FINAL REPORT

REPORT OF INVESTIGATIONS

EVALUATION OF ECONOMIC AND RELIABLE METHODS OF BRINE MANAGEMENT

STONEWALL COUNTY, TEXAS

PERFORMED UNDER TEXAS WATER DEVELOPMENT BOARD CONTRACT
95-483-142, OCTOBER 29, 1995

SUBMITTED:

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University of Texas at El Paso, Center for Environmental Resource Management
To Texas Water Development Board.

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INTRODUCTION

Salt pollution caused by excessive salt pick-up from brine springs in the Upper Brazos River Basin has been a serious condition for well over a century. It was felt that the demands of area interests in a permanent solution to this salt pollution merited a fresh look at the ways and means of permanent abatement of this pollution and the recovery and use of both the salts and the purified water that could result from a complex developed for the purpose. Accordingly, authorization was received from the Texas Water Development Board to examine this problem from a much broader perspective and to arrive at certain concrete conclusions regarding the economic and reliable methods of brine management in this region.

The above referenced Contract, by and between the Texas Water Development Board (TWDB) and the County of Stonewall, Texas, was arranged and agreed by the Honorable Judge Bobby McGough, County Judge of Stonewall County, to be performed by a team of experts assembled together for the purpose, representing the companies itemized below:

Kleber J. Denny, Inc., Houston, Texas (KJD)
International Management Services, Houston, Texas (IMS)
University of Texas at El Paso, El Paso, Texas (UTEP)
J. McNutt & Associates, Dallas, Texas. (JMA)

Part I of this Research Study, entitled: "Collection and Review of Background Information" is the object of this Report, consisting of four components, namely:

I.A.1 Site Visit
I.A.2 Lab Analysis of Samples taken at the Site
I.A.3 Collection & Review of Existing Data

REPORT OF RESULTS OF PART I

I.A.1 SITE VISIT

On December 1, 1995, the principals of KJD and IMS traveled to Aspermont, Texas, the County Seat of Stonewall County, Texas, for a site visit and discussions with the other participants. Present in addition were Mr. J. D. Beffort of the TWDB, Dr. Andrew Swift and Mr. Huan Min Lu of UTEP, Mr. Mark A. Lichtwardt of the Bureau of Reclamation (BUREC), U.S. Department of the Interior and County Judge Bobby McGough of Stonewall County, Texas.

The party proceeded to the location (please see Map A, attached) where the Salt Croton Creek joins the Salt Fork of the Brazos River, it having been previously determined that the input of salt into this junction appeared to be one of the highest anywhere on the Salt Fork. The general area was critically examined for both salt seeps and salt pickup via the tributary of Salt Croton Creek. Samples were taken before and after the entry of the Creek into the Salt Fork. Preliminary analyses made with a hand-held Saltmeter showed that the Croton Creek salt content appeared to average an inordinately high 20-24% concentration, equivalent to about 200,000 to 250,000 parts per million (ppm). The samples taken about a hundred yards downstream from the junction of the Salt Croton Creek into the Salt Fork showed averages of about 4.0 % or some 40,000 ppm.

Photographs were taken of a bend of Salt Croton Creek upstream of its entry into the Salt Fork and of the encrustation of salt crystals on and under the ledges of the banks of Salt Croton Creek. These pictures clearly show (see enclosed) that the concentration of salts in the Creek is high enough to promote precipitation and crystallization upon relatively minor temperature changes. The splash of the water upon the banks and under the ledges of these banks also occasions evaporation of the water, causing the salt to crystallize out readily, another indication of ultra-high salt concentrations. Altogether, it is evident that these high concentrations result from passage - through salt domes - of the springs that feed the Salt Croton Creek and, because of underground temperature conditions, occasion unusually high pickup of the salts. No such encrustations were found in the area of the Salt Fork itself, about one hundred yards downstream of the entry of the Creek into the Fork.

Following the visit to the site, a detailed discussion was held concerning the approaches to the economic and technically sound management of these salt incursions into the Brazos River System. Four previously generated reports (from the UTEP Research Bureau; the U.S. Army Corps of Engineers; the Texas Tech University; the U.S. Bureau of Mines) were examined for past conclusions as to the best way to handle the problem. It was apparent to the team that, if the only methods recommended were those involving impoundment dams, no permanent change could be effected in the salt incursion problem - to say nothing of the obvious fact that somewhere in time, one would run out of impoundment sites and would succeed only in removing vast stretches of land from any other usage.

There was ready consensus that the time had come to examine all of the possible alternatives to utilize the economic and technical values in the salt mixture towards commercial applications. These will be more particularly examined and reported in Part II of this study. Conventional methods of brine disposal, such as re-injection into appropriate underground formations capable of receiving the quantities involved without disruption to the landscape, are currently about the only permissible method of disposal of unneeded brines, especially in West Texas. While certainly effective in the prevention of salt pollution, these methods do not contribute anything to the overall economic inflow of the region in question. As more and more salt pollution areas are identified across the state, it becomes imperative that solutions deal positively with ways and means of utilizing these brines rather than just getting rid of them. If some of these considerations lead to a sizeable net economic gain, then all involved benefit and that is the driving force behind this study. Modern technology now makes possible an affordable approach to desalination such that the areas most prone to salt pollution can now obtain separated salt and a plentiful supply of fresh, clean water with all its attendant benefits.

It is fortuitous that the Salt Croton Creek brine contains little else than common salt (please see I.A.2. below), making it ideal for use as an injection fluid for enhanced crude oil recovery. As an example, conventional water-flood methods of oil recovery depend upon a plentiful supply of fresh water (injected either as water or as steam in a steam-flood operation) and are consequently not economical in this particular region. Using the water from heavily salted streams is a much more viable alternative, inasmuch as the significantly greater density of salt water enhances the recovery of oil from weak or partially depleted formations and also affords a relatively rapid method of generating cash flow needed to put into place other methods of permanent salt removal over the long term. It is realized that this methodology is better described in Part II of this study, but mention needs to be made here inasmuch as the subject came up during the site visit and hence is properly introduced here.

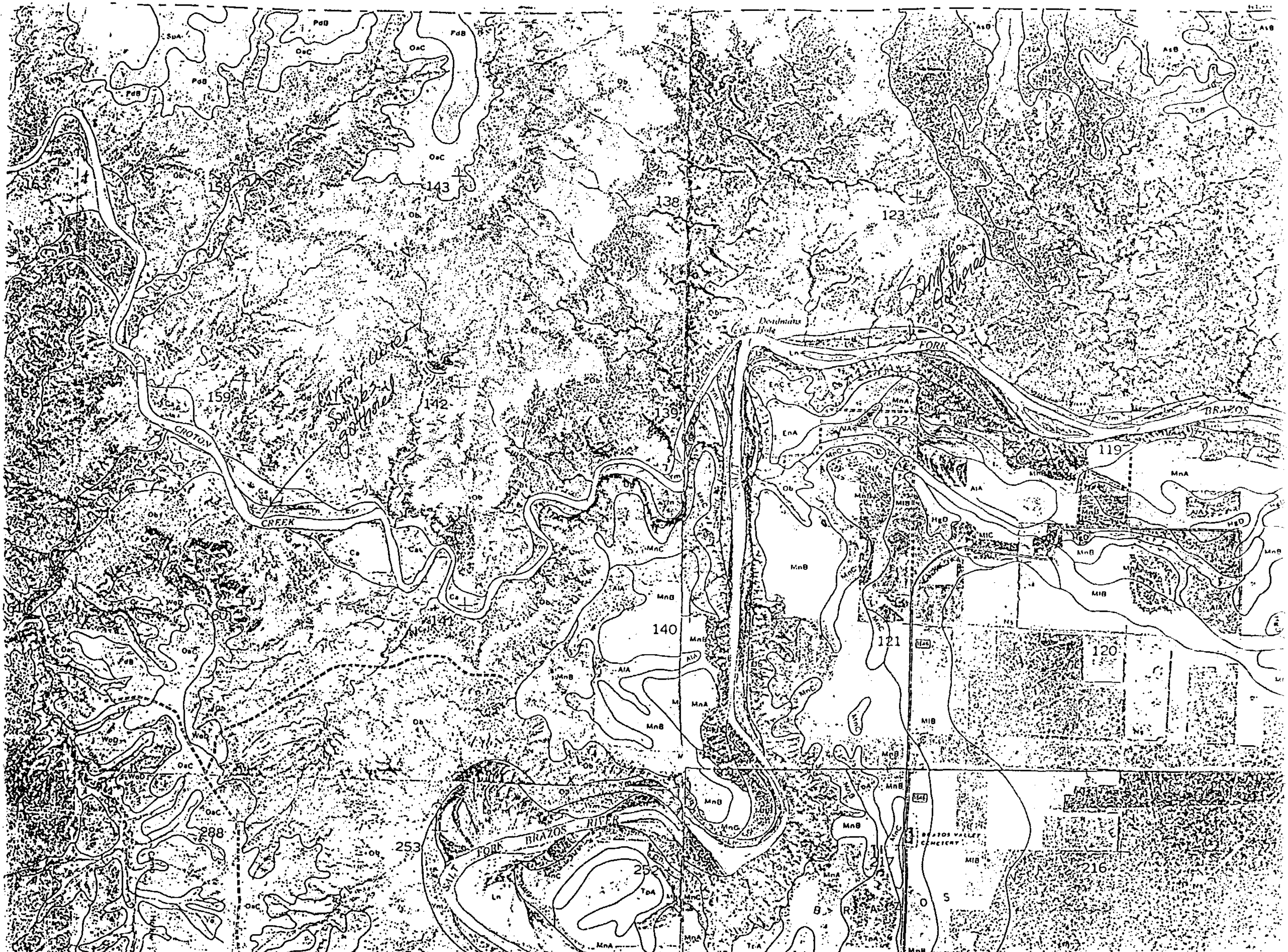
A brief discussion of possible ways and means of financing the eventual effort to render the Salt Fork permanently free of these ultra-heavy concentrations was also held, the consensus here again being that a judicious mix of public and private funding would be needed in order to implement the optimum methods revealed in concept during this study. There was emphatic agreement on the point that the problem was capable of such permanent solution and hence there was little need to continue to "study the problem" after over 25 years of such "studies". The significance of the current effort thus lies in the concentration of attention upon the economically viable applications that could arise and which could be rapidly prioritized towards implementation in a reasonable length of time. That in turn argues for a closely followed determination of the economics of the various applications, such that a total complex could be designed and put into place to permanently reduce the salt pollution of the Brazos River to manageable levels.

The site visit ended with the participants agreeing to exchange all information developed and to remain in close touch as the study unfolded.

UPPER BRAZOS RIVER BASIN MAP

SHOWING SALT LOADS AT SELECTED POINTS

(From U.S. Army Corps of Engineers Report)



MAP A: GENERAL AREA OF SAMPLING FROM SALT CROTON CREEK AND SALT FORK OF THE BRAZOS RIVER

CORPS OF ENGINEERS U.S. ARMY

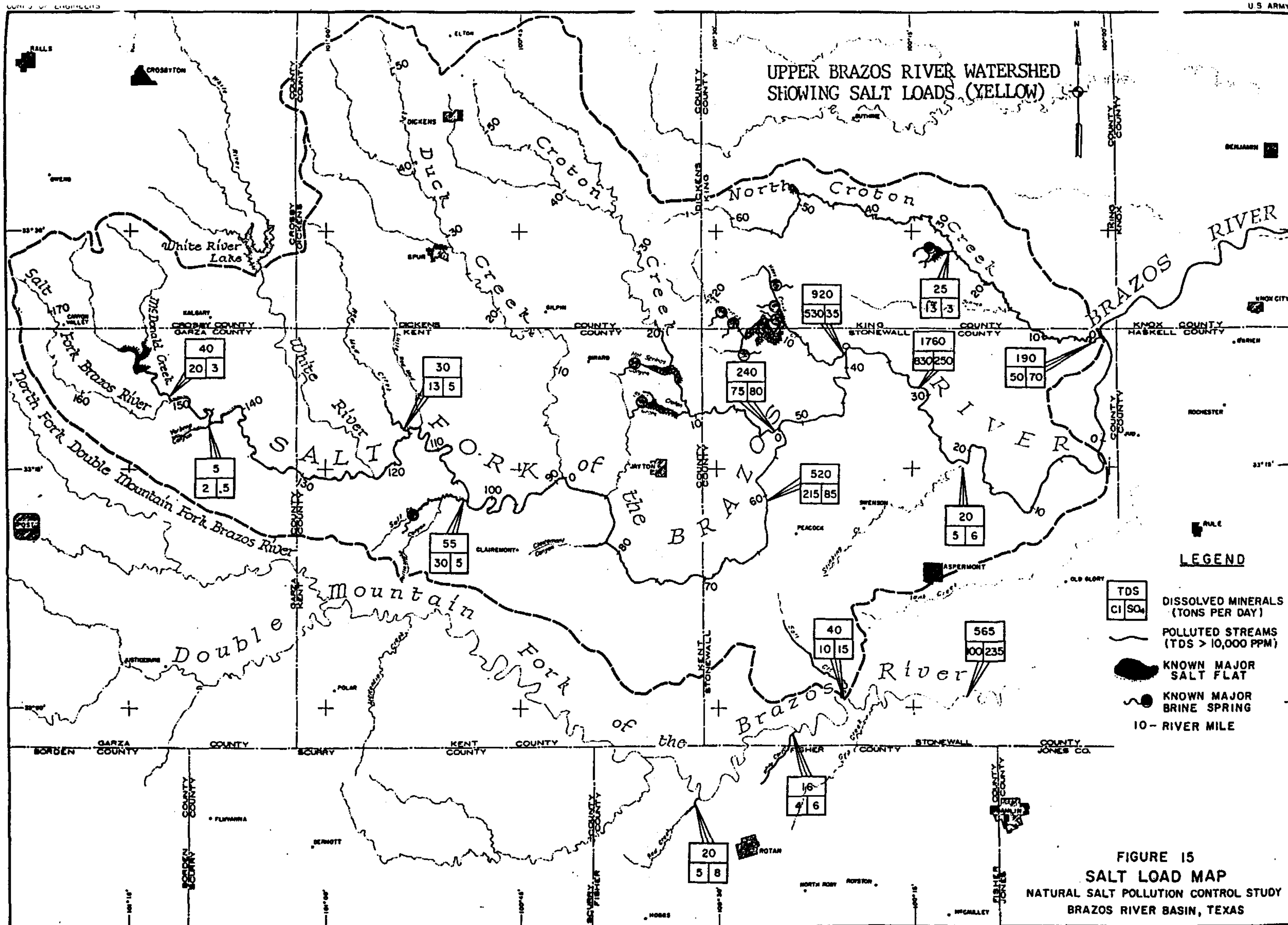


FIGURE 15
SALT LOAD MAP
NATURAL SALT POLLUTION CONTROL STUDY
BRAZOS RIVER BASIN, TEXAS

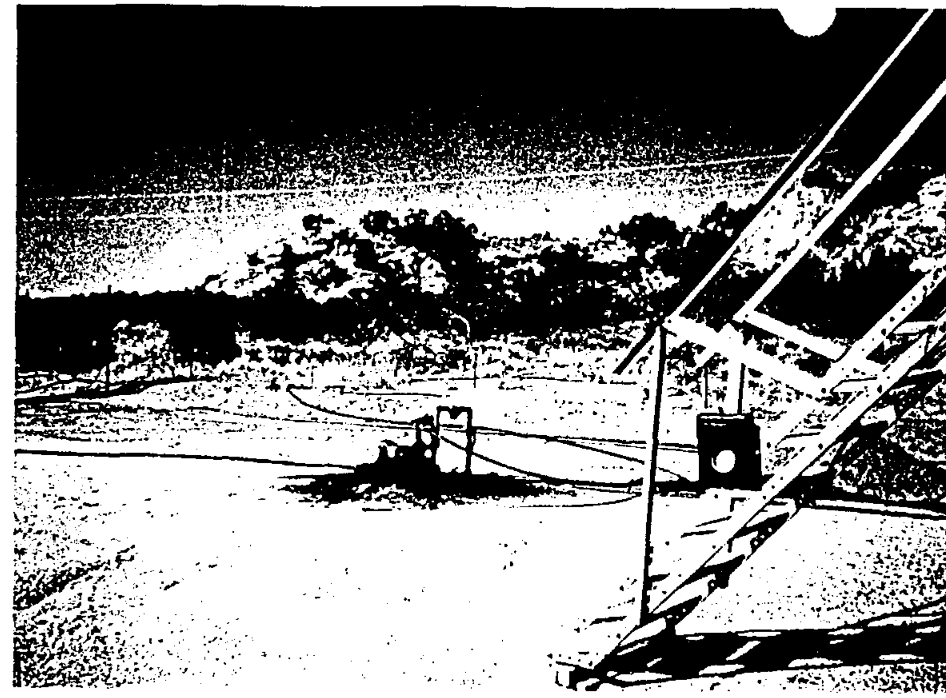
CLOSE-UP OF SALT BUILD-UP AT SHORELINE

SALT CRYSTALLIZATION AT BANK LEDGE, SALT CROTON CREEK

HEAVY SALT DEPOSITS AT POINT OF ENTRY INTO WIDER CREEK

SALT PUDDLE ACCUMULATION ON SHORE, SALT CROTON CREEK

TEAM GROUPED BEFORE OIL-WATER SEPARATOR AT WELL SITE



LOOKING AWAY FROM SEPARATOR PLATFORM TOWARDS DIRT ROAD

GENERAL VIEWS AT SALT CROTON CREEK BEND NEAR POINT OF SAMPLING
NOTE HEAVY ENCRUSTATION OF SALT ON SURFACES AT BANKS

I.A.2. LAB ANALYSES OF SAMPLES TAKEN AT THE SITE

The samples taken at a point above the entrance of the Salt Croton Creek into the Salt Fork of the Brazos River (please see Map A) were analyzed by the Environmental Research Chemistry Laboratory of the U.S. Bureau of Reclamation (BUREC) at Denver, Colorado.

Table I below shows the results of these analyses on the one sample taken as above, code-named J-6258. For the sake of brevity, the concentrations have been converted into Parts per Million (ppm) for each ion.

Ion Type	**Concentration, ppm**
Total Dissolved Solids (TDS)	228,000
Sum of Cations & Anions	281,000
Calcium (Ca)	2,170
Magnesium (Mg)	1,220
Sodium (Na)	91,600
Potassium (K)	251
Carbonate ($-CO_3$)	44
Sulfate ($-SO_4$)	4,420
Chloride (-Cl)	182,000

Examination of these results points to a preponderance of Na and Cl ions, most probably combined as NaCl or common salt. If this assumption is tenable, one has NaCl concentration of ca. 231,000 ppm in the sample, indicating that the true TDS count could be higher than the 228,000 ppm reported. Further, if NaCl alone accounts for some 81+% of the total ion count of 281,000 ppm, then several factors concerning possible separation of the various salts become moot, inasmuch as the total of all the other salts may not represent economically recoverable concentrations.

TABLE 5

IMPACT OF NATURAL SALT POLLUTION
ON SURFACE-WATER SUPPLIES

Source	Yield degraded by natural pollution	
	Main-stem (af/year)	Tributary (1) (af/year)
Present developed supplies:		
Possum Kingdom Lake	86,000	
Lake Palo Pinto		1,300
Lake Granbury	67,100	
Whitney Lake	49,100	
Proctor Lake		4,600
Belton Lake		33,100
Stillhouse Hollow Lake		60,300
Camp Creek Lake		2,600
Somerville Lake		27,700
Diversion structure	85,000(2)	
Sub-Total	287,200	129,600
Authorized supplies:		
Aquilla Lake		9,400
North Fork Lake		1,500
Laneport Lake		6,400
Millican Lake		109,200
Navasota Lake		231,600
Sub-Total	-	358,100
Planned for future development:		
Cameron Lake		88,600
Uncontrolled flows:		
Following completion of all authorized projects (est.)	900,000(2)	
Total	1,187,200	576,300(2)

(1) Portion of the tributary supply allocated for use in San Jacinto and San Jacinto-Brazos service areas. Degradation occurs as the supplies are mixed with main stem Brazos water.

(2) These yields, totaling 1,561,300 acre-feet per year, are expected to be captured from the main stem near Richmond, Texas, for use in the lower Basin and in adjacent service areas.

We conclude that, for practical purposes, one can safely proceed to consider the sample contents as essentially NaCl in solution. As another check, independent testing of the sample specific gravity, as performed by means of a portable Densitometer, showed the specific gravity to be ca. 1.178 (pure water = 1.000) at a temperature of ca. 15^0 Celsius (60^0 F). *The specific gravity of a pure NaCl solution, measured @ 15^0 C is 1.178 and such a solution contains 23.3 % or 233,000 ppm of NaCl* (Source: Brine Tables, J.H.Perry, Chemical Engineer's Handbook)

ADDITIONAL ANALYTICAL INFORMATION

In the interests of determining what additional elements could be included in the salty water flowing in the Salt Croton Creek, sampling was conducted at a point near the Salt Croton Falls area. The report of these analyses is shown below.

Two points of interest are revealed by this further analytical effort: **First**, that there is an amount of bromine in this stream, at least to the extent revealed by the additional sampling, of some 341 parts per million (ppm), which level corresponds to about 5.25 times the concentration in an average sample of Texas Gulf Coast seawater. It is well known that Bromine is extracted from seawater in large quantities at Freeport, Texas, for commercial usage. Thus, if concentrations of 65 ppm at Freeport (average) are considered sufficient to permit commercialization, then surely the potentials of the Salt Croton Creek with respect to Bromine commercialization appear to be quite encouraging.

Secondly, the analysis also revealed a concentration of Strontium of about 46 ppm, estimated to be largely existing as Strontium Sulfate, a common Strontium compound. This quantity may not be sufficiently attractive to be of commercial importance, but one cannot rule this possibility out altogether, at least not without some additional research in both technology and in economics.

ANALYSIS OF SALT CROTON FALLS SAMPLE

LOCATION:	Salt Croton Falls	SWN:	2246103
		COUNTY:	Stonewall
DATE:	04-04-1996		

AQUIFER:
WHITEHORSE GROUP

	MG/L		MG/L		MG/L
Silica		Carbonate	0	Dissolved Solids	232753
Calcium	2292	Bicarbonate	61	Hardness as CaCO3	10109
Magnesium	1054	Sulfate	4734		
Sodium	81415	Chloride	142903	Conductivity	
Potassium	279.5	Fluoride		pH	7.41
Strontium	45.8	Nitrate		Temperature	20° C

ALKALINITY, FIELD, DISSOLVED AS CACO3	52.0
BARIUM, TOTAL (μG/L AS BA)	111.2
BORON, DISSOLVED (μG/L AS B)	4094
BROMIDE, DISSOLVED, (MG/L AS BR)	341.2
IODIDE (MG/L AS I)	12.0
STRONTIUM, TOTAL (μG/L AS SR)	45803.0

I.A.3. COLLECTION AND REVIEW OF EXISTING DATA

The existing data on the salt pollution in the upper reaches of the Brazos River have been gathered, analyzed and processed ever since the 1950's, with several follow-on reports having been generated during the period 1958 through 1994. In all of this period - 36 years - not one instance of actual implementation of any recommendation arising out of any study has come to light. The reasons for this apparent inaction are obscure, but what is all too clear is that the problem will not disappear by itself. All of the studies listed in the Bibliography appended hereto have advanced solutions that are distressingly similar, and are mainly of two types:

1. Build impoundment dams to prevent tributary inputs to the Upper Brazos

2. Divert tributary flows by injection into suitable formations underground.

It is evident that, at best, both types of recommendations are short-term solutions, no matter that, during such short terms, some measurable downstream relief from salt pollution would occur. There is neither surface acreage nor underground reservoir volume sufficient to constitute a reasonably long-term solution (say, at least 25 years). In addition it is equally evident that if either of these two types of solutions were to be put into effect, there would not be any benefit other than the downstream improvement of the salinity of the waters in the Brazos River Basin. The counties that are most directly affected by this excessive pollution are the counties that are adjacent to Stonewall County and the Southeast thereof, in addition to Stonewall County itself. This County is sparsely populated and has no visible means of economic sustenance apart from some agricultural activities that are themselves severely hampered by the continuing heavy salt pollution.

The geographical location of Stonewall County puts it in closer proximity to the vast Metroplex of North Texas (the Abilene to Fort Worth to Dallas Corridor plus its immediate environs), hence closer to the markets that could be developed by an intelligent utilization of the many different potentials that could be generated. We know from actual analyses that the preponderant concentration is that of Sodium Chloride ($NaCl$), a fact that makes it much easier to develop a separation and utilization complex to yield not only pure $NaCl$ but also pure water for potable and industrial use. When this improvement is combined with the agricultural improvements downstream, resulting from greatly reduced salinities, then the entire region is poised for economic takeoff in a self-sustaining manner and permanently so.

This study, then, in its emphasis on all possible applications that would be economically viable, represents a significant departure from previous studies and their respective recommendations, in that all factors, from salt commercialization to water recapture and purification, are to be considered.

We begin this Review by encapsulating the contents of each of the sources listed in the Bibliography at the end of this Report. The source numbers shown below correspond to source numbers in that Bibliography.

Team members have compiled and reviewed available studies and reports pertaining to both the physical and economic aspects of the salt pollution problem in the study area and also currently utilized methods of brine disposal and management. A comprehensive bibliography of this literature is provided at the end of this Report, and a brief summary of pertinent data and other information obtained therefrom, delineated by sub-topics and cross-referenced to the bibliography by means of identifying "source numbers," is presented as follows:

A. Physical Aspects

1. Source and Areal Extent.

Source 3, Volume 1, pp. 11 & 12, and Figure 1:

The study area encompasses approximately 1,500 square miles principally within the hydrologic confines of the Salt Fork Brazos River. Adjacent areas on Double Mountain Fork and North Croton Creek are included because of known salt sources there. The study area includes all or some portions of Crosby, Dickens, Garza, Kent, King and Stonewall Counties, as shown on the General Location Map included as Figure 1.

Source 6, pp. 1 and 2:

The source of salt pollution is primarily brine springs and seeps in the Salt Fork Brazos River Watershed. The area that includes brine seeps and springs is in the Rolling Plains in north-central Texas and is bounded by the caprock escarpment of the southern High Plains on the west, the Salt Fork of the Red River on the north and the Double Mountain Fork of the Brazos River of the south.

2. Magnitude of Salt Load.

Source 2, page 1 and Figure 2:

The Brazos River carries an average daily load of 1,650 tons of sodium chloride into Possum Kingdom Reservoir. More than 85% of this amount is contributed by the Salt Fork Brazos River, and more than 50% of this amount originates from springs and seeps in Croton and Salt Croton Creeks, tributaries to the Salt Fork Brazos River. The enclosed Figure 2 is a map of the Croton Creek-Salt Croton Creek Area.

Source 3, Volume 1, pages 42 and 52 (Table 2) and Figure 15:

Average daily salt loads from the upper Brazos River Basin were determined for a 10-year base period, 1957-1966 by the U.S. Geological Survey. These 10 year statistics were expanded to a 22-year base (1941-1962) in the mathematical model of the Brazos River developed by the E.P.A. Historical stream flow and concentration data were similarly adjusted to fit the 22-year period. Results of the U.S. Geological Survey quality studies, supplemented by data from the mathematical model, are shown on the enclosed Figure 15. Also include is Table 2 entitled Summary of Salt Loads in Brazos River Basin.

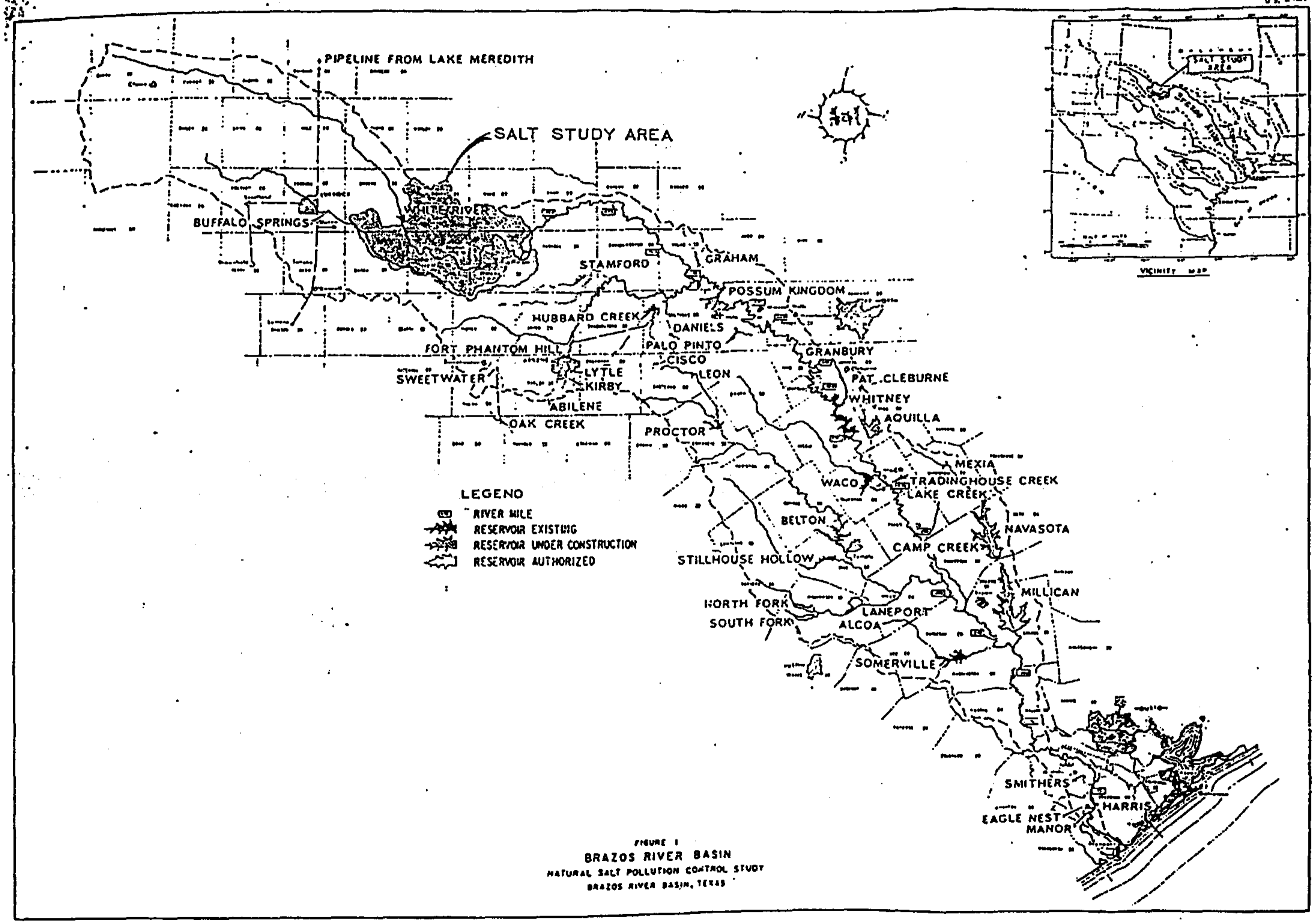


FIGURE 1
BRAZOS RIVER BASIN
NATURAL SALT POLLUTION CONTROL STUDY
BRAZOS RIVER BASIN, TEXAS

Source 5, Page 5:

The major areas of salt water emission are Croton Creek and Salt Croton Creek, and other less contributing areas are also located in the project area. The Salt Croton Creek area is the largest producer of salt waters. Based on studies conducted by the U.S. Geological Survey, it appears that the estimated daily load of chloride for the period from 1957 to 1966 was 530 tons per day. Of this to be tested, about 330 tons of chloride were measured as base flows and about 200 tons per day were measured to be from flood flows. The flood flows from the Croton Creek area are estimated to have contributed about 75 tons of chloride per day during the 1957 to 1966 period. The total of all salt emission sources contribute an average daily load at Possum Kingdom Reservoir of approximately 3400 tons, of which about 1200 tons are chloride and 700 tons are sulfates.

3. Chemical Composition and Physical Properties.

Source 2, Page 9:

THE BRINE

Very salty water, or brine, was encountered in all the test holes. It has been encountered in many of the ranch and stock wells throughout the area that have been deepened in attempts to increase their yields, and it's presence is inferred from electric logs in oil company stratigraphic test holes. All available data indicates that this water underlies the entire area, and discharges in the salt springs and seeps. The total dissolved solids content of the brine averages about 250,000 ppm, although the content is less where diluted with fresh water, or contaminated by drilling mud or mud infiltrate. In contrast to the overlying fresh water, the brine is predominately of the sodium-chloride type. The density of water having a total dissolved solids content of 250,000 ppm is about 1.2 g/ml. This has been confirmed by density measurements or water samples, both in the field and in the laboratory.

Source 3, pages 34, 38, 39 and 40 (Figure 13):

CHLORIDE CONCENTRATION

Chloride concentrations in the upper Brazos River Basin far exceed levels acceptable for any use. This one mineral seriously limits utilization of Brazos flows throughout the river's length. Chloride concentrations in some of the salt springs in the upper Basin regularly exceed 150,000 ppm, which is almost nine times that of sea water and is equal to that in the Dead Sea, the saltiest natural water body.

SULFATES CONCENTRATIONS

Sulfates levels in the Salt Fork drainage area range from about 300 to 2000 ppm, with a mean of about 1000 ppm, and as with chloride, these unacceptable levels are diluted by middle and lower basin flows.

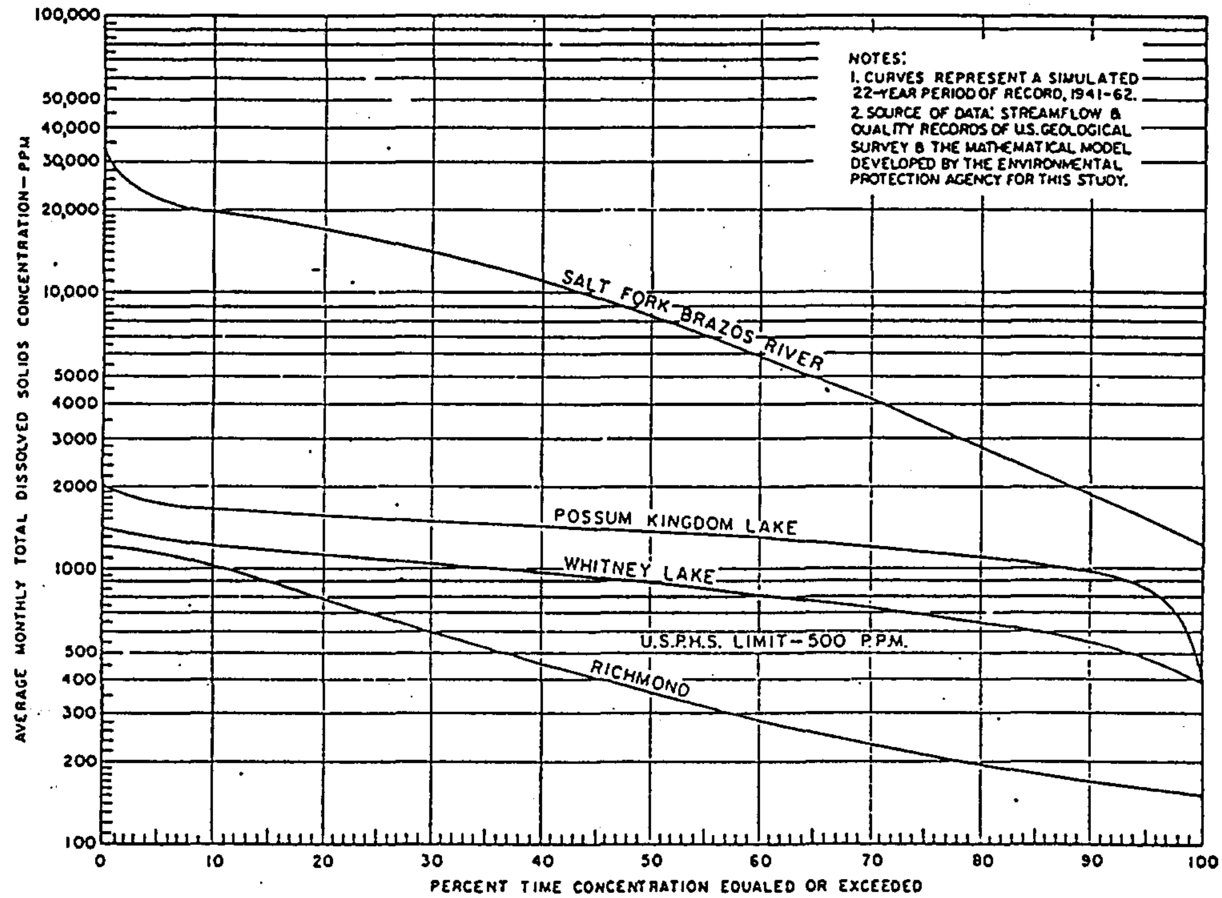


FIGURE 13
CONCENTRATION-DURATION CURVES
FOR TOTAL DISSOLVED SOLIDS
NATURAL SALT POLLUTION CONTROL STUDY
BRAZOS RIVER BASIN, TEXAS

THE FLOW-LOAD RELATION

The Brazos River and tributaries have long periods of low discharges interrupted by occasional large flood discharges. Discharges are stated in cubic feet per second (cfs). A discharge-exceedence frequency is given in figure 14. Average discharges are much higher than median discharges (flow equaled or exceeded 50 percent of the time). For example, the average discharge (152 cfs) of the Salt Fork is about five times the median; while at Richmond, Texas, the average discharge (7,741 cfs) is only about 1.5 times the median because of a more uniform precipitation pattern.

TOTAL DISSOLVED SOLIDS

Total dissolved solids fluctuate because of the same reasons and in the same manner as explained for chloride, and Figure 13 shows this variation and similarity.

Source 6, page 47 (Table 18):

Table 13 lists the average chemical composition and pH for certain brines reported by Richter and Kreitler and others compiled by Core Laboratories, and these are presented as follows:

Table 13 - Chemical Composition of Brines (ppm)

Brine	Na	Ca	Mg	Cl	SO_4	HCO_3	pH
Injection	88,000	2200	1210	135,000	4270	40	6.9
Wolfcamp	26,300	3750	816	48,500	1190	229	7.0
Canyon	45,800	13,400	1810	97,100	688	192	6.4
Strawn	53,000	15,300	2240	117,000	393	172	6.2
Ellenburger	24,600	4710	1180	48,700	1640	417	6.8

B. Economic Aspects

Source 3, Volume 1, Pages 68 and 69 (Table 5):

Water resources of the Brazos River are limited in quantity and little can be done to make them larger. However, citizenry of the Basin have a supply in this river adequate to support their needs now and beyond realistic planning. Nonetheless, lack of water, good water, is a real and increasingly serious economic problem in the Basin. Efficient use of the abundant supplies of the Brazos River is not possible today because natural quality is not acceptable. People have chosen not to use the water whenever other sweeter water is available, which in the past has been available. Whether people would have forgone use of these supplies assuming lack of alternative sources is a matter of conjecture. But the fact exists that no municipality relies on Brazos River resources for its total supply.

The data in Table 5 quantifies the economic impact salt pollution has on existing as well as future water supplies of the Basin. Including the portion of tributary supplies which are to be released into the Brazos River for use downstream, almost 864,000 acre-feet of the total 1,230,000 acre-feet of the existing and authorized annual Basin yields is or will be degraded by natural salt pollution. Such degradation of 70 percent of the Basin's surface supply aptly explains the quantity-quality conflict. There is an estimated potential yield of 900,000 acre-feet over that of existing, authorized, and planned reservoirs which would also be affected by natural pollution. By year 2020 reservoirs listed in Table 5 are projected to be totally utilized after which a gradual demand for the uncontrolled yield would arise. It is assumed that the 900,000 acre-feet yield would subsequently be developed or utilized for this future need.

PART II
EVALUATION OF POTENTIAL METHODS OF BRINE DISPOSAL & MANAGEMENT

ORGANIZATION OF CONTENT

The organization of this Part II is subdivided into three sections, specifically the following:

A. Detailed Descriptions of Each Method

B. Preliminary Analysis of Feasibility of Each Potential Method

C. Development of an Applications Matrix

The intent of each of the above sections is as follows:

Section A. To provide descriptive information about each potential method *on a generic, non-site-specific basis*

Section B. For each potential method described in Section A, to provide a preliminary analysis of feasibility, applicable to both site-specific uses which could be appropriate to Stonewall County and vicinity as well as non-site-specific applications, taking into consideration the following:

a) physical makeup of the brine
b) commercial viability, i.e. product demand, as well as economic, environmental and reliability factors

Section C. For those potential methods which are determined from Section B to hold the most promise for applications for Stonewall County and vicinity, to provide an "application matrix" which will basically be a tabular summary of those applications to be incorporated into a conceptual design of a hypothetical "brine disposition and management complex" at a later date. Additional funding will be required for the preparation of such a conceptual design.

With this organizational format of the content in mind, we present Part II as shown below.

Section A: Detailed Descriptions of Each Potential Method

1. Aquaculture or Fish Farming

In this application, brine is used as a medium for the raising of various species of fish and/or crustaceans. The optimum salt concentrations for successful marine aquacultural development are in the range of 25,000 to 40,000 ppm total dissolved solids (TDS), i.e. the average concentration of sea water. A partial listing of the varieties of fish and crustaceans that could be successfully raised in this manner is as follows:

- Marine Shrimp, simple or multi-crop
- Rainbow Trout
- Hybrid-Striped Bass
- Catfish
- Brine Shrimp

2. Enhanced Oil recovery via Brine Injection (or water flooding)

In this application, the brine is used as a fluid injected under pressure into an oil-bearing formation for the purposes of increasing well yield, enhancing the economics of oil production. Properly designed and operated, water flooding can double or triple the production or maturing wells, yielding valuable increases in revenues and paying rapidly for the costs of installing and operating such systems. The literature on water-flooding is voluminous, although much of it reposes in corporate records that are not quite open to free scrutiny. However, it is not a problem to determine the correct set of conditions for any given water-flooding operation, once the specific characteristics of the oil field such as extent, spacing, producing depths, average API gravity, sulfur content and reservoir mechanics are sufficiently defined.

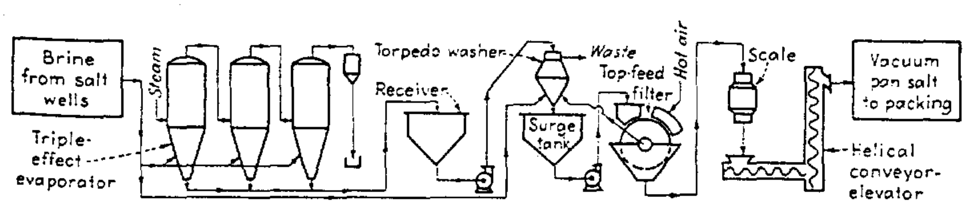
3. Salinity Gradient Solar Ponds

In this application, the brine is the most vital ingredient of the pond's operation. The University of Texas at El Paso (UTEP) has developed a model of a salinity-gradient solar pond that has been in operation for nearly ten years on a demonstration-plant scale. The principles, characteristics, operating details and physical description of the UTEP Solar Pond Facility are included in a brochure entitled: "El Paso Solar Pond" which is enclosed as Appendix A to this Part II. These factors are so well portrayed in the above-referenced brochure that repetition here is not deemed necessary.

Potential applications of solar pond technology include the production of industrial process heat, the generation of base-load electricity and the desalination of brackish water through a combined reverse-osmosis and multistage-flash evaporation process.

4. Salt Separation Applications

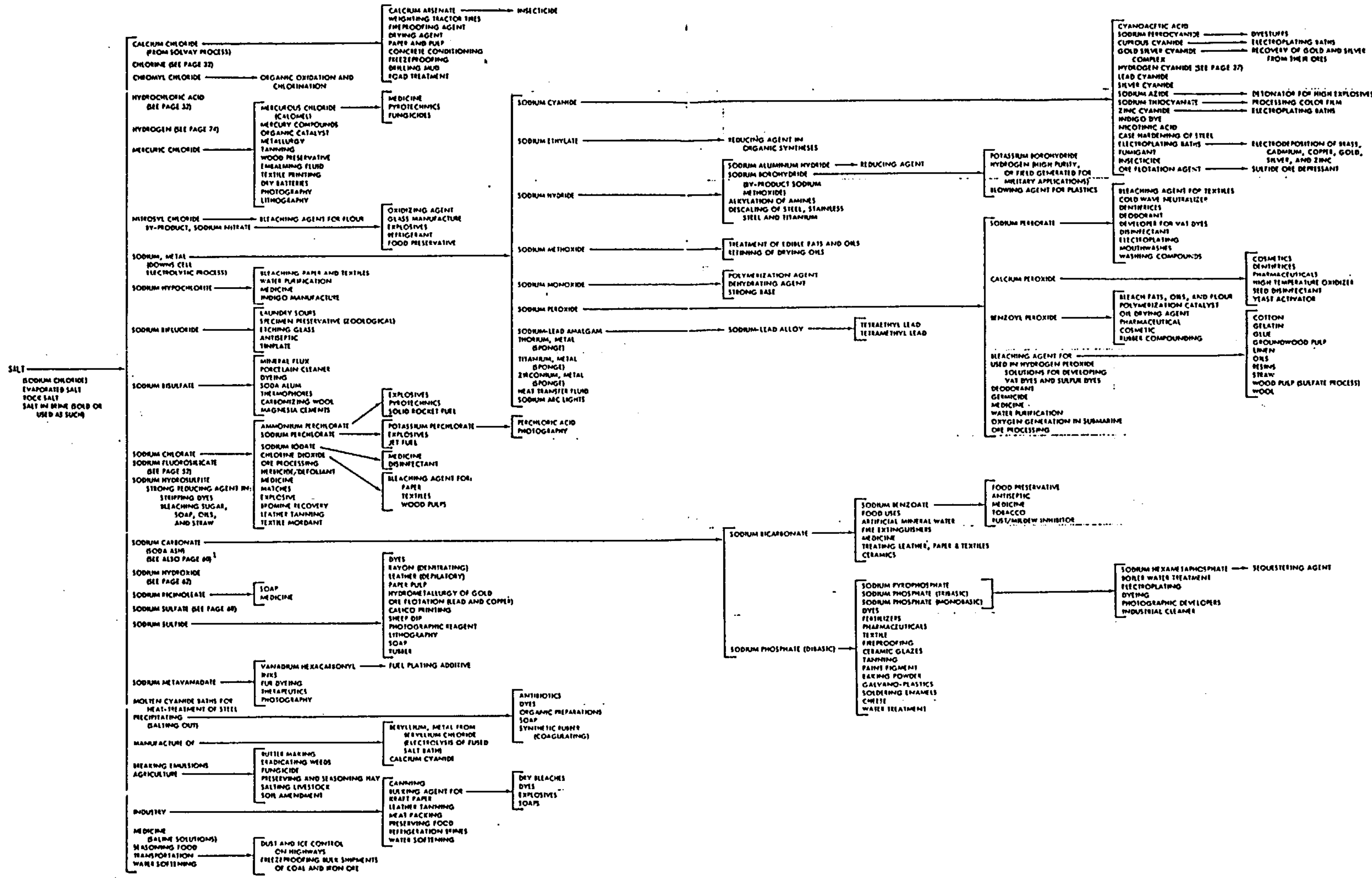
The common element in all of the above various applications is the requirement of separation of the salt from the brine by means of a distillation process, with two of the most prevalent process types being the standard multi-effect evaporator system and the falling-film evaporator system. The choice between those and other process types will depend on the economics of the particular application. A schematic drawing of the former type (using a triple-effect evaporator system) is illustrated below as Figure II.A.1.



Vacuum pan system for producing salt from brine.

Following the separation process via distillation, a myriad of applications is theoretically possible from the resulting salts. Such applications can appropriately be subdivided into three broad alternative categories, specifically those based on (a) direct uses of salt; (b) indirect uses of salt; and © other compounds combined into the salt or derived from the salt via chemical transformation. These are described below:

Direct Uses of Salt - In these applications the salt, predominantly Sodium Chloride or NaCl, is used as salt itself, with varying degrees of purification or refinement, depending upon the particular application. Examples are common table salt, cattle-feed salt, road salt and salt used in food canning and meat packing.



SODIUM CHLORIDE (COMMON SALT) DERIVATIVES

FIGURE II.A.2

Indirect Uses of Salt - In these applications, the salt is used as a feedstock for the manufacture of many products which are derived from Sodium Chloride. A comprehensive outline of these derivatives is presented as Figure II.A.2, following. Some well-known examples would be:

- The manufacture of Sodium Bichromate for use in leather processing
- The manufacture of Chlorine as a disinfectant of potable water
- The manufacture of dry-bleach bulking agents
- The bleaching of Kraft paper

Trace Minerals and Compounds combined with the Salt - If present, these trace minerals would include several halogenated and non-halogenated inorganic compounds, such as Iodine, used in medicine and photography, and Bromine, used in certain medicinals such as sedatives.

Section B. Preliminary Analysis of Feasibility for Each Potential Method

Having described each of the various potential methods on a general, non-site-specific basis in Section A, the focus of Section B is now directed to a preliminary analysis of feasibility of their application, taking into account those several factors outlined above under the heading Organization of Content. Before launching into the content of this preliminary analysis, it is essential to provide some general comments regarding its scope, limitation and organization. Additionally, for purposes of the site-specific preliminary analysis applicable to the area in and around Stonewall County, Texas, it is necessary to describe the physical makeup of the brine pollutants. The general comments are as follows:

Scope: The geographical scope of this preliminary analysis is twofold in that it is intended to cover the feasibility of application of both (1) a general, non-site specific basis, i.e., wherever brine disposal and management methods might be required, and (2) a site-specific basis, i.e., within the vicinity of Stonewall County, Texas.

Limitations: The results of the preliminary analysis are not intended to imply that an affirmative finding of feasibility for a particular method or application is tantamount to a firm recommendation regarding its implementation, a guaranteed economic success and/or a solution without any attendant problems. Rather, the results of this analysis are intended to be viewed only as a screening mechanism to direct interested parties either toward or away from the implementation of a particular method or application, dependent upon the conclusions of the preliminary analysis. Finally, the depth of the preliminary analysis of the various considerations of preliminary feasibility is, by necessity, very abbreviated due to budget limitations. The development of site specific unit cost economics has, in particular, suffered as a result of such limitations.

Organization: The information contained in this preliminary feasibility analysis is organized in such a manner as to provide a brief discussion or comments regarding feasibility from the perspective of each of the four considerations for each of the potential methods, with these four being commercial viability, i.e., product demand, economic factors, environmental factors and reliability factors, in that order. The manner of presentation of the results of the analysis is as follows:

In the case of the non-site specific application, because the number of variables influencing feasibility is practically unlimited, the assumption is made that at some unspecified location somewhere under certain circumstances each of the application methods would be feasible unless there is a definite reason to conclude otherwise. Therefore, a conclusion will be stated only if an application is judged to be infeasible. In the case of the feasibility of applications site specific to Stonewall County and vicinity, a conclusion of preliminary feasibility for any given method of application is evidenced by its inclusion in the "Applications Matrix" which constitutes Section C of this Part II Report.

Physical Makeup of Brine in Stonewall County and vicinity

- For the purpose of assigning estimates of value for certain of these characteristics, a site-specific location on Salt Croton Creek immediately above its confluence with the Salt Fork of the Brazos River has been selected.

- The physical and chemical characteristics of the brine in its natural setting are, for purposes of this general analysis, considered to be a constant for each potential method, and for the site- specific location described above, may be generalized as follows:

  - Total dissolved solids (TDS) concentration - 250,000 ppm$\pm$
  - Salt Load (TDS) - Approximately 900 tons/day
  - Base flow - 1 cfs
  - Average daily flow - 7 cfs
  - Very predominant concentration of sodium chloride (NaCL)
  - Minor concentrations of other salts, including the chlorides and sulfates of potassium, magnesium and calcium

The preliminary analysis of feasibility is presented as follows:

Aquaculture

Commercial Viability

The general availability of fish and crustaceans is being slowly but surely restricted by the increasing pollution of natural waters, fresh or salt, by the environmental and hazardous-material incursions in such water bodies and by the paucity of commercial fishermen. Our national imports of fish and crustaceans have risen far more rapidly than our fish-crustacean catches in territorial waters. Inland aquaculture represents the one really viable alternative under conditions of modern technology and aquaculture management and bids fair to become a sizeable player in this field within the next ten to twenty years. We understand clearly that this is still a relatively high-risk business from many standpoints. We also realize that an inland location such as Stonewall County is far less subject to many of the negatives that obtain near coastal locations, e.g. predators, tidal effects, disease transmission from other species, etc.

There are several advantages and disadvantages to aquaculture in the general region of near and far West Texas. A May, 1991, study of this industry sponsored by the Pecos County Water Improvement District No. 3 and the Texas Agriculture Extension Service had a very good set of factors developed to give a composite picture of pluses and minuses. We have reproduced the relevant section of that study and it is enclosed as Appendix B to this Part II Report.

The markets for aquaculture products have shown near-explosive growth since 1990. Demand has quadrupled during the period 1985 to 1995 and 92% of all fishery products consumed in the U.S.A. are now imported, leading to an import bill second only to oil imports. Both human food and pet-food consumption have risen geometrically in that decade and the "incubation period" for aquaculture investments is at an end, denoting that the industry stands on the threshold of truly exponential growth rates. Consider that the world's population is adding 90 million people each year, net of deaths, and that this total is steadily increasing its fish food consumption lead over all meat products taken together. Example: In 1988, the U.S.A. seafood consumption was 19.8 pounds per capita. The year 2,000 projections indicate a per-capita total of 24+ pounds. This means that the supply of such products will have to practically double from 1990 to 2,000, to a total of over 100 million tons.

By the year 2,000, only 8% of all such food will be domestically fished or cultivated. Contrast this with the fact that over 25% of all shrimp produced in the world comes from shrimp farms, not from oceans as conventionally caught.

We think that the raising of brine shrimp holds particular promise for possible application to the Stonewall County location because the use of agricultural pesticides and residual chemicals is not intensively practiced in this area, many large stretches of land close to the Salt Croton Creek junctions are totally fallow and cattle-ranching is particularly sparse.

Economic Factors - Obvious prerequisites for favorable production costs include the following:

- An abundant brine stream, preferably predominantly sodium chloride, and free of other pollutants
- A climate conducive to a long growing season
- An abundance of inexpensive land
- Impervious soil types to minimize impoundment costs

Similarly, prerequisites for overall market economics include access to a substantial population of consumers via an economical transportation network.

In the case of Stonewall County, the economic factors associated with production costs trend very favorably, while those associated with market access via an economic transportation network are less favorable because of the County's relative remoteness.

Environmental Factors - As stated previously, the optimum salt concentrations for successful marine aquaculture are in the range of 25,000 to 40,000 pm TDS, whereas the concentration of the brine from Salt Croton Creek is estimated to be approximately 250,000 ppm. Accordingly, prior to using the brine as a medium for aquaculture, it will be necessary to adjust the salinity down to, say, 35,000 ppm via desalination and dilution.

Reliability Factors - As in most other technologies, operational expertise and good quality control are essential ingredients of a reliable option. The technology is reasonably well developed, and obvious prerequisites to reliability in addition to the above include cleanliness, proper nutritional practices and harvesting techniques, as well as efficient processing, storing and shipping procedures.

Enhanced Oil Recovery via Brine Injection

Commercial Viability

The multitude of producing wells in and around Stonewall and surrounding counties represent pumped production, and the yield from most of them averages little more than 10 barrels of oil per day. Pumping does not necessarily indicate that a given producing reservoir is being depleted down to innocuous levels of output. Often, it is a sign that the driving force within the reservoir, whether water-drive or gas-drive, is lessened to the point where self-motivated production cannot be sustained any longer. In many such instances, it is proven that waterflood techniques can raise production to significantly higher levels, generating additional cash flow for owners, operators and interest-holders alike.

It is necessary to arrive at an agreement with the owners/ producers in this area of Texas as to one or more demonstrations of water-flood recovery, using the waters of the Salt Croton Creek to determine quantitatively the potentials of such recovery. Other areas that have undergone secondary initial treatment have routinely shown initial improvement of from two to five times the volume of recoverable oil, as a result.

Producing formations of the type encountered in Stonewall and adjacent counties are almost always the first and only producing formations to be exploited. History is replete with examples of further downhole investigations that have shown additional producing formations below the current producing one, to the benefit of all involved.

Economic Factors

Economic factors which contribute to the successful application of water flooding as a means of enhancing oil recovery include the following:

1) Ready availability of brine, reasonably free from sulfates, carbonates and bicarbonates (i.e. nearly all salt is NaCl).

2) Provisions for continuous and constant pumping rates down-hole for pressure build up and maintenance.

Environmental Factors

An important factor to be considered is the physical makeup of the brine, with obvious importance placed on quality parameters which are not conducive to the clogging up of the receiving formation. A second very important factor involves taking the necessary precautions to avoid the pollution of overlying aquifers from which domestic water supplies are derived. In most instances compliance with the regulations promulgated by the Texas Railroad Commission and the Texas Natural Resource Conservation Commission will assure adequate environmental protection. Favorable environmental factors for the wells in the Stonewall County area include the following:

- The brine salts are predominately sodium chloride and do not contain substantial quantities of constituents which tend to clog the receiving formations.

- The area is not underlain by an aquifer from which domestic water supplies are derived.

Reliability Factors

The technology of water flooding is well established and reliable, but a thorough knowledge of the geology and consistent operating expertise are required.

Salinity Gradient Solar Ponds

Commercial Viability

A discussion as to the commercial viability of a salinity gradient solar pond immediately evolves to a discussion of the commercial viability of its potential applications, namely, the production of process heat, the generation of base load electricity and the desalination of brackish water. A brief review of an abstract from a UTEP pre-doctoral thesis entitle: "Economic Feasibility of Utilizing Solar Pond Technology to Produce Industrial Process Heat, Base Load Electricity and Desalted Brackish Water (Esquivel, 1992)" has provided pertinent information regarding the economic feasibility of these three applications and is summarized as follows:

For industrial process heat at medium temperatures (50 - 90° C), results indicate economic feasibility is a function of size, liner costs, and salt costs. Solar ponds are very competitive with the current price for purchasing natural gas or coal and a boiler to produce the heat. Solar pond derived electricity is not competitive with current projected price levels for producing base load electricity using fossil fuel technologies. Three alternatives for desalting water were evaluated to determine the most cost effective method. The first two alternatives included purchasing power and disposing of the brine either in an evaporation pond or a deep injection well. The third alternative included the construction of solar ponds using the waste brine and eventually producing the thermal and electric power requirements to operate a combined reverse osmosis and multistage flash system. The results indicate that the combined process with the solar pond is the most attractive alternative. Two of the three applications analyzed, process heat and desalting, were determined to be economically feasible. If external environmental costs of electric power production are considered, solar pond electric production is also a viable alternative. Finally, all results are based on performance data for El Paso, Texas, and may differ in other regions. A complete copy of this publication is available from Dr. Andrew H.P. Swift, Department of Mechanical & Industrial Engineering, UTEP, El Paso, Texas 79968-0521.

The desalination application is particularly pertinent to Stonewall County. Based on discussions with officials in Stonewall County, both the city of Aspermont and other rural communities in the county are in dire need of additional potable water supplies. The only one currently available is both expensive and of only marginally acceptable quality. More specifically, the City of Aspermont's supply is currently piped in from the town of Haskell, Texas, some 30 miles away, at a wholesale cost of $2.02/1,000 gallons, and the retail rate of this water as distributed to residences reportedly approximates $3.35/1,000 gallons. Accordingly one possibility of commercial viability associated with the advent of a suitably sized salinity-gradient solar pond would be the development of a desalination plant to provide the badly needed additional supply of potable water. Furthermore, the advent of such a desalination plant could conceivably spawn the opportunity for the production of ultra-pure water for various industries ranging from food processing to various electronic components manufactured.

With respect to the possibilities of commercial viability associated with the production of industrial process heat in the range of 50° to 60° C, as mentioned above, several of the most promising potentials include crop drying, distillation, industrial drying and hot water production for process use.

With regard to the production of base load electricity our review of the available research material leads us to conclude that it may not yet be commercially viable under normal circumstances. However, if the external environmental costs of electrical power production are considered, solar pond based power production appears to be a more viable alternative at some future point.

Appendix III contains a more recent anlaysis of these potentials.

Economic Factors

The above mentioned publication contains a very detailed treatment of economic factors, a review of which indicates that several of the most important economic factors contributing to a favorable outcome include the following:

- An abundant supply of brine
- An abundant supply of sunshine
- An abundant supply of inexpensive land
- Minimal costs of liner installation

The Stonewall County area appears to be ideally suited with regard to all these factors, especially since the abundance of brine, coupled with the fact that there is no danger of leakage into an underground water supply of potable water, combine to permit minimal liner costs. Moreover, the existence of a salinity gradient solar pond in this area would serve as an enabling mechanism for a desalination plant.

Environmental Factors

Again, these are discussed in detail in the above referenced publication. One factor of particular importance is the cleanliness of this energy form, there being no emissions to the atmosphere such as those from fossil-fueled power plants.

Reliability Factors

This technology is still in a somewhat experimental stage, but appears to be rapidly approaching proven status.

Salt Separation Applications

Commercial Viability

Direct Uses of Salt, which include common table salt, road salt, cattle feed salt and salt used for food canning, meat packing and leather processing are each discussed as to commercial viability, both generally and as directed to the Stonewall County area, all as shown below.

Table Salt

The major salt companies that dominate these markets have long-established relationships and are thus capable of waging indefinite price wars to maintain their market share and scare off new entrants. The numbers, in a word, are just not there and will not be in for many years to come for a free-standing plant. An alliance with a major salt company to furnish a source of brine is, however, not out of the question.

Road Salt

The use of salt for the deicing of roads, bridges and highways is old in the art. Salt lowers the freezing point of water and thus maintains its liquid state at temperatures below 32^0 F. Thousands of tons of salt have been used for this purpose in large portions of the U.S. each winter. Salt/water mixtures are also highly corrosive and this has led to the development of certain substitutes, principally the acetates of calcium and sodium in appropriate combinations. These newer compounds also lower the freezing point of water but are not as corrosive. Utilization of these acetate mixtures has been successfully tested and it is felt by those in the trade that a steady decline in the volumes of salt for road and highway deicing will cut deeply into salt markets in cold regions.

The Texas Department of Transportation states that their fiscal 1995 usage of road salt approximates 9,000 tons, down from some 12,000 tons in 1990, a small but steady decline.

Salt can only be transported economically over relatively short distances, thus further limiting its economic utility. In summary, the corrosivity of salt, its replacement by acetate mixtures and its high transportation costs beyond short distances all combine to foretell unacceptable economics for anti-freezing applications. In our estimation, the use of road salts for highway deicing is an example of an application that is becoming infeasible from the perspective of commercial viability and an overall basis because of replacement by more acceptable technology.

Cattle Feed and Salt Used for Meat Packing

The study area is not a significant center for cattle feedlots, as is the case in Far West Texas. In addition, the very sparseness of population makes this region a small market indeed for low-cost, low-volume commodities such as cattle-feed salt or salt for meat packing. *Since the economies of scale needed to generate a decent return on invested capital for these types of products are thus* *almost totally absent, we feel that these categories should be eliminated from further consideration.*

Salt for Canning of Foods

This application would be commercially viable only if a food canning facility were to locate in the Stonewall County area for other reasons.

Leather Processing

In far West Texas, the proximity of ample supplies of cattle, slaughterhouses and hides enable leather processing to be conducted economically enough to constitute viability.

The numerous steps involved in taking an animal hide from its initial salt-curing to its final finishing begin with the salting of the hides to cure them prior to further processing. The hides are treated with salt and are then packed in concentrated brine before shipment to a tannery. The tannery then sends the hides to a finishing facility, from which the leather, now cured and tanned, is sent to manufacture of the final products prior to sales at retail.

It is estimated that each average cattle hide requires approximately 20 pounds of salt for proper curing. The 1994 production of cattle hides in Texas amounted to some 5.5 million, the curing of all of which required over 110 million pounds of salt, or 55,000 tons. Adding in the equine hides and those of game and bird species (e.g. ostrich, emu, etc.) brought the 1994 total to 6.3 million hides, the corresponding total salt usage then amounting to 63,000 tons.

Additional salt is used in the preparation of chrome-leather tanning formulae, the average being 44 pounds of salt for each 172 pounds of chrome tan leather. That operation would then add another 4,500 tons of salt per year to the above totals.

The leather industry has long been considered a desirable activity in Texas, but it appeared to have been derailed by a flood of imports. Closer examination of the actual flows of materials revealed that the hides from which these final products were being made came, in at least 40 % of the cases, from the U.S.A. Today, with inflation down as low as in the late thirties, productivity up to be the best in the world and financing costs also low and getting lower, there is a solid case to be made for the development of a full-spectrum leather industry in Texas. The most favored region for this activity appears to be in West Texas.

It should be clearly emphasized that a tannery or other primary leather processing industry in the Stonewall County area is not a currently viable activity, as the overwhelming concentration of availability of cattle hides continues to come from the Texas Panhandle. However, the availability of other hides, (sheep, lambs, hogs, deer, ostrich, emu, etc.) represent useful niche market possibilities for leather processors that do not have the supplies to accommodate a large, standalone leather processing facility.

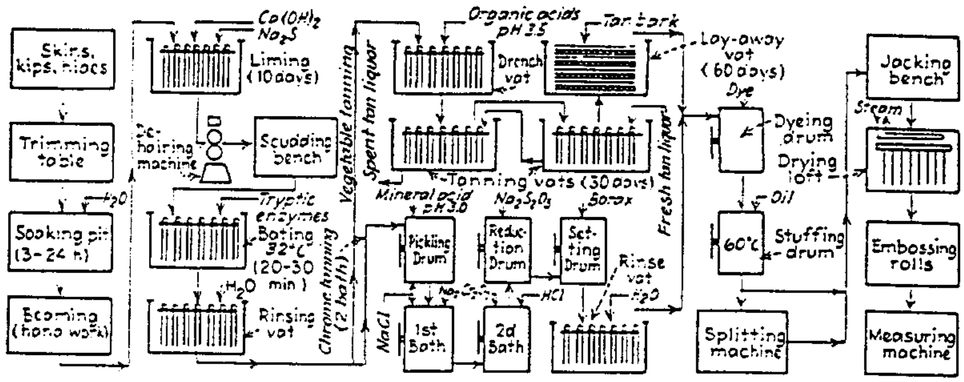
Leather-products activities hold the potential for initiation in the study area, along with a "regional" center for the initial curing of non-cattle hides provided by the sports hunters and the "exotics" raisers, all of which would require shipment of these hides under salt to appropriate processing facilities.

In order to correctly evaluate the potentials for a Leather Processing Factory, it is necessary to determine the answers to some key questions such as follows:

1. Can a sufficiency of hides be made available to the plant at affordable and reliable prices?
2. Is there an adequate and qualified labor supply available at or near the site chosen?
3. Is there an adequate water supply at hand in terms of both quality and quantity?
4. Can wastewater treatment be economically and environmentally exercised?
5. Are markets available affordably within the economic periphery of the plant?
6. Will financing be available on appropriate terms?
7. What competition be faced by the intended plant and under what conditions?

Without attempting to answer any of these questions here, because each question has site-specific factors attached, one can generally state that a minimum-economic-size Leather Processing Plant *that processes cattle hides only* must have assurance of a steady supply of at least 2,000 hides per operating day (total in one year would be 6 days a week for 48 weeks or 288 operating days). A tannery that processes other types of leather (e.g. deer, sheep, lambs, hogs, etc.) can be as small as requiring just 20 to 40 hides a week (cf. The Texas Leather Institute, Lubbock). Any such plant would also require a reliable source of both good-quality water and an abundance of salt of adequate purity, along with the needed quantities of hydrochloric acid, sodium bichromate and lactic acid as purchased chemicals, to name the principal chemical inputs. This points up one of the advantages of having a basic salt component present per se: units to manufacture hydrochloric acid and sodium bichromate can be installed nearby to provide these chemicals to the leather processing plant, as well as to other markets requiring them, once the economics can warrant same.

Fig. II.B.1 immediately below diagrams the processes needed to produce chrome leather, the most commonly used starting point for leather products.



In order to produce 125 kg vegetable tan or 80 kg chrome tan leather, the following materials and utilities are required:

Hides	100 kg	Oil: Sole	2 kg
Lime	10 kg	Belting	8 kg
Na_2S	2 kg	Harness	20 kg
Water	1665 L	Electricity	8 MJ
Dye	11 kg	Direct labor	4.4 work-h

In addition, for vegetable tan, the following material is added:

Lactic acid	1.2 kg	Tan bark	20 kg	Water	1457 L

For chrome tan, the following material is added:

HCl (30%)	25 kg	$Na_2S_2O_3$	15 kg
NaCl	20 kg	Borax	2 kg
$Na_2Cr_2O_7 \cdot 2H_2O$	5 kg	Water	3330 L

Fig. II.B.1: Requirements for Leather Processing, with Chrome Tanning (From: "Shreve's Chemical Processing Industries")

Once again, we are constrained to remark that the evaluation of economic, environmental and reliability factors in leather processing are site-specific and not included under the scope of work of this project. A general remark about the environmental aspect may, however, be usefully noted here. *The wastewater from leather processing operations contains organic chemicals of a toxic and hazardous nature, hence care has to be exercised in design and operational treatment of all by products. Sodium bichromate and hydrochloric acid are both chemicals that demand great respect in their handling and disposal and the costs of installing adequate safety and handling measures must be taken into account in proceeding towards the final economic feasibility. Current regulations are such that these fixed costs must be incorporated into the overall determination of viability and profitability and, often, they can be the factors that would render such a project too expensive for the particular level of investment required.*

One other comment may be appropriate here: a Leather Processing Plant possesses a good balance between capital intensity and labor intensity and hence can be a useful core industry in a given area wherein the other important requirements can also be fulfilled. Many another derivative industry can be located close to a leather plant and the multiplier effect as regards indirectly induced jobs has an encouraging ratio (average) of about 6 to 1. A substantial number of consumer, commercial and industrial products of leather could be manufactured at the same general location, with benefits that are far-reaching in scope. Important product categories are:

Boot and Shoe Cut Stock and Findings (SIC 3131)
Footwear, except Rubber (SIC 3142 through 3149)
Leather Gloves and Mittens (SIC 3151)
Luggage (SIC 3161)
Handbags & Other Personal Leather Goods (SIC 3171 and 3172)
Leather Goods Not Elsewhere Classified (SIC 3199)

While it is true that many of the above product types require low-cost labor to be truly competitive on a world scale, it is also true that the productivity of our labor is about the highest in the world today and, coupled with intelligently chosen automation, can be really competitive in our own domestic markets. It is not commonly realized that a lot of the low-cost labor that is touted in many countries actually obtains its raw materials from the U.S.A. to begin with and transportation of these materials is not exactly the cheapest in the world. Another factor that significantly narrows the gap between our total labor costs and those of the developing countries is the disparity between our labor overheads and theirs: the U.S. averages (1995) is ca. 40% of direct salaries. Many other developing countries average 150 - 200% of direct salaries. This category is ripe for a thorough-going re-evaluation of its parameters for economic justification.

Indirect Uses of Salt

The indirect uses of salt are those in which salt is used as a chemical feedstock for the manufacture of commercially useful products across a wide spectrum. It is true that many major compounds of NaCl are manufactured in plants of large capacity and high capital costs. Hence, products such as caustic soda (NaOH), and other derivatives shown schematically in Figure II. A. 2., require sizeable investments and must be located at or near high-use centers.

One important exception to the above is the production of Sodium Hypochlorite (Na0Cl), a widely used bleaching and disinfecting compound that is made from the chemical reaction between chlorine and sodium hydroxide or caustic soda. Technology advances have made possible the development of small-capacity NaOCl generators that are self-contained and compact, with low capital costs and reliable service.

A detailed description of one such generator is included as Appendix C to this Part II Report. This example is felt to be highly suitable for implementation in the general Stonewall County area and is deemed worthy of serious further pursuit.

Commercial Factors

The uses of NaOCl are many, ranging from disinfecting municipal water supplies to bleaching kraft paper, laundry uses for white-goods cleaning, swimming pool cleaning and wastewater chlorination. It is a well-established product and its availability in many rural regions, hitherto limited or expensive due to transportation costs, may be enhanced by the presence of a generator to product NaOCl in an area such as Stonewall County.

Environmental Factors

The process for manufacturing NaOCl as shown in the brochure in Appendix C is widely accepted as safe, non-polluting and non-hazardous because of its design, mode of operation and length of trouble-free service. Obviously, proper training of operators and appropriate safety measures have to be incorporated into plant operations and, given these normal precautions, such NaOCl generators do not occasion environmental problems.

Reliability Factors

The length of trouble-free services routinely recorded by over 20 years of operation in numerous installations is testimony to the reliability of this system.

NOTE: Trace Inorganic Compounds

An effort to detect and analyze trace amounts of other compounds, e.g., those of Strontium, Iodine and Bromine was made by the Texas Water Development Board. Results are shown below:

Strontium:	45.8 ppm
Iodine:	12.0 ppm
Bromine:	341.2 ppm

The Iodine appears to be truly a trace element and does not constitute an element for further study. Bromine and Strontium are more significant and are discussed as follows:

Bromine

In terms of extractive yields, one may assume that an average of 80% of the contained Bromine can be economically recovered. Thus, if the flow in the Salt Croton Creek, estimated to be at an average of one (1) cubic foot per second, carries salt loads of a recoverable 750 tons per day, then the Bromine concentrations of 341 ppm equally well lead to recoverable loads of 2,260 pounds of Bromine per day. At present, the market value of pure Bromine is pegged at some $0.50 per pound. Assuming that the purification of Bromine from the stream could yield a final saleable quantity of Bromine @ 1,800 pounds per day, being very conservative, then one would face a potential income stream of ca. $ 900.00 per day from the sales of the Bromine alone.

The extraction of Bromine from brines or heavily salted waters is not a very complicated operation at all. As practiced at Freeport, Bromine is almost quantitatively freed from its seawater by blowing warm Chlorine through the incoming salt water, whereby both Chlorine and Bromine are recovered in vapor form off the top of the separator vessel, then led into a chilled receptacle where the Chlorine is separated from the Bromine because the latter will liquefy, while the Chlorine is still a vapor and hence easily separated. The Chlorine is then dried to rid it of excess moisture and is recycled to extract more Bromine, with the addition of enough fresh Chlorine to make up for any process losses.

The Bromine is then refined to final purity via fractional distillation.

Strontium

If the Strontium analyzed in the sample exists as Strontium Sulfate, then extraction of the Strontium requires the use of chemical reactions to effect separation, the details of which are outside the scope of this effort. It may be mentioned in passing that although the quantities of Strontium consumed nationally in the U.S.A. are quite small, they are nonetheless very important in certain applications. For example, the use of Strontium Carbonate as a widely-used X-ray screening agent in television picture-tube face-plate glass still does not have any commercial alternative, with possibly one or two very minor exceptions. Other uses of Strontium compounds include applications as truck signal flares, railroad "fusees", tracer bullets, military signal flares and ceramic permanent magnets. As can be seen, most of these uses are extremely specific and many have obvious defense applications. For the nonce, however, one can only speculate on the commercial viability of this relatively small quantity of Strontium. In truth, no deposits of the Strontium ore, Celestite, in the U.S.A. are worked commercially, it being quite a bit cheaper to import these from Mexico (the world's highest-quality deposits) and the United Kingdom. In non-technical terms, Celestite is Strontium Sulfate.

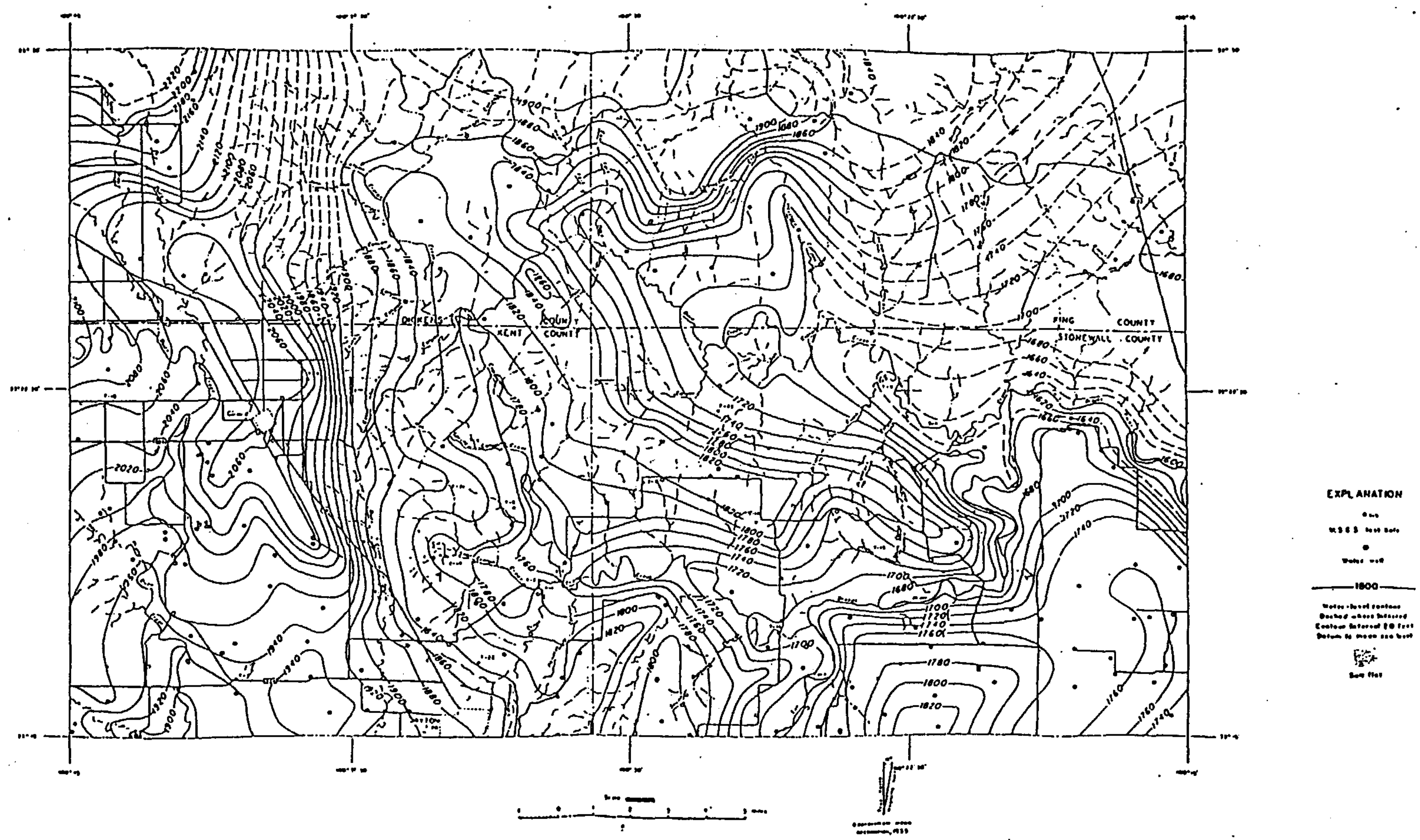


Figure 2.-Map of the Croton Creek-Salt Croton Creek area showing the locations of well and contours on the water table

TABLE 2

SUMMARY OF SALT LOADS IN BRAZOS RIVER BASIN

Stream	Stream flow (cfs): Period of record: Yrs	Stream flow (cfs): Period of record: Mean dischg	Stream flow (cfs): Mean dischg (1957-1966)	Salt loads (tons per day): Chlorides	Salt loads (tons per day): Sulfates	Salt loads (tons per day): Total Dissolved Solids
Salt Fork:						
McDonald Creek	1	1.6	a5	20	3	40
Verbena Canyon	-	-	a0.3	< 2	< 0.5	< 5
Red Mud Creek	-	-	a4	<13	< 5	<30
Salt Creek	-	-	a2	<30	< 5	<55
Duck Creek	-	-	a12.7	< 1	< 5	<11
Salt Fork near Peacock	4	64.2	a78	215	85	520
Croton Creek	7	18.7	a16	75	80	240
Salt Croton Creek	10	7.2	7.2	530	35	920
Salt Fork near Aspermont	27	140	119	830	250	1,760
Stinking Creek	1	11.4	a5	5	6	20
Double Mountain Fork:						
Red Creek	-	-	a3	< 5	< 8	<20
White Canyon	-	-	a2	< 4	< 6	<16
Salt Creek	-	-	a6	<10	<15	<40
Double Mountain Fork near Aspermont	37	177	189	100	235	565
North Croton Creek	1	117	a25	50	70	190
Brazos River at Seymour	42	421	379	940	600	2,520
Clear Fork:						
Hubbard Creek near Breckenridge	11	116	125	29	5	86
Clear Fork at Eliasville	31	399	b450	b165	b60	b480
Brazos River:						
at Possum Kingdom Lake	42	1,112	1,200	1,250	760	3,440
Near Whitney	28	1,684	1,975	1,230	766	3,760
At Richmond	46	7,346	8,464	1,620	1,240	7,550

a Estimated

b Exclusive of area above Hubbard Creek Lake

SOURCE: U. S. Geological Survey report <u>Sources of Saline Water in the Upper Brazos River Basin, Texas</u>, March 1968.

Section C: Development of an Applications Matrix

The above examination of the several possible applications has shown that some of them are indeed worthy of further analysis and more detailed study, under additional authority for same. Accordingly, the Applications Matrix presented below includes only such selections as fulfill the criteria of applicability to Stonewall County and vicinity, as summarized below:

1. Aquaculture or Fish Farming, selected because of its flexibility as to size and type; its commercial viability; the ready availability of sufficient amounts of salt water and its general suitability to the area.

2. Enhanced Oil Recovery, selected because of the presence of nearby oil-fields, nearby salt water and the economic benefits of increased oil production via water flooding to both private and public interests.

3. Salinity Gradient Solar Ponds, selected because of the availability of basic inputs such as land, salt water and more particularly because of potentials for a badly needed additional source of fresh water via desalination.

4. Salt Separation Applications, selected because of the variety of both direct and indirect uses of salt that can be implemented under modest conditions, either singly or in appropriate alliances with large companies. Direct applications most suited seem to be in uses such as Table Salt, wherein the separated salt may be used by a major salt company in a suitable alliance with a Stonewall County entity, private if possible.

   Indirect applications of most usefulness center around the small scale manufacture of NaOCl, as described above. Of lesser immediacy but significant future potential could be the sodium compounds used in leather processing, as described above - again, because of the ability to produce and use same on a small scale.

It is perhaps useful to repeat that each of the above applications requires significant further study before any commercial, economic, environmental and reliability factors can be developed in concrete enough fashion to constitute a tenable data base prior to any implementation. In a word, each needs additional research to corroborate initial findings.

PART III

CONCLUSIONS AND RECOMMENDATIONS

The work done under the current TWDB Contract has led to several conclusions and recommendations, as presented in this Part III of the total effort. It should be borne in mind that the present effort has been restricted to an analysis of several approaches to the removal and possible commercialization of the salt present in the Salt Croton Creek of the Brazos River. In order to determine which of the many alternatives examined could have the potential of not only cleaner water emanating from the Salt Croton Creek but also the economic diversification that could result from the utilization of one or more of the potentials from the recovered salt and other chemical compounds, it becomes necessary to enumerate some conclusions, followed by some recommendations as to further pursuit of these potentials. Carried to their logical conclusion, these recommendations could constitute a viable methodology for the development of a diversified complex, incorporating both cleaner water for various uses, as well as commercial applications for the recovered salt and other chemicals.

If these recommendations can be fully implemented, the economic impact on the Stonewall County and immediately surrounding areas would be significant and would impart to the area added opportunities for job creation and diversified economic activity.

CONCLUSIONS

The major conclusions from this research effort may be listed as follows:

A. Current technology is amply available to effect the almost complete removal of salt from the Salt Croton Creek of the Upper Brazos River, leaving that tributary to add clean water, with no more than approximately 500 ppm of total dissolved solids, to the rest of the Brazos River flow totals, or to furnish high quality potable water to augment municipal water quality.

B. There appears to be a sufficiency of recoverable salt to induce commercial interest in its direct uses.

C. The presence of Bromine in the water, at levels that are 5.25 times the concentration of Bromine in Texas Gulf Coast sea water, constitutes a viable resource for extraction, as Bromine is a chemical of many commercial uses, and happens to be in relatively short supply at the moment.

D. The detected levels of Strontium in the Salt Croton Creek water, about 46 ppm, may have possible commercial viability if extraction methods are shown to be economical. A developing use of the isotope, Strontium-89, is in the treatment of certain types of cancer and this application possesses enough intrinsic merit to warrant a further look at the economics of extraction and purification.

E. In addition to the direct applications of the salt and chemicals enumerated above, there exist several indirect applications, as summarized in the Applications Matrix in Part II above, that definitely merit a closer look as to both the economics of production and the marketing aspects of the final products.

RECOMMENDATIONS

Based on the above broadly applicable conclusions from the current effort, the following recommendations are hereby advanced:

A. Advance the current effort to the next logical phase of investigation, i.e. develop a plan for identifying the need for any additional data regarding concentrated brine, methods for financing the eventual complex(as shown in the Applications Matrix in Part II above), in part through the sale of extracted or co-produced chemicals, and an appraisal plan for bringing private industry into the project for eventual operation.

Purpose: The purpose of this recommended study is to cooperate with the State of Texas and several of its political subdivisions, specifically, the Texas Water Development Board (TWDB), the Brazos River Authority (BRA) and Stonewall County in appraising a multifaceted project which will, upon implementation, accomplish the following:

1. Significantly reduce the chloride levels from a large quantity of natural impaired water originating in the upper reaches of the Brazos River Basin, thereby significantly decreasing the treatment cost of municipal and industrial uses of Brazos River water in downstream reaches of the Basin.

2. Facilitate the development of a site-specific brine utilization and management complex which will demonstrate economically viable applications for a heretofore perceived waste product associated with impaired surface water and will provide economic development benefits for Stonewall County.

3. Significantly contribute to the level of experience associated with the management of brine resulting from desalination processes and make such experience available for technology transfer to other areas.

Need: The need for this study is summarized as follows:

1. To quantify the various parameters of cost and economics of the various components of the chloride reduction and brine utilization and management complex on a *site-specific* basis. Generate, to the extent possible, a highly concise market feasibility for the Strontium in the Salt Croton Creek water, to enable a judgement as to the economic viability of its extraction and commercialization.

2. To accomplish the preliminary design of an integrated complex. This complex would be designed to not only reduce the chloride levels in the Upper Reach of the Brazos River, but also to recover, purify and market the salt and the Bromine, as well as further process the salt into some logically derivative products ranging from water purification chemicals to leather processing chemicals. This complex would include a salinity-gradient solar pond and appurtenances to provide all or a portion of the energy required for the complex, as summarized in the brief entitled: "Analysis of Potential Solar Pond Applications for Brine Management of the Croton Creek" UTEP College of Engineering - included as Appendix III.

B. Appraise the characteristics of selected private companies for their compatibility for operational participation in the implementation aspects of the above complex.

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    Volume 1 - Main Report
    Volume 2 - Appendices I and II
    Volume 3 - Appendices III and VI
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6. Report Entitled *Evaluation and Partial Control of Natural Salt Springs and Seeps in the Dove Creek Area, Upper Brazos River Basin, Part I - Recovery System Design* prepared for U.S. Army Corps of Engineers and Texas Water Development Board Brazos Chloride Study by W.P. James, P.A. Mascianglioli and K.B. Chakka through Texas Engineering Experiment Station, Texas A & M University (February 1994).

7. Report Entitled *Evaluation and Partial Control of Natural Salt Springs and Seeps in the Dove Creek Area, Upper Brazos River Basin, part ii - Preliminary Study of Brine Disposal by Deep Well Injection* prepared for U.S. Army Corps of Engineers and Texas Water Development Board Brazos Chloride Study by W.P. James and M.E. Spongberg, Department of Civil Engineering through the Texas Engineering Experiment Station, Texas A & M University (February 1994).

* Included in its entirety in Appendix I.

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APPENDIX I
ANALYSIS OF NATURAL SALT POLLUTION CONTROL PROJECT ECONOMIC BENEFITS

UPPER BRAZOS RIVER BASIN
(REPRODUCED FROM ORIGINAL REPORT)

NATURAL SALT POLLUTION CONTROL PROJECT

BRAZOS RIVER AUTHORITY

ANALYSIS OF ECONOMIC BENEFITS

3-HOLE PUNCH PLEASE

prepared by

. Clay Roming, P.E.
Consulting Engineer

June, 1984

W. CLAY ROMING, P.E.
CONSULTING ENGINEER

ITE 1 BOX 588
,DY, TEXAS 76524
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June 7, 1984

Mr. Carson Hoge, P.E.
General Manager
Brazos River Authority
P. O. Box 7555
Waco, TX 76710-7555

Re: Natural Salt Pollution Control Project

Dear Mr. Hoge:

The attached report summarizes certain data prepared by the U. S. Army Corps of Engineers as shown in a Preliminary Draft Report dated April, 1983 and studies which I have conducted.

This report is intended as a working document to allow Brazos River water users an opportunity to determine economic benefits which would accrue to individual users if the project as proposed were implemented.

I am available to assist in the review of this report by Brazos River water users.

Sincerely yours,

STATE OF TEXAS
WILLIAM C. ROMING
18617
REGISTERED PROFESSIONAL ENGINEER

W. Clay Roming, P.E.

WCR/mr

Att.

THE BRAZOS RIVER

The Brazos River watershed extends from eastern New Mexico southeasterly across the State of Texas to the Gulf of Mexico. Figure 1 shows the Brazos River Basin and identifies certain features. The basin has an overall length of approximately 640 miles, a maximum width of 120 miles, and a total area of 44,620 square miles, of which about 42,000 are in Texas. Approximately 9,240 square miles of the area, located in the northwest portion of the watershed above the Caprock Escarpment in New Mexico and in the vicinity of Lubbock, Post and Crosbyton in Texas, rarely contribute to the streamflow, so practically all the runoff from the watershed originates within the State of Texas.

The Brazos River itself, the main stream within the watershed, is formed by the confluence of the Salt Fork and the Double Mountain Fork near the eastern boundary of Stonewall County about 900 river miles from the mouth. The two forks, in turn, emerge from the Caprock about 150 miles above the confluence, thus creating a continuous drainage way for the watershed some 1,050 river miles long. The elevation of the streambed at the confluence of the two forks is 1,500 feet above mean sea level. From this point the Brazos descends to the Gulf at a rate diminishing from 3.5 feet per mile to 0.5 feet per mile as it meanders southeastward.

The Brazos has seven principal tributaries including the Salt and Double Mountain Forks which join to form the main stem. The others are the Clear Fork, the Bosque and Little rivers, Yegua Creek, and the Navasota River. In addition there are fifteen sub-tributaries within the watershed, the most important of which is the Leon River, a tributary of the Little.

The climate of the Brazos watershed varies considerably from temperate to sub-tropical. The average annual temperature in the upper reaches is fifty-nine degrees Farenheit increasing to seventy degrees Farenheit in the coastal region. The average annual precipitation is 29.5 inches, ranging from sixteen inches in the northwest to forty-seven inches in the southeast.

The Brazos is Texas' own river in more than a geological sense for a strong argument can be made that the history of Texas began in the lower reaches of the Brazos basin. On August 17, 1821, Stephen F. Austin obtained permission from the Spanish Governor of Texas and Coahuila to explore the country on the Brazos River and to sound the entrances and harbors lying adjacent to the stream. With nine of his men he conducted sufficient explorations to convince himself of the great fertility of the land along the river and returning to Louisiana he continued his plans for colonization. In December, 1821, Austin arrived with his settlers on the Brazos at the point where La Bahia Road crosses the river. On a frosty New Year's Eve he camped on the river and a few days later his associate, Andy Robinson, established the first permanent settlement where the Village of Old Washington now stands.

WATER QUALITY

The quality of Brazos River main stem water is seriously degraded by emissions from major natural salt sources in the upper basin downstream from the Caprock Escarpment. The mineral pollutants consist principally of sodium chloride (common table salt) with moderate amounts of calcium sulfate (gypsum) and other dissolved solids. This natural pollution causes the quality of Brazos River water to be below common standards for most of the 923 mile reach from Stonewall County to the Gulf of Mexico. Only after flows from tributary streams have sufficiently diluted the main stem flow is it generally usable and, even then, at times of low flow throughout the basin the quality is less than desirable.

As previously mentioned, the water quality of the Brazos varies considerably from its headwaters to its mouth. A chemical analysis of the water would show many different minerals dissolved in the water. For purposes of evaluating project effects on water quality, three primary constituents have been considered. These are chlorides (Cl), sulfates (SO_4) and total dissolved solids (TDS).

Chloride compounds occur in almost all natural waters and are found in widely varying concentrations. Sources of chlorides can be of natural origin, dissolved from minerals, contamination from seawater, or from wastes. Once chlorides enter natural waters, these concentrations are affected only by dilution and evaporation because the chloride ion is not adsorbed by soil formations and is not altered or changed by biological processes.

Sulfates are found in natural waters especially in the western United States where sulfate compounds are leached from gypsum and other common materials. Unlike chlorides, sulfates are affected in nature and are part of a life cycle. Several sulfate compounds are highly water soluble.

Total dissolved solids are a very generalized measure of water quality since it is a total of all soluble constituents which are in solution. Water quality in special instances could be very bad when TDS levels would seem to indicate a good quality water. However, total dissolved solids (TDS) levels do serve to indicate the quality of the water.

The Texas Department of Health has adopted "Drinking Water Standards" to assure the safety of public water supplies. These standards address recommended secondary constituent levels for all public water systems and recommended maximum concentrations for chlorides, sulfates and total dissolved solids are 300 milligrams per liter (mg/l), 300 mg/l and 1,000 mg/l respectively.

The drainage area above Possum Kingdom Reservoir, the uppermost lake on the main stem, contributes an average of 14 to 18 percent of the river's flow. This same area is the source of about 45 to 55 percent of total dissolved solids, 75 to 85 percent of the chloride and 65 to 75 percent of the sulfate measured at Richmond, Texas, near the river's mouth. This disparity between flow and dissolved minerals is the result of contamination by highly concentrated ground water brine which is found in the project area under artesian conditions.

The major areas of salt water emission are Croton Creek and Salt Croton Creek. Other less significant contributing areas are located in the project area.

The Salt Croton Creek area is the largest producer of salt water. Based on studies conducted by the U. S. Geological Survey, it appears the estimated daily load of chloride for the period from 1957 to 1966 was 530 tons per day. Of this total, about 330 tons of chloride per day were measured as base flows and about 200 tons per day were measured to be from flood runoff.

The flows from Croton Creek area are estimated to have contributed about 75 tons of chloride per day during the 1957 to 1966 period.

Figure 2 presents the salt pollution process in conceptual form.

The total of all salt emission sources contribute an average daily load at Possum Kingdom Reservoir of approximately 3400 tons, of which about 1200 tons are chloride and 700 tons are sulfate. The impact of these sources is graphically shown in Figure 3. This figure shows the mean, maximum and minimum concentrations of total dissolved solids, chlorides and sulfates as they occur naturally and the concentrations which are expected with the project in operation.

Figures 4 and 5 show the concentrations of TDS and chlorides in relationship to the time which they occur. Sulphates are not shown as they are not as significant a problem.

THE PROJECT

The proposed project for control of the naturally occurring salt emissions in the area in Dickens, Kent, King and Stonewall Counties consists of three lakes interconnected by pipelines. The three lakes are Croton Lake on Croton Creek, Dove Lake on Salt Croton Creek and Kiowa Peak Lake on North Croton Creek. All of the damsites are in the northern part of Stonewall County. The pipelines provide for transfer of the brine from Croton Lake and Dove Lake to Kiowa Peak Lake for total impoundment. This transfer will prevent the development of hydrostatic pressure on the salt flats in Croton and Dove Lakes, which might cause breakouts of new salt flats. Figure 6 shows these proposed facilities.

Control of these emission sources would prevent approximately 650 tons per day of chloride, 180 tons per day of sulfate and 1360 tons per day of total dissolved solids from entering the river. Figures 3, 4 and 5 illustrate the water quality impacts in the river downstream of the project.

Table No. 1 is a tabulation of the chloride, sulfate and total dissolved solids concentrations in various public drinking water systems in several Brazos Basin Counties. This data was obtained from the Division of Water Hygiene of the Texas Department of Health Resources. This data is included to illustrate the general quality of potable water in the Brazos Basin.

The reduction of salinity in Brazos River water will provide substantial benefits to municipal, industrial, and steam electric users of the water.

First, for current users of Brazos River water, the salinity reduction will reduce the cost of treating the water or, alternatively, the amount of salinity related damages will be reduced. Second, for these who are not using Brazos River water, the salinity reduction might cause the water to be more economical than an alternative source.

Agricultural users could expect some benefit through increased yields of present irrigated crops. These benefits are not believed to be of a significant amount inasmuch as the salinity of the water is generally within the tolerance level of the plants.

Other benefits, such as recreation and flood protection would accrue minimally.

The most visible benefit, however, would be the dramatice increase in quality which would make water in Possum Kingdom Reservoir and all points downstream suitable for domestic and all other uses.

The estimated economic impact of these benefits is shown in the next section.

TABLE NO. 1

PUBLIC WATER SYSTEMS QUALITY*

County	System	Sulfates	Chlorides	Total Dissolved Solids
Austin	Bellville	52	54	640
Baylor	Seymour	59	69	760
Bosque	Clifton	50	21	660
Brazoria	Lake Jackson	15	142	899
Brazos	Bryan	4	48	670
Burleson	Coldwell	48	20	442
Crosby	Crosbyton	-	48	-
Falls	Marlin	33	25	279
Fisher	Roby	239	127	760
Fort Bend	Richmond	17	65	434
Garza	Post	28	105	560
Grimes	Navasota	4	87	880
Haskell	Haskell	310	530	1880
Hill	Hillsboro	412	69	1340
Hockley	Levelland	300	318	1200
Hood	Granbury	29	20	800
Jack	Bryson	92	121	780
Johnson	Cleburne	18	16	87
Jones	Stamford	180	143	770
Kent	Jayton	395	131	1070
King	Guthrie	74	85	780
Knox	Knox City	140	166	1070
McLennan	Waco	30	16	271
Milam	Cameron	43	55	485
Palo Pinto	Mineral Wells	59	23	209
Parker	Weatherford	44	52	346
Robertson	Hearne	4	47	640
Scurry	Snyder	-	-	-
Somervell	Glen Rose	22	25	550
Stephens	Breckenridge	40	32	266
Stonewall	Aspermont	46	36	660
Throckmorton	Throckmorton	42	311	680
Waller	Hempstead	4	63	780
Washington	Brenham	65	49	245
Young	Graham	26	132	413

*Data from: Texas State Department of Health
Chemical Analysis of Public Water Systems
Revised 1977

PROJECT ECONOMIC BENEFITS

Economic benefits to users of water affected by the proposed project can be determined by calculating the amount of damages which would be avoided by improvement in water quality. Also considered in the economic analysis, where possible, is the cost of providing equal quality water to that available with the project utilizing supply and treatment techniques currently employed.

These avoided damages or project benefits have been determined for two categories of water users. The two categories are municipal/domestic users and industrial users which include water for steam electric power generation.

As can be seen on Figure 3, the quality of water in the river varies according to geographic location. Presently, major uses of water occur in the lower basin and in the Lake Granbury and Lake Whitney areas. Other uses do occur generally all along the river below the project location, but they are not presently of a significant amount.

For purposes of illustration of the economic benefits which would accrue from the control of salinity, the two areas of major use have been selected for analysis.

The estimated project benefits are derived in the following computations.

Municipal Benefits

Two approaches are used. One is the calculation of costs to the water user without any control of water quality. The other approach is the calculation of cost employing quality control methods other than the development of the project as described previously.

Municipal benefits in the lower basin are as follows: Based upon studies performed for the Office of Saline Water, United States Department of Interior, by Black and Veatch, Consulting Engineers, in 1967, it is estimated that the cost of domestic-municipal water quality related damages would be reduced by $15.70 per acre foot of water used for each 100 milligrams per liter of total dissolved solids removed from the water. This is based on 1967 dollars.

Utilizing the construction cost index published by Engineering News Record, it is possible to convert 1967 dollars to present day dollars.

March, 1967 Const. Cost Index = 1043

March, 1984 Const. Cost Index = 4118

$\frac{4118}{1043}$ (100) - 395% increase

3.95 X $15.70 = $62.01/acre foot/100 mg/l

Refer to Figure 4 which shows a decrease of 75 mg/l in TDS with the project in place. (Enter graph at 50% of time and read 390 mg/l without project and 315 mg/l with project. (390-315 = 75)

A decrease of 75 mg/l will decrease damages by

$\frac{75 \text{ mg/l}}{100 \text{ mg/l}}$ ($62.01/ac. ft.) = $46.51/ac. ft.

Therefore, a user of 10,000 acre feet of water per year could expect to avoid $465,100 (10,000 x $46.51) per year in system damages by implementation of the project.

Generally, users in the lower basin have been able to avoid these damages by pumping at selected time periods when the water quality was better. This system of operation requires a significant amount of untreated water storage which has an attendant cost.

In 1966, Forrest and Cotton, Inc., Consulting Engineers, prepared a study which addressed the problem of selected pumping to lessen the water quality problem.

Based on this study, it has been estimated that water of a quality equal to or better than that provided by the proposed project can be obtained for a current cost of $20.99 per acre foot.

From this it can be seen that a user of 10,000 acre feet per year can spend $209,900 (10,000 x 20.99) to avoid damages of some $465,000.

Municipal damages in the middle basin area are calculated similarly.

Refer to Figure 5 and see that the project will reduce TDS by 340 mg/l (980-640 = 340).

The reduction in damages which could be expected by construction of the project are:

$$\frac{340}{100}(\$62.01) = \$210.83/\text{acre foot}$$

Where high levels of solids are present in water supplies, it is possible to reduce these levels by various methods of treatment. One of these methods is the electrodialysis system. The City of Granbury has such a plant under construction which will provide water of acceptable quality. Generally, water treated by electrodialysis is blended with conventionally treated water in such a proportion to yield acceptable quality water. Based on estimated results of the Granbury plant, the cost of electrodialysis treated water to a quality equal to the quality provided by the proposed project is $78.20 per acre foot.

Using the example as shown in the lower basin, a user who employs electrodialysis treatment will spend $78 per acre foot and avoid $210 per acre foot of damages.

Industrial Benefits

The calculation of project benefits for industrial users is based upon the use of water for cooling purposes.

These benefits are calculated separately for the lower and middle basins.

A report prepared by Daniel, Mann, Johnson & Mendenhall presented the findings of several investigations to quantify damages related to total dissolved solids. Based upon these findings, an amount of damages of $4.26/acre foot/100 mg/l in 1967 dollars has been used in this analysis. 1967 dollars were converted to present day dollars as previously explained and as shown below:

3.95 x $4.26 = $16.83/acre foot/100 mg/l

Basic assumptions used in calculation of industrial benefits are:

1. All water used for cooling
2. 97% of water used is for condenser cooling.
3. 3% of water used is for boiler makeup.
4. No recognition of condenser system damages when TDS is less than 1000 mg/l.
5. Boiler makeup will benefit from total reduction of TDS.
6. Water use will decrease with decrease in TDS concentration.

The lower basin benefits are calculated as follows:

Condenser damages:

Refer to Figure 4

No damages recognized when TDS is less than 1000 mg/l

Without project TDS exceeds 1000 mg/l, 4% of time

During this 4%, TDS averages 1150 mg/l.

$$.04 \times \frac{1150\text{-}1000}{100} \times \$16.83 = \$1.01\text{/ac. ft.}$$

Boiler damages:

Refer to Figure 4

Average quality change = 390-315 = 75 mg/l

$$.03 \times \frac{75}{100} \times \$16.83 = \$0.38\text{/ac. ft.}$$

Decrease in water use:

Estimated at 6%

Estimated cost of water = $10.00/ac. ft.

.06 x 10.00 = $0.60/acre foot

Summary of avoided damages:

Condenser	$1.01/acre foot
Boiler	0.38/acre foot
Decreased Use	0.60/acre foot
Total	$1.99/acre foot

The middle basin benefits are calculated as follows:

Condenser damages:

Refer to Figure 5

Without project, TDS exceeds

1000 mg/l, 50% of time

During this 50%, TDS averages 1350 mg/l

$$.50 \times \frac{1350-1000}{100} \times \$16.83 = \$29.45/\text{ac. ft.}$$

Boiler damages:

Refer to Figure 5

Average quality change = 990-630 = 360 mg/l

$$.03 \times \frac{360}{100} \times \$16.83 = \$1.82/\text{ac. ft.}$$

Decrease in water use:

Estimated at 23%

Estimated cost of water = $10.00/ac. ft.

.23 x $10.00 = $2.30/ac. ft.

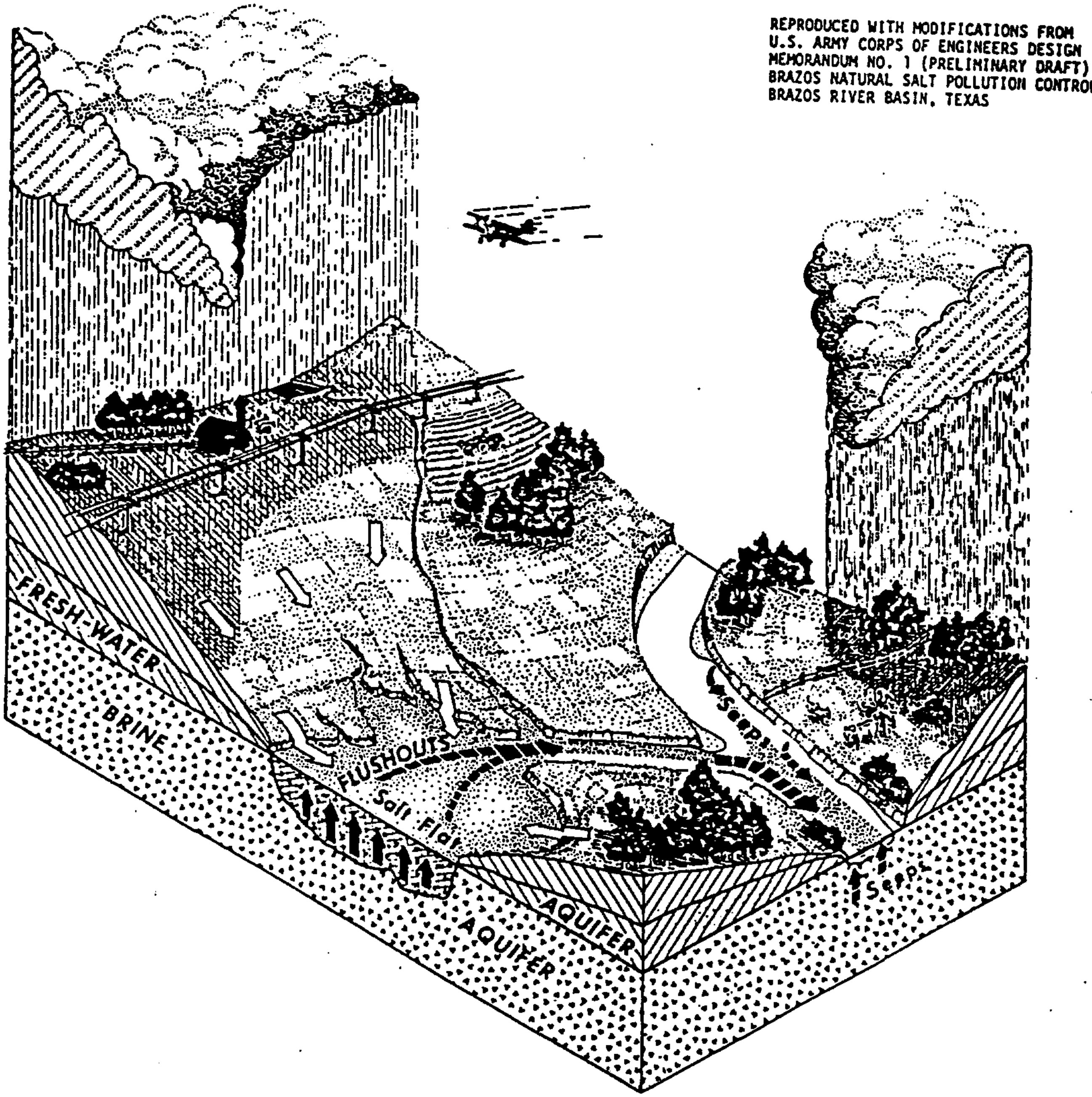
Summary of avoided damages:

Condenser	$29.45/acre foot
Boiler	1.82/acre foot
Decreased Use	2.30/acre foot
Total	$33.57/acre foot

These project benefits and alternate quality enhancement costs are summarized as follows:

Area	Costs in Dollars per Acre Foot: Municipal Users — Benefits	Municipal Users — Alternate Method	Industrial Users — Benefits	Industrial Users — Alternate Method
Lower Basin	$46.51	$20.99	$1.99	*
Middle Basin	$210.83	$78.20	$33.57	*

*Not determined.



Salt Pollution Process

Brine seeping to the surface evaporates leaving a deposit of salt crystals that is subsequently flushed into streams by rainfall runoff.

FIGURE 2

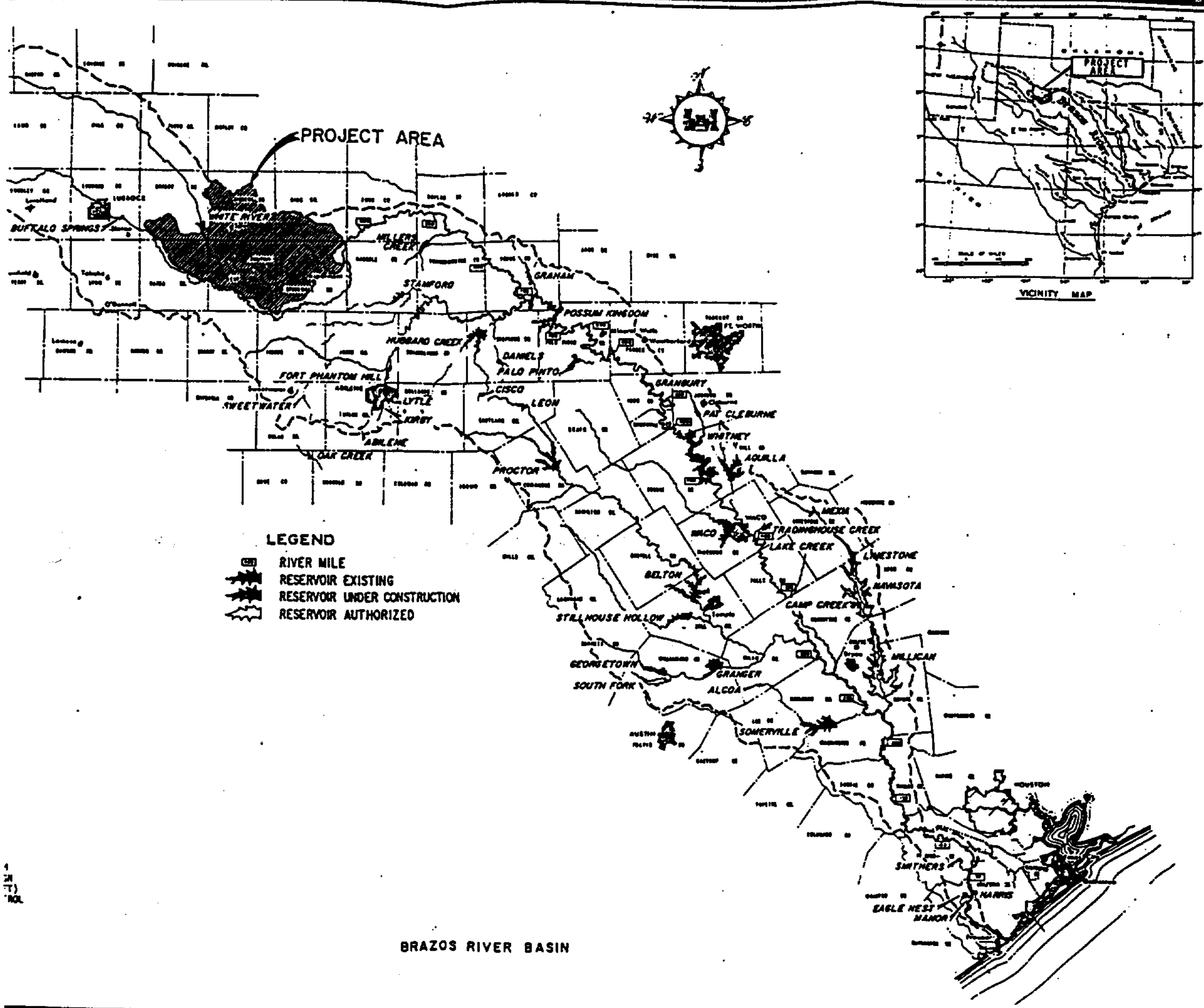

PROJECT AREA
VICINITY MAP
LEGEND
RIVER MILE
RESERVOIR EXISTING
RESERVOIR UNDER CONSTRUCTION
RESERVOIR AUTHORIZED
BUFFALO SPRINGS
WHITE RIVER
MILLERS CREEK
STAMFORD
GRAHAM
POSSUM KINGDOM
HUBBARD CREEK
DANIELS
PALO PINTO
FORT PHANTOM HILL
SWEETWATER
LYTLE
KIRBY
ABILENE
OAK CREEK
CISCO
LEON
PROCTOR
GRANBURY
PAT CLEBURNE
WHITNEY
AQUILLA
MEXIA
WACO
TRADINGHOUSE CREEK
LAKE CREEK
LIMESTONE
NAVASOTA
BELTON
CAMP CREEK
STILLHOUSE HOLLOW
MILLICAN
GEORGETOWN
GRANGER
SOUTH FORK
ALCOA
SOMERVILLE
SMITHERS
HARRIS
EAGLE NEST MANOR
BRAZOS RIVER BASIN

FIGURE 1

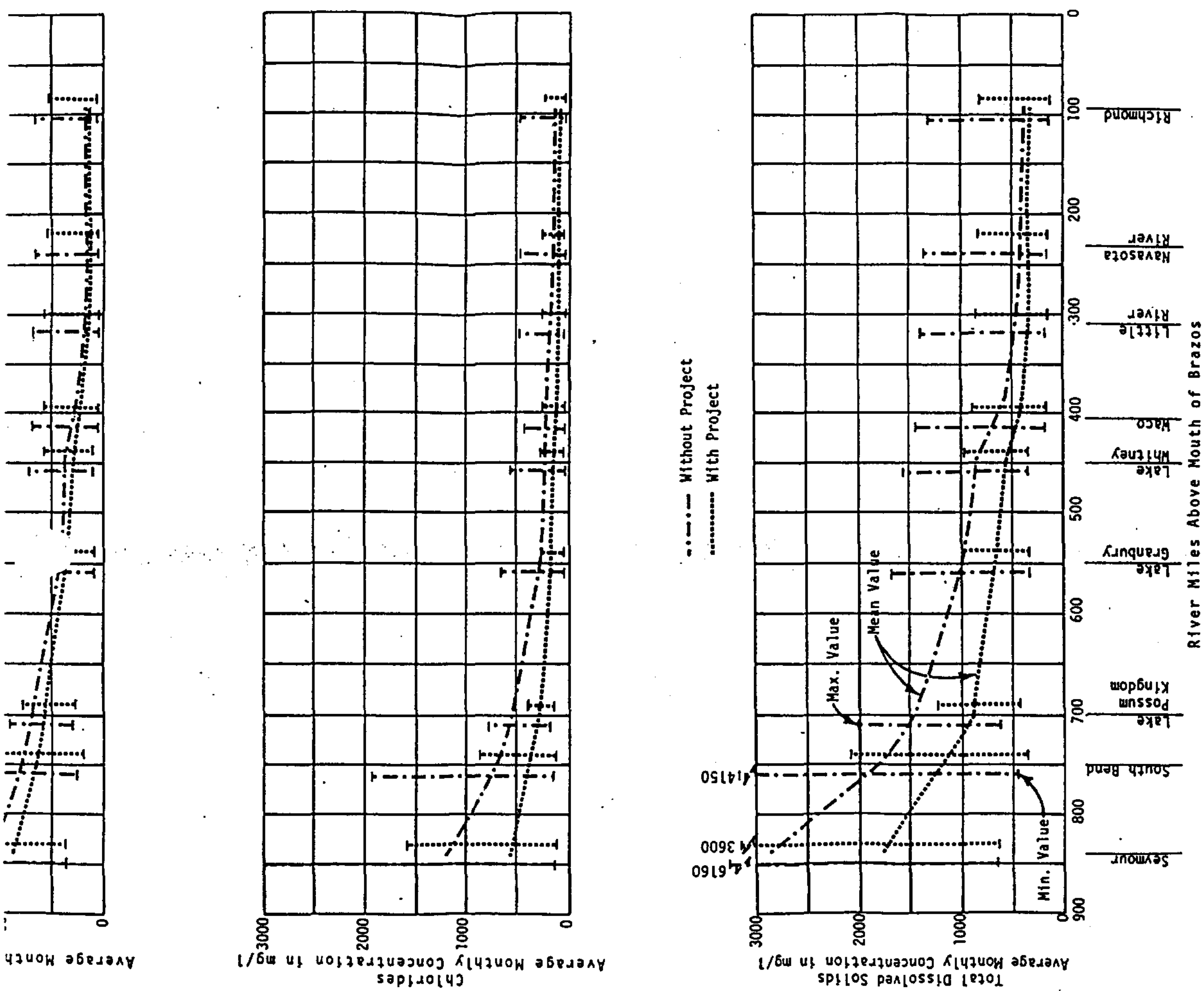
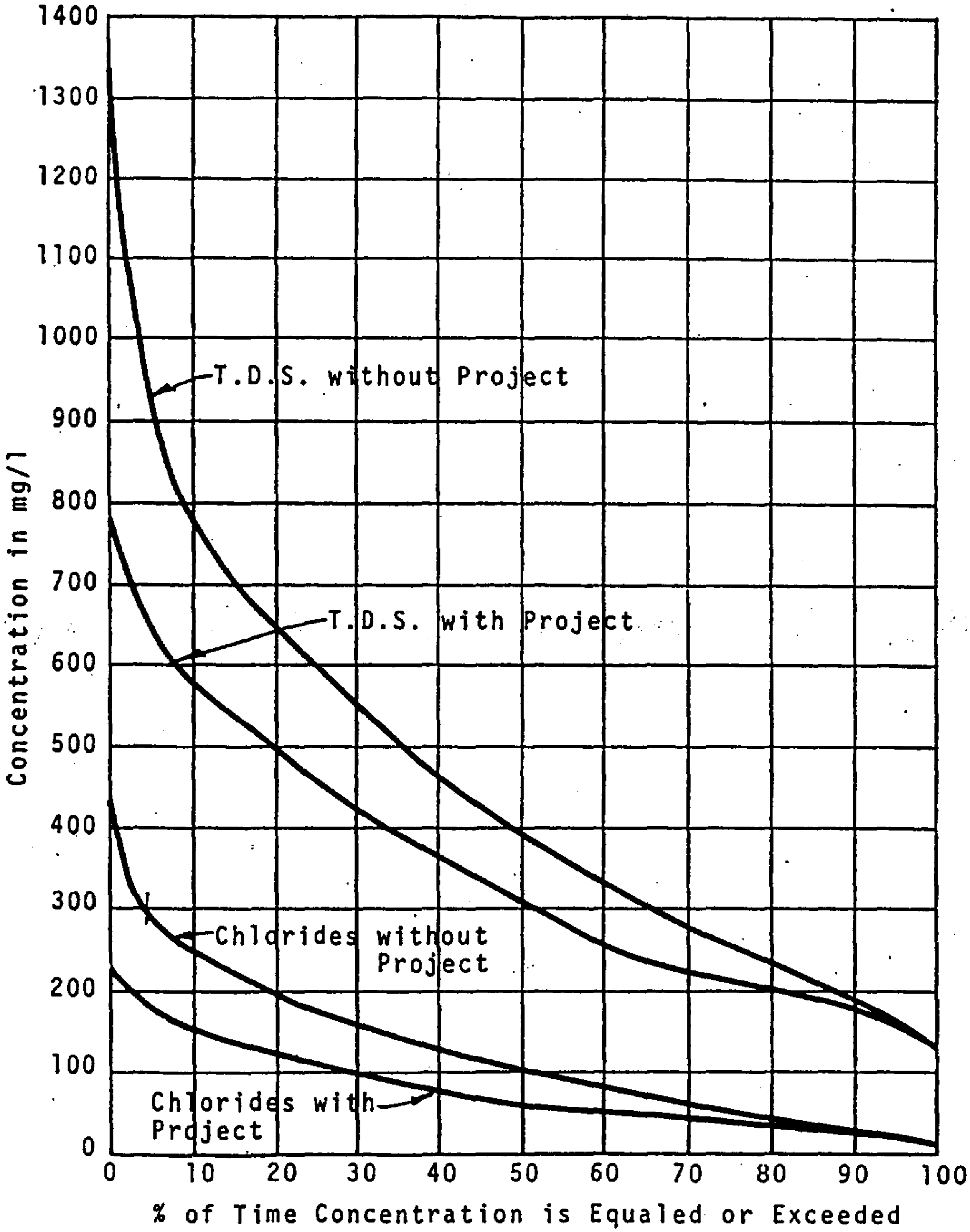
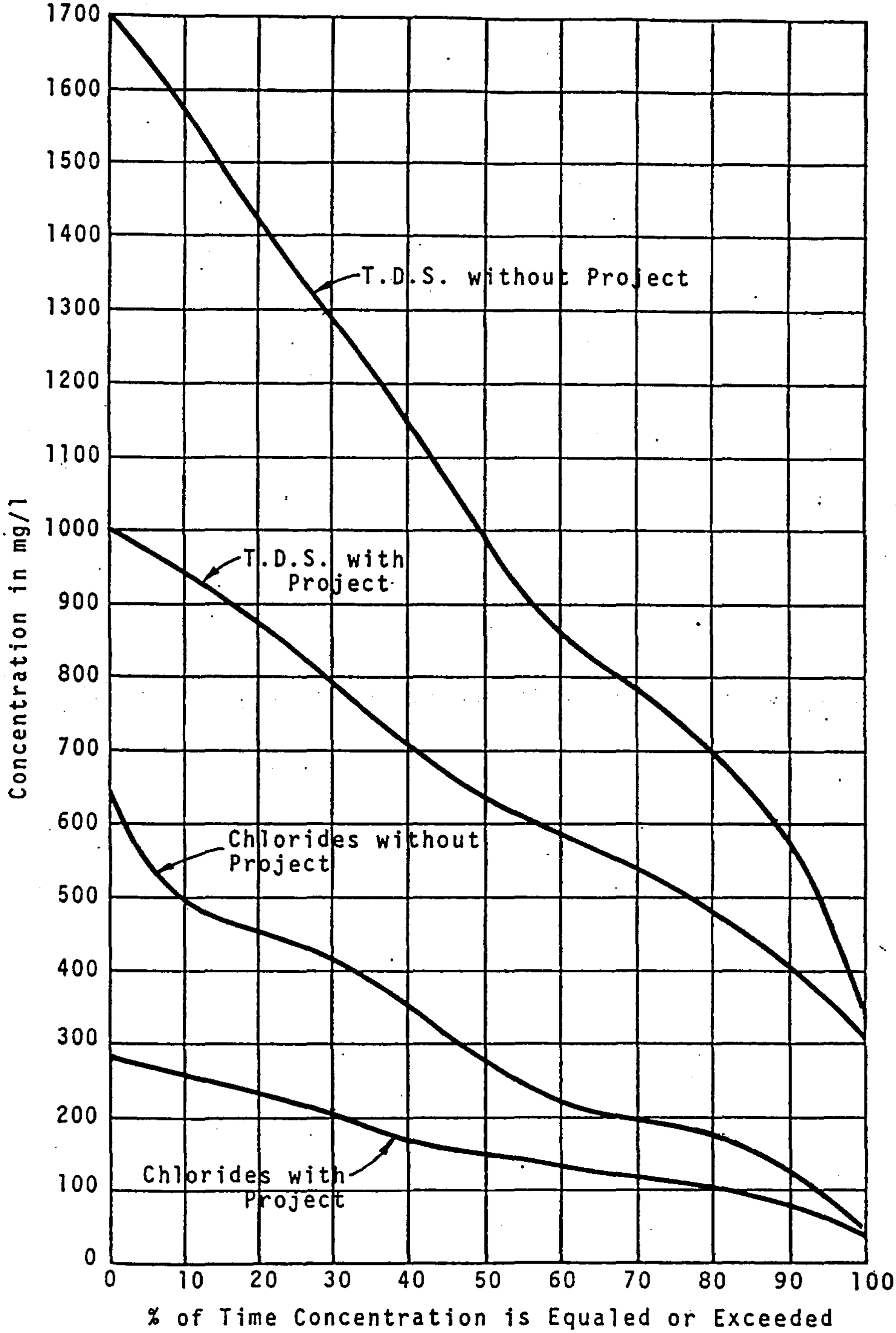

Without Project
With Project
River Miles Above Mouth of Brazos
Richmond
Navasota River
Little River
Waco
Lake Whitney
Lake Granbury
Lake Possum Kingdom
South Bend
Seymour
Max. Value
Mean Value
Min. Value
14150
3600
6160
Average Monthly Concentration in mg/l
Total Dissolved Solids
Average Monthly Concentration in mg/l
Chlorides
Average Month

FIGURE 3



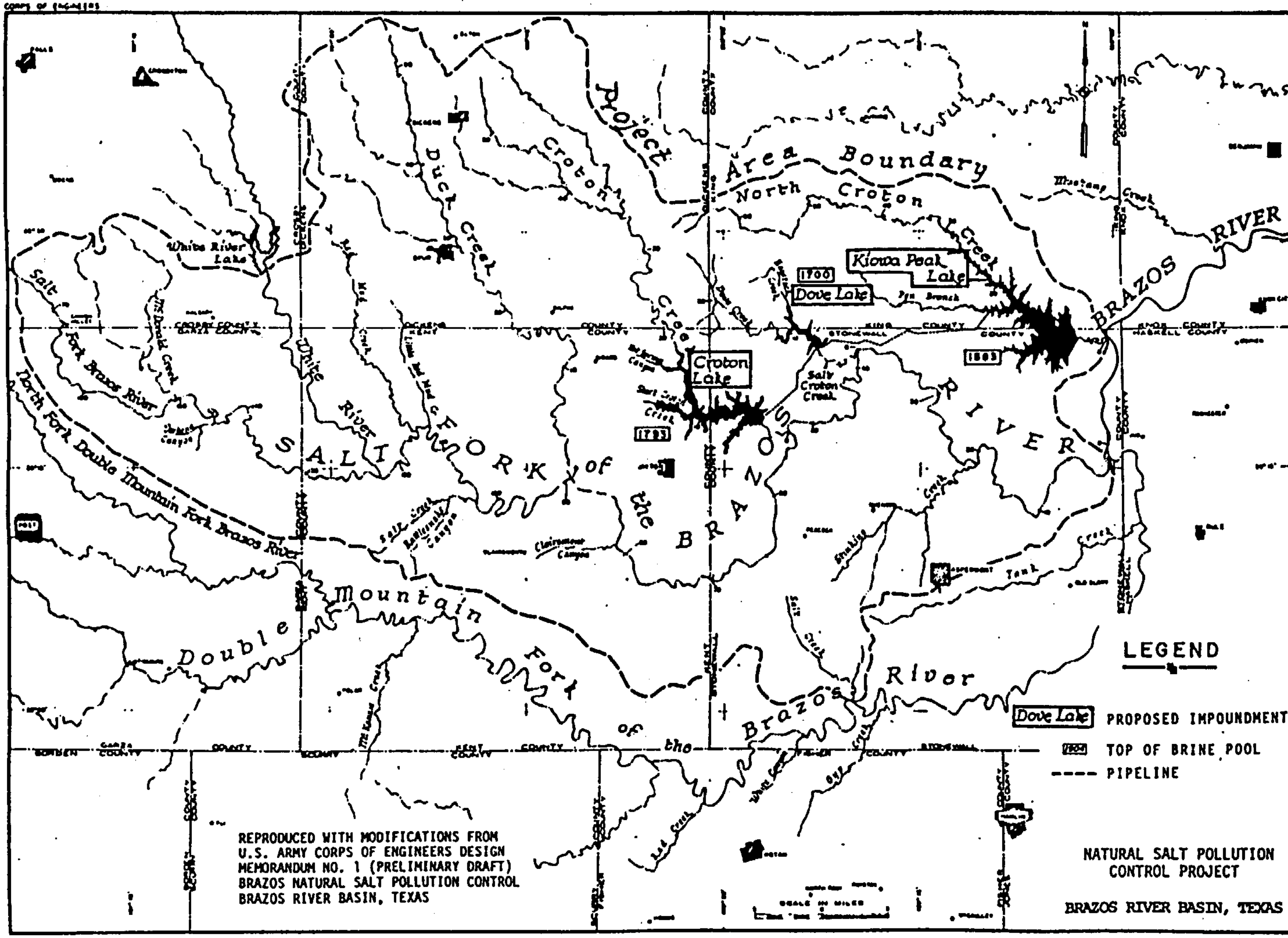
WATER QUALITY NEAR RICHMOND

FIGURE 4



WATER QUALITY AT LAKE GRANBURY

FIGURE 5

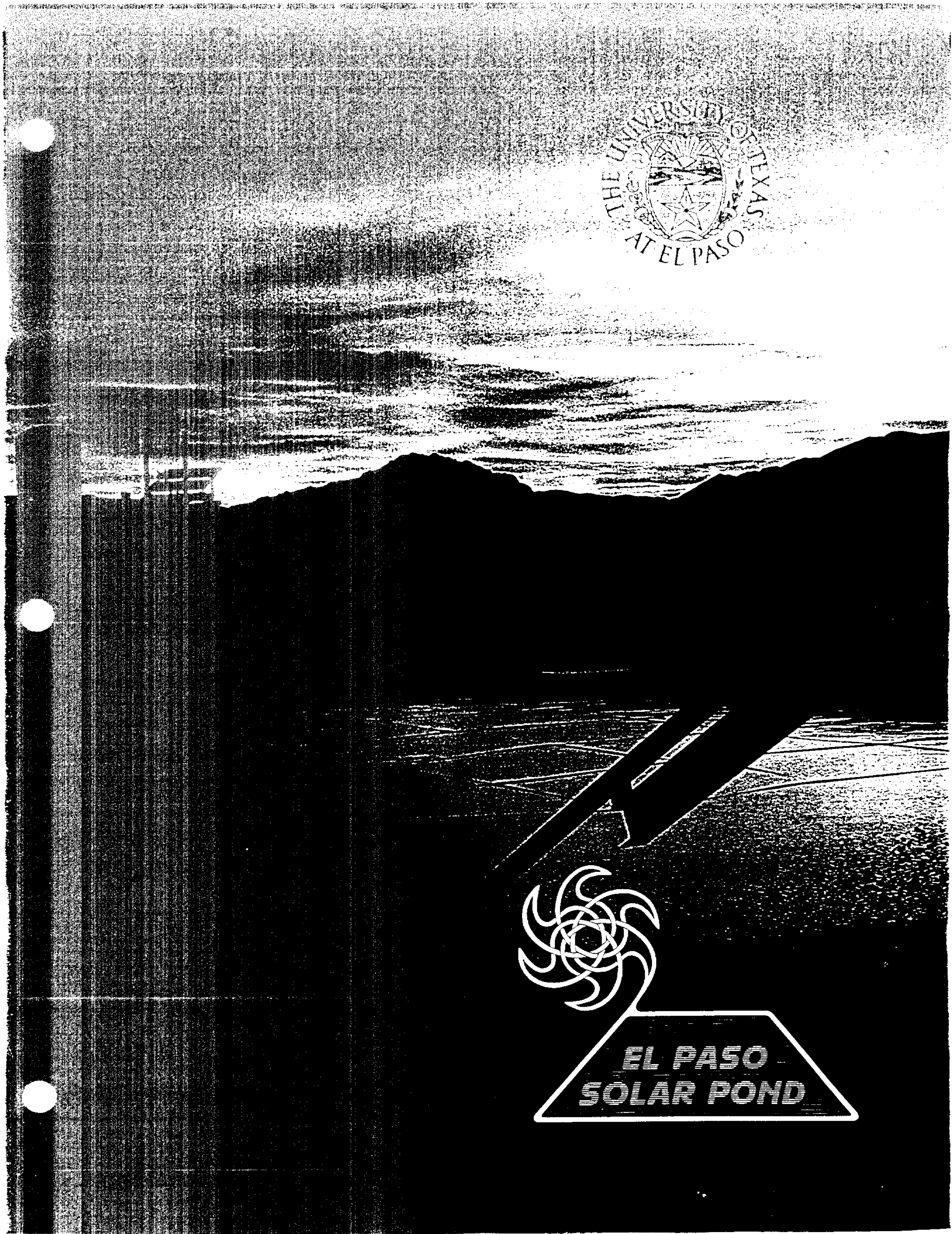


CORPS OF ENGINEERS
Project Area Boundary
North Croton Creek
Croton Creek
Duck Creek
BRAZOS RIVER
Kiowa Peak Lake
Dove Lake
Croton Lake
1700
1803
1793
Salt Croton Creek
White River Lake
Salt Fork Brazos River
North Fork Double Mountain Fork Brazos River
White River
SALT FORK of the BRAZOS RIVER
Double Mountain Fork of the Brazos River
Mustang Creek
Tank Creek
Salt Creek
Clairemont Canyon
LEGEND
Dove Lake PROPOSED IMPOUNDMENT
TOP OF BRINE POOL
PIPELINE
REPRODUCED WITH MODIFICATIONS FROM
U.S. ARMY CORPS OF ENGINEERS DESIGN
MEMORANDUM NO. 1 (PRELIMINARY DRAFT)
BRAZOS NATURAL SALT POLLUTION CONTROL
BRAZOS RIVER BASIN, TEXAS
NATURAL SALT POLLUTION
CONTROL PROJECT
BRAZOS RIVER BASIN, TEXAS

FIGURE 6

APPENDIX II

- THE EL PASO SOLAR POND - BROCHURE
- EXCERPT FROM AQUACULTURE STUDY, PECOS COUNTY WID NO. 3
- THE IONICS, INC., CLOROMAT SYSTEM - BROCHURE

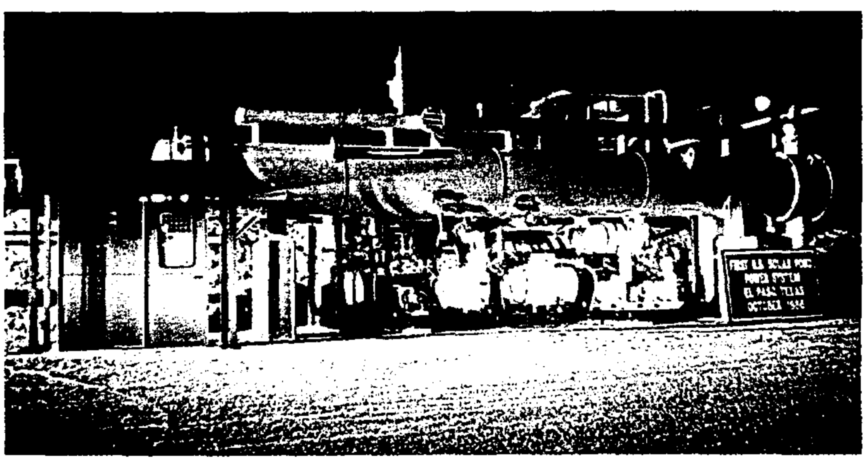

THE UNIVERSITY OF TEXAS
AT EL PASO
EL PASO
SOLAR POND

EL PASO SOLAR POND CONSORTIUM

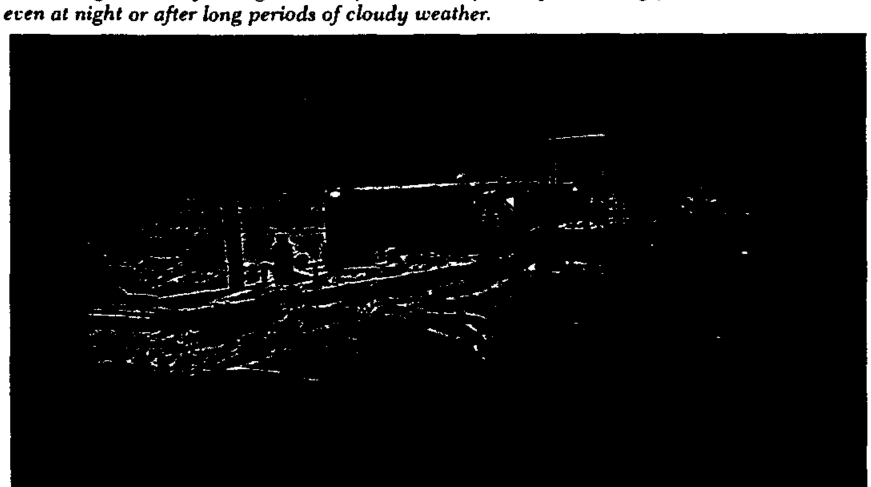
In January 1989, a Solar Pond Consortium of three Texas universities was formed. The University of Texas at El Paso is the lead institution with the University of Houston and Texas A & M University also participating. The purpose of the Consortium is to advance solar pond technology toward commercial applications and to maintain the El Paso Solar Pond as a research, demonstration and training facility for solar pond technology. Major funding is being provided by the State of Texas, Governor's Energy Management Center through the Texas Higher Education Coordinating Board's Energy Research in Applications Program. Additional support is being provided by Bruce Foods Corporation, the U.S. Bureau of Reclamation, and Spintech Corporation. Specific consortium objectives include:

- demonstration of continuous and reliable solar pond operation for process heat production, electrical power generation, and continuous water desalting;
- development of a sustainable salt management system;
- development of an automated pond monitoring system; and
- economic modeling and analysis.

An Advisory Board has been formed that includes individuals from government, industry, and the solar pond research community to monitor and direct the progress of the Consortium.



Generating electricity at night. Solar ponds are capable of delivering power on demand — even at night or after long periods of cloudy weather.



Winter 1987. Solar pond operation continues during extreme weather conditions.

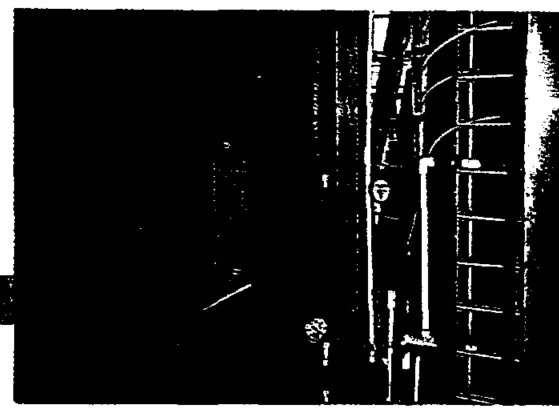
Printing of this brochure is funded in part by the College of Engineering, U.T. El Paso.

[illegible]

The first 24 stage, falling-film low temperature desalting unit was installed in May, 1987. In June, it began producing about 16,000 liters/day (4,600 gal/day) of desalted water; yet another first in the U.S. for the El Paso Solar Pond project. More importantly, this demonstrates that it is possible for solar ponds to provide both the heat and electricity required to efficiently produce potable water from brackish water. Another major advantage of solar pond-coupled desalination units is that they can use the reject brine to produce new solar ponds, addressing one of the major costs of inland desalination — waste brine disposal. The newly constructed ponds can then be used to make more power and fresh water.

In March, 1990, a second desalting unit began producing pure water from brackish sources on a 24-hour basis.

Installation of desalination unit.



Monitoring high quality fresh water produced by desalination unit.

RESEARCH

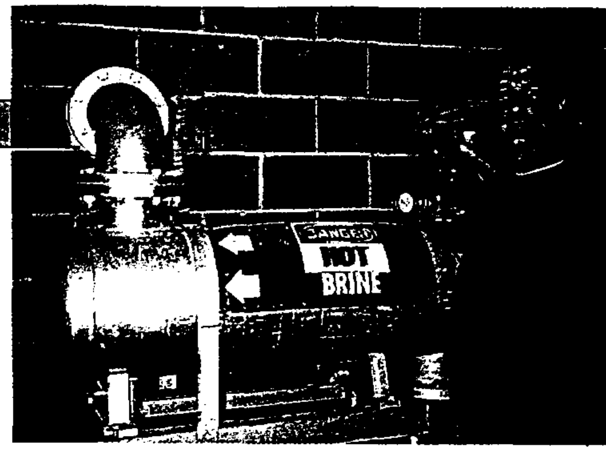
Over 90 graduate and undergraduate students have been involved in the project, performing tasks ranging from construction to applied research. In addition, numerous students have done projects related to the pond, gaining valuable experience in equipment design and construction, lab techniques, problem solving, instrumentation, and documentation. The solar pond provides a unique opportunity to do research in such areas as double diffusive convection, wind/wave interaction, flow in stratified fluids, and computer modeling.

Monitoring pond brine quality.

Students working on shadowgraph used to observe hydrodynamic behavior occurring in pond.

In addition, the state of the art equipment on site provides an excellent opportunity for energy efficiency studies, cost analysis, system studies, heat exchanger evaluations, etc. The El Paso Solar Pond project is the premier solar pond research, development, and demonstration facility in the world today.

STAGE I — PROCESS HEAT



Heat exchanger used to deliver the world's first industrial process heat from a solar pond.

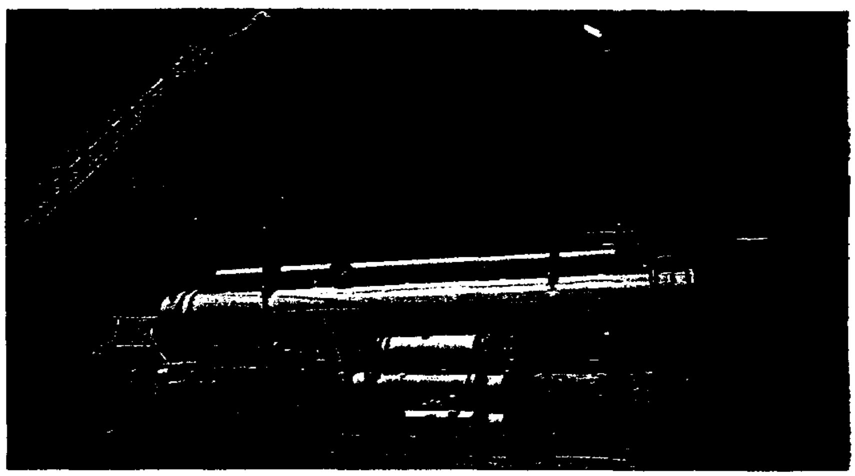
The first application of the El Paso Solar Pond was delivery of industrial process heat. To do this, a heat exchanger was installed to preheat boiler feed water for the Bruce Foods canning operation. Pond generated heat has been delivered in this manner since summer, 1986. Operating at about 85°C (185°F) and delivering about 300 kW thermal, this project was the first in the world to successfully demonstrate the use of solar pond technology to deliver industrial process heat.

Future thermal applications of solar ponds include residential and commercial space heating, dessicant or absorbtion cooling, grain and wood drying, and other uses of low to medium grade heat.

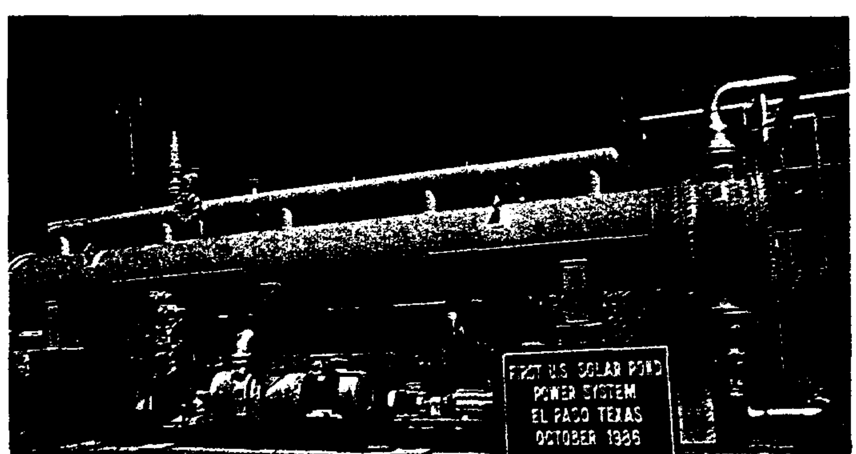
STAGE II — ELECTRICITY GENERATION

An organic Rankine-cycle engine generator was installed on site in July, 1986. In September, the El Paso Solar Pond became the first in the U.S. to generate grid connected power, producing up to 70 kW. Most of this power has been delivered to Bruce Foods Corporation for peak power shaving. This demonstrates one of the primary benefits of solar ponds: power on demand — even at night or after long periods of cloudy weather.

Immediate applications of solar ponds for the generation of electricity include (a) power for remote areas where conventional fuel is expensive and (b) peak power shaving in appropriate locations. The built-in thermal storage of solar ponds makes them an excellent choice for applications requiring high reliability.



Installation of organic Rankine-cycle generator.



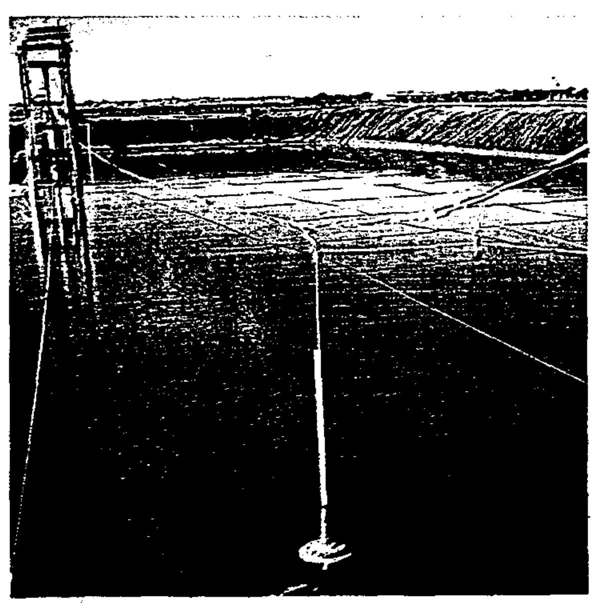
America's first solar pond-based electric generating station.

CONSTRUCTION

The El Paso Solar Pond project began when the University of Texas at El Paso discovered an existing 3350 square meter (0.8 acre), 3 meter (10 feet) deep pond located at Bruce Foods, a canning plant in northeast El Paso, Texas. The lined pond was used by the previous owner as a source of water for fire protection, but a connection to the city water supply by Bruce Foods eliminated the need for the pond. Support was obtained from the Department of the Interior - Bureau of Reclamation, Bruce Foods, and El Paso Electric Company to convert the existing storage pond to a solar pond. Construction began in early 1985, and by spring of that year, a new liner had been placed over the existing one, evaporation ponds (for recycling salt) had been constructed, and inlet and discharge diffusers to deliver hot brine from the pond bottom had been built. Wave suppression nets and an instrumentation tower, both shown in the pond photographs, were also installed. The salt gradient was established and the pond storage zone temperature rose rapidly. Following construction and initial operation of the pond, project emphasis expanded to include useful applications.

2000 tons of impure salt from an underground mine, used to establish the solar pond.

Dissolving salt to make concentrated brine.



23 cm (9 inch) diameter diffuser used to establish and control salinity gradient profile in entire 3350 square meter (0.8 acre) pond.

WHY SOLAR PONDS?

Solar Ponds have several important advantages. They have a low cost per unit area of collector and an inherent storage capacity. Also, they can be easily constructed over large areas, enabling the diffuse solar resource to be concentrated on a grand scale.

Solar Ponds also address three environmental issues arising from the use of conventional fuels. First, heat energy is provided without burning fuel, thus reducing harmful pollution. Second, conventional energy resources are conserved. Third, solar ponds coupled with desalting units can be used to purify contaminated or minerally-impaired water, and the pond itself can become the receptacle for the waste products.

SOLAR PONDS ARE UNIQUE:
During the winter of 1987 this person stands on the frozen surface of the El Paso Solar Pond, while 7 feet below the ice the temperature remains at 154°F — hot enough to generate electricity.

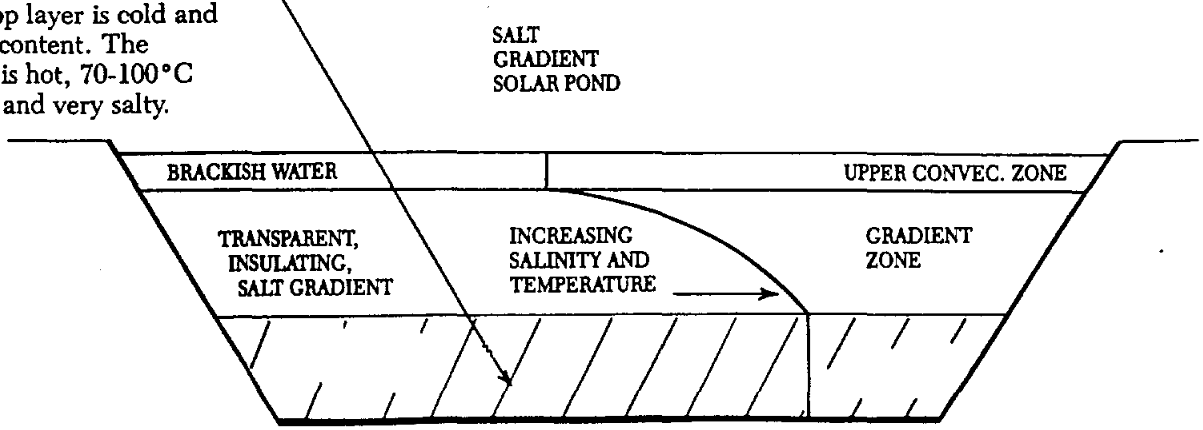
HOW A SOLAR POND WORKS

Most people know that fluids such as water and air rise when heated. Solar ponds stop this process when large quantities of salt are dissolved in the hot bottom layer of the pond, making it too dense to rise to the surface and cool.

Solar Ponds consist of three main layers. The top layer is cold and has little salt content. The bottom layer is hot, 70-100°C (160-212°F), and very salty.

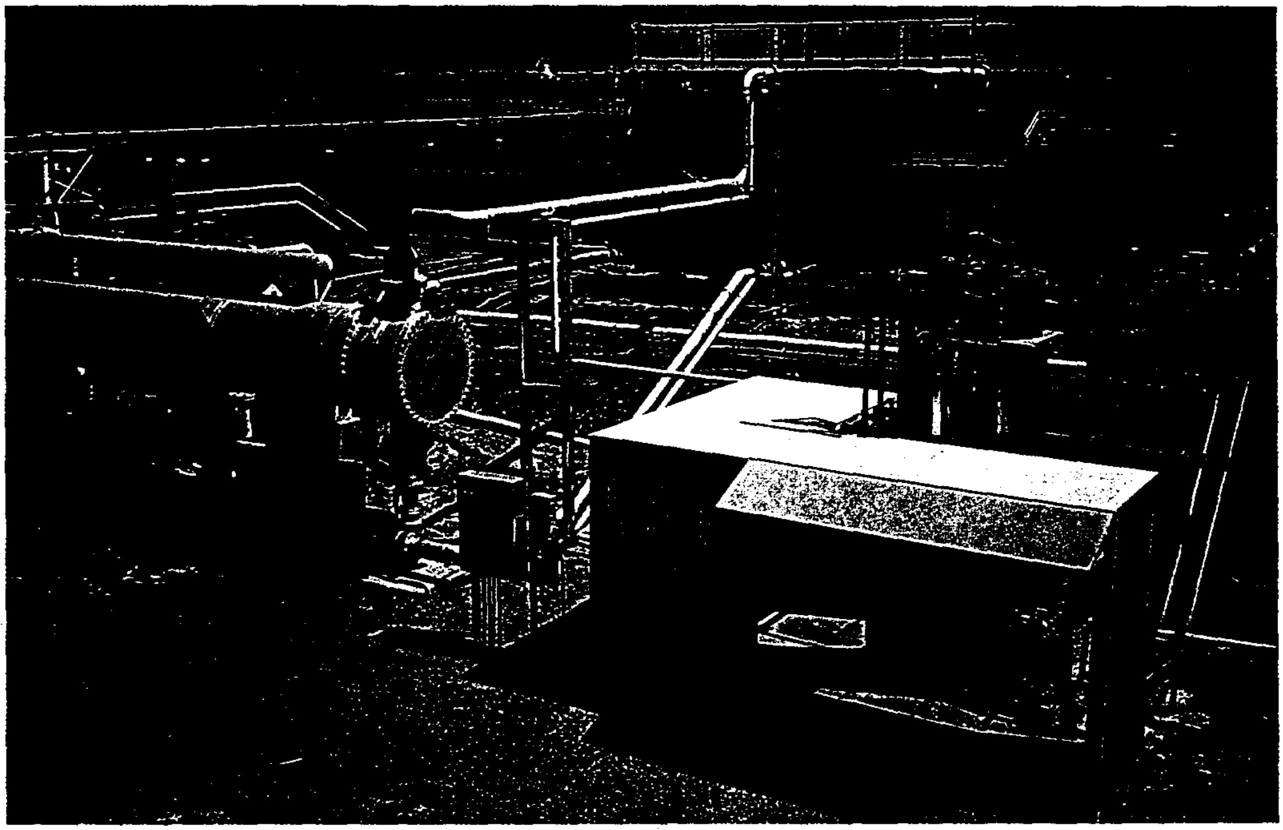
Separating these two layers is the important gradient zone. Here salt content increases with depth as shown by the drawing. Water in the gradient can't rise because the water above it has less salt content and is therefore lighter. Similarly, water can't fall because the water below it has a higher salt content and is heavier. Thus the stable gradient zone can act as a transparent insulator, permitting sunlight to be trapped in the hot bottom layer, from which useful heat is withdrawn.

In this simplified description, no attempt is made to describe the hydrodynamic phenomena which influence zone and interface stability, salt and heat transport, and other complex behavior.



EL PASO SOLAR POND PROJECT

The El Paso Solar Pond project is a research, development, and demonstration project initiated by the University of Texas at El Paso in 1983. It has operated continuously since May, 1986 and has very successfully shown that process heat, electricity, and fresh water can be produced in the southwestern United States using solar pond technology.



CONTRIBUTING ORGANIZATIONS

Advanced Energy Applications Program, U.S. Bureau of Reclamation
Bruce Foods Corporation
El Paso Electric Company
Ormat Turbines
Spintech Corporation
State of Texas, Governor's Energy Management Center
  Energy Research in Applications Program
The University of Texas at El Paso
Wyler Industries

For further information regarding this solar pond project and solar pond applications, please contact:

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EXCERPT FROM AQUACULTURE STUDY

SPONSORED BY
PECOS COUNTY WATER IMPROVEMENT DISTRICT NO. 3
AND THE TEXAS AGRICULTURE EXTENSION SERVICE

MAY, 1991

IV. THE RATIONAL FOR AQUACULTURE IN PECOS COUNTY AND FAR WEST TEXAS

Why would anyone want to consider commercial aquaculture in the desert and use antique seawater to fill his ponds? Aquaculture in west Texas, inspite of its atypical tropical aquaculture environment has alot of pluses. Anyone examining the problems of coastal aquaculture might see alot of advantages in being able to move several hundred miles inland and tap underground saline aquifers in west Texas.

The successful production of commercial quantities of shrimp in several pilot ventures in west Texas begs further exploration and commercial demonstration of this unusual area. These demonstrations would define the differences in technology and economics required for the profitable production of seafood in the west Texas' underground water resources. Unlike some other areas where the local residents are often skeptical of aquaculture, west Texans eagerly embrace the idea of aquaculture developing in their part of the world: simply because they truly need and desire its success for their economic well being. Consequently, the west Texas' people may be just as important a resource for commercial aquaculture development as the underground saline aquifers of west Texas.

Advantages of West Texas Aquaculture

1. Land values are exceptionally low and there is no competition from other high income real estate users, such as condo developers. Large tracts are available for as little as $ 40 per acre.

2. There is no recreational or other competition for the water resource.

3. There is a low probability of being affected by an upstream polluter or effecting a downstream user of the water resource. While the possibility of pollution exists from oil wells contaminating nearby ground water, this is primarily a problem of the past. Oil well casing specification and well abandonment procedures are strictly enforced today. There are hundreds of thousands of acres without an oil well in sight, without almost anything in sight.

4. Being inland, many of the coastal predatory animals are not present.

5. West Texas is out of reach of most coastal storm systems and all hurricane tidal surges. Wind velocities in west Texas in and around Pecos county average about 3 to 4 MPH. Maximum daily averages are experienced between March and June with June having the highest velocities. While maximum velocities are not recorded, local accounts say that winds of 60 MPH are not uncommon. Most commercial greenhouse fabrications should withstand the west Texas wind loads though occasional cover losses could be experienced during storms and frontal system passages.

6. Permits for most aquaculture sites and production (excluding oysters) will be easier to obtain than on the coast.

7. The land locked nature of most sites will give the aquaculturist more control in limiting the accidental distribution of exotic species and consequently should make the acquisition of any exotic species permits easier.

8. Incoming water is free of water borne predators, such as fish, crabs and poachers.

9. Incoming water (well water) should be free of most, if not all, disease organisms.

10. Low population density should reduce the incidence of finger blight (theft).

11. Incoming ground water is relatively nutrient free, with little or no biological oxygen demand.

12. Utilities are about half of what they are on the Texas coast. (See TABLE 8.)

13. High rates of sunshine year round make solar energy for heating greenhouses very effective.

14. Some potential aquaculture sites have natural gas wells available that could be used for cheap power and heating.

Major Disadvantages of West Texas Aquaculture

1. Variable water chemistry and quality of water from site to site make site selection more complicated. However, most sites bioassayed to date appear to be surprisingly suitable for some aquaculture species. West Texas counties have an abundant resource in saline ground waters (estimated volumes over 300 million acre feet have been made, though all of this will not be practically available or desirable for aquaculture).

2. Minimal growing temperatures (74-75 C.) for warm water species, such as Penaeus vannamei, are first realized in west Texas in May and are lost in the first days of September. This means about 30 to 60 days (120-150 days) less growing season for tropical shrimp species than the coast of Texas (150-210 days). If the use of cold tolerant species of shrimp prove feasible, temperature could be less of a negative factor.

3. There are no existing seafood processing facilities in west Texas though there is some freezer cold storage. This has not proven a problem to the small pilot ventures. If commercial aquaculture develops in west Texas processing facilities will follow just like in other areas where commercial seafood production occurs.

4. Currently there are no aquaculture extension services available locally. This may change in the future as increasing aquaculture activities justify the expense of such a program.

5. It is not likely that commercial hatchery systems will be able to develop in west Texas for most marine species due to the ionic differences from the west Texas ground waters and natural seawater. Better quality, cheaper, and quicker shipping of seedstock are universally needed. Co-op hatcheries on the Texas coast have been discussed by local pilot venture operators as a solution to this problem.

6. Little track record of commercial scale aquaculture ventures using saline ground water as their main culture medium exists which is especially important for debt financing ventures.

7. Little economic information has been developed with regard to ground water reuse strategies for large scale aquaculture operation. Water pumped out of the aquifer will have to be put back into the aquifer. Evaporation will have to be kept to a minimum. Organics will have to be removed before putting the water back into the aquifer to prevent the resulting anaerobic degradation toxin by products (ammonia, methane, hydrogen sulfide, etc.) from building up in the aquifer.

Potential Species and Possible Production Strategies for West Texas Aquaculture

Marine Shrimp Production

One crop per year of medium sized shrimp in open ponds is possible. One crop of large shrimp is possible using a greenhouse nursery system to head start postlarvae in March. A two to three crop potential exists if cold tolerant shrimp can be grown in the cool months in west Texas ground waters. Multi-crops or continuous production may be possible with intensive systems in a temperature controlled environment. Commercial scale economics of shrimp production in west Texas are yet to be demonstrated. Several pilot ventures have produced shrimp crops at levels similar to commercial farms on the Texas coast and overseas.

Red Fish Production

One crop per year is possible in open ponds (not well documented to date). Multi-crops or continuous production may be possible with intensive systems in a temperature controlled environment.

Rainbow Trout

Winter only growouts unless grown in a temperature controlled environment. In the limited work with this species todate results have been encouraging. The economics for controlled environment culture have not been demonstrated in west Texas.

Tilapia

One crop per year possible with greenhouse nursery head start. There are some trials currently underway. Multi-crops or continuous production may be possible with intensive systems in a temperature controlled environment. Cheap electricity and waste feed and nutrient sources could make this one of the first profitable species in west Texas. Texas does have restrictions on the use of certain species of tilapia.

Hybrid-Striped Bass

These hardy fish appear to hold great promise for west Texas culture due to their tolerance of a wide range of temperatures and salinities. It is currently illegal to sell hybrid-striped bass in Texas as a food fish though it is legal as a fee fish-out species. There is hope that these laws will be changed in this year. Todate, there have been no known trials in west Texas waters with striped bass hybrids.

Catfish

Similar growout technology used for catfish production in other commercial operations in the U.S. should be successful in west Texas. Many sites may be too salty (above 7 ppt.) especially during high evaporation periods in summer. Some early west Texas catfish trials by inexperienced operators have failed when pond salinities were allowed to evaporate to above the lethal limits for catfish. Obviously site selection with regard to the water resource salinity will be critical with catfish.

Oysters

Limited experiments suggest that oysters will live in at least some west Texas ground water sources. However, due to the low nutrient level of these waters, little planktonic algae or diatoms exist. In preliminary trials oysters apparently starved to death because of insufficient algal foods. Using other aquaculture production metabolites as a source for nutrient for algal and diatom feed production may be a technically and economically feasible way to provide food for oyster production in these relatively sterile waters. However, Texas Department of Shellfish Sanitation (which controls the sale of all oysters in Texas) has not been receptive to aquaculture and are not willing to work with aquaculturists on commercially practical oyster production methods. Today, there are currently no commercial aquaculture oyster production operations in the state of Texas, coastal or otherwise.

Brine Shrimp

Brine shrimp bio-mass and perhaps cyst production probably can be achieved on a seasonal basis in the saltier waters of west Texas. The lack of agriculture and residual pesticides in many areas of west Texas will eliminate these toxins from the brine shrimp production environment. This has been a serious problem for existing brine shrimp producers in surface waters affected by agricultural runoff. If the proper algas and diatoms can be provided to the brine shrimp cultures, they will create the most desirable fatty acid profiles. The resulting brine shrimp products will be a premium aquaculture feed. There is at least one privately sponsored brine shrimp trial underway now in west Texas.

Possible Aquaculture Systems for West Texas

There will probably be two basic approaches to aquaculture in west Texas, semi-intensive and intensive. (Existing pilot ventures employ both by using intensive greenhouse nurseries and semi-intensive aerated growout ponds.) Extensive pond production will create too much water use and too much evaporation.

Semi-intensive operations will probably use earthen ponds and will be limited to areas with soils having sufficient clays (10% +) to efficiently impound water. Reviewing the Soil Conservation Services' soil maps for west Texas counties, it can be seen that the Pecos River Basin will give the greatest probability of finding sites with soils and slopes suitable for aquaculture development. The ideal site would be one where three to six feet of clay soils would overlay a water bearing gravel layer immediately below. This would allow the farm to use efficient axial flow low lift pumps to lift water from a ground water gathering sump dug into the high flowing water bearing gravel layer. This exact situation may be difficult to find and may force the aquaculturist to use wells and more expensive pumping methods such as turbine pumps. Even so, his economic fate should be no worse than catfish farmers using the same turbine pumps in Arkansas and the Mississippi Delta.

Intensive systems will usually employ water proofed containments and will not be limited by soil permeability. Consequently they will be more likely to find and use sites where the water source is closer to the surface in coarse soils with high water flow rates. These conditions also become valuable when the aquaculturist has to return his processed discharge water back to the aquifer. Coarse surface soils that interface with the aquifer will allow high volumes to be returned by gravity (after processing) to the aquifer with a minimum of effort and cost.

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The Modularly Engineered ***Sodium Hypochlorite Generating Plant***

Creating a New Approach to the Supply of Bleach

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Filling total water quality needs for people, industry and our environment. SM

Get the right connection for chlor-alkali chemicals and eliminate...

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For more than 45 years, Ionics has helped municipalities and private industry at more than 2,000 installations in more than 30 countries.

Ionics has more than 20 years experience with membrane cell chlor-alkali technology and is the leading supplier of small capacity membrane cell plants.

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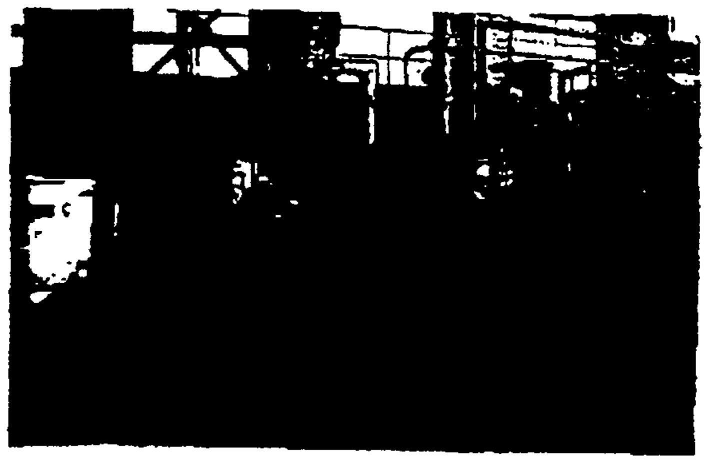

Cloromat® Quality Sodium Hypochlorite is the Purest!

- *Disinfect Potable Water for Distribution*
- *Treat Wastewater for Disposal*
- *Swimming Pool Treatment*
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Ionics manufacturing process is sophisticated, yet simple to install and operate.

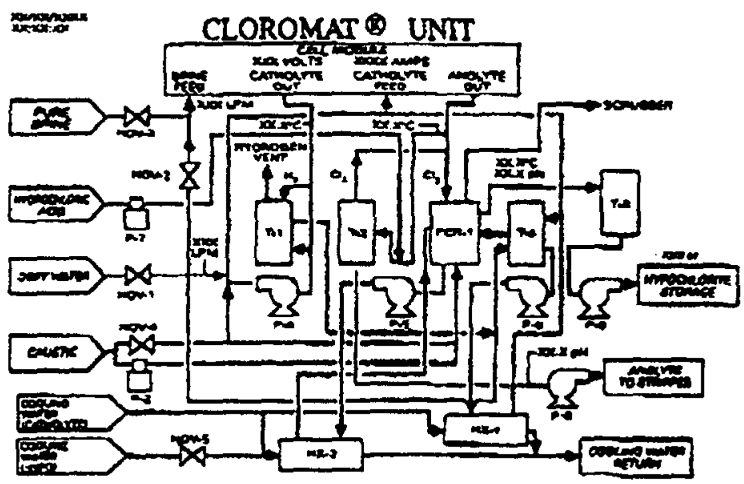
This proven design lets you generate pure, high quality product on-site at a lower cost with greater flexibility and safety.

Ionics' Cloromat System is designed for the small user. The system can generate up to 5 tons of chlorine and 5.65 tons of caustic per day with the typical owner producing 10,000-30,000 gallons per day, (37.5-112.5 m3) of sodium hypochlorite bleach in concentrations ranging from 60-150 grams/liter available chlorine.

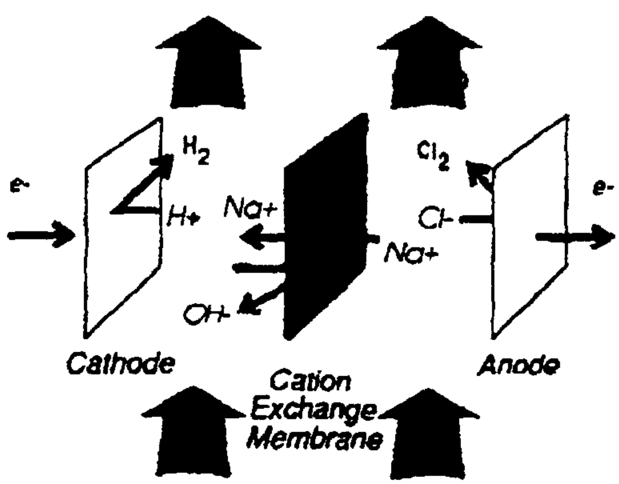
Each system has skid-mounted components with self-contained process and hazard alarms which interface to the Cloromat control panel which uses a graphic operator interface.

Ionics will provide the complete plant or system equipment specifications and process flow diagrams including all ancillary systems necessary for generating sodium hypochlorite solution.

Plus we provide all the expert technical assistance needed to get your operation off the ground and to keep it flying profitably.



MEMBRANE CAUSTIC CHLORINE CELL

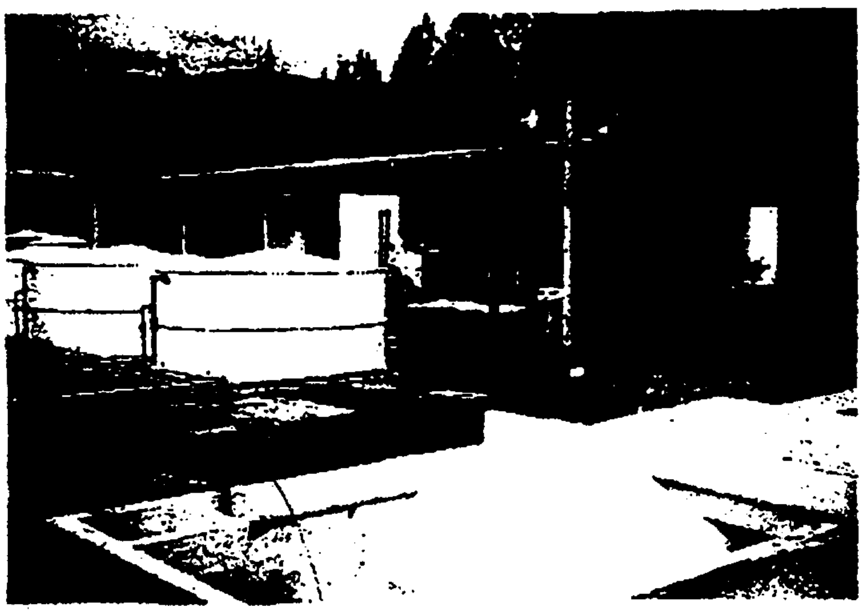


With Ionics membrane cell technology a DC current is forced through the membrane. Chlorine is generated at the positive poles while an equal amount of caustic soda is generated at the negative poles. Hydrogen is a by-product. The chlorine and caustic are immediately reacted to form bleach so that virtually no free chlorine is present in the plant.

Partnership for Success

Ionics offers complete services, ranging from own and operate arrangements to the supply of all process equipment for the Cloromat plant.

Equipment selection depends upon labor cost, technical skills of the labor force and operator, quantity to be produced and raw material costs and availability. With this variety of options, Ionics strives to work closely with all our clients to achieve the most economical performance.



For More Information, Contact:
J. Craig Weeks
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65 Grove Street
Watertown, MA 02272

Tel: 617-926-2500
FAX: 617 924-2225

IONICS, INCORPORATED

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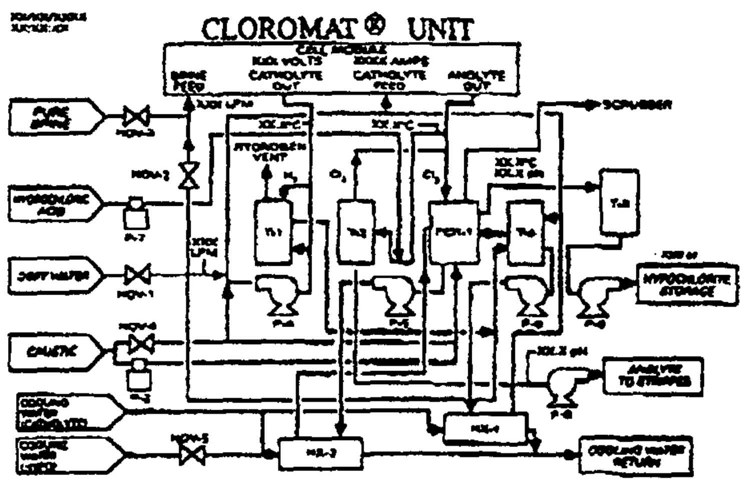
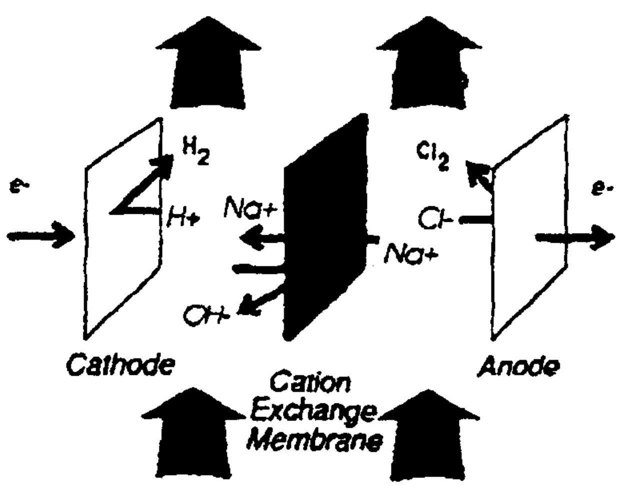


MEMBRANE CAUSTIC CHLORINE CELL



With Ionics' membrane cell technology a DC current moves ions through the membrane. Chlorine is generated at the positive poles while an equal amount of caustic soda is generated at the negative poles. Hydrogen is a by-product. The chlorine and caustic are immediately reacted to form bleach so that virtually no free chlorine is present in the plant.

Applications

- Bleaching
- Swimming Pool Disinfection
- Drinking Water Disinfection
- Cleaning
- Oxidation
- Cooling Water Chlorination
- Process Water Chlorination
- Wastewater Chlorination

Ionics is a diversified, worldwide company specializing in the supply of membrane systems and related equipment, water and chemical supply, and consumer water products.

IONICS
IONICS, INCORPORATED

SPECIALTY CHEMICALS
65 Grove Street
Watertown MA 02172
USA
Tel (617) 926-2500
Fax (617) 926-4304
Telex 922478

Cloromat

Sodium Hypochlorite Generator

5 Tons per Day of Available Chlorine Generating Capacity

IONICS
IONICS, INCORPORATED

The Cloromat System

Now bleach manufacturers and large volume users of chlorine disinfectants can produce sodium hypochlorite on-site without chlorine gas. Ionics Cloromat systems produce sodium hypochlorite electrically from common sodium chloride salt and water. Cloromat systems are safe and economic to operate and are proven in dozens of successful installations around the world.

On-site generation of sodium hypochlorite eliminates the risks of transport, storage, and handling of hazardous chemicals for industrial, commercial and municipal users. Conventional bleach manufacturing techniques use chlorine gas and sodium hydroxide. Ionics Cloromat units simplify raw material procurement, storage, and manufacture of chlorine cleansers, whiteners, and disinfectants. With increasing public concern about the use and transport of hazardous materials, liquid sodium hypochlorite produced by Ionics Cloromat systems provides an environmentally-sound alternative to conventional bleach production.

Sodium hypochlorite is widely recognized as the most effective disinfectant against water-borne pathogens and microbes, with longer disinfection life than alternative chemicals. Industrial and municipal wastewater treatment are among many recent Cloromat applications.

In addition to thorough and dependable Cloromat unit design, installation, and field and service support, Ionics provides comprehensive, single-source plant engineering and system design. Ionics' turnkey capabilities reduce project time from installation to successful startup. Sodium hypochlorite generation with Ionics Cloromat systems is a safe and efficient method to meet your bleach demand at market-competitive costs.

Cloromat Performance

- ***Durable and Proven Membrane Process***
- ***Produces any Bleach Concentration up to 150 g/L Available Chlorine***
- ***Eliminates Dependence on Chemical Suppliers***
- ***Eliminates Transportation and Storage of Chlorine Gas***
- ***Pretested Modular Components Speed Installation and Start-up***
- ***Simple and Reliable Operation by Plant or Ionics Staff***

Cloromat Specifications

Production Capacity: 5 tons available chlorine

Production Rate (gpd): 8,000
as 15% trade sodium hypochlorite (NaOCl)

Power Supply: 3 Phase 50/60 Hz

Total Installed Pump HP: 25

Installed KVA: 950

Feedstocks: Soft Water
Purified Saturated Sodium Chloride Brine
Cooling Water
Sodium Hydroxide
Hydrochloric Acid

Control System: Allen-Bradley PLC 5 with SCADA interface

Unit Consumptions:
(100% mass basis)

drysalt:available chlorine	2.1:1
caustic:available chlorine	0.1:1
acid:available chlorine	0.07:1

Power Consumption: 4000 AC KwHr
(per ton of available chlorine)

Process Discharges: NaCl
Hydrogen

Equipment Area: minimum 10,000 ft²

APPENDIX III

"ANALYSIS OF POTENTIAL SOLAR POND APPLICATIONS FOR BRINE MANAGEMENT OF CROTON CREEK WATERS, STONEWALL COUNTY, TEXAS"

PRELIMINARY STUDY, FINAL REPORT, OCTOBER, 1996, BY J. WALTON ET. AL.

UNIVERSITY OF TEXAS AT EL PASO, CENTER FOR ENVIRONMENTAL RESOURCE MANAGEMENT TO TEXAS WATER DEVELOPMENT BOARD.

ANALYSIS OF POTENTIAL SOLAR POND APPLICATIONS FOR BRINE MANAGEMENT OF CROTON CREEK WATERS, STONEWALL COUNTY, TX

PRELIMINARY STUDY
FINAL REPORT

OCTOBER 1996

BY

JOHN WALTON, ANDREW SWIFT, AND HUANMIN LU
UNIVERSITY OF TEXAS AT EL PASO
CENTER FOR ENVIRONMENTAL RESOURCE MANAGEMENT

TO:

TEXAS WATER DEVELOPMENT BOARD

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Analysis of Potential Solar Pond Applications for Brine Management of Croton Creek Waters, Stonewall County, TX
UTEP College of Engineering

Introduction

The purpose of this study was to investigate the technical and economic feasibility of development of salinity gradient solar ponds using the flow from Croton Creek located in Stonewall County, Texas. Because of the high salinity of the creek waters, solar ponds may represent an economically attractive option for the area. This report is limited to analysis of potential solar pond applications and does not consider all options for brine management in the area.

Croton Creek waters were analyzed and found to be of sufficient density (specific gravity ~1.17) for a solar pond without additional treatment. Chemical analysis indicated that the primary cation is sodium (Na^+) followed by calcium (Ca^{2+}) and magnesium (Mg^{2+}). The geochemical computer program MINTEQ was run in order to characterize the minerals potentially controlling solution composition. The water was found to be very close to saturation with halite (NaCl) and slightly undersaturated with respect to mirabilite (Na_2SO_4). The water is supersaturated with respect to anhyrite ($CaSO_4$) and gypsum ($CaSO_4$).

The ionic composition of the Croton Creek water is dominated by sodium chloride (NaCl) to a much greater extent than sea water, facilitating production of high quality sodium chloride salt. For example the mass ratio of sodium to magnesium (magnesium is undesirable in product salt) is 8.3 in sea water and around 40 in Croton Creek (Stumm and Morgan, 1981). The molar ratio of calcium to sulfate is near one in Croton Creek waters and both anhydrite and gypsum are supersaturated, indicating that most of the calcium and sulfate can be easily precipitated during early evaporation stages.

Two separate numerical and mathematical models were applied to energy production for various applications and desalination associated with a hypothetical salinity gradient solar pond located in Stonewall County. The existing model, PONDFEAS, was run to estimate the thermal efficiency and heat production of salinity gradient solar ponds of differing size and load using site specific data representative of Stonewall County, Texas. A second model was developed at UTEP to estimate the performance of Cascade evaporator and desalination units. The model shows how design parameters, costs, and distilled water production depend on process variables such as pond and ambient air temperatures.

Solar Pond Technology

Salinity-gradient solar ponds combine solar energy collection with long term storage. They are simple in design and low in cost. Such ponds may be a reliable source of heat for a wide range of industrial and agricultural applications such as process heating, space heating, desalination and in some locations electricity generation. A typical salinity-gradient solar pond has three regions. The top region is called the surface zone, or upper convective zone. The middle region is called the gradient zone, or nonconvective zone. The lower region is called the storage zone or lower convective zone.

The lower zone is a homogeneous, concentrated salt solution that can be either convecting or temperature stratified. Above it the nonconvective gradient zone constitutes a thermally insulating layer that contains a salinity gradient. This means that the water closer to the surface is always less concentrated than the water below it. The surface zone is a homogeneous layer of low-salinity brine or fresh water. If the salinity gradient is large enough, there is no convection in the gradient zone even when heat is absorbed in the lower zone, because the hotter, saltier water at the bottom of the gradient remains denser than the colder, less salty water above it.

Because water is transparent to visible light but opaque to infrared radiation, the energy in the form of sunlight that reaches the lower zone and is absorbed there can escape only via conduction. The thermal conductivity of water is moderately low, and if the gradient zone has substantial thickness, heat escapes upward from the lower zone very slowly. This makes the solar pond both a thermal collector and a long-term storage device. Solar ponds have several advantages over other solar technologies. They have low cost per unit area of collector, inherent storage capacity, and are easily constructed over large areas. Therefore, solar pond technology may be an important technology in a shift from carbon based fuels to renewable energy technologies.

Space Heating Applications

One potential use for a solar pond is to produce low grade heat energy for simple heating. Examples include space heating of greenhouses, aquaculture, enhancement of evaporation from a salt works, crop drying, and heating of commercial

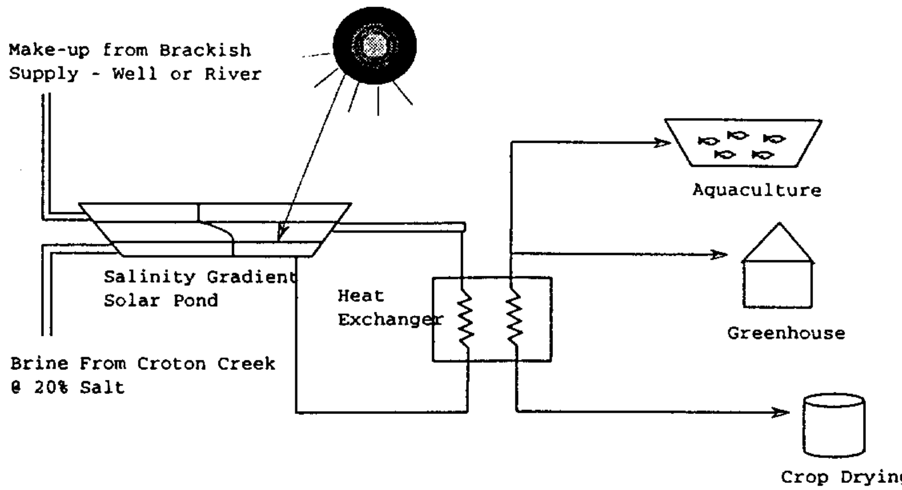

Figure 1. Schematic of space heating applications.

uildings in the winter. Figure 1 shows a schematic of these applications. The solar pond was nodeled with the existing program PONDFEAS, a program developed by G.L. Cler and T.A Newell. PONDFEAS solves the energy equations for a solar pond using the finite difference nethod in order to predict the production of thermal energy. The PONDFEAS program was run nultiple times to determine the potential energy yield from different sizes and loadings of solar onds with site specific weather and ground conditions.

Figure 2 gives the space heat production from solar pond as a function of the fraction of the total pace heating supplied by the solar pond. The heat ; assumed to be provided at 25°C and the heat emand is based upon the differential between mbient temperatures and the space heat emperature of 25°C (i.e., heating degree days). In ie case where the solar pond is to supply 100% of ie space heating demand, the pond must be sized irge enough to supply 100% of the demand in ecember and January – the time of the year when

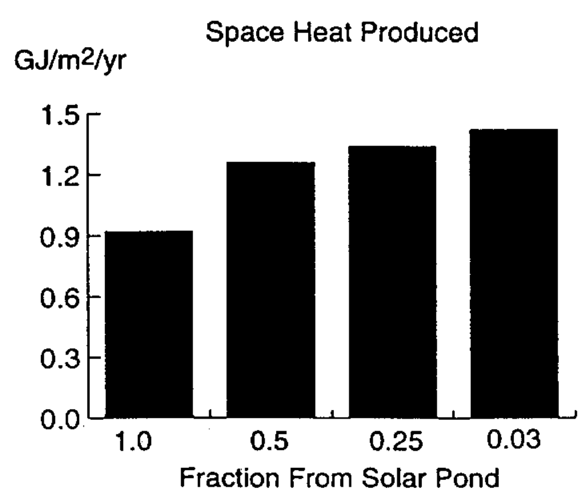

Figure 2. Space heat production.

eating demands are greatest and pond production of heat the lowest. If the solar pond is used to rovide only a portion of the space heating requirements (e.g., supplemental gas heating is used in ecember and January) then greater demands are placed on the solar pond in the Fall and Spring

– times when more solar energy is available. Examination of Figure 2 indicates that solar pond heat is about 30% less expensive when used as supplemental source of heat rather than the sole source of space heat. The estimated levelized cost of energy from a solar pond (space heat application) ranges from 1.5 \$/GJ to 2.2 \$/GJ (note: 1GJ is approximately equal to one million BTU). Energy production ranges from 0.9 to 1.4 GJ/m^2/yr (3400 to 5400 Million BTU/acre/yr).

Salt Production Coupled with Desalination

A second option is to build a solar pond and use the heat from the pond to produce salt for commercial sale (e.g., road salt, livestock food supplements, table salt) along with distilled water. Cascade evaporators have been applied commercially to dry industrial brines for disposal and may be feasible for desalination with a solar pond. The Cascade units have fewer scaling problems than multistage flash distillation units, which is important for highly concentrated brine. The Cascade units work by evaporating brines in an ambient air stream using a supplemental heat source. The operational efficiency of the Cascade units depends upon ambient conditions and the temperature of the heat source. The Cascade evaporators can be used for desalination through addition of a downstream condensation unit. The efficiency of the condensation unit depends upon the salt concentration, process temperature, and ambient air temperature. Figure 3 shows a simplistic schematic of the process. The Cascade units where chosen for this analysis because they require a low temperature heat source as can be supplied by a solar pond. If other energy sources are considered different evaporation and desalination options may be preferable.

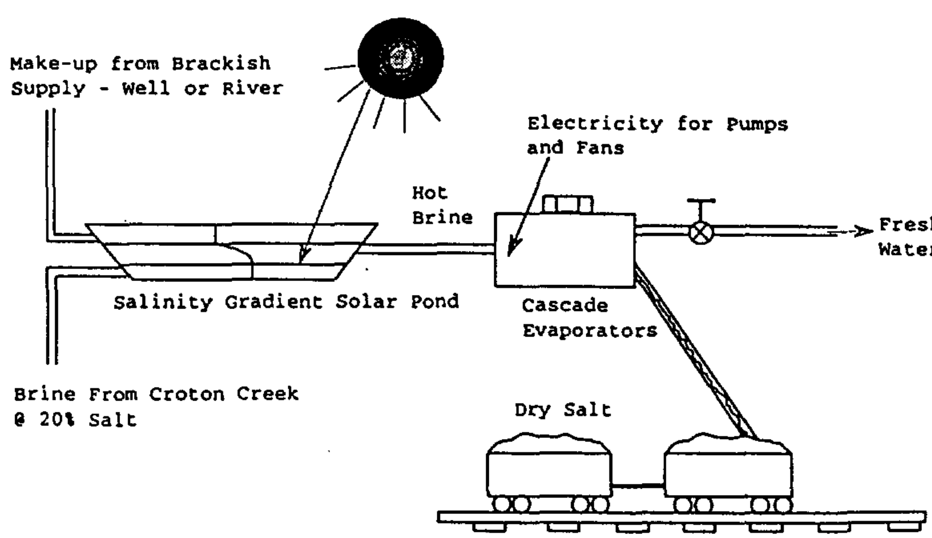

Figure 3. Cascade evaporation schematic.

A new model was developed at UTEP to simulate the energy balance, mass balance, and costs associated with Cascade evaporation and desalination units (Figure 3). The model was applied to the case of treating the entire flow of Croton Creek (assumed to be 450 gallons per minute). The major cost variables are the size of the solar pond required and the number of Cascade evaporator/desalination units. Pond size and number of units required are dependent upon operational variables such as pond temperature and ambient air temperature.

At low pond temperatures, most energy for evaporation comes from the ambient air (i.e., the evaporation units act like swamp coolers). This reduces the size of the solar pond required to produce the required energy, since more energy comes from the air, and the pond efficiency is improved. However at low pond temperatures, none of the evaporated water can be recondensed. Generation of condensate water is beneficial in that product water is produced and some of the energy of condensation can be captured and put back into the process, making it more energy efficient. The calculations shown here assume that 80% of the theoretically available energy from condensation can be captured and put back into the process. The theoretical recovery rate is reduced to account for the hygroscopic nature of the salt solutions. For a saturated sodium chloride solution (assumed in the calculations) the equilibrium water vapor pressure is 75% of the value for pure water. If less than 80% of the theoretical condensation energy can be captured then the operation will be less efficient than shown here at higher pond temperatures. The estimated energy use as a function of pond operational temperature (process temperature) is shown in Figure 4. Pond energy use is small at low process temperature then rises through a maximum when condensation begins to occur above 26°C. Even though solar ponds operate at lower efficiency at higher temperature, the increased condensation results in greater overall efficiency (lower required pond size) at higher pond temperature due to the capture of the heat of condensation.

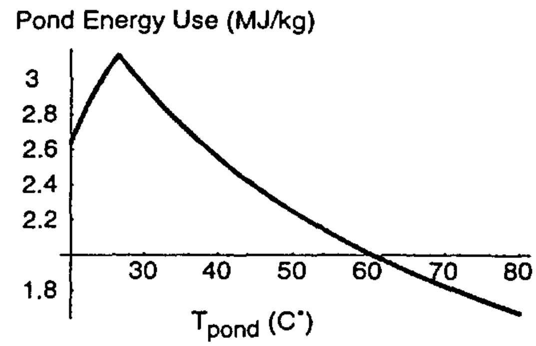

Figure 4. Pond energy use in MJ per kg of water evaporated.

Figure 5 gives the required pond size corresponding to the energy use with process (pond) temperature as a parameter. The number of cascade evaporator units required as a function of process temperature is shown in Figure 6. Air holds more moisture at higher temperatures

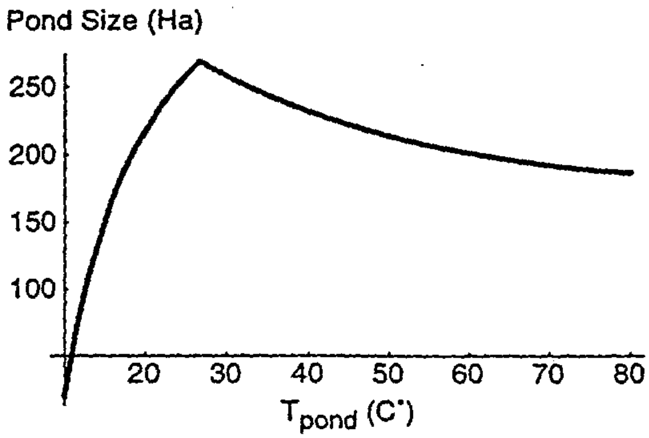

Figure 5. Solar pond size (1 Ha equals 10,000 m^2 or 2.5 acres).

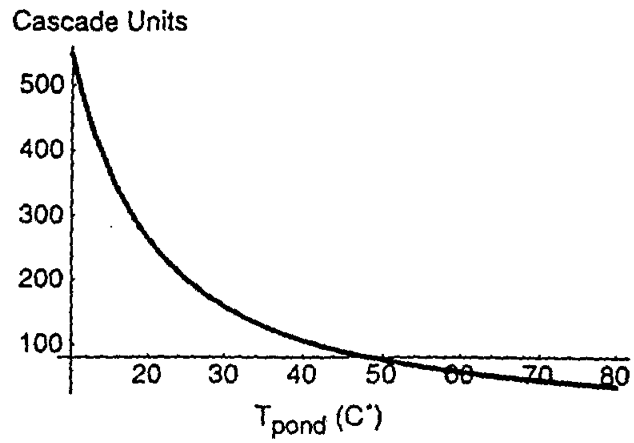

Figure 6. Number of evaporator units.

resulting in more evaporation per unit (and a need for fewer units). The performance assumptions made for the Cascade units, especially the water, salt, and heat recovery rates are based upon engineering projections combined with limited operating experience.

Combining the above calculations with cost factors for the solar pond and Cascade evaporator units gives an estimate of the cost of the combined salt production and desalination system. Figure 7 breaks the costs into levelized annual solar pond, evaporation units, and total cost. All of the above two dimensional graphs were calculated assuming the input ambient air is at the annual average temperature for Stonewall County, Texas. Figure 8 gives the same calculations when ambient air and process temperature are both allowed to vary. Figure 7 represents a cross section of Figure 8 at $T_{air} = 16°C$. A more detailed study would combine monthly temperature and humidity values and calculate monthly performance. This level of detail, however, is beyond the scope of this report.

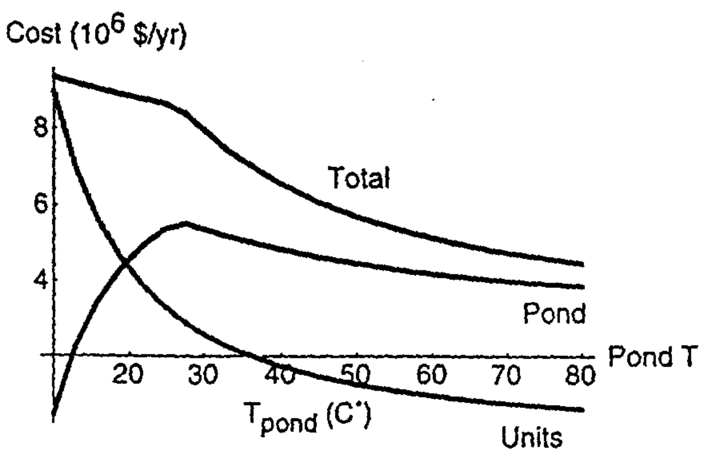

Figure 7. Total levelized annual costs.

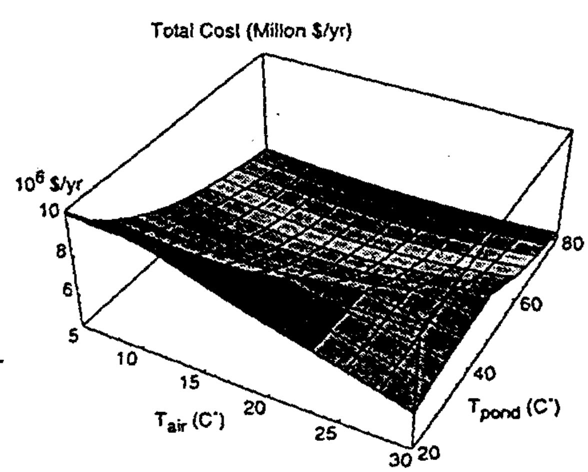

Figure 8. Total levelized annual costs.

Economics

There are three potential sources of income for this scenario: 1) sale of salt, 2) sale of distilled water, and 3) income from the local river authority for salt load reduction downstream.

If salt can be sold at $22/ton then approximately 5 million dollars of income are produced per year from the Croton Creek salt. More exact figures would require a detailed analysis of the product salt production process and salt market. Estimated distilled water production is given in Figure 9. Higher operational temperatures produce a greater degree of water recovery. Water produced can be compared to Croton Creek flow of approximately 450 gpm. At higher process temperatures, this is enough water to supply a town of approximately 5,000 people. At a value of $2/1000 gal this provides income of about $270,000 /yr. The value of the water would be much greater if an industry requiring high quality, distilled water, were present locally. The third source of income is the economic value of keeping the excess salt from entering the Brazos River. We do not have any estimates of the economic value of salt removal although the Bureau of Reclamation has used such values in past studies for other locations.

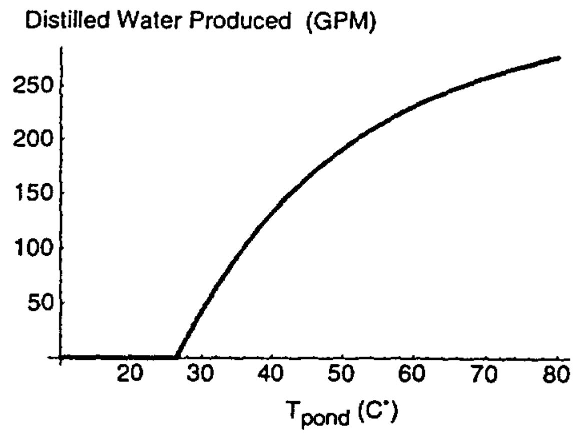

Figure 9. Water produced.

The calculations indicate that for desalination the solar pond should be operated in the high temperature range. With current estimates, the costs for the solar pond desalination and salt production facility are approximately equal to the income produced from selling the salt. Income from water production is not significant. Given the economic risks involved, desalination and salt production using solar pond technology appears economically favorable only if high value can be placed on distilled water production and removal of salts from the Brazos River. The assumed variables of the Cascade units, when applied to product salt recovery and desalination, require pilot scale verification prior to field application.

Salt Production Without Desalination

A third option for the site is to develop a traditional salt works and sell the salt (Figure 10). A good introduction to the operation of a salt works can be found at: (http://www.dampiersalt.com.au/index.html). As an initial estimate we assumed that saturated NaCl brine will evaporate at half the local pan evaporation rate. Using this basis we estimate evaporation ponds of 150 Ha (375 acres) area are required to evaporate the flow of Croton Creek. An initial estimate is that the evaporation ponds and salt works are approximately the same cost as a solar pond with the same area giving an annualized cost in the range of 3-4 million dollars per year. Smaller sized solar ponds could also be incorporated into a salt works. For example:

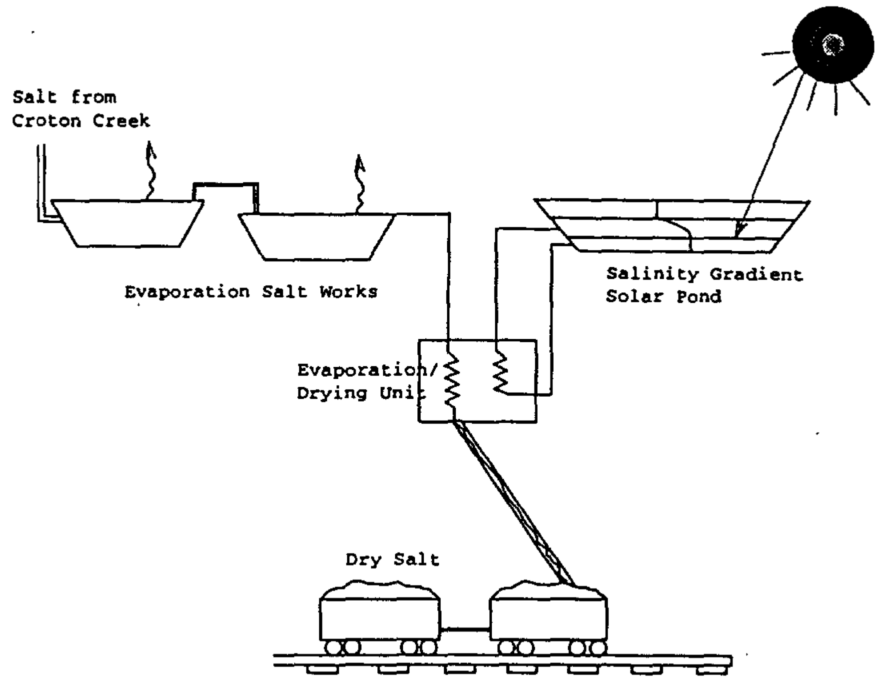

Figure 10. Solar pond for final drying of salt.

- A smaller solar pond could be used for final drying as part of a salt works. The salt should be anhydrous prior to sale and this generally requires a heat source.

- A solar pond could be used to apply supplemental heat for evaporation in a salt works (e.g., heated pipes placed below evaporation ponds). This space heat application for a solar pond is a lower cost method for enhancing evaporation if no desalination is desired.

If the estimated salt price of $22/ton can be obtained then development of a salt works appears economically attractive, based on this very preliminary analysis.

Conclusions

This study uses best estimates of report parameters for the Croton Creek and Stonewall

County, Texas area for using solar pond technologies for brine management. A salinity gradient solar pond is a potential lower cost alternative for supplying space heating for a variety of potential applications using Croton Creek brine. Delivered heat costs on the order of $2/MBTU appear feasible. Desalination of water and salt production with a solar pond does not appear economically feasible unless a high value can be placed upon the avoided cost of keeping Croton Creek brine out of the Brazos River. A traditional salt works to produce salt from Croton Creek by evaporation appears economically feasible based on a preliminary analysis.

If a decision were made to proceed with a solar pond option, a staged development would be most practical. That is, a pilot sized solar pond on the order of 10 to 25 acres would be built to confirm operation and cost estimates and if successful would be followed by larger scale modular development.

A combination of strategies may be attractive, depending on circumstances. For example, solar ponds that use the Croton Creek brine for space heating alone do not address the brine disposal and Brazos River salt avoidance issue. Likewise, an evaporative salt works alone does not take advantage of the inexpensive heat available from a solar pond built using Croton Creek brine. As project proposals are suggested, a more detailed system performance and cost analysis could be completed based on the models used in this study.

References

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