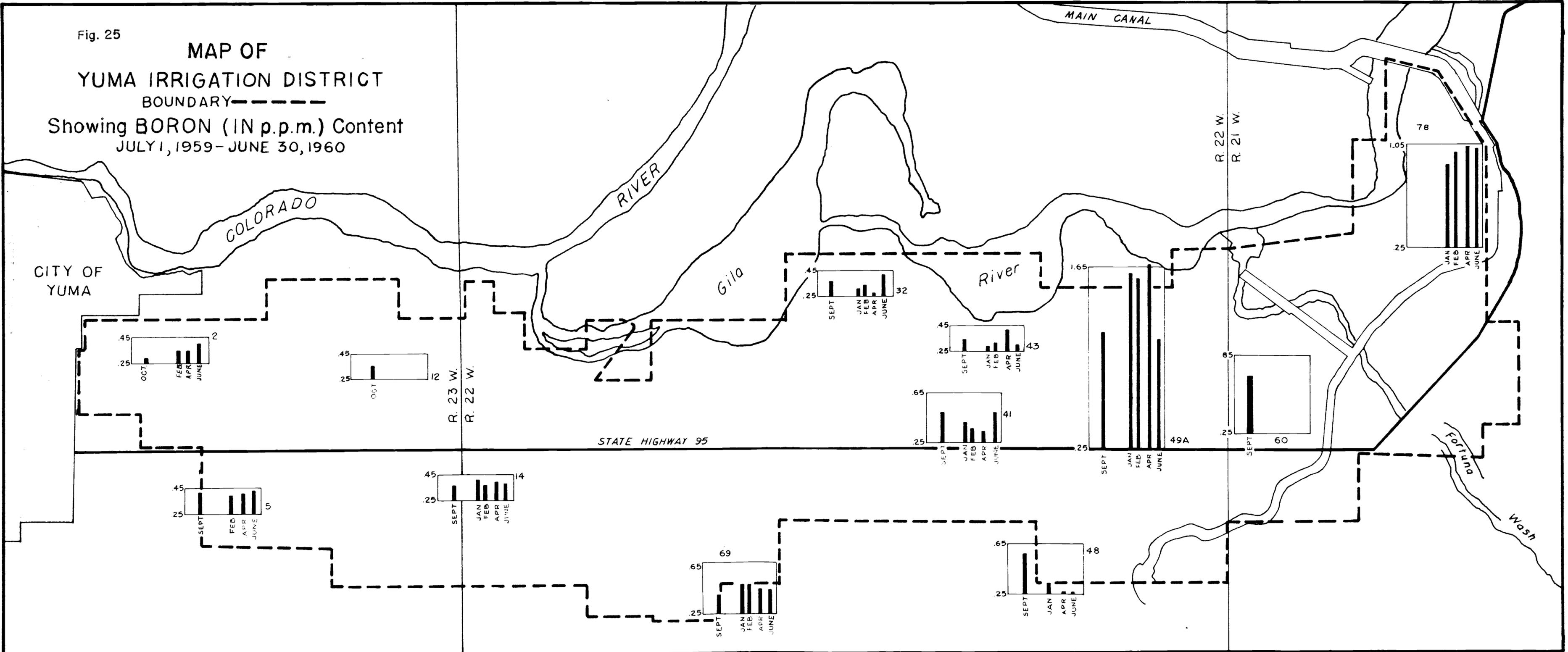
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Fig. 25

MAP OF YUMA IRRIGATION DISTRICT BOUNDARY----- Showing BORON (IN p.p.m.) Content JULY 1, 1959 - JUNE 30, 1960



1.05

MAIN CANAL

RIVER

Gila

River

COLORADO

CITY OF
YUMA

STATE HIGHWAY 95

FORTUNA

Wash

R. 22 W.

R. 21 W.

R. 23 W.

R. 22 W.