SALT BALANCE IN GROUNDWATER OF THE TULARE LAKE BASIN, CALIFORNIA

by
Kenneth D. Schmidt

INTRODUCTION

The Tulare Lake Basin (Figure 1) is located in the southern portion of the San Joaquin Valley and the adjoining Sierra Nevada. Only the valley floor portion of the basin is of direct concern in this discussion, and it is hereafter referred to as the "Tulare Lake Basin". The basin is bounded by the Sierra Nevada Mountains on the east, the Coast Range Mountains on the west, and other mountain ranges on the south. The San Joaquin River bounds the basin on the north and is considered to be outside of the basin. Over five million acres are intensively farmed in the basin at present, and Fresno and Kern Counties lead the nation in value of gross farm products.

Abundant precipitation on watersheds of the western Sierra Nevada produces most of the surface flow water supply to the basin. Historically, much of the surface flow was to lake beds on the valley floor, namely Tulare Lake southwest of Fresno and Buena Vista and Kern Lakes near Bakersfield. Most of the precipitation falls in the winter, and snowmelt in the spring and early summer results in high runoff. Dams have been constructed on all of the major rivers to enable direct use of surface water during the irrigation season. The basin is essentially closed hydrologically at present, that is little surface or groundwater leaves the basin, except during very wet years.

Historically, extensive development of irrigation in the basin resulted in groundwater overdraft. Some of the most extensive subsidence measured in aquifer systems of the world occurred in western Fresno County and Kern County through the late 1960's. The natural water supply has been augmented by importation of surface water from areas to the north. The Friant-Kern Canal, on the east side of the basin, has provided water from the San Joaquin River since 1951. The California Aqueduct was completed on the west side of the valley and importations from the Feather River began in the late 1960's. These water imports have more than doubled the water supply to the Tulare Lake Basin and greatly alleviated land subsidence. The recently completed Cross Valley Canal connects the California Aqueduct and the Friant-Kern Canal near Bakersfield. This will allow delivery of water from the California Aqueduct to the east side of the basin.

Prior to the importation of surface water on the west side, groundwater supplied over two-thirds of the irrigation demand. In the near future, groundwater use will decline to about one-half of the demand. Large urban centers occur at Fresno, Bakersfield, and Visalia and wells are used to supply virtually all of the domestic water use in the basin. However, agricultural use comprises over 95% of the total water use in the basin.

Analysis of water quality problems in agricultural basins of the southwest indicates that long-term salinity increases in the groundwater are perhaps the greatest problem. Little attention has been given to groundwater quality in the past one hundred years, rather most management decisions have been based on quantity considerations. The objective of the author is to discuss concepts that need to be considered in the future long-term management of groundwater quality in the Tulare Lake Basin.

SALT BALANCE CONCEPTS

A simple concept of salt balance in groundwater of the basin is to equate salt input primarily in surface water and salt output primarily in surface and groundwater.

The author is a Groundwater Quality Consultant, Fresno, California.

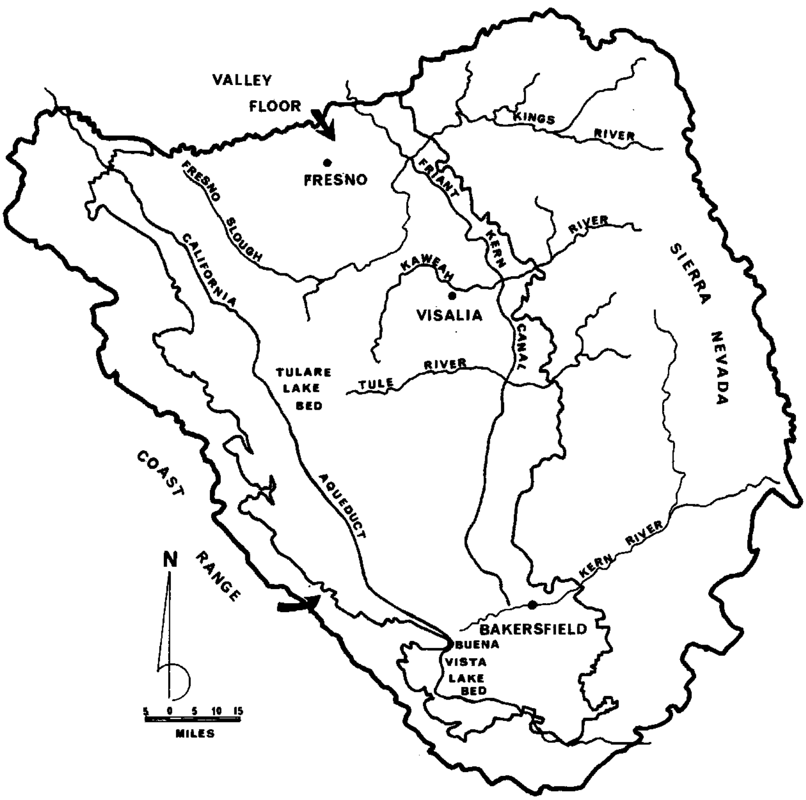

FIGURE 1: TULARE LAKE BASIN

This generalized concept could be highly erroneous in some basins. A better definition of "salt balance" in groundwater is that the salinity throughout the groundwater, in a three-dimensional sense, remains relatively constant with time. Two important factors which are poorly understood and seldom analyzed in many salt balance studies are: 1) precipitation of salts, and 2) dissolution of minerals in the soil-groundwater system. In the Tulare Lake Basin, these are likely major factors, as is suggested by recent work at the U.S. Salinity Laboratory in Riverside, California. (Rhoads and others, 1974)

In the period prior to development (circa 1850), the predominant item of salt input was surface water runoff to the valley floor. The dissolution of mineral matter was minimal in the sense that much of the groundwater recharge occured along major stream channels and the mountain fronts. The primary source of salt output from the groundwater was precipitation of salt. Precipitation of gypsum and calcium and magnesium carbonates was widespread in areas of surface and groundwater discharge along the valley trough and old lake beds. Gypsum is currently mined at some of these sites and redistributed on agricultural lands as a soil amendment. Additional salt left the basin in surface water and groundwater outflow. Man greatly altered the system, originally by controlling much of the surface water runoff and eventually spreading it out over large areas. This has allowed much greater dissolution of minerals in the topsoil and unsaturated zone. The control of runoff and lowering of groundwater levels due to pumping have reduced the salt output in water and also salt precipitation at former points of discharge. More recently, the importation of salts in surface water has greatly increased the salt input.

Historically groundwater quality data are sparse. However, regional sampling was reported by Mendenhall, Dole, and Stabler (1916), Eaton (1935), Davis and others (1959), and the California Department of Water Resources (1971). In small areas, such as Fresno and Bakersfield, a number of annual chemical analyses for individual wells are available, some spanning 20 to 30 years. These data are inadequate to draw valid conclusions on trends in basin-wide groundwater salinity. However, they do suggest that little or no increase in salinity has occurred in groundwater on the east side of the valley.

WATER BUDGET

A study of salt balance in the basin begins with an evaluation of the water budget. More than one-half of the average annual natural streamflow into the basin (3.1 million acre-feet) is supplied by the Kings River. Imported water from the Friant-Kern Canal averages 1.2 million acre-feet per year. Imports from the California Aqueduct were about 900,000 acre-feet in 1970, and will exceed 3 million acre-feet by 2000. Water demand for agricultural use is expected to increase by about 2.5 million acre-feet from 1970 to 2000. Because of the increase in water demand, the total groundwater pumpage will not decrease. Table 1 is a groundwater budget for the Tulare Lake Basin for 1970, 1980, and 2000.

The overdraft prior to importation of California Aqueduct water was about 2.0 million acre-feet per year, largely on the west side of the basin. The overdraft will almost be eliminated by 1980 due to imported surface water. However, the overdraft will be about 1.3 million acre-feet by 2000. At this time much of the overdraft will be on the east side of the basin. The values for future water demand and supply were derived from the Tulare Lake Basin (5D) study by the California Regional Water Quality Control Board (1974). It should be noted that the usable groundwater storage in the basin exceeds several billion acre-feet of water.

SALT INPUT AND OUTPUT

In this section, it is assumed that there is no dissolution or precipitation of salts in the system except for dissolution in the case of leaching beneath newly developed lands. The major sources of salt input and output to the groundwater basin must be itemized. (Table 2) Methods for calculating these items were presented by

TABLE 1- GROUNDWATER BUDGET FOR THE
TULARE LAKE BASIN
(MILLION ACRE-FEET)

Item	1970	1980	2000
Input:			
Natural Streamflow	3.1	3.1	3.1
Imported Water	2.2	4.0	4.4
Output:			
Streamflow and Groundwater Outflow	0.2	0.2	0.2
Evapotranspiration	6.0	6.7	7.9
M & I Consumptive Use	0.2	0.2	0.3
Subsurface Drainage Export	0	0.2	0.4
Overdraft:	1.1	0.2	1.3

TABLE 2- SALT INPUT TO AND OUTPUT FROM THE GROUNDWATER (THOUSAND TONS)

Item	1970	1980	2000
Input:			
Precipitation	25	28	30
Streamflow	393	393	393
Imported Water	359	932	1,021
Soil Amendments	525	599	656
Fertilizers	194	209	233
Animal Wastes	56	61	66
Leaching New Lands	0	850	1,108
Muncipal Wastewaters	42	48	65
Urban Runoff	8	9	10
Industrial Wastes	31	33	39
Oil Field Wastes	201	6	6
Subtotal	1,834	3,168	3,527
Output:			
Streamflow and Groundwater	39	112	102
Subsurface Drainage Export	0	601	1,913
Subtotal	39	713	2,015
Net Accretion:	1,795	2,455	1,515

Source: Modified from California Regional Water Quality Control Board (1974).

California Regional Water Quality Control Board (1974). The major sources of salt input in 1970 were soil amendments (mainly gypsum), streamflow, and imported water. Gypsum is applied in some areas merely to increase the salinity of irrigation water to enhance inffiltration. Oil field wastes (brines) and fertilizers were also significant sources of salt. By 2000, the two dominant sources of salt input are projected to be leaching of relict salts beneath newly developed lands and imported water. Other sizeable inputs are soil amendments and streamflow. By the year 2000, total salt input will have almost doubled from 1970.

Much of the added salt load in the future will be applied on the west side of the basin. Groundwater quality on the west side of the basin is generally inferior compared to that on the east side. Most of the salts from the leaching of new lands will enter groundwaters that have salinities in excess of several thousand parts per million (ppm) at present. The impact of oil field wastes is projected to decrease rapidly between 1970 and 1980 due to regulatory action prohibiting brine disposal through percolation basins or stream channels.

Sources of salt output include surface water and groundwater outflow and the export of subsurface drainage. The salt in water outflow is a relatively small item, however the salt exported in subsurface drainage export is significant. As lands on the west side and in the valley trough are tile drained (assuming the drainage is collected and exported), significant quantities of salt will leave the groundwater basin. The salt accretion (input minus output) under the foregoing assumptions is estimated as about 1.8 million tons per year in 1970, 2.5 million tons in 1980, and 1.5 million tons in 2000. It appears that much of the increased salt brought into the basin on the west side will be removed by the export of subsurface drainage. However, a new accretion of salts will still occur, as in 1970.

APPARENT CHANGES IN SALINITY

Assuming no dissolution or precipitation of salt in the soil-groundwater system except for leaching beneath newly developed lands, the salt accretions mentioned would increase the groundwater salinity. This increase can be estimated by selection of mixing volumes in the aquifers of the basin. The mixing volume is the body through which the salts will be dispersed. For the portion of the valley with a widespread predominant confining bed (the Corcoran Clay), the aquifer above the clay can be used. In areas where this confining bed is absent, a zone based on water levels and well depths can be used. The volume of groundwater in these combined mixing volumes totals about 800 million acre-feet.

On the east side of the basin, the average groundwater salinity ranges from about 300 to 500 ppm. Water and salt balance studies for sub-basins on the east side indicate that salinity would increase from about one to four ppm per year from 1970 to 2000. On the west side of the basin, groundwater salinity in the upper aquifer averages from 3,000 to 4,000 ppm. Salinity increases would range from about 10 to 30 ppm per year from 1970 to 2000.

Due to the layered nature of the alluvium in the basin, the vertical permeability is small compared to the horizontal permeability. Because the salts are applied at the land surface in most cases, and because of this permeability distribution, the actual increases in salinity would occur primarily in the upper parts of the aquifers.

ASSUMPTIONS IN PREVIOUS STUDIES

There are two primary items missing from the foregoing calculations. The first is dissolution of minerals in the topsoil, unsaturated zone, and saturated zone throughout the basin. Lysimeter studies at the U.S. Salinity Laboratory in Riverside, California indicate that this phenomenon may be substantial in magnitude. (Rhoades and others, 1974 and Oster and Rhoads, 1975) No valid field-scale data have been presented for the Tulare Lake Basin on this phenomenon. Long-term changes in soil parameters have occurred due to leaching and fertilizer applications. For example, the soil pH has been lowered and many bases have been leached from the soil into the groundwater on the east side of the basin. Regional changes in groundwater salinity along well defined flow paths in the aquifer need to be assessed in conjunction with water quality changes in the soil and unsaturated zone. The distribution of groundwater salinity in the Fresno area suggests that the salinity increases downgradient due to dissolution of minerals as groundwater flows westward under the Corcoran Clay. The increase appears to be at least several hundred ppm in concentration.

Precipitation of salt at or near the land surface was a major factor historically. At present, some accumulation of salt is taking place in the topsoil on the east side of the valley. Virtually no chemical equilibrium studies have been performed for groundwater quality in the basin. These studies would provide insight into the precipitation-dissolution relationship in the aquifer.

THE LEACHING FRACTION CONCEPT

Rhoades and others (1974) discussed minimizing the salt contribution in irrigation drainage waters. The salt burden of drainage water can be minimized by irrigating with the smallest possible leaching fraction. Minimizing the quantity of drainage water results in a minimum amount of applied salts in the return flow because it:

1) maximizes the precipitation of carbonate minerals and gypsum in the soil.

2) minimizes soil mineral weathering and the dissolution of relict salts in the soil.

3) maximizes the amount of soluble salt from the irrigation water that is retained in the soil profile.

The contribution of salt by mineral weathering is especially important for low salinity irrigation waters. It is also significant for waters of higher salinity at high leaching fractions. Lysimeter studies indicate that the annual salt return can be reduced by about 1 to 5 or more tons per acre by decreasing the leaching fraction from 0.3 to 0.1. Current leaching fractions average about 0.5 or more on the east side of the basin and about 0.3 on the west and south parts of the basin. The concept of reducing salt return in drainage water is an imaginative approach that could become the major method of groundwater salinity control in the basin. However, field-scale tests are necessary before applying this concept on a large scale. Also, there is no reason why it should be applicable throughout the basin.

FUTURE GROUNDWATER MANAGEMENT

Groundwater quality management is closely related to surface water and groundwater quantity management. In the past, inefficient irrigation in the basin has been rationalized on the basis that:

1) none of the excess applied water escapes, since it is in a closed basin.

2) the excess applied water is a source of recharge when surface water is used.

Improving irrigation efficiency could produce the following benefits:

1) positive impact on groundwater quality.

2) more efficient use of fertilizers and soil amendments.

3) energy savings, because allowing excess water to percolate necessitates that it later be pumped to the land surface for use.

4) less imported water (and salt) would be necessary.

5) groundwater overdraft could be decreased, because evaporation losses could be reduced with more efficient irrigation.

Besides more efficient use of water, watershed management could be practised to increase runoff on the watershed and inflow of surface water into the basin. To date there has been little serious consideration of such management.

Groundwater management in the future must be undertaken by consideration of water quality as well as quantity. Appropriate monitoring programs urgently need to be implemented to provide data on trends in groundwater quality.

REFERENCES CITED

California Department of Water Resources. 1971. A General Survey of Electrical Conductivity in Groundwater, San Joaquin Valley, March through June 1971. San Joaquin District.

California Regional Water Quality Control Board. 1974. Tentative Water Quality Control Plan, Tulare Lake Basin (5D), Abstract. Central Valley Region. 79 p.

Davis, G.H., Green, J.H., Olmsted, F.H., and D.W. Brown. 1959. Ground-Water Conditions and Storage Capacity in the San Joaquin Valley, California. U.S. Geological Survey Water-Supply Paper 1469. 287 p.

Eaton, F.M. 1935. Boron in Soils and Irrigation Waters and its Effect on Plants, with Particular Reference to the San Joaquin Valley of California. U.S. Department of Agriculture Technical Bulletin 448. 131 p.

Mendenhall, W.E., Dole, R.B., and H. Stabler. 1916. Ground Water in the San Joaquin Valley. U.S. Geological Survey Water-Supply Paper 398. pp 234-251.

Oster, J.D., and J.D. Rhoades. 1975. Calculated Drainage Water Composition and Salt Burdens Resulting from Irrigation with River Waters in the Western United States. Journal Environmental Quality. 4 (1): 73-79.

Rhoades, J.D., Oster, J.D., Ingvalson, R.D., Tucker, J.M., and M. Clark. 1974. Minimizing the Salt Burdens of Irrigation Drainage Waters. Journal Environmental Quality. 3 (4): 311-316.