available for water supply and that the beneficiaries of this improvement are readily identifiable. Based on this position the users, who are the beneficiaries, should pay for the cost of improvements. The role of the Corps of Engineers in this salinity control question has been to further delineate the source of the salinity and determine technically feasible methods of controlling the salt emissions thereby avoiding continuation of the pollution by brine of the streams.

CONCLUSION

The definition of the stream salinity problem in the rivers of the Southwest has been well documented. The process by which this stream salinity occur has been documented. Technically feasible control systems have been studied, planned, and are implementable. The implementation of these systems requires a resolution of institutional problems including payment for construction and for operation of the control systems. The Southwest is a water-short area and all available sources must be considered and eventually utilized.

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An Economic Evaluation of Salinity Control

Robert D. Brown
Chief, Planning Division
USAED, Tulsa
Tulsa, Oklahoma

PURPOSE

This paper presents a methodology for economic evaluation of corrective measures to improve the quality of water in the Red River Basin, Oklahoma, Texas, Arkansas, and Louisiana. A companion methodology analyzes the improvement of Red River water for agricultural users by evaluating the increase in agricultural productivity. The two methodologies were developed for measuring both the municipal and industrial benefits and the agricultural benefits of the Red River chloride control project. Only the municipal and industrial methodology is discussed here since the agricultural methodology would exceed the scope of this paper. The evaluation procedures were developed for compliance with Federal planning guidelines.[1]

SOURCES AND PROBLEMS

Studies conducted for the project included problem identification, the development of alternative water quality improvement plans, and the evaluation and assessment of the most viable potential solutions. Natural chlorides in the Red River Basin emit from ten localized salt source areas that make up about two-thirds of the average daily load of 3.0×10^6 kilograms (kg) per day of chlorides entering Lake Texoma. Figure 1 shows the salt sources in the Red River Basin. Lake Texoma is the only main stem impoundment on the Red River and lies downstream of the emission areas. The natural salt pollution renders the basin resource unfit for most beneficial uses. Loads from each of the areas vary from about 43.5×10^3 kg per day at

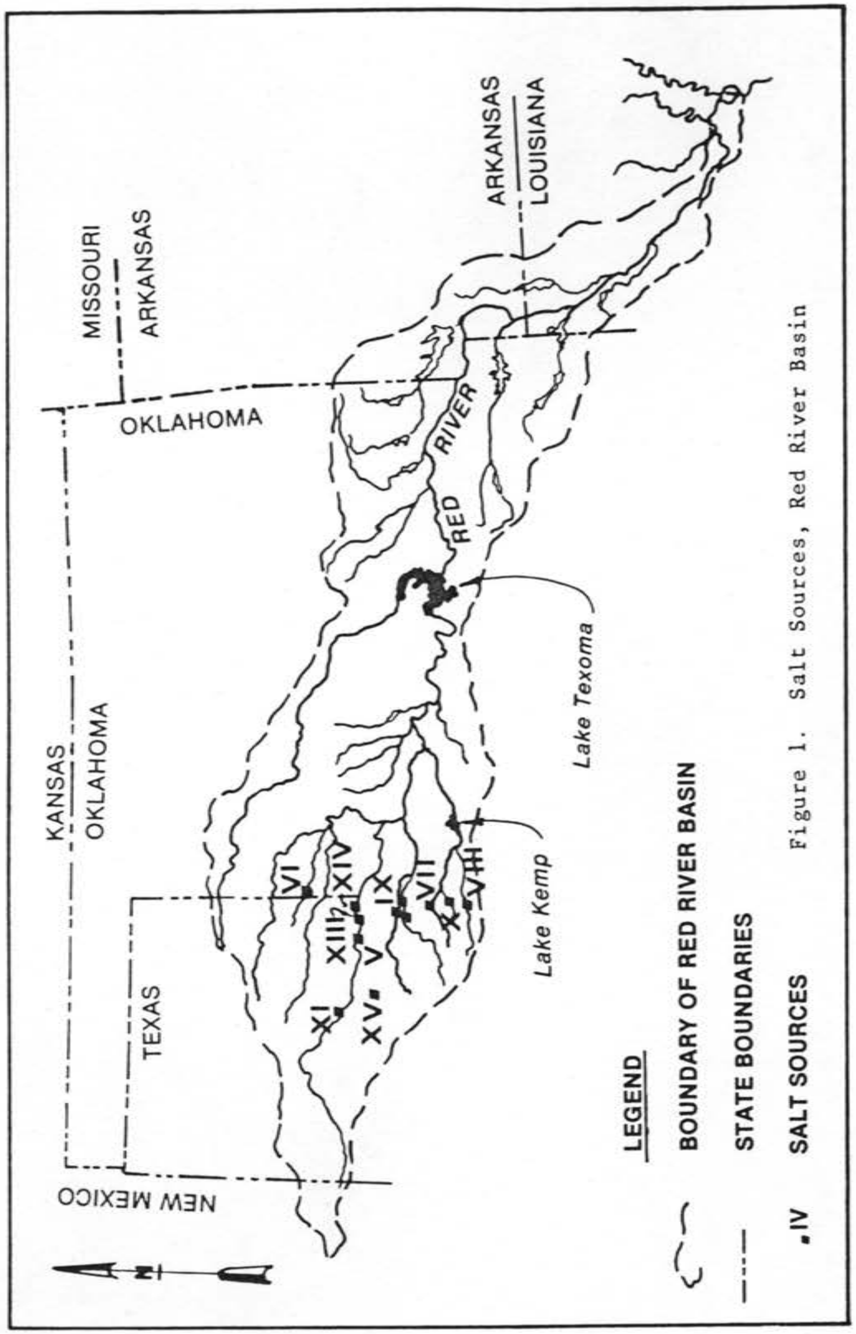

Figure 1. Salt Sources, Red River Basin

source area X in Texas to over 353.7×10^3 kg per day at source area VI in the Oklahoma portion of the basin. Alternative concepts for the control of the brines developed in the early planning stages provided a wide variety of potential alternatives. These included diluting the concentrated flows with imported fresh waters, the construction of desalinization plants, transporting the brines from the emission areas to the gulf via pipeline, diversion of fresh water around the salt emission areas, and collecting the brine flows from the subsurface or surface and disposal of the concentrated brines at off-site containment reservoirs or by deep well injection.[2] After careful analyses of costs, environmental impacts, and technical and economic data, the collection and disposal alternative was selected as the best plan to improve the basin resource at least cost. Areas VI, VII, VIII, IX, and X provide for surface collection of the brines. The collected brines would be transported by pipelines to three disposal lakes. Areas XIII and XIV require subsurface brine collection and disposal by deep well injection. The collection and disposal plan to reduce the brines would control about 45 percent of the 3.0×10^6 kg of chlorides entering Lake Texoma on the average each day. Water users could expect the chloride concentrations to be equal to or less than 250 ppm 94 percent of the time, thus requiring only conventional treatment methods. The total construction cost of the project is estimated at about $178 million based on 1982 price levels. Construction for one of the major areas in Texas, Area VIII, was initiated in 1977. That work included a low flow dam, a 35.4 kilometer pipeline, and a brine containment facility known as Truscott Brine Lake. Construction at the remaining areas is contingent upon approval of the Assistant Secretary of the Army and the appropriation of funds by the Congress.

ECONOMIC EVALUATION

The economic merits of the project were tested with the development of a economic benefit evaluation methodology. The methodology measures the monetary benefits of expected municipal and industrial use of Red River water. The major purpose is to determine the least costly water supply alternative for all reaches in the study area with the Red River considered as a potential supply source to meet projected demands. The study area includes 36 counties and 7 parishes contiguous to the Red River or the major tributaries. These counties are either existing or potential users of Red River water. Also included in the study area are the 8 counties in the

Dallas-Fort Worth metropolitan area. To determine the future use of the Red River as a water supply source, an inventory of existing use and sources was made in the study area. Future water demand in the study area was compared to existing supplies to determine future net needs for water. To meet future net needs all existing and potential water sources, including the Red River, were analyzed to determine water supply yield and cost of water to the potential user. Water supplies were then allocated to future water demands based on the least costly source being used first. In this way it was determined when Red River water would be demanded, and at what cost, compared to the cost of other alternative sources.

Existing Water Use

Major categories of water users were identified, including:

- 368 public systems representing 2.5×10^7 liters per day water use;
- 115 self-supplied industries contacted out of over 500 industries identified, representing 680.4×10^6 liters per day water use;
- 121,500 hectares of irrigated agriculture, with water use of about 1.3×10^7 liters per day;
- 22 steam-electric power plants withdrawing 1.6×10^7 liters per day of water for either once-through or recirculated condenser cooling.

Existing Water Sources

Specific information, such as location and size of source, water quality, water supply yields, and amount of current usage, was recorded for the 140 existing water sources identified. These sources included:

- 31 water-bearing aquifers with use of about 1.2×10^7 liters per day;
- 86 stored surface water providing water use of 8.0×10^7 liters per day;
- 23 streams and bayous with current usage of 295×10^6 liters per day.

Future Municipal Water Demands

Future demands for water by municipalities were determined from population projections and per capita water use rates. Population projections were derived from both Federal and State sources. These projections were based on OBERS 1972 Series E population projections and State projections. Federal and State projections were compared to existing growth patterns for each county. The most probable future projection for each county represented recent trends in the region. Population projections were made by reach and by decade. From these determinations, the study area population was projected from the base year 1978 at 3.9 million to year 2040 at 7.1 million. The base year per capita water use rate was calculated by dividing the average water consumption in liters per day by the population of the counties within each reach. As one means of addressing the conservation issue, the developed water use rate was then held constant through the years 1980 to 2040. Water use rates by reach ranged from 163 liters per capita day in rural areas to 779 liters per capita day in the larger metropolitan areas.

Future Industrial Water Demands

The current self-supplied industrial water usage was projected from the multipliers developed as the result of comparing manufacturers earnings and employment projections. Projections of manufacturers earnings by Standard Industrial Classification (SIC) categories were made to the year 2040. Earnings per employee for each SIC category in each reach were established from available data. The growth rate by earnings in each industry was estimated from 1972 OBERS Series E projections at the national level, and was then applied to project earnings for each industrial classification. Growth rates obtained from those projections were applied to current industrial water use to derive future water needs. The projections developed from this procedure were then adjusted for a reduction in water use resulting from advancements in technology, such as water reuse and other water efficiencies. Of the 105 major industries inventoried, the total use during the inventory period was found to be about 696×10^6 liters per day for the study area. Future industrial water use ranged from 756×10^6 liters per day in 1980 to 1.9×10^7 liters per day by the year 2040 for the study area.

Price and Income Elasticity

Price and income elasticity effects are relative measures of how the demand for water will change with the change in price or the change in consumers income. Price and income elasticity coefficients were developed from field surveys of municipalities and industries for the eastern, central, and western regions of the study area. Through both marginal cost pricing and average cost pricing techniques applied to future sources, it was determined that the municipal and industrial demand projections used in the analysis were reasonable estimates.

Alternative Water Sources to Meet Future Demand

An inventory of potential sources was compiled from information available through state water plans, regional planning agencies, and municipalities. A total of 191 existing and potential sources were identified. This inventory included 31 aquifers, 130 stored surface supplies, and 30 streams and reuse water. A screening process was established using a set of 23 screening criteria to determine the viable sources to meet future needs. The criteria were divided into two main categories: (1) water quality parameters, and (2) environmental and other problems. The water quality criteria included quality thresholds for water use for total dissolved solids (TDS), chlorides (Cl-), and sulfates (SO_4=). The second criterion for screening included considerations for endangered wildlife habitat or groundwater depletions. The screening process yielded 63 alternative future sources. The cost for the existing surface and groundwater sources included the source cost, transportation cost, and operation and maintenance cost to the established demand centers within each reach. Cost information on the existing sources was available through historical records of the sponsoring agencies and from communities and municipalities developing those sources. Cost estimates for sites that could be developed were based on computed, annualized cost of developing the source, transporting the water to the designated demand center, operating and maintaining all facilities, and allowing for major replacement. It was assumed that the surface water would be pumped from a raw water intake to a treatment plant near the demand center. The resultant analysis shows that the alternative future cost ranged from $.03 per thousand liters to $.73 per thousand liters for sources that would be alternatives to the Red River.

Cost of Red River Water

Use of poor quality water is costly to the users because they must either reduce the concentration of the undesirable constituents (TDS, Cl-, SO_4=) or they must sustain damage to their equipment. The total cost to a user of Red River water without the chloride control project is composed of costs for: (1) pretreatment (softening) and reverse osmosis treatment facilities, (2) operation and maintenance of these facilities, (3) disposal of the extracted waste materials, (4) damages to and repair or replacement of equipment (e.g. water pipes, boilers), and (5) transportation. The amount of damages that will occur or the degree of treatment that is necessary is dependent on the concentration of the undesirable constituents. The concentrations of these constituents vary daily and the variations can be summarized in duration curves. Duration curves were developed for each reach to show the variation in terms of the percentage of time that specified concentration levels were exceeded. The determination of costs for Red River water is based on the water quality concentration-duration curves.

There is an upper concentration (threshold value) of a constituent in water that can be tolerated by an industry or municipality using the water before substantial damages to equipment occur. Figure 2 indicates that when the concentration exceeds the threshold value, the user may be willing to pay for treatment costs to improve the quality of the water to the threshold level or may be willing to sustain additional damages, whichever cost is less. In all cases, treatment of Red River water or damages caused by use of Red River water is based on quality equal to the average water quality of alternative sources within a reach. Figure 2(a) and 2(b) can be used jointly to develop the total annual costs sustained by the user. Entering the two figures at the same concentration level shows the functional relationship of total annual costs versus the percentage of time the concentration occurs with and without the project, as shown in figure 2(c).

A water user is faced with two options. In the first, water is treated to the threshold and damages from any residual TDS are suffered. It is possible that the total treatment cost plus residual damage cost could exceed the damage cost which would occur with no treatment. In the second case, the user would choose to use water without treatment. To determine the least costly of the two alternatives, unit costs for both cases were developed for municipal and for the manufacturing industries in each SIC for each reach of the affected streams. For analytical purposes the value of the water is the least cost. A user

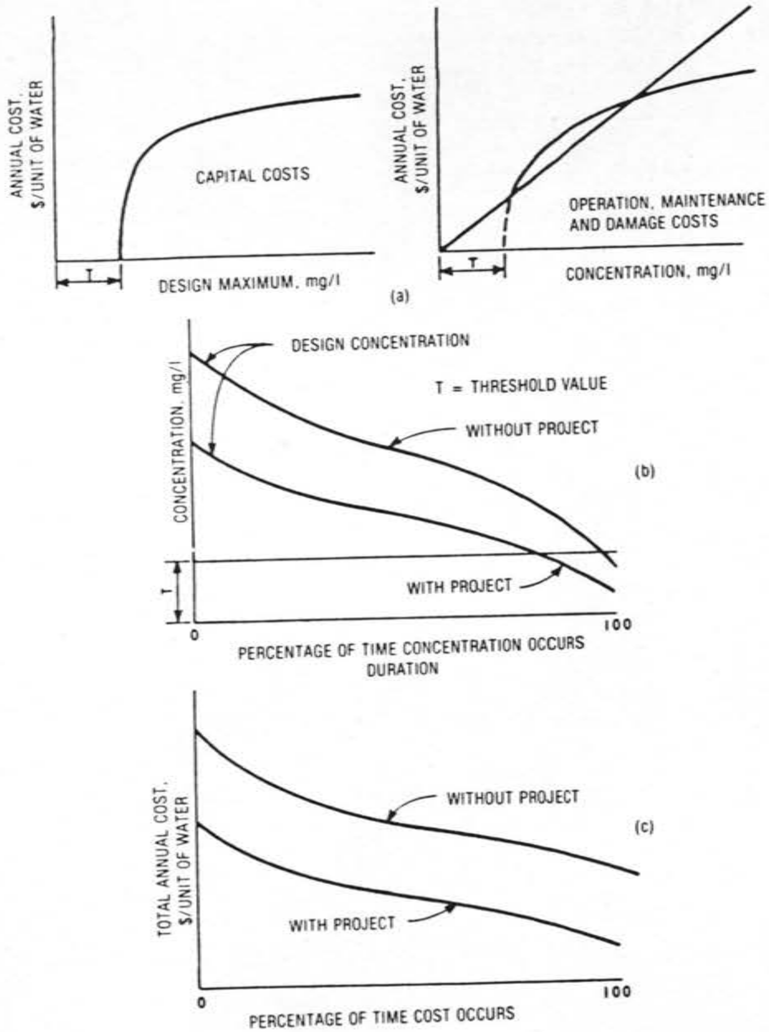

Figure 2. Municipal and industrial costs.

could choose to treat to a higher level, but would incur higher costs.

The total cost of the Red River water for municipal users ranges from $.10 per thousand liters to $1.85 per thousand liters without the project, and $.07 per thousand liters to $.88 per thousand liters with the project. For industrial users the range was from $.03 per thousand liters to $.92 per thousand liters without the project, and from $.02 per thousand liters to $.39 per thousand liters with the project. The lower costs were associated with those reaches in the lower basin where thc concentrations are more diluted by tributary flows in the basin; the higher costs were associated with those reaches of higher brine concentration near the salt sources.

Allocation of Supplies to Demand

The allocation of sources to meet demands depends on the cost of the water supply which, in turn, is based on the quantity and quality of the water. In allocating water supplies to demands, the demands were satisfied based on a priority of use and a least costly source. The order or priority was established as municipal, industrial, steam-electric, and agricultural. Any unsatisfied demand is then met from the next least costly source until the total demand is satisfied. If water is not available from existing sources to satisfy the municipal demand, then the next least costly source is used to supply the demand. If the allocation of water supplies to demands, based on least cost, results in the Red River water being used with or without the project, the quantity of Red River water demanded is computed. Current use of Red River is expected to increase to 158.8 x 10^6 liters per day by 1990 without the project and to 1.1 x 10^7 liters per day by year 2040 with the project.

Municipal and Industrial Benefits

The municipal and industrial benefits are derived from Lake Texoma downstream to Louisiana. In Louisiana and in the Sherman-Denison area of Texas, Red River water is currently being used as a source of water and will continue to be used either with or without the project.

Water quality benefits are calculated when the allocation shows that the Red River water is used with or without the project. The benefits are calculated by multiplying the difference in the unit cost of Red River water with or without the project by the quantity of river water demanded. A water supply benefit is calculated when Red River water is used with the project and not without. The water supply benefit is computed as the unit value of water from the least costly alternative without the project times the quantity of water demanded from the Red River with the project. The average annual value of municipal and industrial benefits from projected water use is $12.8 million.

CONCLUSION

The purpose of this paper was to demonstrate a methodology used, in part, to determine the economic merit of investments for removal of salt pollution in the Red River. The approach was developed as a basis to formulate studies for the Red River chloride control project. The evaluation demonstrates the amount of water demanded, when it is to be withdrawn, and the potential users. Formulation studies to determine the desirability of constructing pollution control measures included not only an economic evaluation, but also environmental, social, and technical considerations. The results of those considerations showed that the Red River chloride control project should be constructed and that the estimated benefit-to-cost ratio is 1.6 to 1.

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Natural Salt Pollution Control Brazos River Basin, Texas

Jerry A. McCrory
Planning Division
U.S. Army Corps of Engineers
Fort Worth, Texas

INTRODUCTION

The quality of Brazos River main stem water is seriously degraded by emissions from major salt sources in the upper Brazos River Basin. The emissions consist of mineral pollutants composed principally of sodium chloride (common table salt) with moderate amounts of calcium sulfate (gypsum) and other dissolved solids. Because of this natural pollution, the 1,486 kilometer main stem Brazos River from Stonewall County, Texas, to the Gulf of Mexico is of generally poor water quality.

SOURCES OF SALINITY

Figure 1 presents a vicinity map showing the Brazos River Basin, the salt study area, and four water quality measuring locations -- Possum Kingdom Reservoir, Lake Granbury, Whitney Lake, and Richmond, Texas. The salt study area, shown in figure 2, was defined as a 3,885 square kilometer area principally within the confines of the Salt Fork Brazos River watershed. Adjacent areas on the Double Mountain Fork Brazos River and North Croton Creek were included because of known salt sources. Portions of six counties were included -- Crosby, Dickens, Garza, Kent, King, and Stonewall Counties, Texas.

Several universities, State agencies, and Federal agencies have investigated the salt problem since the mid-1950's. The U. S. Geological Survey (USGS) published major reports in 1961 and 1968 concerning the natural salt pollution in the upper Brazos River Basin. The 1968 USGS report was the basis for the salt loads shown later. [1]