Erosion and Salinity Problems in Arid Regions

by

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Introduction

The mineral quality problem in southwestern rivers is a complex problem which is critically important not only on a regional basis but also on national and international levels. Mineral quality, commonly termed salinity or total dissolved solids (TDS), is a particularly serious water quality problem on the main stem of the Colorado River whose drainage basin covers one-twelfth of the continental United States and serves as the water supply for a population exceeding ten million people in the Lower Colorado Basin alone (5). If salinity levels continue to rise in this river, then by the year 2010 damages due to salinity may exceed 1.24 billion dollars (6). The predicted adverse salinity impacts include: 1) reduced agricultural productivity, 2) reduced suitability of Colorado River water for municipal and industrial use, and 3) salinity concentrations in the water reaching Mexico which will exceed internationally established standards. The elimination of salinity increases in the Colorado River requires an accurate understanding of both the man-made and natural sources of salinity.

Man-made sources of salinity include municipal and industrial consumptive use of water, irrigation, and evaporation from reservoirs. In the Colorado River above Hoover Dam man-made sources of salinity account for approximately 34% of the total salinity load (5). It should be noted that Blackman et al (7) claim that evaporation from Lakes Powell and Mead alone cause an increase in salinity of 100 milligrams per liter (mg/l) at Hoover Dam.

Natural sources of salinity include both point and non-point or diffuse sources. Point sources such as springs and seeps account for approximately 12% of the total salinity load above Hoover Dam (5), non-point sources include the dryfall of salinity into reservoirs, Woessner (13), and the interaction of surface water with natural salt bearing geologic formations (12). Above Hoover Dam, these non-point sources account for approximately 54% of the total salinity load (5).

In Southern Nevada, Las Vegas Wash has been identified as one of the primary sources of salinity to Lake Mead. Although previous to the development of the Las Vegas metropolitan area Las Vegas Wash was an ephemeral stream, it is now a perennial stream fed by sewage effluent and runoff from the urban area. This change in flow regimes led to the development of extensive marsh areas in the Lower Las Vegas Valley and also serious and extensive erosion. It was the contention of the authors that the erosion of highly saline soils in the Lower Las Vegas Valley could result in a significant contribution to the salinity of the Lower Colorado River. In 1980 the Water and Power Resources Service (WPRS) authorized a reconnaissance level survey of salt storage in the Lower Las Vegas Valley. In this context, salt storage is defined to be the salinity associated with the soil above the water table. Although this research is continuing, a number of preliminary results demonstrating the significance of salt storage and erosion to the Colorado River salinity problem are available.

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Salt Storage in the Lower Las Vegas Valley

The Lower Las Vegas Valley lies within the Basin and Range Province, and the topography is characterized by sub-parallel mountain ranges with a central basin modified by encroaching alluvial fans. The total relief in this valley is 10,700 feet. The surrounding mountains are composed of Paleozoic carbonates and Tertiary volcanics.

Las Vegas Wash is the remnant of a perennial flow referred to as the pluvial Las Vegas River which was active 30,000 years before present (B.P) (1). The drainage extended from Indian Springs, Nevada to the Colorado River which is a distance of 70 miles. Evidence suggests either marshes or shallow lakes occurred in the basin from 30,000 to 15,000 years B.P. and stream flow was again active until 6,000 years B.P. Subsequently, decreased precipitation and spring flow and increasing aridity resulted in an ephemeral drainage (1, 10).

Because only limited resources could be dedicated to assessing the new and controversial concept of salt storage, a small study area 12.27 square miles in extent was defined in the Lower Las Vegas Valley near Henderson (Figure 1). Within this area, 38 sample sites were defined along lines which were selected to provide a maximum amount of information at a minimum cost. At each sample site, a hole was augered from the ground surface to the water table, and soil samples were taken at the surface, one-half foot, one foot, and then at one foot intervals to ten feet. Below ten feet, samples were taken at two foot intervals until the water table was reached.

The soil samples were analyzed by standard ASTM methods to determine the soil moisture, and the mass of readily soluble salts associated with the soil was determined by a procedure developed by the Desert Research Institute. The methodology used was:

1. Thirty grams of oven dried soil was placed in 1,500 milliliters of distilled water - a 50:1 dilution ratio - and the container was tightly capped to prevent evaporation.
2. Each sample bottle was shaken for 30 seconds at 30 minute intervals, a minimum of four times.
3. After 24 hours, the electrical conductivity of the supernatent sample liquid was measured, and the total dissolved solids present were calculated from the electrical conductivity using a calibration curve developed for the study area.

This laboratory procedure determined the salt content of the soil in terms of the (mass of salt) per (mass of dry soil). It is noted that this procedure yields estimates of soil salinity which are slightly higher than the estimates which result from the method recommended by WPRS (4). However, both of these procedures are based on the same principals and an empirical relationship between the methods can be defined for the study area.

The sampling and laboratory programs resulted in a three dimensional array of salt storage values for the study area. Since the soil samples were taken at definite depths below the ground surface, salt storage is actually defined on a set of planes parallel to the ground surface. For numerical convenience, salt storage is by definition zero at all sample locations which are below the water table. It is noted that this convention does not contradict the definition of salt storage and results in 38 values of salt storage being defined on every plane.

The salt in storage between any two adjacent planes can then be determined by numerical integration. If salt storage was defined on a regular cartesian grid with a common origin in each plane, then a very simple integration scheme could be used. However, as noted previously, the sample site locations were chosen to provide information along "arbitrary" lines rather than to provide numerical data which could be easily integrated. Therefore, it was necessary to use a bicubic spline interpolating method to interpolate values of salt storage onto a regular cartesian grid, Foley (8). This method of analysis used the given field data to estimate salt storage values onto a 33 x 33 cartesian grid in each plane. Then, the salt in storage between any two adjacent

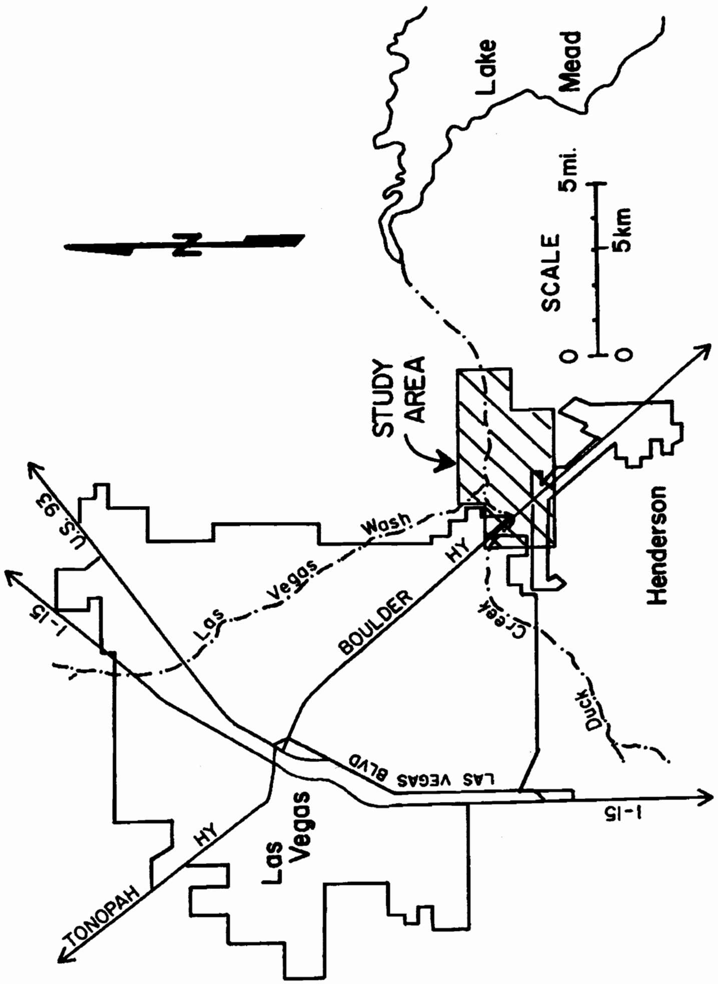

Figure 1: The Lower Las Vegas Valley Showing the Location of Las Vegas Wash and the Salt Storage Study Area Relative to Las Vegas and Lake Mead.

form of stream bed degradation and head cutting. USGS suspended sediment data indicate that at an average daily discharge of 82 cfs per day 240 tons per day of sediment was being removed in 1978. Thus, on the average, 88,000 tons of sediment are removed from the Lower Las Vegas Valley in a year - an estimate based on suspended sediment data.

Flash flood events also remove significant amounts of soil. In February, 1976 an instantaneous suspended sediment load of 28,000 tons per day was measured at a flow rate of 620 cfs. A large flow event in July, 1975 (Q = 2,400 cfs) eroded 1.3 million cubic feet of material or approximately 43,000 tons of soil in the Lower Las Vegas Valley.

Between August, 1975 and April, 1979 flood events and the increased perennial flow in Las Vegas Wash have eroded 16 million cubic feet of channel material or approximately 535,000 tons of soil. Between August, 1975 and April, 1979 the Las Vegas Wash head-cut had advanced at an average rate of four feet per day and eroded channel material at an average rate of 12,860 cubic feet (430 tons of soil) per day. It is noted that this last erosion rate is significantly larger than the estimate derived from the suspended sediment data. Although future rates of erosion will be partially determined by the geology of the area, there is no reason to expect that the actual amount of material eroded will decrease as the main stem erosion spreads to the tributary channels; in fact, the amount of erosion may increase.

Erosion - Salt Storage Interactions

The foregoing material has defined both salt storage in the Lower Las Vegas Valley and the erosion which is occurring along Las Vegas Wash in this area. Although it has always been accepted that the erosion of saline soils contributes to the Colorado River salinity problem, this research is to the authors' knowledge the first instance in which accurate data regarding this situation are available for the Lower Colorado area. USGS records for Las Vegas Wash at North Shore Road indicate that during water year 1978 the average flow was 82 cfs, the average salinity concentration was 2,574 mg/l and the average sediment concentration was 1,086 mg/l. Thus during this time period approximately 210,000 tons of salt and 88,000 tons of sediment were exported from the Las Vegas Valley to Lake Mead by Las Vegas Wash. The interrelationship between the salt storage concept and erosion is summarized in Table 1 under the assumption that the 12.27 square miles of study area soils are representative of the sediment being transported in Las Vegas Wash. It is realized that if unsaturated soil becomes saturated during precipitation and flood events prior to physical erosion, salts may be removed by leaching. The physical displacement and transport of a given volume of soil was utilized in this study to calculate the salinity loading by the Las Vegas Wash to the Colorado River.

Table 1: Computation of Salt Eroded from the Las Vegas Valley

Depth Range ΔD, ft (1)	Volume Corresponding to ΔD, ft^3 (2)	Salt Stored in ΔD M_{sa}, Tons (3)	Soil in Volume M_{so}, Tons (4)	Ratio M_{sa}/M_{so} (5)	Average Salt Transported to Colorado River Via Erosion, Tons/Year (6)
0-0.5	1.710×10^8	9.47×10^5	5.66×10^6	0.167	14,700
0-1.	3.421×10^8	16.1×10^5	13.3×10^6	0.142	12,500
0-5.	17.10×10^8	53.6×10^5	56.6×10^6	0.0947	8,330
0-24.	82.10×10^8	107.2×10^5	$271. \times 10^6$	0.0396	3,480

Table 1 shows the computation of a range of different estimates in column (6) that would result from the erosion of different total depths of soil as shown in column (1). Column (2) shows the volume of the study area for each specified total depth, and column (4) shows the estimated total weight of the soil in the study area based on an assumed specific weight of 66.1 pounds per cubic foot. Column (3) is the estimated total weight of the salt in the study area based on the conductivity measurements and analysis described in the foregoing material. Column (6) is obtained by multiplying the annual suspended sediment load, 88,000 tons, by the salt to soil ratio, column (5).

Although not all of the sediment passing the USGS gage used in this analysis comes from the Lower Las Vegas Valley, 96% of the sediment passing this gage does come from the salt storage area. The estimates in Table 1 are very conservative since the salt storage in the vicinity of Las Vegas Wash is much higher than it is in the remainder of the study area. This is illustrated in Figure 3 in which the third dimension is salt storage in milligrams of salt per kilogram of dry soil. Thus, it is concluded that, depending on where the sediment being eroded is located in the soil column, as much as 7% to as little as 2% of the total salinity entering the Colorado River System from Las Vegas Wash is attributable to erosion. USGS records also demonstrate that in the reach of Las Vegas Wash which passes through the study area the annual increase in salinity transport is 74,000 tons. If only this reach is considered, then erosion may account for as much as 20% of the salinity increase.

In the case of extreme flow events, the contribution of erosion to the salinity problem is even more significant. For example in Las Vegas Wash the July 1975 flow event which removed 43,000 tons of soil also removed between 1,720 to 7,300 tons of salt. Also, between August 1975 and April 1979 between 21,000 and 91,000 tons of salt was removed. In comparison it is noted that Blue Springs near the mouth of the Little Colorado River and considered the largest point source of salinity in the entire Colorado River Basin (5) contributes 518,000 tons of salt per year to the Colorado River System.

In addition to the salt storage study, described here in some detail, the Water Resources Center has also analyzed the solution-salt loading effect of flash floods on the salinity problem in four arid, ephemeral, undeveloped watersheds tributary to Lake Mead, Woessner (13, 14). This study area covered 192 square miles in which eight intermittent flow events were recorded and sampled in 1978 and 1979. The estimated discharge of flash flood water was 1,700 acre feet in 1978 and 780 acre feet in 1979. The average TDS of these waters ranged from 1,270 to 2,000 mg/l. Based on these data, it is concluded that 3,000 and 1,300 tons of salt entered the Colorado River System from the 192 square mile study area at rates of 16 tons per square mile per year and 6.9 tons per square mile per year in 1978 and 1979, respectively. These data lend additional support to the authors contention that erosion is a contributor of salinity to the Colorado River system.

Conclusion

Based on the preliminary results of salt storage-erosion analyses and flash flood salinity loading work, it is concluded that erosion contributes to the salinity problem in the Colorado River System. Analyses of salt storage data revealed that 2% to 7% of the total salt balance for the Las Vegas Wash can be attributed solely to erosion. Analyses of data indicates that erosion may account for 20% of the salinity increase recorded for the reach of Las Vegas Wash which passes through the study area. These results highlight the significance of assessing potential national salinity control measures with complete salt balance information. Additional erosion-salt loading evalutions are necessary.

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REFERENCES

1. ____, "Las Vegas Wash Interim Report No. 2, Water Quality Series: Clark County 208 Water Quality Management Plan, Clark County, Nevada, Las Vegas, Nevada," URS Co., Las Vegas, Nevada, 1977.

2. ____, "Soil Survey: Las Vegas and Eldorado Valley Area, Nevada," U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., 1967.

3. ____, "Comprehensive Plan: Task 1 - Existing Conditions," Clark County Department of Comprehensive Planning, Las Vegas, Nevada, 1980.

4. ____, Earth Manual, U.S. Department of the Interior, Water and Power Resources Service, Second edition, Washington, D.C., 1974, pp. 448-450.

5. ____, "The Mineral Quality Problem in the Colorado River Basin: Summary Report," U.S. Environmental Protection Agency, Washington, D.C., 1971.

6. ____, "River Water Quality Improvement Program," U.S. Department of the Interior, Bureau of Reclamation, Washington, D.C., 1974.

7. Blackman Jr., W.C., Rouse, J.V., Schillinger, G.R., and Shafer Jr., W.H., "Mineral Pollution in the Colorado River Basin," Journal of the Water Pollution Control Federation, Vol. 45, No. 7, July, 1973, pp. 1517-1557.

8. Foley, T.A., "Computer-Aided Surface Interpolation and Graphical Display," Desert Research Institute, Water Resources Center, Reno, Nevada, in press.

9. Maxey, G.B. and Jameson, C.H., "Geology and Water Resources of Las Vegas and Pahrump and Indian Springs Valleys, Clark and Nye Counties, Nevada," State of Nevada Water Resources Bulletin, No. 5, 1948.

10. Mifflin, M.D., personal communication, February, 1981.

11. Patt, R.O., "Las Vegas Valley Water Budget: Relationship of Distribution, Consumptive Use, and Recharge to Shallow Groundwater," EPA-600/2-78-159, U.S. Environmental Protection Agency, Washington, D.C., 1978.

12. Riley, J.P., Bowles, D.S., Chadwick, D.G., and Grenney, W.J., "Preliminary Identification of Price River Basin Salt Pick-up and Transport Processes," Water Resources Bulletin, American Water Resources Association, Vol. 15, No. 4, August, 1979.

13. Woessner, W.W., "Reconnaissance Evaluation of Water Quality - Salinity Loading Relationships of Intermittent Flow Events in a Desert Environment, Las Vegas, Nevada," Water Resources Center, Desert Research Institute, Publication 44021, September, 1980.

14. Woessner, W.W., "Intermittent Flow Events - Salinity Loading Relationships in the Lower Colorado River Basin, Southern Nevada," Hydrology and Water Resources in Arizona and the Southwest, Arizona Sec. AWRA, Tucson, Arizona, Vol. 10, 1980, pp. 109-119.