SALINITY PROBLEMS OF THE SAFFORD VALLEY:
AN INTERDISCIPLINARY ANALYSIS

by

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ABSTRACT

A change in groundwater quality, averaging approximately +0.13 millimhos electrical conductivity and +35 ppm chloride per year, has been documented between 1940 and 1972 with data from ten long-term sample wells.

The decrement in the water quality of the surficial aquifer seems to be attributable to four major mechanisms. An increase in salinity may be expected from leakage of saline water from the artesian aquifer. Such leakage would be stimulated by pumping-caused reduction of confining pressure, and by the puncture of the cap beds by deep wells. Water reaching the aquifer from natural recharge may contribute salts to the system. Such recharging water, if passed through soluble beds, could contribute to the salt. Lateral movement of water through similar deposits may be a contribution, and the concentration and infiltration of agricultural water could also add to aquifer salinity.

The economic analysis of the Safford Valley, based on the modeling of a "Representative Farm" analog, indicates that cotton will remain economical to produce on the basis of the projected salinity trends, for a significant time beyond limits of prediction. The analysis indicates that the optimum salt-resistant crops for the area are being cultivated, and, of these, alfalfa will cease to be productive in large areas of the valley by 1990. The entire valley will not produce alfalfa for profit by 2040.

The methodologies shown in the paper indicate how pumping influences salinity change and outline salinity control recommendations for the area.

SETTING

The Safford Valley, Graham County, Arizona, is a structural intermontane trough averaging 15 miles in width and lying between the Gila and Pinaleno Mountains in southeastern Arizona. The Gila River flows from east to west, for 32 miles through the valley.

The basement complex is at the surface on the upstream limb of the valley and extends at its deepest point to over 5,000 feet below the surface on the downstream limb. The material filling this trough may be divided into three major subdivisions, or facies groups. The lower basin fill is the primary contributor to this material. In this subdivision, a basal conglomerate is overlain by an extensive evaporite facies, which is subsequently overlain by a green clay facies and some delta deposits. The Gila River intercepts

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the lower basin fill in the bottom of the valley. Transitional deposits composed of calcareous and red facies cover the lower basin fill away from the river. The upper basin fill, of which only remnants seem to be apparent, terminates the series with tuffaceous lacustrine, piedmont and conglomerate facies. In plane view, the lower portions of the valley along the Gila River are seen to be Pleistocene and Holocene alluvial deposits, such as sand, gravel, silt and clay. The upper portions of the valley, which comprise the terraces, consist of Upper Pliocene Gila conglomerate, lake beds, lacustrine clays, silts, sand, tuff and limestone (Harbour, 1966).

The Safford Valley is hydrogeologically divided into two aquifer systems. An artesian aquifer system occupies the lower extent of the basin fill, and is believed to extend to the bedrock-fill interface. The upper boundary of the system is, or is in, the green clay facies of the lower basin fill. Since the basement complex deepens in the downstream direction, and since the green clay facies (and red facies into which it grades in the western valley limb) is relatively level, the vertical extent of the aquifer similarly increases in that direction.

A surficial water table aquifer occupies the quaternary alluvial material in the stratigraphy. The upper surface of this aquifer, the water table, seems to conform with the configuration of the land surface when under static conditions.
SALINITY OF THE WATER TABLE AQUIFER

The water of the artesian aquifer is, in general, extremely saline, with electrical conductivity in the neighborhood of 8 millimhos. Extreme variability in salinity among samples from this aquifer has been observed. The water also exhibits thermal properties, and may be above 100°F in many locations (Muller, 1973). The material which makes up this aquifer was deposited in the lightly saline waters of a Pleistocene-Pliocene lake. The water of this lake is believed to still occupy the basal conglomerate facies. The artesian conditions are imposed by the confining forces of the green clay and evaporite facies which also contribute to the salinity of the aquifer. The intertonguing of the basal and evaporite facies brings water into contact with the remnant evaporitic salts of the lake (Knechtel, 1938).

The salinity of the water table aquifer averages approximately 4 millimhos (Muller, 1973), and thus is currently in the acceptable range for its agricultural uses. The identification of sources of salt to this water is more difficult than of those to the artesian aquifer, with a four-input model proposed (Muller, 1973). One input of both water and salt into the water table aquifer is natural recharge. Such recharge, primarily from wash-bottom sources during precipitation periods, is shown to have a lower salinity than groundwater. This source would then improve aquifer salinity, as shown by areas of high quality water at such wash locations on iso-chemical maps.

FLOW OF WATER AND SALT IN PHYSICAL SYSTEM

Figure 2.
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A second input is water which infiltrates from irrigated areas. This would mean pumped irrigation water (groundwater), plus surface water irrigation, plus precipitation, less evaporation. A thermodynamic, chemical equilibrium model was applied to this mechanism (Dutt, 1972), using well cuttings as aquifer samples. It was found that if the water applied to the field had 735 ppm chloride, for example (which was found to be the average in irrigation water), the chloride content would be 2100 ppm by the time it reached the water table at 100 feet. This constitutes a three-fold increase in the salinity as indicated by chloride.

The third input is a source of salts within the aquifer itself, that is, lateral movement of water in the aquifer through soluble beds. The relative scarcity of evaporitic beds in this zone of fill, coupled with the low hydraulic gradients as a force moving water through such beds, limits the significance of this contribution.

The final, and deemed most important, contribution of salts to the system is leakage from the artesian aquifer system. Such leakage occurs through natural imperfections in the cap beds, as well as punctures of these confining layers by deep wells. The pressure of the artesian aquifer encourages such leakage of salts and water into the overlying aquifer. The contact between the water table aquifer and the artesian aquifer is a principal consideration in the development of groundwater resources in the valley. Such development should take into consideration the extent of these contacts under natural conditions as well as alternation of the extent of contacts by foreign conditions caused by pumping. Pumping, by imposing a hydraulic gradient artificial to the location, may set up flow lines in the two aquifers which encourage the occurrence of such contacts, or leaks. The volume of water entering the system in this manner is felt to be significant, although estimates are difficult (Muller, 1973).

At any point in the water table aquifer system these four contributions are believed to make up the salinity increase, although the extent of each mechanism varies from point to point. This increase in salinity has been found to be approximately +0.13 millimhos and +35 ppm chloride per year on the average (Muller, 1973), between 1940 and 1972. The rates do not seem to be uniform throughout the valley. Iso-chemical maps indicate the change may be divided into three major sections. From the Gila River entry point into the valley until Safford there seems to be a uniform, relatively stable, salinity condition with the highest quality water in the valley. From Safford to Pima there is a uniform, low-magnitude increase in salinity. From Pima to the downstream limit of the valley, the area exhibits extremely irregular salinity change conditions. Thus, progressing in the downstream direction, the water becomes more saline, more rapidly deteriorating and deteriorating in a less uniform fashion. Although downgradient movement of salts may be a contributing factor, the correspondence to the increasing artesian aquifer is not considered coincidental. The salinity of the artesian aquifer generally increases in this direction, leakage points are more common, and there may be more head differences between the aquifers. It is therefore recommended that the first area mentioned be that primarily pumped, and the last not pumped at all. Although this recommendation is obviously impossible to implement, canal companies can use wells in the stable region in preference to elsewhere, and further development may be planned with this consideration in mind.
Production functions show productivity of the principal commercial crops in the valley (alfalfa, hay, sorghum, cotton and barley) to be all above 90 percent relative yield (except alfalfa), with the current root soil salinity in the neighborhood of 4 millimhos for the growing season. Yields of alfalfa are shown to have suffered considerably from salinity, with 84 percent relative yield. It shall be assumed that the 85 percent associated with the base year (1972), root zone electrical conductivity (RZEC) is the yield on which per acre gross returns of $146 are based (Wildermuth, 1969). Net returns at this yield are $64 per acre (Wildermuth, 1969), or 44 percent of the gross returns. Thus, alfalfa will yield no return whatever when relative yield falls below 56 percent, if ceteris paribus conditions are maintained. Since base yield (on which gross returns information is established) is only 85 percent relative yield, this value becomes 56 percent of 85 percent yield, or about 48 percent relative yield. The production function shows alfalfa yield to approach this level as RZEC approaches 8 millimhos.

This level, though, is of no economic significance, since the acreage used for alfalfa will be used to produce another crop when net returns per acre from alfalfa fall below net returns from that other crop. In the case of the Safford Valley, the replacement crop will be barley since it is both more profitable and more salt-tolerant than sorghum. (Cotton is, of course, by far the most profitable crop grown in the valley as well as the most salt-tolerant. Acreage used for cotton production is restricted, and it is assumed that the farmer has already exhausted his acreage allotment. It is thus unlikely that alfalfa would be replaced by cotton.)
Barley returns about $36 per acre (Wildermuth, 1969), so it may be assumed barley will replace alfalfa when returns from alfalfa production fall below this value. This, in fact, is an over-simplification, since farmers may grow alfalfa for other than simple costs-and-returns considerations alone. Alfalfa is used, for example, to return depleted nutrients to the soil in crop rotation practices.

Variable costs in the production of alfalfa are $64 to total $146 per acre. Holding variable costs constant, net return reaches $39 per acre, or net return equal to that provided by barley, when gross return is $121. This occurs at 82 percent of base year relative yield of 85 percent, or at 70 percent relative yield. Alfalfa is shown to reach this yield, in the production function, at a RZEC of 5.5 millimhos. At this level, cotton and barley remain virtually unaffected, while the relative yield of sorghum has fallen to 90 percent.

Clearly, as RZEC continues to increase, net returns continue to drop. At 8 millimhos RZEC, only barley is unaffected; sorghum yields have fallen to 83 percent, and cotton to 95 percent. It becomes apparent that within any extreme decrement in RZEC, cotton will remain economically profitable because of its high salt tolerance and because of the $84.40 per acre of cotton allotment currently supplied by the government.

**SALINITY MODEL**

An analysis of water quality data from irrigation wells that have been sampled repeatedly since 1940, and which thus yield 32 years of record, was performed for chloride and electrical conductivity measurements. Electrical conductivity yields an increase of +0.13 millimhos per year for a weighed mean slope. (Note: This is not a line of best fit.) Chloride measurements cluster into three definite groups, which correspond to the previously mentioned three areas. The area to Safford has an annual increase of +5.35 ppm chloride on the average. The Safford to Pima stretch shows a tight cluster of +34.90 ppm chloride per year, and the area beyond Pima increases by +61.52 ppm chloride on the average, per year. These results both support the pumping area recommendations and yield a basis by which to project future changes in the groundwater quality. The electrical conductivity increase rate, when applied to the 1972 electrical conductivity map (Muller, 1973), will yield projected values of electrical conductivity for any given year. If, on the other hand, a level of electrical conductivity is fixed, by using the rate change projection and the 1972 base year data for that point, the year in which the specified level is reached may be computed. The Department of Agriculture's equation to relate root zone soil salinity to salinity of irrigation water (Allison et al., 1954) was applied to the 5.5 millimhos RZEC. The irrigation water value obtained, 9.8 millimhos irrigation water electrical conductivity, was used as the limit for analysis in determining the year such a RZEC level would be reached, by the method just described. It was found that the three regions of salinity appeared here also. The area first to reach this level was that beyond Pima. A contour map of the replacement data of alfalfa shows the first changes from alfalfa production by 1990. The entire region will be unable to support alfalfa by 2010, on the basis of the economic criteria described. The Safford to Pima region will reach this RZEC level circa 2020, while the remaining region will achieve the level in 2040.
**Figure 4.**

**ELECTRICAL CONDUCTIVITY CHANGE**

**Figure 5.**

**CHLORIDE CHANGE**
Cotton is the primary agricultural product of the region, with an estimated 15,200 acres in production, or nearly half of the 32,350 acres of agricultural land (Muller, 1973). Cotton is at the same time the most salt-tolerant crop (with the exception of barley). Of the $173 per acre profit on cotton, $84.40 per acre is a government subsidy payment. Because of this payment, the replacement and no profit levels of the crop are pushed well out of the time range within which this study will make projections. It is safe to say that under ceteris paribus conditions the economic cultivation of cotton is under no danger for a significant time into the predictable future. Further, since cotton is the principal economic element in agricultural profits, the agriculturally-based economy, under these same conditions, is sound.

INTERDISCIPLINARY IMPLICATIONS

Sociologic analysis showed that, in general, the local farmers, based on 41 field interviews (which constitute 25 percent of the farms having 10 or more acres under cultivation), were cognizant of, yet showed little concern for, the water quality situation influencing their land (Muller, 1972). Many did not use salt-control techniques such as furrow shaping or efficient irrigation methods.

An inter-system flow model was constructed in an attempt to synthesize the sociologic, economic and physical systems which operate in the valley. System elements were broken down into state variables, internal characteristics of the system; and functional relationships; working system components. The interconnectors of the three sub-systems mentioned were isolated to be crop yield (physical to economic), net income and operational costs (economic to sociologic), farming practices (sociologic to physical), and observable field characteristics (physical to sociologic). The only factor which is effected by farmer behavior that can affect salinity is pumping practices, an element of farming practices (Muller, 1973). This functional relationship includes the time, location and volume characteristics of pumping which are under the control of the farmer. It is obvious that when irrigation of a crop is required, both time and volume pumped cannot be controlled. Perhaps, if it is a large farm, the selection of which well to be pumped is left to the farmer. The principal point at which pumping practices can extend some leverage on salinity control is through the canal companies which supply water to many of the farmers, since they have wells pumping into the canals throughout the valley. They can exercise the choice of pumping in the areas proposed in this paper. In further development of the water resources, the canal companies may concentrate on the development of wells in the upper valley, and downstream farmers can then depend further on "individual characteristics," which is a rather ambiguous variable describing all learned and experienced behavior of the farmer. Thus, education on salt-control farming methods and on the actual local salinity situation is the method by which salinity control measures may be realized.

Both the ambiguity of "individual characteristics" and the difficulties in introducing modern salinity control methods to farmers are principal sociologic problems which will govern the resolution of the salinity problems in the area. Since there is no terminal danger for productive agriculture, such a resolution would be a slowing of the water quality decrement and the maintenance of high relative yields.
**RECOMMENDATIONS**

In general, the obvious primary recommendation is to employ all the high quality river water allowable by the Gila Compact (Greiner, 1971). This is currently being done. Second, the pumping regime proposed should be both currently phased in and considered in the further development of groundwater resources in the valley. Third, salt-control farming methods should be encouraged by farmer information programs; and further investigation in methods such as night sprinkler irrigation is suggested. Fourth, although currently sugar beets have disease problems in the region, continued research at the Safford Farm branch of the Agriculture Experiment Station (Turner, 1971) should be encouraged for the possibility of future re-introduction of sugar beets as an economic and extremely salt-tolerant crop. Fifth, well drilling practices should be encouraged which would avoid puncture of the artesian aquifer confining layer and wells that do intercept this layer should be plugged in a manner such that the flow of saline water is both not allowed to contaminate the irrigation aquifer and is not allowed to flow into the local water sources. It should be noted that these recommendations emphasize the ceteris paribus nature of the investigation and conclusions. Factors such as the introduction of extensive copper mining or fluctuation of market status of the crops concerned has not been considered. Under these conditions, the valley has a long and productive agricultural life for the future, and with the recommendations employed may have even higher yields and an even longer period of productivity. Planning should be the fundamental consideration of the region's inhabitants.

**REFERENCES**


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