KLEBER J. DENNY, INC.

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FINAL REPORT OF INVESTIGATIONS ON

UTILIZATION OF GEOPRESSURED/GEOTHERMAL RESOURCES (GP/GT)

FOR ADDITIONAL WATER SUPPLY IN THE

LOWER RIO GRANDE VALLEY

Prepared For:

Texas Water Development Board Pursuant To Contract No. 93-483-373

Coordinated By:

Kleber J. Denny, Inc.

February 10, 1994

Houston Office
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312 Grandview, San Antonio, Texas 78209 (512) 828-1640

February 10, 1994

Mr. Craig D. Pedersen
Executive Administrator
Texas Water Development Board
P.O. Box 1231
1700 North Congress Avenue
Austin, Texas 78711-3231

Attention: Mr. J.D. Beffort, Contract Manager

Re: **TWDB Contract No. 93-483-73: Water Research Grant to Evaluate Utilization of Geopressured/Geothermal (GP/GT) Resources for Additional Water Supply in the Lower Rio Grande Valley (LRGV), Texas.**

Dear Mr. Pedersen:

Pursuant to the terms of our Contract, the purpose of this correspondence is to transmit to your office twelve (12) copies of the **Report of Investigations** (i.e. Task No. IV) which is basically a compilation of our work in satisfaction of the above referenced Grant. Additionally, we are returning to your J.D. Beffort under this cover that portion of our previously submitted draft which he lent us recently for purposes of our incorporating his review comments.

Finally, by your receipt of this correspondence, we are requesting the release of the $7,500 amount held in retainage upon your acceptance of this **Report of Investigations**.

We greatly appreciate the opportunity to be of service to you, and we look forward to a continuing working relationship with TWDB.

Best regards,

Kleber J. Denny, P.E.

Kleber J. Denny, P.E.
President

cc: Mr. F.J. Spencer

Enclosures

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TABLE OF CONTENTS

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FINAL REPORT ON

TEXAS WATER DEVELOPMENT BOARD RESEARCH CONTRACT NO. 93-383-473

APPROVED JUNE 17, 1993

INVESTIGATION OF THE GEOPRESSURED/GEOTHERMAL WATER RESOURCE IN THE LOWER RIO GRANDE VALLEY OF TEXAS

EXECUTIVE SUMMARY

A. INTRODUCTION

The existence of a series of sizeable reservoirs of hot, pressurized, salty waters underneath the Counties of Hidalgo, Cameron and (to a much lesser extent) Willacy in the Lower Rio Grande Valley (LRGV) of Texas had been estimated in general terms ever since the mid-Seventies. Preliminary studies by the Alternate Energy Department of the University of Texas - Austin had shown the likelihood of these reservoirs at depths estimated at from 8,000 to 15,000 feet underground and had attempted some initial measures of temperature, pressure, salinity and quantities.

The U.S. Department of Energy had also funded some research into these Geopressured/Geothermal (GP/GT) resources along the Western Louisiana and Upper Southeast Texas Coasts, beginning in 1976. These attempts were considered significant enough to warrant the formation of a Joint Government/Industry GP/GT Consortium for Commercialization of these resources in 1990.

Thus, a fairly large body of initial work had established the existence and major features of these waters. It was felt important to investigate the potentials for the utilization of these deep GP/GT waters, both as a source of heat for the desalination of shallow, brackish waters that underlie much of the LRGV as well as for the resources that they contained. These included dissolved natural gas, the pressures that could be harnessed for electrical power production and, eventually, the considerable quantities of water that could constitute a vital alternate and independent water supply.

In the particular case of the occurrences of both the shallow, brackish groundwaters as well as the deep GP/GT waters underneath the LRGV, a group operating as Kleber J. Denny, Inc., decided to take the lead in approaching the Texas Water Development board (TWDB) with an Unsolicited Proposal for an Investigation into the Utilization of the GP/GT Resource as an Alternative Source of Water and Energy for the LRGV. This decision has been very timely in light of the following developments:

A. The quality of water from the Lower Rio Grande River has been found to be steadily deteriorating as a result of the combination of a prolonged drought and a variety of increasing contaminants into the River, all of which have raised the real concern of safeguarding the Public Health

B. The advent of the El Cuchillo Dam Project in Mexico (now nearing completion and expected to be in operation by the beginning of the second quarter of 1994) has spelt possible disruptions to the overall flow of the Rio Grande River in the LRGV segment

C. The ultimate fate of the Channel Dams project, intended to create an additional 110,000 acre-feet of water supply for the City of Brownsville, has remained in doubt, as several factors entered the picture to impose constraints on both the timetable and the estimated costs of this project.

As a result of the submission of the above Unsolicited Proposal to the TWDB and several subsequent meetings, the Staff of the TWDB recommended to the full Board that this Proposal be accepted, and same was so approved on June 17, 1993.

This Draft Final Report describes the scope of this Investigation and the results obtained therefrom, along with a set of Conclusions and Recommendations for further work.

B. SUMMARY OF CONCLUSIONS

A. Ample water exists throughout the study area in both shallow, brackish groundwaters and in deep GP/GT zones.

B. The thermal energy of the GP/GT waters is ample for the purposes of driving purification units using one or more desalination processes.

C. The entrained natural gas in the GP/GT resource exists in quantities sufficient to provide ample on-site power for the desalination complex.

D. There is enough potential hydraulic energy in the GP/GT fluids to warrant significant further investigation as to its utilization commercially.

E. Autodesalination is seen to be currently infeasible on a technical basis thus obviating its use as a viable alternative.

F. Brine disposal must receive high-priority attention, with quantification of economics necessary.

REPORT ON

TASK NO. I: CO-LOCATION STUDIES

A. INTRODUCTION

The first task in our Work Statement is entitled: "Co-Location Studies" and seeks to establish a base of information as to the locations within Cameron and Hidalgo Counties that constitute the best potentials for tapping into each of the shallow, brackish groundwater occurrences and the deep GP/GT resource occurrences, wherever they are found close to defined population centers in these two Counties. The preliminary screening of Willacy County established that the underground resources did not appear to be of significant magnitude, compared to those of the other counties in the study area.

The objective of this Task is to identify where both shallow waters and deep-water/energy sources occur close to each other in relation to the surface, but obviously separated by varying depths below the surface. In each such co-location, one would expect to maximize the lowest-cost approach to yield significant quantities of treated, potable water once the efforts of this investigation are completed.

B. METHOD

In order to simultaneously examine the locations of

1. the GP/GT Fairways,
2. the productive zones of mildly/moderately brackish groundwater and
3. population centers,

transparent drawings illustrating the locations and characteristics of 1. and 2.above in relation to County lines have been prepared for both Cameron and Hidalgo Counties. These drawings are then overlaid on base maps which illustrate 3. above for both Counties. The sources of information used for each layer are as follows:

C. RECOMMENDATIONS

In light of the above conclusions, it is strongly recommended that:

A. The TWDB see its way clear to permitting a continuation of these efforts to enable the development of key parameters for a combined water-power complex that would yield optimal economics for desalinated water. A major incentive for this continuation is the high potential of reducing the overall costs of desalinated water via on-site power production, energy costs being the largest single component of overall desalination costs

B. Significant attention be devoted to the opportunities and problems involved in generating electrical power from the hydraulic velocity of the GP/GT waters to enable important reductions in the overall costs of desalinated fresh water derived from both shallow and deep sources. This would be in addition to the savings resulting from on-site utilization of the separated Natural Gas for the production of electrical power as well

C. The major objective of this continued effort be the development of sufficient information to enable the implementation of a suitably sized demonstration plant. Of particular importance is the further study to determine the feasibility of combining the injection well for the GP/GT brine disposal, with that for the brine disposal from the desalination plant as a means of further economy.

D. The chemical and thermal potentials of both brine streams (as in D above) be carefully and critically evaluated for the longer-range onset of additional industries in the LRGV to commercialize said potentials.

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1. GP/GT Fairways

Information provided by Mr. R. W. Rodgers, Professor of Geology at U.T./Pan American, Edinburg, Texas. The identity of each letter presented in this overlay is as below:

A - Coastal Miocene Trend(includes prospective reservoirs studied under recent USDOE Contract No. 2069)
B - Lower-Salinity Frio Trend
C - Frio-Vicksburg Trend
D - Vicksburg Trend

Professor Rodgers has qualitatively ranked the overall potential of these Fairways as shown below:

Fairway	Ranking
A	Medium
B	Medium
C	High
D	Low

2. Productive Zones of Mildly/Moderately Brackish Groundwater

Most of the information ,utilized in this layer was obtained from Figures 5 and 12 of the TWDB Report No. 316 entitled: "Evaluation of Groundwater Resources in the Lower Rio Grande Valley, Texas" (1990). Figure 5 is entitled: "Approximate Productive Areas of The Major Sources of Groundwater in the Lower Rio Grande Valley" and Figure 12 is entitled: "Chemical Quality of Water in the Evangeline and Chicot Aquifers". The approximate configuration of the 5,000 mg/l.TDS contour line was taken from Figure 7 of the Texas Department of Water Resources Report No. 279, entitled: "Occurrence and Quality of Groundwater in the Vicinity of Brownsville, Texas (1983)". Figure 7 is entitled: "Dissolved Solids Concentration in Water from The Deep Zone". Copies of several of these Figures are enclosed in this Report.

The identity of each number presented in this overlay is as follows:

(1) - Upper Part of Chicot Aquifer: Alluvial Deposits of the Rio Grande (Recent and Pleistocene)
(2) - Middle Part of Chicot Aquifer: Beaumont Formation (Pleistocene)
(3) - Lower Part of Chico Aquifer and Evangeline Aquifer: Lissie Formation (Pleistocene) and Goliad Formation (Pliocene)
(4) - Oakville Sandstone(Miocene).

3. Population Densities

Base Maps of Cameron and Hidalgo Counties were utilized to represent the population densities of both incorporated and Colonia areas of each county. It is our understanding that these maps were the basis for the information in the TWDB Report entitled: "Water and Wastewater for the Colonias of the Lower Rio Grande Valley of Texas"

C. SUMMARY AND CONCLUSIONS

The pertinent results of the Co-Location Studies for Cameron and Hidalgo Counties are presented on the enclosed Figures 1 and 2, respectively; these being compilations of the various overlays.

1. The occurrences of brackish groundwaters at shallow depths are extensive enough so that choices of locations will not be unduly constrained

2. Preliminary screening of the GP/GT Resource occurrences has revealed that area A in the Rodgers Map, already extensively studied in the previous USDOE investigation referred to above, should not require further study. Area D of the Rodgers Map is also shown to be less desirable from the standpoint of both the extractable heat energy and the water quality. Thus, it is concluded that Areas B and C of the Rodgers Map are those that clearly merit further study in the Resource Assessment portion of this investigation and will be those on which we will concentrate henceforth

3. A sufficiency of population densities appears to overlie - or be in close proximity to - both shallow groundwater and deep GP/GT sources to enable promising utilization of these resources in the future.

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FIGURE 1

CO-LOCATION
FOR

Cameron County

Productive zone in major water-bearing stratum

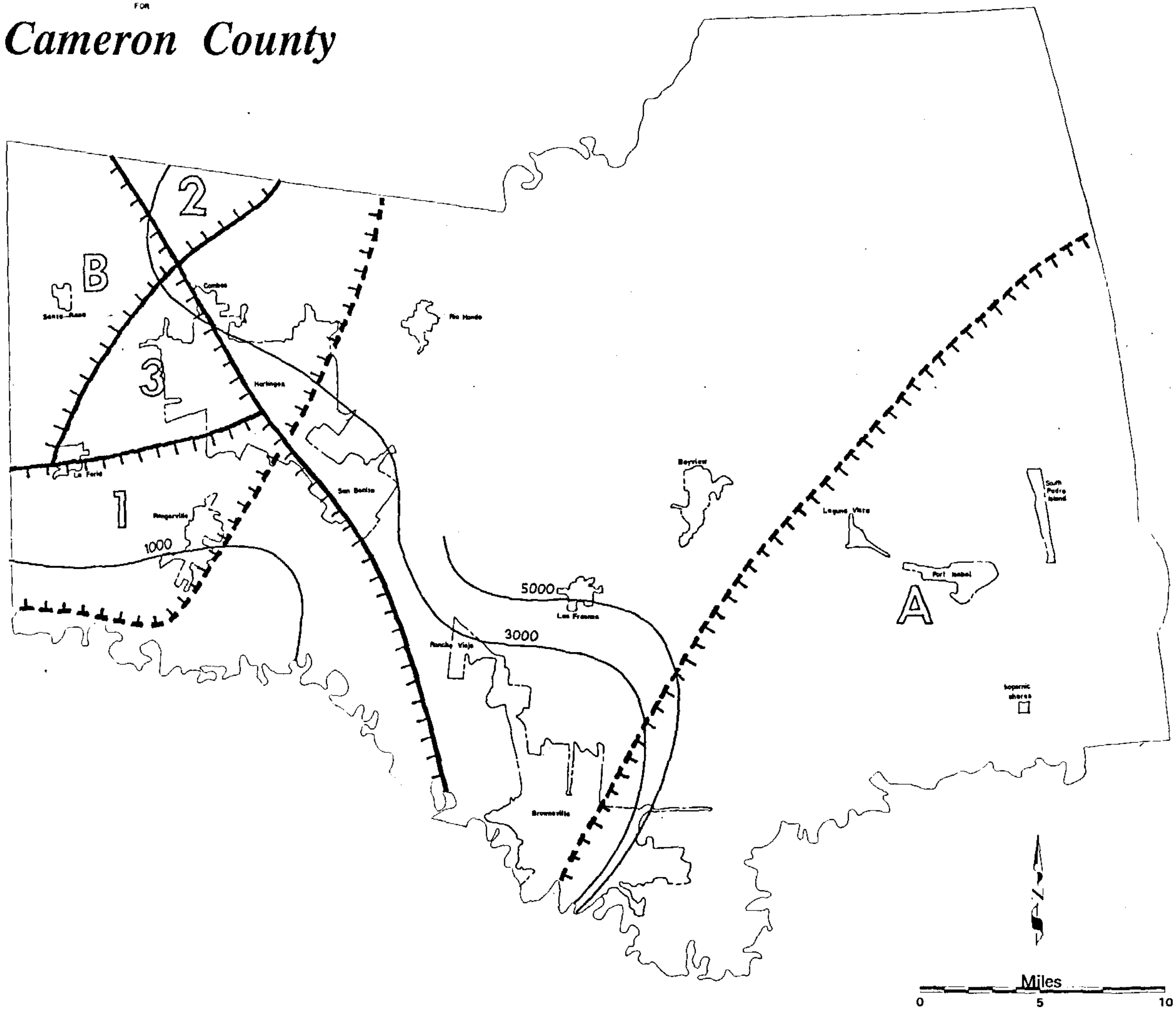
Barbs along boundary point into zone. Identifying number is explained in the accompanying report.

Line of constant tds in Chicot and Evangeline aquifers

Number is total concentration of dissolved solids (tds) in mg/l and is written on the side of the line where the concentration is higher.

Geothermal fairway

Barbs along boundary point into fairway. Identifying letter is explained in the accompanying report.



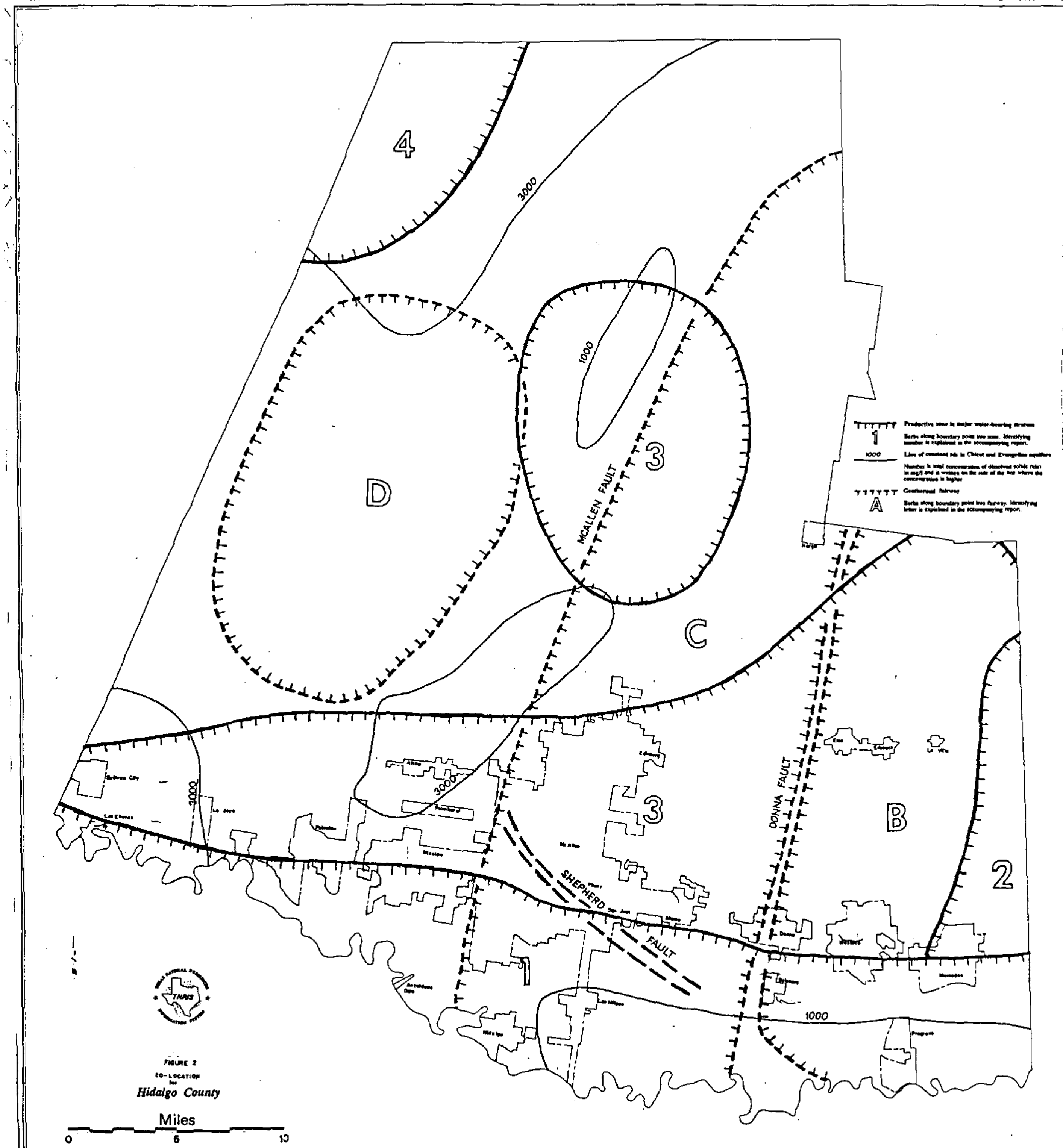


FIGURE 2
CO-LOCATION
for
Hidalgo County

REPORT ON

TASK NO. II - RESOURCE ASSESSMENT

Introduction

The content of this Report is appropriately divided into two separate Sections, specifically, the following:

Section I - An assessment of the Geopressured/Geothermal (GP/GT) Resource

and

Section II - An assessment of the Brackish Groundwater Resource

Additionally, the content of Section I is subdivided into two parts, specifically, the following:

Part A - Geologic Assessment

and

Part B - Simulation of GP/GT resource potential

As stated at the conclusion of our Report on Task No. 1: Co-Location Studies, the geographic focus of Section I of this report on **Task No. 2** is: Fairway Areas B and C as identified in the Co-Location Studies. Likewise, the geographic focus of Section II is on those areas illustrated in Figure 5 of TWDB's Report No. 316, entitled "Approximate Productive Areas of the Major Sources of Groundwater in the Lower Rio Grande Valley", particularly those areas exhibiting TDS levels less than 5,000 ppm.

In general, the intent of the Report on Task No. 2 is to present pertinent information regarding the recoverable volumes and physical and chemical characteristics of both the GP/GT and Brackish Groundwater resources in those geographic areas mentioned above. The task of converting the information presented in the Report into projected quantities of water - available for industrial and municipal purposes - and that of developing the magnitude of the various energy forms for desalination are to be presented in **Task No. 3 - Alternate-Design Systems Evaluation.**

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Table 5

Selected Formation Water Analysis for Oligocene - Age Reservoirs, McAllen Ranch Area

Well	Depth (m)	Na	K	Li	Ca	Mg	Sr	Ba	Zn	Fe	Mn	Cl	SO_4	H_4SiO_4	Br	I	B	T.Alk.	δO	δD	87/86	δB	$\%CO_2$
B-16	3983	3258	308	6	163	2	21	5		5.2	.2	5090		377	20		90	701	6.9	-31	0.70671	20	
B-21	4113	2741	288	6	57	1	8	4	1.2	9.0	0.1	4170		432	16		75	804	4.8	-15	0.70691	22	
B-22	4085	2837	318	5	164	2	22	6	0.5	6.6	0.2	4470		272	17		61	553	5.1	-20	0.70694	21	0.3
B-20	4135	2023	181	4	84	1	13	4	0.3	3.0	0.1	3210		249	12		55	628	5.7	-24	0.70684	20	
B-15	4082	2657	290	5	147	1	13	2	0.9	12.6	0.6	4120		401	16		93	582	6.9	-23	0.70740	22	
B-12	4162	3574	523	8	36	1	9	5		7.3	0.1	5199		417	20		100	789	6.6	-21	0.70710	22	
B-24		3327	360	6	165	2	23	5	0.1	14.7	0.2	5218		404	21		99	318	6.4	-16	0.70676	20	

1) Based on information provided by Dr. Hand, Professor of Geology at U.T. Austin.

2) Concentrations are in mg/L except for Br (mg/Kg). δ18O and δD are reported relative to SMOW and δ11B is relative to NBS#951, all in permil. T. Alk. is total titration alkalinity as bicarbonate. $\%CO_2$ is volume % CO_2 in co-produced gas.

Part A - Geologic Assessment

Introduction

The South Texas area within the Rio Grande Embayment has long been of interest for the possibility of geopressured-geothermal energy production from the high temperature, thick, massive sands of the deep Frio and Vicksburg Formations. These sands are part of a sequence of thick wedges of sediment containing enormous volumes of rock. The wedges consist of interbedded sand and shale, massive sandstone, and massive shale. Originally, these sand bodies formed extensive aquifers with considerable lateral extent (Henry and Morton, 1982). Within the Rio Grande Embayment, depositional pattern is also strongly affected by a series of major growth fault systems which affected both the sediment distribution and resulting structural style (Fig. 1).

Two reservoir areas, containing thick sand sequences and outlined by major north-south trending growth faults, have been defined (Fig. 2). Reservoir area C, defined by the major McAllen growth fault on the west, and the Donna fault on the east, contains two potential sand sequences: the Marks sand (Fig. 4), with an average depth of 9,881 feet, average pressure gradient of 0.73 psi/ft and an average temperature of 279°F, and the Bond sand (Fig. 5), with an average depth of 10,626 feet, average pressure gradient of 0.76 psi/ft., and an average temperature of 296°F.

Reservoir area B, defined by the Donna fault on the west and the Weslaco fault on the east, contains several thick sand sequences. However, the sand at 10,000 feet (Fig. 6) with an average depth of 10,033 feet, average pressure gradient of 0.745 psi/ft., and average temperature of 264°F, was picked as a potential reservoir because of its lateral persistence, and the extremely low salinity (4,000 ppm Cl) of the connate water.

It should be noted here that the depths referred to in the discussion, and indicated in the tables, are log depths uncorrected to sea level. All logs did not indicate the elevation from which the log was taken, and all logs did not indicate the ground elevation or the elevation of the rig floor and Kelly bushing. Average elevation within the study area is less than 100 feet above sea level; therefore, all depths should be corrected by a factor of approximately 80 feet. This difference does not have a bearing on values for temperature, pressure, porosity and permeability.

While both reservoirs have similar pressure gradients, reservoir C has much higher average temperatures, and reservoir B has much lower water salinities. Reservoir B would appear to have potential as a water source in addition to the geopressure-geothermal potential.

Previous Investigations

Previous investigations of the geothermal-geopressure potential of reservoirs in the south Texas area have been carried out by numerous entities, both private and public. Gulf Geothermal Corp. of Baton Rouge, La., and Magma Gulf Co. of Houston, Tx., conducted studies in the early 1970's with the intent to lease large tracts for possible drilling (Durham and others, 1974).

R. H. Wallace of the United States Geological Survey had earlier noted the extremely low salinity ("fresh") water sands in the deep Frio and Vicksburg formations in the eastern part of the Rio Grande Embayment (Wallace, 1974). S. S. Papadopulos of the U.S.G.S. demonstrated the hypothetical flow from a geopressured reservoir using the area outlined by the growth faults in Hidalgo County (Papadopulos, 1974). The Texas Bureau of Economic Geology (Bebout and others, 1975) has conducted a number of studies, which included the South Texas area, for the United States Department of Energy. One of the most extensive studies of the area was conducted by the Southwest Research Institute for the former United States Energy Research and Development Administration (Swanson and Others, 1976).

Procedure

Numerous regional studies of the South Texas area have resulted in the delineation of a number of geothermal-geopressure "fairways," primarily defined by specific sediment packages, and bracketed by major growth fault trends (Woodruff and others, 1982). Three of these fairways occur in Hidalgo County: a western fairway bounded by the Vicksburg fault trend in eastern Starr County and the McAllen fault, a central fairway outlined by the McAllen and Donna faults, and an eastern fairway outlined by the Donna fault and the Weslaco fault.

A preliminary evaluation of the three principal trends led to the conclusion that only the central and eastern fairways demonstrated sufficient potential for further investigation. Although temperatures and pressures in the western fairway are very high, the sands are not thick enough nor laterally persistent. The trend is also extensively faulted with numerous transverse faults and antithetic faults relative to the main faults. Reported porosities and permeabilities of the sands are also extremely low.

Focus was then directed to the central and eastern fairways which were designated Reservoir Areas C and B respectively. Using the available published information in addition to proprietary fault maps from Magma Gulf Co., and isopach maps from Mayfair Minerals Co., an analysis of all sands below the top of geopressure was conducted. Some 30 well logs in the two areas were analyzed, and 5 wells in each reservoir were chosen as key wells to represent the lateral variations of the sands within the reservoir (Tables 1 and 3). Two sands in Reservoir Area C were determined to have the optimum characteristics for production based on log characteristics (Fig. 4 and 5). These were primarily based on uniformity and lateral continuity of the sands, which included thicknesses sufficient to offset variation caused by faulting (Fig. 3). One sand in Reservoir area B was chosen, primarily because of the depth and extremely low salinity of the water (Fig. 6). Potential porosity and permeability values were based on both spontaneous potential and resistivity characteristics. Although there are numerous seismic lines in the area, no seismic data were acquired or evaluated because of budget limitations.

Geology

In the Rio Grande Embayment the Oligocene lower and middle Frio Formations are characterized by enormous thicknesses of sediment deposited as discrete sequences of sand and mud, which represent an orderly succession of lithologies reflecting depositional environment. Both deltaic progradation and delta-flank aggradation characterize the Frio sediments in the area. Thick sequences of shelf and upper-slope prodelta mudstone and delta-front sandstone are overlain by equally thick massive, shoreface to coastal-barrier sandstone (Finley and others, 1989).

The massive clays deposited in deep water have low densities compared to the superjacent sandstone bodies, and are also water saturated. The rapid deposition and sediment loading create unstable conditions which initiate and sustain movement of faults, slumps, and diapirs (Henry and Morton, 1982). Major growth faults were formed contemporaneously with deposition which caused substantial thickening of the sedimentary sequences. These growth faults form broadly arcuate zones parallel to the coast which contain sediment sequences that increase in thickness toward the faults, or away from the basin (Fig. 3).

Subsequently, with increased depth of burial, the sediments were subjected to increased pressures and temperatures. Compaction of the sediments resulted in pore waters being expelled from the clays into the more porous and permeable sandstones. Diagenesis at the clay-sandstone contacts resulted in permeability barriers which prevented further movement of the pore waters. These fluids became over-pressured by the weight of the compacting overlying sediments, and acted as thermal barriers by reducing heat flow in the sediments.

The sandstones were deposited in nearshore environments that included distributary channel or delta-front environments, or as barrier islands and strand plains in the interdeltaic areas. These massive sandstones, when originally deposited, formed extensive aquifers with considerable lateral extent (Henry and Morton, 1982). Growth faulting, with the attendant thicknesses of sediments, has resulted in a structural setting in the Rio Grande Embayment which includes major fault trends and minor associated faults, some of which are parallel, and some of which are transverse to the main trends (Figs. 2,3). Syndepositional units which thicken toward the main faults form folds, or rollovers, which dip markedly into the faults. Rapid sedimentation also resulted in shale ridges, and shale diapirs (Collins, 1983). Well No. 5 (Fig. 1 and 2) penetrated a shale diapir which displaced the section vertically upward (Table 1).

Within the study area, the dominant growth fault is the McAllen fault, which extends from south of the Rio Grande northward as much as 150 miles (Collins, 1983) (Figs 1 and 3). This fault may be due to instability, or weakness, in the basement which resulted in activity throughout the Oligocene-Miocene depositional interval. The greatest movement, or activity, of the fault occurred during deposition of the marine (lower and middle) Frio sequence (Collins, 1983). To the east in the study area, the Donna fault created a relatively stable area (Collins, 1983). The movement on the Donna fault was not as continuous, and the displacement was not as great, as along the McAllen fault. This differential movement resulted in a flattening of the dip towards the Donna fault. The relatively small Weslaco fault, farther to the east, results in a "reversal" of the dip away from the McAllen fault and toward the Gulf Basin.

The Shepherd fault (Figs. 1,2), which is transverse to the main McAllen fault, was also active during the time of deposition of Frio sediments. The same stratigraphic section is present on both sides of the Shepherd fault, but the section is thicker on the downthrown (north) side of the fault (Collins, 1983).

Sediment thickening toward the McAllen and Shepherd faults has resulted in a structural axis which migrates upward in the section, and geographically toward the northeast. This axis trends from the southeast (Donna) toward the northwest (Edinburg) (Fig.2). Along this axis, or flattening of the dip angle, faulting is less persistent, which results in greater continuity of the aquifers (Swanson and others, 1976). Swanson referred to this area as "a promising area for the occurrence of continuous geopressured reservoirs of broad areal extent ..." (Swanson and others, 1976).

Throughout both potential reservoir areas, the approximate depths to the top of the geopressured zone averages approximately 9,000 feet. The geopressured zone ranges from approximately 8,500 feet on the west side of Reservoir area C to 9,500 feet on the east side of Reservoir area B, with relatively uniform depth throughout the study area (Fig. 2). The minimum depth of the 300°F isotherm appears to center in an area which includes the northwest-southeast trending axis between the cities of Edinburg and Donna.

Salinities of the connate water in Reservoir Area C ranges from 9,000 to 15,000 ppm Cl (Swanson and others, 1976). Higher temperatures occur at greater depths (approximately 12,000 feet) in the eastern part of the study area, in Reservoir Area B, but the extremely low salinity, moderate temperature, geopressured sands at shallower depths (Table 4) make this an optimum area for production of useable water.

Data for the quantity of entrained gas in the water are not available. However, estimates based on comparisons of gas-to-water ratios, using salinity of the water, would indicate ratios as high as 25-30 SCF/BBl.

Reservoir Area C

Area C includes the area located between the McAllen fault to the west, the Donna fault to the east, the transverse trending Shepherd fault to the south, and extends northeast to a point of limited well control (Fig. 2). This outline defines a maximum reservoir area of some 255 square miles. A reservoir defined by outlining the area within lines drawn between key wells results in a reservoir of approximately 90 square miles (Fig. 2).

The Frio sediment pattern within this section is dominated by the major growth fault to the west, the McAllen fault, and the Donna fault to the east. The lower Frio sediments are cut by numerous faults which dip toward the coast. This faulting dies out in the shallower Frio section (Fig. 3). Rapid sedimentation of the lower Frio resulted in sands thickening away from the coast toward the McAllen fault, with a resultant reversal of dip. Dip angles increase toward the major fault and decrease, or flatten, toward the northeast (Fig. 3). Although the lower Frio section is cut by numerous faults, the thickness of the sands within this section is greater than the displacement along the faults. This allows for a connection of the reservoir sands within the Marks and Bond sand sequence (Fig. 3) (Collins, 1983).

The Marks sand (Fig. 4) occurs within an interval from 7,760'-8,230' in the southeast side of the area to 10,970-11,990' in the west. The sand continues to thicken and increase in depth as it dips to the west toward the McAllen fault. Because of increased faulting related to the main fault, the area of the reservoir should be considered to be limited to the west before the main fault is encountered (Fig. 3). To the northeast, the dip flattens creating a high which lies along an axis which trends from the northwest to the southeast along a line from Edinburg to Donna (Fig. 2).

Within Reservoir Area C, average depth to the top of the Marks sand is 9,881 feet. Average thickness of the sand is 409 feet, and average net sand thickness is 245 feet, or an average of 63 percent sand. Average pressure at the top of the sand is 7,333 psi, with an average pressure gradient of 0.73 psi/ft. Average temperature (A.A.P.G. corrected) is 279°F. The median temperature is, however, nearer 300°F in the area near the center of the reservoir. Porosity estimated from log resistivity and spontaneous potential averages 17 per cent, and permeability averages 14 md (millidarcies, designated by the symbol K). The average KH (millidarcies x average thickness of sands in feet) is 3,528. These data are summarized in Table 2.

No core data were available for the Marks sand, but log characteristics indicate the sand to be a fairly uniform shoreface to coastal barrier sandstone on the west to distal shoreface sands on the east. Individual sands within the section thin and show a more marked variation in resistivity.

Within Reservoir Area C, the Bond Sand occurs within the interval from 8,550 to 9,520 feet in well No. 5, to 11,670 to 12,220 in well No. 3 (Fig. 5). The average depth is 10,626 feet, and the average thickness is 635 feet. The net sand average is 334 feet, or 53 per cent sand. Pressure at the top of the sand averages 8,045 psi, and the average gradient is 0.76 psi/ft. Average temperature (A.A.P.G. corrected) is 296°F. Temperatures are again higher than the average nearer the center of the reservoir. Porosity and permeability were estimated from the resistivity and spontaneous potential character of the logs. These values were compared to reported values, and the lower values were used for simulation purposes. Porosity averages 18 per cent, and permeability 13.8 md. The average KH is 4,609.

The spontaneous potential curves were not good in all the wells; therefore, estimates of sand characteristics were derived primarily from the resistivity curves. Log characteristics would indicate the Bond Sand to be a more distal fine-grained shoreface sand with less reworking of sediment than the Marks Sand.

Like the Marks Sand, which was deposited in shallower water, the Bond Sand dips from east to west towards the McAllen fault, and thickens towards the fault. A flattening of dip also occurs toward the northeast along the axis of the high which extends from Edinburg to Donna (Fig. 2).

The possibility exists for this lower section to be cut by faulting, but the sand is persistent and laterally continuous throughout the area of key well control.

Reservoir Area B

Reservoir Area B is bounded on the west by the Donna fault which extends from the Rio Grande northward into Willacy County. It is bounded on the east by the Weslaco fault which extends from the Rio Grande northward along the Cameron County-Hidalgo County line into Willacy County (Fig. 1). Within area B, the reservoir is bounded on the south and north by lines which define the limits of key well control (Fig. 2). Small faults associated with both the Donna and Weslaco faults limit the reservoir to the north. The reservoir may extend somewhat farther to the south, but the extent is limited based on available well control. The south edge of the reservoir is not affected by the Shepherd fault which limits the south edge of reservoir area C. Within the area outlined, the reservoir could contain as much as 120 square miles (Fig. 2).

Within the area of Reservoir B there are numerous thick sands below the top of the geopressured zone. The "10,000 foot" sand is below the top of the geopressured zone, and is laterally continuous within the area. Additionally, this sand has the lowest reported salinity (4,000 ppm Cl) of any of the sands for which data are available. The top of the sand occurs at 9,550 feet on the west side of the reservoir and at 10,360 feet on the east side. The dip is relatively flat across the top of the Weslaco high or "uplift," although the dip angle begins to increase markedly at greater depth.

Within Reservoir Area B, the sand averages 10,033 feet in depth, with an average thickness of 517 feet. Net sand thickness averages 411 feet, or 78 per cent net sand. The pressure at the top of the sand averages 7,493 psi, and the geopressure gradient is 0.745 psi/foot. The average porosity is 15 percent and the average permeability is 16 md. Average temperature at the top of the sand is 264°F (A.A.P.G. corrected). Porosity and permeability values were estimated from resistivity and spontaneous potential log values. The average KH is 6106. These data are summarized in Table 4.

The 10,000 foot sand was deposited in shallower water of the prograding delta system than were the Marks and Bond sands of Reservoir area C. This massive sand appears to be a series of reworked distributary-mouth bar sands and shoreface sandstones with great lateral continuity within the area of Reservoir B (Fig. 6).

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Part B - Simulation of GP/GT Resource Potential

Introduction

The Geologic Assessment of the areas of interest identified three potential reservoirs, one in Area B and two in Area C. These are shown on Figure 1 of Part A. The reservoir rocks were described by well logs and correlated across the two areas of interest.

This information was then digitized to form the input to a numerical simulator. Using simulation techniques, flow rates and pressures can be calculated for wells drilled into each potential reservoir. A predicted performance for a test well in each reservoir was computed and a pattern of multiple wells was also calculated for each reservoir.

Model Development

The areas between the major faults as shown on Figure 1 were broken into computing grid blocks. In Area C the grid consisted of a 29 by 22 grid block mesh that covers an area of 220 mi^2. This represents the area between the McAllen Fault and the Donna Fault. This is intended to represent the maximum reservoir area possible. As an alternate to show the sensitivity to reservoir size a second grid was constructed that covered 90 mi^2. This area represents only the area included within the limits of well control. Area B was covered by a 30 by 34 grid block mesh. This grid covers the 120 mi^2 included between the Donna Fault and the Weslaco Fault and is further represented as the maximum case. The minimum case for this East Sand again represents the minimum area included within the well control.

The reservoir properties used were determined by the geologic assessment and shown on Tables 2 and 4. These properties include sand thickness, porosity, permeability, and initial pressure gradient. The remaining properties needed for the simulation include the fluid descriptions and the well parameters. The PVT relationships were developed for brines using the best correlations available. The PVT properties of the gas and brine are shown below.

FLUID PROPERTIES

Pressure psia	Gas FVF rb/Mcf	Gas Visc cp	Water FVF rb/STB	Sol'n Gas Scf/STB	Water Visc. cp
1000.00	3.1957	.0140	1.0368	5.4	.30
2000.00	1.5359	.0160	1.0338	9.7	.30
3000.00	1.0276	.0188	1.0307	13.2	.30
4000.00	.8084	.0215	1.0276	16.0	.30
5000.00	.6899	.0243	1.0246	18.4	.30
6000.00	.6154	.0270	1.0215	20.6	.30
7000.00	.5659	.0295	1.0185	22.5	.30
8000.00	.5311	.0319	1.0154	24.2	.30
9000.00	.5047	.0341	1.0123	25.8	.30
10000.00	.4831	.0362	1.0093	27.3	.30

Since the reservoir flow is all single phase water, relative permeability curves are not needed nor is structure important since the sands will be in hydraulic equilibrium. This completes the data needed for the reservoir description.

The wells were described using large diameter flow string (5 inch diameter). The wells were assumed to be completely penetrating with a zero skin. The flow restriction was 25,000 bbl/d (approximately 1,000,000 gal/day) or what the well could deliver against a 5500 psi bottom hole flowing pressure. Surface pressures were then calculated from those flowing conditions. This results in some slightly anomalous behavior in some of the performance curves where the rate declines. A slightly increasing wellhead pressure is computed. This is because the bottom hole pressure is held constant and the declining fluid rate produces less pipe friction.

Simulation Results

Several simulation runs were made for each of the three identified reservoirs. First, a single test well performance was calculated for each reservoir for each the minimum case and maximum case. Then patterns of wells were superimposed on their reservoir. Each reservoir had patterns of 3, 6 and 9 producing wells.

The results of the single test well simulations are shown on Figures 7-12. These show that the Mark Sand having the thinnest section begins to decline in rate almost immediately for both the minimum and maximum reservoir sizes. The Bond Sand maintains the 25,000 bbl/d rate for about nine years in the maximum case and about six years in the minimum case. The East Sand maintains the 25,000 bbl/d for the full fifteen year period of investigation for both the minimum and maximum cases. Gas rates for all these cases are shown on the appropriate charts, but follow the solution gas relationship shown on Table 3.

The pattern runs are shown on Figures 13-18. In all cases the patterns of wells show declining production rates, even for the East Sand which showed no decline at all in the single well case. To understand the charts and more importantly the reservoir mechanics, notice how the patterns deviate from the maximum constant rate. As more wells are added to the pattern, the deviation occurs earlier in time.

Recoverable Volumes

We can take the same data described above to make some additional charts that show the volumes of brine that are recoverable from the reservoirs. These charts are shown as Figures 19-24. These charts show the recovery of gas and brine as a function of the number of wells in the reservoir.

It is of interest to follow the cumulative recovery curves from the minimum cases to the maximum cases. These show that the smaller reservoirs cannot support as many wells. Further, the curvature of these cumulative recovery charts shows the declining effectiveness of adding additional wells to the reservoirs. For example, for the East Sand Maximum case the fifteen year brine recovery is about 370 million bbl or 123 MMbbl/well. Six additional wells will contribute a total of 477 MMbbl or an average of only 79.5 MMbbl each, a decrease of about 35% per well. This shows that the spacing of development wells is an important economic issue.

Discussion

These simulation cases were developed to illustrate the capability of the GP/GT reservoirs that have been identified. Nearly all the data were estimated from old well logs or derived from correlations. To the extent that these estimates are accurate, the predicted performance is reasonable.

Many of the controlling parameters in the various simulations were somewhat arbitrary. For example, the 25,000 bbl/d maximum production rate is arbitrary. The only reason for selecting that limit is that has been historically the maximum production rates that similar wells in the Gulf Coast have been produced. The limiting bottomhole pressure was selected to yield surface pressures in excess of 500 psi. The composition of the produced gas will vary with the pressure of the wellhead separation equipment. The lower the pressure, the higher the CO_2 content of the gas. Experience has shown a pressure of 500 psi will produce pipeline quality gas.

It must be pointed out that although there have been test wells in the Gulf Coast area that have produced these volumes over sustained periods, there are no prototype pattern developments. While this has not been demonstrated physically, the technology that controls the fluid flow is well understood and the projection of the patterns from the test wells is much more reliable than the test well projections themselves.

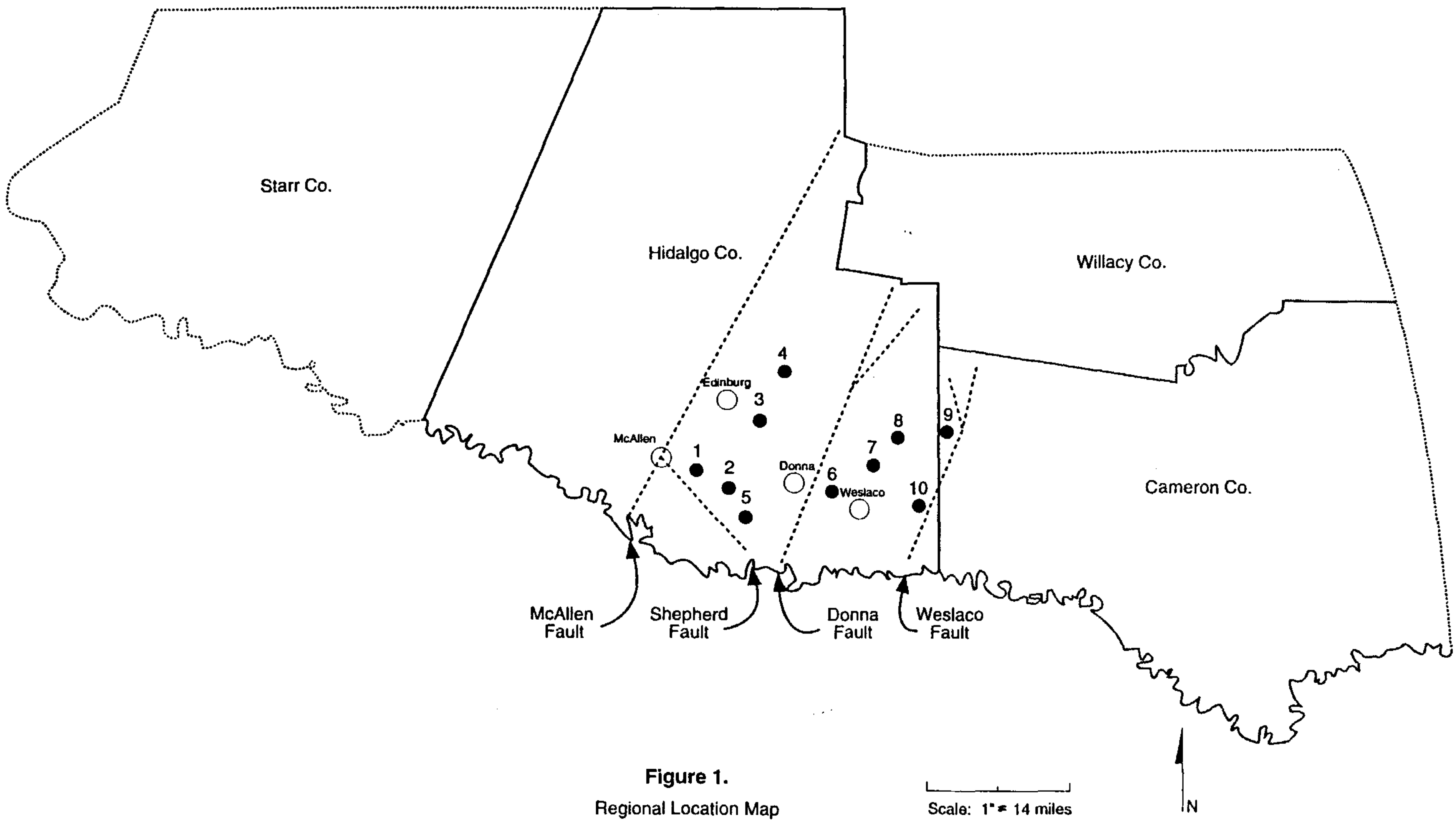


Figure 1.

Regional Location Map

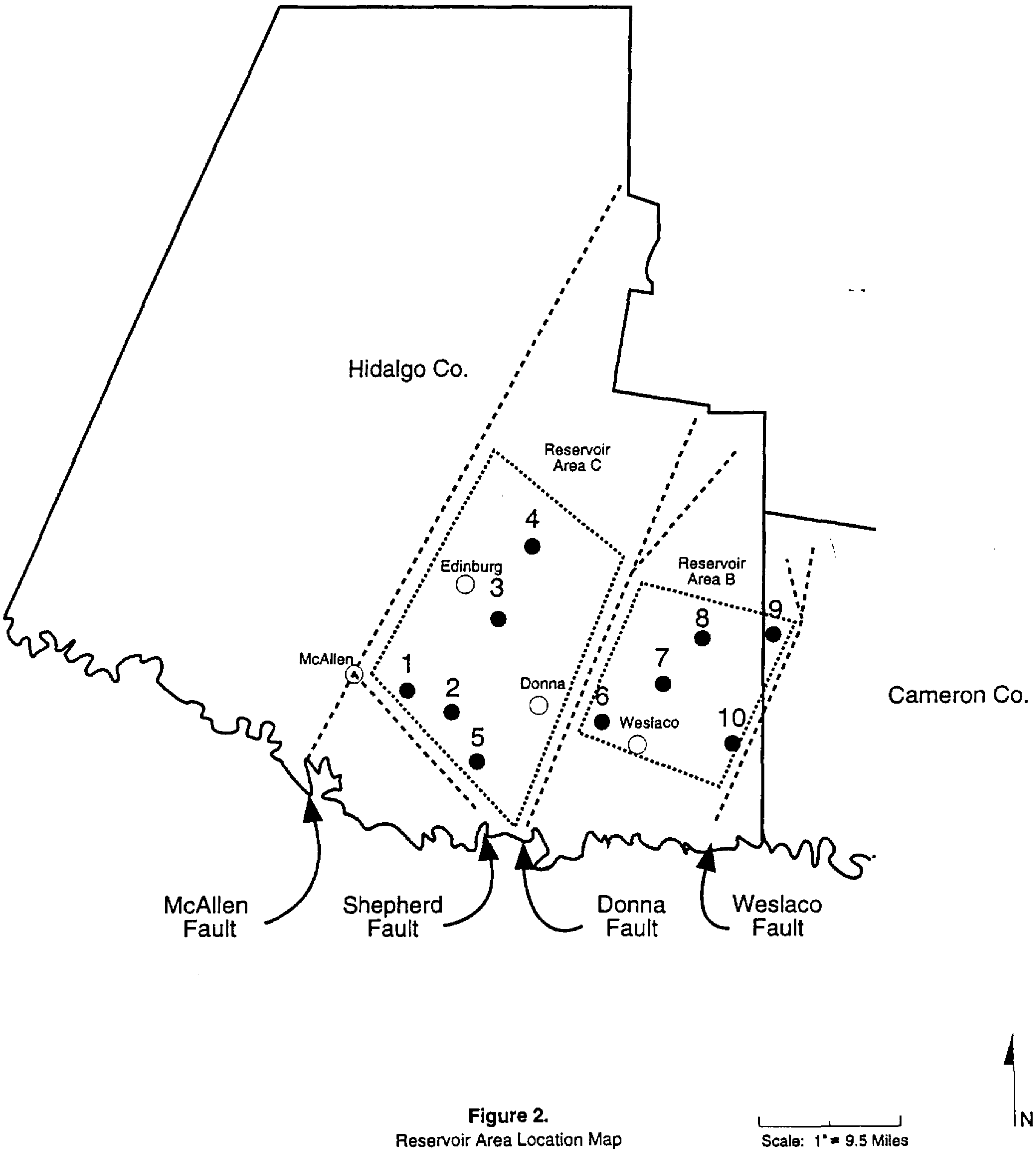


Figure 2.
Reservoir Area Location Map

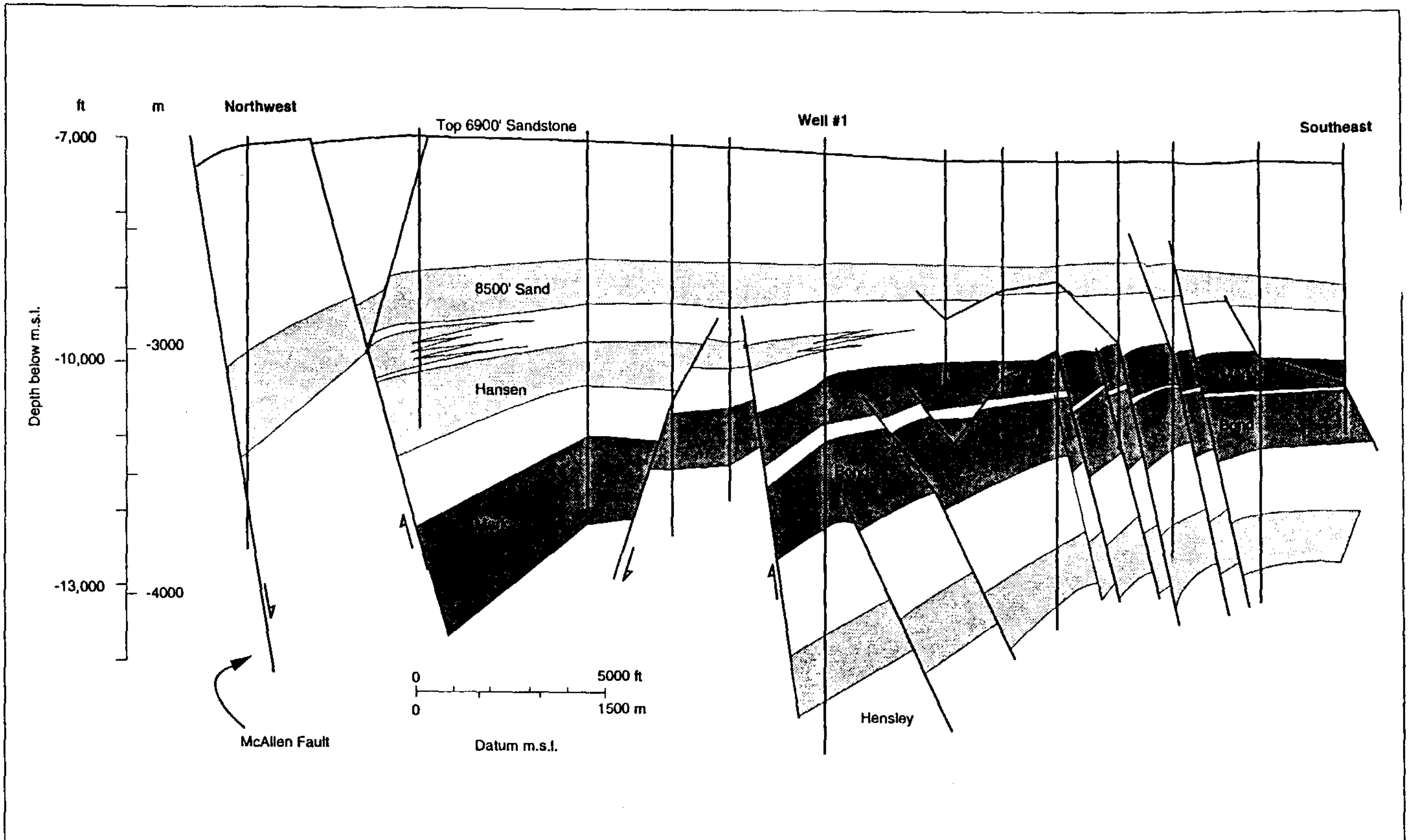


Figure 3.

Northwest - Southeast cross section
McAllen - Pharr Area. Modified from Collins (1983)
Bureau of Economic Geology (1989)

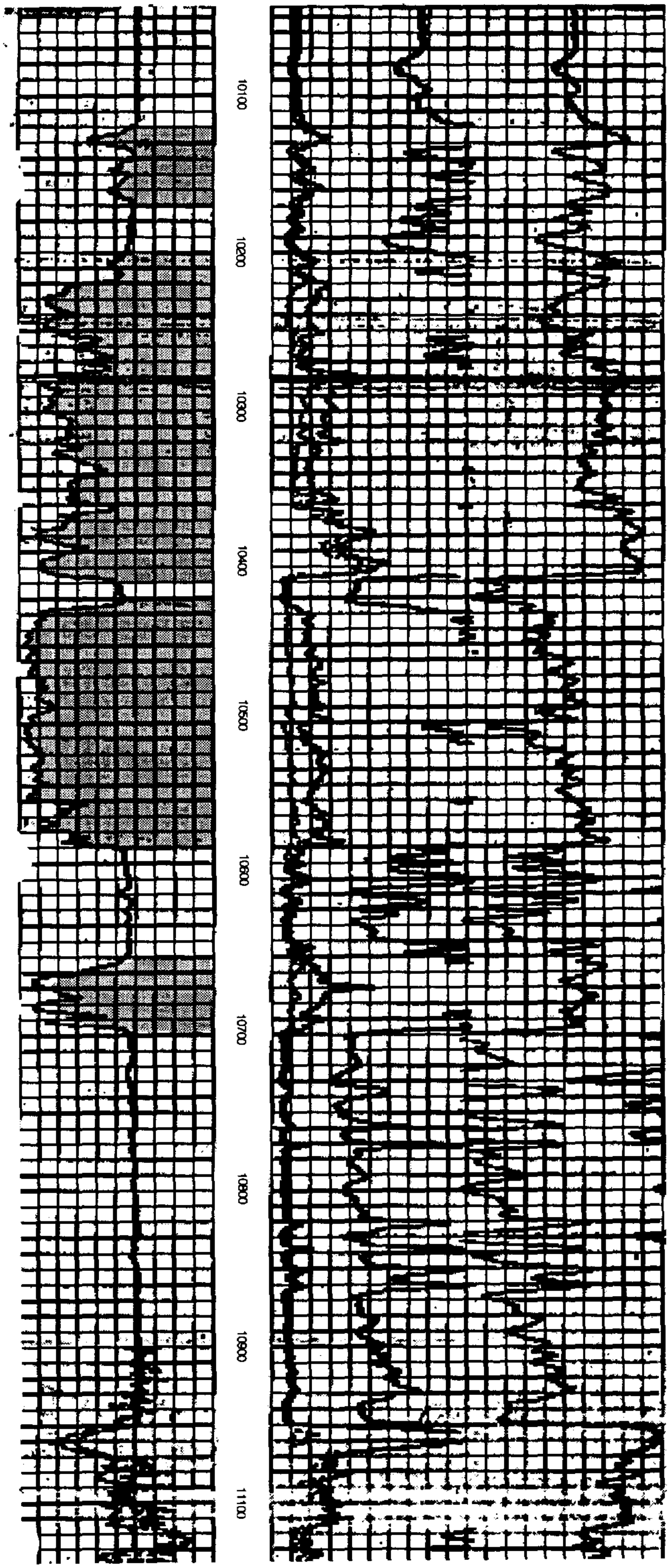


Figure 4.
Marks Sand - Reservoir Area C.

Tenneco-McAllen
Field Wide Unit #36

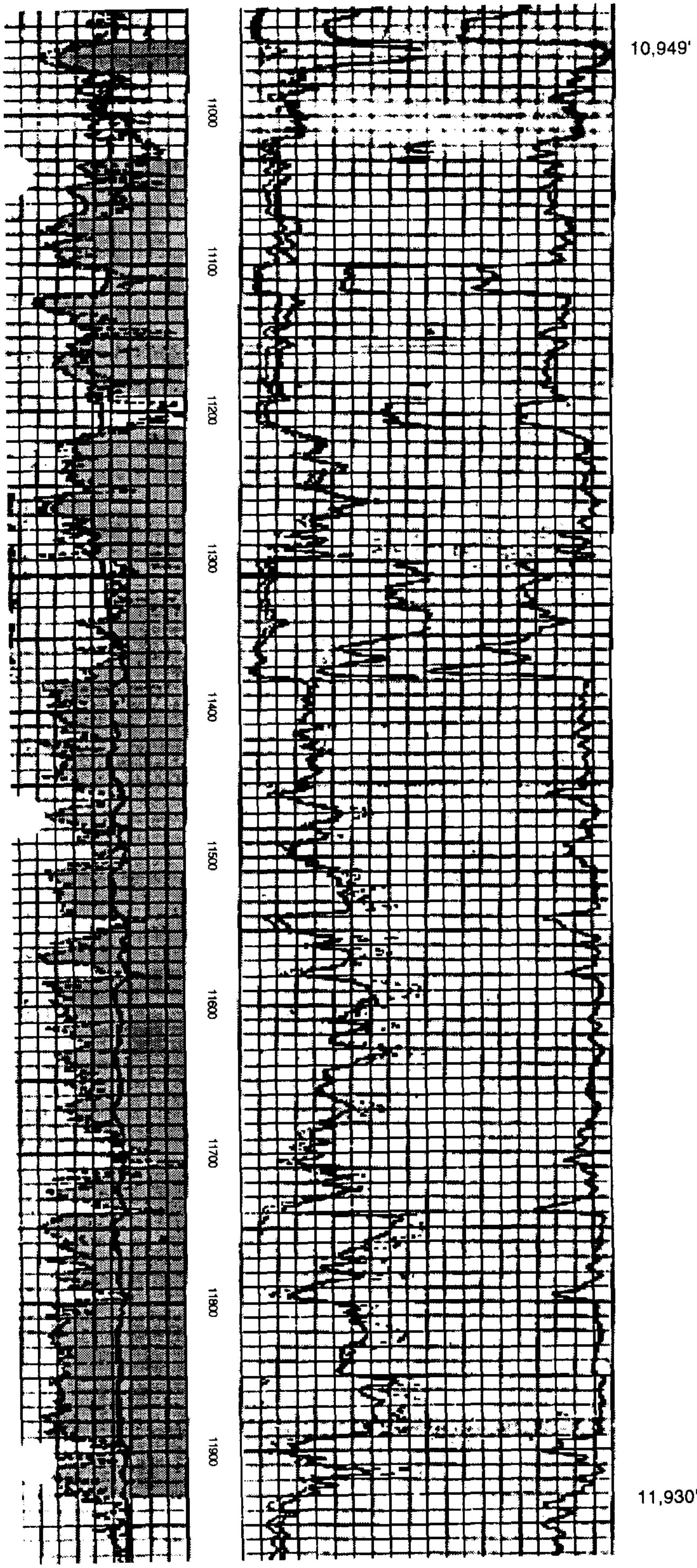


Figure 5.
Bond Sand - Reservoir Area C.

Tenneco-McAllen
Field Wide Unit #36

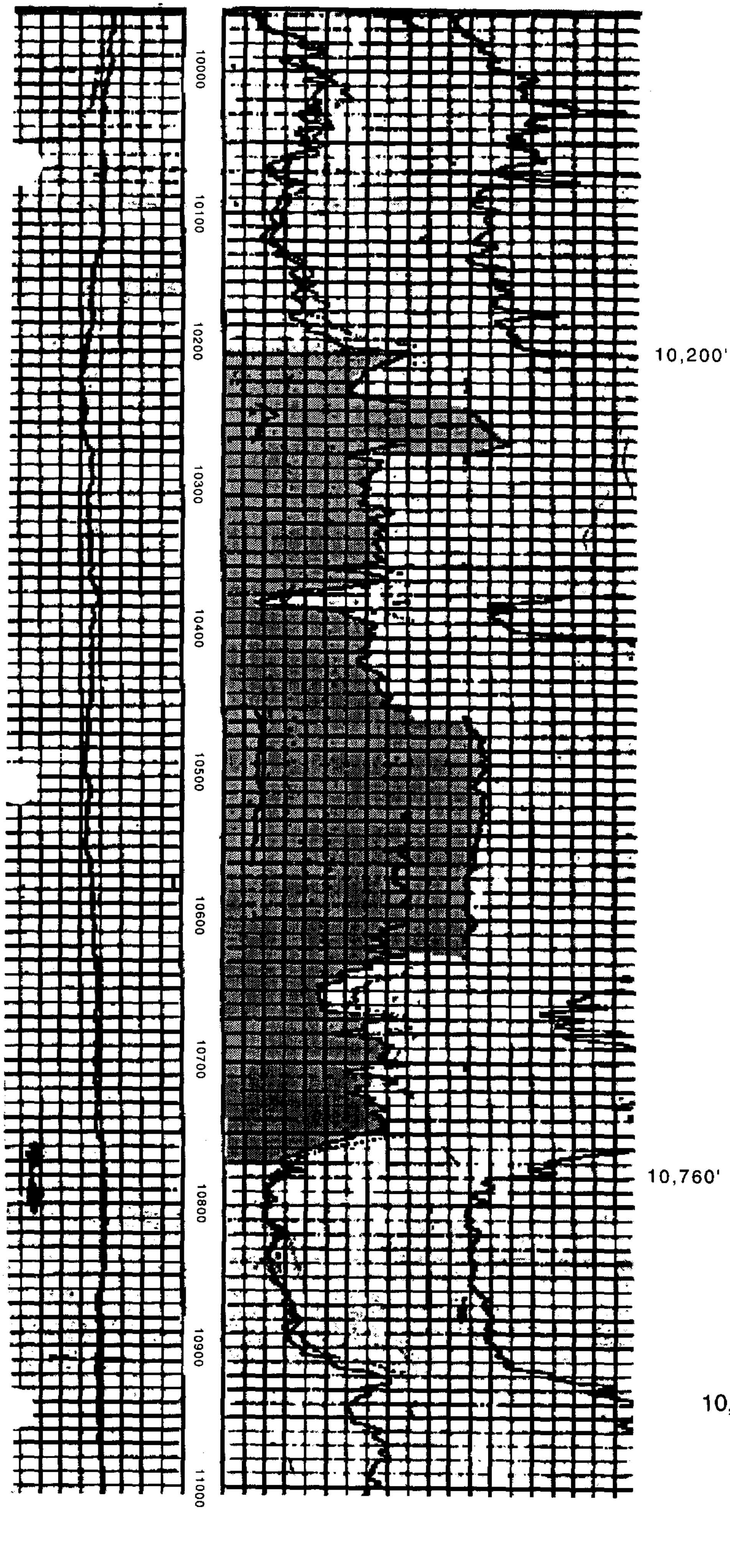


Figure 6.
10,000 ft. Sand - Reservoir Area B.

Northern Pump Co.
Harris Unit #2

MARK SAND (MAXIMUM)

Geo2 Fluid Production

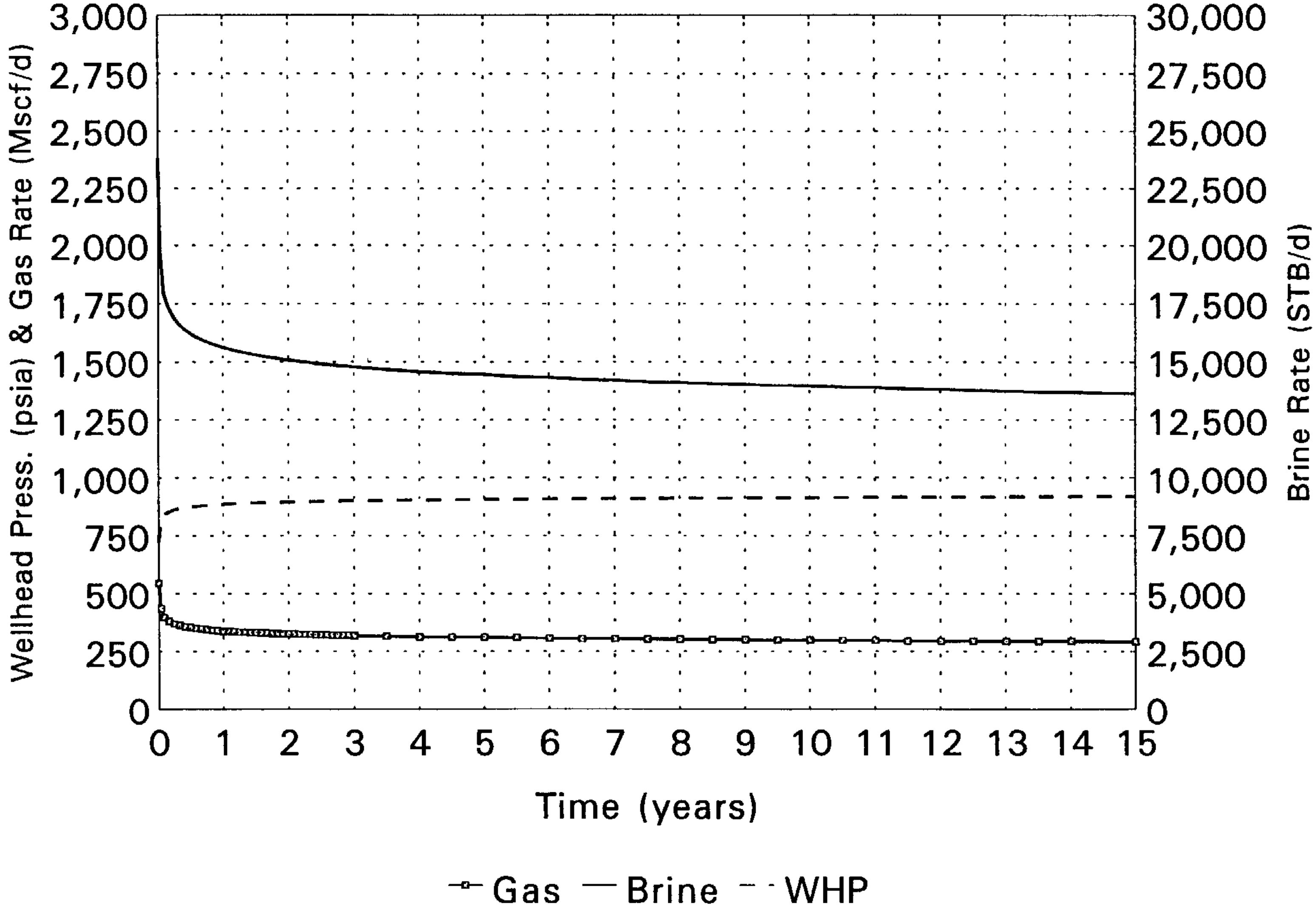


FIGURE 7

MARK SAND (MINIMUM)

Geo2 Fluid Production

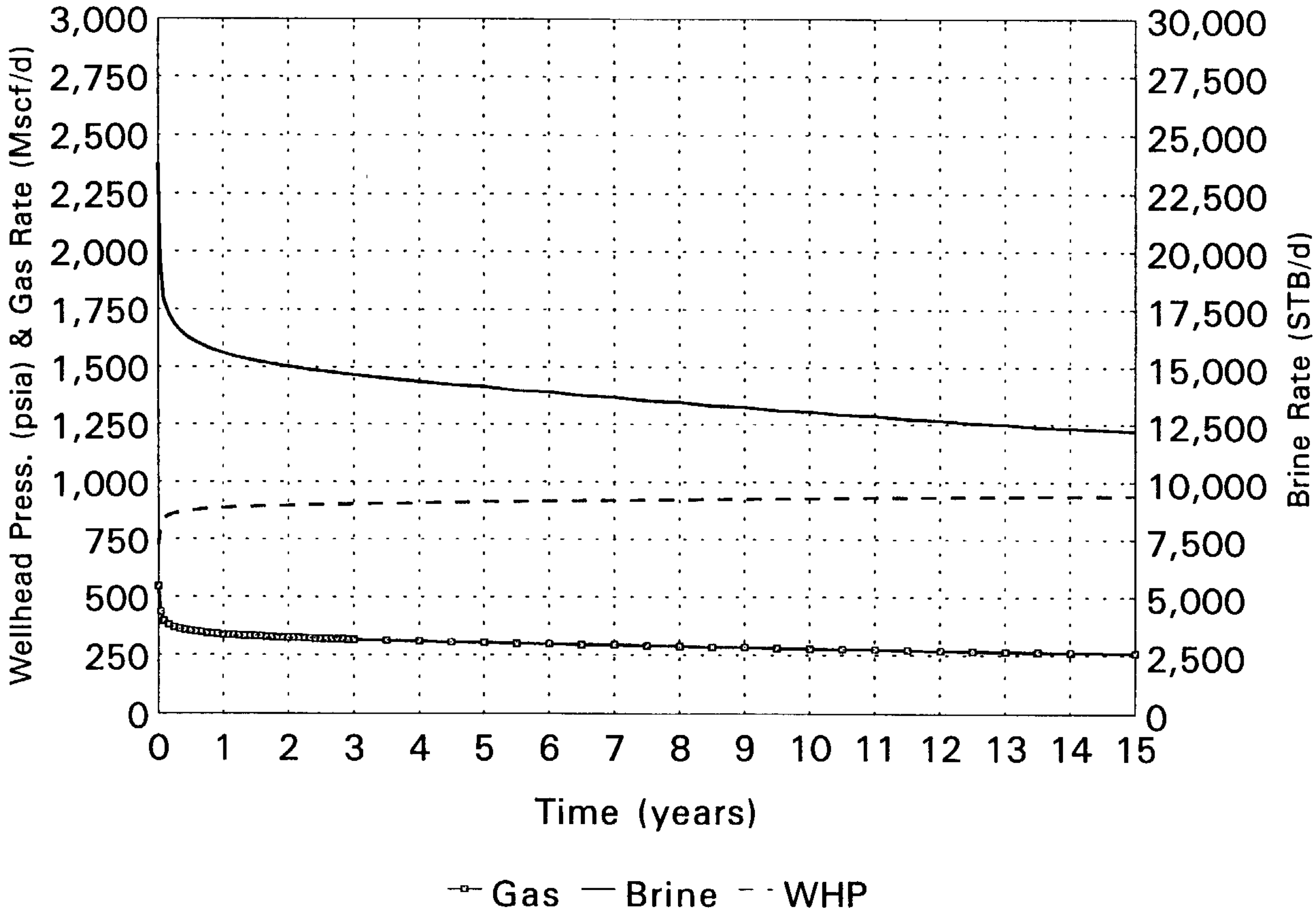


FIGURE 8

BOND SAND (MAXIMUM)

Geo2 Fluid Production

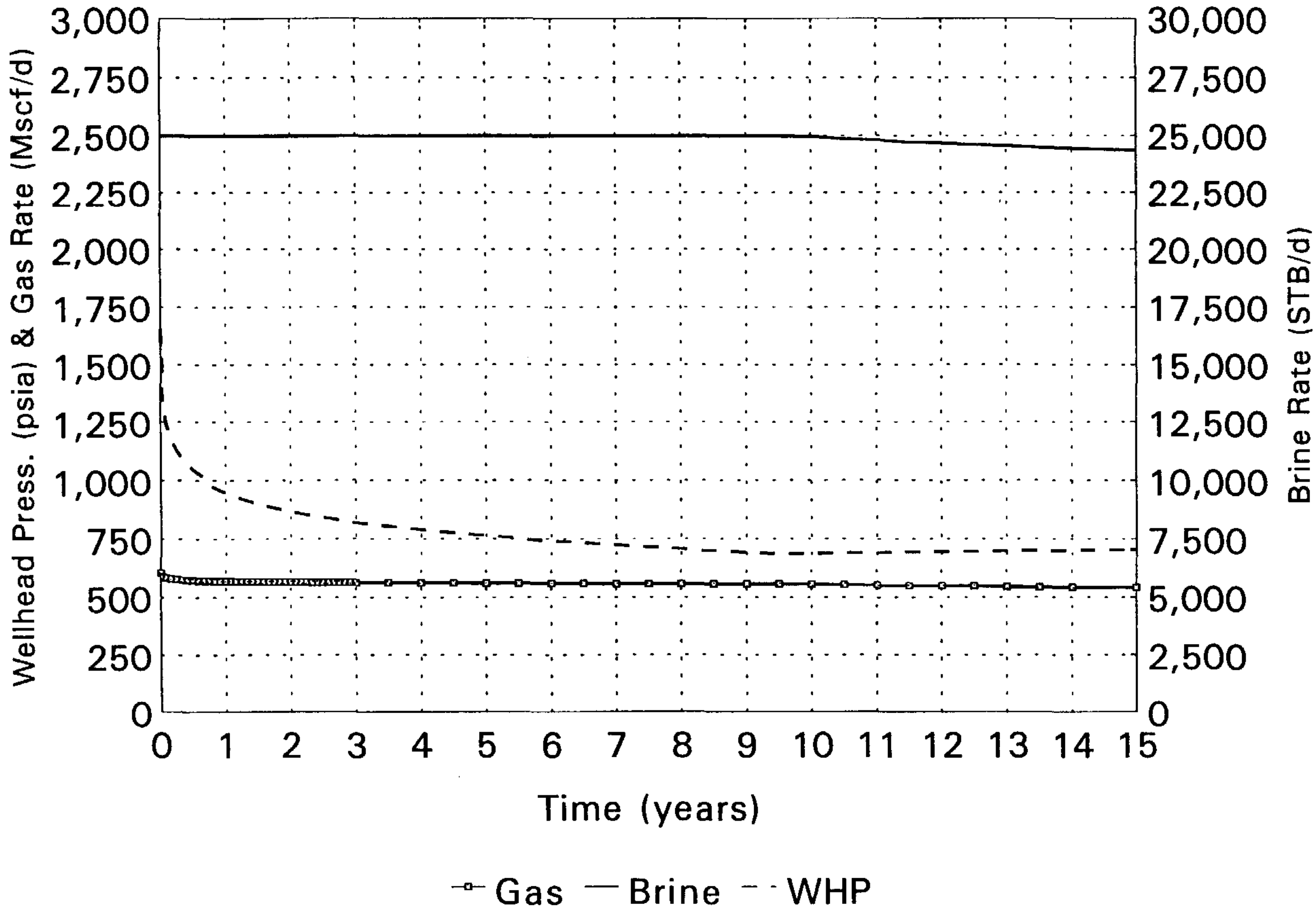


FIGURE 9

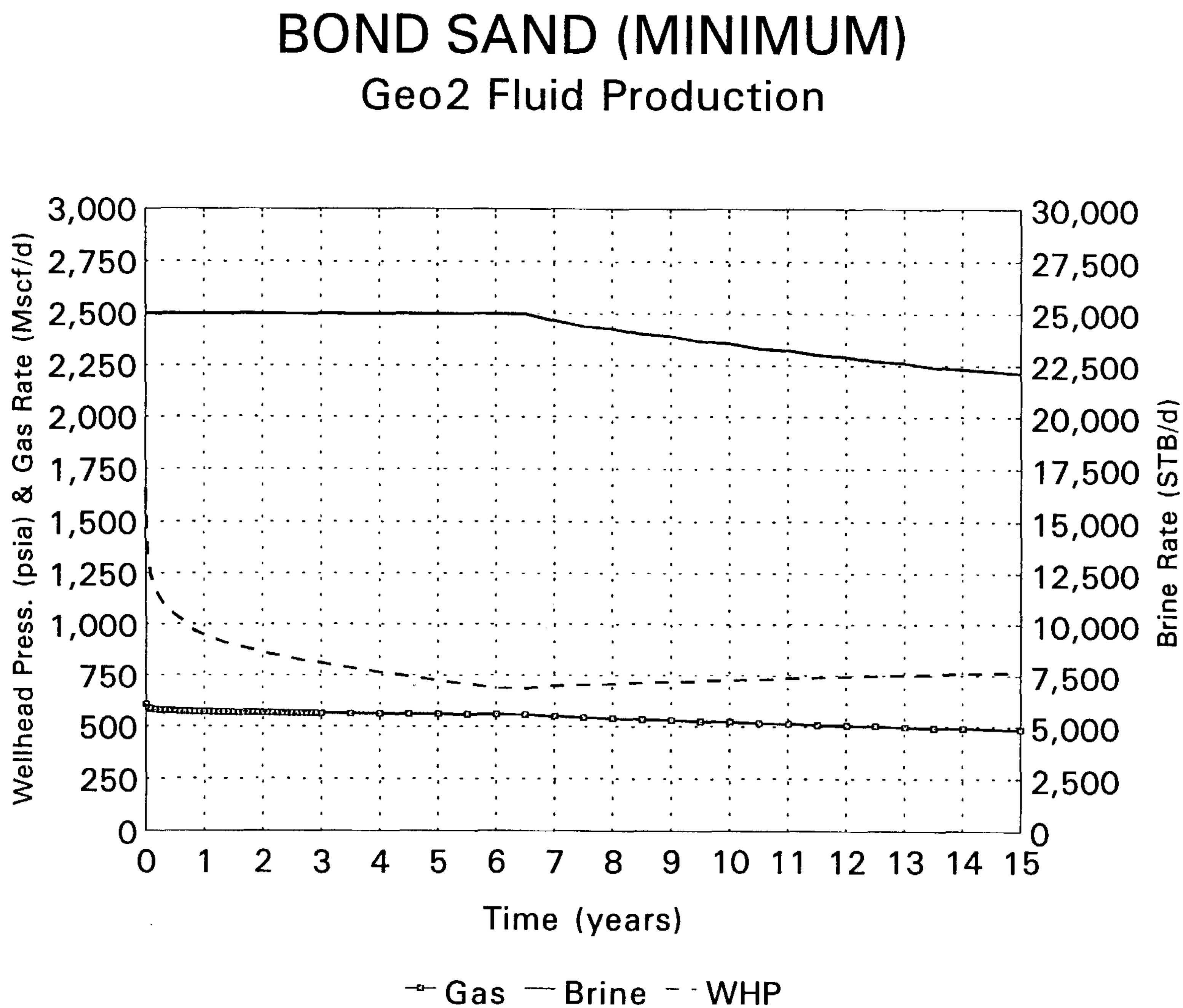

BOND SAND (MINIMUM)
Geo2 Fluid Production
Wellhead Press. (psia) & Gas Rate (Mscf/d)
3,000
2,750
2,500
2,250
2,000
1,750
1,500
1,250
1,000
750
500
250
0
Brine Rate (STB/d)
30,000
27,500
25,000
22,500
20,000
17,500
15,000
12,500
10,000
7,500
5,000
2,500
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Time (years)
Gas
Brine
WHP

FIGURE 10

EAST SAND (MAXIMUM)

Geo2 Fluid Production

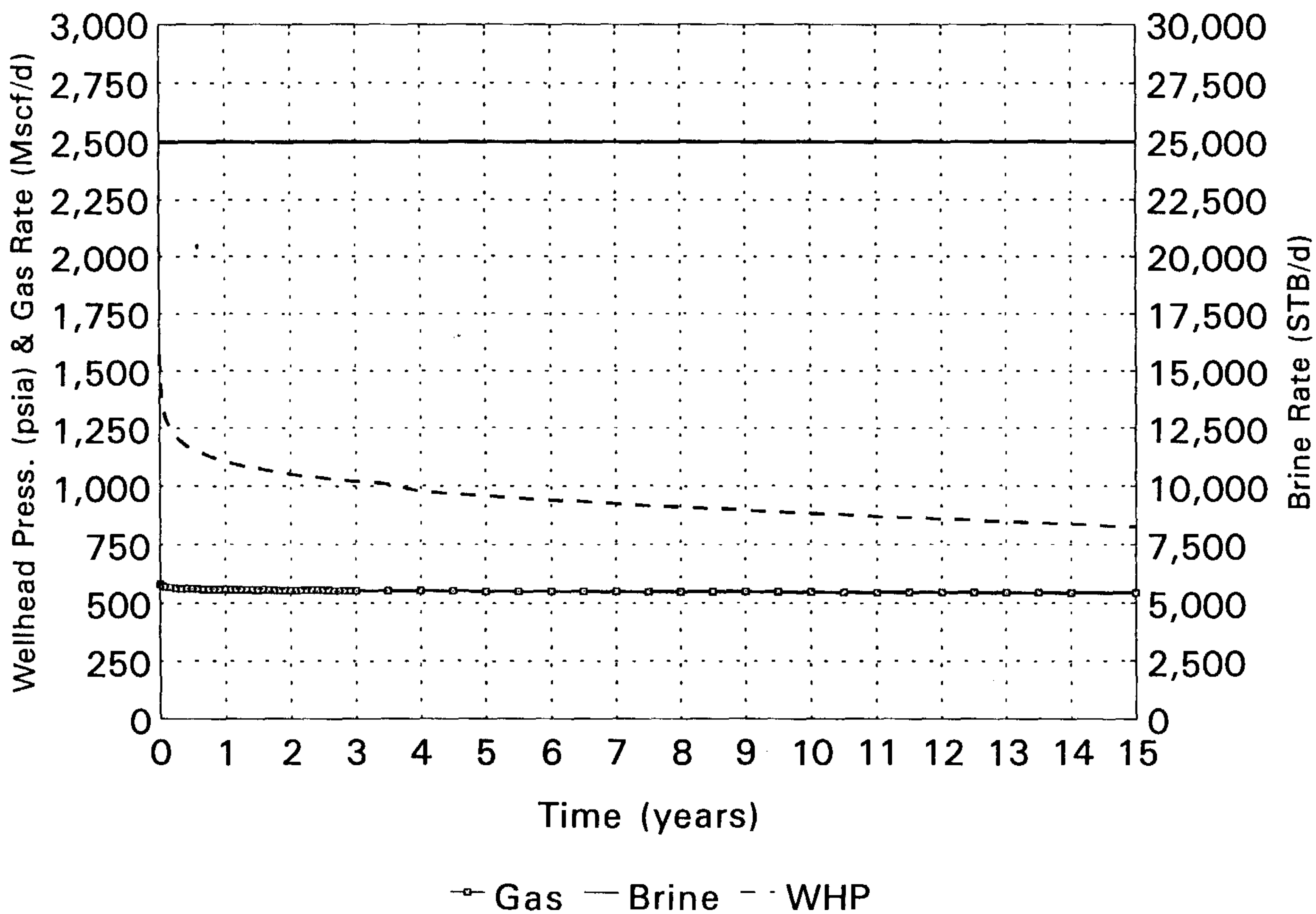


FIGURE 11

EAST SAND (MINIMUM)

Geo2 Fluid Production

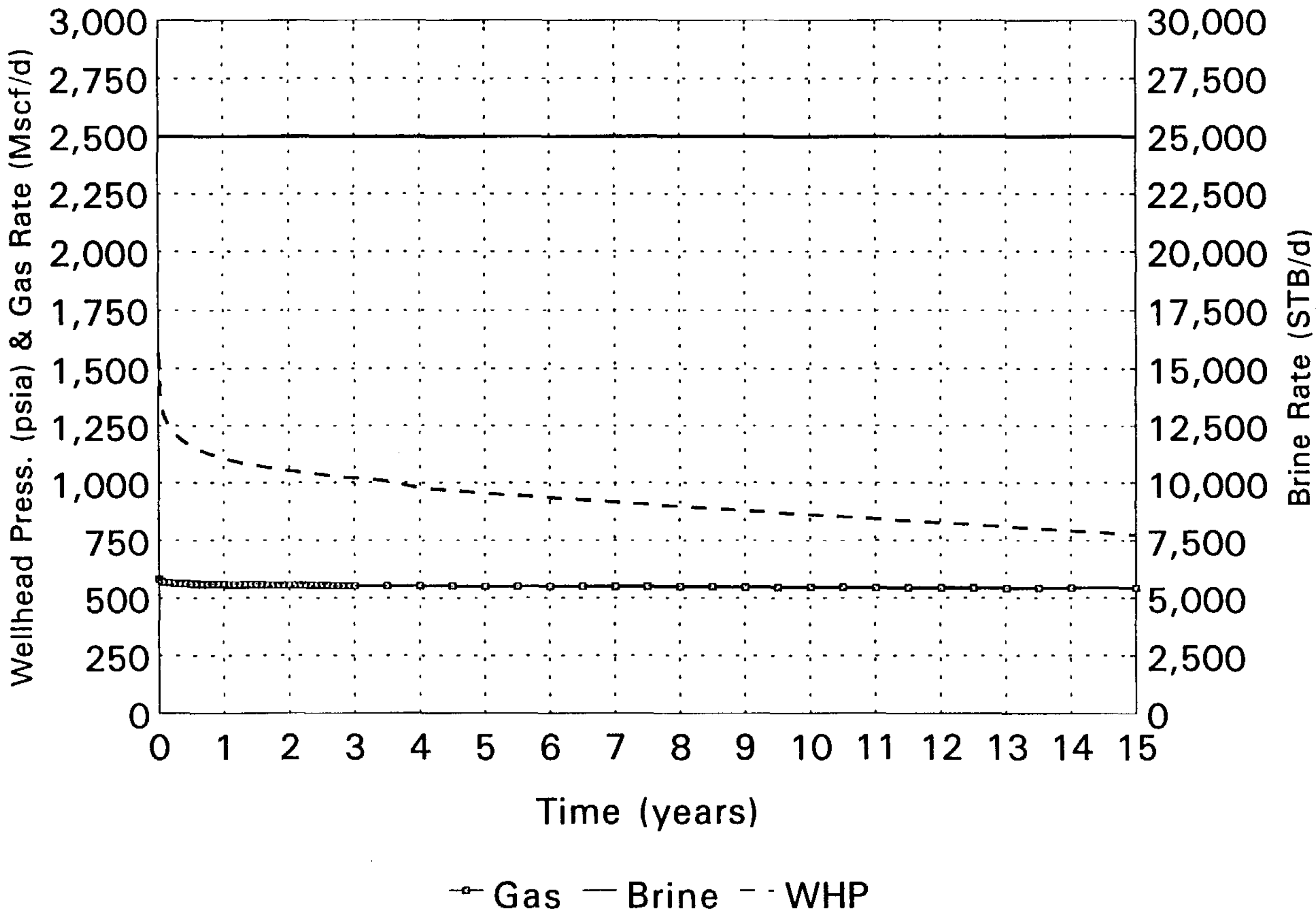


FIGURE 12

MARK SAND (MAXIMUM)
Geo2 Fluid Production

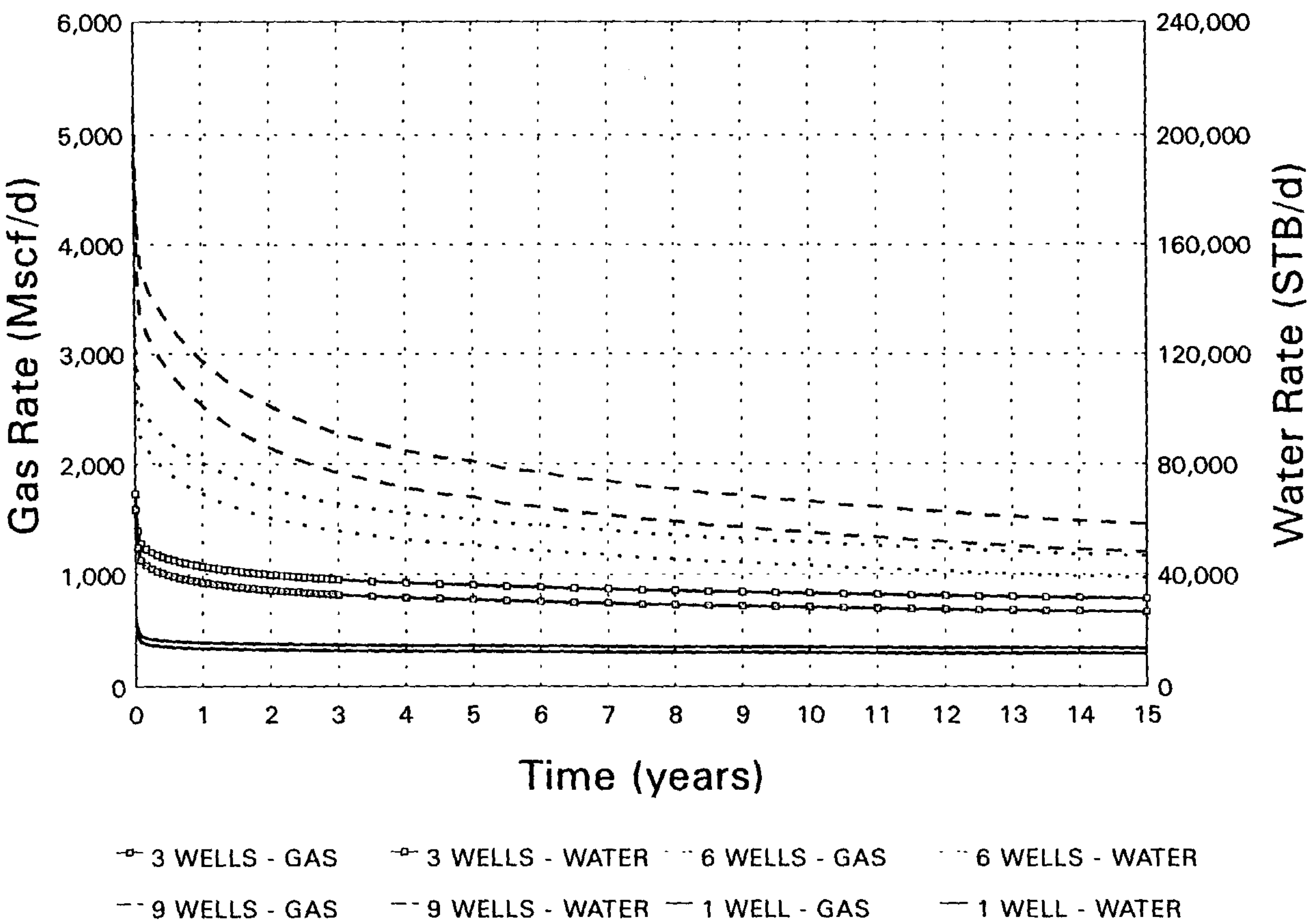


FIGURE 13

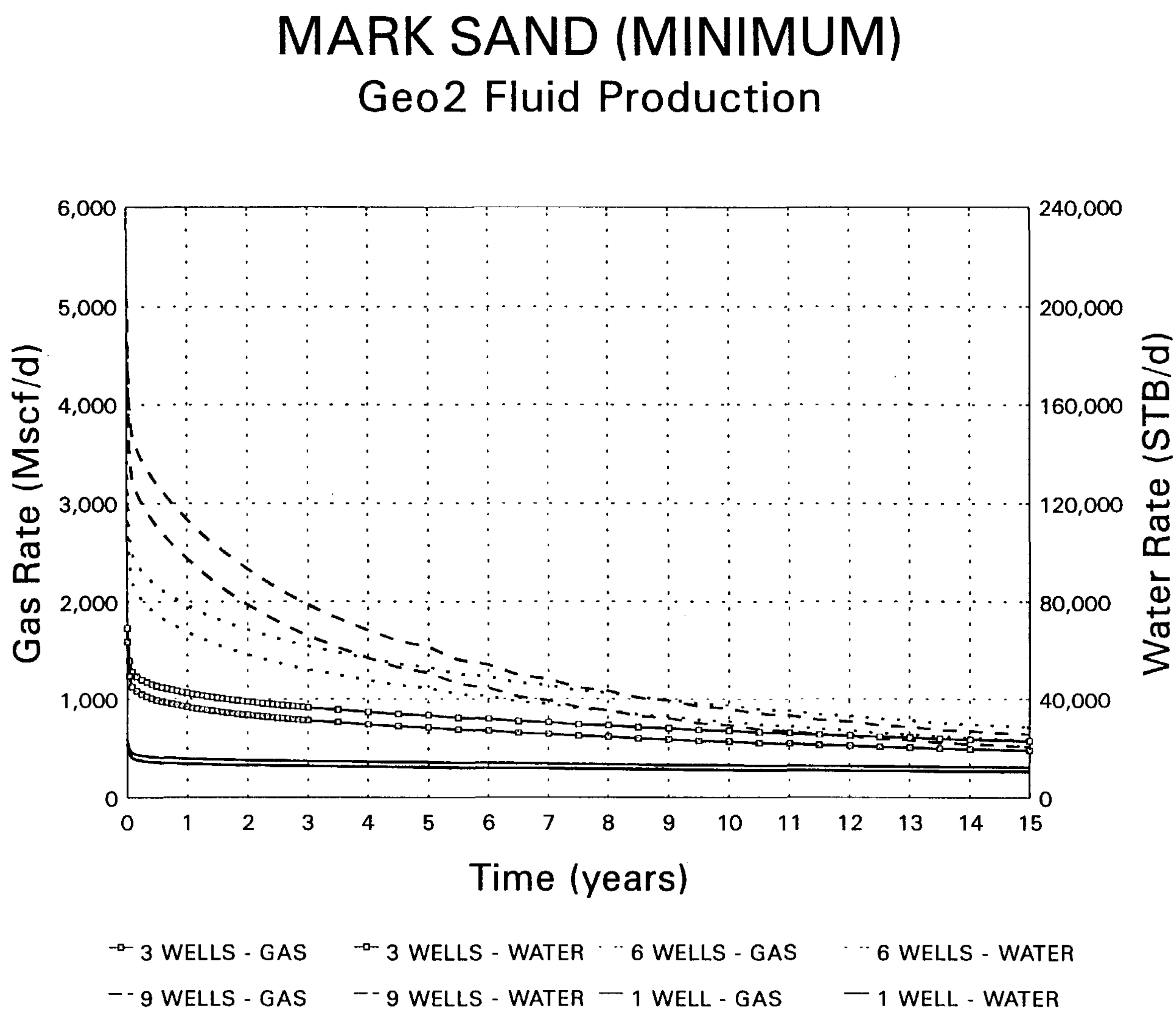

MARK SAND (MINIMUM)
Geo2 Fluid Production
Gas Rate (Mscf/d)
Water Rate (STB/d)
Time (years)
0
1,000
2,000
3,000
4,000
5,000
6,000
40,000
80,000
120,000
160,000
200,000
240,000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
3 WELLS - GAS
3 WELLS - WATER
6 WELLS - GAS
6 WELLS - WATER
9 WELLS - GAS
9 WELLS - WATER
1 WELL - GAS
1 WELL - WATER

FIGURE 14

BOND SAND (MAXIMUM)

Geo2 Fluid Production

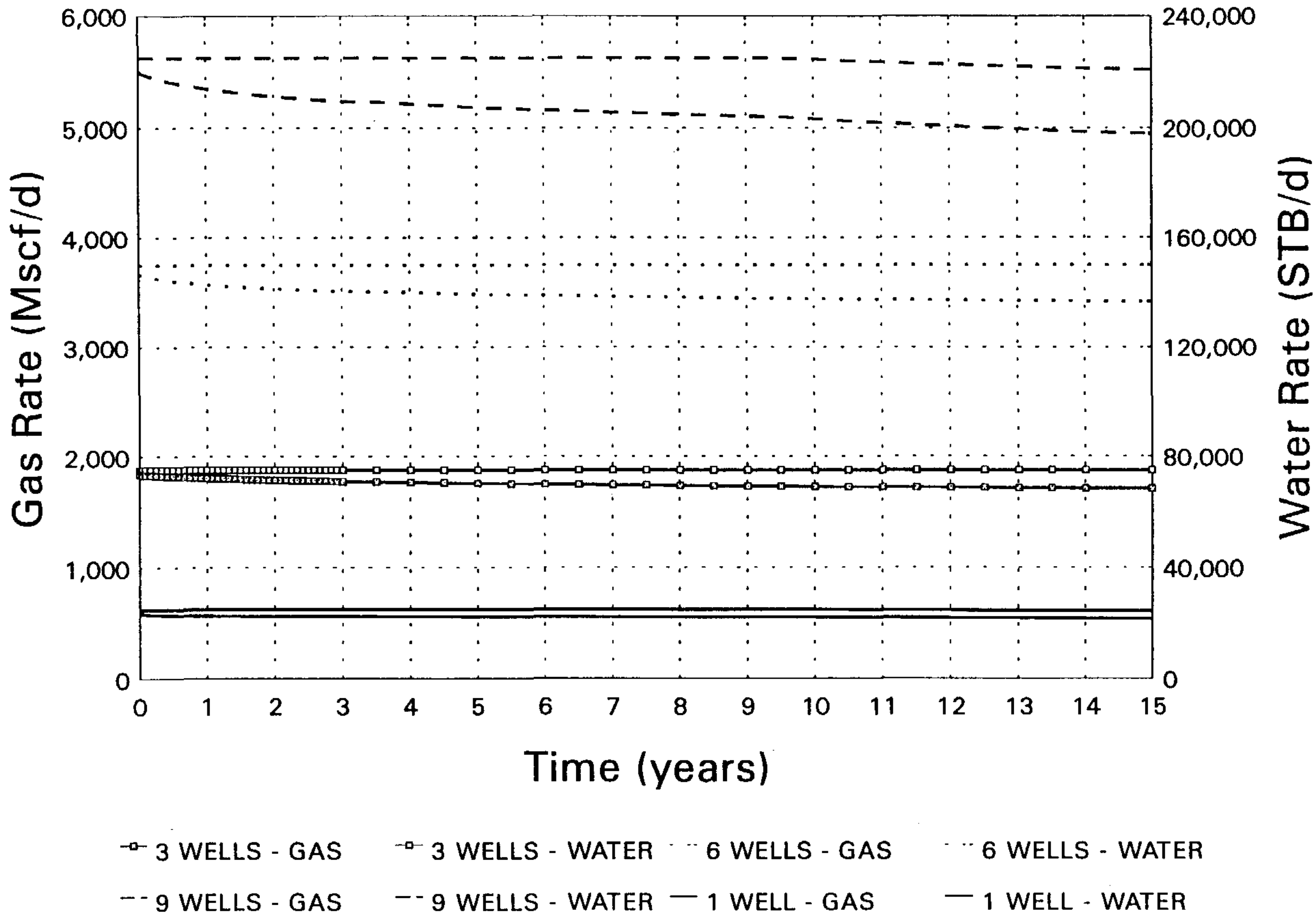


FIGURE 15

BOND SAND (MINIMUM)
Geo2 Fluid Production

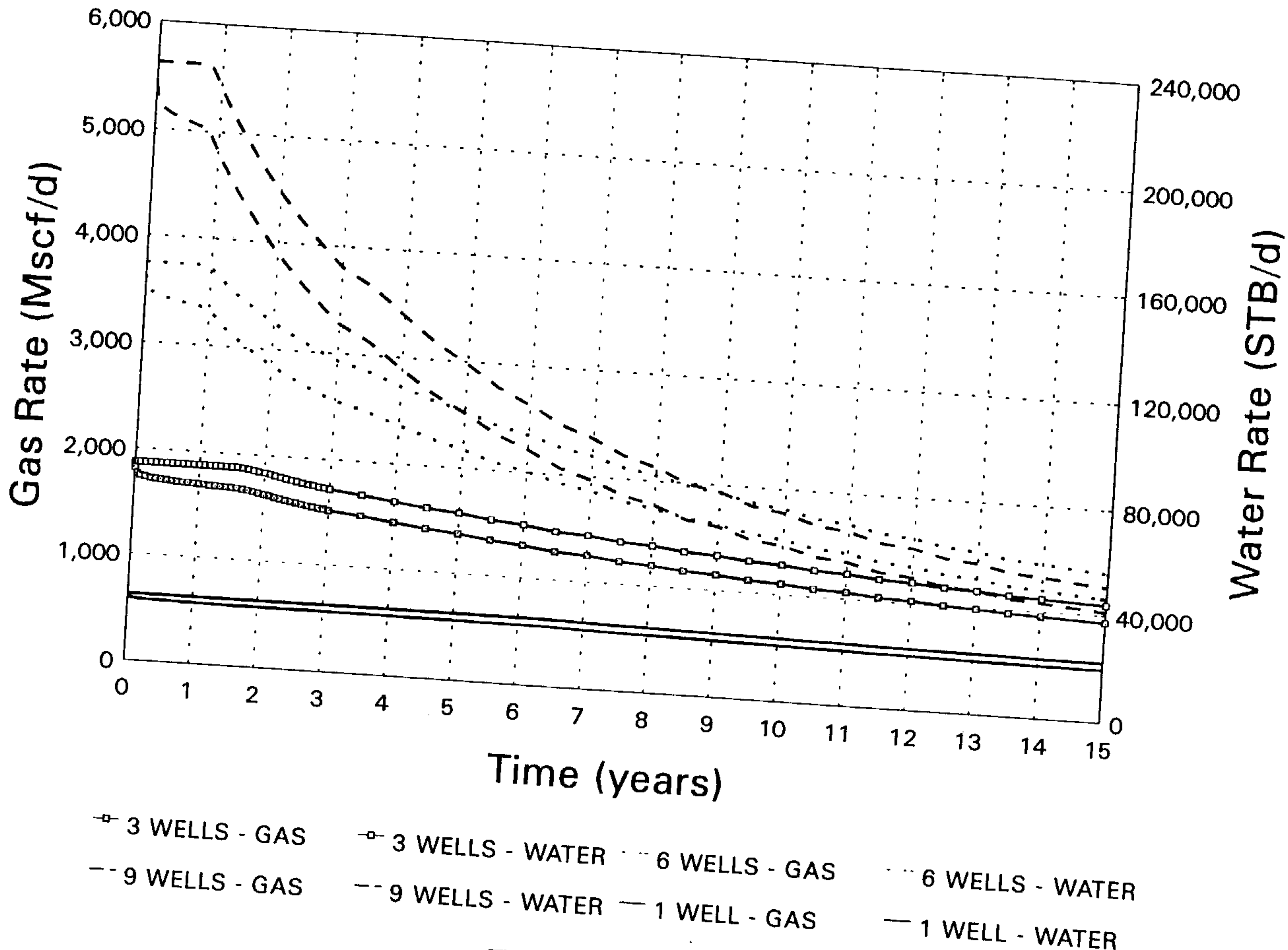


FIGURE 16

EAST SAND (MINIMUM)

Geo2 Fluid Production
Multi-Well Cases

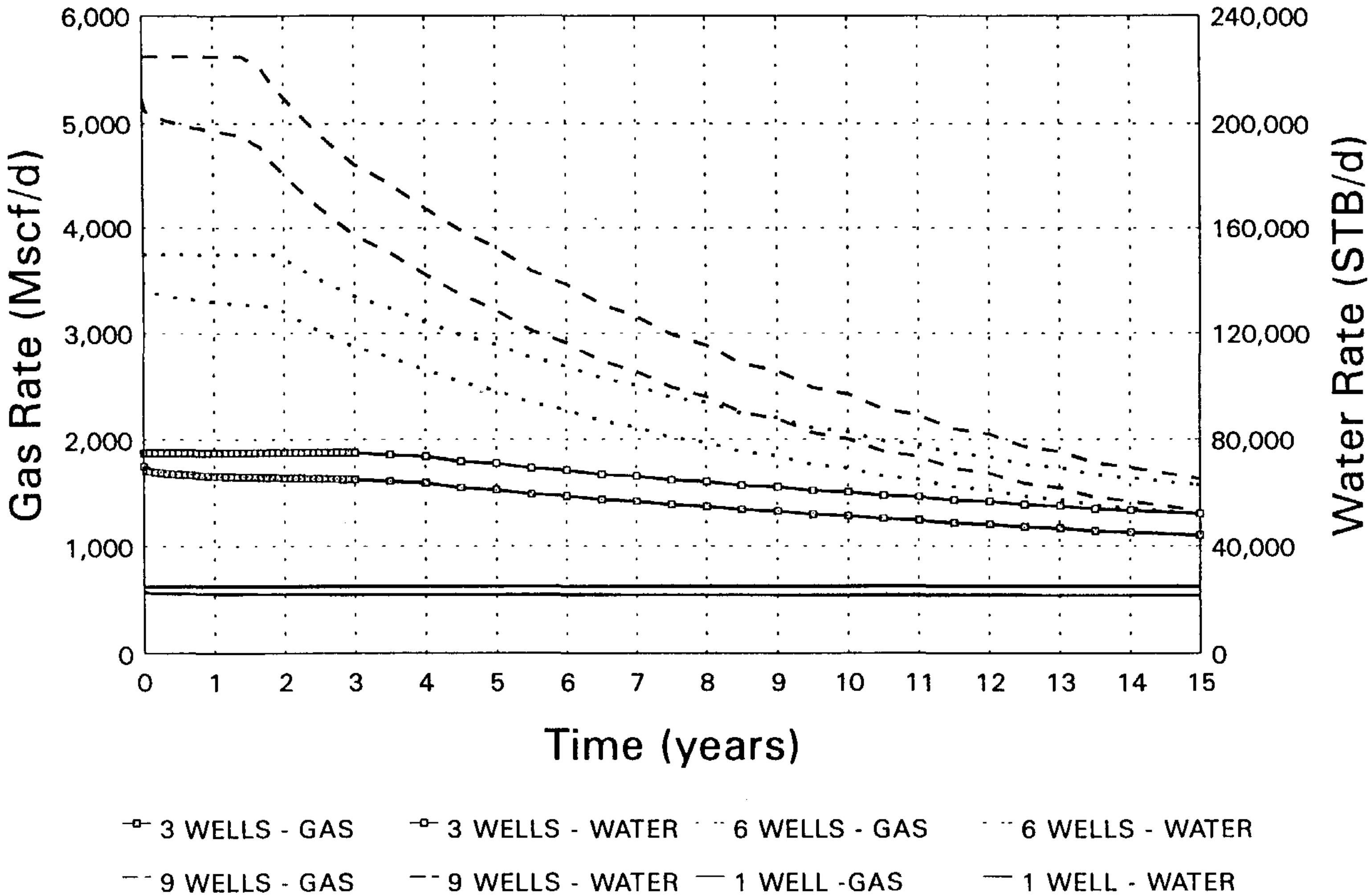
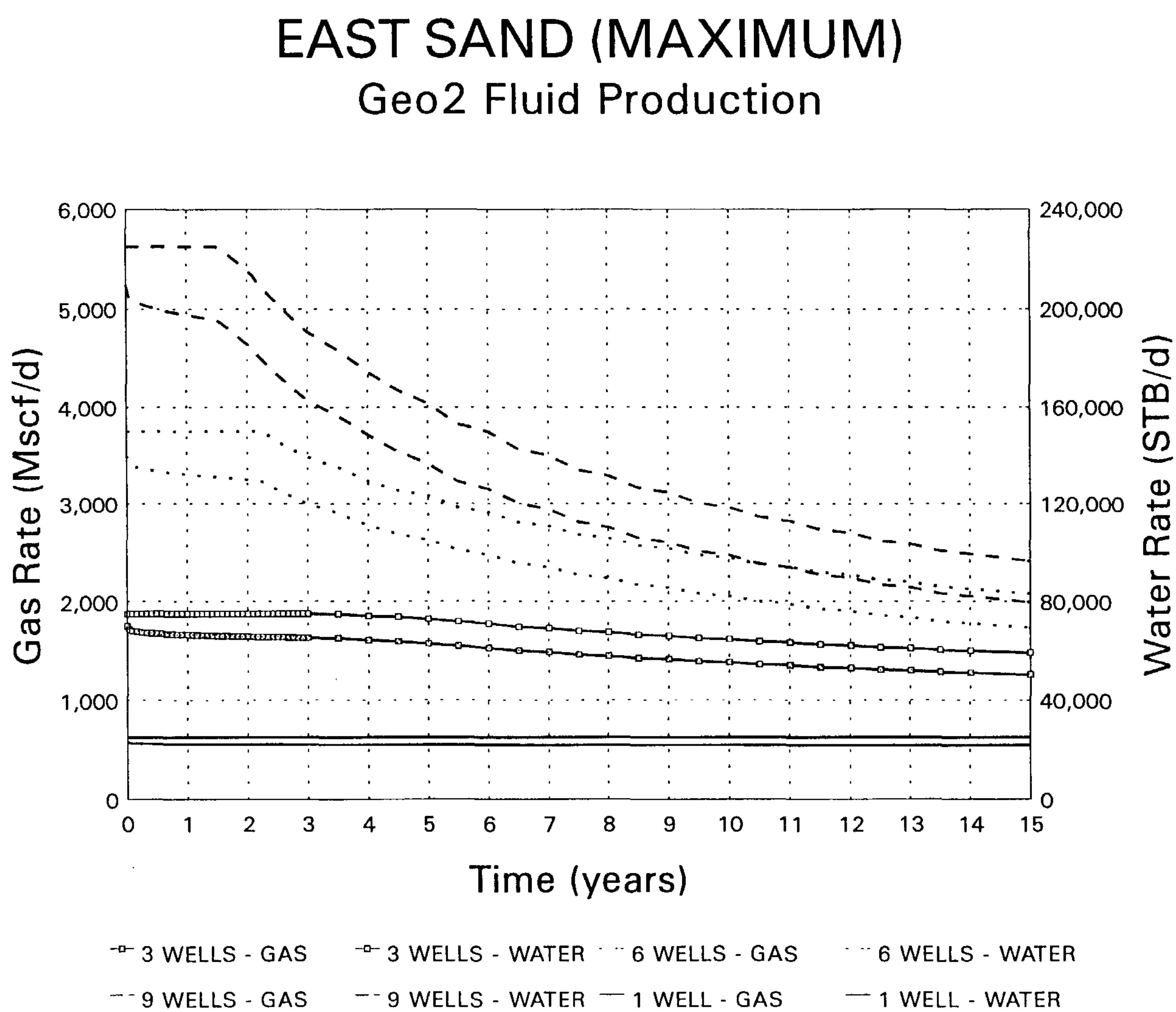


FIGURE 17



EAST SAND (MAXIMUM)
Geo2 Fluid Production
Gas Rate (Mscf/d)
Water Rate (STB/d)
0
1,000
2,000
3,000
4,000
5,000
6,000
0
40,000
80,000
120,000
160,000
200,000
240,000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (years)
3 WELLS - GAS
3 WELLS - WATER
6 WELLS - GAS
6 WELLS - WATER
9 WELLS - GAS
9 WELLS - WATER
1 WELL - GAS
1 WELL - WATER

FIGURE 18

MARK SAND (MAXIMUM)

15 Year Cumulative Production
Geo2 Fluid Production

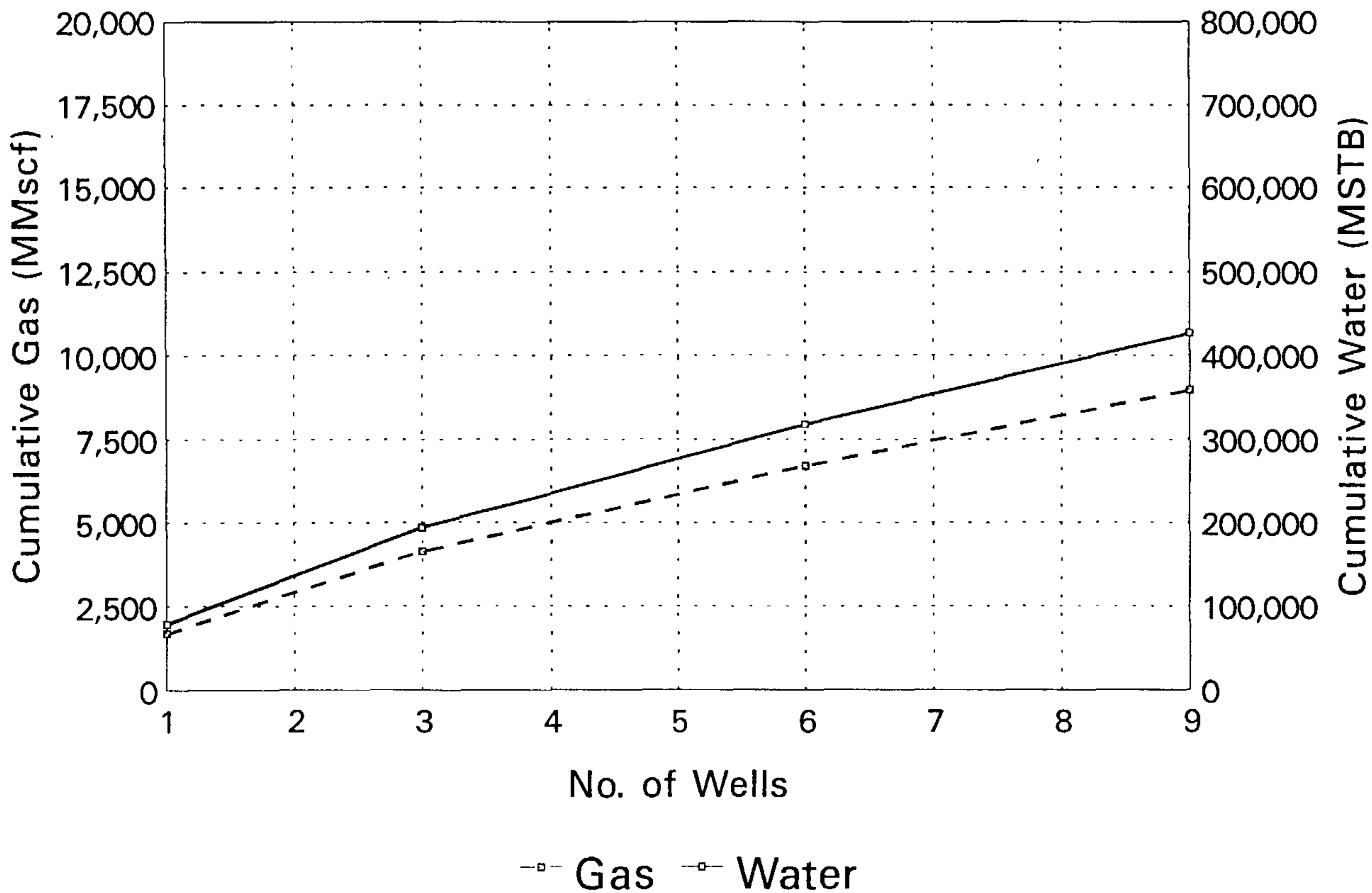


FIGURE 19

MARK SAND (MINIMUM)

15 Year Cumulative Production
Geo2 Fluid Production

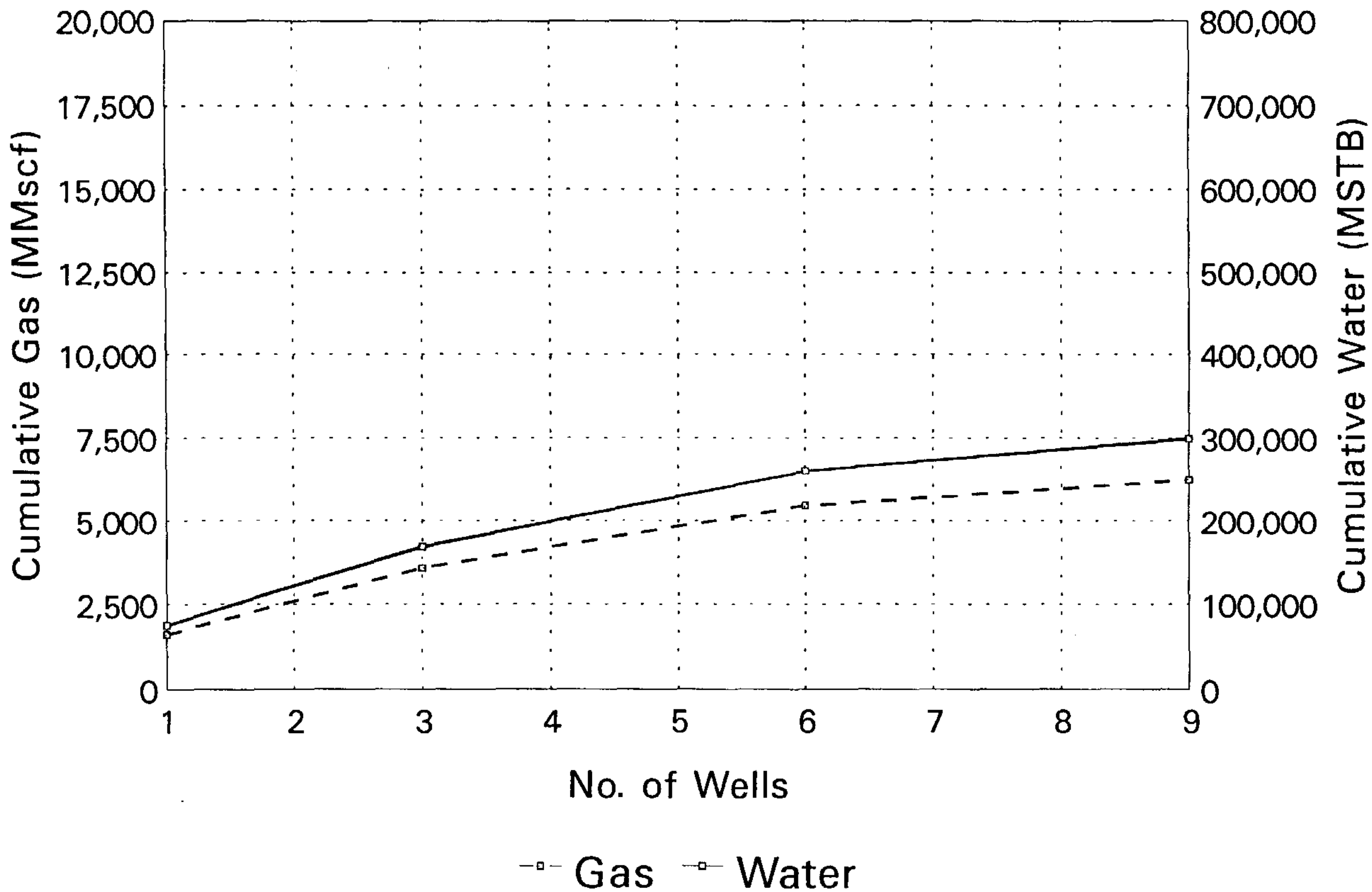


FIGURE 20

BOND SAND (MAXIMUM)

15 Year Cumulative Production
Geo2 Fluid Production

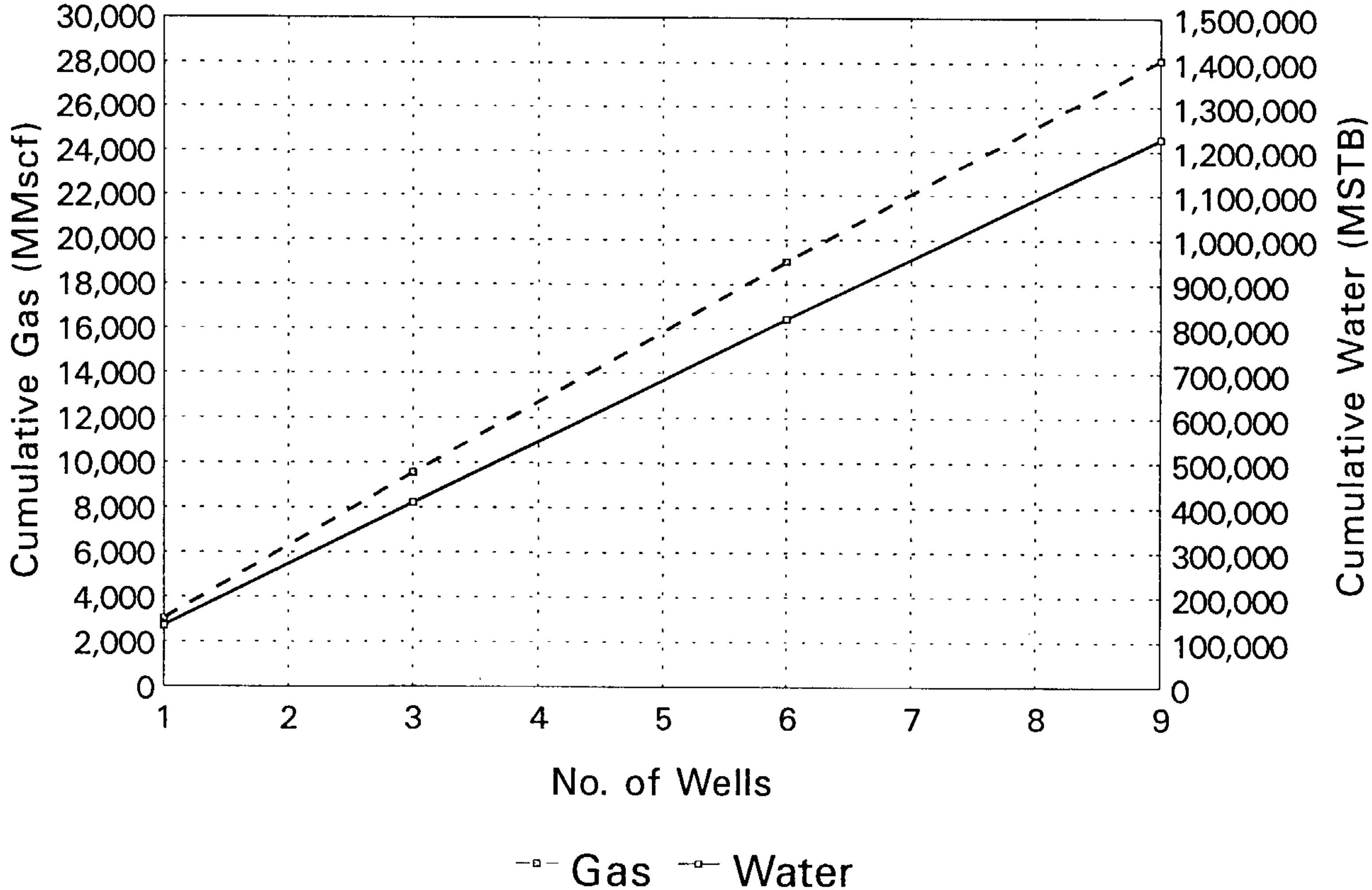


FIGURE 21

BOND SAND (MINIMUM)

15 Year Cumulative Production

Geo2 Fluid Production

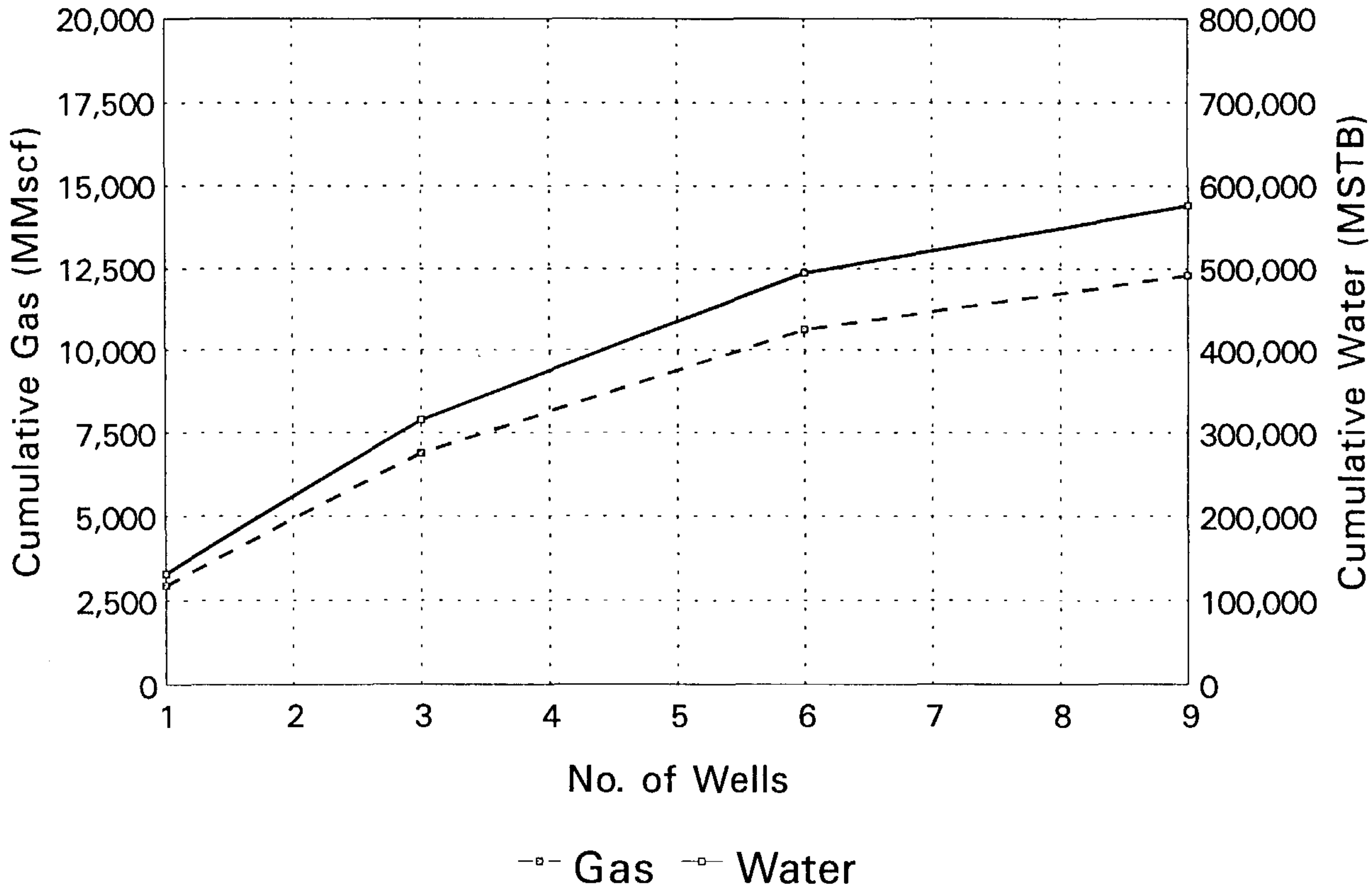


FIGURE 22

EAST SAND (MAXIMUM)

15 Year Cumulative Production

Geo2 Fluid Production

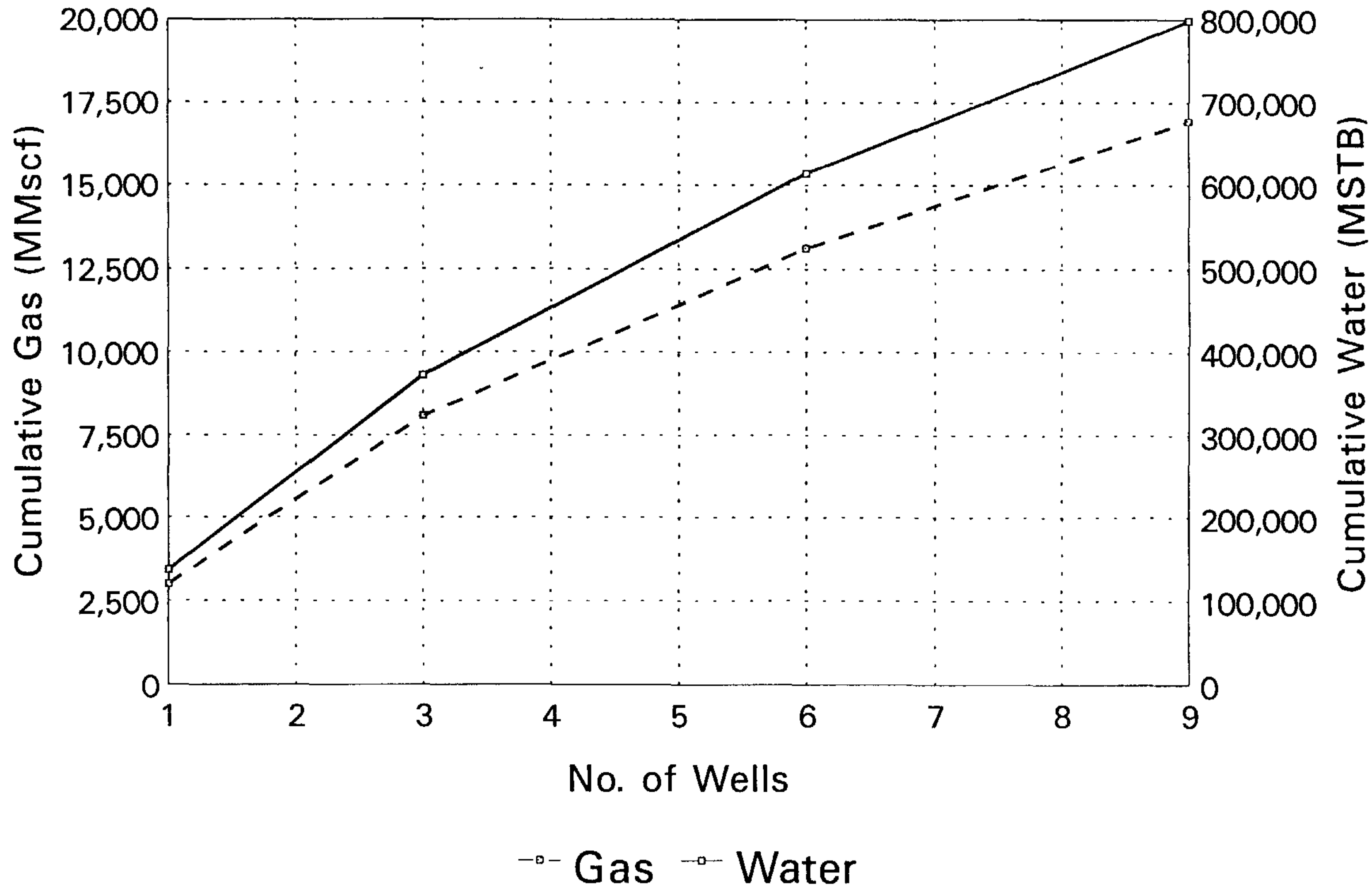


FIGURE 23

EAST SAND (MINIMUM)
15 Year Cumulative Production
Geo2 Fluid Production

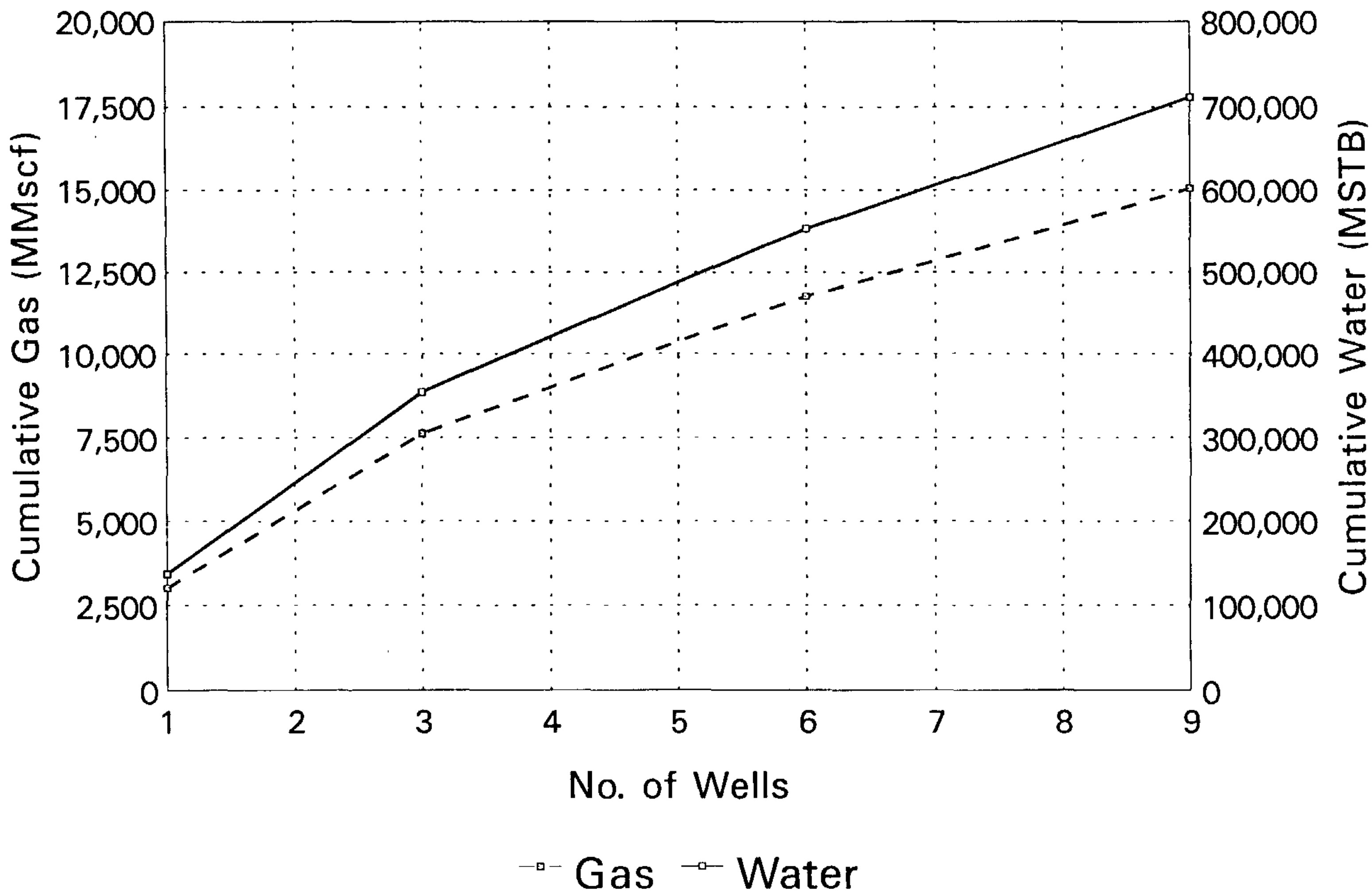


FIGURE 24

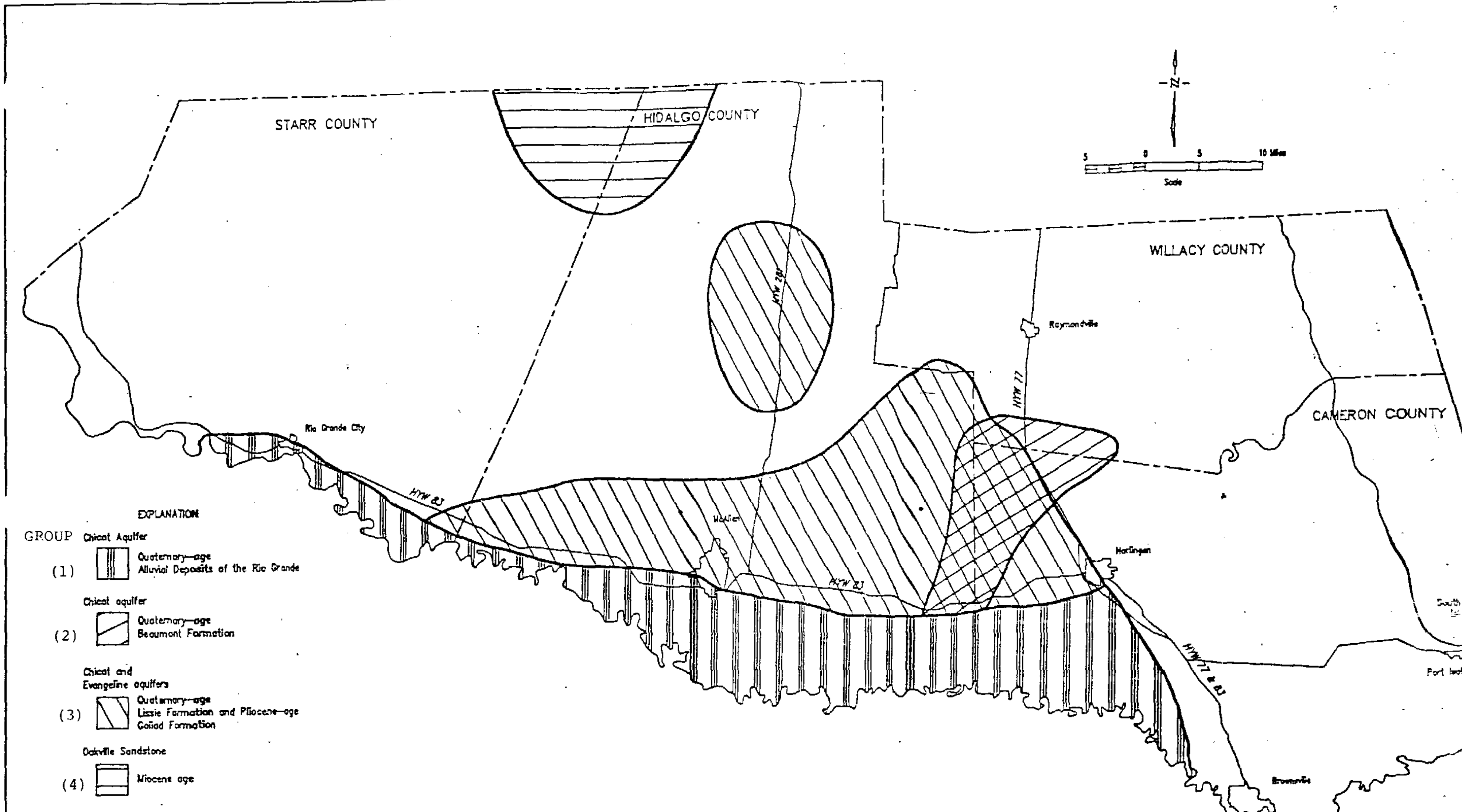


FIGURE 25 (Same as Figure 5 from TWDB Report 316)

APPROXIMATE PRODUCTIVE AREAS OF THE MAJOR SOURCES OF GROUND WATER IN THE LOWER RIO GRANDE VALLEY

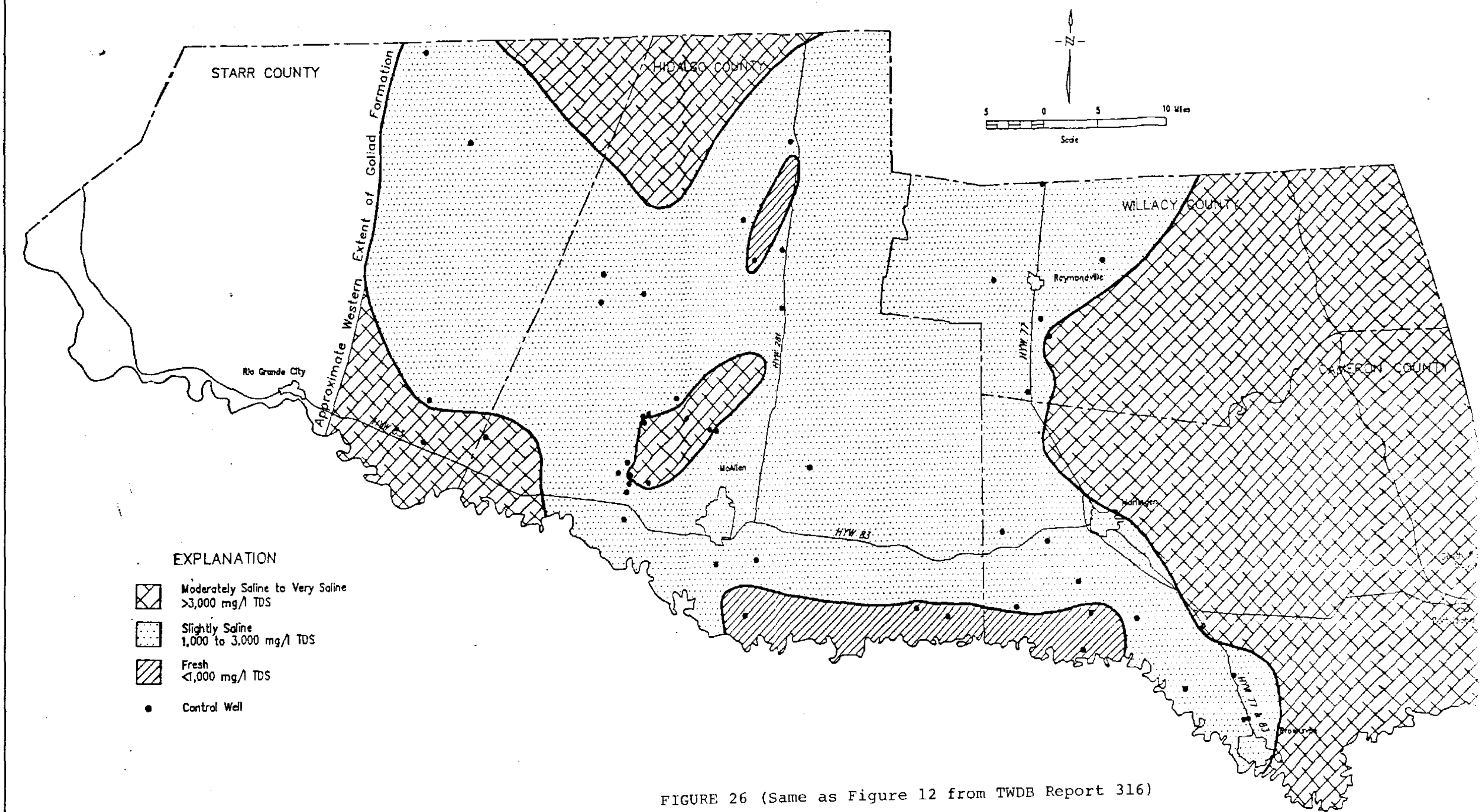


FIGURE 26 (Same as Figure 12 from TWDB Report 316)

CHEMICAL QUALITY OF WATER IN THE EVANGELINE AND CHICOT AQUIFERS

Part A - Geologic Assessment

Introduction

The South Texas area within the Rio Grande Embayment has long been of interest for the possibility of geopressured-geothermal energy production from the high temperature, thick, massive sands of the deep Frio and Vicksburg Formations. These sands are part of a sequence of thick wedges of sediment containing enormous volumes of rock. The wedges consist of interbedded sand and shale, massive sandstone, and massive shale. Originally, these sand bodies formed extensive aquifers with considerable lateral extent (Henry and Morton, 1982). Within the Rio Grande Embayment, depositional pattern is also strongly affected by a series of major growth fault systems which affected both the sediment distribution and resulting structural style (Fig. 1).

Two reservoir areas, containing thick sand sequences and outlined by major north-south trending growth faults, have been defined (Fig. 2). Reservoir area C, defined by the major McAllen growth fault on the west, and the Donna fault on the east, contains two potential sand sequences: the Marks sand (Fig. 4), with an average depth of 9,881 feet, average pressure gradient of 0.73 psi/ft and an average temperature of 279°F, and the Bond sand (Fig. 5), with an average depth of 10,626 feet, average pressure gradient of 0.76 psi/ft., and an average temperature of 296°F.

Reservoir area B, defined by the Donna fault on the west and the Weslaco fault on the east, contains several thick sand sequences. However, the sand at 10,000 feet (Fig. 6) with an average depth of 10,033 feet, average pressure gradient of 0.745 psi/ft., and average temperature of 264°F, was picked as a potential reservoir because of its lateral persistence, and the extremely low salinity (4,000 ppm Cl) of the connate water.

It should be noted here that the depths referred to in the discussion, and indicated in the tables, are log depths uncorrected to sea level. All logs did not indicate the elevation from which the log was taken, and all logs did not indicate the ground elevation or the elevation of the rig floor and Kelly bushing. Average elevation within the study area is less than 100 feet above sea level; therefore, all depths should be corrected by a factor of approximately 80 feet. This difference does not have a bearing on values for temperature, pressure, porosity and permeability.

While both reservoirs have similar pressure gradients, reservoir C has much higher average temperatures, and reservoir B has much lower water salinities. Reservoir B would appear to have potential as a water source in addition to the geopressure-geothermal potential.

Previous Investigations

Previous investigations of the geothermal-geopressure potential of reservoirs in the south Texas area have been carried out by numerous entities, both private and public. Gulf Geothermal Corp. of Baton Rouge, La., and Magma Gulf Co. of Houston, Tx., conducted studies in the early 1970's with the intent to lease large tracts for possible drilling (Durham and others, 1974).

R. H. Wallace of the United States Geological Survey had earlier noted the extremely low salinity ("fresh") water sands in the deep Frio and Vicksburg formations in the eastern part of the Rio Grande Embayment (Wallace, 1974). S. S. Papadopulos of the U.S.G.S. demonstrated the hypothetical flow from a geopressured reservoir using the area outlined by the growth faults in Hidalgo County (Papadopulos, 1974). The Texas Bureau of Economic Geology (Bebout and others, 1975) has conducted a number of studies, which included the South Texas area, for the United States Department of Energy. One of the most extensive studies of the area was conducted by the Southwest Research Institute for the former United States Energy Research and Development Administration (Swanson and Others, 1976).

Procedure

Numerous regional studies of the South Texas area have resulted in the delineation of a number of geothermal-geopressure "fairways," primarily defined by specific sediment packages, and bracketed by major growth fault trends (Woodruff and others, 1982). Three of these fairways occur in Hidalgo County: a western fairway bounded by the Vicksburg fault trend in eastern Starr County and the McAllen fault, a central fairway outlined by the McAllen and Donna faults, and an eastern fairway outlined by the Donna fault and the Weslaco fault.

A preliminary evaluation of the three principal trends led to the conclusion that only the central and eastern fairways demonstrated sufficient potential for further investigation. Although temperatures and pressures in the western fairway are very high, the sands are not thick enough nor laterally persistent. The trend is also extensively faulted with numerous transverse faults and antithetic faults relative to the main faults. Reported porosities and permeabilities of the sands are also extremely low.

Focus was then directed to the central and eastern fairways which were designated Reservoir Areas C and B respectively. Using the available published information in addition to proprietary fault maps from Magma Gulf Co., and isopach maps from Mayfair Minerals Co., an analysis of all sands below the top of geopressure was conducted. Some 30 well logs in the two areas were analyzed, and 5 wells in each reservoir were chosen as key wells to represent the lateral variations of the sands within the reservoir (Tables 1 and 3). Two sands in Reservoir Area C were determined to have the optimum characteristics for production based on log characteristics (Fig. 4 and 5). These were primarily based on uniformity and lateral continuity of the sands, which included thicknesses sufficient to offset variation caused by faulting (Fig. 3). One sand in Reservoir area B was chosen, primarily because of the depth and extremely low salinity of the water (Fig. 6). Potential porosity and permeability values were based on both spontaneous potential and resistivity characteristics. Although there are numerous seismic lines in the area, no seismic data were acquired or evaluated because of budget limitations.

Geology

In the Rio Grande Embayment the Oligocene lower and middle Frio Formations are characterized by enormous thicknesses of sediment deposited as discrete sequences of sand and mud, which represent an orderly succession of lithologies reflecting depositional environment. Both deltaic progradation and delta-flank aggradation characterize the Frio sediments in the area. Thick sequences of shelf and upper-slope prodelta mudstone and delta-front sandstone are overlain by equally thick massive, shoreface to coastal-barrier sandstone (Finley and others, 1989).

The massive clays deposited in deep water have low densities compared to the superjacent sandstone bodies, and are also water saturated. The rapid deposition and sediment loading create unstable conditions which initiate and sustain movement of faults, slumps, and diapirs (Henry and Morton, 1982). Major growth faults were formed contemporaneously with deposition which caused substantial thickening of the sedimentary sequences. These growth faults form broadly arcuate zones parallel to the coast which contain sediment sequences that increase in thickness toward the faults, or away from the basin (Fig. 3).

Subsequently, with increased depth of burial, the sediments were subjected to increased pressures and temperatures. Compaction of the sediments resulted in pore waters being expelled from the clays into the more porous and permeable sandstones. Diagenesis at the clay-sandstone contacts resulted in permeability barriers which prevented further movement of the pore waters. These fluids became over-pressured by the weight of the compacting overlying sediments, and acted as thermal barriers by reducing heat flow in the sediments.

The sandstones were deposited in nearshore environments that included distributary channel or delta-front environments, or as barrier islands and strand plains in the interdeltaic areas. These massive sandstones, when originally deposited, formed extensive aquifers with considerable lateral extent (Henry and Morton, 1982). Growth faulting, with the attendant thicknesses of sediments, has resulted in a structural setting in the Rio Grande Embayment which includes major fault trends and minor associated faults, some of which are parallel, and some of which are transverse to the main trends (Figs. 2,3). Syndepositional units which thicken toward the main faults form folds, or rollovers, which dip markedly into the faults. Rapid sedimentation also resulted in shale ridges, and shale diapirs (Collins, 1983). Well No. 5 (Fig. 1 and 2) penetrated a shale diapir which displaced the section vertically upward (Table 1).

Within the study area, the dominant growth fault is the McAllen fault, which extends from south of the Rio Grande northward as much as 150 miles (Collins, 1983) (Figs 1 and 3). This fault may be due to instability, or weakness, in the basement which resulted in activity throughout the Oligocene-Miocene depositional interval. The greatest movement, or activity, of the fault occurred during deposition of the marine (lower and middle) Frio sequence (Collins, 1983). To the east in the study area, the Donna fault created a relatively stable area (Collins, 1983). The movement on the Donna fault was not as continuous, and the displacement was not as great, as along the McAllen fault. This differential movement resulted in a flattening of the dip towards the Donna fault. The relatively small Weslaco fault, farther to the east, results in a "reversal" of the dip away from the McAllen fault and toward the Gulf Basin.

The Shepherd fault (Figs. 1,2), which is transverse to the main McAllen fault, was also active during the time of deposition of Frio sediments. The same stratigraphic section is present on both sides of the Shepherd fault, but the section is thicker on the downthrown (north) side of the fault (Collins, 1983).

Sediment thickening toward the McAllen and Shepherd faults has resulted in a structural axis which migrates upward in the section, and geographically toward the northeast. This axis trends from the southeast (Donna) toward the northwest (Edinburg) (Fig.2). Along this axis, or flattening of the dip angle, faulting is less persistent, which results in greater continuity of the aquifers (Swanson and others, 1976). Swanson referred to this area as "a promising area for the occurrence of continuous geopressured reservoirs of broad areal extent ..." (Swanson and others, 1976).

Throughout both potential reservoir areas, the approximate depths to the top of the geopressured zone averages approximately 9,000 feet. The geopressured zone ranges from approximately 8,500 feet on the west side of Reservoir area C to 9,500 feet on the east side of Reservoir area B, with relatively uniform depth throughout the study area (Fig. 2). The minimum depth of the 300°F isotherm appears to center in an area which includes the northwest-southeast trending axis between the cities of Edinburg and Donna.

Salinities of the connate water in Reservoir Area C ranges from 9,000 to 15,000 ppm Cl (Swanson and others, 1976). Higher temperatures occur at greater depths (approximately 12,000 feet) in the eastern part of the study area, in Reservoir Area B, but the extremely low salinity, moderate temperature, geopressured sands at shallower depths (Table 4) make this an optimum area for production of useable water.

Data for the quantity of entrained gas in the water are not available. However, estimates based on comparisons of gas-to-water ratios, using salinity of the water, would indicate ratios as high as 25-30 SCF/BBl.

Reservoir Area C

Area C includes the area located between the McAllen fault to the west, the Donna fault to the east, the transverse trending Shepherd fault to the south, and extends northeast to a point of limited well control (Fig. 2). This outline defines a maximum reservoir area of some 255 square miles. A reservoir defined by outlining the area within lines drawn between key wells results in a reservoir of approximately 90 square miles (Fig. 2).

The Frio sediment pattern within this section is dominated by the major growth fault to the west, the McAllen fault, and the Donna fault to the east. The lower Frio sediments are cut by numerous faults which dip toward the coast. This faulting dies out in the shallower Frio section (Fig. 3). Rapid sedimentation of the lower Frio resulted in sands thickening away from the coast toward the McAllen fault, with a resultant reversal of dip. Dip angles increase toward the major fault and decrease, or flatten, toward the northeast (Fig. 3). Although the lower Frio section is cut by numerous faults, the thickness of the sands within this section is greater than the displacement along the faults. This allows for a connection of the reservoir sands within the Marks and Bond sand sequence (Fig. 3) (Collins, 1983).

The Marks sand (Fig. 4) occurs within an interval from 7,760'-8,230' in the southeast side of the area to 10,970-11,990' in the west. The sand continues to thicken and increase in depth as it dips to the west toward the McAllen fault. Because of increased faulting related to the main fault, the area of the reservoir should be considered to be limited to the west before the main fault is encountered (Fig. 3). To the northeast, the dip flattens creating a high which lies along an axis which trends from the northwest to the southeast along a line from Edinburg to Donna (Fig. 2).

Within Reservoir Area C, average depth to the top of the Marks sand is 9,881 feet. Average thickness of the sand is 409 feet, and average net sand thickness is 245 feet, or an average of 63 percent sand. Average pressure at the top of the sand is 7,333 psi, with an average pressure gradient of 0.73 psi/ft. Average temperature (A.A.P.G. corrected) is 279°F. The median temperature is, however, nearer 300°F in the area near the center of the reservoir. Porosity estimated from log resistivity and spontaneous potential averages 17 per cent, and permeability averages 14 md (millidarcies, designated by the symbol K). The average KH (millidarcies x average thickness of sands in feet) is 3,528. These data are summarized in Table 2.

No core data were available for the Marks sand, but log characteristics indicate the sand to be a fairly uniform shoreface to coastal barrier sandstone on the west to distal shoreface sands on the east. Individual sands within the section thin and show a more marked variation in resistivity.

Within Reservoir Area C, the Bond Sand occurs within the interval from 8,550 to 9,520 feet in well No. 5, to 11,670 to 12,220 in well No. 3 (Fig. 5). The average depth is 10,626 feet, and the average thickness is 635 feet. The net sand average is 334 feet, or 53 per cent sand. Pressure at the top of the sand averages 8,045 psi, and the average gradient is 0.76 psi/ft. Average temperature (A.A.P.G. corrected) is 296°F. Temperatures are again higher than the average nearer the center of the reservoir. Porosity and permeability were estimated from the resistivity and spontaneous potential character of the logs. These values were compared to reported values, and the lower values were used for simulation purposes. Porosity averages 18 per cent, and permeability 13.8 md. The average KH is 4,609.

The spontaneous potential curves were not good in all the wells; therefore, estimates of sand characteristics were derived primarily from the resistivity curves. Log characteristics would indicate the Bond Sand to be a more distal fine-grained shoreface sand with less reworking of sediment than the Marks Sand.

Like the Marks Sand, which was deposited in shallower water, the Bond Sand dips from east to west towards the McAllen fault, and thickens towards the fault. A flattening of dip also occurs toward the northeast along the axis of the high which extends from Edinburg to Donna (Fig. 2).

The possibility exists for this lower section to be cut by faulting, but the sand is persistent and laterally continuous throughout the area of key well control.

Reservoir Area B

Reservoir Area B is bounded on the west by the Donna fault which extends from the Rio Grande northward into Willacy County. It is bounded on the east by the Weslaco fault which extends from the Rio Grande northward along the Cameron County-Hidalgo County line into Willacy County (Fig. 1). Within area B, the reservoir is bounded on the south and north by lines which define the limits of key well control (Fig. 2). Small faults associated with both the Donna and Weslaco faults limit the reservoir to the north. The reservoir may extend somewhat farther to the south, but the extent is limited based on available well control. The south edge of the reservoir is not affected by the Shepherd fault which limits the south edge of reservoir area C. Within the area outlined, the reservoir could contain as much as 120 square miles (Fig. 2).

Within the area of Reservoir B there are numerous thick sands below the top of the geopressured zone. The "10,000 foot" sand is below the top of the geopressured zone, and is laterally continuous within the area. Additionally, this sand has the lowest reported salinity (4,000 ppm Cl) of any of the sands for which data are available. The top of the sand occurs at 9,550 feet on the west side of the reservoir and at 10,360 feet on the east side. The dip is relatively flat across the top of the Weslaco high or "uplift," although the dip angle begins to increase markedly at greater depth.

Within Reservoir Area B, the sand averages 10,033 feet in depth, with an average thickness of 517 feet. Net sand thickness averages 411 feet, or 78 per cent net sand. The pressure at the top of the sand averages 7,493 psi, and the geopressure gradient is 0.745 psi/foot. The average porosity is 15 percent and the average permeability is 16 md. Average temperature at the top of the sand is 264°F (A.A.P.G. corrected). Porosity and permeability values were estimated from resistivity and spontaneous potential log values. The average KH is 6106. These data are summarized in Table 4.

The 10,000 foot sand was deposited in shallower water of the prograding delta system than were the Marks and Bond sands of Reservoir area C. This massive sand appears to be a series of reworked distributary-mouth bar sands and shoreface sandstones with great lateral continuity within the area of Reservoir B (Fig. 6).

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Part B - Simulation of GP/GT Resource Potential

Introduction

The Geologic Assessment of the areas of interest identified three potential reservoirs, one in Area B and two in Area C. These are shown on Figure 1 of Part A. The reservoir rocks were described by well logs and correlated across the two areas of interest.

This information was then digitized to form the input to a numerical simulator. Using simulation techniques, flow rates and pressures can be calculated for wells drilled into each potential reservoir. A predicted performance for a test well in each reservoir was computed and a pattern of multiple wells was also calculated for each reservoir.

Model Development

The areas between the major faults as shown on Figure 1 were broken into computing grid blocks. In Area C the grid consisted of a 29 by 22 grid block mesh that covers an area of 220 mi^2. This represents the area between the McAllen Fault and the Donna Fault. This is intended to represent the maximum reservoir area possible. As an alternate to show the sensitivity to reservoir size a second grid was constructed that covered 90 mi^2. This area represents only the area included within the limits of well control. Area B was covered by a 30 by 34 grid block mesh. This grid covers the 120 mi^2 included between the Donna Fault and the Weslaco Fault and is further represented as the maximum case. The minimum case for this East Sand again represents the minimum area included within the well control.

The reservoir properties used were determined by the geologic assessment and shown on Tables 2 and 4. These properties include sand thickness, porosity, permeability, and initial pressure gradient. The remaining properties needed for the simulation include the fluid descriptions and the well parameters. The PVT relationships were developed for brines using the best correlations available. The PVT properties of the gas and brine are shown below.

FLUID PROPERTIES

Pressure psia	Gas FVF rb/Mcf	Gas Visc cp	Water FVF rb/STB	Sol'n Gas Scf/STB	Water Visc. cp
1000.00	3.1957	.0140	1.0368	5.4	.30
2000.00	1.5359	.0160	1.0338	9.7	.30
3000.00	1.0276	.0188	1.0307	13.2	.30
4000.00	.8084	.0215	1.0276	16.0	.30
5000.00	.6899	.0243	1.0246	18.4	.30
6000.00	.6154	.0270	1.0215	20.6	.30
7000.00	.5659	.0295	1.0185	22.5	.30
8000.00	.5311	.0319	1.0154	24.2	.30
9000.00	.5047	.0341	1.0123	25.8	.30
10000.00	.4831	.0362	1.0093	27.3	.30

Since the reservoir flow is all single phase water, relative permeability curves are not needed nor is structure important since the sands will be in hydraulic equilibrium. This completes the data needed for the reservoir description.

The wells were described using large diameter flow string (5 inch diameter). The wells were assumed to be completely penetrating with a zero skin. The flow restriction was 25,000 bbl/d (approximately 1,000,000 gal/day) or what the well could deliver against a 5500 psi bottom hole flowing pressure. Surface pressures were then calculated from those flowing conditions. This results in some slightly anomalous behavior in some of the performance curves where the rate declines. A slightly increasing wellhead pressure is computed. This is because the bottom hole pressure is held constant and the declining fluid rate produces less pipe friction.

Simulation Results

Several simulation runs were made for each of the three identified reservoirs. First, a single test well performance was calculated for each reservoir for each the minimum case and maximum case. Then patterns of wells were superimposed on their reservoir. Each reservoir had patterns of 3, 6 and 9 producing wells.

The results of the single test well simulations are shown on Figures 7-12. These show that the Mark Sand having the thinnest section begins to decline in rate almost immediately for both the minimum and maximum reservoir sizes. The Bond Sand maintains the 25,000 bbl/d rate for about nine years in the maximum case and about six years in the minimum case. The East Sand maintains the 25,000 bbl/d for the full fifteen year period of investigation for both the minimum and maximum cases. Gas rates for all these cases are shown on the appropriate charts, but follow the solution gas relationship shown on Table 3.

The pattern runs are shown on Figures 13-18. In all cases the patterns of wells show declining production rates, even for the East Sand which showed no decline at all in the single well case. To understand the charts and more importantly the reservoir mechanics, notice how the patterns deviate from the maximum constant rate. As more wells are added to the pattern, the deviation occurs earlier in time.

Recoverable Volumes

We can take the same data described above to make some additional charts that show the volumes of brine that are recoverable from the reservoirs. These charts are shown as Figures 19-24. These charts show the recovery of gas and brine as a function of the number of wells in the reservoir.

It is of interest to follow the cumulative recovery curves from the minimum cases to the maximum cases. These show that the smaller reservoirs cannot support as many wells. Further, the curvature of these cumulative recovery charts shows the declining effectiveness of adding additional wells to the reservoirs. For example, for the East Sand Maximum case the fifteen year brine recovery is about 370 million bbl or 123 MMbbl/well. Six additional wells will contribute a total of 477 MMbbl or an average of only 79.5 MMbbl each, a decrease of about 35% per well. This shows that the spacing of development wells is an important economic issue.

Discussion

These simulation cases were developed to illustrate the capability of the GP/GT reservoirs that have been identified. Nearly all the data were estimated from old well logs or derived from correlations. To the extent that these estimates are accurate, the predicted performance is reasonable.

Many of the controlling parameters in the various simulations were somewhat arbitrary. For example, the 25,000 bbl/d maximum production rate is arbitrary. The only reason for selecting that limit is that has been historically the maximum production rates that similar wells in the Gulf Coast have been produced. The limiting bottomhole pressure was selected to yield surface pressures in excess of 500 psi. The composition of the produced gas will vary with the pressure of the wellhead separation equipment. The lower the pressure, the higher the CO_2 content of the gas. Experience has shown a pressure of 500 psi will produce pipeline quality gas.

It must be pointed out that although there have been test wells in the Gulf Coast area that have produced these volumes over sustained periods, there are no prototype pattern developments. While this has not been demonstrated physically, the technology that controls the fluid flow is well understood and the projection of the patterns from the test wells is much more reliable than the test well projections themselves.

Section II: An Assessment of the Brackish Groundwater Reource

Our first step in making an adequate assessment of the Brackish Groundwater resource in Cameron and Hidalgo counties was to obtain known available information regarding the subject matter. In order to do so, we have done the following:

1. Researched available reports in the library of the Texas Natural Resource Conservation Commission (formerly Texas Water Commission).

2. Met with and obtained available information from several members of the Texas Water Development Boards' staff, namely, John Ashworth, Mark Berryman and Richard Preston.

3. Met with and gained useful directions from Ridge Kaiser, P.E., a Principal in the firm of R.W. Harden and Associates, Inc., Consulting Hydrologists and Geologists.

4. Contacted representatives of the engineering departments of the cities of Brownsville, Harlingen, McAllen and Mission to obtain any available information they might have.

Through our research we have determined that the most useful and currently available public sources of information regarding the subject matter are four publications prepared by the Texas Water Development Board and other pertinent agencies of the State of Texas. A listing of these publications is as follows:

Bulletin 6014 - Volumes I and II entitled Groundwater Resources of the Lower Rio Grande Valley Area, Texas prepared by the Texas Board of Water Engineers in cooperation with the Geological Survey, United States Department of the Interior and the Lower Rio Grande Valley Chamber of Commerce, Inc. (February 1961).

Report 238 entitled Ground-Water Availability in Texas Estimates and Projections through 2030 prepared by the Texas Department of Water Resources (September 1979, Third printing in July 1987).

Report 279 entitled Occurrence and Quality of Ground Water in the Vicinity of Brownsville, Texas, prepared by the Texas Department of Water Resources (September, 1983).

Report 316 entitled Evaluation of Ground-Water Resources in the Lower Rio Grande Valley, Texas, prepared by the Texas Water Development Board (January 1990).

We have reviewed the content of each of these publications and have extracted therefrom a summary of the information deemed most relevant for this assessment. This summary is presented in a matrix-format in the enclosed tabulation and notes entitled: Locations and Descriptions of Productive Zones of Brackish Groundwater in Cameron and Hidalgo Counties, Texas.

As regards additional information, we include the following:

1. The water supply section of the Planning Division of the Texas Water Development Board is reportedly currently preparing a report entitled Gulf Coast Regional Aquifer Assessment. This report should be completed by the end of calendar year 1993, and it should contain a substantial amount of additional information as regards projections of recoverable volumes of Brackish Groundwater in the study area.

2. Pursuant to a previous undertaking, we were involved with the development of a report entitled Availability of Brackish Groundwater near Brownsville, Texas prepared by R.W. Harden and Associates, Inc. For the purpose of providing some relatively more detailed information regarding well field development, etc., we are including herein, as Appendix A, a synopsis of certain information in that Report.

Matrix of

Locations(1) and Descriptions(2) of Productive Zones of Brackish Groundwaters in Cameron and Hidalgo Counties, Texas

System	Series	Formation	Character of Material	Hydrologic Units: Report: 316(3)	Hydrologic Units: Bulletin 6014(4)	Generalized Water-Bearing Characteristics(5)	Projections of Recoverable Volumes: Individual Well Yields (gal/min)	Projections of Recoverable Volumes: Potential Supply Volumes	Quality Considerations(7)
QUATERNARY	Recent	Alluvial Deposits of the Rio Grande	Sand & Silt	Chicot Aquifer	Mercedes Sebastian Shallow Groundwater Reservoir Lower Rio Grande Groundwater Reservoir	Yields moderate to large quantities of fresh to slightly slightly saline water near the Rio Grande in Cameron and Hidalgo Counties.	For Lower Rio Grande Groundwater Reservoir: Maximum Yield = 2900 gpm Average Yield = 1200 gpm	No perennial yield data is presently available for the overall study areas, although it has been estimated that the entire reservoir would yield 75,000 acre-feet of water per foot of drawdown of the water table.(4)	Concentrations of silica (SiO_2) in the range of 30 to 50 ppm have been identified in certain wells, and these concentrations of silica could severely affect water recovery from the RO process.
QUATERNARY	Pleistocene	Beaumont Formation	Mostly Clay With Some Sand & Silt			Yields moderate to large quantities of fresh to moderately saline water.			
TERTIARY		Lissie Formation & Goliad Formation	Clay, Silt, Sand, Gravel, & Caliche		Linn-Faysville Groundwater Reservoir		No available data for Mercedes Sebastian and Linn-Faysville Groundwater Reservoirs	In that portion of the study area just west of Brownsville, at least 350,000 acre-feet of fresh to slightly saline groundwater is estimated to be in storage, and computer simulations have indicated that, by maintaining a spacing of 2000 feet, a supply of 9-10 mgd can be produced on a long term basis.(6)	
TERTIARY	Pliocene		Clay, Sand, Sandstone, Marl, Caliche, Limestone, & Conglomerate	Evangeline Aquifer		Yields moderate to large quantities of fresh to slightly saline water			High sulfate (SO_4) concentrations are also prevalent in some areas and could affect water recovery from both the EDR and RO processes.
TERTIARY	Miocene	Oakville Sandstone	Mudstone, Claystone, Sandstone, Tuff & Clay	Oakville Sandstone	Oakville Sandstone	Yields moderate quantities of slightly to moderately saline water in north-western Hildalgo County	Maximum Yield = 600 gpm Average Yield = 125 gpm	No available data.	

Notes:

(1) Refer to Exhibit 1, a reprint of Figure 5 from TWDB's Report 316 entitled Productive Areas of the Major Sources of Groundwater in the Lower Rio Grande Valley

(2) A substantial part of the information presented in this matrix has been taken from Table 1 of TWDB's Report 316 entitled Stratigraphic and Hydrologic Section of the Lower Rio Grande Valley Area

(3) Taken from Table 1 of TWDB Report No. 316

(4) Based on information taken from Texas Board of Water Engineers' Bulletin 6014, Volume 1

(5) Yields of wells: small = <50 gallons per minute; moderate = 50 to 500 gallons per minute; large = > 500 gallons per minute
Chemical Quality of Water: fresh = <1,000 milligrams per liter); slightly saline = 1,000 to 3,000 mg/l; moderately saline = 3,000 to 10,000 mg/l.

(6) Based on information taken from TDWR's Report No. 279.

(7) Refer to Exhibit 2, a reprint of Figure 12 from TWDB's Report 316 entitled Chemical Quality of Water in the Evangeline and Chicot Aquifers for an indication of TDS levels. Other quality considerations are summarized below.

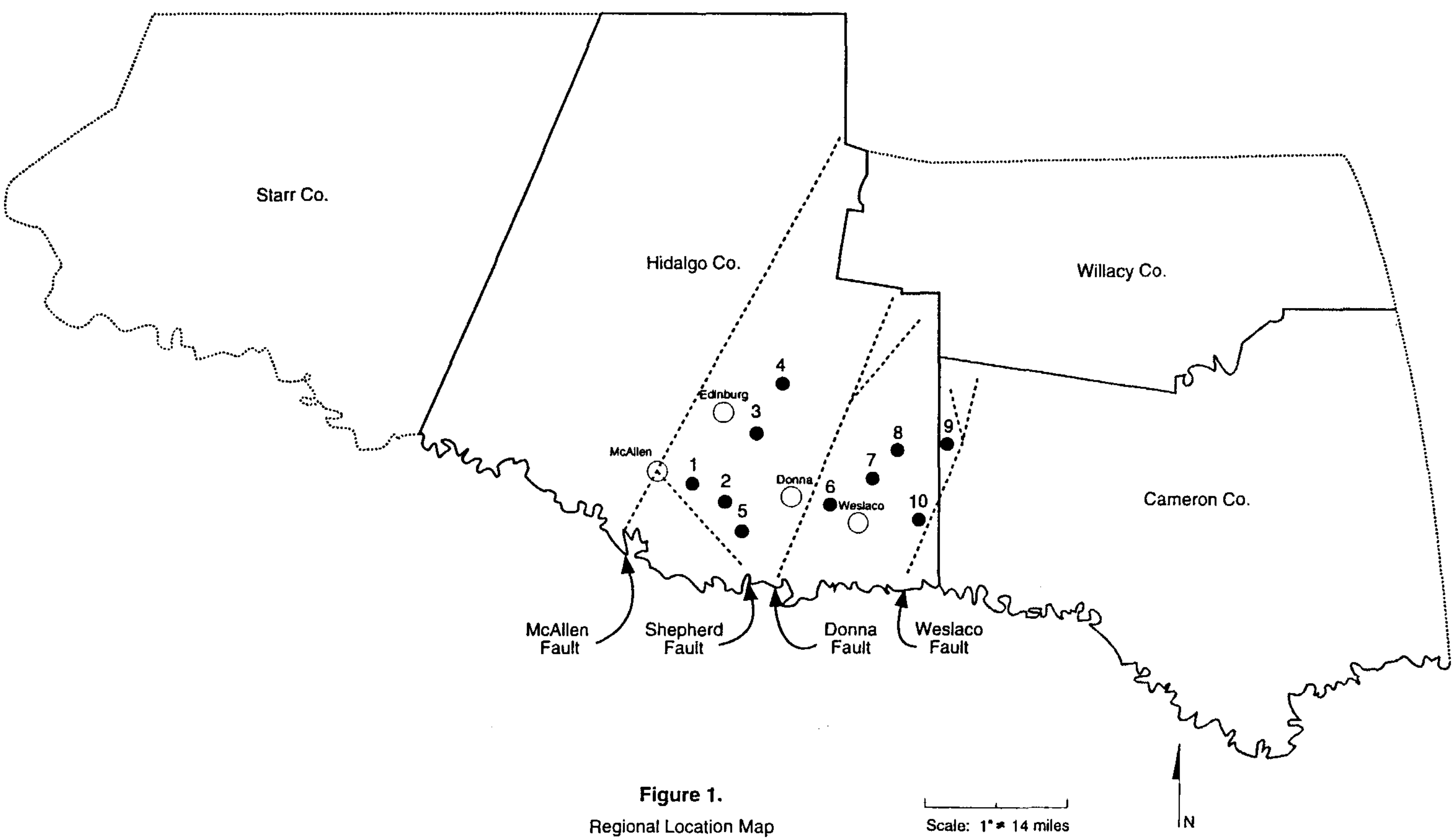


Figure 1.

Regional Location Map

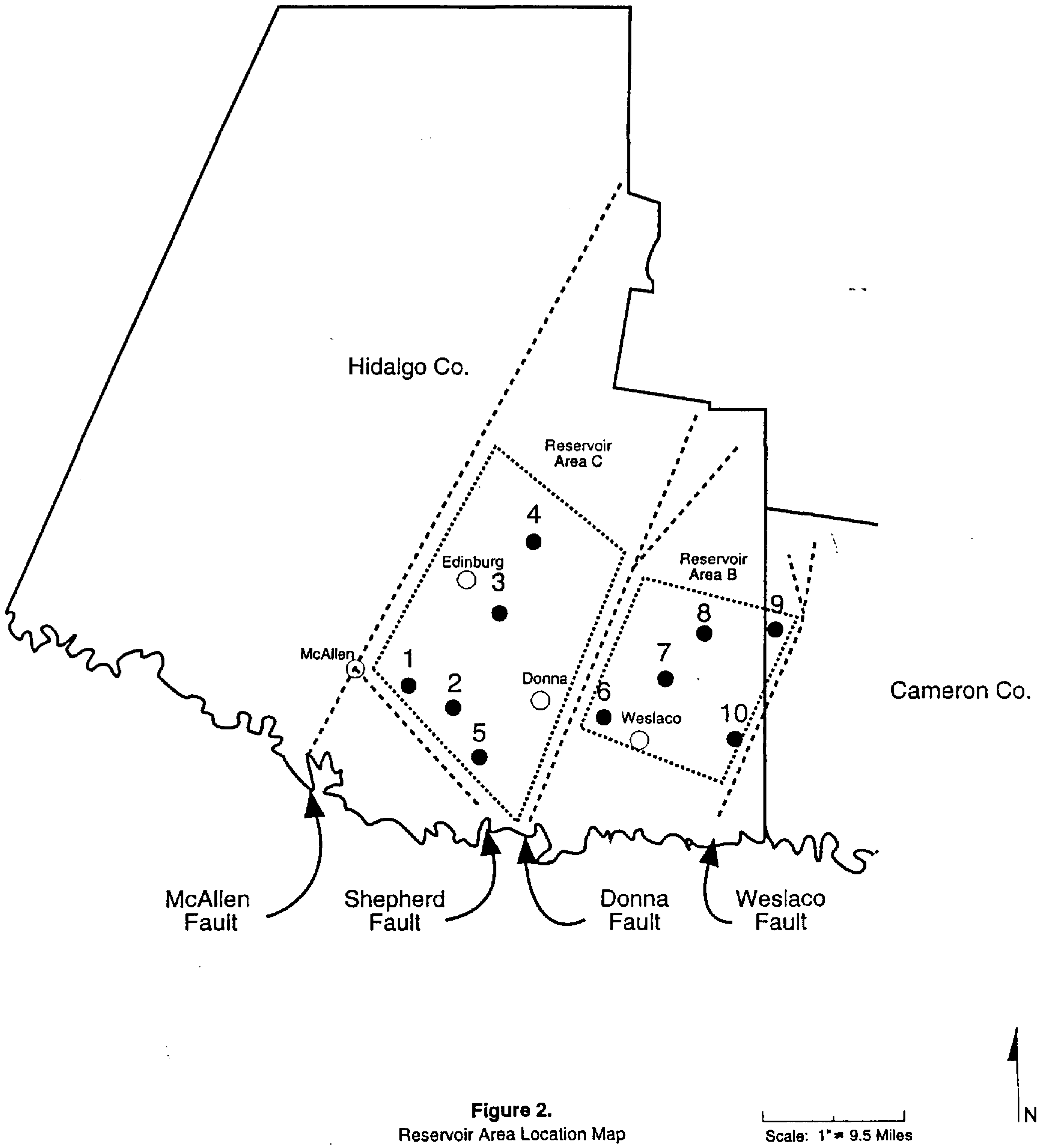


Figure 2.
Reservoir Area Location Map

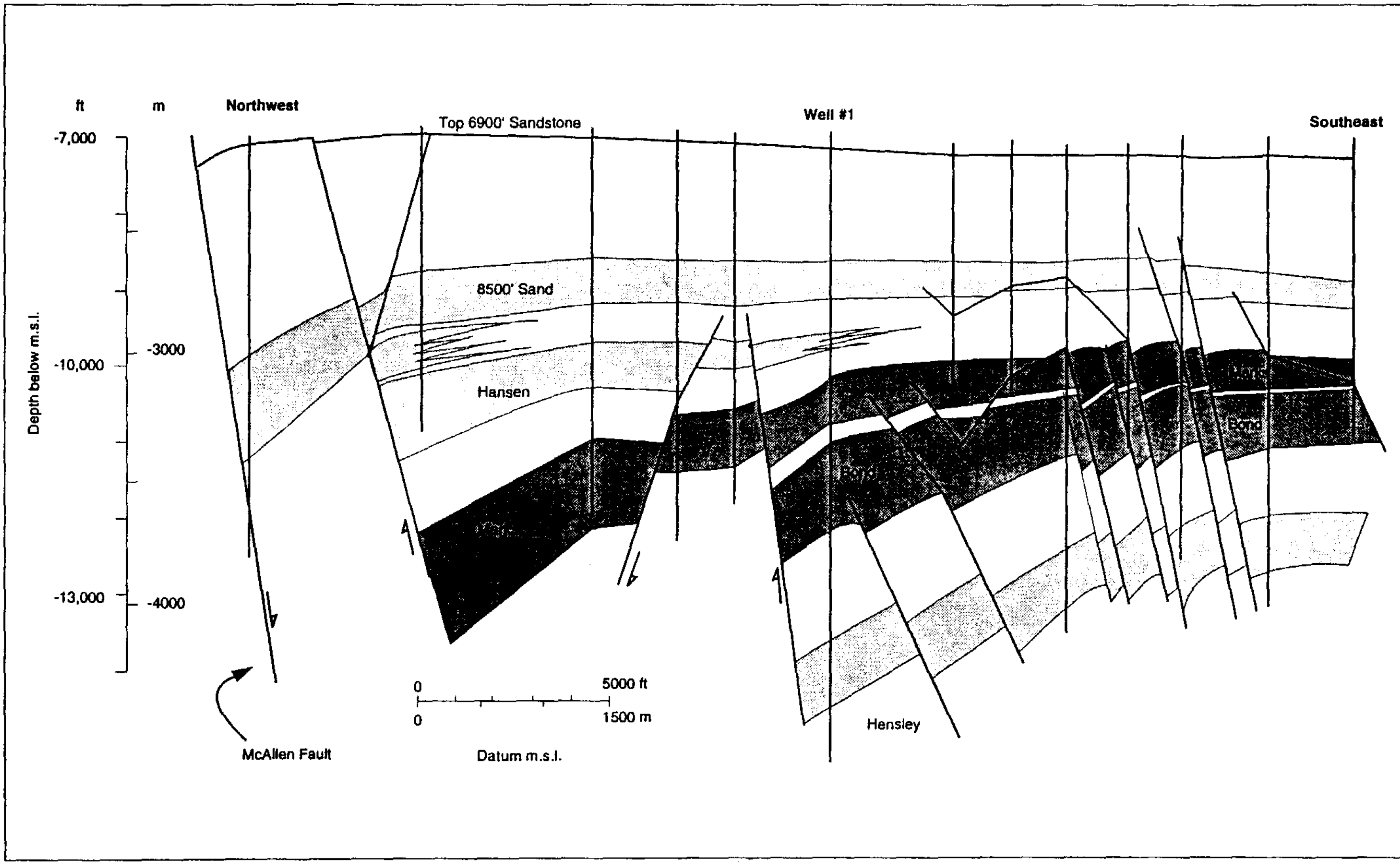
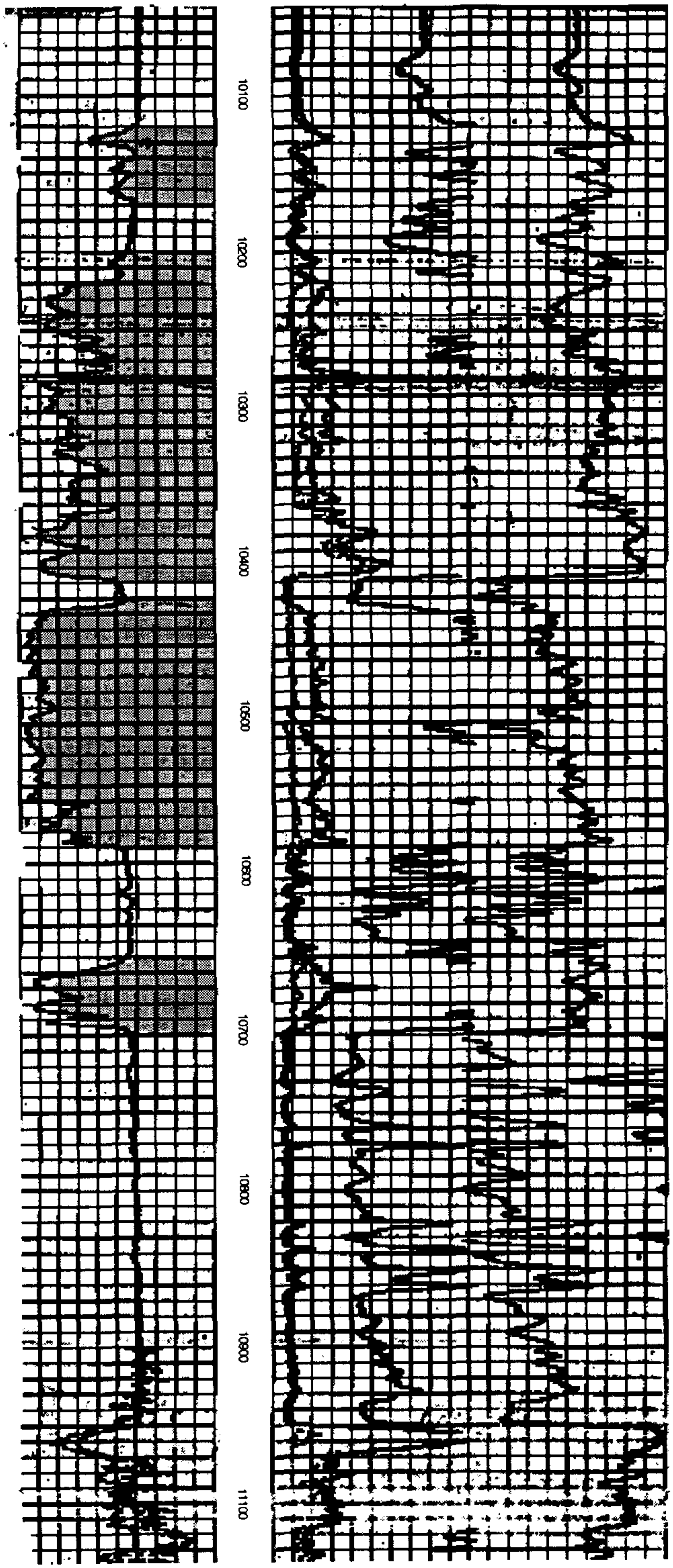


Figure 3.

Northwest - Southeast cross section
McAllen - Pharr Area. Modified from Collins (1983)
Bureau of Economic Geology (1989)



10,116'

10,695'

Figure 4.
Marks Sand - Reservoir Area C.

Tenneco-McAllen
Field Wide Unit #36

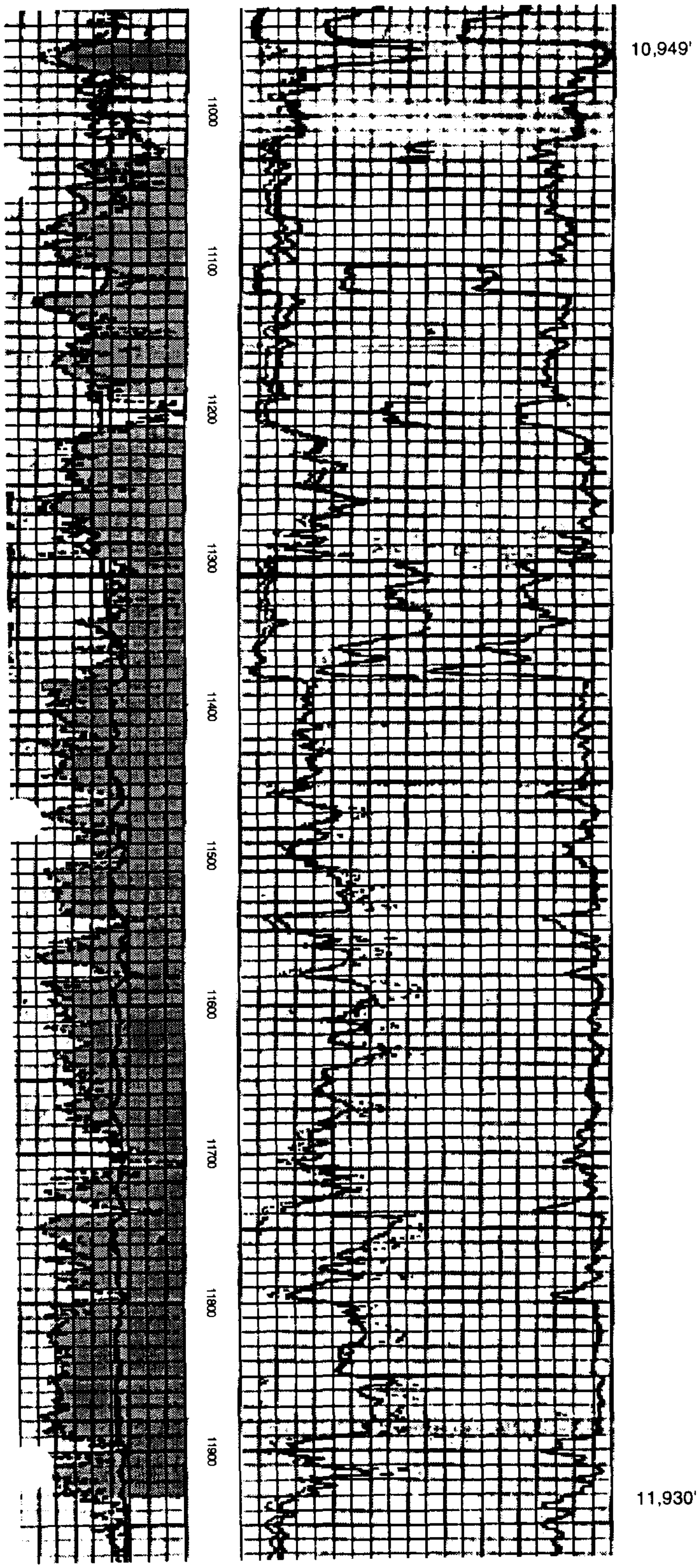


Figure 5.
Bond Sand - Reservoir Area C.

Tenneco-McAllen
Field Wide Unit #36

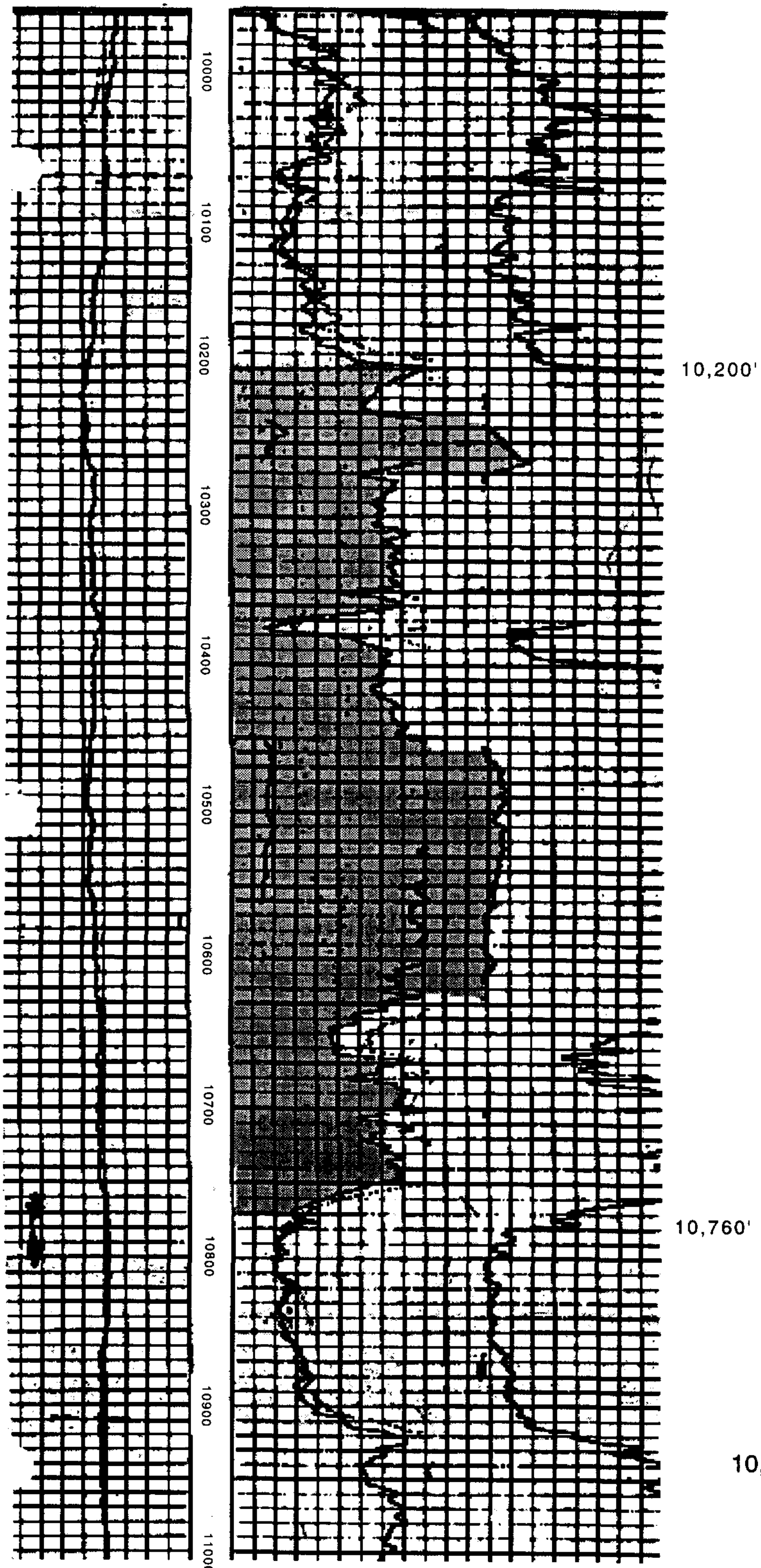


Figure 6.
10,000 ft. Sand - Reservoir Area B.

Northern Pump Co.
Harris Unit #2

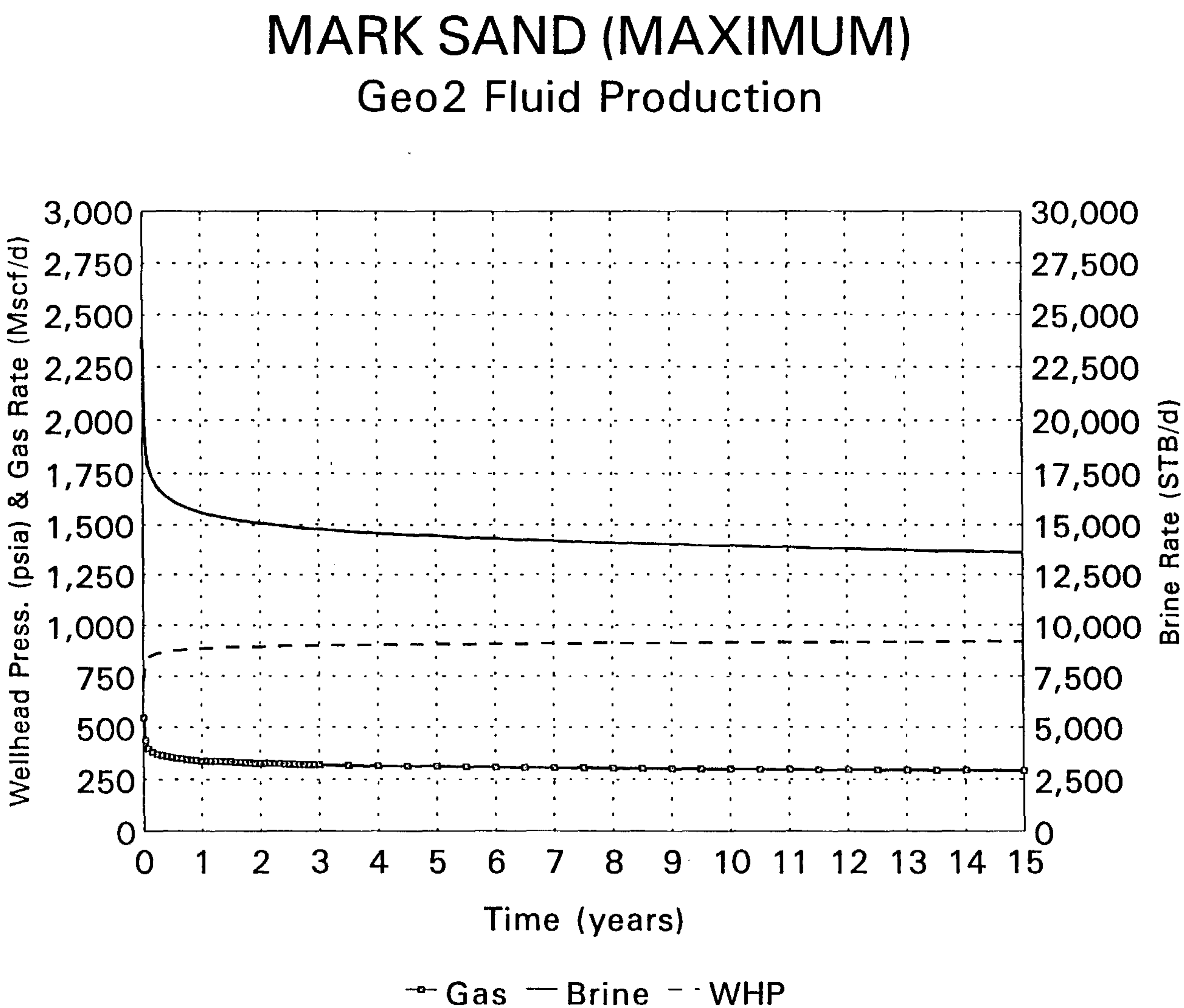

MARK SAND (MAXIMUM)
Geo2 Fluid Production
Wellhead Press. (psia) & Gas Rate (Mscf/d)
3,000
2,750
2,500
2,250
2,000
1,750
1,500
1,250
1,000
750
500
250
0
30,000
27,500
25,000
22,500
20,000
17,500
15,000
12,500
10,000
7,500
5,000
2,500
0
Brine Rate (STB/d)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Time (years)
Gas
Brine
WHP

FIGURE 7

MARK SAND (MINIMUM)

Geo2 Fluid Production

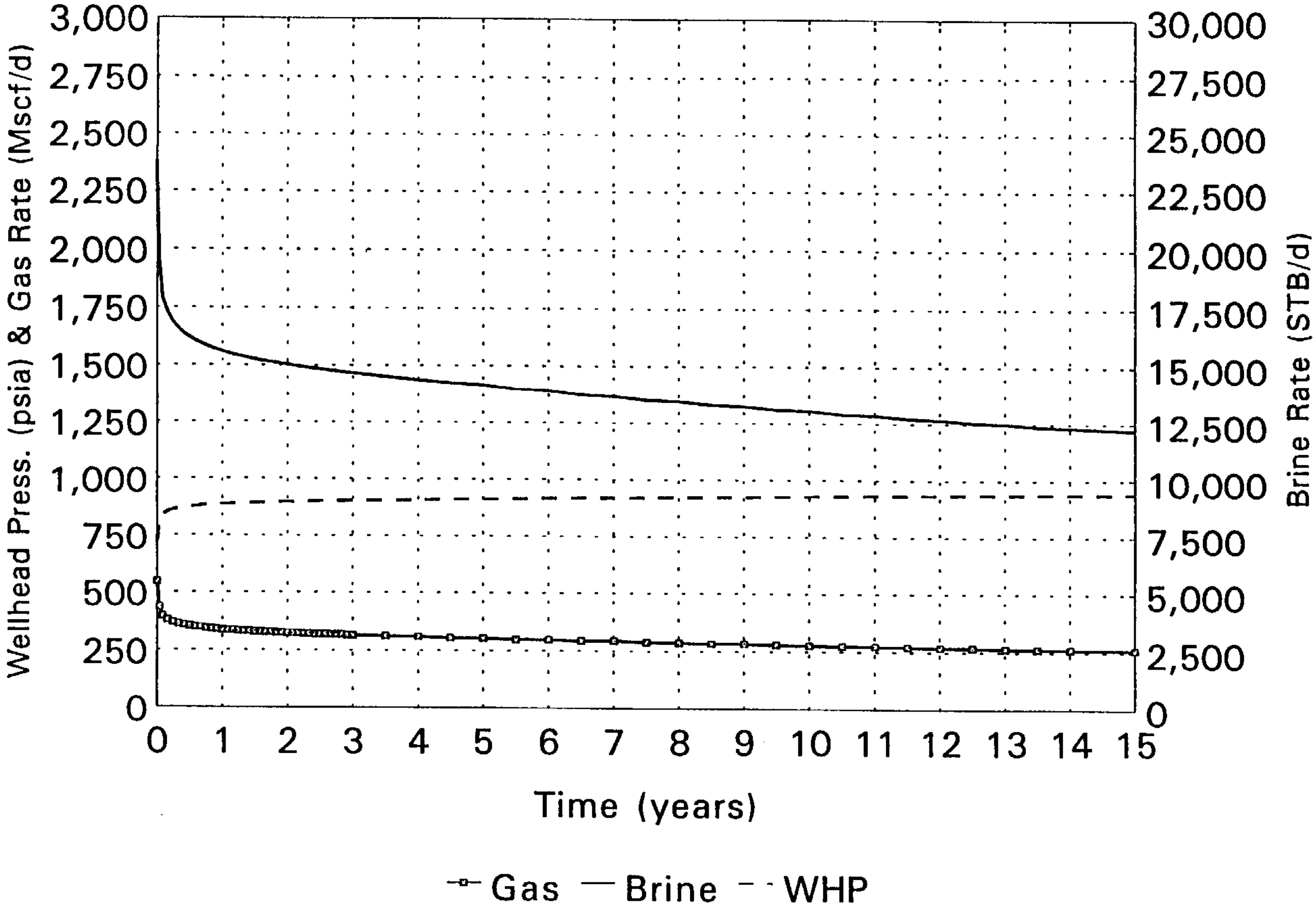


FIGURE 8

BOND SAND (MAXIMUM)

Geo2 Fluid Production

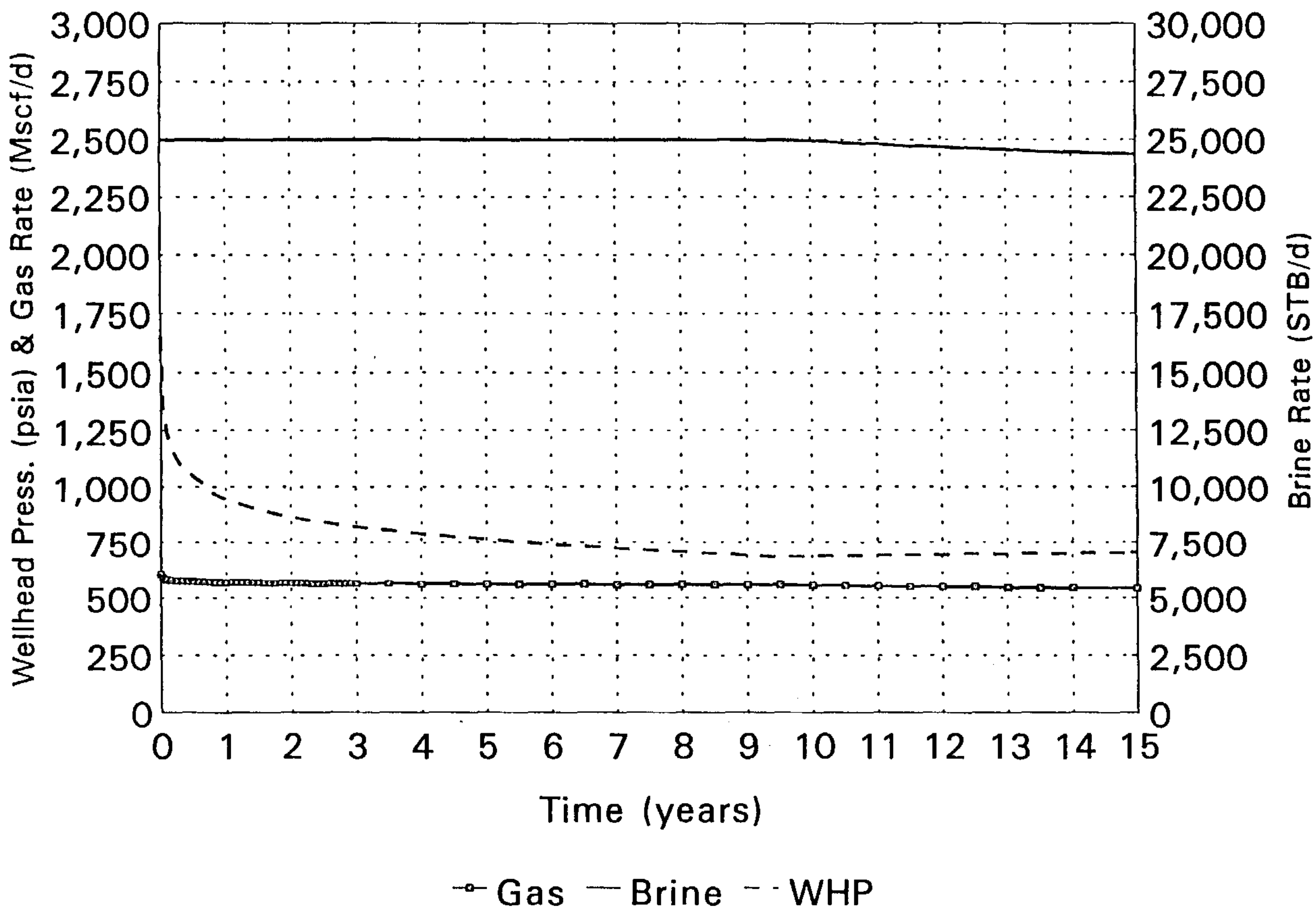


FIGURE 9

BOND SAND (MINIMUM)

Geo2 Fluid Production

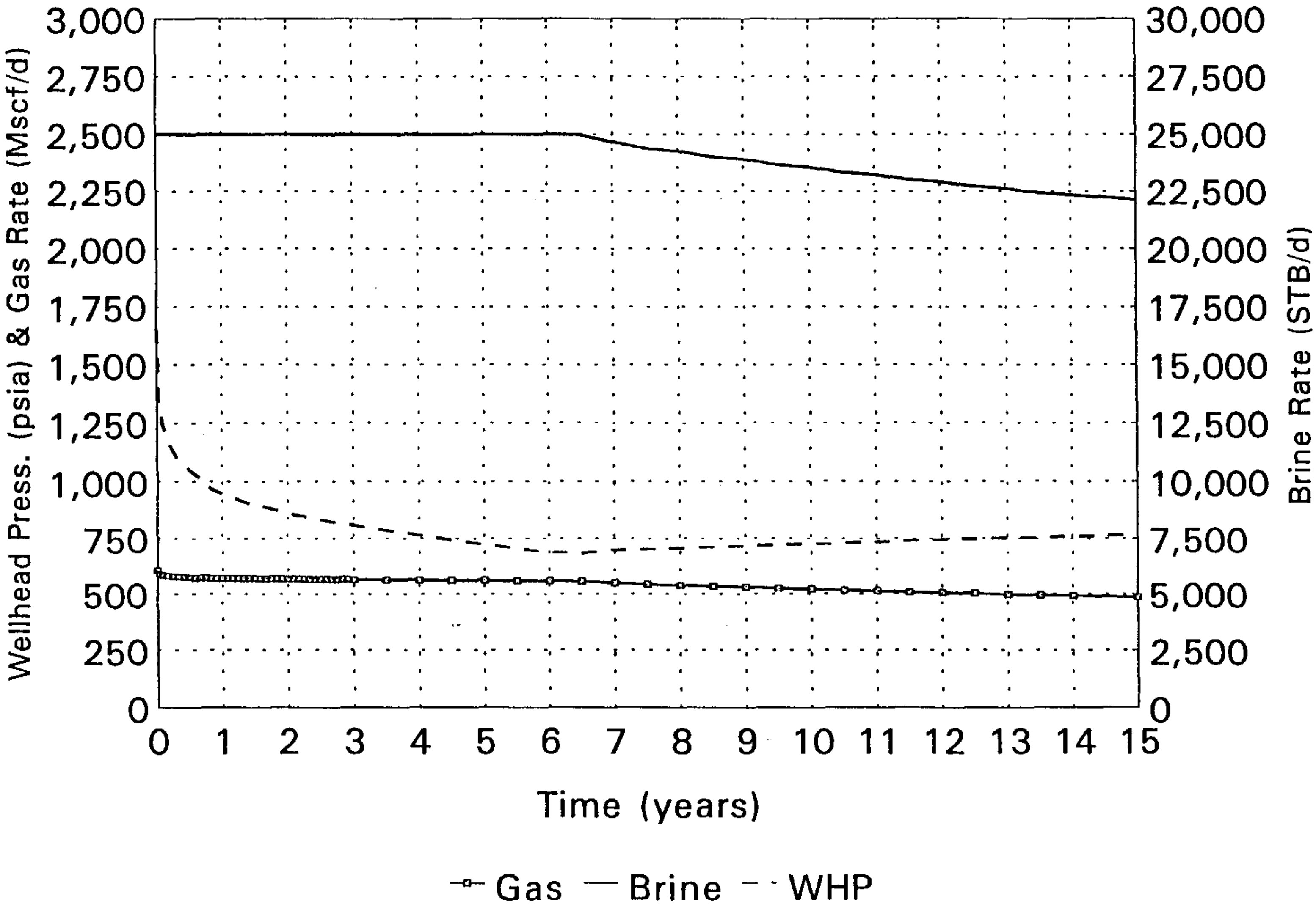


FIGURE 10

EAST SAND (MAXIMUM)

Geo2 Fluid Production

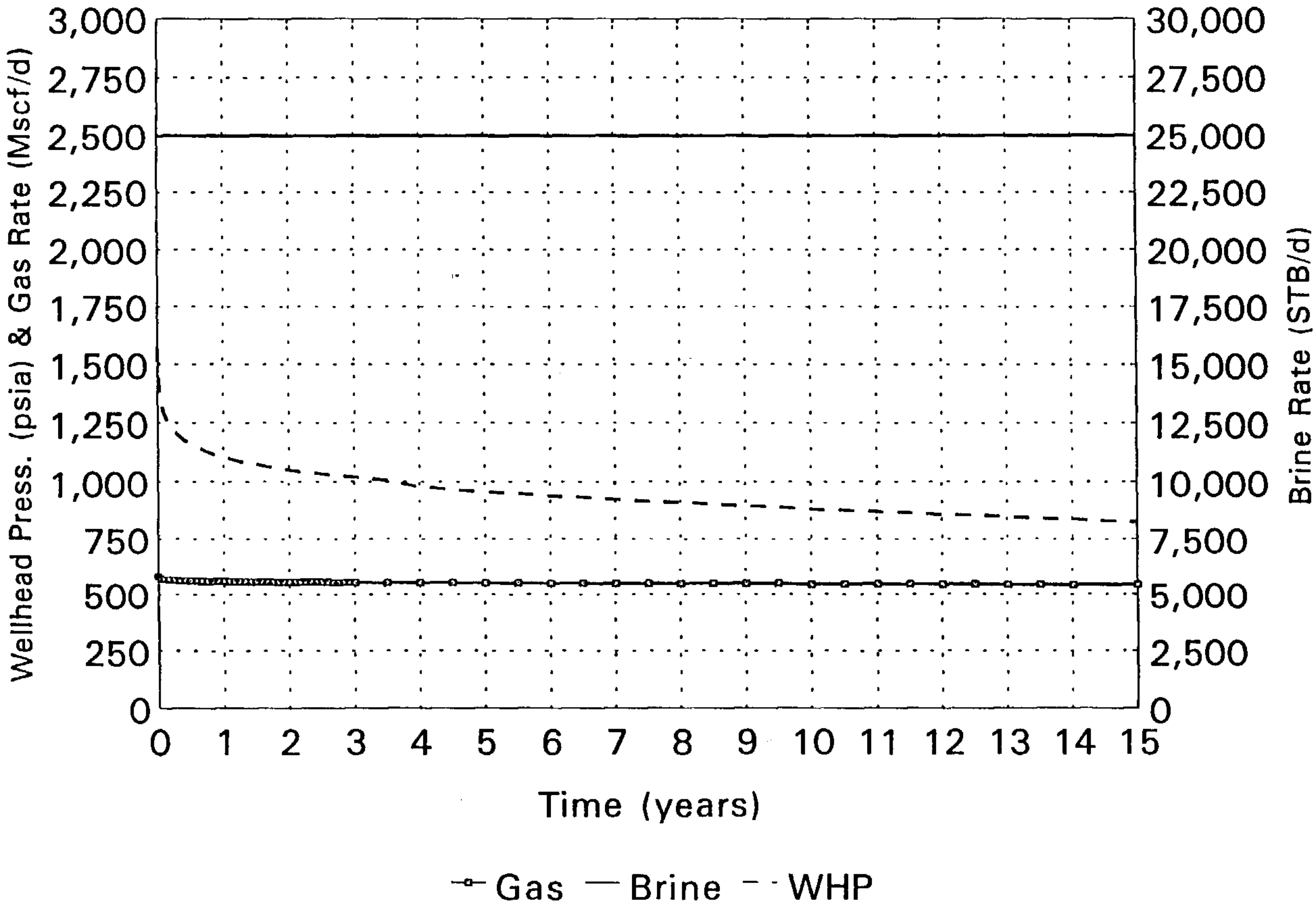


FIGURE 11

EAST SAND (MINIMUM)
Geo2 Fluid Production

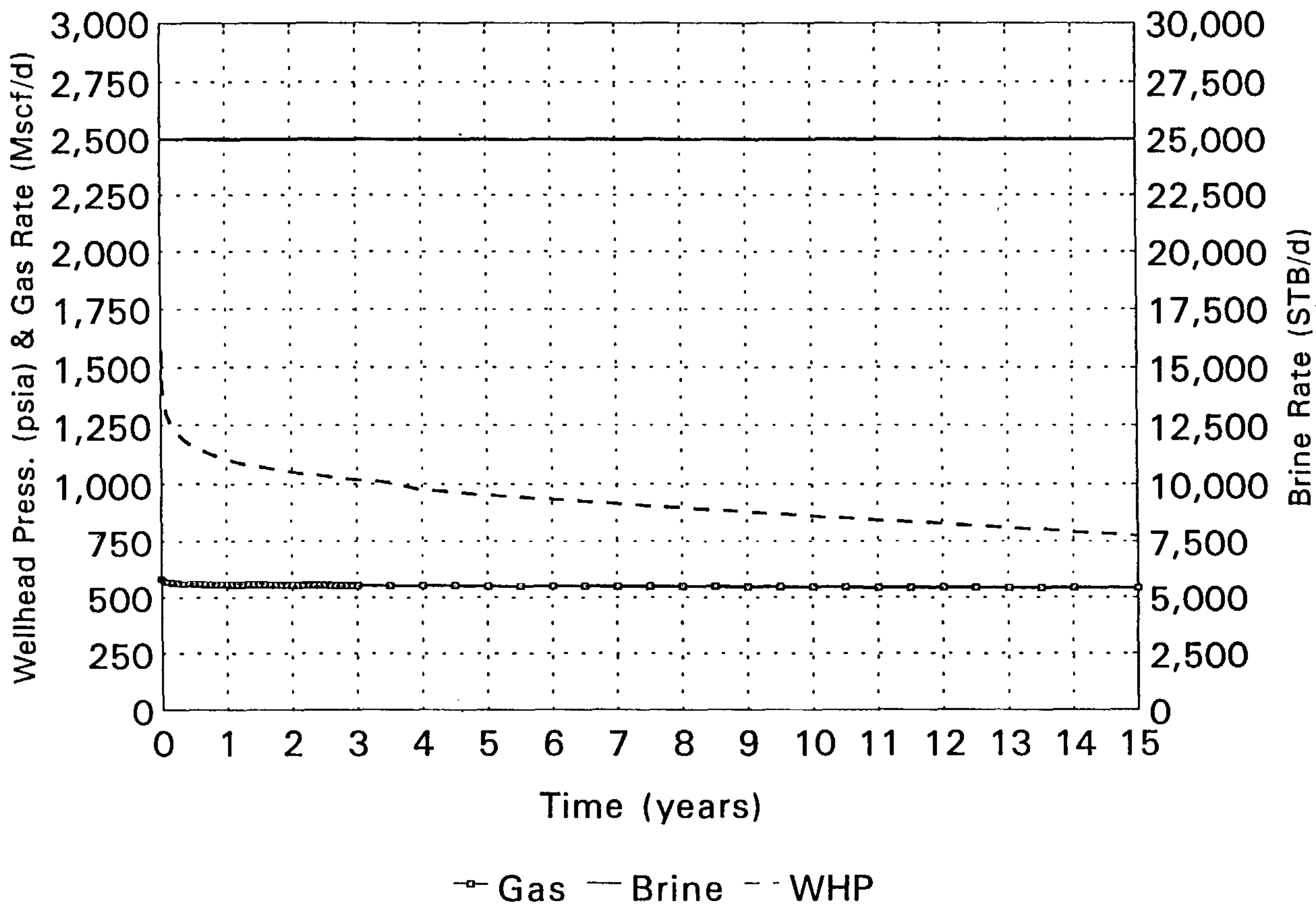


FIGURE 12

MARK SAND (MAXIMUM)
Geo2 Fluid Production

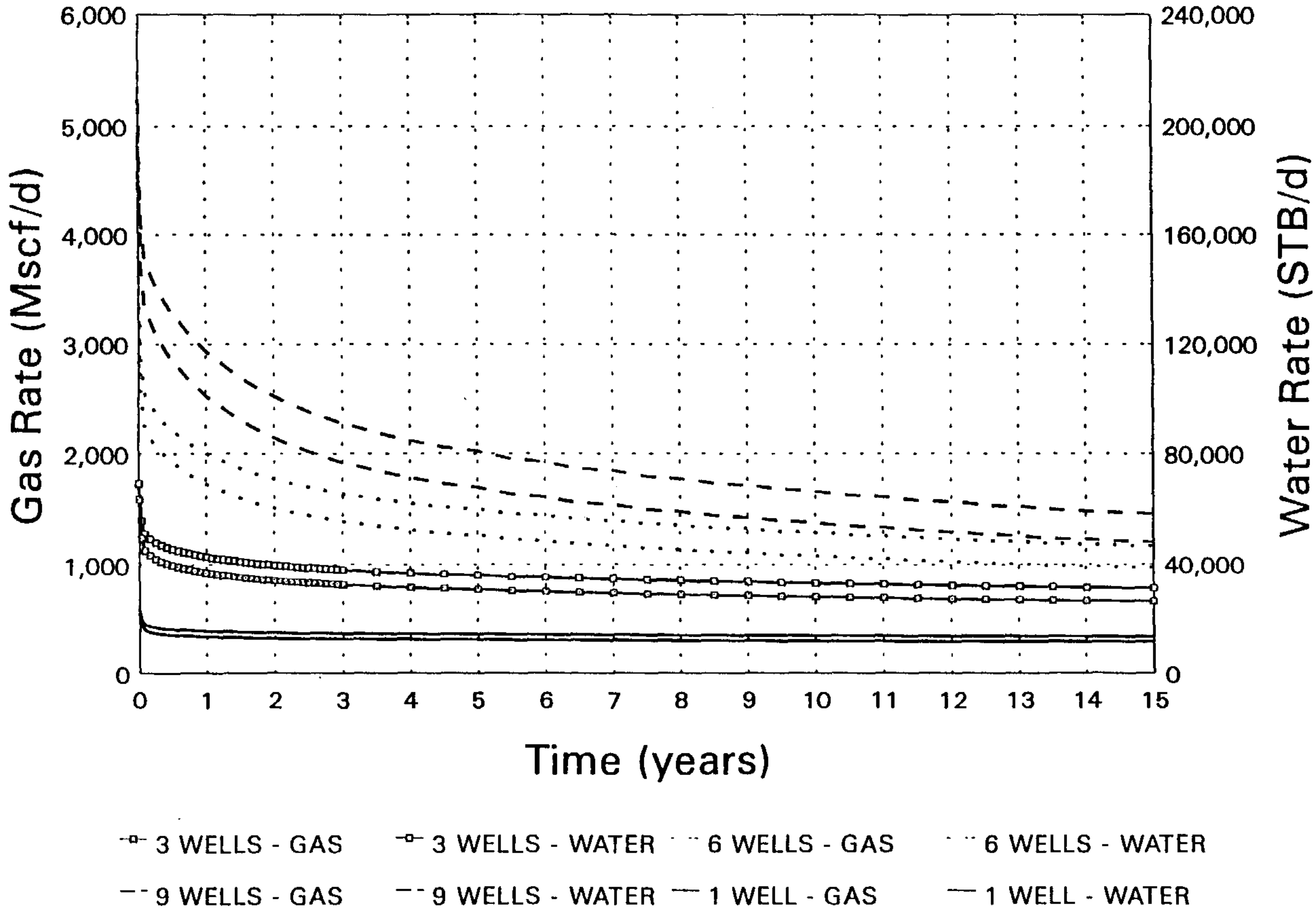


FIGURE 13

MARK SAND (MINIMUM)
Geo2 Fluid Production

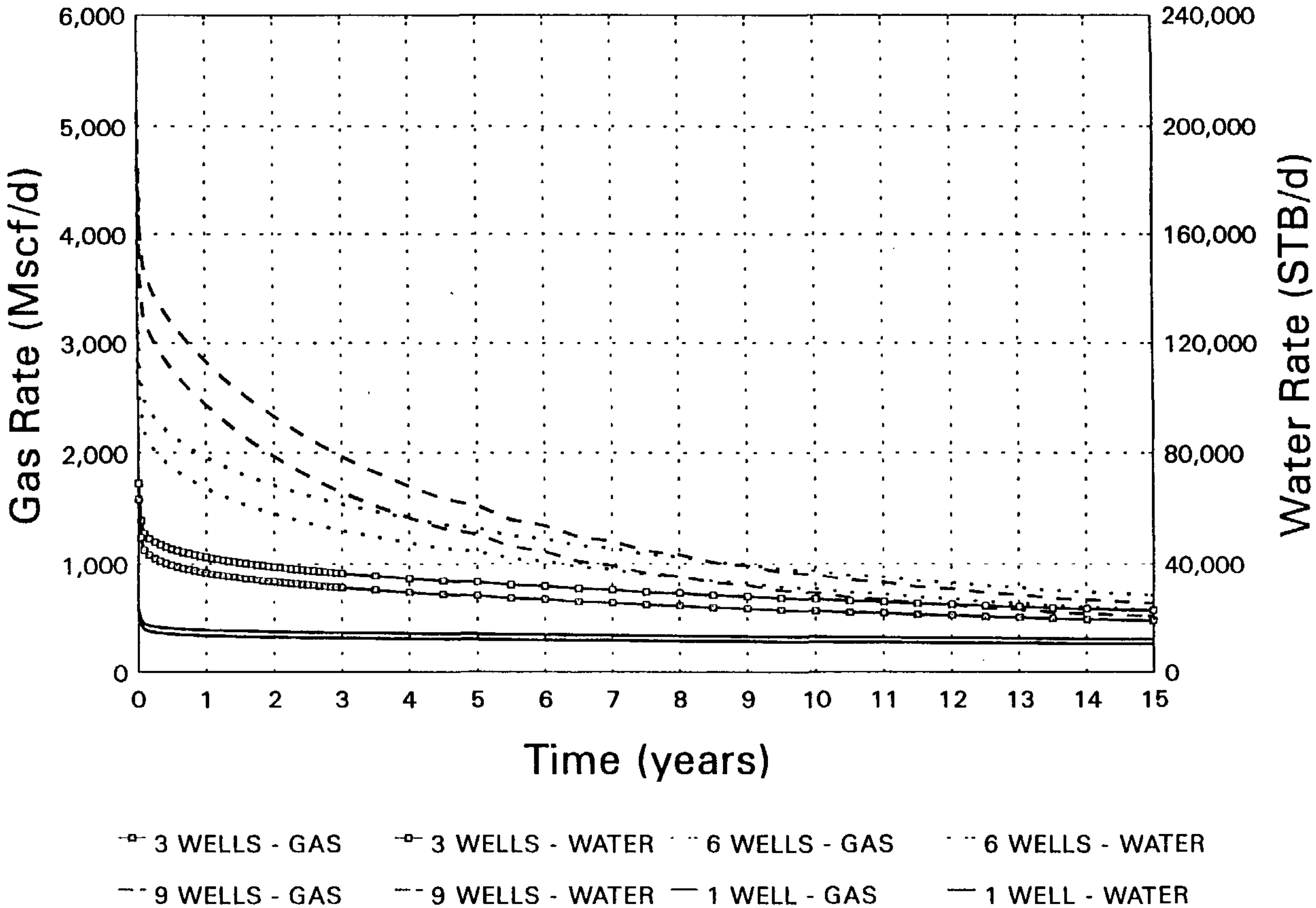


FIGURE 14

BOND SAND (MAXIMUM)

Geo2 Fluid Production

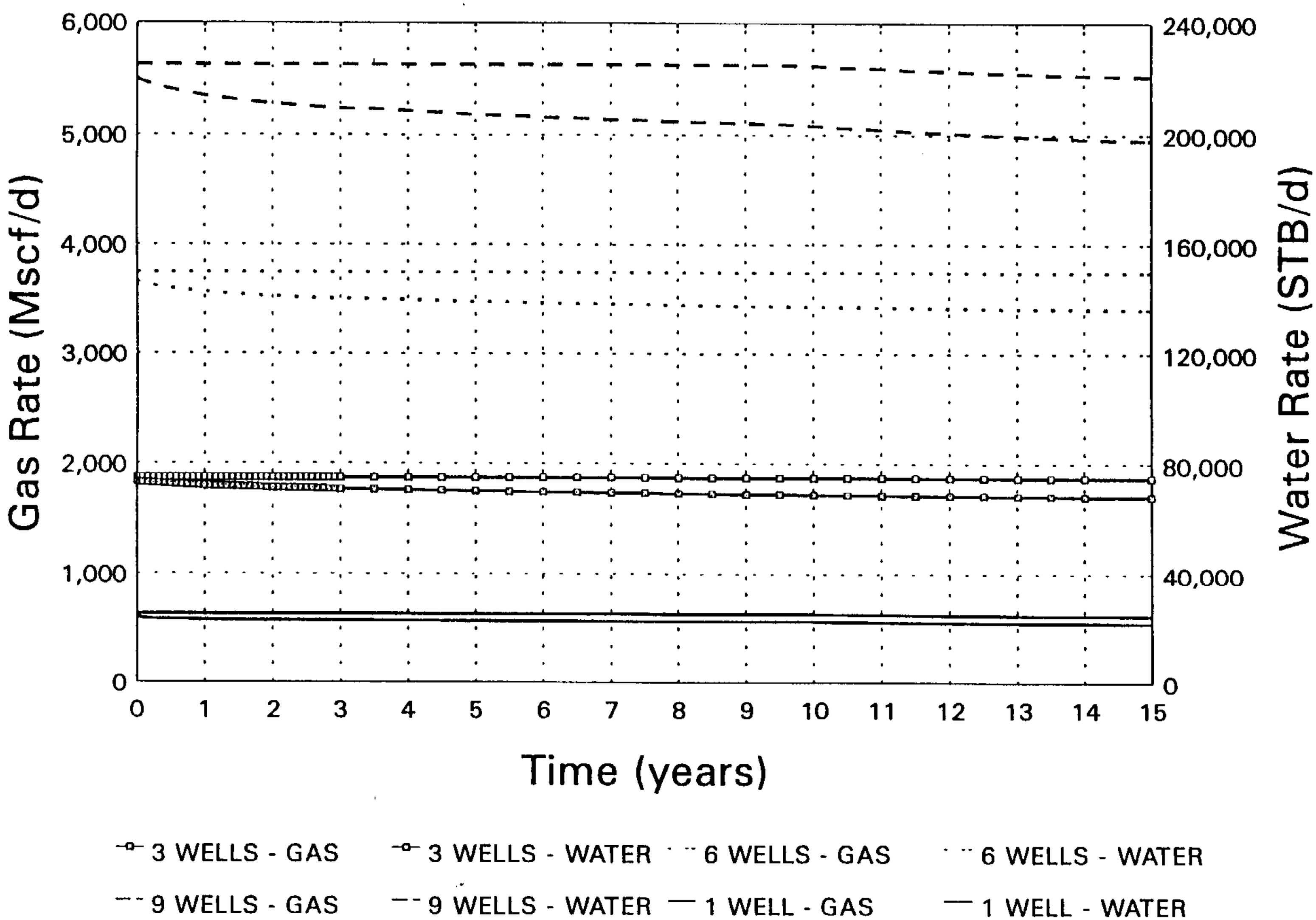


FIGURE 15

BOND SAND (MINIMUM)

Geo2 Fluid Production

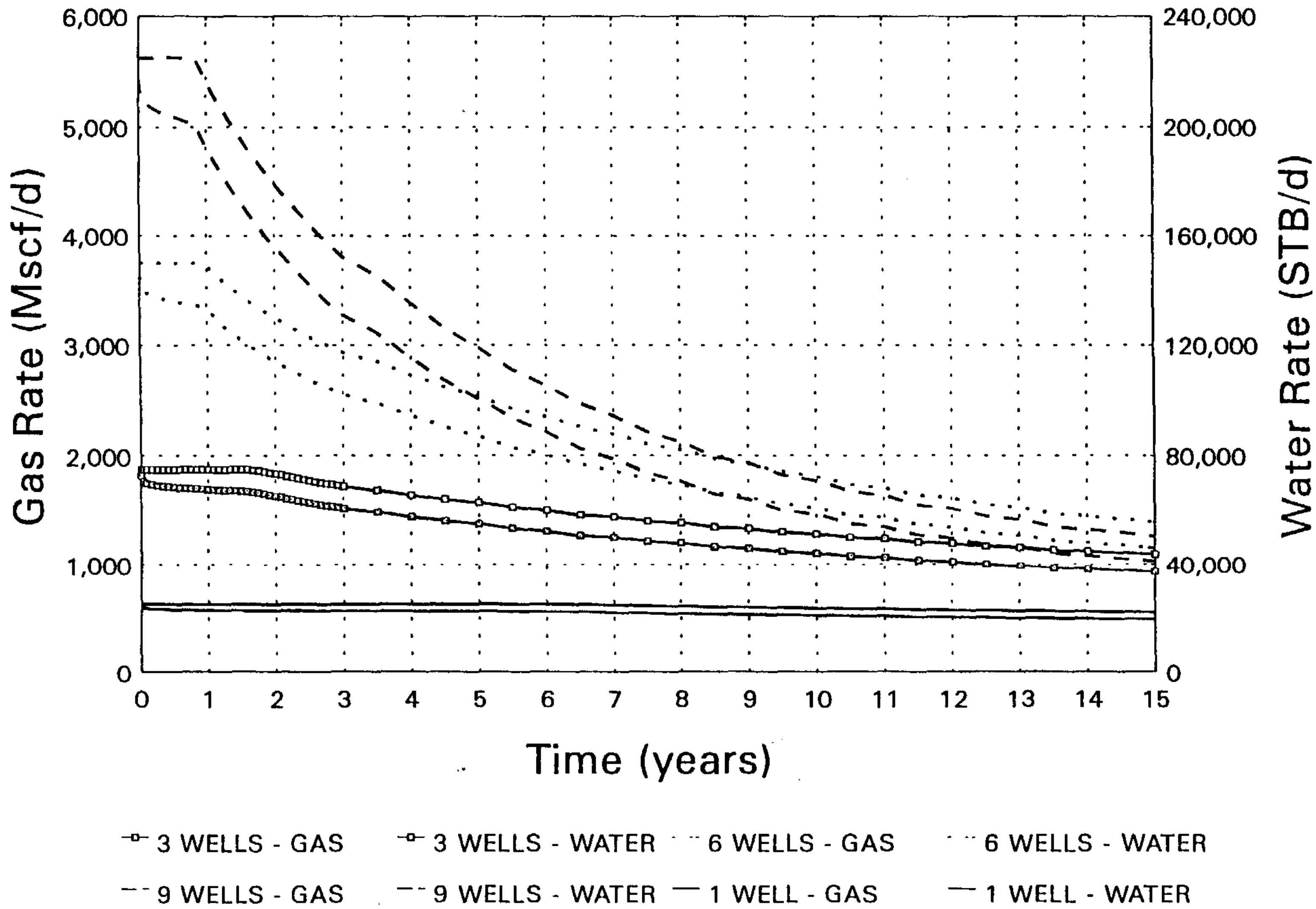


FIGURE 16

EAST SAND (MINIMUM)
Geo2 Fluid Production
Multi-Well Cases

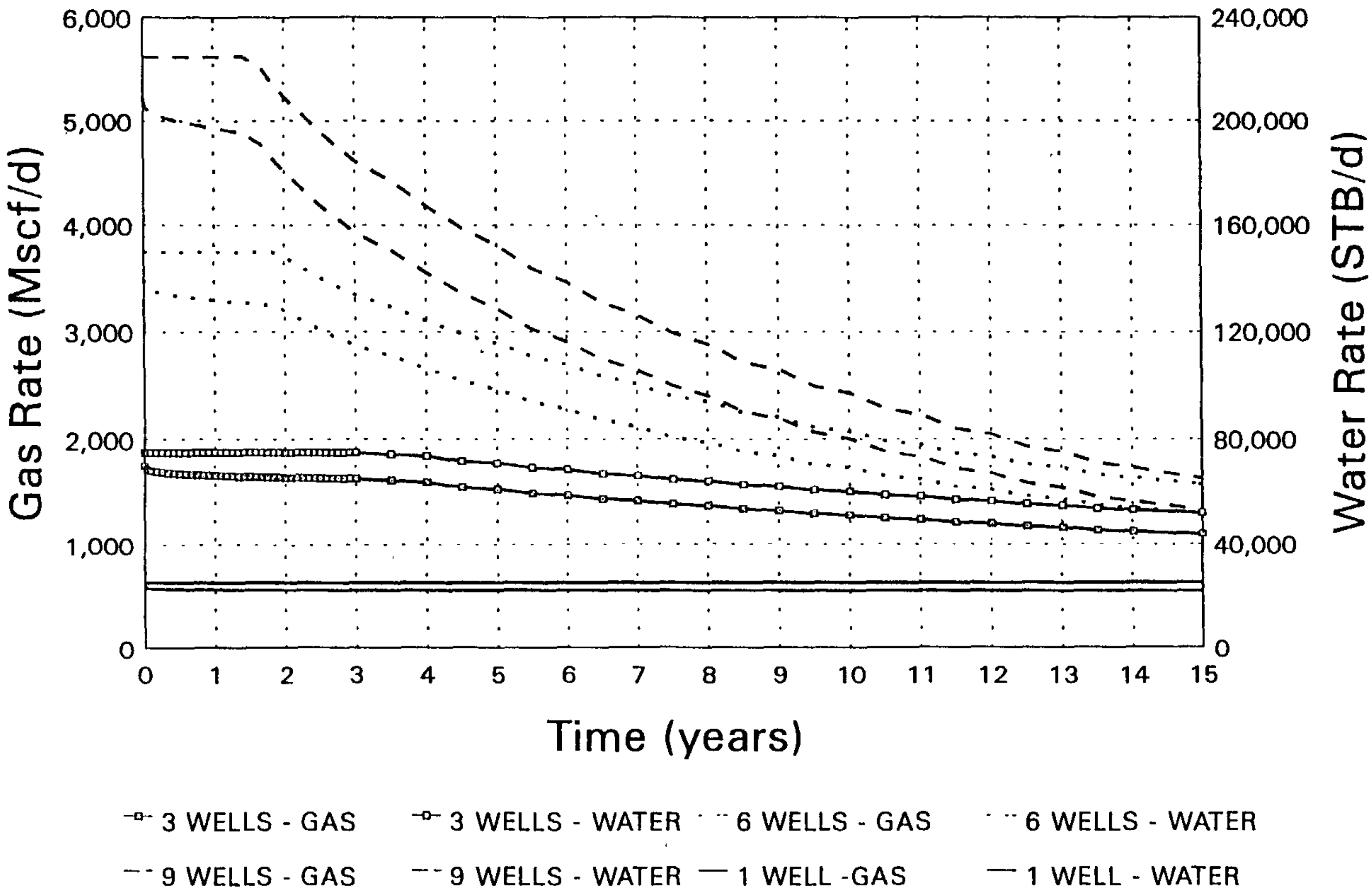


FIGURE 17

EAST SAND (MAXIMUM)

Geo2 Fluid Production

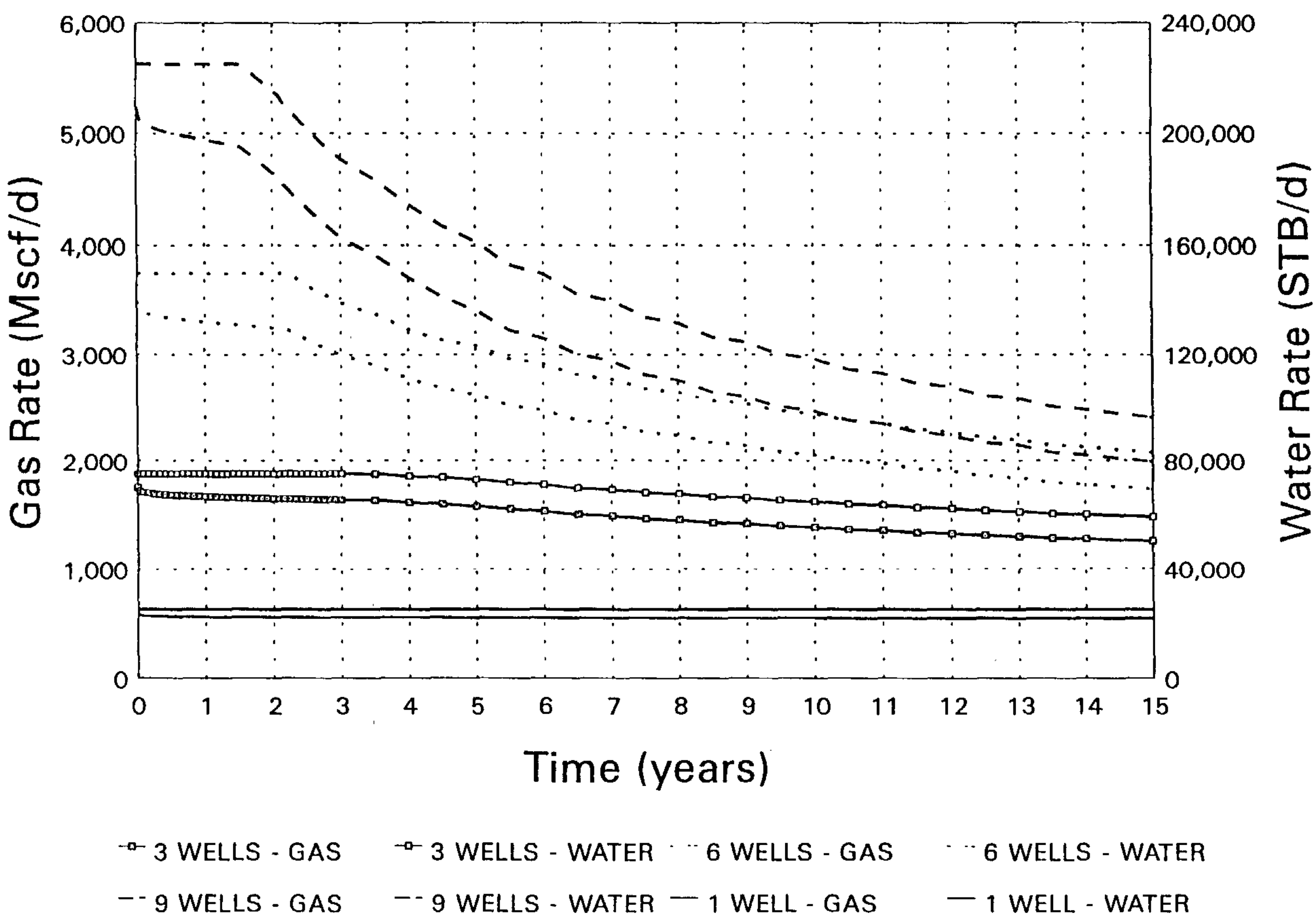


FIGURE 18

MARK SAND (MAXIMUM)
15 Year Cumulative Production
Geo2 Fluid Production

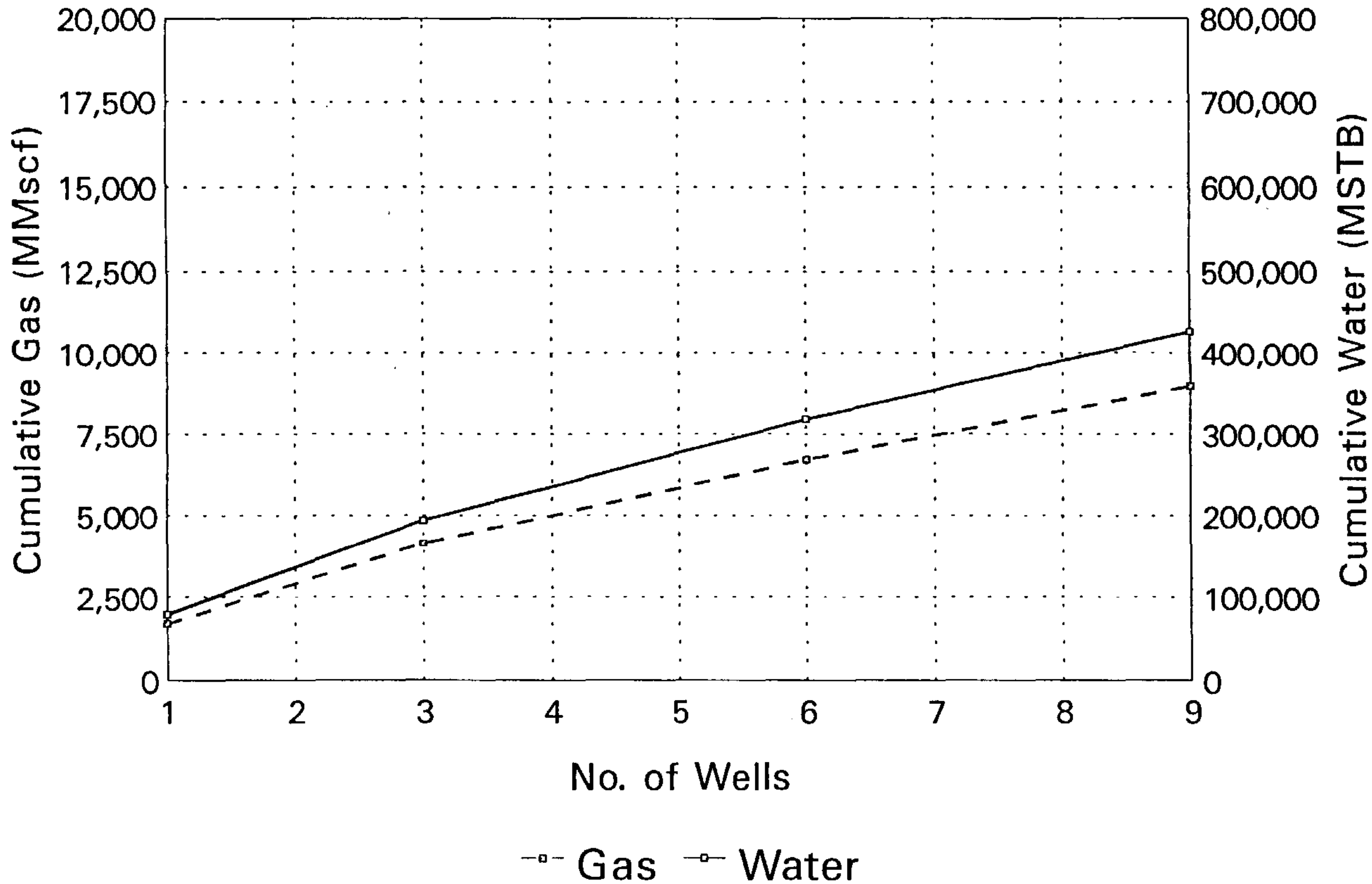


FIGURE 19

MARK SAND (MINIMUM)

15 Year Cumulative Production
Geo2 Fluid Production

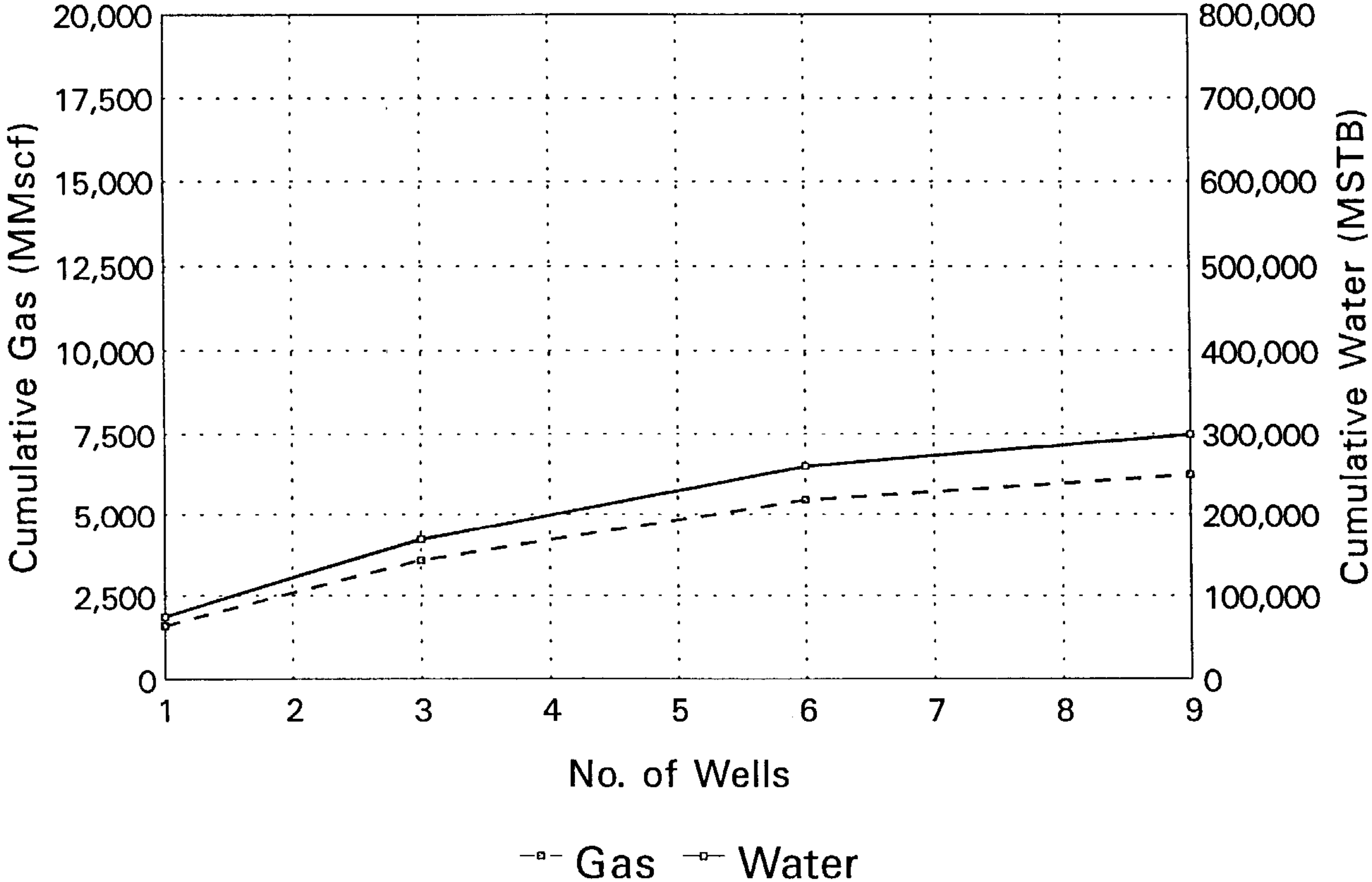


FIGURE 20

BOND SAND (MAXIMUM)
15 Year Cumulative Production
Geo2 Fluid Production

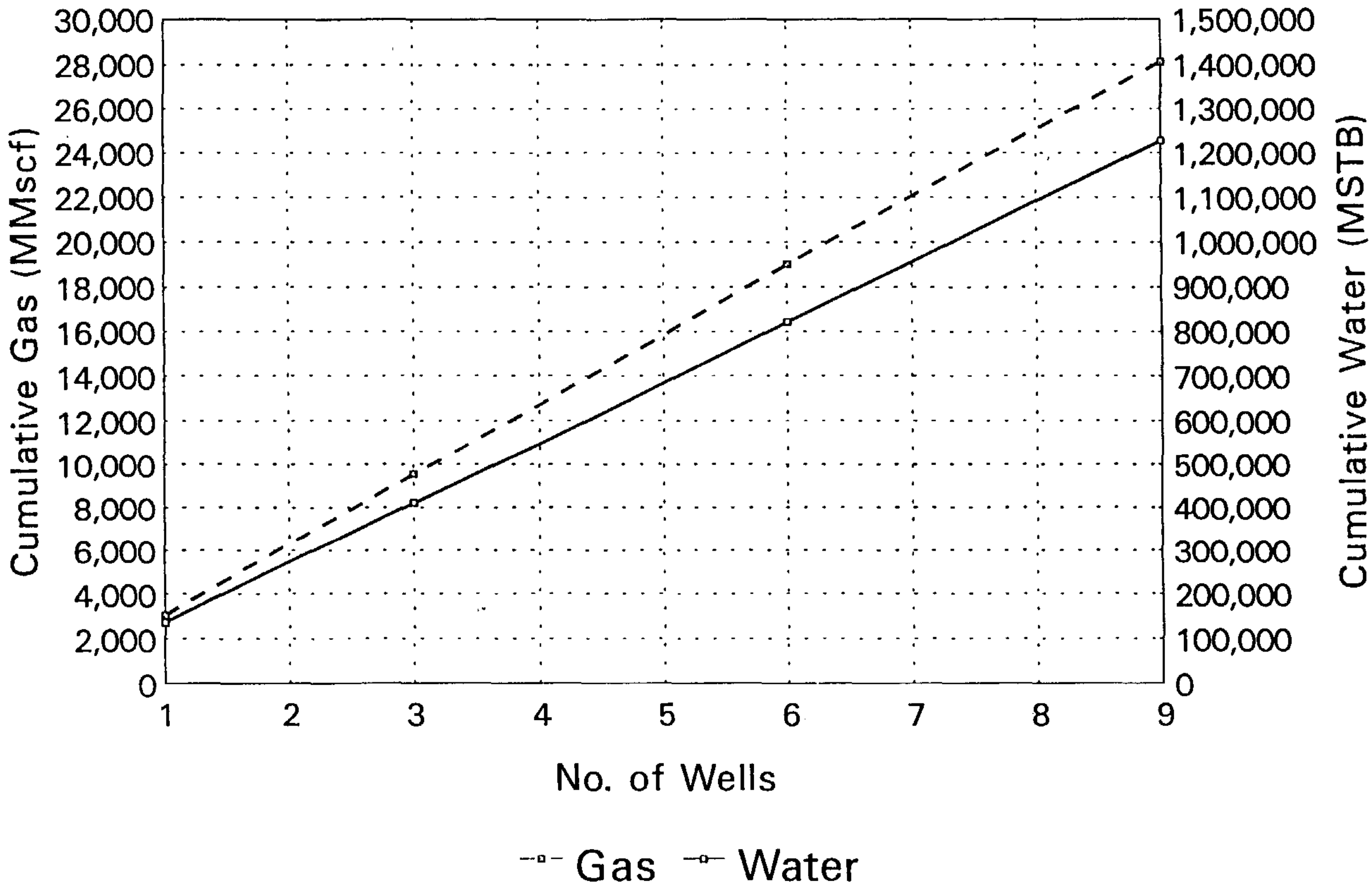


FIGURE 21

BOND SAND (MINIMUM)
15 Year Cumulative Production
Geo2 Fluid Production

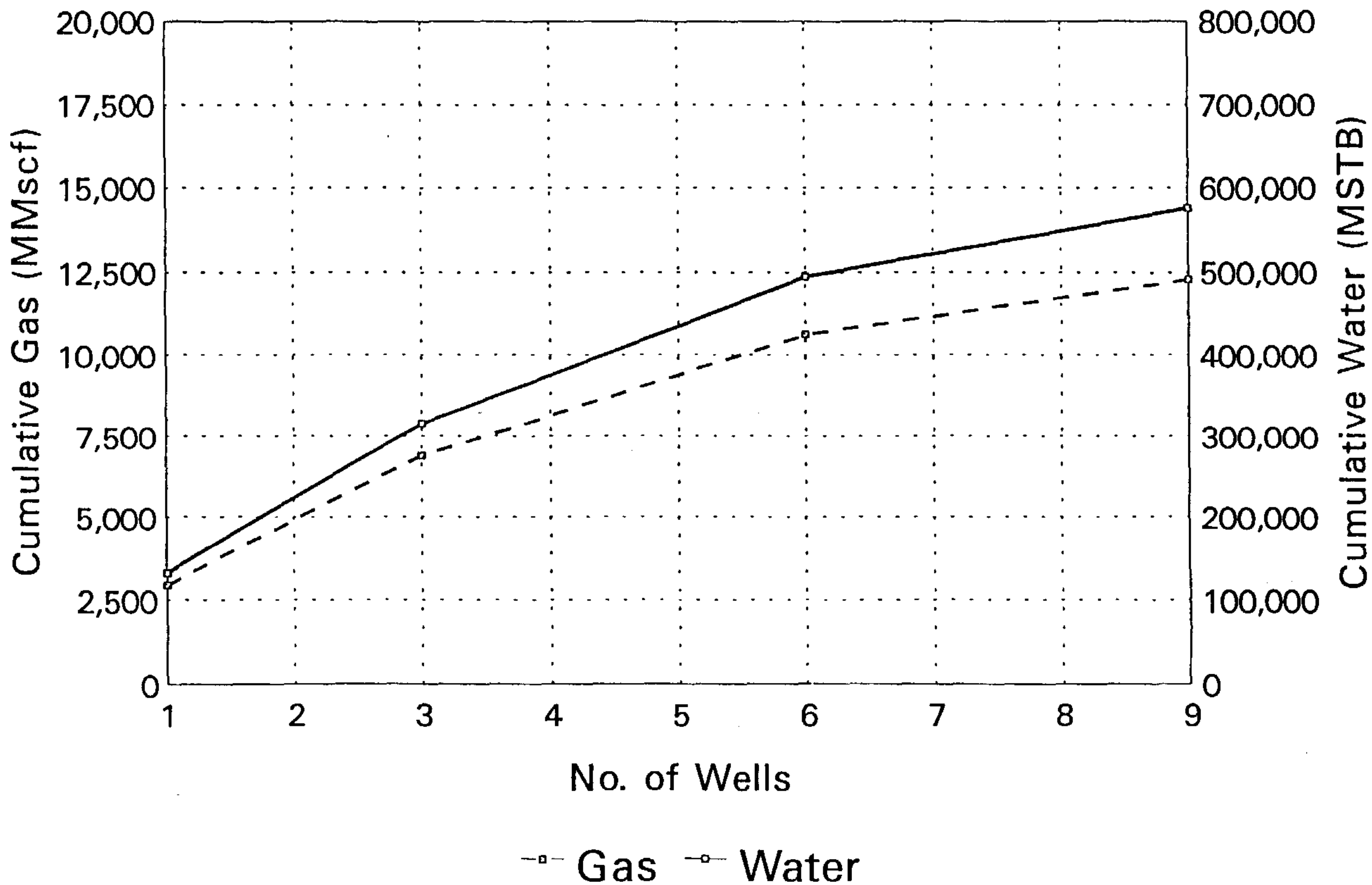


FIGURE 22

EAST SAND (MAXIMUM)

15 Year Cumulative Production
Geo2 Fluid Production

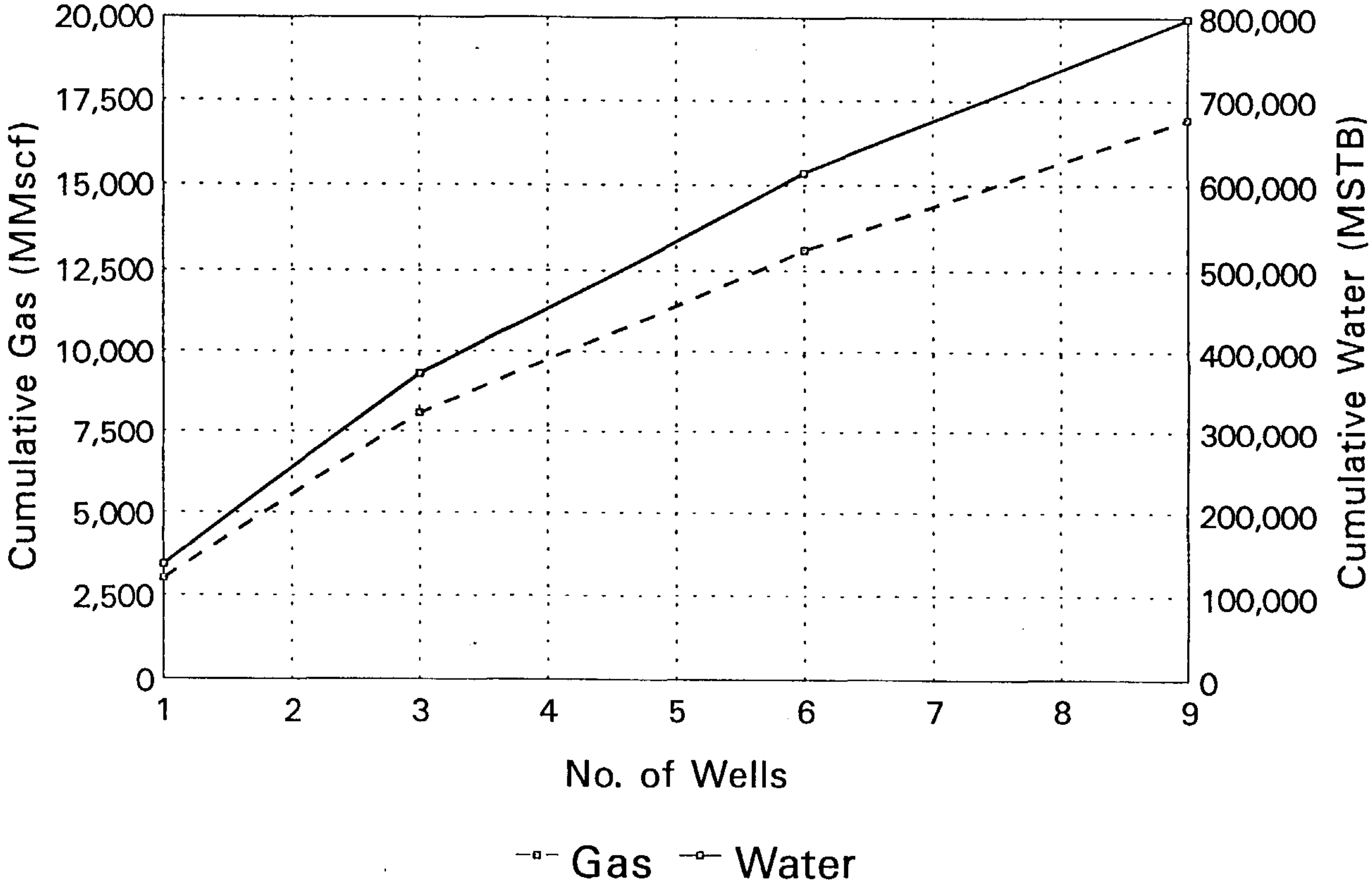


FIGURE 23

EAST SAND (MINIMUM)
15 Year Cumulative Production
Geo2 Fluid Production

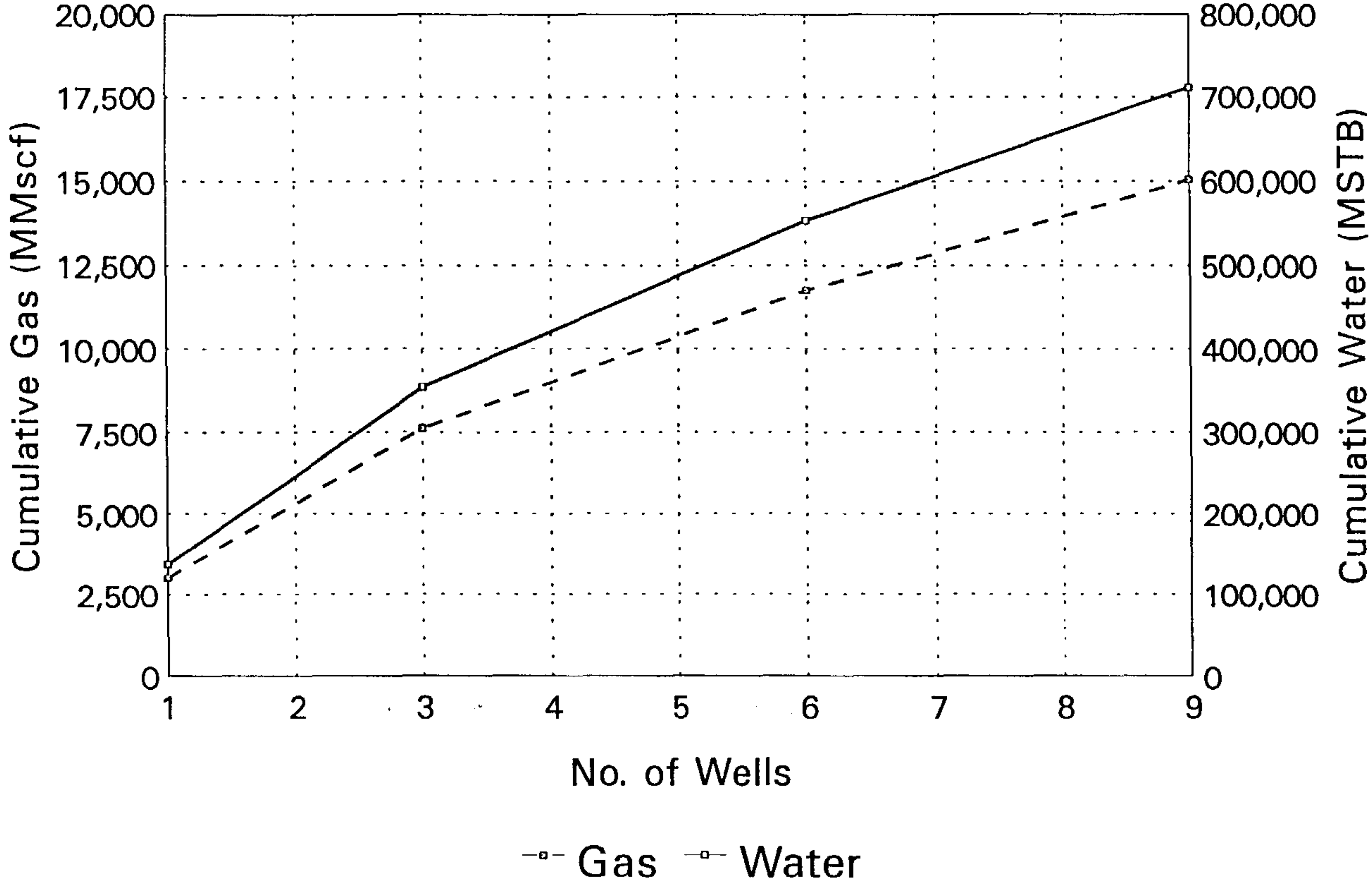


FIGURE 24

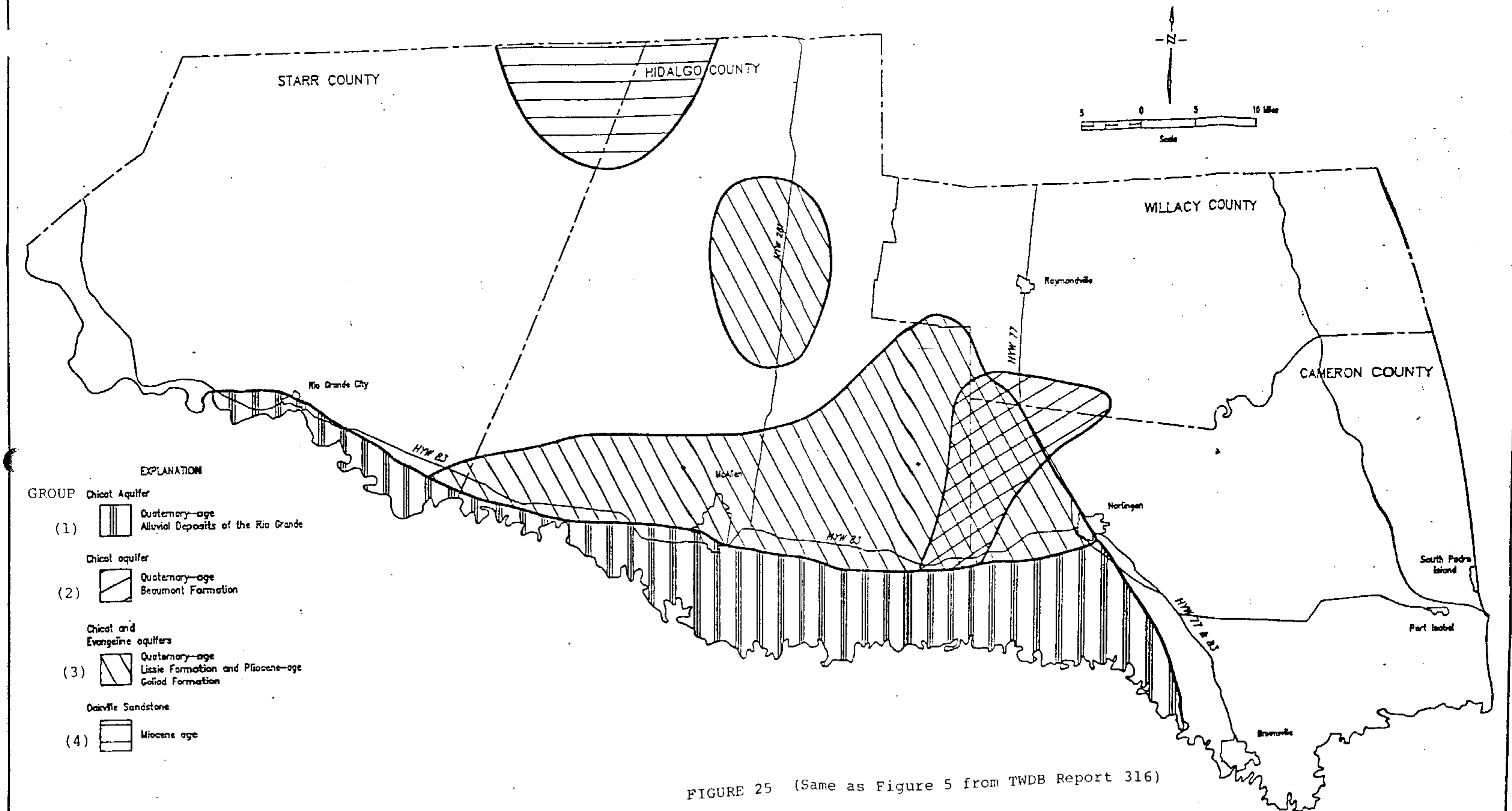


FIGURE 25 (Same as Figure 5 from TWDB Report 316)

APPROXIMATE PRODUCTIVE AREAS OF THE MAJOR SOURCES OF GROUND WATER IN THE LOWER RIO GRANDE VALLEY

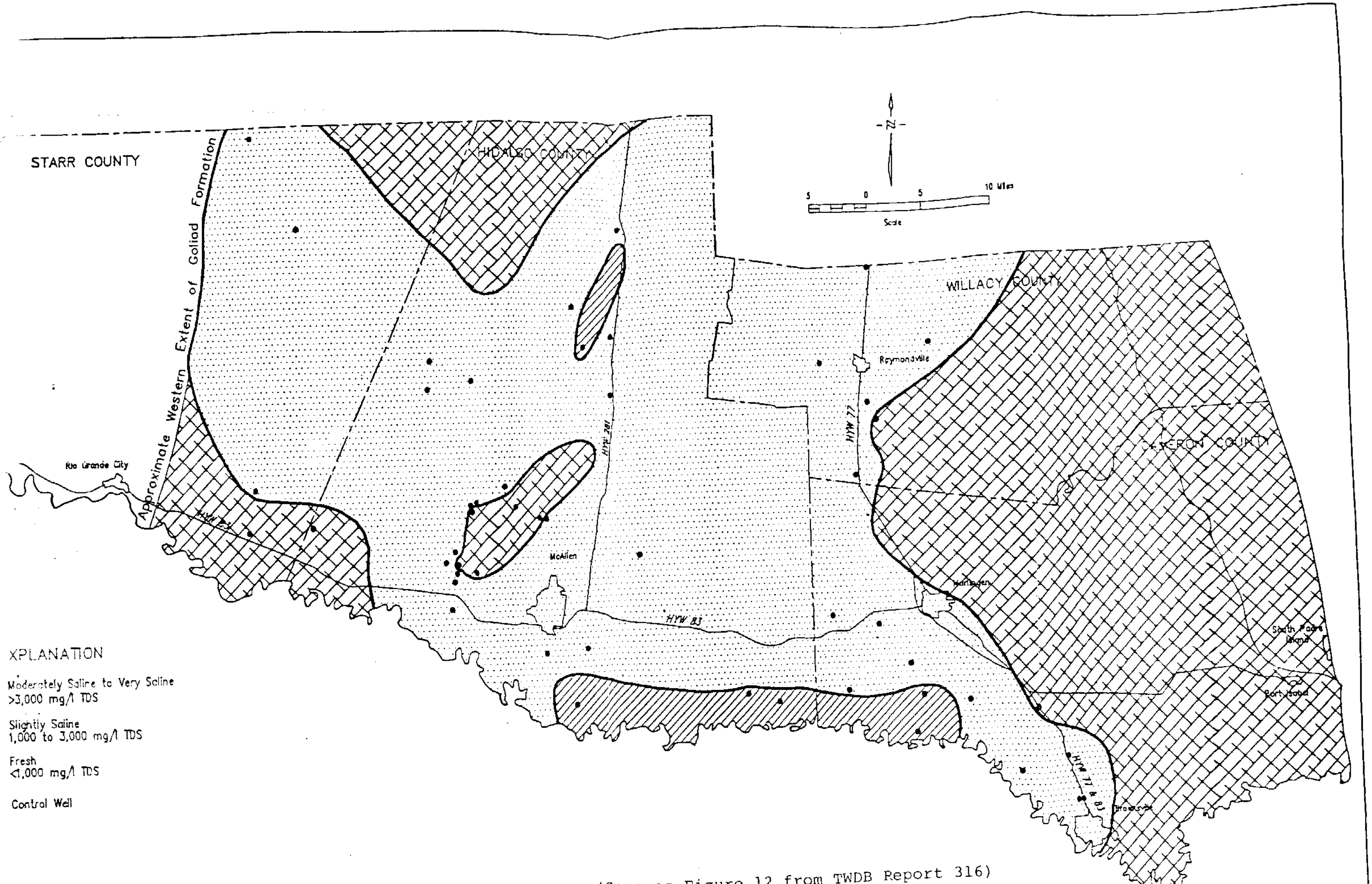


FIGURE 26 (Same as Figure 12 from TWDB Report 316)

CHEMICAL QUALITY OF WATER IN THE EVANGELINE AND CHICOT AQUIFERS

Well Name (Number)	Sand Depth (Ft.)	Net Sand (Ft.)	% Sand	T ° F (1)	Pressure Top of Sand PSI	Pressure Gradient PSI/Ft.	Porosity est. Ø (%)	Permeability (est.) K (in md)	KH (md x Ft.)
1 Tenneco-McAllen Field Wide Unit #36	Marks 10,116 - 10,695	290	50	300	7,581	0.75	18	20	5,400
	Bond 10,949 - 11,930	455	46	295	8,094	0.77	20	18	6,030
2 Delhi-Taylor-Mayfair Pharr Field Wide Unit #17	Marks 9,860 - 10,170	270	87	299	7,312	0.74	18	20	6,200
	Bond 10,492 - 10,640	148	57	306	7,977	0.76	20	18	2,960
3 Standard Oil of Texas #1 German	Marks 10,970 - 11,290	200	62	301	8,482	0.77	20	10	2,000
	Bond 11,670 - 12,220	330	60	307	9,221	0.79	20	10	3,300
4 Union Producing Co. Wysong Unit #2	Marks 10,700 - 11,070	250	67	270	8,197	0.76	15	10	2,500
	Bond 11,470 - 12,000	270	50	281	9,010	0.78	10	8	2,160
5 Sinclair Oil Co. #2 Houston Unit	Marks 7,760 - 8,230	215	46	224	5,094	0.65	15	12	2,580
	Bond 8,550 - 9,520	530	54	292	5,927	0.70	20	15	7,950

1. Corrected Temperature (AAPG)

Table 1.

Wells - Reservoir Area C.

Sand	Sand Depth (Ft.)	Thickness (Ft.)	Net Sand (Ft.)	% Sand	T ° F (1)	Pressure Top of Sand PSI	Pressure Gradient PSI/Ft.	Porosity (est.) Ø (%)	Permeability (est.) K (in md)	KH (md x Ft.)
Marks	9,881	409	245	63	279	7333	0.73	17	14	3528
Bond	10,626	635	334	53	296	8046	0.76	18	13.8	4609

Table 2.

Averages for Wells 1-5
Reservoir Area C.

Sand	Sand Depth (Ft.)	Thickness (Ft.)	Net Sand (Ft.)	% Sand	T ° F (1)	Pressure Top of Sand PSI	Pressure Gradient PSI/Ft.	Porosity (est.) Ø (%)	Permeability (est.) K (in md)	KH (md x Ft.)
10,000' Sand	10,033	517	411	78.26	264	7,493	0.75	15	16.6	6,210

Table 4.

Averages for Wells 6-10
Reservoir Area B.

1. Corrected Temperature (AAPG)

Well Name (Number)	Sand Depth (Ft.)	Net Sand (Ft.)	% Sand	T ° F (1)	Pressure Top of Sand PSI	Pressure Gradient PSI/Ft.	Porosity (est.) Ø (%)	Permeability (est.) K (in md)	KH (md x Ft.)
6 Lone Star-Denzer Unit # 1	9,550 - 9,900	230	65.0	259	6,983	0.73	17 15	33 15	7,590
7 Northern Pump Co. Harris Unit #2	10,200 - 10,760	520	92.8	268	7,669	0.75	15 `3	13 5	6,760
8 J.H. Huber Corp. Miller "A" # 1	10,220 - 10,680	335	72.8	266	7,690	0.75	14 13	12 6	4,020
9 Hydrocarbon Prod. Co. Bevers et al # 1.	9,835 - 10,400	490	86.0	269	7,284	0.74	16 14	16 9	7,840
10 Shell Oil Co. W.H. Drawe # 1	10,360 - 11,010	480	74.0	258	7,838	0.76	14 12	9 4	4,320

1. Corrected Temperature (AAPG)

Table 3.

Wells - Reservoir Area B.

TABLE 5

TEXAS WATER DEVELOPMENT BOARD
GROUND WATER DATA SYSTEM
GROUND WATER QUALITY SAMPLES

	PH		SILICA (SiO2) MG/L	CALCIUM (Ca) MG/L	MAGNESIUM (Mg) MG/L	SODIUM (Na) MG/L	POTASSIUM (K) MG/L	CARBONATE (CO3) MG/L	BICARB (HCO3) MG/L	SULFATE (SO4) MG/L	CHLORIDE (Cl) MG/L	FLOURIDE (F) MG/L	NITRATE (NO3) MG/L	DISSOLVED SOLIDS MG/L	HARDNES as CaC MG/L
							GROUP 1								
MAX PH	8.4	MEAN	34.9	104.5	46.4	535.4	1.8	0.2	466.1	531.1	487.7	1.2	2.5	1972.8	448.
MIN PH	6.8	STD DEVIATION	6.56	83.02	28.99	301.99	5.03	1.00	114.56	304.14	415.76	0.59	5.63	1024.34	321.
		MAX READING	52.0	456.0	146.0	1390.0	28.0	8.0	961.0	1630.0	1855.0	3.5	42.8	4967.0	1691.
		MIN READING	21.00	13.00	9.00	107.00	0.00	0.00	143.00	105.00	88.00	0.00	0.00	706.00	0.
							GROUP 2								
	7.9	(ONLY 1 LISTING)	31	140	56	606	1	0	359	457	773	1.3	3.9	2245	5
							GROUP 3								
MAX PH	8.3	MEAN	38.2	107.3	41.4	525.4	6.2	0.0	332.6	333.4	677.1	2.4	19.2	1914.2	423.
MIN PH	7.1	STD DEVIATION	22.67	62.50	17.35	299.91	8.65	0.00	87.25	263.42	397.27	4.15	23.53	920.45	221.
		MAX READING	86	356	87	1230	29	0	574	975	1680	22	85.7	4056	11
		MIN READING	15	30	13	185	0	0	204	66	233	0.4	0	835	
							GROUP 4								
MAX PH	8.3	MEAN	16.6	62.4	24.0	622.4	5.7	0.0	243.3	294.0	799.3	1.1	3.7	1949.4	256.
MIN PH	7.7	STD DEVIATION	5.88	55.54	17.92	134.78	6.82	0.00	57.33	97.50	313.34	0.67	5.63	543.09	205.
		MAX READING	23	174	48	808	19	0	320	446	1156	2.5	14.6	2562	61
		MIN READING	3	2	1	410	0	0	120	192	324	0.1	0	1111	1

Notes: Please refer to <u>Figure 25 entitled Approximate Productive Areas of the Major Sources of Groundwater in the Lower Rio Grande Valley for proper identification of Groups 1-4.</u>

REPORT ON

TASK III: ALTERNATE-DESIGN SYSTEMS EVALUATION

A. PROCESS TYPES REVIEW

INTRODUCTION

Dr. Alan D.K. Laird, Professor Emeritus of the Seawater Conversion Laboratory of The University of California at Berkeley and a Co-Editor of the definitive work: "Principles of Desalination" with Dr. K.S. Spiegler (Academic Press) remarked during a speech, that: "The gradual spread of desalination throughout the world will continue as potential users become aware of its benefits. Its costs ... will come down as economies of scale assert themselves and where people's priorities shift increasingly towards this technology, in the face of dwindling groundwater supplies and decreasing water quality. But whatever its rate of growth, those who wrest fresh water from our planet's finite supply of saline and soiled water - as a chemical of life - will rely increasingly on desalination as an essential tool."

Three major processes exist today for the commercial-scale conversion of brackish groundwaters and/or seawater to potable quality water, most often delivered at a guaranteed maximum concentration of 500 ppm of Total Dissolved solids (TDS). They are:

The Reverse Osmosis Process (RO)

The Electrodialysis Reversal Process (EDR)

The Multistage Flash Evaporation Process (MSF)

As a general rule (since in reality the specific process selected is almost totally a function of the salinity of the raw water as a principal determinant), the RO Process is useful for the desalination of waters containing up to 35,000 ppm TDS, with the addition of "seawater" membranes for TDS levels above 10,000 ppm; the EDR finds its best applications at concentrations not exceeding 6,000 ppm TDS; the MSF Process is useful over the entire range of salinities, up to a high of 50,000 ppm TDS.

Selection of the appropriate process is also a site-specific function, inasmuch as it is dictated by location, length of raw-water lines to the plant, proximity to disposal receptacles, etc.

The RO and the EDR Processes are basically molecular-diffusion processes wherein a semi-permeable membrane stack is utilized to separate the salts from the water, in varying process configurations. The MSF Process, in any of its variations, is basically a distillation-based process, with the differences in its versions based on methods of energy and efficiency improvement, thus influencing total operating costs.

Some pro-forma economics for the RO and the EDR Processes, using purchased grid electricity as the power source, are presented herein, the MSF pro-formas to follow later on.

This process review is especially timely, inasmuch as the weather patterns of many coastal and near-coastal areas of the U.S.A. are changing perceptibly, causing not only severe drought in the LRGV, but also having a progressively depressive effect on surface water quality. These decreases in water quality cause a plenitude of associated problems, from the obvious ones such as fouling and scaling of lines to the not so obvious ones of excessive soil leaching during flash floods, contributing to appreciably increased salinities in, for instance, the waters of the Lower Rio Grande River.

States such as Florida and California also count in the roster of States now accelerating efforts to tap desalination technology to supplement water supplies in these times. This interest, belated though it characteristically is, is being fed by population growth in booming areas such as those in the South and West that are seriously behind in their water resource development programs. Some are of the opinion that even the Northeast and other more developed, water-rich areas may need their own desalination plants within the next 5 to 15 years.

Yet, the attitude persists that "if only the rains come, we would not need to spend lots of capital building desal plants, because the water from them is going to be a lot more expensive than fresh water from the sky!" The utilities director of San Luis Obispo in California reportedly said to an interviewer in later 1991 that: "...we'd rather hope for more rainfall than build a desal plant..." One is reminded of a 1986 meeting in the offices of the Secretary for Water and Drainage in Mexico City, agreeing with a delegation from water-starved Monterrey, that .. "rain dances aside, you people will have to recognize that expensive is still better than none!" In the original Spanish:.."mejor caro que nada!"

Several locations in Florida are at the point already where desalinated water costs are competitive with conventional water supply sources, largely due to the fact that a series of rate increases has placed the cities in a position of having to pay up to $2.50 per 1,000 gallons or literally go without. Add to that the fact that communities such as Mount Pleasant, S.C. and Suffolk, V.A. had to go to desalination in order to rectify the unacceptable salinity levels in their well water, and the pervasiveness of this problem becomes more and more evident. Texas and, particularly the LRGV, has a unique opportunity to forestall such dire circumstances and undertake a sound and far-sighted program to develop a plentiful and independent source of water, both shallow and deep, for its long-term future.

A1.: ELECTRODIALYSIS REVERSAL PROCESS

The Electrodialysis Reversal Process (EDR) is today the most technically advanced of all the membrane-related processes for the purification of brackish waters. An outgrowth of the previously developed Reverse Osmosis Process (described below), the EDR Process contributes several significant advantages to its practitioners, chiefly:

Reduced operating costs via more efficient use of current densities

Employment of periodic current reversal (hence the name) for the prevention of fouling of the membrane stacks

Greater sensitivity to anodic and cathodic radicals in salt separation, such that the chlorides and the sulfates are more completely removed

Greater recycling efficiency of the concentrated brine stream, for improved system performance.

Basically, the EDR Process employs a series of semipermeable membranes (stacks) to progressively remove the salts from the feedwater via electrolytic action. Salts, when dissolved in water, are present in the form of negatively and positively charged ions. When an electric current is applied, positively charged ions in the brackish water, such as sodium, are forced through the cation-permeable membrane toward the cathode. Negatively charged ions such as chloride are forced through the anion-permeable membrane toward the anode. The water in the compartment between membranes is thus depleted of salt while the water in the adjacent compartments increases in mineral content.

The membrane stack, or the EDR process unit itself, consists of several sets of anion- and cation-permeable membranes. The quantity of salts removed by passage through one stack may range from 30 to 65 percent of the entering minerals, depending on the stack design and the characteristics of the membranes themselves. Additional stacks are added in series to increase salt removal towards the desired level of purity. Each added stack is known as a stage. Total volume of water processed is achieved by arranging additional stacks in parallel.

The EDR Process operating costs are significantly influenced by the cost of energy at the plant site, as is indeed the case with the Reverse Osmosis and the Multistage Flash Evaporation Processes as well. Whether the energy needed is in the form of electrical power or steam of a certain quality, this category of costs rules the final outcome of the economics of these processes.

Recent improvements in the design and spatial arrangement of EDR plants has led to the availability of "packaged units" that are very compact compared to earlier versions, possessing a "small footprint" as one would say in the computer world. This feature enables the effective use of these installations, in skid-mounted fashion, in remote locations where power can be brought in or indeed produced at the site by various means. This overall portability is a key feature in the success of several EDR installations wherever space is at a premium.

Ruggedness of design and ease of maintenance are also additional features that have propelled the EDR Process to the top of the list of processes selected for desalination of brackish waters, it being clearly understood throughout that this process works best when raw-water salt contents do not exceed 5,000 to 6,000 ppm TDS.

There are some built-in limitations in the EDR Process that must be very carefully handled, if a serious loss of efficiency and onstream time is not to be encountered. Concentrations of Iron and Manganese in the incoming feedwater have a major deleterious effect upon the operability of the membranes. Of somewhat lesser importance is the concentration of Calcium in the feedwater. Tolerable limits for each of these ions is as follows:

Calcium: Less than 400 ppm in the brine discharge stream

Iron and Manganese: Less than 0.3 ppm together. This imposes a great strain on the precision and accuracy of the analyses to be made of the feedwater prior to its introduction into the EDR unit. Potassium Permanganate is the preferred chemical employed for the removal of Iron and Manganese and, thankfully, the amounts needed represent a very small fraction of the total operating costs. Capital costs of the Iron/Manganese removal equipment are, however, not insignificant. In a specific case, this equipment cost nearly an additional $2,000,000 on an installed basis, for feedwater concentrations of 0.6 ppm (total for both the Iron and the Manganese).

Yet another possible problem with the EDR Process is that any Silica in the feed water may tend to concentrate upon (rather than be removed by) the membranes. Desilicifiers may be necessary to sustain economic operation.

Please see FIG. 3 for a flow diagram of the EDR Process.

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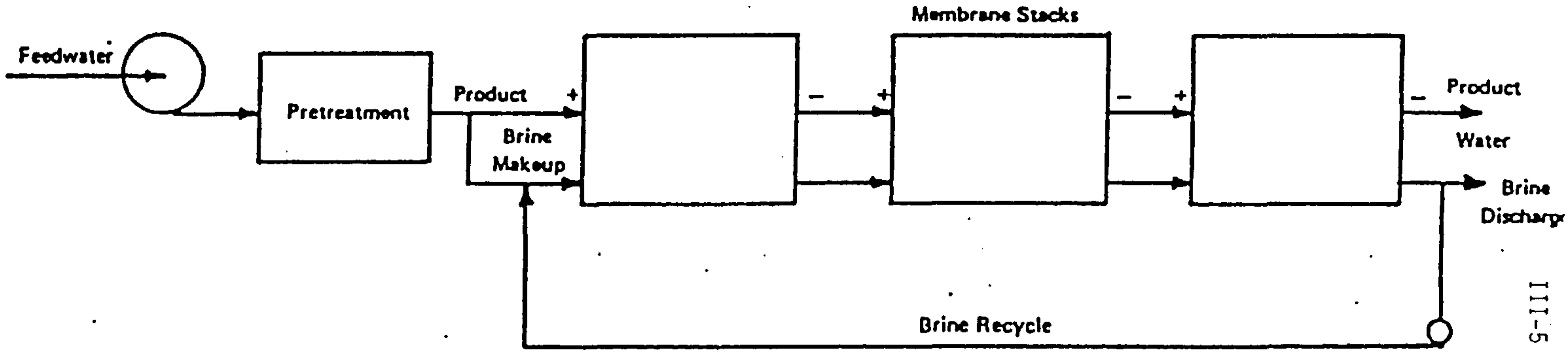

Source: Southwest Research Institute

Figure 3

SCHEMATIC FLOW DIAGRAM OF THE ELECTRODIALYSIS PROCESS

(FROM A REPORT BY THE SwRI TO THE TWDB, JUNE, 1967)

It is not surprising, therefore, that the development of the EDR process followed logically as an answer to these RO constraints, noting that current reversal in the EDR process on a set frequency is an elegant and efficient way to avoid (or at least greatly reduce) the advent of "concentration polarization".

The one clear difference between the operational requirements of the RO Process as compared to the EDR Process is the much higher pressures at which RO operations have to be optimized. Pressure ranges from 400 to 1,000 psig are not uncommon, and these occasion higher fixed costs for electricity for pumping, in addition to the electrical power costs for the rest of the RO Process. It has been estimated that electrical costs for pumping alone can reach as high as 50 cents per thousand gallons. This is the reason that part of these costs are sought to be recovered by the inclusion of a power recovery turbine in the brine discharge line of RO plants. Approximately 20% of such losses are estimated to be reasonably recoverable.

On balance, then, the overall operating costs of an RO plant as opposed to an EDR plant are higher for otherwise equivalent conditions. Process selection, however has to be influenced by the fact that EDR plants cannot cope with salinity conditions in excess of 6,000 ppm TDS, and this fact alone guarantees that there will always be a significant share of total installations that will accrue to the RO Process.

Please see FIG. 4 for a flow diagram of the RO Process.

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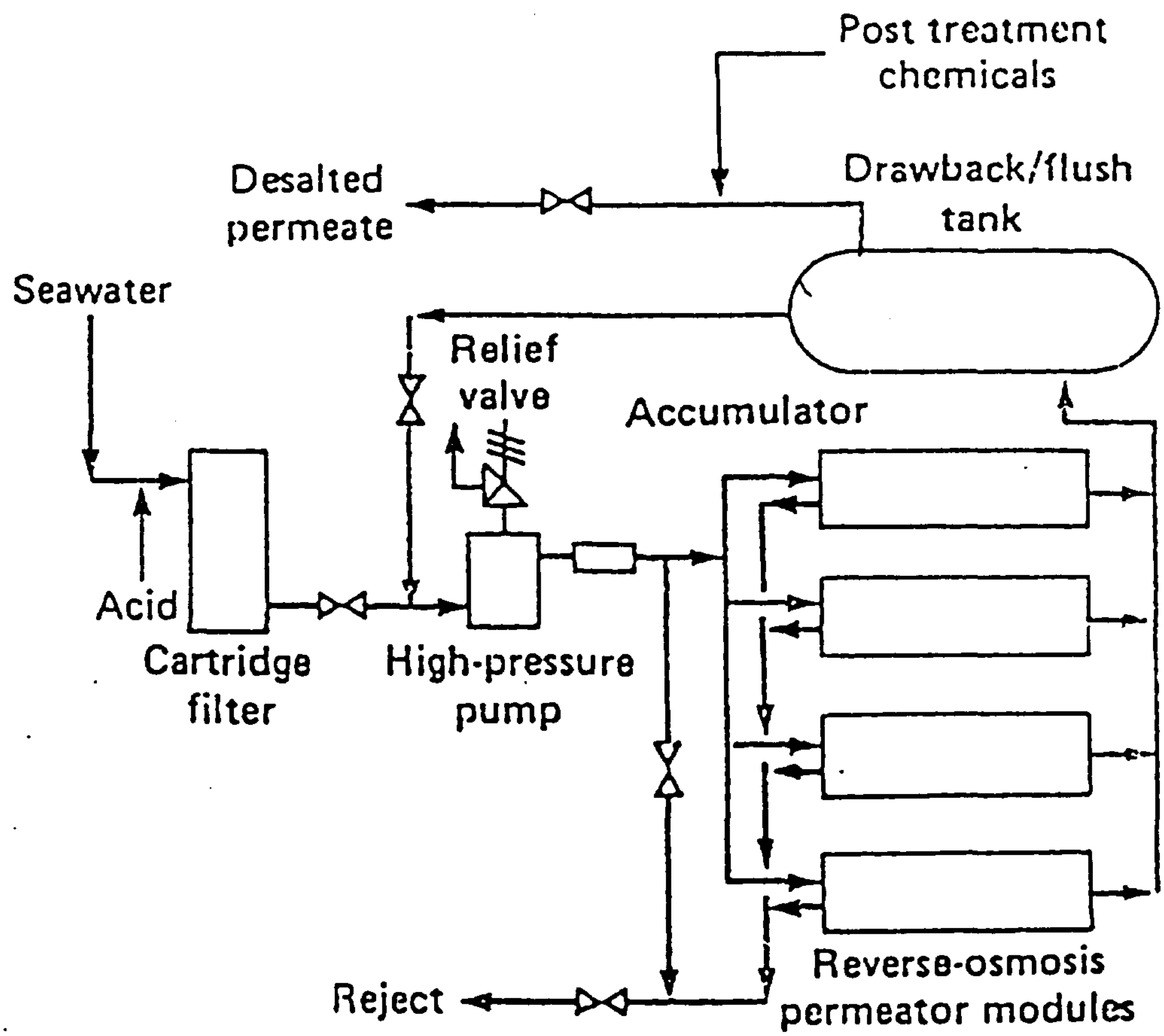
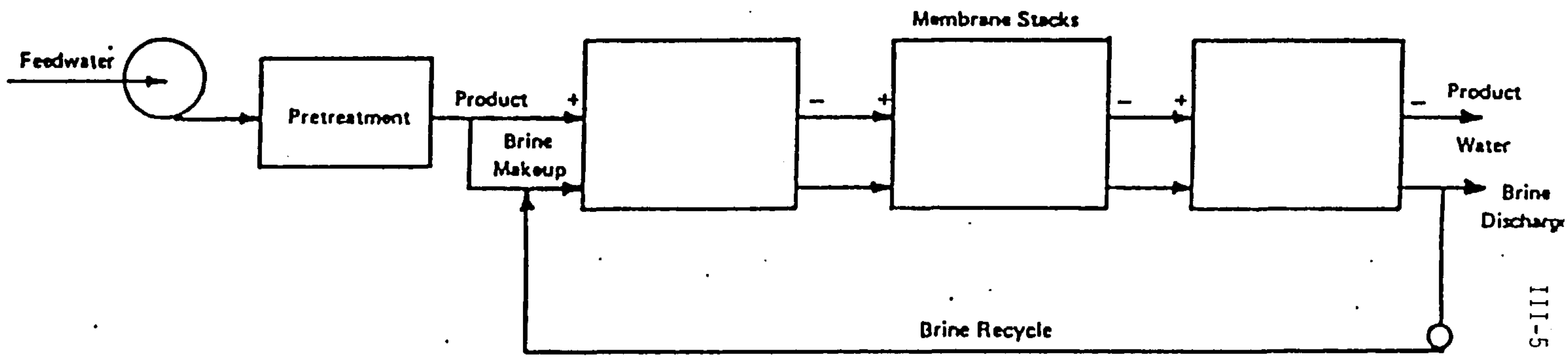


Reverse osmosis (From Chem. Eng. 2/7/83, Wagner & Finegan)

FIGURE 4



Source: Southwest Research Institute

Figure 3

SCHEMATIC FLOW DIAGRAM OF THE ELECTRODIALYSIS PROCESS

(FROM A REPORT BY THE SwRI TO THE TWDB, JUNE, 1967)

A2: THE REVERSE OSMOSIS PROCESS

The oldest of the membrane-related processes is the Reverse Osmosis (RO) Process, the earliest installations of which date back to before 1950, no matter that these early units were strictly laboratory-sized and often were more trouble than they were worth. Shipboard-sized units, capable of desalting up to 15,000 gallons per day of seawater, appeared on vessels in the early Sixties. It was not until 1966 that commercial-sized units, capable of desalting up to 100,000 GPD, were installed in municipal use, one of these early types being installed in the City of Plains, Texas, in 1967.

The RO Process relies on a natural phenomenon: Osmosis, involving fluid flow across a membrane called "semipermeable". The term arises from the fact that certain components of a solution, usually the solvent, can pass through such a membrane while others, usually dissolved solids, cannot. The direction of solvent flow is determined by its chemical potential which is a function of pressure, temperature and the concentration of the dissolved solids.

Thus, if pure water is on both sides of a semipermeable membrane at equal pressure and temperature, no net flow can be realized inasmuch as the chemical potential is equal on both sides. If a soluble salt is now added to one side of the membrane, the potential on that side is reduced, causing flow to occur from the pure water side to the salt water side, thus diluting the concentration of salt in the water on that side. If a reversal of this flow is desired, the pressure on the salt water side is increased and now the flow occurs from the salt side to the pure side. This reversal mechanism gives the process its name and accomplishes the desalting of the feedwater without a change of phase (i.e. the water is not required to be converted into steam prior to its desalination).

As can now be perceived, the design of the membrane, its chemical composition and its physical characteristics (e.g. pore size, etc.) must be carefully balanced for the intended job. Most desalination-plant RO membranes are designed for the flow of water across them. It must be realized that since this is a specific design balance predicated on the passage of water, dissolved compounds which are chemically similar to water will also pass readily through the membrane, since they will interact with the membrane in a similar manner. If the composition of the feedwater is such that these compounds are present in excessive quantities, then pre-treatment of the feedwater becomes a must. It is for this reason that detailed analyses of the feedwater are required, including tests for biological compounds that would affect the TOC, BOD, COD, etc., as well as tests for colloidal matter that may entrain such compounds.

As to the rest of the features of an RO Process unit, they are quite similar to the EDR unit, in that feedwater needs to be pre-treated, brine discharge is recycled for greater efficiency, temperature and pressure are carefully controlled (albeit pressures in an RO Process are altogether higher than those in an EDR Process unit) and the ease of operation is sensitive to the salinity of the feedwater.

Today's RO units can handle salinities up to those found in seawater (35,000 ppm TDS), although their best performance is usually realized when salinities are no greater than some 15,000 ppm TDS. Part of this constraint arises from the fact that, after a period of continuous operation, the membranes suffer from "concentration polarization", a phenomenon in which the salt concentration on the face of the membrane exposed to the feedwater side is greater than that in the feedwater itself. This then requires periodic flushing and dilution procedures that can raise overall operating costs significantly, especially in those cases where membranes are required to maintain high water flows per unit area. Recent advances in

III-9

Comparative Assumed Input Information - EDR versus RO

	EDR	RO
Feedwater:	Rio Ground Water Reservoir	Rio Ground Water Reservoir
General Geographical Area:	McA - HRL*	HRL - BRO**
Plant Capacity:	5.0 MGD	5.0 MGD
Current Building Cost Index:	3,014	3,014
Current Labor Cost Index:	4,720	4,720
Interest Rate:	6.5%	6.5%
Amortization Period:	20 years	20 years
Cost of Electric Power from Grid:	$0.07/KWH	$0.07/KWH
Length of Feedwater Pipeline:	2 miles	2 miles
Elevation of Desalt Plant:	57 ft.	30 ft.
Elevation of Well Field:	57 ft.	30 ft.
Well Pumping Depth-Feedwater Supply:	220 ft.	220 ft.
Well Depth - Brine Disposal:	3,000 ft.	3,000 ft.
Land Cost:	$3,000/ac.	$3,000/ac.
Right-of-Way Cost:	$5,000/ac.	$5,000/ac.
Water Analysis:		
Total Dissolved Solids:	2,477 ppm	4,130 ppm
Sodium/Potassium:	630 ppm	1,220 ppm
Chloride:	454 ppm	1,250 ppm
Calcium:	59 ppm	143 ppm
Iron:	0.9 ppm	0.4 ppm
Manganese:	< 1 ppm	< 1 ppm
Magnesium:	62 ppm	99 ppm
Temperature:	80°F	80°F
Net Evaporation Rate:	40 in./yr.	50 in./yr.
Goal:	Product water of <500 ppm TDS	Product water of <500 ppm TDS

* McAllen to Harlingen

** Harlingen-Brownsville (west side)

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PRO-FORMA CALCULATIONS FOR ELECTRODIALYSIS REVERSAL PROCESS (EDR)

Cost Elements		Capital Costs/($x1000)	Annual Costs/$x1000)	Water Costs, $/1,000gal
Capital Costs				
1.	Plant and Equipment[2]	4,925	446.94	0.2709
2.	Feedwater Pretreatment[2]	600	54.45	0.0330
3.	Feedwater Supply[3]	1,600	145.20	0.0880
4.	Water Transmission	780	70.79	0.0429
5.	Brine Disposal	1,388	125.96	0.0763
	Total Capital Costs	$ 9,293.00	$ 843.34	$ 0.5111
Operation and Maintenance Costs				
6.	Operating and Maintenance Labor			$/1,000 gal.
a.	Plant and Equipment[2]			0.050
b.	Feedwater Pretreatment			0.036
c.	Feedwater Supply			0.026
d.	Water Transmission			n.r.[1]
e.	Brine Disposal			0.200
	Total Operating and Maintenance Labor			$ 0.312
7.	Other Operation and Maintenance Costs			
a.	Payroll Extras (15% of 6a)			0.008
b.	General and Administrative Overhead (30% of 6a + 7a)			0.017
c.	Supplies and Maintenance Materials			0.030
d.	Membrane Assembly or Replacement Tubing[2]			0.200
e.	Chemicals[2]			0.030
f.	Fuel or Steam			n.r[1]
g.	Electric Power			
	Plant and Equipment[2]			0.392
	Feedwater Supply			0.108
	Water Transmission			n.r[1]
	Total Other Operation and Maintenance Costs			$ 0.785
	Total Operation and Maintenance Costs			$ 1.097
	Total Water Cost (Total Capital Plus O. & M. Costs)			$ 1.6081

(1) none required
(2) Based on recent information from Ionics, Inc., with an assumed water recovery factor of 80% and adding a factor of 20% to cover indirect capital costs comprised of interest during construction, engineering and contingencies, and factor for land costs.
(3) Based on a recent study by R.W. Harden Assoc. Total of 10 wells and a land cost factor

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PRO-FORMA CALCULATIONS FOR REVERSE OSMOSIS PROCESS (RO)

Cost Elements	Costs/yr.($x1000)	Costs/yr.($x1000)	Water Costs, $/1,000 gal.
Capital Costs			
1. Plant and Equipment[2]	4,505	408.83	.2478
2. Feedwater Pretreatment	0	0	0
3. Feedwater Supply[3]	1,600	145.20	.0880
4. Water Transmission	780	70.79	.0429
5. Brine Disposal	1,735.3	157.48	.0954
Total Capital Costs	$ 8,620.3	$ 782.3	$ .4741
Operation and Maintenance Costs			
6. Operating and Maintenance Labor			$/1,000 gal.
a. Plant and Equipment[3]			.05
b. Feedwater Pretreatment			0
c. Feedwater Supply			.026
d. Water Transmission			n.r.[1]
e. Brine Disposal			.19
Total Operating and Maintenance Labor			$ .266
7. Other Operation and Maintenance Costs			
a. Payroll Extras (15% of 6a)			.008
b. General and Administrative Overhead (30% of 6a + 7a)			.017
c. Supplies and Maintenance Materials			.028
d. Membrane Assembly or Replacement Tubing[2]			.23
e. Chemicals[2]			.075
f. Fuel or Steam			n.r[1]
g. Electric Power			
Plant and Equipment[2]			.28
Feedwater Supply			.108
Water Transmission			n.r[1]
Total Other Operation and Maintenance Costs			$ .746
Total Operation and Maintenance Costs			$ 1.012
Total Water Cost (Total Capital Plus O. & M. Costs)			$ 1.4861

(1) none required

(2) Based on recent information from Ionics, Inc., cost information includes effect of 83%/17% blending; therefore, actual plant size equal to 4.2 MGD, with Thin Film Composite (TFC) membranes and a water recovery factor of 75%. A factor of 20% has been added to cover indirect capital costs comprised of interest during construction, engineering and contingencies. Also, a factor has been added for land cost.

(3) Based on a recent study by R.W. Harden Assoc. Total of 10 wells and a land cost factor added.

A3: THE MULTI-STAGE FLASH EVAPORATION (MSF) PROCESS

1. Introduction

The Multi-stage Flash (MSF) desalination process has more than 32 years of operating history behind it and accounted (in 1992) for over 80% of installed world desalination plant capacity. Although its dominant position is now being challenged by other processes that have a higher overall energy efficiency, MSF is likely to continue as an important process in dual-purpose stations producing water and electricity and in applications where steam can be made cheaply using waste heat. In order to understand the basic principles of the MSF process, a description of the simple once-through system is first presented. This is followed by an explanation of the more complicated brine-recycle MSF process, which has become the most widely used MSF system on account of its lower operating costs.

2. Once-through MSF Process

A diagrammatic representation of the once-through MSF process is shown in FIG-1.

Water at atmospheric pressure normally boils at 100°C, but if the pressure in reduced, the water will boil at a lower temperature. The MSF process takes advantage of this phenomenon by passing heated seawater through a series of box-like stages, each held at successively lower pressure. The seawater spontaneously boils (flashes) as it enters the bottom of each stage and water vapor is given off. The latent heat of the vapor is obtained from the sensible heat in the seawater and therefore the seawater temperature falls by a few degrees before passing to the next stage. The latent heat of the vapor is returned to the process by condensing the vapor onto a tube bundle at the top of the same stage. The vapor passes through knitted-wire mist separator pads to remove any entrained brine droplets and the condensed vapor then forms the freshwater product of the plant.

The seawater flowing in the tube bundles at the top of each flash chamber gets progressively hotter as it passes from stage to stage up the plant, but it is always a few degrees cooler than the flashing seawater at the bottom of the same stage. After leaving the hottest stage, the seawater therefore goes to a separate vessel called a "brine heater", connected to an external heating steam source, to have its temperature raised before it is returned to the base of the first flash chamber. At the other end of the plant, cold seawater is taken in and warm, concentrated seawater (brine) is rejected to the sea or to other acceptable receiving bodies of water or injected underground.

The product water itself is passed from stage to stage through the plant and contributes slightly to the heat economy by flashing at entry to each lower-pressure stage, thus giving up its sensible heat and cooling before final withdrawal from the last stage.

The average brine flow inside a typical MSF plant is about 8 times the product output. In order to prevent the precipitation of alkaline scales on the heat transfer surfaces in the hotter stages and in the brine heater, the seawater has to be chemically treated in some way. In the once-through MSF process, all the seawater flows through all the plant and has to be treated, leading to a very large chemical cost. For this reason, the more conservative brine-recycle MSF plant described below has been developed.

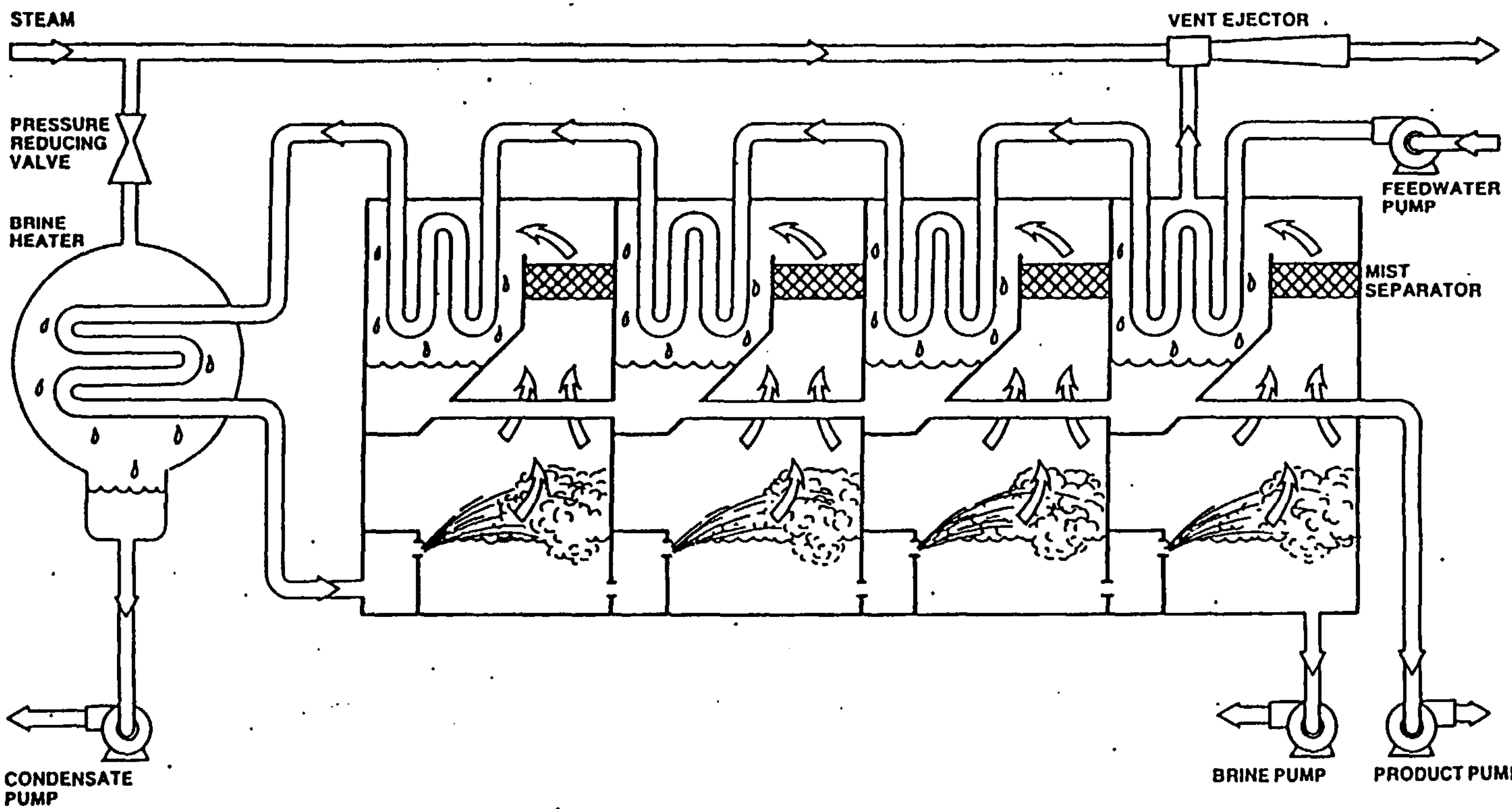

FIG-1: TYPICAL FLOW DIAGRAM OF ONCE THROUGH MSF PLANT

3. Brine-recycle MSF Process

A diagrammatic representation of the brine-recycle MSF process is shown in FIG-2.

To reduce the cost of chemicals needed for anti-scale pretreatment, instead of rejecting all of the brine at the cold end of the plant, most of it is recycled to the tube bundle of an intermediate stage. The particular recycle stage is chosen so that the raw seawater used for cooling the remaining stages never reaches a temperature at which anti-scale treatment would be required. By this means, only the comparatively small portion of seawater actually used as make-up to the plant has to be treated with chemicals to prevent scale from precipitating in the hotter parts of the plant.

The stages that are cooled with raw seawater are referred to collectively as the "heat rejection section" and the stages in which brine is recycled through the tubes are referred to collectively as the "heat recovery section". In a "long-tube" evaporator, the heat rejection section often forms a separate module. In a "cross-tube" evaporator, there is seldom any actual separation between the recovery and reject sections, so that the flashing brine flows continuously in the bottom of the plant and the changes in flow through the tubes at the top of the plant are achieved by external piping connections to the waterboxes.

To avoid build up of high salt concentrations in the brine recycle MSF plant, with consequent danger of forming hard sulphate scales, a proportion of the recirculating brine is rejected, or "blown down", from the cold end of the plant and replaced by new seawater. The make-up flow thus has to be equal to the product flow plus the blow down flow. The make-up or feedwater flow is typically about twice the product flow, but is still only about 25% of the total seawater that has to be treated in the equivalent once-through MSF plant. The saving in pretreatment chemical costs has thus made the brine recycle MSF plant the most popular design.

4. Outline Plant Description

An MSF plant basically consists of a long metal vessel usually rectangular in section, with vertical dividing plates to form a series of individual box-like stages. There is a tube bundle near the top of each stage onto which the flashed vapor condenses. A product tray is located under the tube bundle to catch the condensed water drops as they fall from the tubes. The tray is usually sloped towards one side of the stage, so that the product water drains into a trough that runs the length of the vessel, with water seals between each stage to prevent vapor passage. The main vessel is usually made from carbon steel plate with lining or cladding of some parts as corrosion protection. Troughs, trays, partitions and other internal components are often made of or clad with stainless steel.

In a cross-tube MSF plant, the tubes run from side to side of the vessel, at right angles to the brine channel. In a long-tube MSF plant, the tubes run from end to end of the vessel, parallel to the brine channel. Tube materials are usually selected from among aluminum brass, cupro-nickel and titanium, depending on seawater/brine conditions and temperature regime in the plant. The tube bundles may incorporate open passages to allow vapor to easily penetrate to the center and also to allow non-condensible gases to escape. Vent pipes or orifices in the stage division plates cascade the non-condensible gases to the cold end of the vessel, where they are withdrawn by the ejector system. If there are many stages, intermediate venting points may be used.

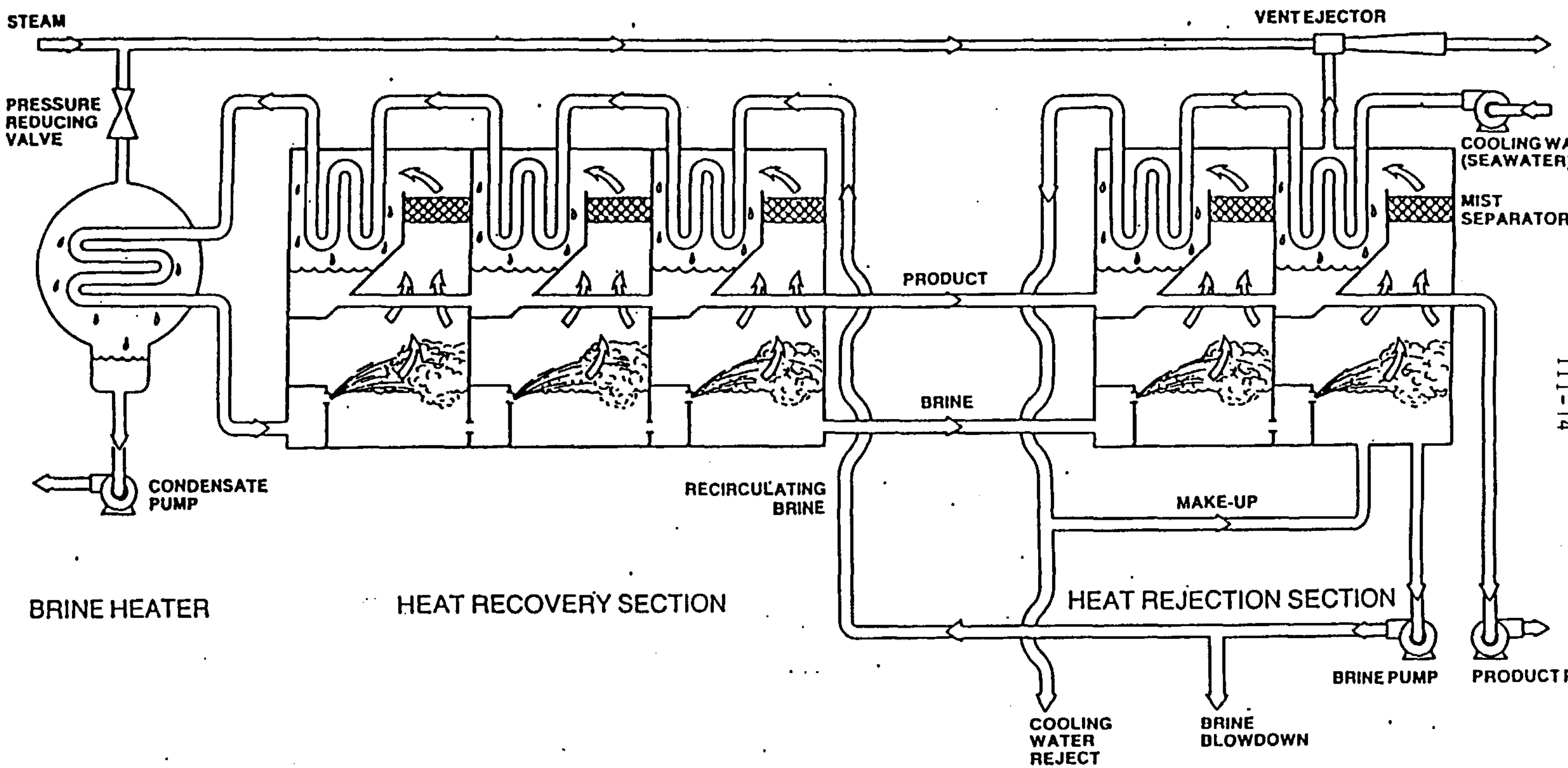

FIG -2: TYPICAL FLOW DIAGRAM OF BRINE RECIRCULATING MSF PLANT

The tube plates are usually rectangular and made of non-ferrous material compatible with the tubes. Intermediate tube support plates are spaced across the vessel to maintain tube separation and prevent vibration. In spite of continuing research into use of enhanced-profile tubes, plain circular tubes are still the usual supply. In the cross-tube MSF plant, there may be several seawater passes through each stage, with corresponding complexity of the waterbox designs at each end of the tube bundle. Depending on temperature regime and fluid chemistry, water boxes are usually lined with either epoxy resin, neoprene, butyl rubber or cupro-nickel and may incorporate sacrificial anodes to minimize corrosion/erosion of tube ends and tube plates.

Inside each evaporator stage there are mist-separator pads, usually filling the whole horizontal cross-section adjacent to the distillate trays. These are normally of knitted stainless steel or monel wire, supported on a stainless steel framework. The area of the vessel shell above the mist-separator pad is generally less prone to corrosion than the main body of the flash chamber, since it does not get splashed with brine. It is therefore customary not to apply any protective cladding or lining to the vessel above mist-separator level, except in the hottest one or two stages, where carbon dioxide may be released from the brine. These hottest stages are often lined throughout with stainless steel and separately vented to the ejector system.

At the bottom of each stage, brine boxes incorporating gates and weirs control the interstage flow and prevent "unsealing" between stages during start-up and load changing, when liquid levels tend to fluctuate widely. Because of the high brine velocities and extreme turbulence, these components are almost invariably made of stainless steel.

The brine heater is usually a separate vessel in the form of conventional steam/water shell-and-tube cylindrical heat exchanger, with carbon steel shell and non-ferrous tubes. It may have several passes on the brine side and a number of steam entries at the top.

The venting system often incorporates a separate hogging ejector for quick start-up and either a two or three stage ejector system, with intermediate and final condensers for normal operation. Sophisticated materials and/or linings are often used to minimize corrosion of the ejector system under the aggressive working conditions.

To economize on installation area, cross-tube evaporator vessels are sometimes built in a two-tier arrangement. When considering plot layouts for both long and cross-tube MSF plants, allowance has to be made for tube-withdrawal space. Nearly all MSF plants are installed outdoors. In places with tropical or aggressive climates, some components such as pumps and control devices may have weather-protective canopies or sunshades. Very small plants can sometimes be shipped and delivered to site as fully-finished units and even for very large plants, special transport and handling facilities are often constructed as part of the project, such that finished modules weighing up to about 2,000 tons can be brought to site and placed on their foundations.

5. <u>Cogeneration of Electricity and Water</u>

By far the largest use of MSF plant is in combined-cycle (or dual-purpose) municipal installations producing both drinking water and electricity. By combining power and water in a single undertaking, a number of capital and operation cost savings can be achieved.

a) The separate seawater intake, screening and chlorination plant, pumps, pipework and outfall system for the power plant condensers can be eliminated.

b) A single steam-raising boiler can replace the separate boilers otherwise required with consequent savings also in make-up water treatment, fuel storage and handling systems.

c) By expanding the same steam first through a turbine to generate electricity, and then using it to make water by condensing it in the brine heater of an MSF plant, there is a considerable saving in total energy use, i.e. fuel cost.

d) Common support facilities and services such as control room, offices, workshops, stores, laboratory, fire system etc. can be used.

e) The total station staff complement for operation, maintenance and administration is hardly greater than that required for a power station alone.

Combined steam stations producing up to 1000 MW of electric power and 470,000 T/D of drinking water have been built in the Middle East to supply the needs of whole cities. But as well as the combination with steam turbine power stations, MSF plants can be economically combined with gas-turbine or diesel power stations, using waste heat boilers installed in the stacks. For small plants though, one of the other available processes such as Reheat Thermo-compression (RH) or Vacuum Vapor Compression (VVC) is likely to be more economic.

6. Special Types and Applications

New ideas for improving the MSF process, both by novel plant designs and by hybrid combinations with other processes such as multiple-effect and vapor compression, are constantly being introduced. Few of these novel ideas have achieved much commercial success, largely due to the conservative nature of the market. Big desalination plants are an expensive investment and customers tend to be wary of acting as guinea pigs for trying out unproven systems.

Similarly, many ingenious applications of MSF plant have been suggested, such as salt recovery from geothermal brines and making irrigation water for agro-industrial complexes. But in spite of the flood of studies and reports that swell the volumes of conference proceedings, more than 99% of all commercially installed MSF desalination plant is employed in producing drinking water or boiler feed water from seawater.

But this is not to say that there are no successful advances in MSF plant design. Plant volumes are gradually becoming smaller; new and cheaper corrosion-resistant materials are being brought into use; operating regimes are being extended by the introduction of improved chemical additives. Although Reverse Osmosis is becoming an increasing competitor against MSF, the MSF process itself is benefiting from the keen competition and is responding to the challenge by cost-saving improvements in design that will ensure a continuing place in the market for years to come.

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III. ALTERNATIVE-DESIGN SYSTEMS EVALUATION

B. BRINE DISPOSAL METHODS

GENERAL

Two issues pervade all of geothermal fluids utilization--the resource and the economics of producing and utilizing it and the effluent and the economics of disposing of it in an environmentally acceptable manner. Clearly, the resource must be available; its availability, however, will not be attractive unless the effluents can be disposed of economically. The purpose of this chapter is to discuss the accumulated evidence concerning brine disposal alternatives (whether GP/GT derived or from desalination waste streams) from the standpoint of technology, economics, and the environment. It is an interesting commentary on our technical and philosophical outlook that brine disposal has heretofore received dramatically less attention from the geothermal industry than has resource assessment and production.

EVIDENCE OF LARGE SCALE BRINE DISPOSAL

Large quantities of brine effluent produced by the Frasch sulfur industry and the oil and gas industry are disposed of annually along the Gulf Coast Plain. The Frasch sulfur industry currently disposes of its high salinity mine "bleed" fluids by draining them into bodies of saline water or by holding them in large ponds preparatory to discharge into fresh water streams at flood stage. Although new disposal projects of this type are possible, the probability of such a project being permitted is low. For some years the oil and gas industry used brine pits for oil field brine disposal; that practice led to saline creeks, salination of potable ground water, and a change to deep, protected subsurface disposal.

Many producing oil and gas fields produce large quantities of brine along with petroleum products; a good example is the East Texas field. There the problem was so important that a special company--the East Texas Salt Water Disposal Company--was established to collect and dispose of the brines produced by member operators. The quantities of brine injected daily are large, but it is important to note that the brines are injected over a very large area. Considerable quantities of saline water (> 3,000 ppm dissolved solids) are injected into oil and gas fields for secondary recovery and pressure maintenance purposes. The Texas Railroad Commission (1972) reported that secondary recovery saline water injection in all Texas districts during 1971 amounted to 1.31×10^9 BBL. Districts 2, 3, and 4, which include the Texas Gulf Coast Plain, had secondary recovery saline water injection of 218×10^6 BBLs in 1971 (or about 600,000 BBL/Day) in an area of about 50,000 square miles.

It is true that not all oil and gas field brines are injected into producing reservoirs for secondary recovery or pressure maintenance. The volume of fluids not injected for secondary recovery or pressure maintenance is probably much larger than that used for recovery and maintenance.

Saline water injection strictly for disposal is performed under approximately 190 separate permits in Nueces County and 150 in San Patricio County (Railroad Commission, 1975), as an example. Many of these operations are located within the Corpus Christi fairway. The injection zone depths are from 1,000 to 7,000 feet below sea level. The production zones from which the fluids originate are located from 1,000 to 7,000 feet below sea level. Injection wellhead pressures range from 50 to 1,000 psia.

Data for the injection flow rates and pressures and the receiving aquifer's performance need to be assessed more completely. Data useful for estimating total quantity of fluids received by the reservoir appear not to be generally available. However, secondary recovery data from the Railroad Commission indicates that injection pressures vary from atmospheric to 2,400 psia at wellhead. Wellhead flow rates in secondary recovery operations are reported to range from 75 to 10,000 BBL/Day with the majority under 5,000 BBL/Day. Accumulated injection ranges up to 85 x 10^6 BBL injected since 1936. The secondary recovery data indicates only what injection rates and accumulated storage volumes have been achieved. As oil reservoir engineering will prevail, actual rates and storage volumes may be very far from those achievable or optimum for fluid disposal. The pressures used may be more indicative of those required for disposal, although the average porosities and permeabilities of the traps or structures, from which petroleum production derives, may not be indicative of those properties in sand bodies in large blocks.

The data available from oil and gas operations does not provide sufficient detail or evidence for assessing the potential of subsurface disposal because most of these are proprietary.

SPECIALIST OPINION - SUBSURFACE DISPOSAL

Two specialist organizations have provided opinion concerning the potential for subsurface disposal. A drilling and services organization considers that injection of 20,000 BBL/Day into 5 - 6,000 foot wells of reasonable cost is possible. Such wells might inject up to 400,000 BBL/Day into a large reservoir using 20 wells. If operated for 15 years, the receiving reservoir will need to store 2.2 x 10^9 BBL.[*] A second specialist organization notes that up to 1,000 gallons per minute (35,000 BBL/Day) can be injected into a 5,000 to 6,000-foot well. Such a well would have a good-sized injection tubing terminating in a gravel-packed, under-reamed injection section.

The latter organization pointed out that, in order to determine the potential for subsurface disposal, the following steps are necessary:

(1) Geological mapping of the subsurface sands using well log data.

(2) Determination of porosity and permeability using core data and well log data.

(3) Reservoir engineering calculations.

(4) Preliminary design of injection wells and injection well surface equipment.

(5) Slim hole boring program with coring, reservoir fluid sampling, and production testing programs.

(*) 2.2 Billion Barrels or Ca. 2,700,000 acre-feet.

Certain of the technical issues which arise within the context of GP/GT brine effluent disposal are common to disposal practice for other wastes:

(1) Removal of entrained particulate matter and all matter not in solution.

(2) Dissolved or entrained oxygen prevention or limitation; corrosion and deposition control.

(3) pH control and tailoring, to ensure proper levels of acidity or alkalinity.

(4) Elimination or mitigation of transient conditions such as sudden changes in temperature and/or pressure.

Other technical issues arise which are not common to disposal practice for other wastes:

(1) Temperatures higher than usual.

(2) Total flow rates and storage volumes abnormally high.

(3) Possibilities for rapid and unheralded changes in temperature and pressure when bypassing the desalination plant (because of shutdowns), thus causing possible damage to the re-injection well(s).

SURFACE DISPOSAL

Surface disposal may not be a viable or permittable alternative, but it must be investigated for two reasons: subsurface disposal may not be available at a given site and the subsurface disposal permit process requires the evaluation of at least some, if not all, alternatives. The problems posed by surface disposal are enumerated below:

(1) Total quantity of fluids produced daily.

(2) Salinity of fluids and protection of potable water supplies.

(3) Requirements for surge protection -
   (a) Pipeline system emergency shutdown.
   (b) Utilization system bypass.

(4) Noxious or poisonous gases removal or conversion.

(5) Dissolved or entrained oxygen prevention or mitigation; corrosion control.

(6) Solids removal and/or deposition control.

(7) Thermal transient prevention or mitigation.*

* Rapid and unheralded changes in temperature and pressure when bypassing the desalination plant because of shutdowns.

(8) Thermal content of fluids and thermal enrichment to environment near point of disposal.

(9) Entrained and dissolved solids removal before fluid disposal.

(10) Creation of appropriate fluid mixing zones to eliminate stratification and other effects in the recipient water body.

(11) Maximum salinity and temperature deviations from natural salinity and temperature environment of receiving water body.

(12) Pipeline leakage detection.

(13) Mitigation of subsidence or seismic event effects upon disposal system integrity.

(14) Optimization of economics and energetics impacts of facility.

(15) Maximum economic distance from utilization facility to disposal point.

(16) Impact of topographic features and soil conditions upon design and economics of disposal system.

(17) Impact of pipeline upon environment.

(18) Impact of permitting process and regulations upon design and economics of disposal system.

Evidence that these issues have been systematically studied seems not to be available. Petroleum operators and Frasch sulfur operators no doubt have studied some or most aspects of this problem. Such information is probably proprietary.

In summarizing, almost the entirety of the above possible problem areas can be safely put aside, since all such surface disposal is now considered to be in violation of the Texas Natural Resource Conservation Commission (TNRCC) Stream Quality Standards. Surface disposal, thus, becomes a very unlikely option.

III B-1

STREAM DISCHARGE POSSIBILITIES FOR SPENT BRINES, S. TEXAS

Before the advent of environmental regulations that control the discharge of any liquid into flowing bodies of water, it was generally supposed for most cases that available and nearby streams could adequately handle most discharges of spent brines from either oil/gas production or from other sources. At present, there is a growing body of State-level regulations that controls and directs such disposals and we therefore start this review by presenting relevant excerpts from several agencies concerned with this overall problem, as seen below.

It must be recognized that it is no longer sufficient to demonstrate that a given quantity of salt water, containing several inorganic salts not in and of themselves toxic or noxious, will be adequately diluted by disposal into a very much larger body of flowing water. Today, several factors in the disposal plan must be weighed and considered in sufficient detail to satisfy the involved agencies that no permanent or even temporary deleterious effects would arise as a result of stream discharges.

The situation is further complicated by the fact that the total pollution potentials of non-point discharges into streams (e.g. surface runoff from fields, farms, etc.), although repeatedly studied, still do not lend themselves to rigorous control except in rare cases where their runoffs are totally prevented from occurring in the first place. It is clear that the quantities of pollutants thus carried into flowing bodies of water are far in excess of most single-point or defined-points discharges. A single heavy downpour can occasion the discharge of several million gallons of water into streams, carrying with it high quantities of insecticides, pesticides, fertilizers and the like, all of which can pollute under a wide variety of conditions, to say nothing of sizeable salt leachates from the soil itself.

In the LRGV, in particular, the heavy preponderance of agricultural activities renders non-point discharges a dominant contributor of stream pollution. Against that background, discharges of up to, say, thirty acre-feet per day (as estimated from a desalination plant of some 10-15 million gallons per day capacity) appear to be quite small. Measured against the average flow of water in the Rio Grande, for instance, these quantities of brines appear insignificant. However, the regulations pertaining to such brine discharges needs must be obeyed rigorously, if permits for same are to be obtained and maintained.

We begin, therefore, with an extract of these regulations that are pertinent to the case of GP/GT brine disposal, emphasizing that all of these regulations were historically accurate, but are now totally absorbed into the respective domains of the TNRCC* Stream Quality Standards Act, the Texas R.R. Commission and the U.S.E.P.A.

Regulations Governing the Production and Disposal of Saline and/or Geothermal Fluids

Several state and federal agencies including the Railroad Commission of Texas, the TNRCC, and the Environmental Protection Agency have regulatory responsibilities that directly or indirectly influence development of both a geothermal test well and, subsequently, a geothermal energy production/generation facility. Only those regulations that affect the production and disposal of saline water will be consideredhere. The TNRCC is charged under the amended Texas Clean Air Act of 1967 with safeguarding the "air resources of the state from pollution by controlling or abating air pollution and emissions of contaminants..." (Texas Legislature, 1967). At this time, it is not known if geothermal fluids will contain any potential air pollutants.

* Texas Natural Resource Conservation Commission

The primary environmental concern of the Texas Railroad Commission and the TNRCC with respect to geothermal development was the impact of the disposal of hot saline geothermal fluids. The Railroad Commission of Texas (1975) will regulate the drilling and operation of geothermal resource wells and the disposal of fluids from geothermal resource wells. Under Rule 8 (A), "Fresh water, whether above or below the surface, shall be protected from pollution...."

(B) The operation of each "... geothermal resource well or well drilled for exploratory purposes ... shall be carried on so that no pollution of any stream or water course of this state, or any subsurface waters, will occur as the result of the escape or release or injection of geothermal resource or other mineralized waters from any well."

(C) (1) All operators conducting"... geothermal resources development and production are prohibited from using salt water disposal pits for storage and evaporation of... geothermal resource waters ..."

(C) (1) (b) "Impervious collecting pits may be approved for use in conjunction with approved salt water disposal operations ...."

(c) "Discharge of ... geothermal resource waters into a surface drainage water course, whether it be a dry creek, a flowing creek, or a river, except when permitted by the Commission is not an acceptable disposal operation and is prohibited."

(D) (1) "The (well) operator shall not pollute the waters of the Texas offshore and adjacent estuarine zones (salt water bearing bays, inlets, and estuaries) or damage the aquatic life therein."

(2) "... geothermal resource well drilling and producing operations shall be conducted in such a manner to preclude the pollution of the waters of the Texas offshore and adjacent estuarine zones."

(a) "The disposal of liquid waste material into the Texas offshore and adjacent estuarine zones shall be limited to salt water and other materials which have been treated, when necessary, for the removal of constituents which may be harmful to aquatic life or injurious to life or property."

The Texas Railroad Commission (1975) also regulates the injection of saline water. Under Rule 9 (A), "Salt water ... unfit for domestic, stock, irrigation, or other general use may be disposed of ... by injection into the following formations:

(1) "All non-producing zones of oil, gas or geothermal resources bearing formations that contain water mineralized by processes of nature to such a degree that the water is unfit for domestic, stock, irrigation, or their general uses."

Water quality standards developed originally by the Texas Water Quality Board* were approved by the Environmental Protection Agency in October 1973 and were amended in 1975 (Texas Water Quality Board, 1975). These standards are in compliance with the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500, U.S. Congress, 1973). Under these standards, "it is the policy of the state ... to maintain the quality of water in the state consistent with the public health and

* Now TNRCC

enjoyment, the propagation and protection of aquatic life, the operation of existing industries and the economic development of the state ...." Furthermore, " ... no waste discharges may be made which will result in the lowering of the quality of these waters unless and until it has been demonstrated to the TNRCC that the change is justifiable as a result of desirable social or economic development (TNRCC, p. 1)."

The suggested limitation to thermal pollution as outlined in the Texas Water Quality Standards is of interest:

1. 2.75°C (5°F) rise over ambient temperature for fresh-water streams.

2. 1.65°C (3°F) rise over ambient temperature for fresh-water impoundment.

3. 2.2°C (4°F) rise or a maximum temperature of 52.5°C (95°) in fall, spring, and winter, and .85°C (1.5°F) rise or a maximum temperature of 52.5°C (95°F) in summer for tidal reaches of rivers and bay and Gulf waters (TNRCC, 1975).

The TNRCC recognized that salinities of estuaries are highly variable and that the dominant factor affecting salinity variations is the weather. Salinity standards are presently incompletely defined but are under study.

The preceding review of the regulations and policies of Texas agencies that apply to the disposal of salt water indicates that:

1. Temporary salt-water collecting or storage pits are permitted.

2. Salt water treated to remove harmful constituents may be released into bays, estuaries, and the Gulf of Mexico.

3. Under certain circumstances, the discharge of salt water into natural water courses is permitted.

4. The reinjection of salt water into saline aquifers is permitted.

5. The lowering of standards for certain water bodies is permitted if sufficient need for economic development can be demonstrated.

Once again we point out that agencies such as the TNRCC and the Texas Air Control Board no longer exist as separate entities. Their functions have been absorbed and consolidated into the Texas Natural Resource Conservation Commission (TNRCC).

III. B-2

BRINE DISPOSAL VIA INJECTION INTO APPLICABLE UNDERGROUND FORMATIONS

In a major oil and gas producing State such as Texas, the framework and procedures for proper underground disposal of brines are inherent in hydrocarbon production regimes.

Thousands of disposal permits have been issued by the Texas Railroad Commission (TRC), which has principal jurisdiction over this alternative for brine disposal. There are four major parameters for allowable underground disposal that are key to the acquisition of an appropriate disposal permit, namely:

A. Proper analyses of existing well logs to select receiving formations

B. Porosity, permeability and reservoir capacity data in selected formations

C. Proper design of injection well(s) and surface systems

D. Pressure and flow constraints for intended pumping rates into receiving formations

Certain other constraints may also be relevant but, in general, satisfaction of the above four parameters is generally tantamount to permit approval.

Certain factors unique to GP/GT brines are also significant in reservoir evaluation prior to selection of the proper receiving formations. These are the temperatures and flow rates of the brines in question and the necessity to plan for adequate reservoir capacity in a given formation, such that disposal may proceed over a reasonably long period of time, at least ten years.

A good preliminary idea of the capacity of some South Texas receiving formations may be derived from referring back to the introduction to this Section III B, on page 16, wherein a professional, independent organization active in brine disposal has stated that: "injection of 20,000 BBL/Day into five 6,000 foot wells of reasonable cost is possible.... If operated for 15 years, the receiving reservoir will need to store 2.2 x 10^9 BBL". In TWDB terms, that quantity equals 285,000 acre-feet over 15 years, or roughly a little less than 2,000 acre-feet per year.

The qualifying procedures and other relevant details are herein excerpted and reproduced from the TRC Manual entitled: "Underground Injection Control Reference Manual", April 1992 Revision. (Please refer to Appendix B).

In summary, Underground Disposal of Brines in Texas is a well formulated and highly standardized technique that represents a particularly cost-effective and environmentally safe method of brine disposal.

III. B-3

THERMAL ENHANCED OIL RECOVERY USING GEOPRESSURED - GEOTHERMAL FLUIDS

Concept and Methodology

The concept of GP/GT TEOR is very simple. Geopressured-geothermal reservoirs contain high pressure, high temperature, and usually, gas saturated brine. The concept is to use these fluids to recover oil from a shallow reservoir found structurally above the geopressured-geothermal reservoir. The high pressure of the GP/GT reservoir compared with the low pressure of the target reservoir allows moving the fluid to the target reservoir simply by pressure differential. The high temperature of the brine will heat the oil in the target reservoir and thus reduce its viscosity to a level where it can be pumped. Thus, viscosity reduction techniques have made the greatest contribution to EOR when compared with other tertiary recovery processes especially when considering the efficiency of recovering heavy oil. The explanation is seen in the temperature - viscosity - oil gravity relationships. Hence, the advantages of using the GP/GT fluids in TEOR are as follows:

- A source of high temperature water
- Internal drive method determined by the pressure differential that will pump the GP/GT brine hydraulically into the target reservoir.
- No emissions from the burning of crude oil.
- No outside use of fresh water.
- Possible use of natural gas from the GP/GT fluids to drive surface equipment.

PROCESS FEASIBILITY

Three steps are important in proving the GP/GT TEOR technology. The first step in proving the technology is a co-locational analysis to find suitable GP/GT and target reservoirs. Analyses are being undertaken by The University of Texas at Austin for Texas heavy oil fields; and, by Louisiana State University for Louisiana heavy oil occurrence. As an example, a test field (Alworth Field) has been proposed for Texas and is available as part of an industry cost-sharing proposal with Fanion Production Company. The target reservoir is the Cole Sandstone, at a depth of 1,000 ft. The field is presently marginally economical and is currently producing about 20 bpd (8°API) from five producing wells. The viscosity of 18°API gravity oil can be reduced from about 100 centipoise at a temperature of 90°F (32°C) to 10 centipoise if it is heated to 200°F (93°C). The shallow location of the reservoirs in this field, its simple structure, and the availability of industry cost-sharing provide good conditions for the completion of an successful test of a TEOR project using GP/GT fluids. It appears probable that other test fields may be developed in Cameron and Hidalgo Counties.

The second step is to assess the technological problems involved in hot fluid injection as they pertain to the utilization of the GP/GT resource in TEOR. This requires a knowledge of the chemical and thermodynamic properties of both the target reservoirs, rock matrix and fluid content, and the GP/GT brine. Because of the specificity of the reactions, each situation may need to be treated differently. Additional research in this area should go hand-in-hand with field testing. The well in the target reservoir must be designed to handle the thermal stress and the equipment must be able to handle the pressure, temperature, and flow rate as well as the water quality.

In steam and water flooding, the quality of feedwater dictates the type of treatment it undergoes. The GP/GT fluid represents extreme conditions from the viewpoint of conventional TEOR feedwater. Subsurface waters increase their TDS and chloride content with increasing depth in an attempt to maintain thermodynamic equilibrium during progressive burial. Maintenance of equilibrium between brine and quartz, feldspars, sheet silicates, and carbonates appear to be particularly important factors which influence brine composition. Exchange between brine and host sediments profoundly alters the isotopic composition of these waters. The normal desired characteristics for the feedwater used in steam and hot water flooding are given by Burger et al. (1985) as follows:

$<$ 5 mg/L suspended solids,
organics,
dissolved gases,
magnesium or calcium ions, i.e. zero hardness, and
$<$ 0.4 mg/L iron.

These conditions are impossible to meet in GP/GT fluids. The brines are saturated with both methane and carbon dioxide and are highly buffered with bicarbonate. Gas in solution can probably be produced without deleterious effect on the useful aspects of the GP/GT fluid. Besides CO_2 other gases include N_2, CH_4, H_2, Ar, and higher saturated hydrocarbons. These are less soluble than CO_2 by a large factor and this greatly affects flash initiation (bubble point) and therefore, scaling.

Nonetheless, modern methods of chemical control of scaling and deposition promise a relatively trouble-free operation.

A positive factor is that injection wells for GP/GT brines have been used in coastal regions of the Gulf Coast Basin for many years. Moreover, the continuous use of the injection wells at the DOE Gladys McCall site and the DOE Pleasant Bayou site suggest that the problem should not exist.

The third step concerns production of the GP/GT fluids. Clearly, temperature and hydraulic head are not a problem. Early attempts to develop the GP/GT fluid technology in the 1980's encountered problems due to the precipitation and deposition of scale in the producing wells, and corrosion of equipment. The DOE GP/GT program provided an economic analysis of brine utilization and has shown that production of the fluid is economically feasible.

III. B-4

BINARY POWER PRODUCTION USING GP/GT BRINES

The heat content of GP/GT brines constitutes a valuable resource for exploitation in the production of supplemental quantities of electrical power via proper use of binary power generators, perhaps coupled with solar ponds. The practice of using binary generators is already well established, as are uses of solar ponds, particularly in Israel. The residual heat content of GP/GT brines, combined with heat absorption from sunlight in solar ponds, enables the efficient production of electricity at costs considerably below those of conventionally generated electrical power.

Solar pond technology is still evolving but, to date, it already constitutes a viable technique for the use of submerged binary-power generators to drive a highly volatile working fluid around a closed loop in which is included a turbine that generates electricity. Because the working fluid vaporizes at relatively low temperatures (in the range of 100° to 150°F), it enables the effective use of "exhaust" temperatures after the hot emerging GP/GT brines have been utilized at higher temperatures for, say, desalination of mildly to moderately brackish groundwaters.

A comprehensive paper on Binary Power generation was presented at the Government/Industry Consortium Conference for the Commercialization of the GP/GT Resource, held in February, 1991, at Austin, Texas, under the auspices of the UT/Balcones Research Center and the UT Center for Alternate Energy Studies. We have reproduced it herein in full, to illustrate the potentials of this technique as a method of utilizing the energy residuals in GP/GT brines prior to their eventual disposal or other viable techniques covered in this section, and it is enclosed as Appendix C.

It is clear from our investigations, that the multiple energy potentials in GP/GT brines constitute a valuable resource for the enhancement of the economics of electrical power production as well as those of desalination. To the extent that these energy potentials can be realized in an economic manner, the costs of producing potable water as well as significant quantities of electricity could be reduced to levels that would make such water and power more competitively available, either for on-site usage or for the open market, depending upon the particulars of a given site-specific operation.

III. B-5 & 6

BYPRODUCT SALTS RECOVERY, WITH OR WITHOUT EVAPORATION PONDS

The most obvious example of economic recovery of various inorganic salts from brines is at the Great Salt Lake in Utah. There, the Great Salt Lake Chemicals Company has been extracting various salts for the last six decades and treating them to produce purified versions of useful industrial chemicals such as the Chlorides of Sodium and Magnesium, the Carbonates of Potassium and Calcium, etc.

Near the Searles Lake area of California, a similar operation is recovering chemical values from mixed salts pumped out of these deep brines and commercializing many compounds, in addition to the chemical elements Bromine and Iodine. Midland, Michigan, and Owens Lake brines are yet two more examples of this kind of byproduct recovery.

All of the above utilize large-scale settling and evaporation ponds (most of them man-made except, of course, for the Great Salt Lake itself), to permit the sun's power to drive off all or most of the water, depositing a dense layer of solid, mixed, inorganic salts on the "hardpan" or lake or pond bottom. After several years of this type of settling and compaction, the salt beds are strong enough to sustain the weight of harvesting machinery, which gathers these salts and conveys them to a beneficiation plant for further separation and purification prior to sale.

If the LRGV-region brines from GP/GT sources possess salt compositions somewhat similar to those found from the Pleasant Bayou Brines (from the USDOE Test Well), then one would expect to find significant concentrations of the Chlorides and Carbonates of Sodium, Potassium, Calcium, Magnesium and Strontium, with much smaller quantities of Lithium, Manganese and Barium and recoverable quantities of Bromine. Obviously, until the analyses of these LRGV brines become definitely established, one cannot attempt any meaningful development of recoveries and subsequent commercial values.

The question of whether to recover these salts after a period of natural evaporation by sunlight - which would require extensive acreage to be set aside for long periods of time - or by passage through an inorganic salt recovery plant is again one of economics, determinable only after some good and reliable analyses are at hand for the basic mixed-salt composition. On the one hand, it can be said that use of settling and evaporation ponds constitutes the least expensive initial investment, but a sizeable cost pattern for harvesting and beneficiation, whereas the chemical-plant route bespeaks a high initial capital investment and a moderate to high cost of beneficiation, if the relevant concentrations are high enough to be economically recoverable.

One interesting alternative that has been advanced, emanating from modern Israeli practice, is to create adequately sized evaporation ponds that can also accommodate binary-power generators, so that the costs of electricity to run the plant are importantly defrayed, at least in part.

Another economically viable alternative is to harvest the entire salt mixture, dry it adequately and sell the mixture as such to a chemical company that needs an assured source of this type of raw material for further processing. As it stands, all such chemical companies are forced to locate near their sources of raw materials and this would be an attractive way in which to induce the location of one or more such chemical companies to the LRGV region, for the start of a new industry, reasonably balanced between capital intensity and labor intensity.

The attached Figure shows graphically the many industrial and commercial products that are possible from the salts contained in various types of brines found within the U.S.A.

It might be mentioned in passing that, with the availability of inexpensive electrical power from the energy potentials in these GP/GT brines, it should be possible to develop an Electrolytic Industry that can then extract chlorine from the various Chlorides. Chlorine is one of the most important chemicals in any modern society and, along with Sulfuric Acid, betokens the economic importance of any area that possesses such resources, from which an entire chemical-industry foundation may arise leading to divers other chemicals of commerce and industry. The LRGV region has long been eyed by several chemical companies over the years and their reluctance has traditionally been based on the fact that the availability of good water, inexpensive electricity and abundant chemical raw materials has been quite limited.

The GP/GT brine resource, at full development, can go a long way towards curing these constraints and spawning, in the process, a hefty contribution towards the economic diversification of the LRGV region, especially now that it finds itself at the nexus of a tripartite Trade Bloc that is destined, with the advent of NAFTA, to be the new North American front line, so to speak.

We reproduce in Appendix D of this Report, a composite representation of all the economically recoverable values from the many resource components that go to make up the total GP/GT Resource. That particular effort is reported in a comprehensive paper presented at the same GP/GT Conference reported above, at Austin, Texas in February, 1991.

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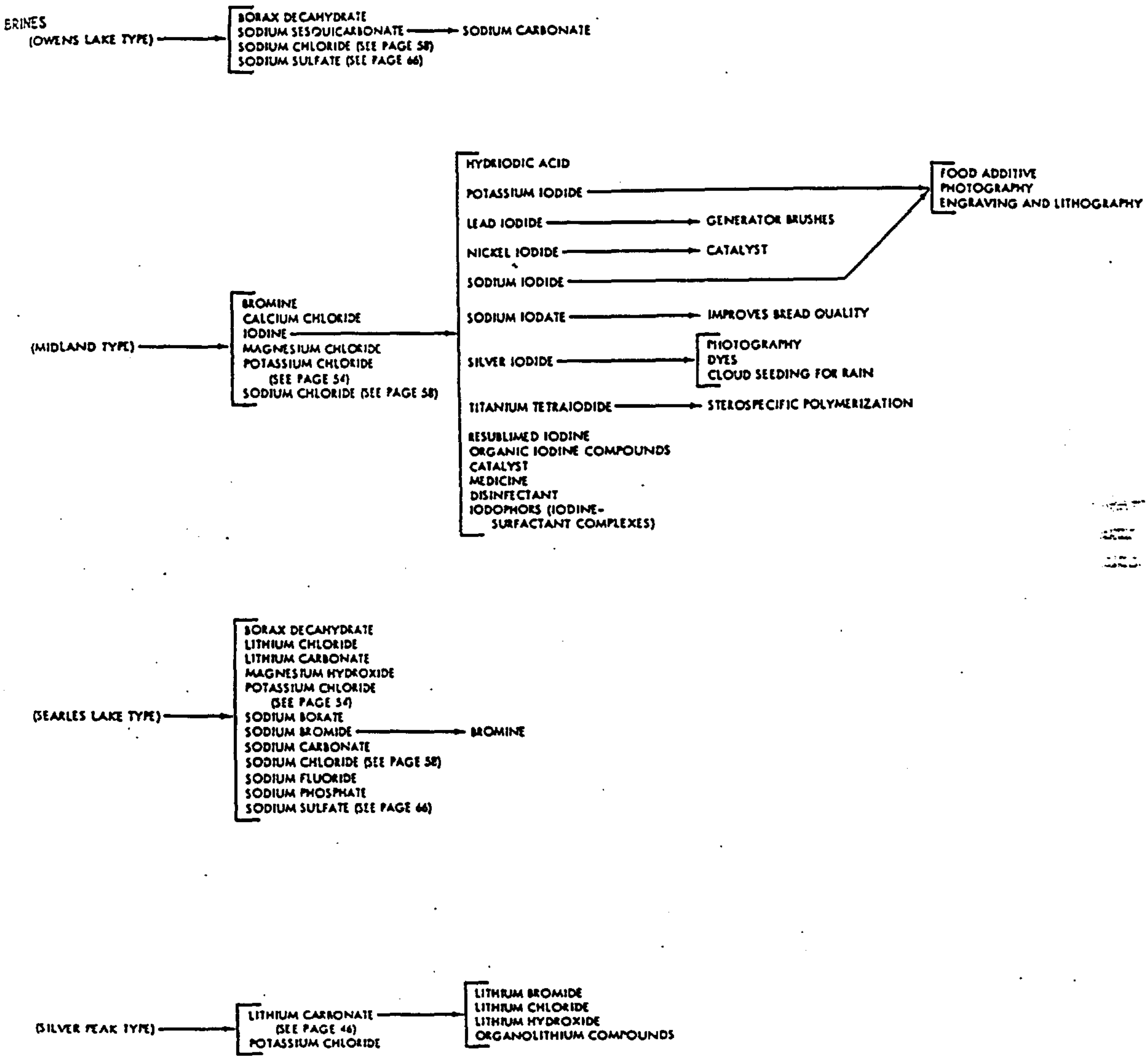
BRINES
(OWENS LAKE TYPE)
BORAX DECAHYDRATE
SODIUM SESQUICARBONATE
SODIUM CHLORIDE (SEE PAGE 58)
SODIUM SULFATE (SEE PAGE 66)
SODIUM CARBONATE
(MIDLAND TYPE)
BROMINE
CALCIUM CHLORIDE
IODINE
MAGNESIUM CHLORIDE
POTASSIUM CHLORIDE (SEE PAGE 54)
SODIUM CHLORIDE (SEE PAGE 58)
HYDRIODIC ACID
POTASSIUM IODIDE
LEAD IODIDE
NICKEL IODIDE
SODIUM IODIDE
SODIUM IODATE
SILVER IODIDE
TITANIUM TETRAIODIDE
RESUBLIMED IODINE
ORGANIC IODINE COMPOUNDS
CATALYST
MEDICINE
DISINFECTANT
IODOPHORS (IODINE-SURFACTANT COMPLEXES)
FOOD ADDITIVE
PHOTOGRAPHY
ENGRAVING AND LITHOGRAPHY
GENERATOR BRUSHES
CATALYST
IMPROVES BREAD QUALITY
PHOTOGRAPHY
DYES
CLOUD SEEDING FOR RAIN
STEROSPECIFIC POLYMERIZATION
(SEARLES LAKE TYPE)
BORAX DECAHYDRATE
LITHIUM CHLORIDE
LITHIUM CARBONATE
MAGNESIUM HYDROXIDE
POTASSIUM CHLORIDE (SEE PAGE 54)
SODIUM BORATE
SODIUM BROMIDE
SODIUM CARBONATE
SODIUM CHLORIDE (SEE PAGE 58)
SODIUM FLUORIDE
SODIUM PHOSPHATE
SODIUM SULFATE (SEE PAGE 66)
BROMINE
(SILVER PEAK TYPE)
LITHIUM CARBONATE (SEE PAGE 46)
POTASSIUM CHLORIDE
LITHIUM BROMIDE
LITHIUM CHLORIDE
LITHIUM HYDROXIDE
ORGANOLITHIUM COMPOUNDS

TASK IIIC

PROCESS(ES) BEST SUITED TO EFFICIENT RECOVERY AND CONVERSION TO POTABLE WATER

As discussed in Section IIIA, "the best suited" process(es), so to speak, for the efficient recovery and conversion to potable water from brackish water "varying from mildly to very brackish" will fall into one of three process types, specifically the following:

1. Electrodialysis Reversal (EDR)
2. Reverse Osmosis (RO)
3. Multistage Flash Evaporation and major variations (MSF)

The procedure involved in making a decision among the EDR, RO, and MSF alternatives for the purpose of incorporating one or more of them into the design and implementation of a GP/GT powered desalination plant of sufficient size and economy to provide a total or supplementary supply of potable water to a municipality or region is iterative and requires a thorough evaluation of:

(a) the availability and chemical composition of nearby feedwater source(s),

(b) the availability and characteristics of significant quantities of GP/GT energy, and

(c) comparative feasibility, technical and economic.

These evaluations are presented as follows:

A. Availability and Chemical Composition of Nearby Feedwater Source(s)

A substantial amount of information regarding the availability and chemical composition of both the deep GP/GT fluids and the relatively shallow aquifer systems is presented in the write up on Task II – Resource Assessment of this Report. As regards co-location between the deep GP/GT zones and the shallow aquifer systems, a comparison of Figure II entitled Reservoir Area Location Map (taken from Section I of the write up) and Figure 5 entitled Approximate Productive Areas of the Major Sources of Ground Water in the Lower Rio Grande Valley (taken from Section II of the write up) indicates that, for the most part, the locations of these two resources coincide horizontally, and that only in that portion of Hidalgo County to the north and east of McAllen is there an area which is probably underlain by the deep GP/FT fluids, but not a productive zone of shallow ground water with relatively low salinity levels.

Based on a review of the information in the write up on Task II and the co-locations findings described above, the results of this facet of the evaluation are summarized as follows:

1. Substantial portions of Hidalgo County and the western part of Cameron County are underlain by sufficiently large quantities of mildly to moderately brackish shallow ground water to justify their use via desalination as major sources of potable water supply.

2. Generally speaking, the same areas from (1) are also underlain by very significant quantities of GP/GT fluids which are primarily useful as an energy source to power the desalination systems, but could, if proven feasible, be converted to potable water via auto-desalination, most probably utilizing the MSF process.

3. Because of the aforementioned horizontal coincidence of the two resources in most areas, coupled with the fact that the cost of desalination practically always increases with increasing salinity levels, in the majority of applications the shallow brackish groundwaters aquifers should be utilized as the feed water sources, while utilizing the GP/GT fluids to provide the necessary energy. A possible exception to this majority case could be the above mentioned area to the north and east of McAllen, which appears to be underlain by significant quantities of the GP/GT resource, but not significant quantities of mildly to moderately brackish groundwater in shallow aquifers. This minority area could prove to be a possible location for an auto-desalination application if certain conditions of feasibility are met.

B. Availability and Characteristics of Significant Quantities of GP/GT Energy.

Part B of Section I of the write up for Task 2 is entitled Simulation of GP/GT Resource Potential, and it provides a substantial amount of information regarding the projected availability and characteristics of the GP/GT energy available from the deep zones. Specifically, it presents such information for three different sand zones, one found in the Reservoir B Area and referred to herein as the East Sand, and two found in the Reservoir C Area, namely the Marks Sand and the Bond Sand. A summary of the pertinent energy parameters for each sand, taken primarily from Figures 4-9 of Part B of Section I, and averaged over a projected productive life of 15 years, is presented as follows:

	East Sand		Bond Sand		Marks Sand	
	Max	Min	Max	Min	Max	Min
Brine Production (Barrels/Day)	25,000	25,000	24,900	23,500	14,750	14,125
Gas Production (MSCF/Day)	600	600	600	550	300	275
Wellhead Pressure (PSIA)	950	950	850	850	850	850
Bottom Hole Temp. (°F)	264	264	296	296	279	279
Brine Salinity (mg/l)	15,000	9,000	50,000	40,000	50,000	40,000

C. Comparative Feasibility - Technical and Economic

In this analysis of Comparative Feasibility, four different alternatives "couplings" of desalination process types to feedwater sources, in addition to three different forms of GP/GT energy, namely E(B), E(G), and E(P) need to be considered at the outset. These four "alternative couplings" are as follows:

Alternative	Process Type	Feedwater Sources
A	Autodesalination using MSF (or a variation thereof)	GP/GT brine water from deep zone
B	MSF (or a variation thereof)	Mildly brackish groundwater from shallow aquifers
C	RO	Mildly brackish groundwater from shallow aquifers
D	EDR	Mildly brackish groundwater from shallow aquifers

The methodology required for the determination of one or more "best suited processes" for an economic conversion to potable water for a substantial municipal supply involves a step-by-step process of elimination, with the steps being as follows:

Step 1 - Establish a comparative ranking of the four "alternative couplings" and three GP/GT energy forms on the basis of technical feasibility, and eliminate from further consideration all "alternatives"/GP/GT forms except those with the highest rankings.

Step 2 - For the alternatives/GP/GT forms remaining after Step 1, establish a comparative ranking on the basis of economic feasibility, and arrive at the "best suited processes".

Step 3 - In Section IV to follow, prepare pro-forma economics for "best suited processes".

Step 1 - Technical Feasibility

Process Types

Alternative A - On the basis of the physical chemistry characteristics of the GP/GT brine from the deep zone with it's very high potential for scaling, the "autodesalination" alternative is precluded from further consideration. Please refer to Appendix G prepared by Dr. Jim McNutt.

Alternative B - Although to a much lesser extent than for Alternative A, the physical chemistry characteristics of the brackish groundwater, specifically the silica content with its high potential for scale formation, limit the efficiency of the MSF alternative, giving it a relatively low ranking in terms of technical feasibility. Statistical information regarding the silica content (SiO_2) for the Group 1-4 shallow brackish groundwater is enclosed as Table 1 of Section II in the write up for Task No. 2 - Resource Assessment.

Alternative C and D - The primary basis for a comparison of technical feasibility between EDR and RO as applied to the Group 1-4 brackish groundwaters from relatively shallow aquifers is a preliminary evaulation prepared by Mr. Gene Reahl of Ionics, Inc., and it is enclosed herein as Appendix _. Mr. Reahl was provided with a copy of Table 1 (mentioned under Alternative B), and also with TWDB/Groundwater Data System Infrequent Constituent Reports for wells in Cameron and Hidalgo Counties. A summary of Mr. Reahl's comments regarding comparative technical feasibility is as follows:

1. Group 1 through Group 4 waters contain levels of boron in excess of 1.4 ppm which will cause severe problems for fruits, plants and other growing things, but waters containing boron levels up to 45 ppm can be consumed by humans with no problems. Because only potable water for human consumption, as opposed to irrigation water, is under consideration herein, the impact of the presence of boron is ignored. However, if boron reduction is required, both EDR and RO could reduce same by having the feedwater pH raised to 8.5 - 9.5.

2. As regards silica (SiO_2), the content of same in the Group 1 through 3 waters is such as to significantly limit the level of recovery of product water much more for the RO process than for the EDR process. The Group 4 waters contain much lower levels of (SiO_2), and for such waters its presence is not as adverse. Because high levels of product water recovery are essential to minimize brine disposal, most probably via injection wells, the impact of (SiO_2) in most of the groundwaters under consideration is to give a substantial comparative advantage to EDR.

3. The presence of calcium and bicarbonate in each "Group" of water at the "mean levels" indicated in the analyses can, to some extent, negatively impact both the RO and EDR processes. For RO, the presence of such levels of these constituents requires the feeding of sulfuric acid to the feedwater in order to control the level of $CaCo_3$ scaling in the RO brine. In the case of EDR, with such levels of these constituents in the feedwater, their impact is to necessitate an increase in electrical power in order to maintain higher water recovery levels.

In summary, both Alternatives A and B should be eliminated from further consideration on the grounds of technical feasibility, whereas Alternative C and D, namely EDR and RO, should be carried forward to Step 2. As regards rank, EDR appears to have an advantage over RO, primarily because of the impact of SiO_2.

Energy Forms

At the outset it should be noted that both the EDR and RO processes use electrical power as their energy source. Accordingly, in evaluating the comparative technical feasibility associated with the three energy forms, namely E(B), E(G), and E(P), the two important criteria are (a) the magnitude of the source of energy insofar as its ability to power a sizable EDR or RO plant and (b) the state of the technology associated with the transformation of each energy form into electrical power utilizing commercially available equipment. As regards the magnitude of the sources, this information is presented earlier in the Section under the heading Order-of-Magnitude Projected Quantity Ranges, and the evaluation for each form is presented as follows:

E(B) - Based on the above mentioned projections, the quantities available from E(B) are more than adequate, although higher temperatures would be more desirable. As regards the status of the technology, our one source of available literature[1] suggests that both the Kalina Cycle System 12 and the Cascade Rankine Cycle may be on the verge of commercial utilization for geothermal power generation, but that there are still some unknowns.

E(G) - Again, based on the above mentioned projections, the quantities of entrained natural gas are more than adequate. As regards the state of the technology, the use of gas turbine generators such as those built by Stewart & Stevenson is very well established to provide an efficient conversion to electrical power.

E(P) - Based on the above mentioned projections, the hydraulic energy available via a Pelton Wheel arrangement is significant, but probably not adequate to serve as the sole source of energy production. This arrangement should, therefore, be utilized as a supplementary rather than predominant, energy form. As regards the status of the technology, based on information received from Canyon Industries[2], the magnitude of the energy source is sufficient to be incorporated into a commercially available Geopressured hydroelectric project, using a Pelton-type turbine. However, a number of uncertainties including flashing and cavitation, i.e. related primarily to the chemical makeup of the Geopressured fluid, require further study.

In summary E(G) should be relied on as the predominant and definitely workable energy form to power a significantly sized desalination plant, and its use easily merits the highest ranking from the perspective of technical feasibility. In contrast, at the present time, consideration should be given to the use of E(B) and E(P) as sources supplementary to E(G) until specific technical uncertainties have been resolved.

Step 2 - Economic Feasibility

Process Types

Alternatives C and D - As in the case of technical feasibility, the primary basis for a comparison of economic feasibility between EDR and RO, as applied to the Group 1-4 brackish ground waters from relatively shallow aquifers is the aforementioned preliminary evaluation prepared by Mr. Eugene Reahl of Ionics, Inc., and enclosed herein as Appendix G. Pages 3-6 of the evaluation provide information comparing EDR with RO from the prespective of feedwater requirements in relation to product water (i.e. percent water recovery) and also the brine streams for the Group 1-4 waters.

The remaining pages of the evaluation are devoted to a comparison between the capital and O&M costs and energy requirements for a 1 MGD RO based system and those for a comparably sized EDR based system for each Group of waters. A review of the comparative costs data indicates relatively insignificant cost differentials and energy requirements as among the four Groups. Accordingly, since the Group 1 waters appear to be the most prevalent in the study area and Mr. Reahl's evaluation provides the most detail for this Group, a summary of the comparative economic evaluation for this Group, based on an assumed cost of $0.08/KWH for electrical power, is presented as follows:

	RO Based System (with blend)	EDR Based System (no blend)
Capital Cost per 1 MGD module of product water	$665,000	$940,000
O&M costs/ 1000 gallons of 500 ppm product water	$0.50	$0.563
Electrical Energy Consumption		
a. KWHr/1000 gallon product water	3.4	4.4
b. KWHr/day/ 1 mgd product water	3400	4400

Based on this comparative data the economic evaluation definitely favors the RO over the EDR system, in part because the use of blending in the RO system implies a smaller plant to yield the same amount of product water. However, as stressed in Mr. Reahl's comments and footnotes, the cost projections do not include the capital and O&M costs and associated energy requirements for the raw water wells, piping to desalter, brine transfer to deep injection wells nor the deep injection wells themselves. Mr. Reahl's comments also stress that the impact of adding these components to the evaluation would serve to narrow or possibly eliminate the cost differentials as between the RO and EDR alternatives.

In summary, in view of the potential of narrowing or eliminating the cost differential, coupled with the previously established technical feasibility advantages to EDR, it is appropriate to carry both the RO and EDR alternatives forward to Step 3 - Pro Forma Analysis.

Energy Forms

Because of the aforementioned limitations on the application of the E(B) and E(P) energy forms, coupled with only a limited amount of available information regarding the economics associated with these forms, a detailed comparative analysis of these three alternatives is simply not merited nor accomplishable at this time. Instead, outlined below are very order-of-magnitude projections of representative costs in terms of $1/KW, for applications associated with these three forms, along with an indication of the sources of information from which they were calculated. Such projections ar presented as follows:

Energy Form	Application	Source of Information	Order-of-Magnitude of Cost +
E(B)	Kalina-Cycle System 12	See note (1) on page _	$1572/KW
E(B)	Cascade Rankine Cycle	See note (1) on page _	$2871/KW
E(G)	Gas Turbine Generators (3MW)	Stewart and Stevenson Data	600/KW
E(P)	Impulse (Pelton) type turbine with induction type generator and controls	See note (2) on page _	$ 240/KW
E(G)	Conventional Thermoelectric	Published Literature	$1200 - 2000/KW (as a comparison)

It should be noted that all of the projected cost figures presented above are exclusive of the cost of the GP/GT well and appurtenances.

In summary, notwithstanding the apparent substantial comparative economic advantage of the application of E(P) over E(G), only the application of E(G) is to be carried forward into Step 3 - Proforma Analysis because of (a) the much greater quantities and (b) the certainty of its technical application. Notwithstanding, based upon the comparative cost information above, it seems very worthwhile to further investigate the application of E(P) to aid in reducing the net cos of on-site power generation in an operating complex. This aspect definitely merits a continuation of the present effort.

Three different forms of GP/GT energy are available from the resources described above, specifically, the following:

1. Thermal energy available from the heat content of the hot brine, hereinafter referred to as E (b)
2. Thermal energy available from the heat content of the entrained natural gas, hereinafter referred to as E(g), and
3. Hydraulic energy available from the wellhead pressure, hereinafter referred to as E(p).

Order of magnitude projections of the quantities of the GP/GT energy available from these three forms, based on three wells, one drilled into each of the three sands presented above, and expressed in terms of ranges of British Thermal Units per hour (BTUs per hour), Horsepower, (HP) and Kilowatts (KW), are presented as follows:

Order of Magnitude Projected Quantity Ranges[1]

	BTU's/Hr x 10^3			Horsepower			Kilowatts		
Energy Form	East Sand	Bond Sand	Marks Sand	East Sand	Bond Sand	Marks Sand	East Sand	Bond Sand	Marks Sand
E(B)	36,488	34,298-36,342	20,615-21,528	14,325	13,466-14,268	8,094-8,452	10,691	10,050-10,648	6,038 6,305
E(G)	10,104	9,261-10,104	4,630-5,051	3,968	3,637-3,968	1,819-1,985	2,960	2,713-2,960	1,438-1,480
E(P)	825	694 735	417-435	364	306-324	184-192	272	228-242	137-143

The quantity ranges presented above are applicable to the situation wherein only one GP/GT well is completed in each of the three producing sand zones. The impact of multiple-well completions, in each of the sand zones, on the range in values of the various parameters is illustrated in Figures 10-15 of Part B of Section I, and several charts illustrating the 15-year cumulative production for each sand zone are enclosed as Figures 16-21. In general, it can be stated that, while the aggregate quantity values of the various parameters significantly increase with the number of wells, the unit productivity of any given well declines significantly over time. Moveover, very detailed benefit/cost analyses would be required to determine the optimal number and spacing of wells, the comparative advantages and disadvantages of centralized versus decentralized desalination plants, etc. Because the preparation of such analyses is beyond the scope of this present study, all further discussion and data will be focussed on the quantity values of the various parameters associated with a single GP/GT well.

Notes: (1) Please refer to Appendix E for Support Calculations.

Section IIID - Pro-Forma Economics

for Best Suited Process(es)

Preliminary pro-forma economics comparing the EDR and RO processes for an assumed 5 mgd plant installation using mildly to moderately shallow groundwaters as feedwater sources and purchasing electrical power from the utility grid at an assumed cost of $.07/KWH, have been prepared previously and were included as a part of Section IIIA of this Report.

During the period of time between the preparation of the above described pro-forma economics and the present, several important advances in our level of knowledge have occurred by virtue of our work. These are summarized as follows:

1. We have quantified the projected magnitude of energy, particularly E(G) associated with a single GP/GT well as being in the range of about 3 megawatts (MW), and have tentatively concluded that this amount of energy is more than sufficient to power a 5mgd desalination plant using either the RO or EDR process, and including the power requirements associated with the well field, etc.

2. Based on the previous work by R.W. Harden, we have determined that, for the Group 1 waters, there is a sustainable supply of at least 5 mgd.

3. We have obtained much additional information regarding the quality parameters of the Group 1-4 waters.

By virtue of these advances, we are now able to provide still preliminary, but much more refined, pro-forma estimates comparing EDR with RO and, most importantly, quantifying the impact, in terms of potential co[illegible] savings to the total water cost, which will be derived from installation and operation of a GP/GT well a[illegible] appurtenances, as opposed to purchasing electric power from the utility grid, as the method of powering the desalination plant complex.

With this background in mind, the content of this Section III-D consists of the following:

Exhibit IIID-1 -	Calculation of the projected order-of-magnitude units cost of electrical power produced from the E(G) component of a GP/GT well drilled into the East Sand or the Bond Sand. Cost expressed in $/KW Hr.
Exhibit IIID-2 -	Assumed input data for pro-forma economic comparisons of EDR versus RO(3)
Exhibit IIID-3 -	Pro-forma calculations for EDR using GP/GT power (3)
Exhibit IIID-4 -	Pro-forma calculations for RO using GP/GT power(3)
Exhibit IIID-5 -	Comparison of purchased power costs versus on-site GP/GT power generation

Note: (1) Based on a report entitled Kalina Cycle System 12 and Cascade Rankine Cycle for Geothermal Power Generation - preliminary design and cost comparison prepared for Exergy Inc. by the Calpine Corp.

(2) A copy of this information is enclosed as Appendix H.

(3) Using the same format as utilized previously in Section IIIA.

Exhibit IIID-1

Calculation of the Projected Order-of-Magnitude Unit Cost of Electrical Power Produced From the E(G) Component of a GP/GT Well Drilled Into the East Sand or the Bond Sand Cost Expressed in $/KWHR

A. Projected Annual Costs

1. Determination of Projected Capital Cost[1] **Item**	**Projected Cost**
a. Drill and complete GP/GT well to depth of 10,000 ft +/-	$1,350,000*
b. Separator and other surface equipment	350,000
c. Brine disposal well (3000 feet deep)	300,000
d. Gas gathering line (10,000 ft)	25,000
e. 3 MW Gas Generator and Interconnection[2]	1,900,000
f. Generator Synchronizing Switchgear (2)	150,000
Subtotal	$4,075,000
+ allowance for engineering & contingencies (10%)	408,000
Total Projected Capital costs	$4,483,000

2. **Annualization of Projected Capital Costs** - Assuming 15 year loan at 8% interest, Annual Debt Service = $114,672/MM x 4.483 MM = $514,075

3. Annual Maintenance and Operation Cost (1)

a. GP/GT Well and appurtenances	$175,000	
b. Gas turbine Generator (1% of capital cost)	20,000	195,000

4. Annual GP/GT Lease Payments (400 acres x $125/acre)	50,000
Total Projected Annual Cost=	$ 759,075

B. Projected Annual Production of Electrical Power =
0.9 x 3000 KW x 365 days x 24 hours/day = 23,652,000 kw hr.

C. Projected Unit Cost of Electrical Power Production = $759,075/year ÷ 23,652,000 kw/hr/yr = $0.03209/kw hr
Round to $0.032/KWHr.

Notes: (1) Projected costs based on detailed estimates prepared for USDOE Grant
(2) Based on budgeting data provided by Stewart & Stevensen and Siemens Energy & Automation.

* If an existing GP/GT well, capped off, may be re-entered, the cost thereof would be $350,000, reducing total capital costs to $3,383,000, annual debt service to $387,935 and hence, total cost of electrical power from $0.032/KWHr to $0.0267/KWHr. Evidently, re-entry is critical to the lowest possible electricity cost.

Exhibit IIID-2

Assumed Input Data for Pro-forma Economic Comparison of EDR versus RO

Feedwater:	Rio Grande Ground Water Reservoir
General Geographical Area:	McAllen - Harlingen
Plant Capacity:	5.0 MGD of Product Water
Current Building Cost Index:	3,014
Current Labor Cost Index:	4,720
Interest Rate:	8.0%
Amortization Period:	15 years
Cost of Electric Power from Onsite Power Generation:	$.032/KW.HR.[1]
Length of Feedwater Pipeline:	2 miles
Elevation of Desalt Plant:	57 feet
Elevation of Well Field:	57 feet
Well Pumping Depth Feedwater Supply:	220 feet
Well Depth - Brine Disposal:	3,000 feet
Land Cost:	$3,000/ac.
Right-of-Way Cost:	$5,000/ac.
Water Analysis: [2]	
Temperature:	24 degrees C.
Net Evaporation Rate:	40 in./yr.
Goal:	Product water of $<$500ppm TDS

(1) Via GP/GT well and appurtenances. Refer to Exhibit IIID-1.

(2) Refer to the enclosed Table 1. Mean values for Group 1 waters used for proforma. Also, review of Infrequent Constituent reports indicates that concentration of iron, manganese, etc. are insignificant.

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EXHIBIT IIID-3

PRO-FORMA CALCULATIONS FOR ELECTRODIALYSIS REVERSAL PROCESS (EDR)

USING GP/GT POWER @ $0.032/KWHR

Cost Elements		Capital Costs/($x1000)	Annual Costs/($x1000)	Water Costs, $/1,000 gal.
Capital Costs				
1.	Plant and Equipment[2]	$5,640	$646.75	$0.392
2.	Feedwater Pretreatment	n.r[1]	n.r[1]	n.r.[1]
3.	Feedwater Supply[3]	1,600	183.48	0.111
4.	Water Transmission	780	89.44	0.054
5.	Brine Disposal	1,096	125.68	0.076
	Total Capital Costs	$ 9,116.00	$ 1,045.35	$ 0.633

Operation and Maintenance Costs			
6.	Operating and Maintenance Labor		$/1,000 gal.
	a.	Plant and Equipment[2]	0.052
	b.	Feedwater Pretreatment	0
	c.	Feedwater Supply	0.026
	d.	Water Transmission	n.r.[1]
	e.	Brine Disposal	0.22
		Total Operating and Maintenance Labor	$ 0.298
7.	Other Operation and Maintenance Costs		
	a.	Payroll Extras (15% of 6a)	0.008
	b.	General and Administrative Overhead (30% of 6a + 7a)	0.018
	c.	Supplies and Maintenance Materials	0.030
	d.	Membrane Assembly or Replacement Tubing[2]	0.16
	e.	Chemicals[2]	0.0225
	f.	Fuel or Steam	n.r[1]
	g.	Electric Power	0
		Plant and Equipment[2]	.1264
		Feedwater Supply	.0465
		Water Transmission	n.r[1]
		Total Other Operation and Maintenance Costs	$ 0.4114
		Total Operation and Maintenance Costs	$ .7094
		Total Water Cost (Total Capital Plus O. & M. Costs)	$ 1.3424

EXHIBIT IIID-4

PRO-FORMA CALCULATIONS FOR REVERSE OSMOSIS PROCESS (RO)

USING GP/FT POWER @ $0.32/KWHR

Cost Elements		Capital Costs/($x1000)	Annual Costs/($x1000)	Water Costs, $/1,000 gal.
Capital Costs				
1.	Plant and Equipment(2)	$3,990	$457.54	$0.2773
2.	Feedwater Pretreatment	0	0	0
3.	Feedwater Supply(3)	1,760	201.82	0.1223
4.	Water Transmission	820	94.03	0.0570
5.	Brine Disposal	1,279	146.67	0.0889
	Total Capital Costs	$ 7,849.0	$ 900.06	$ 0.5455
Operation and Maintenance Costs				
6.	Operating and Maintenance Labor			$/1,000 gal.
	a. Plant and Equipment(2)			0.060
	b. Feedwater Pretreatment			0
	c. Feedwater Supply			.029
	d. Water Transmission			n.r.(1)
	e. Brine Disposal			0.21
	Total Operating and Maintenance Labor			$ 0.299
7.	Other Operation and Maintenance Costs			
	a. Payroll Extras (15% of 6a)			0.009
	b. General and Administrative Overhead (30% of 6a + 7a)			0.021
	c. Supplies and Maintenance Materials			0.03
	d. Membrane Assembly or Replacement Tubing(2)			0.165
	e. Chemicals(2)			0.039
	f. Fuel or Steam			n.r(1)
	g. Electric Power			0
	Plant and Equipment(2)			0.104
	Feedwater Supply			0.051
	Water Transmission			n.r(1)
	Total Other Operation and Maintenance Costs			$ 0.419
	Total Operation and Maintenance Costs			$ .718
	Total Water Cost (Total Capital Plus O. & M. Costs)			$ 1.2635

(1) none required
(2) Based on recent information from Ionics, Inc., cost information includes effect of 80.5%/19.5% blending; therefore, actual plant size equal to 4 MGD, and a water recovery factor of 82.5%. A factor of 20% has been added to cover indirect capital costs comprised of interest during construction, engineering and contingencies. Also, a factor has been added for land cost. No 20% factor added for M&O related costs
(3) Based on a recent study by R.W. Harden Assoc. Total of 11 wells and a land cost factor added.

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Exhibit IIID-5

Comparison of Purchased Power Costs Versus On-Site GP/GT Power Generation

Information regarding the process electrical energy consumption involved in the RO and EDR process is provided on page 8 of the **preliminary evaluation** by Mr. Reahl of Ionics Inc. and, for the treatment of the Group I waters, is summarized as follows:

Process	Total KW HR/Day/1MGD Product Water
Reverse Osmosis (RO)	3220
EDR	3950

Comparable information for the well field pumping, which constitutes the other primary consumptive element of a desalination project using ground water as a source of feedwater, has previously been developed by the Desalting Manual used in the proformas for Exhibits C and D. Based on the calculations from that Manual, the consumption associated with the well fields for the RO and EDR process is estimated as follows:

Well Field	Total KW HR/Day/1MGD Product Water(1)
Reverse Osmosis (11 wells)	1568
EDR (10 wells)	1454

Based on a 5 MGD capacity plant complex operating 24 hrs/day and 330 day/year, and using the sum of the consumptive factors presented above (i.e. process + well field), the total KW Hrs. expended in a year from the RO and EDR facilities are estimated as follows:

RO = 4788 KW HR/Day/MGD x 5MGD x 330 Days/Year = 7,900,200 KW Hrs.
EDR = 5404 KW HR/Day/MGD x 5MGD x 330 Days/Year = 8,916,600 KW Hrs.

A comparison of these projected amounts to the total projected capability of the 3000 KW GP/GT powered complex, i.e., about 23.65 million KW HR/Year, indicates that the complex would easily have the capability to serve a 10 MGD desalting facility, either RO or EDR, as opposed to 5 MGD plants. Accordingly, estimates of the Projected annual savings in power cost to be derived from the use of onsite GP/GT power generation, as opposed to purchasing power rom the utility grid at an assumed rate of $0.07/KW HR, are presented as follows:

<u>Projected Annual Saving for 10 MGD Capacity RO Plant</u> = 15,800,400 KWHR/Yr. x $0.038/KWHR cost differential (i.e. $0.07 -0.032) = <u>$600,415</u>

<u>Projected Annual savings for 10 MGD Capacity EDR Plant</u> = 17,833,200 KWHR/Yr x $0.038/KWHR cost differential = $677,662

(1) Based on the relation that the power requirement is equal to the product of the TDH (total dynamic head, i.e., well depth + 100 feet) x a factor of .004 KWHR/ftTDH/1000 gallons.

Appendices

APPENDIX A

Appendix A

Preliminary Estimates of Well Field Development For A Brackish Groundwater Supply From The Gravel Zone in the Vicinity of Brownsville, Texas

Note: Information taken from a report entitled

Availability of Brackish Groundwater Near Brownsville, Texas

Prepared by R.W. Harden & Associates, Inc., Consulting Hydrologists & Geologists, Austin, Texas for Toyo Menka Kaisha, Ltd., (August 1990)

Areas of Application

The information developed in the Harden study was specifically focussed on a geographical area just to the Northeast of Brownsville. However, as stated in that Study, water in the gravel zone increases in mineralization from West to East, and the water quantity available from the gravel zone is dependent on location. Reference to Figure 4 of the Study, a copy of which is enclosed, generally indicates the following:

1. For TDS concentrations less than 5000 ppm, the well field would need to be located to the West of the Southern Pacific Rail Line and FM 1847.

2. For TDS concentrations less than 3000 ppm, the well field would need to be located to the West of the Missouri Pacific Rail Line and Highways 77 and 83.

Definition of Gravel Zone

That zone within the alluvial deposits at a depth of approximately 180 feet below ground level and typically containing coarse gravels of potential high water productivity.

Well Field Development

1. Based on available information, it is estimated that a 20-year sustainable yield of approximately 5 mgd can likely be developed from the gravel zone.

2. Pumping rates (yields) per well of 350 gpm are estimated, requiring an estimated 10 wells for a 5 mgd supply.

3. Wells should generally be spaced approximately 2000 to 2500 feet apart, making the length of the well field about 4 to 5 miles. Well depths should approximate 220 feet.

4. The capital cost of the well field is estimated to be approximately $1,500,000, or about $150,000 per well. These estimates include all costs for the construction by a reputable, experienced contractor of a production water well installation including pilot hole drilling, well construction, testing, pumps, motors, foundation, engineering, appropriate bonds, and with well efficiency and sand content guarantees. The estimated costs do not include property acquisition, prior test drilling, power lines, electrical controls, pipelines, right-of-way, or any special costs to discharge or dispose of mineralized water during construction or testing. To account for the fact that wells for brackish, rather than fresh, water are being developed, the costs of the pumping equipment incorporated into the well and well field costs presented above have been increased by 50%.

5. The next step in proceeding with a well field development of the gravel zone would be a test drilling program. This work would include drilling approximately 5 (five) test holes, geophysical logging, water sampling, water quality analysis, planning, inspection and evaluation. The estimated cost for such a program would be approximately $300,000.

APPENDIX B

Underground Injection Control Reference Manual

RAILROAD COMMISSION OF TEXAS

Lena Guerrero, Chairman
James E. (Jim) Nugent, Commissioner
Bob Krueger, Commissioner

Published By
Oil and Gas Division
David M. Garlick, Director

This Underground Injection Control Manual is for informational and instructional purposes only and is not to be regarded as a detailed study of underground injection practices and procedures.

The intent of this manual is to outline the basic compliance and reporting requirements to be met by operators engaged in underground injection operations. Operators should consult the appropriate rule for more specific or detailed information. The Underground Injection Control staff is available to answer questions and provide assistance.

The earth's crust is composed entirely of rock, which may be either porous or non-porous. Oil and gas are usually found in porous rocks which form a reservoir. Salt water, which occurs with the oil and gas in the reservoir, is produced along with the oil and gas. The salt water or produced water may be returned by fluid injection into the reservoir from which it originated for secondary and enhanced recovery operations, but also may be disposed of into porous rocks not productive of oil or gas.

The ideal fluid injection or disposal well is one utilizing a porous zone of relatively low or moderate pressures which is sealed above and below the porous zone by unbroken impermeable strata. The receiving zone must be permeable and of sufficient thickness and lateral dimensions to contain the volume of fluid to be injected without increasing injection pressure to the point that it will fracture the sealing layers of rock above and below the disposal zone. Fluid injection and disposal wells must be designed and operated to perform the specific job for which they were intended, which is to confine the injected fluids to the approved strata and to protect fresh water resources. Fresh water is the one natural resource without which life cannot be sustained. The objective of the Railroad Commission Underground Injection Control Program is to ensure that our surface and subsurface fresh water is free of pollution or contamination which could result from unsound installations and operations. Proper well completion, injection procedures, monitoring and care will ensure that quality fresh water sources will be available for all generations to come.

Federal and State Laws

Federal Requirements

The Safe Drinking Water Act makes specific provisions for protecting underground drinking water sources. The new federal law set up, for the first time, provisions for controlling underground injection practices. It is the intent of Congress that the states have the responsibility for primary enforcement of the Act.

Congress, during the formulation of the Safe Drinking Water Act in 1974, recognized the need for protection of underground drinking water sources from contamination from underground injection, and the need for effective state regulatory measures. Therefore, it directed the U. S. Environmental Protection Agency (EPA) to develop underground injection regulations with which to guide states in establishing their own programs. The Act provides that if a state does not adopt a program consistent with federal requirements, then the EPA must develop and implement the program in the state.

The main points which the EPA regulations sought to convey to the states were: (1) to identify underground sources of drinking water and define what constituted endangerment of these sources; (2) to direct the states to set up their own underground injection control programs to protect these drinking water sources; (3) to describe the requirements of such programs and permit systems; (4) to set forth procedures to assure enforcement of these requirements by the states or by the federal government if the states fail to do so; and (5) to list construction, permitting, operating, monitoring and reporting requirements for specific types of wells.

Underground Injection—What Is It?

Underground injection is the introduction of water, gas or other fluid into an underground stratum by injection down a well. It is a complex and costly technology; however, it is a very useful technique with many applications and has become a practical solution to some very difficult disposal and storage problems.

The production of oil and gas frequently is accompanied by salt water, and disposal of the salt water has always been somewhat of a problem. Underground injection has been used extensively to dispose of salt water and gradually, due largely to the enactment of environmental laws designed to protect surface waters from pollution, it came into favor for the disposal of industrial wastes as well.

Fluid injection wells are used for four major operations: (1) PRESSURE MAINTENANCE, to introduce a fluid into a producing formation to maintain underground pressures which would otherwise be reduced by virtue of the production of oil and/or gas; (2) CYCLING or RECYCLING, to introduce residue gas into a formation after liquefiable hydrocarbons have been extracted from gas produced from the formation; (3) SECONDARY RECOVERY operations, to introduce a fluid to decrease the viscosity of oil, reduce its surface tension, lighten its specific gravity, and/or to drive oil into producing wells, resulting in greater production of oil; and (4) TERTIARY RECOVERY operations, to introduce chemicals or energy as required for displacement and for the control of flow rate and flow pattern in the reservoir.

[NOTE: For federal income tax purposes, injection wells may be treated as part of production, and costs of drilling may be capitalized or deducted as intangibles. Ref: Burke and Bowhoy, "Income Taxation of Natural Resources", Sec. 14.13, and 15.21 (1981).]

There are approximately 54,000 injection/disposal wells in Texas which are associated with oil and gas production and are on the Railroad Commission computer system. As a result, information concerning permits, lease names or lease numbers, counties, and operators can be retrieved from the "system" instantaneously via system terminals.

On April 23, 1982, Texas became one of the first two states in the Nation to be granted "primary enforcement responsibility" by the EPA. (The other state was Louisiana.) The success of the program depends on how well you, as injection well operators, comply with the program requirements and how well we all communicate with each other. From experience, we know that many failures in compliance matters are actually failures to communicate. It is for that reason that this seminar was organized: to communicate with you and to explain to you what the program involves and what is expected of you. While our objective is to properly fulfill federal and state mandates, our aim is to provide you with the information and assistance which will ease your problems.

Background

The Commission's jurisdiction and responsibilities in petroleum regulation have increased steadily through the years. Today, its broad authority over oil and gas production is derived from the *Texas Natural Resources Code* and from Chapters 26, 27, and 29 of the *Texas Water Code*. The Commission has been active in the control of underground injection activities for more than forty years. The first permit to inject water into a productive reservoir was issued in 1938.

On January 2, 1980, the Underground Injection Control (UIC) Section of the Oil and Gas Division was created to administer a program consistent with state and federal law, including: oversight of the injection, disposal, and hydrocarbon storage well permits already issued; processing and issuing of new permit applications; and coordination with EPA and other federal and state agencies in a concerted program to protect fresh water in Texas.

The State UIC Program in Texas is jointly enforced by two agencies: the Texas Water Commission and the Railroad Commission. The Railroad Commission has jurisdiction over Class II wells injecting "oil and gas waste," a term that is defined in Chapter 27 of the *Texas Water Code* to include the disposal of salt water and other produced fluids, disposal associated with the underground storage of hydrocarbons, and injection arising out of, or incidental to, the operation of gasoline plants, natural gas processing plants, and pressure maintenance or repressuring plants. The Commission also has authority over Class II wells used for enhanced recovery of oil and gas (§91.101, *Natural Resources Code*) and underground hydrocarbon storage wells (§91.201 et.seq., *Natural Resources Code*).

The 69th Session of the Texas Legislature amended the Texas Injection Well Act (Texas Water Code - Chapter 27) to transfer brine mining injection wells from the Texas Water Commission to the Railroad Commission effective September 1, 1985. Brine mining injection operations produce brine by injecting fresh water, dissolving salt strata, and producing the brine, usually through the same well. This type of well is classified by EPA as a Class III well, or one which injects for the extraction of minerals.

Chapter II

Summary of Injection Control Rules

Underground injection procedures governing operations in Texas are prescribed by Statewide Rules 9, 46, and 74, Chapter 27 of the *Texas Water Code*, and Title 3 of the *Texas Natural Resources Code*. Highlights of these directives are outlined below; however, it is essential that individuals or entities engaged in underground injection operations be thoroughly familiar and comply with these requirements on a timely basis. A copy of all Statewide Rules may be procured by contacting the Secretary, Railroad Commission of Texas, Capitol Station, P.O. Box 12967, Austin, Texas 78711.

The *Statewide Rules* applicable to disposal wells, injection wells, and hydrocarbon storage wells are Rules 9, 46, and 74, respectively. These rules are summarized below; however, the complete Rules 9, 46, and 74 and applicable forms with instructions may be found in Appendixes B and C, respectively, in this report.

The Commission has adopted Statewide Rule 81 concerning brine mining injection wells. Rule 81 will become effective upon approval by EPA of the Commission's regulatory program for these wells.

Rule 9—Disposal Wells

Information regarding the disposal of salt water, or other oil and gas waste, by injection into a porous formation not productive of oil, gas, or geothermal resources is outlined in Statewide Rule 9. Other matters contained in the Rule consist of filing of application (Form W-14); notice and opportunity for hearings; protested applications; geological requirements; and special equipment requirements.

The Rule also outlines instructions regarding records maintenance, and monitoring and reporting, testing and plugging disposal wells. Further, it outlines instructions regarding penalties to be imposed for noncompliance with the Rule. Permit revocation may result as a consequence of noncompliance.

Rule 46— Fluid Injection into Productive Reservoirs

Statewide Rule 46 governs applications for the permitting of fluid injection into reservoirs productive of oil, gas or geothermal resources. Application for a permit is on Railroad Commission Forms H-1 and H-1A. The Rule also contains matters regarding: the application review; notice and opportunity for hearing; protested applications; and modification, suspension or termination of permits for one or more of several causes.

Included in Statewide Rule 46 are requirements regarding: casing and cementing (in accordance with Statewide Rule 13); special equipment (tubing and packer, pressure observation valves); records maintenance; monitoring and reporting; testing; plugging; and penalties for violations of the Rule.

Rule 74—Underground Hydrocarbon Storage

This Rule prescribes the methodology applicable to the permitting of an underground hydrocarbon storage facility. It outlines the procedures for: filing of applications (Form H-4); technical requirements pertinent to the storage facility; notice of and opportunity for hearing; transfer of permits; and subsequent Commission action.

Rule 74 also prescribes the system for monitoring and reporting, testing, plugging of the well, and the penalties to be assessed for violations of the Rule.

Brine Mining Injection Wells

Pending implementation of Rule 81, new wells will be considered for temporary injection permits. A drilling permit, a requirement of Statewide Rule 5, is necessary before a brine mining injection well is drilled. Drilling, casing, and cementing must be in accordance with Rule 13. Specific instructions in regard to applying for a brine mining injection well permit may be obtained from Underground Injection Control in Austin.

General

In general, Rules 9, 46, and 74 are basically the same, except for the type of well. In other words, the application procedures, permitting, monitoring and reporting, etc., all read about the same except that each Rule pertains to a different type of operation.

Therefore, a general summary covering all facets of Rules 9, 46, and 74 is provided below:

I. Differences Between Disposal Wells, Injection Wells and Hydrocarbon Storage Wells

A. Disposal Wells

1. Used to dispose of salt water or other waste by injection into porous formation not productive of oil, gas, or geothermal resources

2. Regulated by Statewide Rule 9

3. Subject to special surface facility requirements if a commercial disposal well

B. Injection Wells

1. Used to inject water (salt or fresh), steam, gas, or other energy sources into porous reservoirs productive of oil, gas, or geothermal resources

2. Normally used for secondary or enhanced recovery projects

3. Regulated by Statewide Rule 46

4. Special requirements if fresh water injection proposed

C. Hydrocarbon Storage Wells

1. Used to inject and store LPG, crude oil, and other products in underground salt domes and salt formations

2. Regulated by Statewide Rule 74

II. Summary of Requirements for Statewide Rules 9, 46, and 74

A. Application

1. File original with Austin Office

2. Enclose $100 per well fee with a Rule 9 or 46 application

3. Mail copy to District Office

B. Notice

1. Must be furnished to:

a. surface owner

b. offset operators

c. county and city clerks

2. Must be published in newspaper of general circulation for that county (one publication for a Rule 9 or 46 application; three consecutive publications for a Rule 74 application)

C. Letter from Texas Water Commission

D. Area of Review

1. Operator must show that all abandoned wells within 1/4-mile radius have been plugged in a manner that will prevent movement of fluids from one zone to another or:

2. Operator must show proof that lesser area will be affected by injection

E. Casing and Cementing (to be done in compliance with Rule 13)

F. Special Equipment

1. Tubing and packer: All newly drilled or converted disposal and injection wells to be equipped with tubing and packer. All existing disposal wells shall have been equipped with tubing and packer by January 1, 1984

2. Observation valves to be on tubing and each annulus

G. Exceptions to Special Equipment

1. Requires written request

2. $50 fee

H. Completion Forms W-2 or G-1 (to be filed within 30 days)

I. Monitoring and Recording of Injection Pressure and Volumes

1. Injection pressures and volumes to be monitored and records kept

2. Pressure changes indicative of failure to be reported to District Office within 24 hours

3. Annual report to be filed on proper form (Form H-10)

J. Testing of Casing

1. Must be done:

a. Upon completion, prior to beginning injection operations

b. After workover

c. At least once every five (5) years by rule or more frequently if required by permit

2. Testing Criteria:

a. Must be tested to maximum injection pressure or 500 psig, whichever is less, but not less than 200 psig

b. Successful test—a pressure drop of 10 percent or less under the condition that the pressure stabilizes and is maintained and monitored for a minimum of 30 minutes after stabilizing

3. File Form H-5

4. Optional monitoring of tubing/casing annulus pressure reported on Form H-10 may be accepted in lieu of 5 - year pressure testing if the reported information indicates mechanical integrity

5. A temperature or radioactive tracer survey may be used as an alternative to pressure testing a well not equipped with tubing and packer

a. Requires prior written approval unless required as a permit condition

b. Survey must cover interval from surface to below the injection zone

c. Radioactive tracer survey must be performed at maximum operating injection rate and pressure, unless the Commission approves otherwise.

d. Temperature survey must be performed after a continuous injection period of 24 hours followed by an appropriate shut-in period.

K. Subsequent Commission Action (permit may be modified, suspended, or terminated by the Commission for just cause)

L. Transfer (permit may be transferred from one operator to another only after 15-day notice period prior to date of transfer)

M. Plugging (must be done in compliance with Statewide Rule 14)

III. Inspection of Disposal and Injection Wells by RRC Personnel

A. Surface Pollution Check

1. For leaks in equipment or lines and valves

2. For salt water or oil spills around well

B. Observation Valve Check (for serviceable condition)

C. Correct Sign Check

D. Pressure Check

1. Tubing (injection pressure): Should be compared to permitted injection pressure for this well

2. Casing pressure (tubing/casing annulus): Corresponding tubing and casing pressures during injection and shut down may indicate communication between tubing and casing

3. Bradenhead (surface pipe pressure): Pressure on surface casing could indicate migration of fluids through wellbore annulus from lower zones or casing leak

E. Proration Schedule Check (to ensure proper status; if well is not listed or if incorrect status is shown on proration schedule, well may not be approved for injection or disposal)

F. Check for compliance with special surface facility requirements if a commercial disposal well

IV. Special "Down Hole" Surveys

Special "Down Hole" surveys must be approved in advance by UIC in Austin, for a specific wellbore unless they are expressly required by the injection/disposal authority.

A. Radioactive Tracer Survey: Fluid is pumped into well at the maximum permitted injection pressure. Radioactive Iodine is ejected into the flow at various depths, from the ground surface through the injection perforations, and is measured as it flows down the wellbore. If any radioactive material leaves the wellbore, the measuring tool will lose contact with it, or record a "hot spot" where the radioactive material is leaking from the wellbore.

B. Spinner or Flow Meter Survey: Fluid is pumped into the well at a fixed rate. A flow measuring tool is used to measure the volume of fluid flow across the wellbore. A decrease of flow volume usually indicates a casing leak or perforations. This method is usually used in conjunction with other tools due to a lack of sensitivity.

C. Differential Temperature Log: After normal injection activity, a water injection well is shut-in for twelve (12) to eighteen (18) hours, a gas injection well is shut-in for one (1) to four (4) hours. During the logging process, the geothermal gradient, and the rate at which that gradient is changing (differential), are recorded from ground surface through the injection perforations. Abrupt shifts in temperature readings indicate possible wellbore integrity problems and will need further testing to prove integrity and allow continued injection activity.

All applications for Class II wells come to the UIC section where they are evaluated and processed. If a hearing is requested or required, the UIC Section requests that a hearing be scheduled; the Commission provides notice to all interested persons. After the hearing, the examiner recommends final action by the Commissioners who decide if the permit should be issued. If no protests or complaints are received on an application, the Director of Underground Injection Control may administratively approve the application.

Conditions Generally Applicable

Under Rules 9, 46, and 74 of the Statewide Rules, operators of injection and disposal wells associated with oil and gas exploration, drilling, production, transportation, or underground storage must obtain a permit from the Commission. Thus, all Class II wells in Texas must be approved by the Commission before injection operations can legally begin. Pursuant to Rules 9, 46, and 74, and the applicable application forms, such permits will only be approved if the applicant satisfies his burden of showing that all reasonable efforts have been made to assure the protection of fresh water.

An applicant for a Class II well is required to certify that he is authorized to submit the application on behalf of the operator and that the information provided is true and correct, under penalties prescribed in §91.143 of the *Texas Natural Resources Code*. Commission forms also require the applicant to state his title and give the operator's name, address, and operator number. The operator number is prescribed after the Organization Report (Form P-5) is filed. The Organization Report is the initial and principal instrument required of organizations doing business before the Commission. It requires the operator to specify the nature of his business and the names and addresses of the corporate officers and partners, as well as other pertinent information.

Once a permit is granted, the operator is bound by all applicable Commission rules and permit conditions by virtue of accepting the right to operate pursuant to the conditional permit. It is necessary to examine permit conditions, as well as Statewide Rules, in order to ascertain what actions are necessary for compliance. Further, the statutes provide that the Commission may include other permit conditions to protect fresh water from pollution.

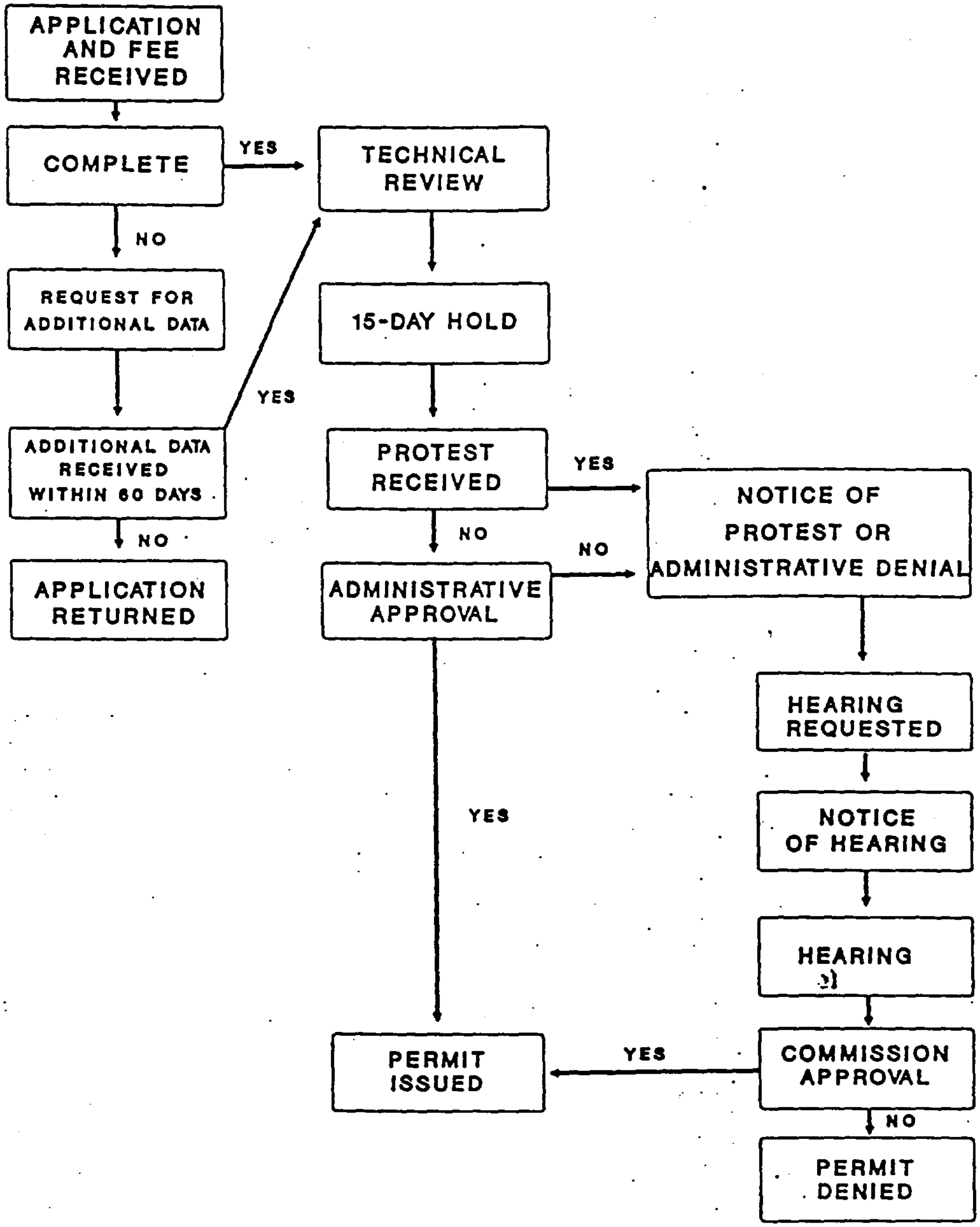
Transfer and Modification of Permit

A Class II permit may be transferred only after notice to the Commission. Written notice of intent to transfer the permit must be submitted to the Commission by filing Form P-4 at least 15 days prior to the date the operator plans for the transfer to occur. Permit transfer will not occur until the Form P-4 has been approved by the Commission. A Class II permit may be terminated, revoked, or modified for just cause such as a substantial change in well operation, pollution of fresh water, substantial violations of the permit conditions or rules, misrepresentation, or other evidence indicating that injected fluids are escaping from the authorized zone. Notice and opportunity for hearing are provided in the same manner as in the initial permit process.

Project Permits

Project permits may be granted for fluid injection operations for the enhanced recovery of

FLOWCHART: INJECTION/DISPOSAL WELL APPLICATIONS



underground hydrocarbon storage facility wells. Project permits provide that new wells drilled or converted after the project was originally approved must be permitted by the Commission.

Temporary Authorities

Where an emergency or other good cause exists, a temporary authority may be issued on an expedited basis if, in the Director's judgement, the operation is not likely to affect other parties or cause pollution of fresh water. A temporary authority so issued will be suspended if a protest is received in accordance with Statewide Rules prior to the issuance of a regular permit.

Geological Requirements

The geological formation or authorized strata must be isolated from overlying or underlying strata that contain oil, gas, geothermal, water or other resources by sufficient thickness of relatively impermeable strata. A sufficient thickness of relatively impermeable strata is generally considered to consist of an accumulative total of 250 feet of clay or shale. Variances in the total thickness required to effectively separate are considered on the basis of continuity of strata, thickness of individual stratum and the presence of relatively impermeable strata other than clay or shale. No Class II well will be permitted where faults, fractures, structure or other geologic factors indicate that isolation of the authorized zone is jeopardized. The operator must submit adequate geological information to show compliance with this requirement.

Casing and Cementing

Class II wells must be cased and cemented in accordance with Rule 13 to prevent the movement of fluids into sources of fresh water. Rule 13 requires that surface casing be set and cemented so as to protect fresh water strata, as defined by the Texas Water Commission. Cementing is required to be circulated to the surface by the pump and plug method, and the specifications for cement quality and casing integrity set out in the Rule must be met.

Wells that are converted from producers to injection into the same productive formation meet UIC cementing requirements if they were completed in compliance with Rule 13.

Wells that are converted to disposal into a formation above the productive formation must meet UIC criteria of adequate cement to confine the injected fluids. These criteria are 100 feet of bonded cement as determined from a bond log, 250 feet of cement as evidenced by a temperature survey, or 400 to 600 feet of cement determined by slurry yield calculation. The flexibility in annular footage allows for consideration of the type of cement used and the characteristics of the formation.

Area of Review

Statewide Rules require that Class II disposal and injection well operators must examine the data of record for wells that penetrate the proposed injection zone within a one quarter (¼) mile radius of the proposed well to determine if all abandoned wells have been plugged in a manner that will prevent the movement of fluids into strata other than the authorized zone. Applicants for new permits must submit a map showing the location of all wells of public record within ¼ mile as part of their permit application. For those wells that penetrate the top of the injection zone, the applicant must attach a tabulation of the wells showing the dates the wells were drilled and the present status of the wells. Alternatively, if the applicant can show, by computation, that a lesser area will be affected by pressure increases, then the lesser area may be used in lieu of the fixed radius. In cases where the Director has knowledge of geologic, hydrologic, or engineering conditions specific to a given operation which ensure that wells within the area of review will not serve as conduits for migration of fluids into fresh water resources, a permit may be issued without requiring corrective action on wells within the area of review. Under this situation, the Director may waive certain data submission requirements. No permit will be issued, however, where the information submitted indicates that fresh water sources will be endangered unless permit conditions require appropriate corrective action in the area.

Tubing and Packer Requirements

On all newly drilled or converted disposal and injection wells, injection must be through tubing set on a packer unless an exception is granted by the Director for good cause.

Operating Requirements

Maximum injection pressure limitations have been part of the Commission's permitting program for many years and will continue to be required as a condition of each Class II permit issued. Pressure limitations are established to provide adequate assurance that injection will not initiate fractures in the confining zones.

Monitoring and Reporting

The operator of each Class II well is required by the *Statewide Rules* and by each new permit to monitor the injection pressure and volume on a monthly basis and to report the results annually on the prescribed form (Form H-10). For Class II wells, except hydrocarbon storage facilities, any downhole problem must be reported to the appropriate district office within twenty-four (24) hours and confirmed in writing within five (5) working days. Operators of hydrocarbon storage facilities must report problems to the appropriate district office immediately and must confirm this report in writing within five (5) days. An automatic data processing system was developed for the monitoring and annual reports.

Mechanical Integrity

The *Statewide Rules* require that all Class II wells be pressure-tested at least once every five (5) years to determine if leaks exist in the casing, tubing, or packer. Permits require pressure tests prior to beginning injection operations and after each workover. Some permits require annual pressure tests. The appropriate district office must be notified before conducting the pressure test to allow a Commission representative to witness the test. The operator must then file a record of this test with the district office (Form H-5). As an alternative to this pressure-testing, the operator may monitor the casing-tubing annulus pressure and report the results annually to demonstrate that no additional pressure-testing is needed. Also, an exception to testing may be granted upon demonstration to the Director of a viable alternative monitoring program. Mechanical integrity testing must also be performed, pursuant to Rule 74, for storage wells.

Completion Reports

A Completion Report (Form W-2 or G-1) must be filed with the appropriate district office within thirty (30) days of completion or conversion to disposal, injection, or underground hydrocarbon storage operations to reflect the new or current completion.

Exceptions

Tubing and packer must be set and pressure valves provided on disposal and injection wells, and wells must be pressure-tested at least once every five (5) years. The Statewide Rules provide that the Director may grant exceptions to any of these provisions upon proof of good cause.

Rule 13 requires that surface casing be cemented by the pump and plug method so as to fill the annular space to the surface. The surface casing is to be set to the depth recommended by the Texas Water Commission to protect fresh water strata or by special field rules establishing the depth to set surface casing. The Commission may grant exceptions to this requirement and authorize use of the multistage completion process. Multistage cementing is not normally authorized, in lieu of setting surface casing, as a means to protect fresh water strata for wells drilled expressly as Class II wells.

Plugging and Abandonment

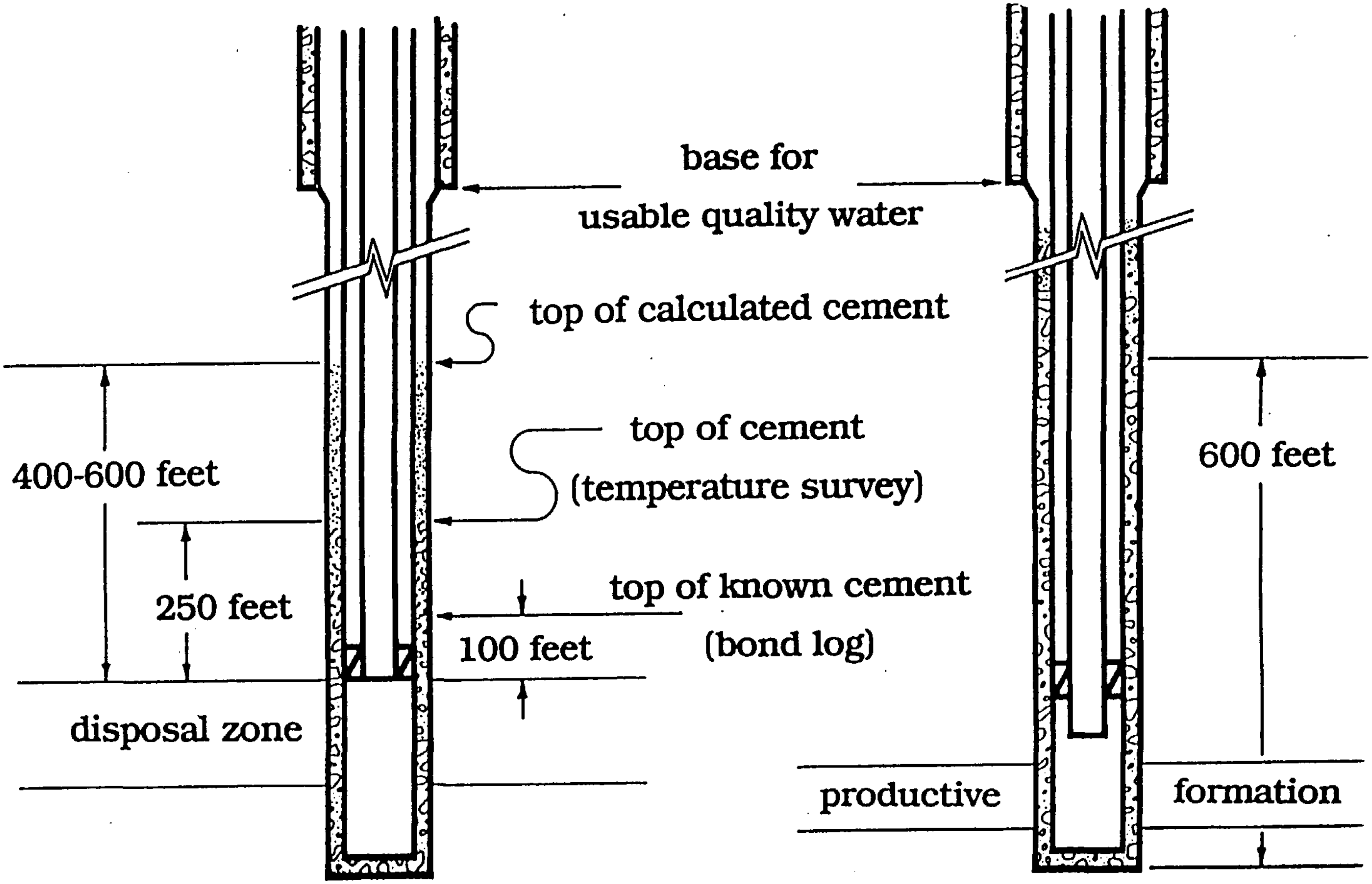
All Class II wells are required to be plugged upon abandonment, in accordance with Rule 14. Notice of Intention to Plug and Abandon (Form W-3A) must be filed with the appropriate district office and received five (5) days prior to the beginning of plugging operations. Plugging operations shall not begin prior to the date shown on the Form W-3A unless authorized by the District Director.

The general requirements of Rule 14 must be complied with in plugging all Class II wells. The purpose of the requirements is to assure the protection of all formations bearing usable-quality water, oil, gas, or geothermal resources. Each well is also subject to the specific requirements of Rule 14 that are applicable to the well completion situation. Special conditions that are specific to the well, field, or area may require additional plugging requirements at the discretion of the District Director.

An operator may request an extension of time to plug a well by submitting an "Application for Extension to Statewide Rule 14(b)(2)" (Form E-14PB or E-14LC) with accompanying financial security for the exception to remain in effect. Applications regarding wells which are associated with an active enhanced recovery project do not generally require financial security for plugging unless a technical review questions the feasibility of the future use of the well.

Within thirty (30) days after plugging any well, a complete record (Form W-3) must be filed in duplicate with the appropriate district office.

Criteria for Determining the Adequacy of Cement



APPENDIX C

MODULAR POWER PLANTS FOR GEOPRESSURED RESOURCES

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This paper gives an overview of modular power plants for geopressured resources and presents estimates for installed equipment costs and revenue produced with a representative geopressured resource.

The modular power plant utilizes process equipment that is skid-mounted and has been assembled, wired, and plumbed at the factory. Field installation requirements can be limited to plumbing the resource to and from the module and making the power connections to the distribution grid. For larger installations, several skids may be required and interskid connections would be made in the field.

The main advantages of modularized plants are as follows:

- Quick project completion; the plant can be on line six months ARO.
- Designed for wellhead operation; this approach is particularly well suited to geopressured resources that require high pressure geofluid piping between the well and the plant.
- Designed with fully automated control system; eliminates the need for a full time operator.
- Module can be moved to new wells if resource productivity decays.

A modular plant for a geopressured resource will have equipment that can tap all three potential revenue streams of the resource (see Figure 1).

1. A hydraulic pressure let-down turbine will produce electrical power by reducing the pressure of the geofluid coming from the well. The hydraulic turbine discharges a mixture of natural gas, steam, and hot water.

2. The natural gas can generate revenue by:

   2.1 Cleaning it to pipeline standards and selling it directly.

2.2 The gas can be burned in a gas engine to produce electric power.

3. The geopressured hot water is used in a binary module to produce electric power.

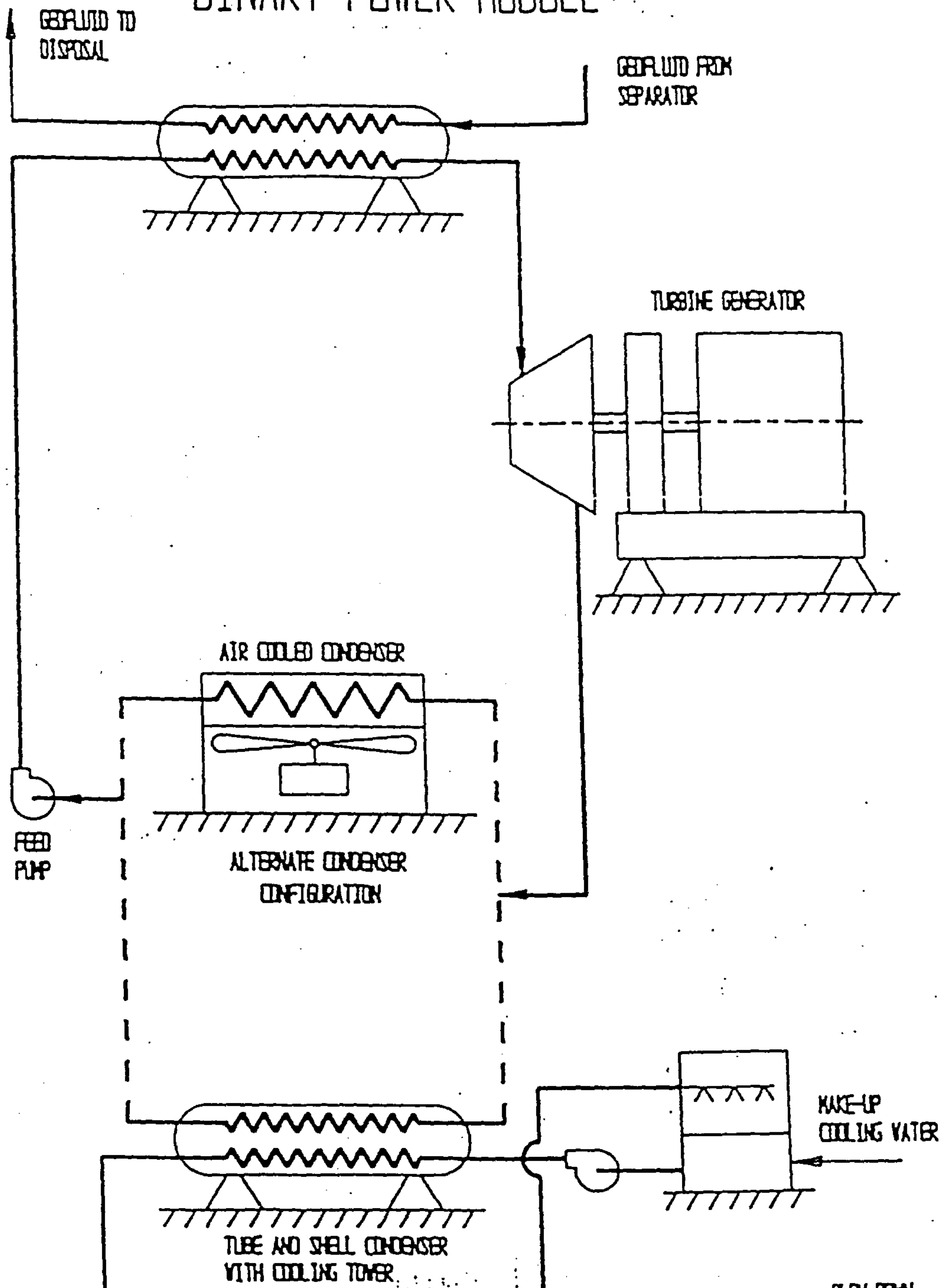
The main components of the binary module are shown in Figure 2. It consists of heat exchangers which transfer heat energy from the geothermal water to the working fluid. The heat supplied is sufficient to completely vaporize the working fluid at a relative high pressure. The vaporized working fluid is expanded through a turbine where shaft power is produced to drive a generator. The working fluid then flows to the condenser where heat is rejected to a heat sink (such as the evaporation of water or ambient air). The liquid working fluid from the condenser is pumped back to the heat exchanger, thus completing the cycle. The design of the binary module, including the selection of the working fluid, is tailored to match the resource temperature to provide the maximum utilization for that resource. The equipment layout for a binary module is shown in Figure 3.

The characteristics for a representative geopressured resource are shown at the top of Table 1 along with the assumed sales rate for gas and electric power. Following this are the estimated costs for the equipment as outlined previously and the revenue produced by the different energy sources. Option I is for a plant in which the gas is sold directly. Option II is for a plant in which the gas is burned to produce electricity. It should be noted that the binary module in Option II is larger than Option I. This is because the binary module in Option II uses some of the waste heat from the gas engine in addition to that from the geofluid.

The results of this simplified model indicate that while the cost of Option II (converting the gas to electricity) is higher than Option I, the increased revenue has actually improved the rate of return. A detailed economic analysis with actual sales rates and costs are based on actual resource characteristics should be performed before the final option is selected. This model indicates that there may be options that are superior to the direct sale of the gas.

FIGURE 2

BINARY POWER MODULE



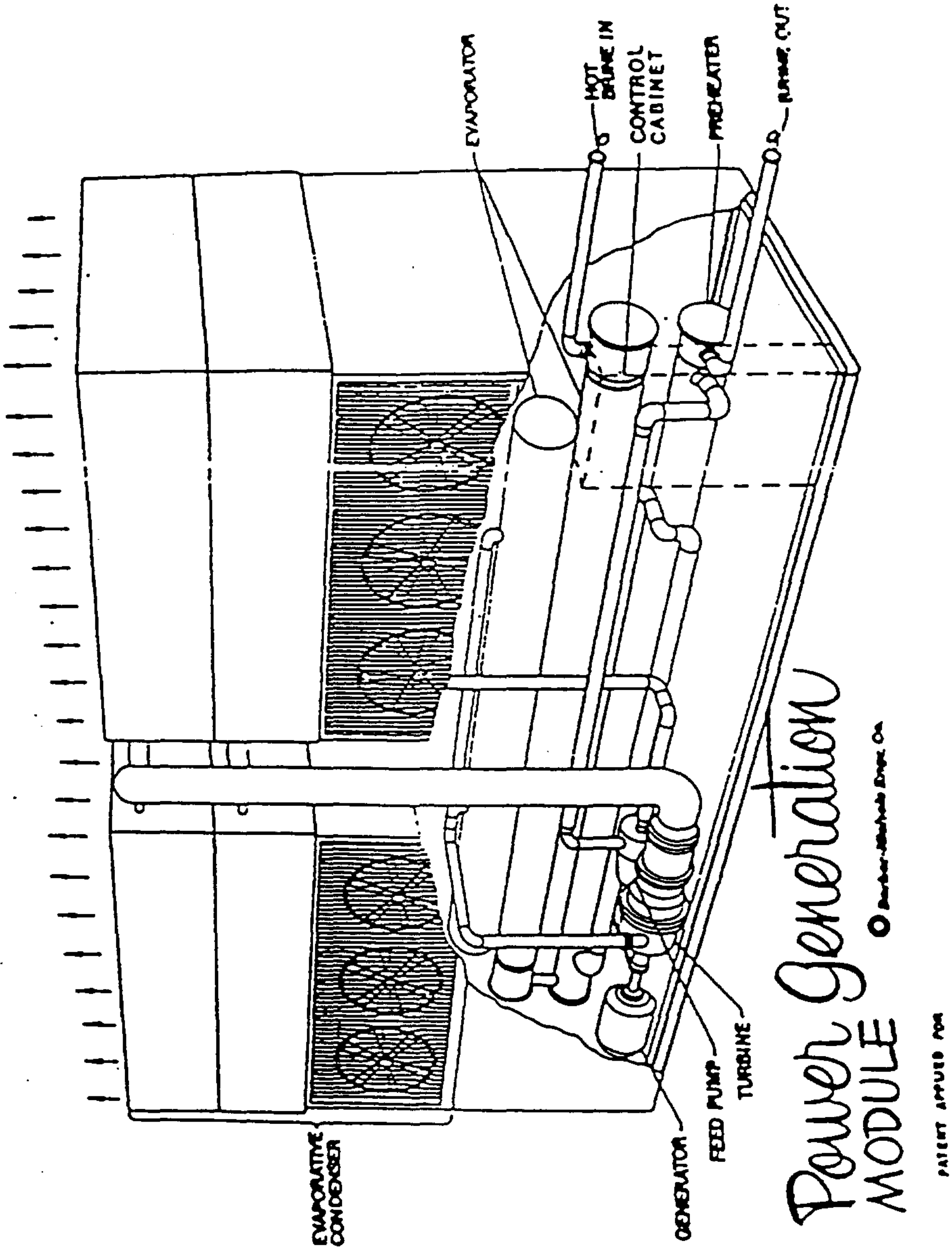

EVAPORATIVE CONDENSER
GENERATOR
FEED PUMP
TURBINE
EVAPORATOR
HOT BRINE IN
CONTROL CABINET
PREHEATER
BRINE OUT
Power Generation MODULE
PATENT APPLIED FOR

FIGURE 3

TABLE 1
GEOPRESSURED PLANT
APPROXIMATE COST AND REVENUE

Resource Characteristics:	40,000 bbl/day
	30 SCF of natural gas per barrel
	300°F brine
	4000 psi wellhead pressure
Sales Rates:	$0.05 per kW-hr for power
	$0.18 per therm for gas

OPTION I - SELL GAS

	Output	Cost	Annual Revenue
Well Completion		$2,000,000	$
Hydraulic Power	1050 kW	500,000	460,000
Gas Clean-Up	830 SCFM	250,000	780,000
Binary Power	2000 kW	3,000,000	880,000
		$5,750,000	$2,120,000

OPTION II - CONVERT GAS

Well Completion		$2,000,000	$
Hydraulic Power	1050 kW	500,000	460,000
Gas Engine Power	4400 kW	2,200,000	1,930,000
Binary Power	3300 kW	4,300,000	1,430,000
		$9,000,000	$3,820,000

APPENDIX D

EGG-EP-9839
September 1991

Idaho National Engineering Laboratory

Managed by the U.S. Department of Energy

The Feasibility of Applying Geopressured–Geothermal Resources to Direct Uses

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Work performed under DOE Contract No. DE-AC07-76ID01570

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THE FEASIBILITY OF APPLYING GEOPRESSURED-GEOTHERMAL RESOURCES TO DIRECT USES

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September 1991

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Prepared for the
U.S. Department of Energy
Field Office, Idaho
Under DOE Contract No. DE-AC07-761D01570

ABSTRACT

This study concludes that direct use technologies, especially desalinated water production, can contribute significantly to the value added process and the overall economic viability in developing a geopressured resource. Although agriculture and aquaculture applications are marginal projects when they are the only use of a geopressured well, the small margin of profitability can contribute to improving the overall economics of the direct use development. The added complexity from a technical and management aspect may add to the overall risk and unpredictability of the project.

Six combinations of direct uses received economic evaluation that resulted in 15% discounted payback periods ranging from 4 to over 10 years. These are listed in Table 4. Many other combinations are possible depending on the resource and market variables. Selection of appropriate technologies and sizes of applications will be established by the developer that engages in geopressured resource utilization.

Currently, many areas of the country where geopressured resources are located also have surplus electrical capacity and generation, thus power utilities have been selling power for less than 2 cents per kWH, well below a reasonable breakeven value for geopressured produced electricity. However, when the energy demand of the integrated geopressured facility is large enough to install power generation equipment, operating expenses can be reduced by not paying the 10 to 12 cents per kWH utility rate.

The study includes an analysis of a geothermal turbine unit installed with a desalination and an agriculture/aquaculture facility, taking advantage of the cascading energy values. Results suggest that this scenario becomes profitable only where the market price for electricity exceeds five cents per kWH.

ACKNOWLEDGMENT

Work supported by the U.S. Department of Energy, Assistant Secretary for Conservation and Renewable Energy Office of Utility Technologies, Under DOE Contract No. DE-AC07-76ID01570.

CONTENTS

FIGURES

TABLES

THE FEASIBILITY OF APPLYING GEOPRESSURED-GEOTHERMAL RESOURCES TO DIRECT USES

INTRODUCTION

Natural gas and the high temperatures and pressures found in geopressured-geothermal (geopressured) resources create the opportunity for many new applications. The objectives of this feasibility study are to provide a brief overview of the various direct uses that are under consideration to utilize the relatively clean and environmentally benign energy that is available in the geopressured resource, to identify the areas of greatest industry interest, and to identify those applications that appear to have the greatest potential for utilization and impact. Information regarding the various direct uses was obtained from industry, academic, government, and other organizations through personal contact, publications, and documentation. Based on the information obtained, thermally enhanced oil recovery, supercritical fluid processing for waste remediation, desalination, and agriculture/aquaculture applications appear to have the greatest potential for significant near-term development. This study addresses the various uses that were identified, with economic emphasis on desalination and agriculture/aquaculture applications. Thermally enhanced oil recovery and supercritical fluid processing for waste remediation are subjects of separate feasibility studies, also being prepared by the INEL.

BACKGROUND

As one of the prime contractors for the U.S. Department of Energy (DOE) at The Idaho National Engineering Laboratory (INEL), EG&G Idaho, Inc. is presently evaluating potential direct uses for geopressured resources, as are a number of industries, firms, organizations, and educational institutions. In addition, EG&G Idaho, Inc. (hereafter referred to as INEL) is spearheading the formation of an industrial consortium that would use the available energy in geopressured resources for multiple uses. Some of the uses under consideration include desalination, agriculture/aquaculture, sulfur frasching, the use of supercritical processes for detoxification of pollutants, brine production, power generation using natural gas driven engine generators or binary cycle power plants, food and other types of processing, chemical extraction, thermally enhanced oil recovery, and others.

A broad based infrastructure of designers and developers are available to apply their expertise toward the application of hydrothermal direct use projects for geopressured resources as a result of the development of hydrothermal energy. The use of hydrothermal resources in the United States (U.S.) for direct use projects was mostly limited to pool/health spa applications and for space and district heating before about 1973. With the oil price increases of the 1970s, the DOE initiated numerous incentive and technical programs that caused significant growth of the hydrothermal direct use industry. These activities resulted in numerous applications in agriculture, aquaculture, space conditioning, industrial uses, and various types of processing (Lunis and Lineau, 1988).

In recent years, DOE has been sponsoring the Geopressured-Geothermal Research Program, which includes the operation of three test wells in the Gulf Coast area. On behalf of DOE, the INEL provides technical support for the assessment and evaluation of the technical and production characteristics of this undeveloped resource. One result of these activities was the initiation of an industrial consortium at Rice

University, January 10, 1990 with 65 participants from industry, educational institutions, the federal government, and state and development organizations. A following consortium meeting held September 11th at the University of Texas in Austin, heralds the transition to commercialization for this undeveloped resource (Negus-de Wys, 1990).

APPROACH

Interest is being expressed for a variety of applications that could utilize the thermal and hydraulic energy that is available in geopressured resources. As a result of that interest (and the continuing development of DOE's geopressured program), various organizations, institutions, firms, and individuals were contacted to aid in the identification of potential uses that would be of interest to industry. A literature search was conducted to determine what development has occurred in using geopressured resources and the types of applications utilized. From this preliminary investigation, Figure 1 was developed to identify numerous potential uses and their approximate process temperature requirements.

Additionally, a brief overview of the areas of interest and development concerns were identified in integrated geopressured applications.

Four areas of interest were selected to receive further evaluation. These areas are:

1. direct uses application
2. supercritical fluid processing
3. hydraulic and thermal energy
4. thermally enhanced oil recovery.

This report addresses the feasibility of applying geopressured resources to direct uses; the three remaining subjects are separate feasibility studies. Selection criteria were established to limit the number of direct use applications that would receive economic analysis. These criteria are:

- Industry interest
- The greatest near-term impact
- Technical feasibility of the application.

Economic analyses were performed for two direct uses that best fit the selection criteria.

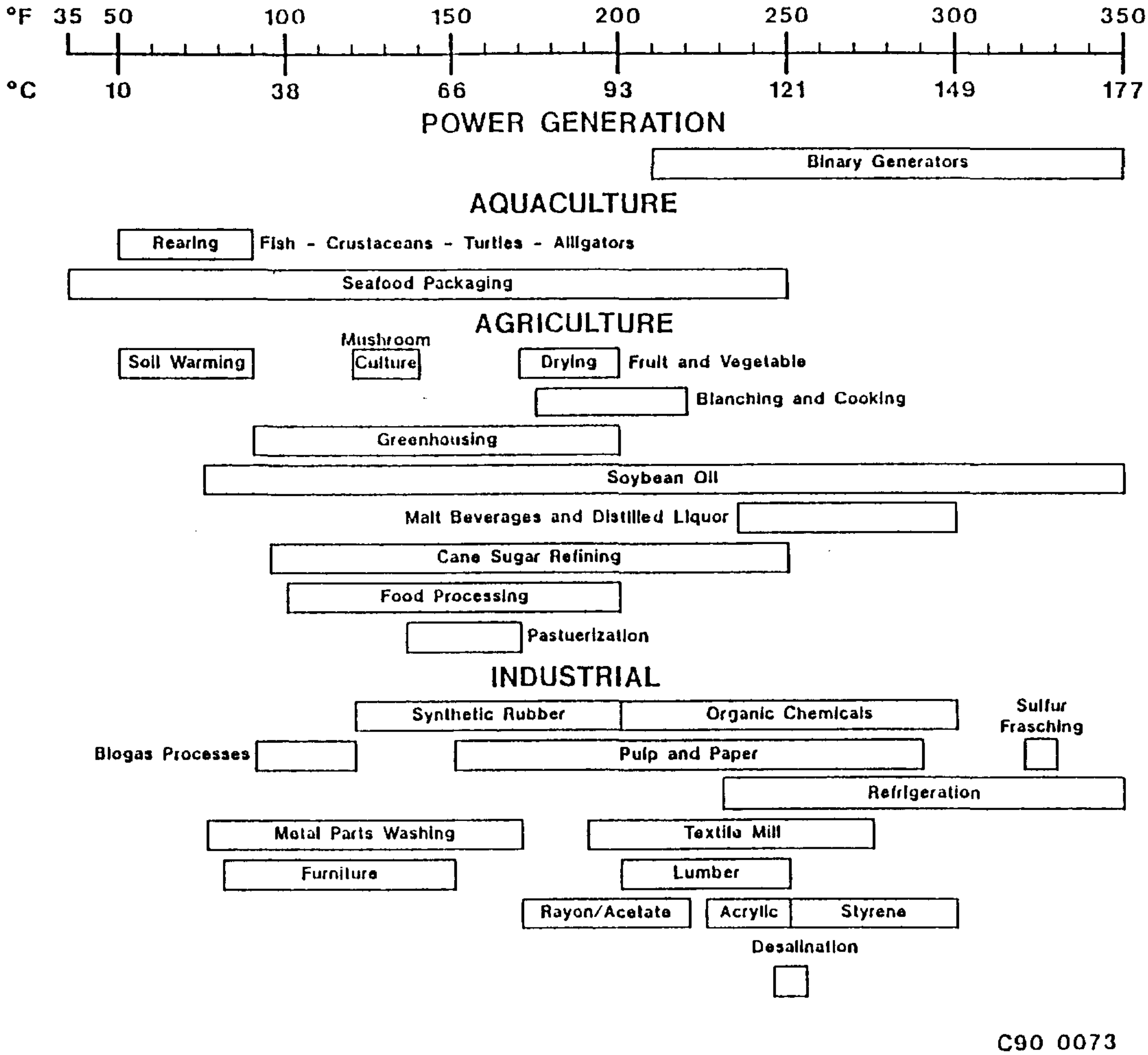

Figure 1. Potential geopressured applications and their temperature requirements.

FINDINGS AND CONCLUSIONS

Applying geopressured-geothermal resources to direct use is feasible. Of the various applications that were considered, desalination and agriculture/aquaculture appear to have high potential for near-term economic utilization. The sale of methane gas contained in the geopressured fluid will probably be accomplished irrespective of the applications selected to use the energy contained in the geopressured fluid. Additionally, commercialization would also include electric power generation, which was effectively proven at the DOE geopressure test facility at Pleasant Bayou, located about 50 mi south of Houston, TX.

Evaluation of the various applications indicates that multiple uses incorporated at a common location increases the odds of profitability. For example, a complex served by a 20,000 barrels per day geopressured well that provides for the sale of the contained methane gas, the sale of potable water produced by desalination, bottled water, and the brines resulting from desalination will have a 15% discounted payback period of ~ 4.3 years (Figure 2). The addition of an agriculture/aquaculture complex producing roses and catfish that is made up of a 4 acre greenhouse structure, service building, three 20-ft diameter aquaculture tanks in an enclosure, and an 8 x 45 ft outdoor raceway would reduce the payback period to ~4 years (Figure 3). However, when electricity production is added to the gas/potable water/bottled water/brine complex, the expected discounted payback period increased to more than 10 years when the electricity is sold for 6 cents/kWh. If the complex is selling gas at market price, electricity at 6 cents/kWh, and includes an agriculture/aquaculture facility, the discounted payback is >10 years because of the high front end costs for the electric generation equipment and the relatively small return for the agriculture/aquaculture facility.

Practically, the actual installation will be determined by the specific geopressured resource. Utility restrictions and financial requirements have typically limited these developments because of the complexity of operation and management.

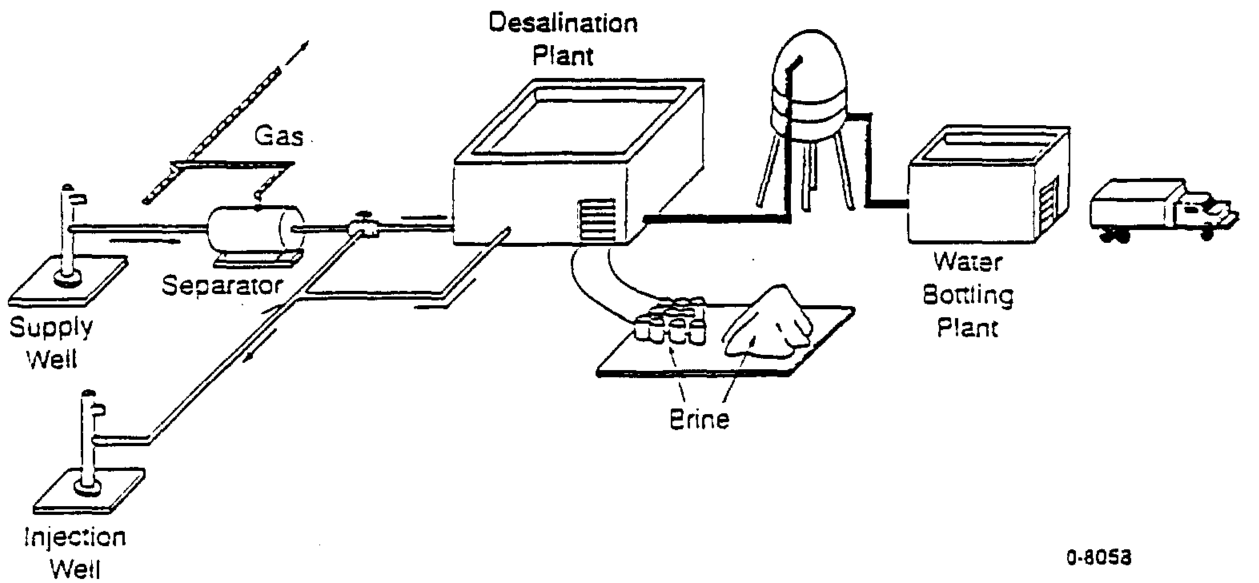

Figure 2. Feasible desalination facility.

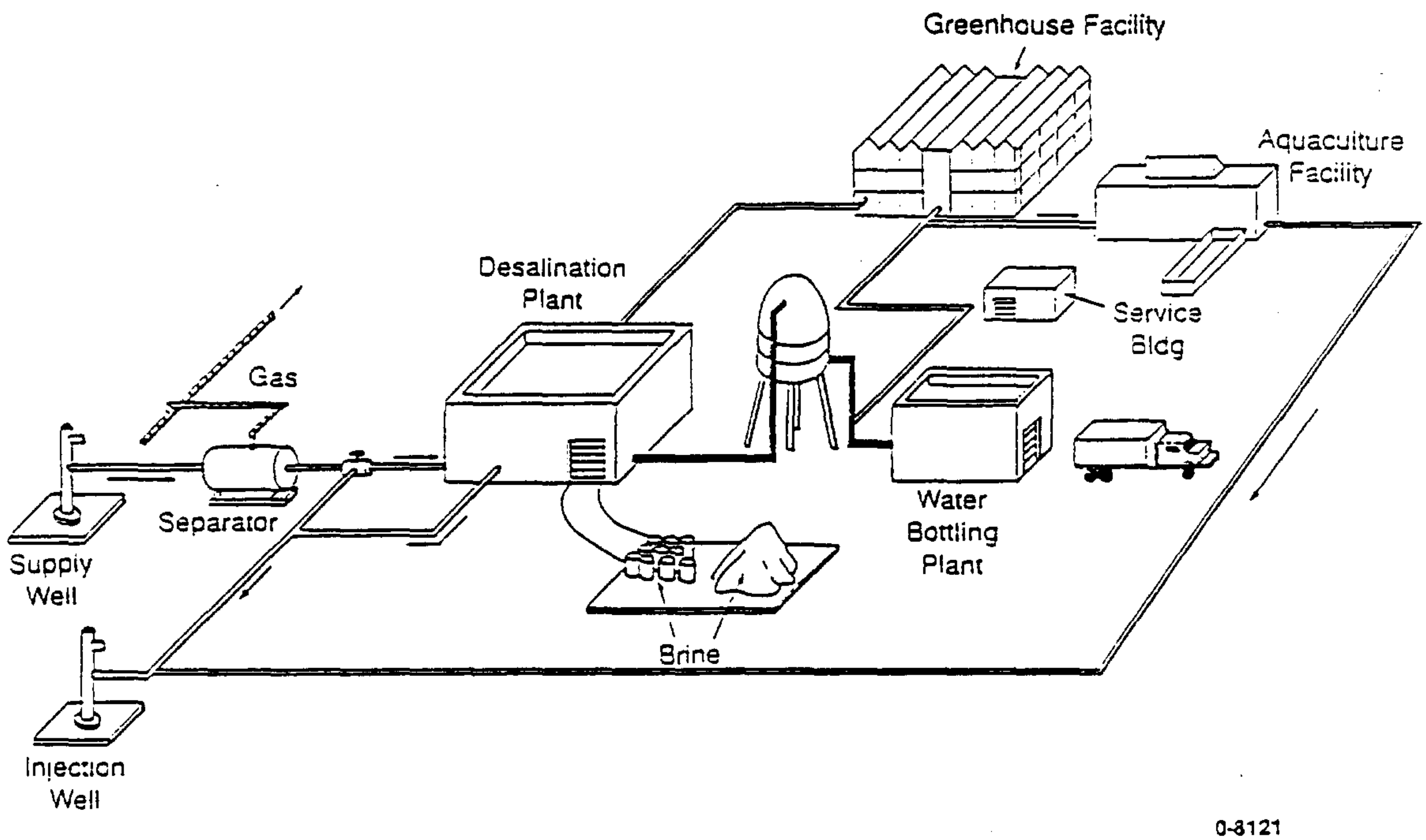

Figure 3. Feasible desalination/agriculture/aquaculture complex.

HYDROTHERMAL-GEOTHERMAL DEVELOPMENTS

Various developments have been accomplished using hydrothermal resources for power production, industrial applications, processing, aquaculture/agriculture, heating and cooling, resort, and spa use. Direct use technologies have been proven to be technically and economically sound, with 45 states having experienced significant geothermal direct use development in the last 10 years. The total installed direct use capacity is 7.2 billion Btu/h (2100 MWt), with an annual energy use of over 18,000 billion Btu/y (5 million bbl of oil energy equivalent). The significant increase in the use of hydrothermal energy for direct uses, especially since 1970, is displayed graphically in Figure 4 (Lienau, 1990). The rapid growth after 1970 is primarily caused by the oil price shocks of the 1970s and resultant Department Of Energy development assistance programs. These same programs have resulted in technical expertise being available to apply the technologies developed for hydrothermal energy toward the energy found in geopressured resources. The principal sources of technical expertise are available at the Oregon Institute of Technology Geo-Heat Center in Klamath Falls, Oregon, the Idaho National Engineering Laboratory in Idaho Falls, Idaho, State energy offices, and from an infrastructure of developers, designers, and builders located throughout the United States.

Cascading of geothermal energy for numerous applications is more commonly practiced in nations other than in the U.S. For example, a geothermal power plant operated by Ente Nazionale per l'Energia Elettrica (ENEL), near Piancastagnaio, Italy, utilizes the waste heat industrially to provide additional employment in the region. A greenhouse complex that employs up to 500 people and a drying facility that employs up to 160 persons is being developed. Neither the greenhouse nor the drying facility would be profitable using fossil fuel for energy (Lund, 1987).

Another direct use application is located north of Tianjin, China, where 97°C fluids are effectively being used in cascaded farm operations for an extensive chicken hatching/rearing /processing facility, fish rearing, greenhousing, and a geothermal equipment research facility (Lienau, 1990).

Near Kawerau, New Zealand, geothermal steam generated by separate flash plants located in the geothermal field, is used in a variety of cascading operations that is probably the largest known industrial development. The steam is used to operate equipment, dry timber, process paper, and produce electric power in the Tasman pulp and paper company facility (Lienau, 1989).

In the Mostovsky Krasnodersky region of Russia, a village uses cascading applications from a geothermal well cluster that includes space heating, a livestock rearing facility, an industrial complex of furniture, feed, concrete, and hide reprocessing production heated irrigation fields, and fish culture ponds (Tikhonov, 1986).

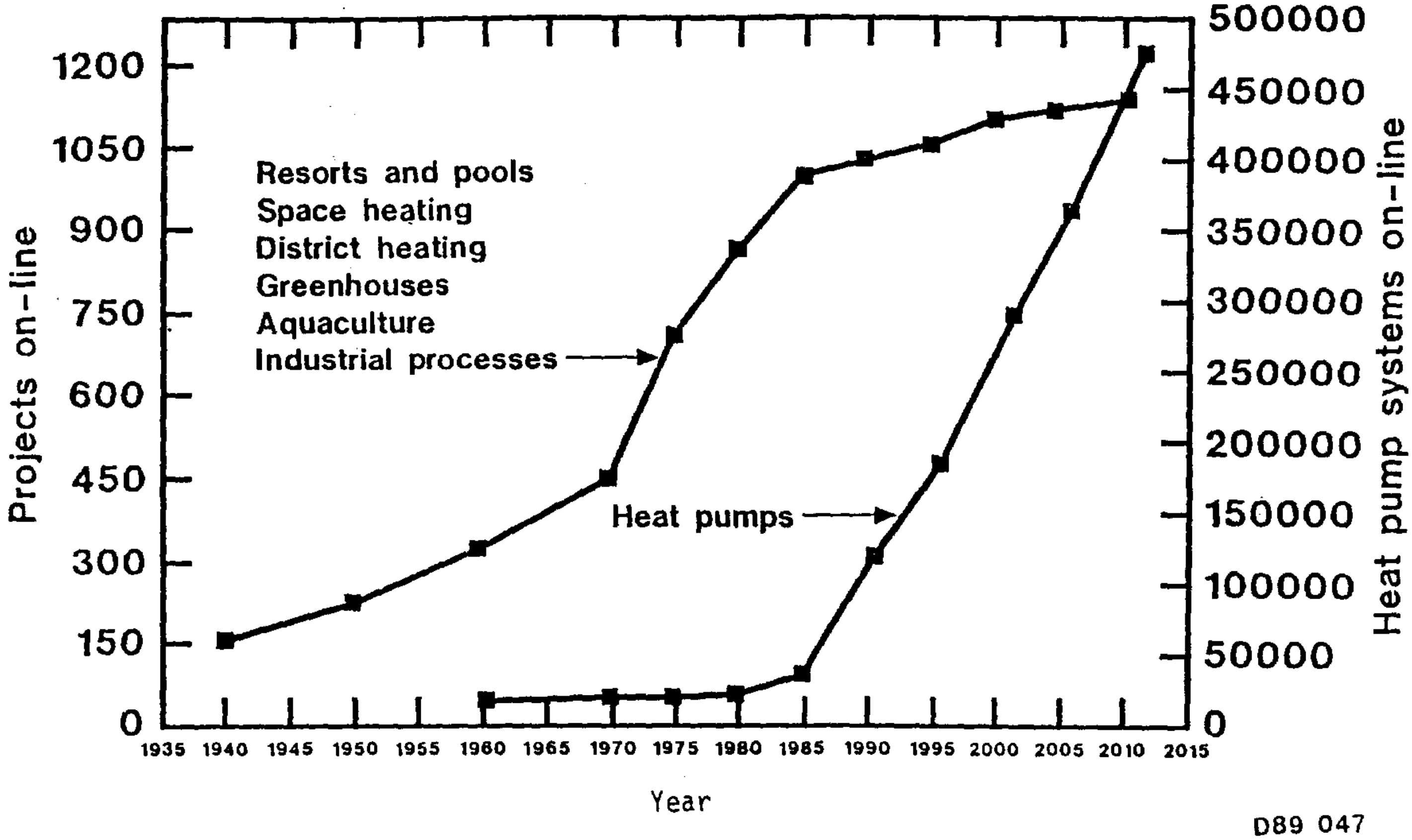

Figure 4. Growth in hydrothermal-geothermal applications (Lienau, 1990-1).

THE GEOPRESSURED RESOURCE

Geopressured resources vary considerably from hydrothermal resources. The contained gases, and higher well pressures contained in geopressured resources can significantly increase the opportunities and methods of application that can be developed. This section provides information about what the geopressured resource is, where it may be found, and applicable salient features and considerations.

Figure 5 displays the distribution of known hydrothermal resources in the United States. It should be noted that the present state of knowledge of geothermal resources of all types is very limited. It is known with reasonable certainty, that there are many more low-temperature 195°F (90°C) hydrothermal-geothermal occurrences than there are high-temperature 300°F (150°C) areas (Wright and Culver, 1989).

Geopressured-geothermal resources are a normal phase of basin evolution and are found in many locations throughout the U.S. (Figure 6) and the world. Geopressured resources have three energy forms: thermal, hydraulic, and methane gas. These three forms of energy can be converted to higher value forms of energy using the available technologies. The thermal energy can be converted to electricity using an organic Rankine cycle generator. The hydraulic energy can be converted to electricity with a hydraulic turbine. Dissolved methane gas can be separated and sold, burned, compressed, liquefied, or converted to methanol or to electricity by fueling a turbine (Negus-de Wys, 1989).

Geopressured resources normally exist between 12,000 to 20,000 ft below the surface. Flow rates can vary between 10,000 to 40,000 bpd. Temperatures will range from 273 to 500°F. Bottom hole pressures vary from 12,000 to 18,500 lb/in.^{2} absolute (psia). Salinity will be present in the amount of 20,000 to 200,000 mg/L. Gas content will vary between 23 to 100 standard cubic feet (scf) per barrel of fluid (Negus-de Wys, 1989).

Resource potentials are significant for hydrothermal resources, but are even higher for geopressured resources. According to Muffler (1978) of the United States Geological Survey (USGS), hydrothermal resources have energy potentials equal to 23,000 megawatts electric (MWe), ± 3400 MWe, for 30 years. On the other hand, geopressured resources are estimated to contain from 23,000 to 240,000 MWe for 30 years in the Gulf region of the United States; Louisiana alone has the potential for 4100 to 43,000 MWe for 30 years. Geopressured resources are known to exist in other sedimentary basins of the U.S., such as the central valley of California. However, the USGS made no thermal potential estimate of those areas because of limited knowledge at the time of preparation of Circular 790 (Muffler, 1978).

The current development of geopressured resources for direct uses is limited to the workover of existing geopressured wells, which are the result of oil and gas field exploration and development. In 1981, between 2000 and 3000 geopressured wells would have been available each year in the Texas and Louisiana areas, respectively. Since that time, drilling activity has been significantly reduced, and it is estimated that ~200 to 300 geopressured wells are currently available each year. (It should be noted that not all of these wells would be available for development.) Typically, these wells are plugged and abandoned if sufficient oil and gas resources are not found. Increased oil field activity will obviously increase the number of wells drilled to geopressured zones.

Limited geopressured data is available. The University of Texas at Austin is performing a collocation study for Texas, and Louisiana State University is doing the same for Louisiana. Data are presented in the thermal enhanced oil recovery feasibility report from INEL.

Even more limited is the development of geopressured resources. Western Resource Technology, Inc., is actively developing geopressured wells; they have drilled one well to date and have 12 geopressured projects in various stages of development. British American Gas

Production Co. has leased 4000 acres around the DOE Hulin Well site south of Lafayette, LA, and has options for another 10,000 acres. Their primary purpose is to obtain the gas contained in geopressured resources.

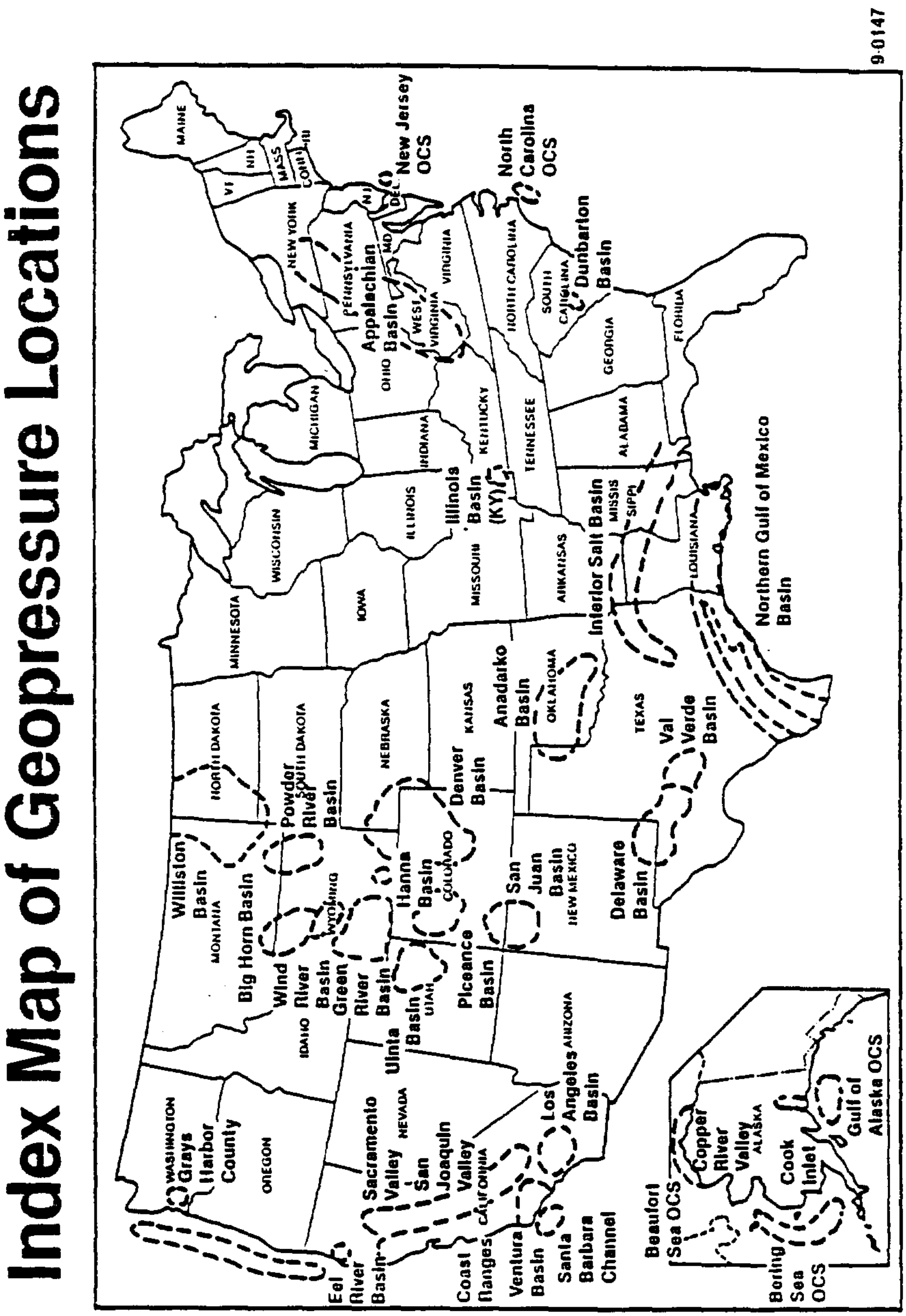

Figure 5. Location of geopressured-geothermal basins in the United States (Negus-de Wys, 1990).

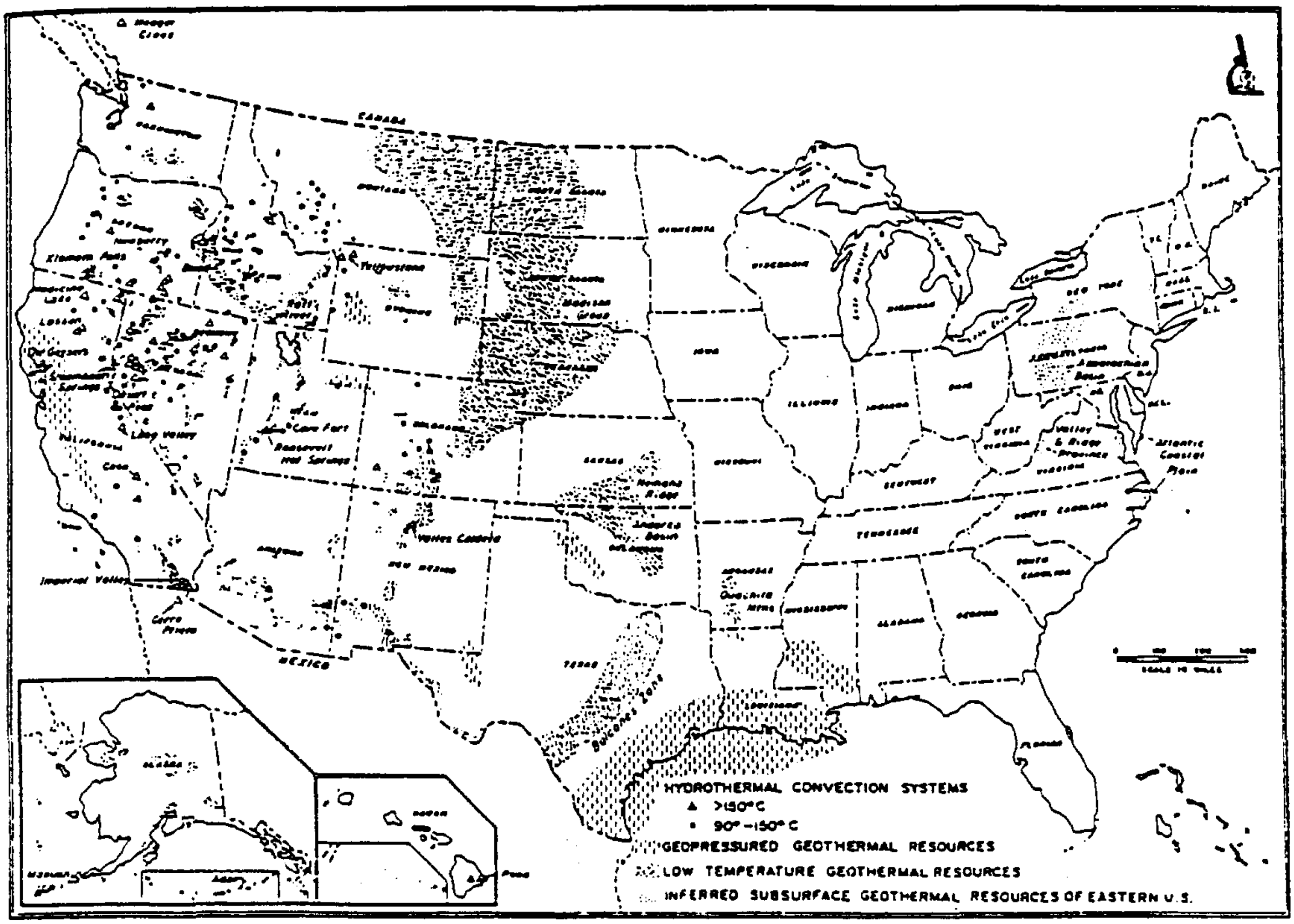

Figure 6. Hydrothermal resources in the United States (Wright and Culver, 1989).

GEOPRESSURED DEVELOPMENTS

This section provides a summary of the current development status of using the energy found in geopressured resources. Although this study is directed toward direct uses, current information about power production is included. The use of geopressured resources will probably have the greatest potential for economic viability when an integrated operation is installed. The hypothesized facility in Figure 7 identifies the various applications under consideration. The actual installation will probably be a mix of the applications discussed on the following pages.

POWER GENERATION

Power can be generated utilizing the thermal, hydraulic and methane energy contained in geopressured resources. About 1 MW generated at the DOE Pleasant Bayou test facility located ~50 miles south of Houston, TX. This facility incorporated a binary power plant and two gas fired generators to produce power, proving the commercial viability of this type of application. The sale of power between 5 and 6 cents/kWh appears to be the revenue needed for a profitable installation when properly coupled with other applications. The use of a modified Pelton turbine to capture the hydraulic energy has the potential to result in a decrease in the breakeven cost of electricity of between 2 and 2-1/2 cents/kWh. This assumes a flow rate of 24,500 bpd that can sustain the operation of a 500 kW generator.

Potential Industrial Applications

Various industrial applications are being considered that utilize the thermal and hydraulic energy available in geopressured resources. Information about potential and current developments are contained in this section. The developer, location, development and any available cost information are provided in the following discussions.

Desalination

Desalination is a proven technology using conventional energy forms. As the relative cost of water increases, desalination will become a more viable option -- not only to extract the potable water from geopressured resources in inland areas, but also from the ocean for near-coastal and other demands.

Fresh water can potentially be removed from geopressured fluids to meet critical freshwater needs in the water scarce regions of California, the lower Rio Grande Valley of Texas, and other areas, both nationally and internationally.

G. S. Nitschke (Boeing, WA) and J. A. Harris (Wichita State University) proposed a system that will use the pressure gradient of the reservoir to produce electricity by way of a pressure reduction turbine and generator combination. The natural gas would be separated for sale or on-site use, and the thermal energy would be used to produce potable water through a multi-effect distillation unit. In turn, the remaining saturated brines could be sold. The brine is ideal for solar ponds that utilize binary power generators, a method effectively proven in Israel. Solar pond power could be used for further water production in a conventional reverse osmosis desalination scheme fed with seawater. It is suggested that such a scheme could produce as much as 40% of the total water load in California (Nitschke and Harris, 1990).

F. J. Spencer (International Management Services) has identified six areas of use that he is encouraging for utilization of geopressured resources, particularly in the entire lower Rio Grande Valley, south TX, in the coming decade. The proposed areas are:

1. Recover dissolved methane and sell it as pipeline gas
2. Use the geopressured fluid or gas pressure or both to drive turbines for power production
3. Use the steam content of the geopressured fluid to drive conventional turbines for power production

4. Use the heat in the fluid for many industrial processes
5. Use the fluid directly depending on salinity, for both aquaculture and industry
6. Desalinate the fluid and use the salts contained in the fluid as starting points for chemicals (Spencer, 1990).

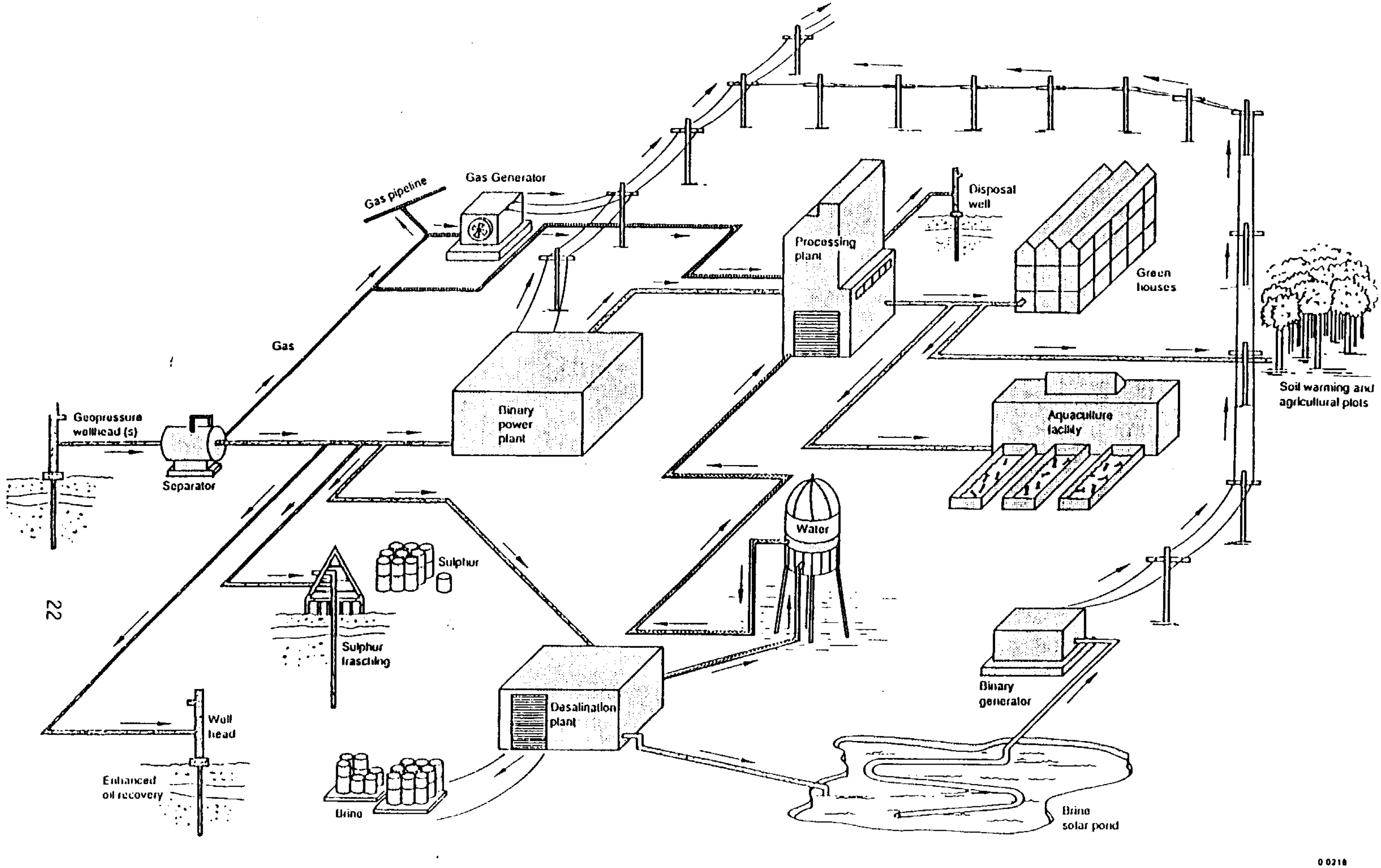

Figure 7. Potential geopressured integrated facility.

The feasibility of utilizing geopressured resources to produce potable water by desalination appears to have high near-term probability of successful application, especially in areas of limited water supplies such as the lower Rio Grande Valley region of south Texas, and the central valley of California.

Studies made by Dorfman and others during the early program years of the geopressured program indicate the Hidalgo county geopressured reservoir could sustain a brine flow of 16,830,000 bpd without undue depletion over a 20 year life, and a brine flow of 45,600,000 bpd is estimated for Cameron and Hidalgo Counties (Dorfman and Morton, 1985). After salt removal, ~1.15 billion gal/d of desalinated water could be recovered in a region that is characteristically low in water supplies (Spencer, 1990).

Both of these areas have geopressured basins that have the potential to be utilized for desalination. See Figure 6 for the approximate location of the Sacramento Valley, San Joaquin Valley, and Los Angeles Basins in California, and the Northern Gulf of Mexico Basin in Texas. As reported by the Department of Water Resources, State of California, in their drought Contingency Planning Guidelines for 1989, California realized a \$2.4 billion loss in the drought of 1976 to 1977, and the current drought is worse. The suggestions for dealing with the drought are all conventional (more surface reservoirs, water purchases from surrounding states, etc.) Also, grandiose schemes such as digging a canal to the Columbia River and moving icebergs from Antarctica are being suggested by the City of Los Angeles. The Seattle Times, May 27, 1990, notes that under a scheme called the North American Water and Power Alliance, the Ralph Parsons Co., Pasadena, CA has developed a gigantic water-transfer plan that includes waterways snaking down the continent from Alaska, through Canada and the Northwest, to serve the freshwater needs of southern California. The estimated cost is \$200 billion. By contrast, Nitschke and Harris'(1990) proposed system would provide ~40% of California's water demand at a cost of ~\$24 billion (Table 1). This approach would include using geopressured resources found in the

Sacramento Valley and San Joaquin Valley geopressured basins. The system would involve electricity production using pressure reduction turbine and generator combinations, gas use and sales, and freshwater production from the geopressured brines. The brine would be used in solar ponds for binary power production.

Table 1. Proposed freshwater supplies from geopressured fluids for California

FACTOR	UNIT
No. of wells in Geop-Geo. field	1000 (1 well/30 mi^2)
Well production life	10 y
Tax rate to reflect federal assistance	25%
Utilities prices	gas: $2.00/Mcf elec: $.045/kWh water: $1/1000 gal
Lease costs	1/8 on gas rev. only
Plug & abandon costs (future use of well for liquid waste disposal)	none
2nd Law efficiency on Rankine cycle (solar pond power prod.)	80%
Desalination power (reverse osmosis; range: 3 to 80 Wh/gal)	30 Wh/gal
Initial well/system elec (power added to gas-lift for brine transport)	14.4 MWh/d
Total solar pond area	850 mi^2
Daily well-grid water (at height of prod.)	530 E06 gal/d
Solar pond water (at full production)	1.1 E10 gal/d
% of total CA water (solar pond at full prod., based on 1985 consum.)	40%

NOTE: The cost of the pipelines and the solar ponds power generation/ desalination facilities are estimated at $10 billion each for a total capital investment of $24 billion (including the $4 billion for the 1000 well/system grid @ $4 million each). Note that no benefit allowance is made for either using wells for waste disposal or earthquake control possibilities.

Gas Use and Sales

Gas contained in the geopressured fluid can be separated, used directly, or sold to a pipeline company, or all three. This was effectively accomplished at the DOE Pleasant Bayou facility. The gas was used to drive two gas engine generators. The gas could also be used for refrigeration and to drive pumps.

The methane gas contained in geopressured fluids increases the profitability of utilizing a geopressured resource and increases the options that are available for direct uses. The contained gases can vary between 23 and 120 scf/bbl of fluid. The Pleasant Bayou facility produced 23 scf/bbl, which was effectively used to drive two 325 kW gas engine generators. For an integrated facility, the selection of applications will determine the extent to which the contained gas will be used to produce electricity, power equipment, or be sold directly to a gas pipeline company. Another consideration is whether or not the sales price for electricity is lower or higher than gas prices.

Electricity purchased from HL&P costs between 10 and 12 cents/kWh. Accordingly, if the power needs of an integrated facility are large enough, it could be economically feasible to install a gas engine, a binary cycle power plant, or a hydraulic turbine to meet facility needs.

Pollutant Removal

The Air Force Engineering and Services Center, the DOE Hazardous Waste Remedial Actions Program, and the Los Alamos National Laboratory are investigating the use of supercritical water (above 705°F and 3208 psia) processes for the destruction of hazardous wastes (Rofer, 1990). Processing methods appear suitable but require additional development. The feasibility of the utilization of the energy contained in geopressured resources for supercritical water processes is under investigation at the INEL.

Groundwater Services, Inc. Houston, TX, is performing a pilot study for the recovery of non-aqueous phase liquids at a superfund site, and the evaluation of geopressured-geothermal brine as a potential remediation evaluation of geopressured-geothermal brine as a potential remediation technology. Dense non-aqueous phase liquids (DNAPL) greatly complicate groundwater remediation because the heavy DNAPL will sense and follow topographic lows within an aquifer system, and because DNAPL is difficult to extract using conventional pumping methods. These problems are now being observed at the Motco Superfund Site near Houston, TX, where DNAPL is present in a shallow surficial aquifer. As observed in pilot test activities, waterflooding and well-bore vacuum enhanced recovery increased recovery rates (Conner, 1990).

The use of geopressured fluids for the remediation or removal of hazardous wastes, or both, appears to have significant potential for development, especially considering the increasing emphasis on controlling hazardous wastes. Accordingly, a separate feasibility study is being prepared by the INEL.

Thermal Enhanced Oil Recovery

Geopressured resources, often encountered while drilling for oil and gas, can provide hot brines under pressure to flood reservoirs containing medium or heavy oils to enhance recovery. The INEL is proposing a program for the thermal enhanced recovery of heavy oil from the Alworth Field in the "Mirando" trend of south Texas. It is not possible to consider a hot water-steam type flood in this part of Texas because of the lack of steam quality fresh water; however, geopressured brines can be considered. In the San Joaquin Basin of California, cyclic steam injection has been used successfully but is now under scrutiny because of the pollution generated by the equipment used in producing the steam; in contrast, using geopressured brines offers an environmentally clean process (Negus-de Wys, 1989).

The potential impacts and feasibility appear very high. Industry is proposing a demonstration project. Accordingly, the INEL is preparing a feasibility study.

Sulfur Frasching

Sulfur can be recovered from salt dome deposits using a process devised by Dr. Herman Frasch. This process was perfected commercially in 1903. The technique melts the sulfur while still underground in porous limestone and calcite deposits. Superheated water (320 to 330°F) with pressures of 125 to 200 psi is injected into the sulfur deposits. As the sulfur melts, it is forced to the surface where it can be transported in liquid form, solidified, or made into flakes or pellets (Carlson, 1976).

Adequate pressure and temperature are available in geopressured fluid to perform sulfur frasching with geopressured fluid. The production of sulfur is limited to three producers in the U.S.; Freeport-McMoran, Inc., New Orleans, LA, Pennzoil Sulphur Company, Houston, TX, and Texas Gulf Chemical, Houston, who is phasing down its sulfur operation. Freeport-McMoran needs sulfur mostly for their phosphate fertilizer production. They have two mines on-shore near New Orleans, LA, and one offshore. Freeport-McMoran recently announced the first sulfur discovery since about 1970 at Main Pass, offshore Louisiana.

The production of sulfur is very capital intensive, precluding small operations. For example, the cost of developing the newly found Main Pass deposit, located in 220 ft of water, will be ~$554 million. Transportation is about one-half the cost of production. In the 1950s, Freeport-McMoran obtained a patent for the use of salt water in the Frasch process at one of its locations. In theory, there are no basic physical, chemical, or biological restrictions to this process, and although there will be a slight entrapment of salt into the final well-side product, the advantage of not having to pipe or ship quantities of freshwater to the rig makes this a minor price to pay. Despite the fact that the patent expired almost 10 years ago, Freeport-McMoran is the only company currently using this technology (Darling, 1989). Accordingly, the potential exists to use geopressured fluids directly in the Frasching process.

Sulphur deposits appear to be very limited; however, they are located in regions that may contain geopressured resources. The potential for contribution to the sulphur industry appears very high with the Frasch process if a constant supply of superheated water (320 to 330°F) under pressure (125 to 200 psia) can be met by a geopressured resource.

Frasch mining takes place in five countries: Poland, United States, Canada, USSR, and Iraq. Poland is the largest producer and has the largest reserve base. The non-U.S. Frasch producers are state controlled, volume oriented, and do not have the same motives as privately owned organizations in the U.S. The result is a concentration of market pressure on U.S. producers during periods of market weakness (Eckert, 1987). If geopressured fluids could be effectively used for Frasching, the market position of the U.S. could be significantly improved.

A feasibility analysis would be in order to establish the extent of the impact of using geopressured resources for frasching. This effort could include colocation of geopressured resources to known sulphur deposits, and investigating the feasibility of using geopressured brines directly in the process, using heat exchangers where fresh water would be available or produced by desalination from geopressured brines.

Petroleum and Natural Gas Pipelining

Petroleum and natural gas pipelining require large quantities of energy to operate the systems. Pipeline companies operate throughout geopressured areas and could benefit from technology developments using the energy available in geopressured resources (Carlson, 1976).

Geopressured resources could be used as an energy source for the transport of petroleum and natural gas because oil and gas wells are often located near geopressured resources; however, this investigation did not evaluate the potential or investigate the feasibility in-depth. No industry interest has been noted from contacts, through current program activities, or the geopressured industrial consortium. It is recommended that additional effort be expended to determine potential impacts and feasibility.

Coal Desulfurization and Preparation

There are a number of processes that are used to process solid or liquid fuel from high-sulfur, high ash coal. Much of the lignite found along the Texas Gulf Coast region is either high sulfur, high ash, or both. These types of processes require large quantities of process heat, pumping, and conveying; geopressured energy could be applicable to all or part of these energy needs (Carlson, 1976).

Processes used for coal desulfurization and preparation have heat requirements that can be met with geopressured resources. The extent to which these needs can be fulfilled using geopressured fluids remains to be investigated. No industry interest has been expressed to date, but pending geopressured industrial consortium activities may result in stated industry interests. The colocation of geopressured resources to this industry, areas of applications, and potential uses could be investigated to ascertain potential impacts and feasibility.

Lumber and Concrete Products Kilning

Typical kilns for lumber drying and concrete products require low-quality steam or heated air. These facilities could easily operate with the available heat in geopressured resources (Carlson, 1976).

Lumber and concrete products kilning require low-quality steam or heated air for processing. Geopressured resources contain temperatures adequate to meet the needs of this industry. To date, industry has expressed no specific interest, and the extent of the potential utilization and impact remains to be investigated.

Paper and Cane Sugar Industries

Numerous pulp and paper mills exist in geopressured regions. About 38 pulp and paper mills are located in Texas and Louisiana. Eleven mills in these two states are located in potential geopressured regions and have a gross energy consumption of about 78 trillion Btu/year. Louisiana also has about 43 raw sugar mills and six sugar refineries that consume over 12 trillion Btu/year (Hornburg, 1975). Although these data were assembled in 1975, they provide a relative value for current considerations.

The overall conclusion of a study made by DSS Engineers, Inc., Ft. Lauderdale, FL, (Hornburg, 1975) is that utilization of thermal energy from geopressured fluid in pulp and paper mills and new sugar refineries is technically sound and economically feasible, providing that the natural gas and the pressure contained in the fluid is recovered concurrently. Studies on specific sites and facilities are needed to refine and verify the information developed.

Chemical Processing

An analysis made by DDS Engineers, Inc., Ft. Lauderdale, FL, (Hornburg, 1975) of the processes used in the industrial organic chemicals group showed that acetic acid, acetic anhydride, ethyl alcohol, and isopropyl alcohol can be produced with almost all the energy needed being supplied by geothermal fluids. A similar analysis of the industrial inorganic chemicals group revealed that sulfur, bromine, aluminum sulfate, and alums could be produced with energy supplied by geothermal fluids. Additionally, it was found that large quantities of low-level heat are used to concentrate sodium hydroxide, which is produced concurrently with chlorine (Hornburg, 1975).

The energy contained in geopressured fluids can meet the needs of numerous chemical processes that occur in geopressured regions. Industrial organic chemical processing could amount to ~30.5 trillion Btu for production in Texas and Louisiana (1980 basis). For inorganics, an estimated 60 trillion Btu/y could be utilized (Hornburg, 1975). It is recommended that this potential area of use receive investigation.

Chemicals in Geopressured Fluids

Geopressured fluids contain varying amounts of various chemicals. Table 2 identifies the contents and their amounts found in an analysis of the Pleasant Bayou, TX, geopressured well. Certain of these chemicals may be extracted to add to the overall economics of a geopressured facility.

Wherever the geopressured fluid shows bromine concentrations of at least 60 to 70 ppm, a proven recovery process (Figure 8) may be utilized to release the bromine in pure form. Bromine is a vital ingredient in photographic films. Today, nearly half of the bromine supply is derived from seawater, and the other half comes from deep underground brines in California, Utah, and Arkansas. In a typical case, a single well flowing at a rate of 20,000 bpd, and a bromine content of 65 ppm could yield ~450 lb (100% extraction) of bromine, with a market value of ~$250/day. The concentrated brines from desalination effluent are rich sources of various chemicals (Figure 9) whose economic extraction may be best accomplished by way of accumulation in solar ponds from which harvesting and processing of the various salts could be undertaken as at the Great Salt Lake in Utah.

TABLE 2. PLEASANT BAYOU BRINE ANALYSIS.

DESCRIPTION	CONTENT (MG/L)[a]
Spec Gravity @ 60°F	1.080
Total Dissolved Solids	133,900
Alkalinity (mg C_aCO_3/L)	301
Ammonia	86
Arsenic	<0.5
Barium	767
Boron	25
Bromide	75
Cadmium	<0.1
Calcium	7,960
Chloride	72,000
Chromium	<0.1
Copper	<0.1
Fluoride	1.6
Iodide	23
Iron	45
Lead	<1
Lithium	32
Manganese	16
Magnesium	604
Mercury	<0.005
Nickel	<0.25
Potassium	561
Silica (SiO_2)	108
Sodium	36,700
Strontium	850
Sulfate	6
Tin	<0.25
Zinc	0.56

a. All results are in milligrams per liter unless otherwise specified.
Sampled after choke (Negus-de Wys, 1990).

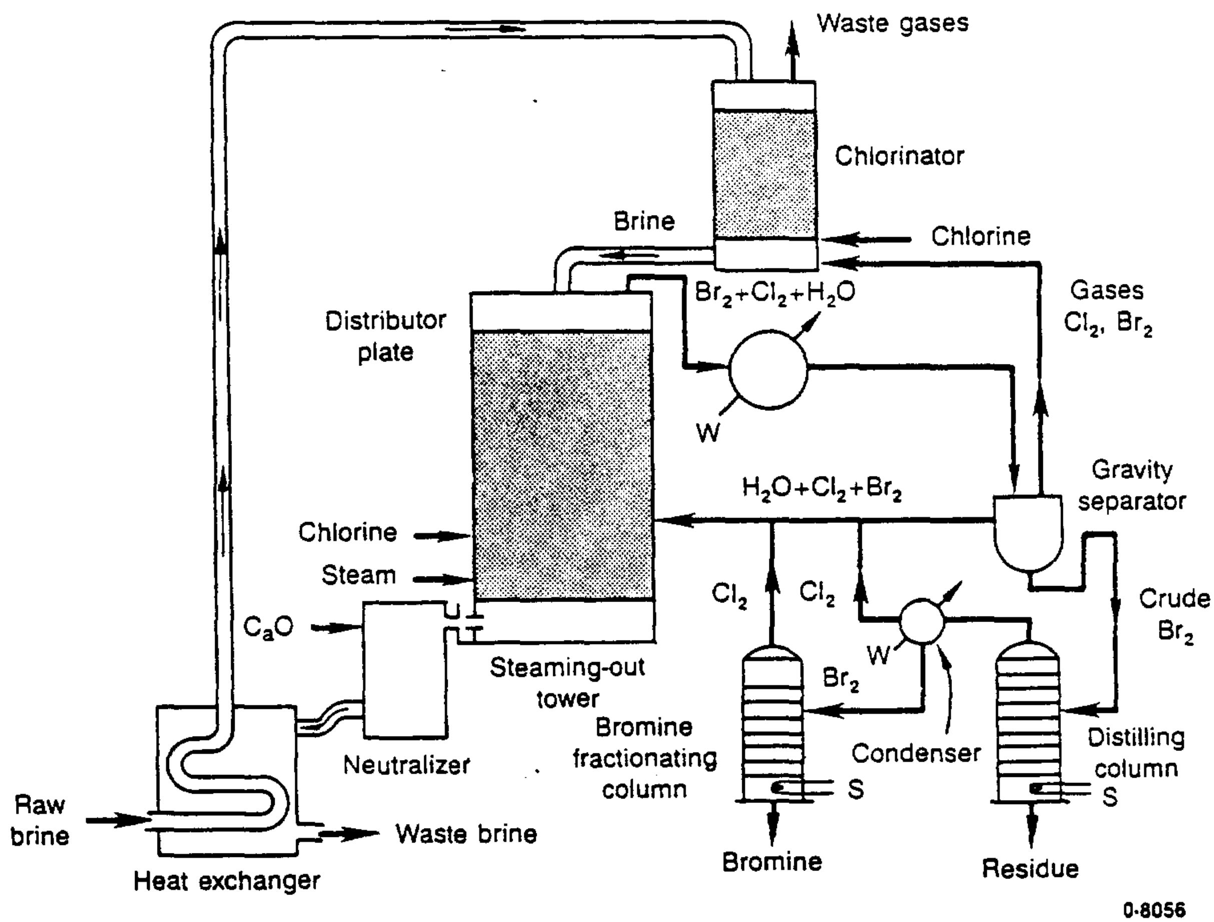

Figure 8. Extraction of bromine from seawater or selected brines (DOW process, modified).

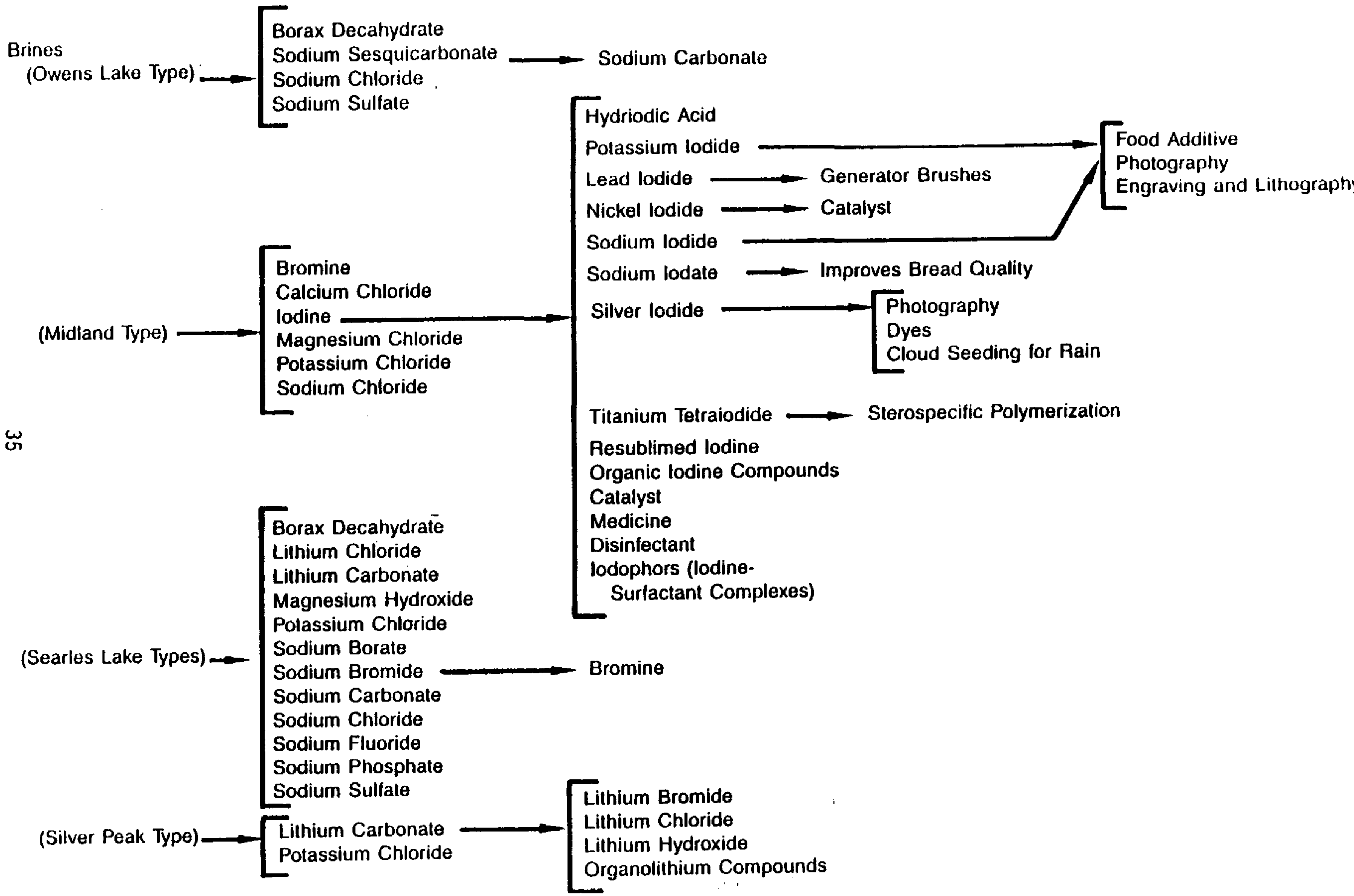

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Figure 9. Salt brine derivatives.

Potential Agriculture/Aquaculture Applications

Various agriculture/aquaculture applications are under consideration that could use the fluids and energy found in geopressured resources. One or more of these applications can be installed in cascaded uses where the hot fluids that have been used for one process are then used in another application.

Current commercial production of both aquatic and agriculture products is commercially limited by cold winter weather when growth rates can be severely hampered by lowered and fluctuating temperatures. This in turn disrupts established markets, often making it necessary to create new markets when the products are once again available. For example, alligators grown in Louisiana achieve a marketable length of ~4 ft in 3 years with ambient temperatures. If the surrounding air and water temperature is maintained near 90°F, alligators will grow to 7 ft in the same 3 year period, doubling the potential income (Ray, 1990). Fish growth rates can be increased 50 to 100% with constant temperatures. Thus, utilizing the heat and fluid available in geopressured resources for agriculture/aquaculture applications can significantly improve growth rates, marketability, and profits. A brief summary follows of some agriculture/aquaculture applications under consideration for use at geopressured resources.

Greenhousing

A large variety of fruits, vegetables, flowers, and ornamentals can be grown in geothermally heated greenhouses; this has been proven using hydrothermal resources. The type of product selected for growth at a geopressured site will depend on the market. Heat from a geopressured resource would be utilized in greenhouses by separating actual heating equipment from the geopressured fluid. For operation purposes, a heat exchanger is placed between two circulating loops, the geopressured loop and the clean loop. Heating equipment could be finned pipe, unit heaters, finned coils or soil heating, depending on growers choice and resource temperature.

The potential for greenhousing with geopressured resources is very promising in Southern Louisiana and Southern Texas. It is recommended that

DOE make a well available to a developer for demonstration of the validity of using geopressured resources for this type of use.

The negative impacts of cold weather on the citrus industry and disruption of the marketing of agricultural crops continues to result in the considerable interest by industry, universities, and market development organizations, especially in Louisiana and Texas. Agro-Flex, a broad-based 13 parish nonprofit rural economic development program for Southwestern Louisiana, is continuing to conduct numerous market studies to select appropriate crops and to align the interested organizations and industry to aid in development in their geographic region. Victor Bendel Co., Hindale, IL, is a frozen food brokerage that is seeking ways to curtail frost damage to citrus trees and has expressed interest in using geopressured resources for this application. Riviana Foods, Houston, TX, is principally involved in rice processing and has expressed interest in using the geopressured energy for their plant needs. Although their demand for heat occurs over a relatively short period of time, in the summer when rice is harvested; they may have different operations in the future and would consider using geopressured energy. Lou Ana Foods, Inc., Opelousas, LA, has expressed interest in verifying the use of geopressured energy for greenhousing of various crops.

Production Plot Warming and Frost Protection

The effects of frost can be mitigated, and the growing season for different agricultural products can be extended by applying heated water to warm the soil through underground piping or above ground sprinkler systems and distribution systems, or both. Hydrothermal fluids (depending upon their chemical content) can be applied directly to agricultural plots; this was effectively proven in the Raft River Valley of southeastern Idaho where DOE operated a geothermal test facility in the late 1970s and early 1980s.

The potential to reduce the impact of frost upon agricultural crops, especially citrus trees, and to extend growing seasons for various crops in order to improve marketability appears very high in southern Texas and southern Louisiana where geopressured resources are potentially available.

The University of Southwestern Louisiana proposes to use geothermal heat from a geopressured facility to protect and extend the production of citrus crops. An open field unit would be developed with several experimental plots. One field would have much higher densities than those used in conventional citrus orchards to reduce heat loss from air movement among the trees; another would be heated by installing a subsurface system of hot water piping using geothermal fluids, and a third would be heated using a warm water sprinkler system (Huner and others, 1990).

Greenhouse production of citrus has been practiced on an extremely limited scale with enough success to warrant its investigation. Because some thermal protection of citrus is provided by greenhouses alone, only a minimal amount of supplemental heat would be necessary. The combination of greenhouse citrus production and the utilization of geothermal heat commands further study.

The University of Southwestern Louisiana proposes to utilize four greenhouses, each planted with a single cultivar of citrus at high density population to compare and evaluate geothermal heat as a practical means of providing greenhouse heat. Three methods of heating would be used; (a) a subsurface network of hot water piping to provide soil warming and radiant heating, (b) a hot water mist sprinkler system geared primarily toward protection, and (c) hot air to be supplied in a duct system that can be supplemented by solar radiation (a solar system is presently under construction in association with the university's Center for Greenhouse Research) (Huner and others, 1990).

Rearing of Fish, Crustaceans, Exotics, Turtles, and Alligators

Aquaculture involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The principal species being raised are catfish, bass, tilapia, sturgeon, shrimp, and tropical fish. Redfish and striped bass are also being reared. Aquaculture is one of the fastest growing applications for using low-temperature geothermal energy (Lienau, 1989). This growth is in response to an ever increasing demand for fish products, especially in Japan and other Asiatic countries. Controlled rearing temperatures increase growth rates by 50 to 100%; thus, increasing the number of harvests per year. In addition, the use of geothermal fluids in controlled rearing has been proven to reduce the incidence of disease.

The use of geopressured fluids to maintain optimum growth temperatures for fish, crustaceans, exotics, turtles, and alligators has a very high potential for application in Southern Texas, Southern Louisiana, and other areas where geopressured fluids are potentially available. Alligator culture is an emerging and lucrative industry. As previously noted, maintaining growth temperatures at ~90°F can cause an alligator to grow to ~7 ft in 3 years, whereas those grown under ambient conditions only reach a length of 4 ft in the same time period. Fish Breeders of Idaho is planning to utilize their 90°F hydrothermal resource to evaluate the rearing of a small quantity of alligators (Ray, 1990). The University of Southwestern Louisiana is proposing to determine the cost effectiveness of using waste heat from a geopressured facility to warm alligator cultivation units, to evaluate the use of biofilters to control waste levels in culture water, and to observe the benefits of eliminating cold shocks from periodic water changes (Huner and others, 1990).

Grant Emery, Sun City, CA, is seeking a site of 600 to 1000 acres to rear 8 to 9 million tilapia/a year for sale in the east coast market. He is interested in using a combination of solar and geopressured energies to maintain 85°F temperatures for the tilapia rearing.

Considerable interest has been expressed by various members of the Texas Aquaculture Association in the use of "thermal refuges" to shelter pond-reared fish during extreme winter conditions. One approach involves placing a cover over suspended cables on a corner of a pond forming a triangular shelter area. The cover is spread 1 to 2 ft above the surface of the pond, and on the side facing the pond. The cover is extended underwater and weighted in order to form a wall between the refuge and the open pond. A space is left for fish passage. Warm water is introduced to provide heat in the sheltered area, providing a warmed water refuge for the pond fish (Rafferty, 1990). Geopressured heated water can be utilized for this type of application.

Snapping turtles are important components of the aquatic fauna throughout the south. However, exploitation of snapping turtle resources has made them scarce and in great demand. Research has indicated that it may be feasible to cultivate them in the same way alligators are cultured. The University of Southwestern Louisiana is proposing to use a reptilian unit to investigate snapping turtle growth in culture units (Huner and others, 1990).

The soft-shell crustacean industry in Louisiana is becoming an important part of the aquaculture industry. One of the principal problems is the high cost of heating to maintain optimum growth temperatures (75 to 81°F) during the winter months. The University of Southwestern Louisiana is proposing to use part of an intensive aquaculture unit to examine the cost effectiveness of using geothermal heat to heat soft-shell crustacean units and to assess the feasibility of cultivating high value ornamental fishes in such systems (Huner and others, 1990).

Fingerling food fishes including tilapia, catfish, and striped bass are typically cultivated in open earthen ponds. This places them at considerable risk to predation, especially by birds. Winter water temperatures also curtail their growth, or in the case of tilapia, cause death when temperatures drop below 50°F. Intensive culture in enclosed units offers the potential for protection from predators, and an enhanced growth rate, by controlling water temperatures. The University of Southwestern Louisiana proposes to examine the cost effectiveness of using geothermal heat to heat a finfish fingerling unit, and to assess the feasibility of "head starting" fingerling food fish by cultivating them intensively during the cold months. Integration of ornamental fish into the system during warm months would be investigated (Huner and others, 1990).

The capability of growing exotic tropical species such as freshwater prawns and tilapia in heated nursery systems has been proven. These systems often use floating water hyacinths to provide substrate for the animals and remove waste products from the water. None of these systems have been economical because of the cost of heating the system, as well as the lack of use of water hyacinths. In southeast Asia, water hyacinths are composted for use as food supplements for carp and tilapia, suggesting that they might be useful as a food supplement for crawfish. The University of Southwestern Louisiana is proposing to use a symbiotic greenhouse aquaculture unit to determine the cost effectiveness of using geothermal heat for nursery production of exotic tropical species and to generate water hyacinths for composting and use as crawfish food supplements (Huner and others, 1990).

Processing

Temperatures available in geopressured resources are generally adequate for food and grain processing, and packaging. Specific applications are determined by market needs, the types of food and grains available, and transportation economics. Cooling needs can be met by using refrigeration units that use energy from the hot geothermal fluids, or from gas-fired units using gas that is available in the geopressured resource. The refrigeration units can also be driven with electricity from a binary cycle generator installed at a geopressured facility.

Agricultural crops and fish processing have high potentials for development in areas where potential geopressured resources are located. Agro-flex is investigating various applications for use in the 13 parishes in Louisiana that the organization represents. Installing facilities to process products resulting from an integrated geopressured facility could prove to be an economical adjunct.

ECONOMIC CONSIDERATIONS

This section includes a discussion of economic considerations for geopressured application. Specific cost information is provided for the areas that appear to have the greatest potential for direct use, such as desalination, an integrated agriculture/aquaculture facility, and gas and brine sales.

GENERAL

Current economics do not allow a geopressured well to be developed for the exploitation of only natural gas because of the high investment costs and marginal quantity and quality gas produced. However, because of the size of the geopressured reservoir and the presence of hot fluids under high pressures, it is possible that a mix of applications that exploit these resources could prove to be economical. It is the purpose of this economic study to investigate if a cascading of energy applications such as gas sales, desalination of water, and agriculture/aquaculture would be economical from a developers point of view.

Specific market needs in geopressured regions will encourage those applications that will produce the greatest net return and benefits. For example, the lower Rio Grande Valley of Texas and the central valley of California have the concurrent need of potable water and presence of geopressured resources. Site specific desalination and agriculture/aquaculture applications could result in the profitable development of a geopressured resource.

It is essential that all available options are evaluated and balanced to derive optimal scenarios in which the guiding principle is to extract the highest return on investment under the specific constraints that are imposed upon the installation. The use of other energy feedstocks, such as common fossil fuels and other wastes, biomass, etc., should also be considered so that environmental considerations, conservation of energy, and careful design all contribute to a synergy.

The choice of sites can have a significant impact on the total installed and operating cost of a facility. Soil characteristics, climate, freshwater availability, waste disposal requirements, market accessibility, availability of goods and services, utility requirements and regional sales prices for gas and electricity are but a few of the considerations that affect the selection of a specific site.

Generalized costs have been developed for workover of geopressured wells, a desalination facility, and an agriculture/aquaculture installation, the combination of which appears to possess the greatest potential for near term utilization. Throughout the analyses, conservative values are assigned to all cost and revenue items. Obviously, any one cost assumption cannot address all of the factors appropriate to a site specific location. It is critical that these generalized costs are not given "gospel" status and are presented as conservative analyses for an assumed installation.

The costs associated with the development of any one facility are affected by previous experiences and the interpretation, interpolation, and extrapolation of data for planned installations. Because of the numerous market and resource variables and because an exact duplicate of an existing facility is likely not available, both capital and operating costs are going to be hard to derive by a mere examination of past data. Any responsible application of technologies that exploit the available energy in a geopressured resource will have to be matched by the economic skills of market analysis and product development.

ECONOMIC METHODOLOGY AND ASSUMPTIONS

The Present Value (PV) methodology is used to calculate the discounted payback and Net Present Value (NPV) of selling a selected array of products from a geopressured-geothermal resource. Often referred to as a Discounted Cash Flow Analysis (DCFA), PV analysis is an economic method or process of equating all past, present, and future costs and revenues to a common point-of-time value. Analysts generally prefer PV analysis over other economic techniques because cash flows are accounted on a real-time, common economic techniques because cash flows are accounted on a real-time, common dollar basis. This common dollar basis is obtained by discounting all after-tax cash values to a PV cash value using a discount rate. This discount rate is a percentage by which future value dollars are reduced year to year to a present value. Because the discount process substantially reduces the PV of projects with economic lives >5 a year, selection of a discount rate is a very important consideration. A 15% discount rate is a commonly accepted discount rate in developing mineral resources while a 26% discount rate allows for a higher risk typically associated with gas and oil development. Because the cascaded or multi-use of the geopressured-geothermal brine increases the complexity while also diversifying the product mix, a 15% discount rate was assumed.

Results of this study are presented in a discounted payback and NPV analysis. (The breakeven analysis was not used because of the array of combinations available and assigning market ratios between each product). Discounted payback is defined as the minimum time required for the project to generate enough discounted revenues to equal the initial investment of the project. Investors and lending institutions typically use this method to assess the time to recover their investment. The shorter the payback, the less risky the investment because market conditions are less likely to change in the shorter period of time than in a longer period of time. NPV is another method of analysis that determines the net value added to an investment. As the name implies, the initial investment is subtracted from the present value of operating revenues less costs. Again, investors and lending institutions typically use this method of analysis to assess the overall profitability of a project, selecting the project with the greatest NPV.

Desalination Economics

There has not been sufficient replication under similar conditions to warrant extrapolation of prior economic data. Regardless of the desalination process, there are a number of variables that will affect the cost of a facility:

1. Quality and quantity of raw geopressured fluid

2. Temperature of raw geopressured fluid
3. Degree of desalination desired
4. By-products (electricity, chemicals, gas, mixed salts)
5. Spent geopressured fluid disposal
6. Geopressured fluid utilization constraints
7. Piping features
8. Site-specific factors
9. Suppliers of desalination equipment
10. Environmental considerations and constraints.

Experience gained by International Management Services has shown that the production cost of potable water can range from $8/1000 gal to practically zero, depending upon the particular mix of conditions.

A fundamental consideration in the selection of a desalination process is the required amount of energy to produce desalinated water, i.e., pounds of product water per pound of steam. The relative cost of other energy feedstocks (i.e. natural gas, diesel oil, fuel oil, etc.) that could be used to drive a desalination facility should be considered in the selection process. Current analysis of these tradeoffs indicate that when other products or energies can be produced and marketed from a geopressured resource, the cost of energy for desalination approaches zero; in effect, the sale of water has to recover only the cost of capital equipment and operating costs.

Site selection can have a significant impact on the installed cost and operating expense of a desalination plant. Site-specific constraints, climatology, soil bearing characteristics, and brine disposal all affect the cost. Whether or not a market is available or could be developed is a very important consideration.

The sale of other by-product chemicals, such as bromine, could improve the viability of a desalination plant. For example, the demand for concentrated brines in Mexico is high and steady and can be marketed for $2/ton. Vulcan Chemicals also quoted the cost for NaCl saturated brine in the Hutchinson-Wichita, KS area as $2/ton.

Assuming a geopressured well can produce 20,000 bpd of fluid @ 300°F and for 10 years, desalination of geopressured brine integrated with the production of methane gas is an economically viable investment in a water starved region. Assuming a 15% discount, payback will occur in 4.3 years and have a NPV is $4,355,000 in 10 years. If the bottled water facility is not included, the discounted payback period is 8.2 a year with a NPV of $546,633 (Figure 11). This analysis shows the significant impact of using a bottled water facility to greatly increase revenues.

Adding a binary power generator and selling electricity at 6 cents/kWh and selling gas and bulk and bottled water will result in a discounted payback period of 6.2 a year and a NPV of over $2,862,000.

AGRICULTURE/AQUACULTURE ECONOMICS

Based on the data assumed for a typical geopressured well, the potential is marginal for development of agriculture and aquaculture in most instances although feasible in site specific areas primarily targeted for a high value added product. Economic analysis is based on the following well conditions:

- Flow = 580 gpm (20,000 bpd)
- Temperature = 290°F
- Total chlorides = 72,000 mg/L (ppm)
- Location = Pleasant Bayou, TX
- The geopressured fluid is cooled to ~250°F as it passes through a binary power generator before it is made available for the greenhouse facility.

There are many possible combinations in which a facility can be developed; each approach will alter the project costs and profitability. Because this industry is in a development stage and immature financially, it is most likely that a facility would be installed in phases as markets develop. Phased development would require a lower initial capital requirement. Accordingly, the analysis developed costs for the first phase of a multi-phase greenhouse and aquaculture facility. Phase 1 of this installation would include three fiberglass covered greenhouses, each 42 x 348 ft. A fiberglass covered cooling pad house 21 x 348 ft would be attached to one side wall. The cooling pad house would not be heated. A 84 x 50 ft sheet metal covered service building is included. Following the agriculture application, an aquaculture facility would be an enclosed 36 x 96 ft fiberglass "greenhouse" which would house three 20 ft diameter aquaculture tanks. Following the aquaculture facility, would be an 8 x 45 ft outdoor recirculating raceway tank. Figures 10 and 11 illustrate the heat exchanger arrangement for the Phase 1 installation.

Eight phases of future expansion could result in 8 acres of greenhouses, and 2.8 acres of recirculating aquaculture raceways or 3.2 surface acres of flow-through raceways. Figure 12 depicts a possible eight phase installation with one aquaculture facility. The aquaculture facility could be repeated for each phase of greenhouses, if so desired.

Phase 1 cost estimates (Table 3) for installed greenhouses are from Campbell Glasshouses, Inc. Greenhouse structure costs will vary by location. The geothermal heating systems components are estimated from aquaculture systems costs provided by Red Ewald, Inc. (Appendix C). These costs are provided for rigid wall type structures and are not used for the economic analysis given later in this study. Data used in the economic analysis are from the Comparative Performance Analysis prepared by Southwest Technology Development Institute.

Table 3. Agriculture/aquaculture first Phase Cost Estimate

Greenhouse/Pad House (51,156 ft^2)	$352,600
Service Building (4,200 ft^2)	43,300
Mechanical Equipment (Heat exchanger, etc.)	11,900
Aquaculture Enclosed Facility	90,700
Aquaculture Outdoor Raceway	16,300
15% Overhead and Profit	77,000
20% Contingency	102,700
TOTAL	$694,500

Note: Well development costs are addressed separately

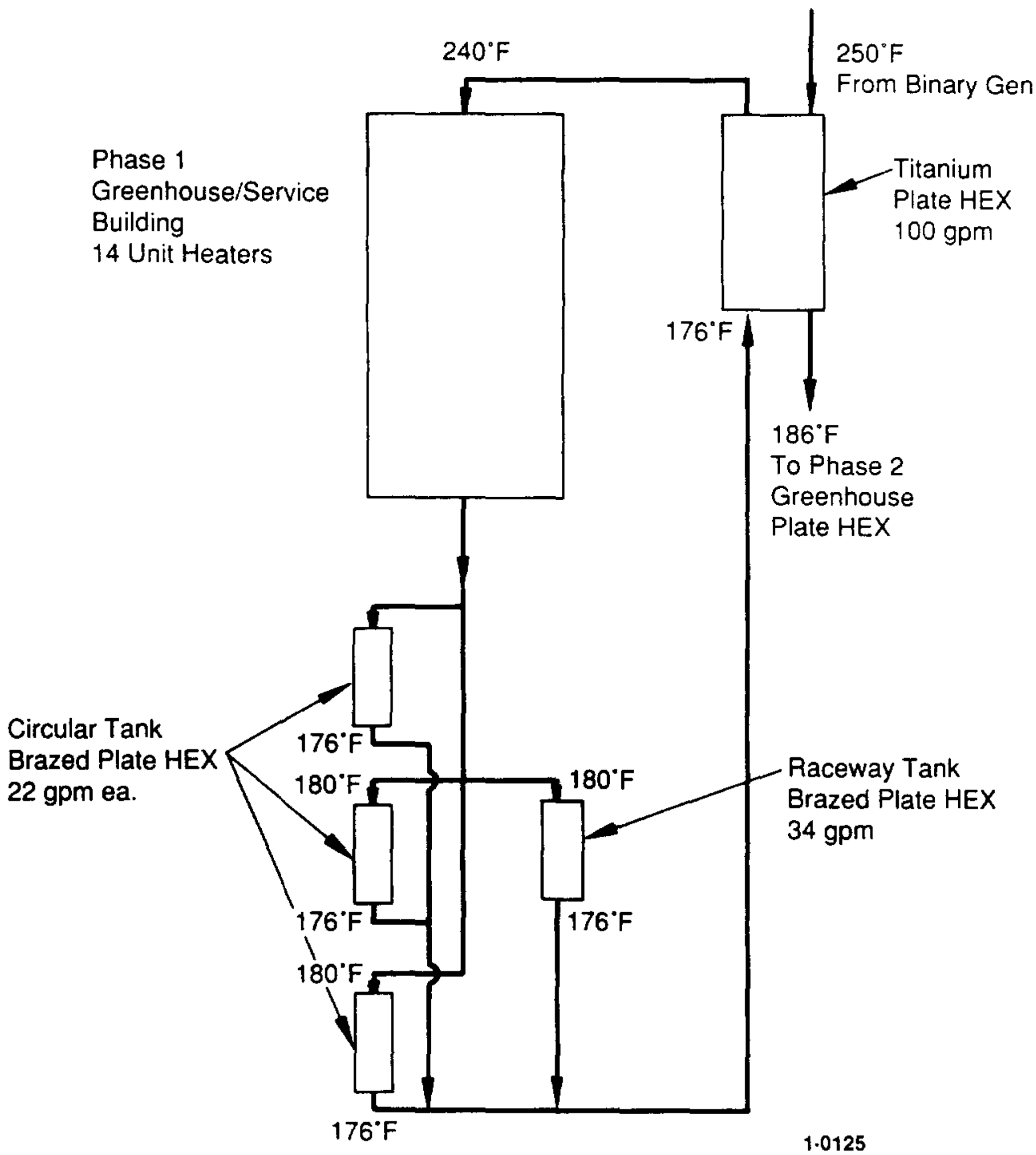

Figure 10. Process flow diagram for phase 1 greenhouse/aquaculture complex.

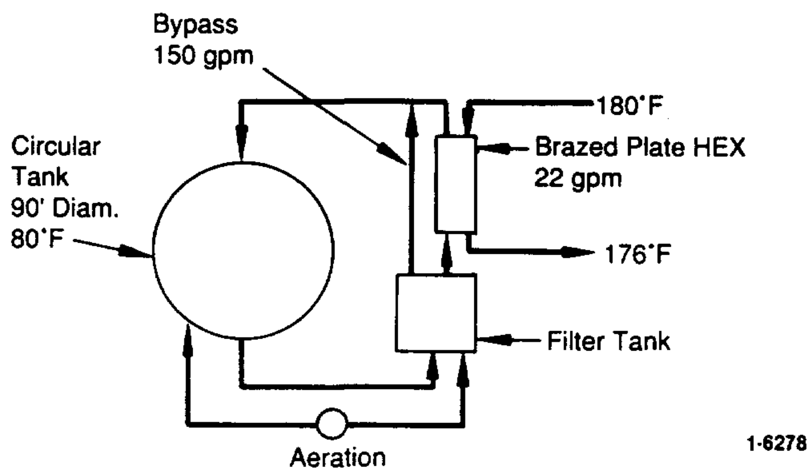

Figure 11. Aquaculture high density recirculation system.

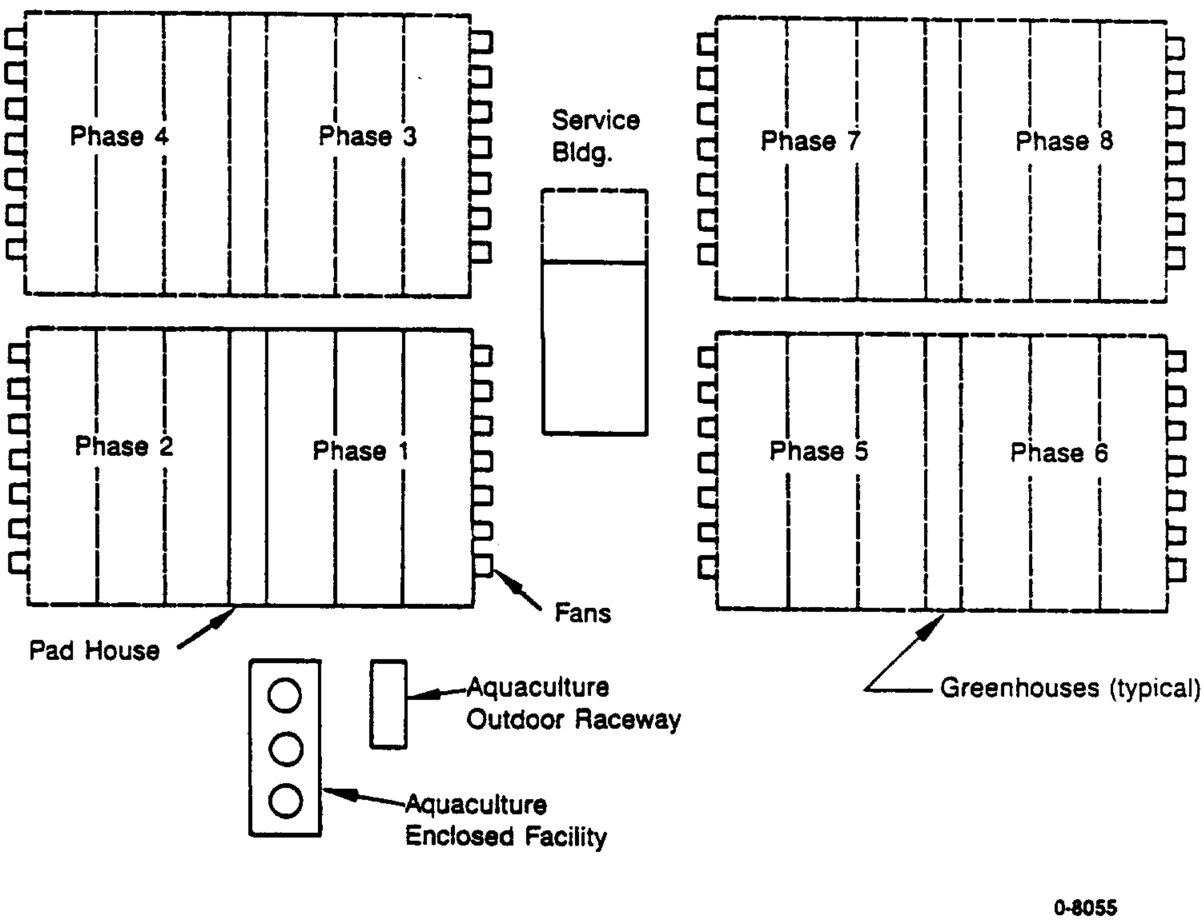

Figure 12. Potential greenhouse/aquaculture complex.

Potable water for agriculture and aquaculture needs could be obtained from surface water sources, wells, or through desalination using the geopressured fluids. Costs related to surface water usage are normally considered relatively minor. Desalination costs are addressed in a previous section. A freshwater well and 10,000 gal storage tank would cost ~$46,000.

The Southwest Technology Development Institute, New Mexico State University at Las Cruces, New Mexico continues to be extensively involved in the utilization of geothermal resources, especially for greenhouses. The following information is from comparative performance analyses that were prepared by Whittier and Fischer (1990).

Profitability of a greenhouse operation varies for each site, but is directly attributable to one major operating factor that controls the industry: greenhouse space represents a fixed production area. There are few options within reason, to increase annual production from the greenhouse. Because production is fixed, annual revenue is similarly fixed. Opportunities for increasing profitability come from lowering operating costs (Whittier and Fischer, 1990, Appendix F). Using the energy available in geopressured resources may become a means toward this end.

There are many factors that affect the profitability of greenhousing. Capital costs for an installed greenhouse complex vary by location, depending upon such factors as the amount of available sunlight, heating and cooling needs, etc. The amount of available sunlight also affects production levels, especially for cut flowers. State corporate franchise tax rates, variations in Workers' Compensation rates in different states, local labor wage rates, transportation rates, labor availability, property tax rates, cost of energy, water requirements, and market availability also impact the profit margin. A new firm will wish to carefully evaluate individual sites on a case-by-case basis before selecting a location (Whittier and Fischer, 1990, Appendix F).

A comparative performance analysis (Whittier and Fischer, 1990, Appendix F). has been conducted to examine the various factors associated with establishing and operating a commercial rose cut-flower greenhouse in ten different locations across the United States. Plant productivity, defined as net blooms produced per plant per year, is largely dependent upon local climatic conditions and technological improvements. Regional variations in productivity have been explicitly analyzed. The greenhouse operation is assumed to be four acres in size and the facilities utilize current technologies. The operation is designed as a professionally organized company with an owner/manager, grower, and salesperson. The primary product is a red hybrid tea rose for the wholesale market, generally located in large metropolitan areas. The analysis strongly indicates that new installations for cut-flower rose production are profitable in several areas in the southwest U.S., particularly in New Mexico, Arizona, and Texas. No one area stands out as a favored location; however, Las Cruces, N.M., has the highest net present value and return on investment of those sites investigated (Whittier and Fischer, 1990, Appendix F).

Based on the pro forma model results for the Las Cruces area, an area that may be more typical of areas in the gulf coast region where geopressured resources exist, a cut-flower rose operation may be established and operated in a southwest location at a profitable level. Because of lower real estate prices and the lack of high intensity discharge lighting in the southwest, less capital is required to start a new greenhouse business. However, this analysis does not factor in the cost of a developing geopressured well as the heat source. If the geopressured facility only sells methane and the agriculture/aquaculture products, adding the well results in a 15% discounted payback period of slightly over 10 years. Because of the marginal economics of this facility, an aquaculture/agriculture facility could be coupled with other uses such as a desalination facility to be more profitable. When the facility includes methane, desalinated water, bottled water, salt, and agriculture/aquaculture products, the discounted payback period is reduced to 4 years, with a 10 years NPV of about $6 million. The addition of electricity generation with a methane agriculture/aquaculture facility significantly increases the discounted payback period to over 10 years, when the power is sold at 6 cents/kWh.

DESALINATION/AGRICULTURE/AQUACULTURE ECONOMIC RESULTS

The study included one more analysis, a geothermal turbine unit was installed with desalination and an agriculture/aquaculture facility, taking advantage of the cascading energy values. Results suggest that this scenario becomes profitable only where the market price for electricity exceeds 5 cents/kWH. Currently, many areas of the country that have geopressured resources also have a surplus electrical capacity and generation, thus power utilities have been offering less than 2 cents per kWH, well below the reasonable breakeven value of 5 cents per KWH. However, when the energy demand of the integrated facility is large enough to install power generation equipment, savings will be obtained by not having to paying the 10 to 12 cents per kWH utility rate.

This study indicates that employment of other direct use technologies, specifically desalinated water production, can contribute significantly to the value added process and the overall economic viability in developing a geopressured resource. Additionally, although agriculture and aquaculture applications are marginal projects when they are the only application with a geopressure well, the small margin of profitability can contribute to improving the overall economics of additional direct use developments. The added complexity will have to be balanced with the increased technical and management complexity and may add to the overall risk and unpredictability of the project.

Table 4. Discounted payback periods for various geopressured integrated facilities.

Facility Type	15% Discounted Payback Period (y)	10 y NPV[a] ($)
Methane gas/brine salts/bulk and bottled water/agriculture/aquaculture	4.0	5,800
Methane gas/brine salts/bulk and bottled water	4.3	4,355,000
Electricity @ 6 cents/kWh/methane gas/bulk and bottled water	6.2	2,862,600
Methane gas/brine salts/bulk water	8.2	546,600
Methane gas/agriculture/aquaculture	>10.0	(19,000)
Electricity @ 6 cents/kWh/methane gas/agriculture/aquaculture	>10.0	(1,511,400)

[a] Net present value.

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APPENDIX A

SEATTLE TIMES EDITORIAL
"CALIFORNIA WON'T FACE WATERING TRUTH
MAY 27, 1990

CALIFORNIANS WON'T FACE WATERY TRUTH

Mindy Cameron
Times editorial page editor

Once upon a time there was a scheme called the North American Water and Power Alliance. NAWAPA was a grandiose plan for rearranging resources, a way to undo Mother Nature's design and better serve a booming population.

The gigantic water transfer plan was born in the '60s at a Pasadena engineering firm, Ralph Parsons Co. It was the brainchild of engineers with a can-do bravado second to none.

When I first heard about NAWAPA, I thought it was a joke. It was 1977. The young vigorous environmental movement was gaining momentum, so much so that President Carter had dared to propose major reforms of water use and scrapping 19 water-development projects. Surely in this new age no one was seriously contemplating such a colossal transfer of water?

But it was no joke to the folks at Parsons. Then, as now, Southern California was in the midst of a drought. Many experts were trying to solve the puzzle of the region's perpetual water shortage.

Ralph Parsons Co. was touting NAWAPA as the answer. A promotional film explained the scheme. Water, a solemn voice proclaimed "is a continental problem which requires a solution that is also continental."

This was serious stuff. As the graphics unfolded on the screen, showing waterways snaking down the continent from Alaska, through Canada, the Northwest, the voice described the awesome proportions of the plan: larger than the Alaska pipeline; $200 billion hundreds of dams; huge tunnels through mountains; canals hundreds of feet wide.

NAWAPA lives on in the mid of Los Angeles County Supervisor Kenneth Hahn who this month persuaded his colleagues to back his proposal to divert water from the Columbia and Snake Rivers to Southern California.

Sure, it's a nutty idea to those of us who are accustomed to having rivers do most of their work within their banks.

But water and rivers have a different meaning to some Southern Californians.

Life there depends on imported water. Los Angeles survives -and thrives - thanks to the world's largest water transfer system. The longest of the three watery lifelines is a 444-mile, man-made river system. It even defies gravity. Fourteen pumps lift water nearly 2,000 feet over the Tehachapi Mountains north of Los Angeles.

Unfortunately, the great effort by which this water is provided has not fostered greater appreciation by users. To the contrary.

Agriculture accounts for 85 percent for all the water used in California. Much of it is squandered by farms, including many huge agriculture conglomerates, whose water rates are kept low through federally subsidized irrigation projects of the Bureau of Reclamation. There is little incentive to switch from wasteful flood irrigation practices to drip or other, more conservative methods of crop irrigation. Domestic use is much the same story. The few communities not tied to the state's huge water system are notable exceptions. Marin County for example, has had water-conservation requirments in place for years. The latest dry cycle is forcing water rationing on other communities.

But despite the clear warning signs of the late '70s, Southern California has refused to come to grips with its most basic reality. It is a desert region of severely limited water resources. In direct definance of that reality, lush new suburbs, often, surrounding man-made lakes, continue to crop up in the arid hills farther and farther from Los Angeles.

California bashing is a favorite Northwest pastime right now. There's plenty of evidence to suggest they don't deserve the blame we have so gleefully laid at their doorstep Californians aren't responsible for our crowded freeways, our spiraling housing costs, our dwindling open spaces.

But now the folks who run Los Angeles County have fired what they call "a shot in the dark." Kenneth Han's proposal would have the governors of seven Western states and President Bush respond to the latest drought cycle in Southern California by ordering the U.S. Corps of Engineers to design and build the aqueducts to transfer water from the Northwest to Southern California.

It won't happen of course But all of a sudden Hahn's shot in the dark gives substance to what until now has been a frivolous exercise.

Fire away Bash at will Californians who persist in the notion that their playground is the center of the universe are an easy and deserving target. Why in the world should the rest of us serve up our precious resources to keep their desert blooming?

Mindy Camerons column appears Sunday on The Times editorial page.

APPENDIX B

HEATING REQUIREMENTS FOR THERMAL REFUGE AREAS
(K. RAFFERTY, OREGON INSTITUTE OF TECHNOLOGY GEO-HAT CENTER)

MEMO

DATE: February 19, 1990

TO: Interested TAA Members

FROM: Kevin Rafferty, Geo-Heat Center

SUBJECT: Heating Requirements for Thermal Refuge Areas

Following this year's Texas Aquaculture Association meeting and field trip, I had the opportunity to meet with several of the commercial growers and tour their facilities (including: Redfish Unlimited, Southwest Mariculture and Sealantic Inc.). Much of the discussion on the field trip and in subsequent meetings focused on the issue "thermal refuges" to shelter the fish during extreme winter conditions.

The design for a refuge which seemed acceptable for most operators involves an arrangement modeled after that used successfully by Richie Farms this winter. In this case a cover was suspended by cables over a corner of the pond forming a triangular sheltered area. The cover was installed approximately level with the pond banks (only a foot or two off the water). On the side facing the pond, the cover was extended underwater and weighted in order to form a wall between the refuge and the open pond. A space was left between the cover and the bottom of the pond for fish passage.

Richie Farms had the advantage of using an 86°F well to provide heat for their thermal shelter. For most other operators, some other source (boilers, etc.) would be required to provide the heat input. The enclosed curves were developed to assist in heater sizing.

Three curves are provided, one each for 50°, 60° and 70°F pond water. This temperature refers to the value which would apply to the water <u>under</u> the cover. Three types of lines appear on each graph. The lines sloping from lower left to upper right correspond to outside air temperature and represent the heat loss through the cover (from the air under the cover to the outside air). The lower curve, sloping from the upper left to the lower right represents the heat gain from the pond surface to the air under the cover. The upper curve sloping from upper left to lower right is a plot of the required heat input to the water. To use the graphs, first select the graph associated with the minimum temperature which you wish to maintain in the refuge (50°, 60° or 70°F). Using the minimum outside temperature which you feel appropriate to your location, find the intersection between the curve for that temperature and the heat gain curve. Proceed vertically to the intersection with the heat input curve. From the intersection proceed horizontally to the y-axis to read the heat input requirement in Btu/hr per square foot of sheltered pond surface.

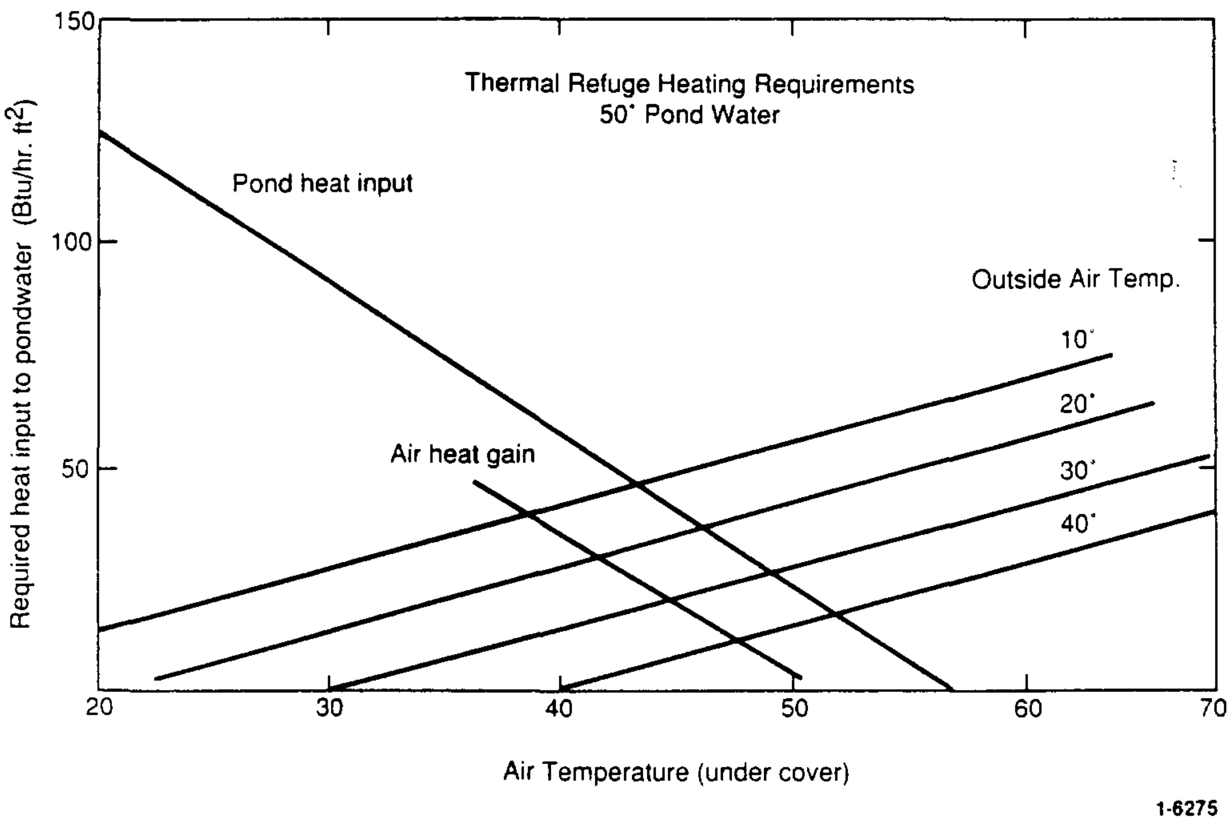
The following example (see 60° graph) illustrates the use of the graphs. Assume that a grower wishes to cover 5,000 ft^2 of pond and maintain 60°F in the refuge area. The location is such that 20° can be safely used for the design outside temperature. Based on these factors, the heating requirement for the refuge would amount to 72 Btu/hr per square foot of pond surface under the cover. The total requirement for 5,000 ft^2 would be 5,000 ft^2 x 72 Btu/hr·ft^2 = 360,000 Btu/hr. As a result, the heater selected for this application should be capable of a minimum of 360,000 Btu/hr output.

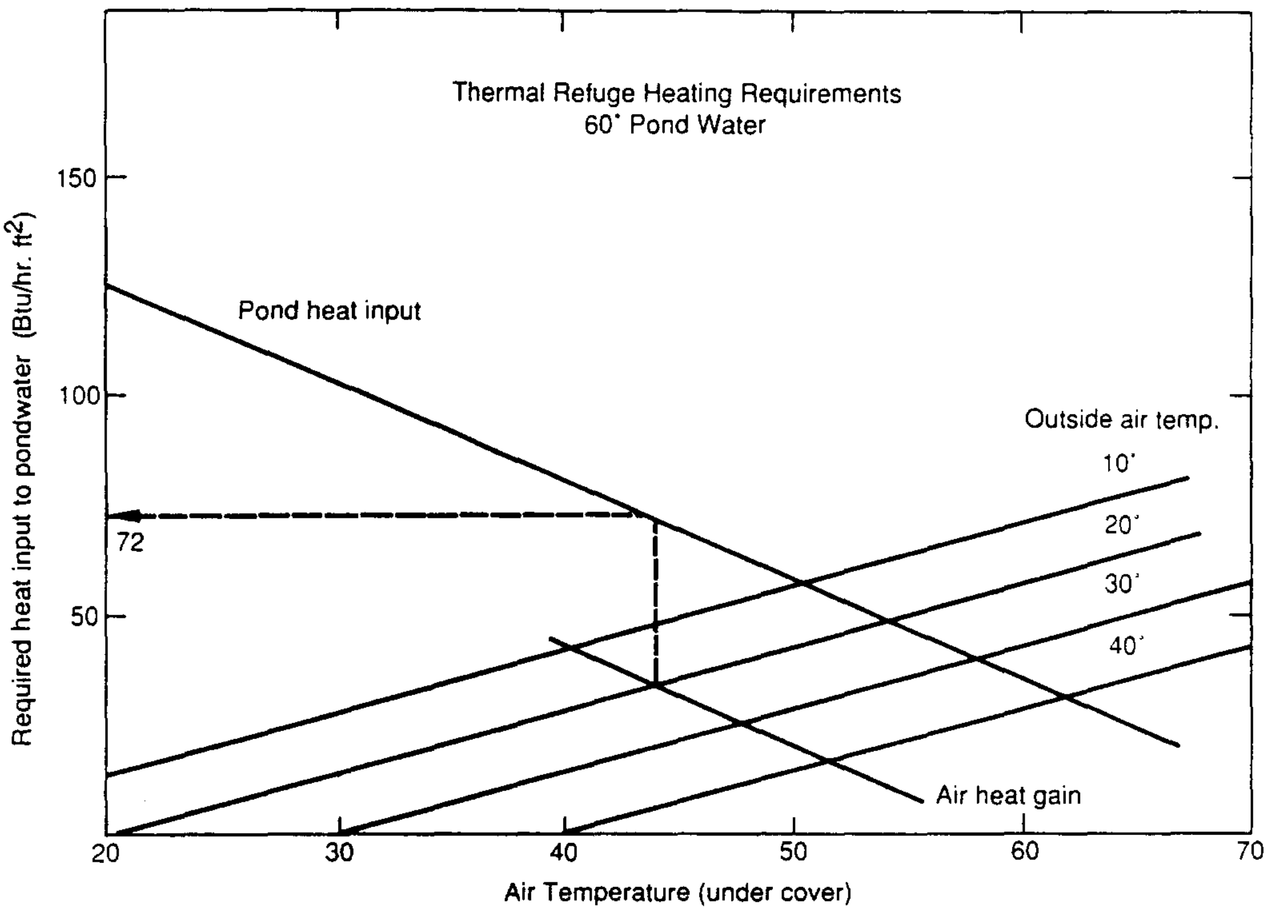
I must stress that the values used to develop these graphs are calculated heat losses. I have no direct experience with this type of cover to use as verification of the calculations. As a result, I have used a conservative approach to develop the numbers.

There are two considerations with regard to the use of this type of thermal refuge which warrant emphasis.

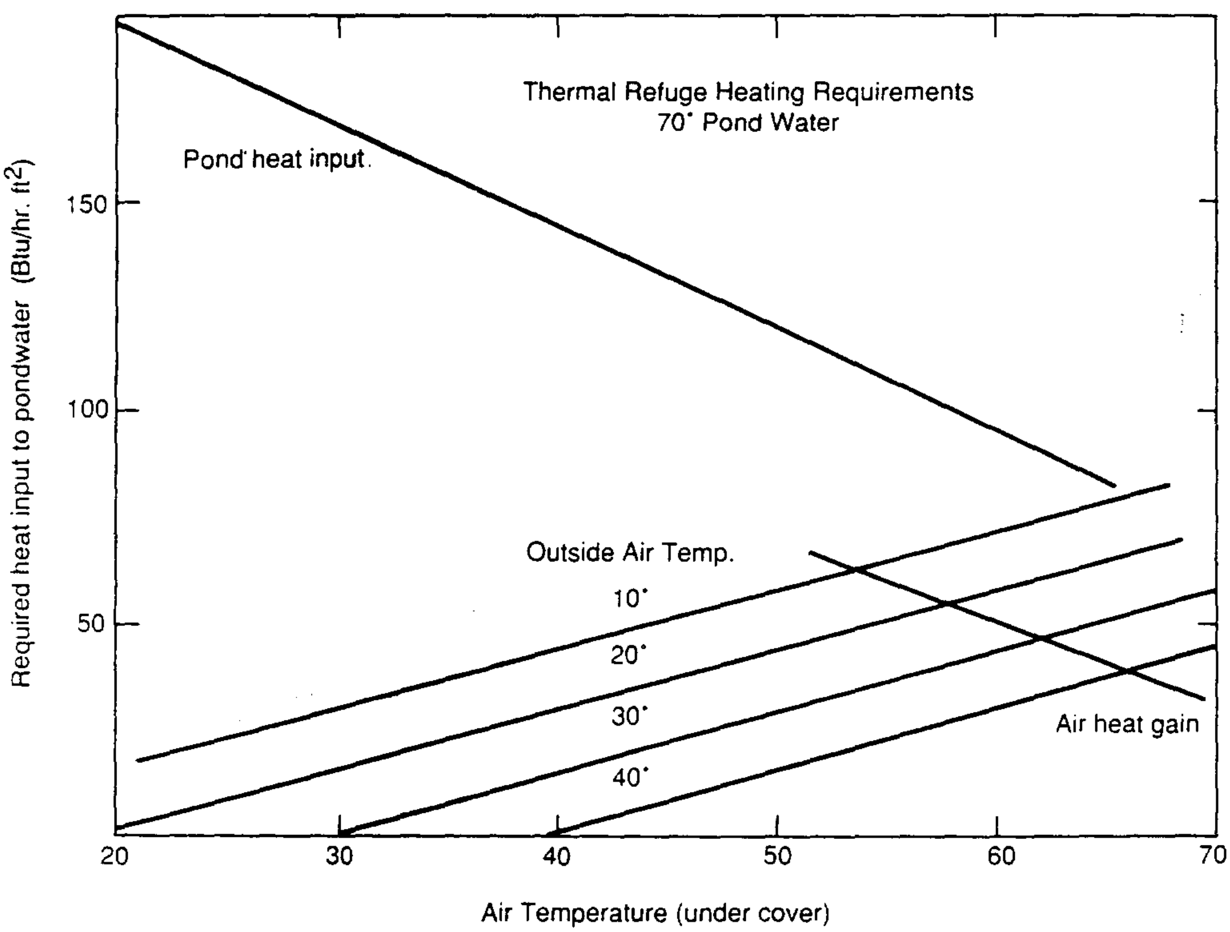
1. When installing the cover, it is most important to keep it <u>above</u> the water. Once the cover is permitted to rest on the surface of the water, its effectiveness is severely compromised. You may wish to consider using "floats" of some sort (styrofoam, tire tubes, etc.) to prevent the cover from falling onto the pond surface.

2. It is important to anticipate the need for the thermal refuge and begin adding heat as far in advance of need as possible. The heat loss values which appear in the graphs assume that the water under the shelter is already at the required temperature. Heating input necessary to bring the water up from a lower temperature can be significant. Using the example pond, and assuming an average depth of 4 ft, a total of 150,000 gallons would be contained under the cover (5,000 ft^2). To heat this water from 50° to 60° would require a total of 12,500,000 Btu or 35 hours of continuous operation at full heater capacity. If it will be necessary to bring the refuge temperature up to the desired value (from a lower temperature), this heaing load should be the basis for heater sizing rather than the steady state approach outlined above.


Thermal Refuge Heating Requirements
50° Pond Water
Pond heat input
Air heat gain
Outside Air Temp.
10°
20°
30°
40°
150
100
50
20
30
40
50
60
70
Required heat input to pondwater (Btu/hr. ft^2)
Air Temperature (under cover)
1-6275


Thermal Refuge Heating Requirements
60° Pond Water
Required heat input to pondwater (Btu/hr. ft^2)
150
100
50
Pond heat input
Outside air temp.
10°
20°
30°
40°
72
Air heat gain
20
30
40
50
60
70
Air Temperature (under cover)

1-6274


Thermal Refuge Heating Requirements
70° Pond Water
Pond heat input
Outside Air Temp.
10°
20°
30°
40°
Air heat gain
Required heat input to pondwater (Btu/hr. ft²)
150
100
50
20
30
40
50
60
70
Air Temperature (under cover)

1-6276

APPENDIX C

INTEGRATED APPLICATIONS ECONOMIC ANALYSES

25-Sep-90 : date
08:35:39 AM : time

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
MODEL NAME: GG10-A3
MODEL ANALYSIS: Methane/Salts/Bulk & Bottled Water/Agri & Aqua Products

RESULTS :

10-YR NPV	$5,357,976
Discounted Payback	4.0 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$6,996,516
Borrowed	2,469,390		
Owners Equity	4,391,310		
Capitalized Interest	135,816		

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$6,996,516
TOTAL DEVELOPMENT COST		2,199,750	
Geopress-Geothermal Well	2,199,750		
Pipeline Right-of-Way	0		
TOTAL CAPITAL BUILDING/EQUIPMENT COST.		4,037,250	
Geotherm & Elec Eq	199,500		
Gas Separator & Trans	120,750		
Bulk Water/Salt	1,569,750		
Bottled Water	630,000		
Rose/Greenhouse	887,250		
Fish/Aquaculture	210,000		
Working Funds	420,000		
CONTINGENCIES		623,700	
CAPITALIZED INTEREST		135,816	
GROSS OPERATING REVENUES			$4,117,857
TOTAL COSTS (yr-1)		1,565,878	
Geopress-Geotherm/Elec	366,450		
Methane Gas	108,306		
Bulk Water/Salt	324,975		
Bottled Water	246,750		
Rose/Greenhouse	338,363		
Fish/Aquaculture	42,000		
Contingencies	138,534		
TOTAL REVENUES (yr-1)		5,683,735	
Geopress-Geotherm/Elec	926,676		
Methane Gas	0		
Bulk Water/Salt	1,626,003		
Bottled Water	1,844,176		
Rose/Greenhouse	1,226,400		
Fish/Aquaculture	60,480		
TOTAL POST-OPERATION COSTS			$301,346
SALVAGE (at end of project life)			$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR)	15.0 %
Debt Ratio	40.0 %
Interest Rate	11.0 %
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0 %
Taxes :	
Federal Tax	38.0 %
State Tax	2.0 %
Severance Tax	5.0 %
Ad Valorem Tax	7.2 %
Inflation Rate	5.0 %
Cost Escalation :	
Development and Capital Cost	0.0 %
Op/Post-Op Costs & Expenses	0.0 %
Revenue Escalation :	
Electricity	0.0 %
Bulk & Bottled Water/Salts	0.5 %
Methane Gas	1.0 %
Fish/Aquaculture	0.0 %
Roses/Greenhouse	0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life	10 yrs
Brine Temp @ Surface	300 F
Barrels per Day	20,000 BPD
Gas Concentration / Barrel	80 scf/B
Gas Quality	90 %
Bottom Hole Pressure	15,000 psi
Flowing Wellhead Pressure	2,000 psi

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
MODEL NAME: GG10-A3
MODEL ANALYSIS: Methane/Salts/Bulk & Bottled Water Products

25-Sep-90 : date
08:37:24 AM : time

RESULTS :

10-YR NPV	$4,355,070
Discounted Payback	4.3 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS		$5,762,988
Borrowed	1,986,600	
Owners Equity	3,667,125	
Capitalized Interest	109,263	

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$5,762,988
TOTAL DEVELOPMENT COST		2,199,750	
Geopress-Geothermal Well	2,199,750		
Pipeline Right-of-Way	0		
TOTAL CAPITAL BUILDING/EQUIPMENT COST.		2,940,000	
Geotherm & Elec Eq	199,500		
Gas Separator & Trans	120,750		
Bulk Water/Salt	1,569,750		
Bottled Water	630,000		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
Working Funds	420,000		
CONTINGENCIES		513,975	
CAPITALIZED INTEREST		109,263	
GROSS OPERATING REVENUES			$3,245,176
TOTAL COSTS (yr-1)		1,151,679	
Geopress-Geotherm/Elec	366,450		
Methane Gas	108,806		
Bulk Water/Salt	324,975		
Bottled Water	246,750		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
Contingencies	104,698		
TOTAL REVENUES (yr-1)		4,396,855	
Geopress-Geotherm/Elec	926,676		
Methane Gas	0		
Bulk Water/Salt	1,626,003		
Bottled Water	1,844,176		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
TOTAL POST-OPERATION COSTS			$301,346
SALVAGE (at end of project life)			$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR)	15.0 %
Debt Ratio	40.0 %
Interest Rate	11.0 %
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0 %
Taxes :	
Federal Tax	38.0 %
State Tax	2.0 %
Severance Tax	5.0 %
Ad Valorem Tax	7.2 %
Inflation Rate	5.0 %
Cost Escalation :	
Development and Capital Cost	0.0 %
Op/Post-Op Costs & Expenses	0.0 %
Revenue Escalation :	
Electricity	0.0 %
Bulk & Bottled Water/Salts	0.5 %
Methane Gas	1.0 %
Fish/Aquaculture	0.0 %
Roses/Greenhouse	0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life	10 yrs
Brine Temp @ Surface	300 F
Barrels per Day	20,000 BPD
Gas Concentration / Barrel	80 scf/B
Gas Quality	90 %
Bottom Hole Pressure	15,000 psi
Flowing Wellhead Pressure	2,000 psi

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
MODEL NAME: GG10-A4
MODEL ANALYSIS: Electricity@$0.060/Methane/Bulk & Bottled Water Products

25-Sep-90 : date
08:39:18 AM : time

RESULTS :

10-YR NPV	$2,862,583
Discounted Payback	6.2 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$8,867,466
Borrowed	3,201,660		
Owners Equity	5,489,715		
Capitalized Interest	176,091		

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$8,867,466
TOTAL DEVELOPMENT COST		2,199,750	
Geopress-Geothermal Well	2,199,750		
Pipeline Right-of-Way	0		
TOTAL CAPITAL BUILDING/EQUIPMENT COST.		5,701,500	
Geotherm & Elec Eq	2,961,000		
Gas Separator & Trans	120,750		
Bulk Water/Salt	1,569,750		
Bottled Water	630,000		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
Working Funds	420,000		
CONTINGENCIES		790,125	
CAPITALIZED INTEREST		176,091	
GROSS OPERATING REVENUES			$3,502,789
TOTAL COSTS (yr-1)		1,465,262	
Geopress-Geotherm/Elec	651,525		
Methane Gas	108,806		
Bulk Water/Salt	324,975		
Bottled Water	246,750		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
Contingencies	133,206		
TOTAL REVENUES (yr-1)		4,968,051	
Geopress-Geotherm/Elec	926,676		
Methane Gas	571,196		
Bulk Water/Salt	1,626,003		
Bottled Water	1,844,176		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
TOTAL POST-OPERATION COSTS			$301,346
SALVAGE (at end of project life)			$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR)	15.0 %
Debt Ratio	40.0 %
Interest Rate	11.0 %
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0 %
Taxes :	
Federal Tax	38.0 %
State Tax	2.0 %
Severance Tax	5.0 %
Ad Valorem Tax	7.2 %
Inflation Rate	5.0 %
Cost Escalation :	
Development and Capital Cost	0.0 %
Op/Post-Op Costs & Expenses	0.0 %
Revenue Escalation :	
Electricity	0.0 %
Bulk & Bottled Water/Salts	0.5 %
Methane Gas	1.0 %
Fish/Aquaculture	0.0 %
Roses/Greenhouse	0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life	10 yrs
Brine Temp @ Surface	300 F
Barrels per Day	20,000 BPD
Gas Concentration / Barrel	80 scf/B
Gas Quality	90 %
Bottom Hole Pressure	15,000 psi
Flowing Wellhead Pressure	2,000 psi

25-Sep-90 : date
08:59:32 AM : time

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
MODEL NAME: GG10-A1
MODEL ANALYSIS: No Electricity/Methane/Salts/Bulk Water Products

RESULTS :

10-YR NPV	$546,633
Discounted Payback	8.2 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS		$5,054,742
Borrowed	1,709,400	
Owners Equity	3,251,325	
Capitalized Interest	94,017	

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$5,054,742
TOTAL DEVELOPMENT COST		2,199,750	
Geopress-Geothermal Well	2,199,750		
Pipeline Right-of-Way	0		
TOTAL CAPITAL BUILDING/EQUIPMENT COST.		2,310,000	
Geotherm & Elec Eq	199,500		
Gas Separator & Trans	120,750		
Bulk Water/Salt	1,569,750		
Bottled Water	0		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
Working Funds	420,000		
CONTINGENCIES		450,975	
CAPITALIZED INTEREST		94,017	
GROSS OPERATING REVENUES			$1,672,425
TOTAL COSTS (yr-1)		880,254	
Geopress-Geotherm/Elec	366,450		
Methane Gas	108,806		
Bulk Water/Salt	324,975		
Bottled Water	0		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
Contingencies	80,023		
TOTAL REVENUES (yr-1)		2,552,679	
Geopress-Geotherm/Elec	926,676		
Methane Gas	0		
Bulk Water/Salt	1,626,003		
Bottled Water	0		
Rose/Greenhouse	0		
Fish/Aquaculture	0		
TOTAL POST-OPERATION COSTS			$301,346
SALVAGE (at end of project life)			$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR)	15.0 %
Debt Ratio	40.0 %
Interest Rate	11.0 %
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0 %
Taxes :	
Federal Tax	38.0 %
State Tax	2.0 %
Severance Tax	5.0 %
Ad Valorem Tax	7.2 %
Inflation Rate	5.0 %
Cost Escalation :	
Development and Capital Cost	0.0 %
Op/Post-Op Costs & Expenses	0.0 %
Revenue Escalation :	
Electricity	0.0 %
Bulk & Bottled Water/Salts	0.5 %
Methane Gas	1.0 %
Fish/Aquaculture	0.0 %
Roses/Greenhouse	0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life	10 yrs
Brine Temp @ Surface	300 F
Barrels per Day	20,000 BPD
Gas Concentration / Barrel	80 scf/B
Gas Quality	90 %
Bottom Hole Pressure	15,000 psi
Flowing Wellhead Pressure	2,000 psi

25-Sep-90 : date
08:51:16 AM : time

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
MODEL NAME: GG10-A2
MODEL ANALYSIS: No Electricity/Methane/Agri & Aquaulture Products

RESULTS :

10-YR NPV	($18,902)
Discounted Payback	0.0 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$4,523,558
Borrowed	1,501,500		
Owners Equity	2,939,475		
Capitalized Interest	82,583		

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$4,523,558
TOTAL DEVELOPMENT COST		2,199,750	
Geopress-Geothermal Well	2,199,750		
Pipeline Right-of-Way	0		
TOTAL CAPITAL BUILDING/EQUIPMENT COST.		1,837,500	
Geotherm & Elec Eq	199,500		
Gas Separator & Trans	120,750		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	887,250		
Fish/Aquaculture	210,000		
Working Funds	420,000		
CONTINGENCIES		403,725	
CAPITALIZED INTEREST		82,583	
GROSS OPERATING REVENUES			$1,293,900
TOTAL COSTS (yr-1)		919,656	
Geopress-Geotherm/Elec	366,450		
Methane Gas	108,806		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	322,613		
Fish/Aquaculture	42,000		
Contingencies	79,787		
TOTAL REVENUES (yr-1)		2,213,556	
Geopress-Geotherm/Elec	926,676		
Methane Gas	0		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	1,226,400		
Fish/Aquaculture	60,480		
TOTAL POST-OPERATION COSTS			$301,346
SALVAGE (at end of project life)			$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR)	15.0 %
Debt Ratio	40.0 %
Interest Rate	11.0 %
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0 %
Taxes :	
Federal Tax	38.0 %
State Tax	2.0 %
Severance Tax	5.0 %
Ad Valorem Tax	7.2 %
Inflation Rate	5.0 %
Cost Escalation :	
Development and Capital Cost	0.0 %
Op/Post-Op Costs & Expenses	0.0 %
Revenue Escalation :	
Electricity	0.0 %
Bulk & Bottled Water/Salts	0.5 %
Methane Gas	1.0 %
Fish/Aquaculture	0.0 %
Roses/Greenhouse	0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life	10 yrs
Brine Temp @ Surface	300 F
Barrels per Day	20,000 BPD
Gas Concentration / Barrel	80 scf/B
Gas Quality	90 %
Bottom Hole Pressure	15,000 psi
Flowing Wellhead Pressure	2,000 psi

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
MODEL NAME: GG10-A2
MODEL ANALYSIS: Electricity@$0.060/Methane/Agri & Aquaulture Products

25-Sep-90 : date
08:44:33 AM : time

RESULTS :

10-YR NPV	($1,511,389)
Discounted Payback	0.0 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$7,628,036
Borrowed	2,716,560		
Owners Equity	4,762,065		
Capitalized Interest	149,411		

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$7,628,036
TOTAL DEVELOPMENT COST		2,199,750	
Geopress-Geothermal Well	2,199,750		
Pipeline Right-of-Way	0		
TOTAL CAPITAL BUILDING/EQUIPMENT COST.		4,599,000	
Geotherm & Elec Eq	2,961,000		
Gas Separator & Trans	120,750		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	887,250		
Fish/Aquaculture	210,000		
Working Funds	420,000		
CONTINGENCIES		679,875	
CAPITALIZED INTEREST		149,411	
GROSS OPERATING REVENUES			$1,551,513
TOTAL COSTS (yr-1)		1,233,238	
Geopress-Geotherm/Elec	651,525		
Methane Gas	108,806		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	322,613		
Fish/Aquaculture	42,000		
Contingencies	108,294		
TOTAL REVENUES (yr-1)		2,784,751	
Geopress-Geotherm/Elec	926,676		
Methane Gas	571,196		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	1,226,400		
Fish/Aquaculture	60,480		
TOTAL POST-OPERATION COSTS			$301,346
SALVAGE (at end of project life)			$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR)	15.0 %
Debt Ratio	40.0 %
Interest Rate	11.0 %
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0 %
Taxes :	
Federal Tax	38.0 %
State Tax	2.0 %
Severance Tax	5.0 %
Ad Valorem Tax	7.2 %
Inflation Rate	5.0 %
Cost Escalation :	
Development and Capital Cost	0.0 %
Op/Post-Op Costs & Expenses	0.0 %
Revenue Escalation :	
Electricity	0.0 %
Bulk & Bottled Water/Salts	0.5 %
Methane Gas	1.0 %
Fish/Aquaculture	0.0 %
Roses/Greenhouse	0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life	10 yrs
Brine Temp @ Surface	300 F
Barrels per Day	20,000 BPD
Gas Concentration / Barrel	80 scf/B
Gas Quality	90 %
Bottom Hole Pressure	15,000 psi
Flowing Wellhead Pressure	2,000 psi

25-Sep-90 : date
08:48:02 AM : time

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
MODEL NAME: GG10-A2
MODEL ANALYSIS: Electricity@$0.025/Methane/Agri & Aquaulture Products

RESULTS :

10-YR NPV	($2,409,299)
Discounted Payback	0.0 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$7,628,036
Borrowed	2,716,560		
Owners Equity	4,762,065		
Capitalized Interest	149,411		

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS			$7,628,036
TOTAL DEVELOPMENT COST		2,199,750	
Geopress-Geothermal Well	2,199,750		
Pipeline Right-of-Way	0		
TOTAL CAPITAL BUILDING/EQUIPMENT COST.		4,599,000	
Geotherm & Elec Eq	2,961,000		
Gas Separator & Trans	120,750		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	887,250		
Fish/Aquaculture	210,000		
Working Funds	420,000		
CONTINGENCIES		679,875	
CAPITALIZED INTEREST		149,411	
GROSS OPERATING REVENUES			$1,218,316
TOTAL COSTS (yr-1)		1,233,238	
Geopress-Geotherm/Elec	551,525		
Methane Gas	108,806		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	322,613		
Fish/Aquaculture	42,000		
Contingencies	108,294		
TOTAL REVENUES (yr-1)		2,451,554	
Geopress-Geotherm/Elec	926,676		
Methane Gas	237,998		
Bulk Water/Salt	0		
Bottled Water	0		
Rose/Greenhouse	1,226,400		
Fish/Aquaculture	60,480		
TOTAL POST-OPERATION COSTS			$301,346
SALVAGE (at end of project life)			$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR)	15.0 %
Debt Ratio	40.0 %
Interest Rate	11.0 %
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0 %
Taxes :	
Federal Tax	38.0 %
State Tax	2.0 %
Severance Tax	5.0 %
Ad Valorem Tax	7.2 %
Inflation Rate	5.0 %
Cost Escalation :	
Development and Capital Cost	0.0 %
Op/Post-Op Costs & Expenses	0.0 %
Revenue Escalation :	
Electricity	0.0 %
Bulk & Bottled Water/Salts	0.5 %
Methane Gas	1.0 %
Fish/Aquaculture	0.0 %
Roses/Greenhouse	0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life	10 yrs
Brine Temp @ Surface	300 F
Barrels per Day	20,000 BPD
Gas Concentration / Barrel	80 scf/B
Gas Quality	90 %
Bottom Hole Pressure	15,000 psi
Flowing Wellhead Pressure	2,000 psi

APPENDIX D

PRELIMINARY FEASIBILITY FOR GREENHOUSE/AQUACULTURE FACILITY AT PLEASANT BAYOU, TEXAS.
(P. J. LIENAU, OREGON INSTITUTE OF TECHNOLOGY GEO-HEAT CENTER)

FAX TRANSMITTAL

CGI
CAMPBELL GLASSHOUSES, INC.
DESIGN • CONSULTING • FABRICATION • INSTALLATION
COMPLETE GREENHOUSE SYSTEMS
P. O. Box 678
LINCOLNSHIRE, ILLINOIS 60069

DATE: 20 July 1990

TIME: 6:00 am

FAX NUMBER: 503-885-1115

TO: OREGON INSTITUTE OF TECHNOLOGY
GEO-HEAT CENTER

ATTN: PAUL LIENAU

TELEPHONE
708-541-7272
•
24-HOUR FAX
708-541-0217

REFERENCE: QUOTATION REQUEST

REMARKS: Three Proposals are attached as requested.
Please let me know how I can be of further assistance
at this time.

FROM: Jim Campbell

CGI
CAMPBELL GLASSHOUSES, INC.
DESIGN • CONSULTING • FABRICATION • INSTALLATION
COMPLETE GREENHOUSE SYSTEMS

19 July 1990

Paul Lienau
Geo-Heat Center
OREGON INSTITUTE OF TECHNOLOGY
3201 Campus Drive
Klamath Falls, Oregon 97601

Dear Mr. Lienau:

Thank you for your recent inquiry regarding proposal quotations for your proposed facility in Texas. Per your request I've attached three separate Proposals for the different phases of the project which you described.

Please understand that these are budget prices which will be confirmed when the final details and building schedule are determined.

I'll be sending you a packet of descriptive and technical literature for your files. Also I did not include a computer system quotation at this time, but I will be happy to have an exact specified quotation prepared if that will be of help to you now.

Please FAX today any response or further requests for assistance. I will be pleased to work with you in bringing this project to a positive reality.

Sincerely,

James A. Campbell
President

Encl.

P. O. Box 678, Lincolnshire, Illinois 60069 • Telephone: 708-541-7272 • Fax: 708-541-0217

CAMPBELL GLASSHOUSES, INC.

DESIGN • CONSULTING • FABRICATION • INSTALLATION
COMPLETE GREENHOUSE SYSTEMS

PROPOSAL I

PAUL LIENAU
Geo-Heat Center
Oregon Institute of Technology
3201 Campus Drive
Klamath Falls, Oregon 97601

19 July 1990

CAMPBELL GLASSHOUSES proposes to provide materials and installation labor for the following facility planned to be built in Texas:

STRUCTURES: Three (3) Greenhouses, each 42' X 348'
One (1) Greenhouse, 21' X 348'
Total square footage = 51,156

Houses to be gutter-connected together. Gutters to be set 10' above grade. Trusses to be set 12' on centers. The large houses to each have nine (9) runs of roof purlins and the small house to have five (5) runs.

GLAZING: OPTION 1 - 5 oz. Fiberglass Panels

All surfaces to be glazed with 5 oz. clear corrugated Fiberglass panels.

OPTION 2 - 8mm Polycarbonate Panels

All surfaces to be glazed with 8mm clear polycarbonate structured panels with an aluminum glazing bar system.

VENTILATION: Each house to have two (2) continuous runs of ridge vents, 36" wide, to be operated automatically and independently.

SCREENS: Each vent opening to be provided with an insect screen in an aluminum frame.

HEATING: A total of twenty-eight (28) hot water unit heaters with fourteen (14) Fact fan systems complete with poly distribution tubing to be installed.

CAMPBELL GLASSHOUSES, INC.

DESIGN • CONSULTING • FABRICATION • INSTALLATION
COMPLETE GREENHOUSE SYSTEMS

COOLING: An evaporative pad cooling system, 6" X 4' X 348', to be installed. The opposite sidewall to contain twenty-two (22) exhaust fans, 48", 1 H.P., complete with slant wall box, blade guard, and automatic shutter.

FREIGHT: F.O.B. jobsite prepaid.

TOTAL PRICE: OPTION 1 GLAZING: $345,950

OPTION 2 GLAZING: $456,000

TERMS: Mutually acceptable terms to be arranged.

ACCEPTANCE: OPTION 1:

OREGON INSTITUTE OF TECHNOLOGY　　DATE

James A. Campbell　　19 July '90

James A. Campbell, President　　DATE
CAMPBELL GLASSHOUSES, INC.

OPTION 2:

OREGON INSTITUTE OF TECHNOLOGY　　DATE

James A. Campbell　　19 July '90

James A. Campbell, President　　DATE
CAMPBELL GLASSHOUSES, INC.

CAMPBELL GLASSHOUSES, INC.

DESIGN • CONSULTING • FABRICATION • INSTALLATION
COMPLETE GREENHOUSE SYSTEMS

PROPOSAL II

PAUL LIENAU
Geo- Heat Center
Oregon Institute of Technology
3201 Campus Drive
Klamath Falls, Oregon 97601

19 July 1990

CAMPBELL GLASSHOUSES proposes to provide material and installation labor for the following facility to be built in Texas:

STRUCTURES: One (1) Greenhouse, 36' X 192'
Total square footage = 6,912

Gutters to be set 10' above grade. Trusses to be set on 12' centers. Nine (9) runs of roof purlins.

GLAZING: All surfaces to be glazed with 5 oz. clear corrugated Fiberglass panels.

COOLING: One sidewall to contain ten (10) exhaust fans, 42", 1/2 H.P., complete with slant wall box, blade guard, and automatic shutter. The other sidewall to a continuous run of vent, 48" wide, to be operated automatically.

HEATING: Four (4) hot water unit haeters with two (2) Fact fan systems to be installed complete with poly distribution tubing.

FREIGHT: F.O.B. jobsite prepaid.

TOTAL PRICE: $50,500

TERMS: Mutually acceptable terms to be arranged.

ACCEPTANCE:

________________________ __________
OREGON INSTITUTE OF TECHNOLOGY DATE

James A. Campbell 19 July '90

James A. Campbell, President
CAMPBELL GLASSHOUSES, INC.
DATE

CAMPBELL GLASSHOUSES, INC.

DESIGN • CONSULTING • FABRICATION • INSTALLATION
COMPLETE GREENHOUSE SYSTEMS

PROPOSAL III

PAUL LIENAU
Geo-Heat Center
Oregon Institute of Technology
3201 Campus Drive
Klamath Falls, Oregon 97601

19 July 1990

CAMPBELL GLASSHOUSES, proposes to provide materials and installation labor for the following facility to be built in Texas:

STRUCTURES:	One (1) Service Building, 50' X 84' Total square footage = 4,200 Gutters to be set 14' above grade. Trusses to be set on 12' centers. Eleven (11) runs of roof purlins.
GLAZING:	All surfaces to be glazed with 26 ga. corrugated steel panels.
COOLING:	Not included in quotation.
HEATING:	Not included in quotation.
DOOR:	One 10' X 12' overhead door to be provided.
FREIGHT:	F.O.B. prepaid to jobsite.
TOTAL PRICE:	$ 42,000
TERMS:	Mutually acceptable terms to be arranged.
ACCEPTANCE:	

OREGON INSTITUTE OF TECHNOLOGY ________ DATE ________

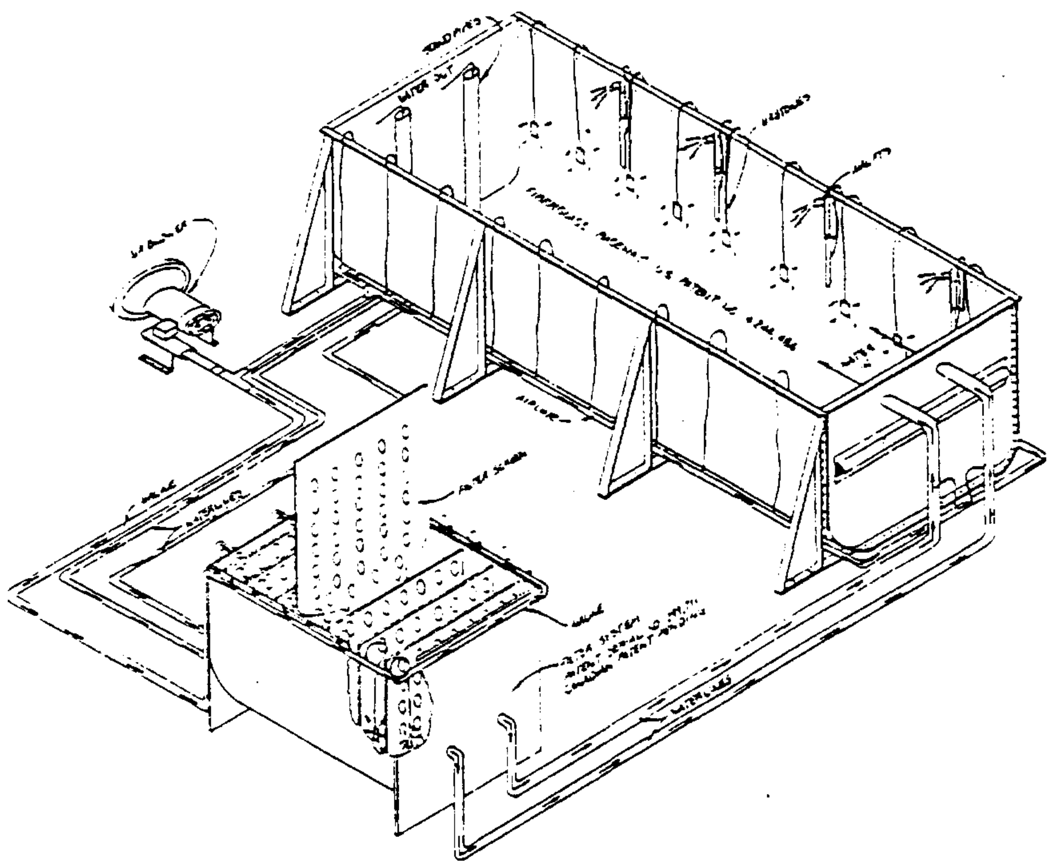
James A. Campbell

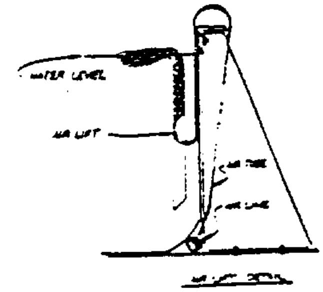
James A. Campbell, President
CAMPBELL GLASSHOUSES

19 July '90
DATE

RED EWALD, INC.

SCHEMATIC DRAWING OF HIGH DENSITY RECIRCULATING GROWOUT SYSTEM





P.O. BOX 519, KARNES CITY, TEXAS 78118-0519 • TELEX: 767685
512/780-3304 • CALL TOLL FREE 1-800-531-3606 • IN TEXAS 1-800-242-3524

RED EWALD, INC.

10,000 GALLON RACEWAY CULTURE SYSTEM

Quantity	Description
1	RW-7 8' x 4' x 45', Fiberglass Raceway Tank with four 4" PVC fittings
1	VRSF-16 4' x 4' x 16', Vertical Screen Filter Tank with 14 screens and with four 4" PVC fittings
1	Aeration-Plumbing Package, includes a 2 Hp, 1 phase regenerative air blower, airstones, PVC pipe, PVC fittings, tubing, and miscellaneous hardware needed for system set up.
	Price for one (1) 10,000 gallon Raceway System..................$15,280.00

PVC parts may, in some locations, be purchased for less money than through Red Ewald, Inc. (Approximate savings $100 to $500).

Note: Price does not include any shipping or crating charges.

This Price List effective March 10, 1986. Prices, materials, and/or specifications subject to change with or without notice. Warranty on tanks limited to repair or replacement of tanks only.

P.O. BOX 519, KARNES CITY, TEXAS 78118-0519 • TELEX: 767685

AEU EWALD, INC.

1-800-531-3606 US
1-800-242-3524 TX
512-780-4272 FAX
767685 TELEX

FISH CULTURE TANKS - PRICE LIST

FIBERGLASS RACEWAY TANKS
(U.S. PATENT #4,244,486)

Maximum Raceway Length - 45'

Model	Width (ID)	Width (OD)	Height	Gallons/Ft.	Price/Ft.	Price of 2 Ends
RW-1	6'	8'	2'	85	$57.00	$400.00
RW-2	6'	9'	3'	130	63.00	550.00
RW-3	8'	10'	2'	115	68.00	550.00
RW-4	8'	11'	3'	175	74.00	660.00
RW-5	10'	12'	2'	145	74.00	660.00
RW-6	10'	13'	3'	220	85.00	825.00
RW-7	8'	11'	4'	230	90.00	880.00
RW-8	4'	7'	3'	85	57.00	440.00
RW-9	4'	7'	4'	115	62.00	750.00

To figure price: Multiply price per ft. x length of raceway and add price of 2 ends.

RACEWAY BAFFLE FOR CIRCULAR FLOW: 4' baffle - $29.00 per linear ft.; 3' baffle - $24.00 per linear ft.; 2' baffle - $20.00 per linear ft.

Recommended length of baffle is the length of raceway less the width.

RECTANGULAR FISH REARING TROUGHS

Model	Gallons	Height	Width	Length	Weight	Price
FRT-35	30	12"	20"	24"	16 lbs.	$ 82.00
FRT-1	33	6"	12"	108"	30 lbs.	110.00
FRT-31	33	8"	6"	152"	48 lbs.	176.00
FRT-7	40	6"	24"	72"	25 lbs.	122.00
FRT-6	50	12"	22"	45"	30 lbs.	138.00
FRT-29	54	6"	26"	96"	45 lbs.	170.00
FRT-17	78	18"	20"	50"	38 lbs.	149.00
FRT-25	80	12"	22"	34"	42 lbs.	160.00
FRT-2	100	12"	22"	96"	45 lbs.	170.00
FRT-18	100	24"	26"	36"	42 lbs.	170.00
FRT-26	110	10"	36"	72"	50 lbs.	193.00
FRT-33 +	110	14"	22"	96"	50 lbs.	193.00
FRT-27	120	24"	24"	48"	52 lbs.	205.00
FRT-34	150	12"	20"	144"	80 lbs.	257.00
FRT-16	175	16"	20"	144"	125 lbs.	363.00
FRT-21	180	22"	44"	44"	110 lbs.	375.00
FRT-8	240	12"	45"	92"	120 lbs.	397.00
FRT-22 *	240	30"	48"	48"	150 lbs.	506.00
FRT-32	245	18"	33"	95"	130 lbs.	494.00
FRT-28	280	30"	30"	72"	150 lbs.	498.00
FRT-3	300	24"	25"	120"	160 lbs.	519.00
FRT-20	300	18"	30"	130"	175 lbs.	550.00
FRT-24	345	24"	28"	120"	170 lbs.	550.00
FRT-23	470	36"	37"	84"	250 lbs.	835.00
FRT-5 **	500	24"	24"	216"	390 lbs.	1,255.00
FRT-13	600	20"	48"	144"	250 lbs.	882.00
FRT-14	750	20"	60"	144"	300 lbs.	1,045.00
FRT-19 **	1000	36"	37"	180"	600 lbs.	1,395.00

* Tank has sloping bottom (3") and is mounted on legs with 12" ground clearance.

** Tank has bracing rib to prevent bowing in sidewalls.

\+ Tank slopes 2" from sidewall to centerline and has 8 screen slots.

NOTE: Dimensions are based on I.D. measurement at the top. Check with factory if O.D. is critical.

ROUND FISH CULTURE TANKS

Model	Gallons	Diameter	Height	Weight	Price	Price With Skirt *
FCT-[illegible]	[illegible]	[illegible]	[illegible]	[illegible] lbs.	$ [illegible]	$ [illegible]
FCT-35	35	[illegible]	[illegible]	[illegible] lbs.	73.00	[illegible]
FCT-40	40	24"	12"	23 lbs.	86.00	[illegible]
FCT-60	60	24"	[illegible]	[illegible] lbs.	110.00	205.00
FCT-65	65	24"	[illegible]	[illegible] lbs.	93.00	[illegible]
FCT-75	75	28"	[illegible]	[illegible] lbs.	100.00	[illegible]
FCT-100	100	47"	15"	32 lbs.	104.00	[illegible]
FCT-200	200	52"	16"	65 lbs.	162.00	353.00
FCT-240 +	240	48"	24"	55 lbs.	220.00	357.00
FCT-300	300	61"	24"	70 lbs.	225.00	425.00
FCT-340	340	60"	30"	30 lbs.	248.00	447.00
FCT-440	440	60"	36"	98 lbs.	313.00	514.00
FCT-450	450	72"	24"	100 lbs.	320.00	557.00
FCT-550	550	72"	30"	120 lbs.	380.00	622.00
FCT-575 +	575	72"	34"	125 lbs.	395.00	662.00
FCT-660	660	91"	24"	135 lbs.	416.00	740.00
FCT-750 **	750	96"	24"	175 lbs.	582.00	n/a
FCT-850	850	84"	36"	170 lbs.	544.00	827.00
FCT-1050	1050	96"	36"	220 lbs.	699.00	1,119.00
FCT-1090 +	1090	96"	40"	230 lbs.	724.00	1,155.00
FCT-1690 **	1690	144"	24"	325 lbs.	1,024.00	n/a
FCT-1700 **	1700	120"	36"	325 lbs.	1,024.00	n/a
FCT-2350 **	2350	120"	48"	360 lbs.	1,213.00	n/a
FCT-2500 **	2500	144"	36"	400 lbs.	1,296.00	n/a
FCT-2900 **	2900	120"	60"	425 lbs.	1,375.00	n/a
FCT-2960 **	2960	144"	42"	420 lbs.	1,360.00	n/a
FCT-3300 **	3300	144"	48"	440 lbs.	1,431.00	n/a
FCT-3400S ****	3400	144"	60"	1200 lbs.	3,465.00	included
FCT-4200 **	4200	144"	60"	510 lbs.	1,648.00	n/a
FCT-4960 **	4960	156"	60"	750 lbs.	1,342.00	n/a
FCT-4700 ***	4700	240"	24"	600 lbs.	1,942.00	n/a
FCT-5284 **	5284	180"	48"	650 lbs.	2,074.00	n/a
FCT-7000 ***	7000	240"	36"	700 lbs.	2,199.00	n/a
FCT-9400 ***	9400	240"	48"	825 lbs.	2,756.00	n/a
FCT-12000 ***	12000	240"	60"	950 lbs.	3,019.00	n/a
FCT-14000 ***	14000	240"	72"	1200 lbs.	3,334.00	n/a
FCT-15000 ***	15000	30'	3'	2000 lbs.	5,040.00	n/a
FCT-20500 ***	20500	30'	4'	2300 lbs.	6,146.00	n/a
FCT-26000 ***	26000	30'	5'	2475 lbs.	7,240.00	n/a
FCT-31000 ***	31000	30'	6'	3250 lbs.	8,395.00	n/a
FCT-52000 ***	52000	30'	10'	5400 lbs.	15,655.00	n/a
FCT-15225 +++	15225	36'	2'	2800 lbs.	9,332.00	n/a
FCT-22840 +++	22840	36'	3'	2500 lbs.	11,077.00	n/a
FCT-30450 +++	30450	36'	4'	3650 lbs.	12,332.00	n/a
FCT-38066 +++	38066	36'	5'	4150 lbs.	13,657.00	n/a
FCT-45680 +++	45680	36'	6'	4770 lbs.	14,395.00	n/a
FCT-18700 ++	18700	40'	2'	2750 lbs.	7,819.00	n/a
FCT-28170 ++	28170	40'	3'	2950 lbs.	8,427.00	n/a
FCT-37560 ++	37560	40'	4'	3855 lbs.	10,893.00	n/a
FCT-46950 ++	46950	40'	5'	4800 lbs.	13,478.00	n/a
FCT-56340 ++	56340	40'	6'	5400 lbs.	14,920.00	n/a

NOTE: FOR ADDITIONAL INFORMATION ON ROUND FISH CULTURE TANKS, SEE TOP OF PAGE THREE.

NOTES CONTINUED FROM PAGE TWO.

NOTE For FCT's, inside diameter at the top is given. If O.D. is critical, call the factory.

- * Skirt is built into tank and provides 6" bottom clearance.
- ** One (1) piece bottom and side panels.
- *** Two (2) piece bottom and side panels.
- **** Special two (2) piece tank for large broodfish. Has sloped bottom and skirt built into tank.
- \- Bottom is sloped 4" to the center of the tank (height given above includes this slope).
- \-- Three (3) piece bottom and 12 side panels.
- \--- Three (3) piece bottom and 11 side panels.

ALL PRICES ARE F.O.B. KARNES CITY, TEXAS. ALL MULTI-PIECE (PANEL) TANKS ARE PRICED AND SHIPPED UNASSEMBLED BUT DO INCLUDE AN ASSEMBLY KIT (BOLTS, RESINS, GLASS AND PUTTY).

NOTE: ALL RED EWALD, INC. FISH CULTURE TANKS ARE MANUFACTURED USING FDA APPROVED FOOD GRADE USE RESINS AND GELCOATS.

VERTICAL SCREEN FILTERS * (U.S. PATENT #4,806,237)

MODEL	WIDTH	HEIGHT	LENGTH	SCREENS	WEIGHT	PRICE
VRSF-3	26"	24"	38"	6	30 lbs.	$ 450.00
VRSF-10	2'	2'	10'	12	200 lbs.	1,275.00
VRSF-9	2'	2'	8'	8	220 lbs.	1,210.00
VRSF-8	4'	4'	8'	8	500 lbs.	2,320.00
VRSF-16	4'	4'	16'	16	850 lbs.	4,565.00

* Addition of air stones between each screen increase filter efficiency.

CONE BOTTOM REARING TANKS

MODEL	GALLONS	CONE ANGLE	DIA.	DEPTH	WT.	PRICE W/O SKIRT	PRICE W/SKIRT	HT.W/SKIRT
CBT-1	120	60 deg.	30"	60"	70 lbs.	$220.00	$330.00	68"
CBT-2	40	45 deg.	24"	36"	30 lbs.	131.00	205.00	48"
CBT-3	130	45 deg.	36"	42"	50 lbs.	205.00	378.00	50"
CBT-4	500	45 deg.	48"	80"	150 lbs.	577.00	866.00	38"
CBT-5	12	45 deg.	16"	24"	10 lbs.	53.00	100.00	30"
CBT-6	18	45 deg.	18"	25"	12 lbs.	63.00	105.00	31"
CBT-7	12	75 deg.	16"	34"	12 lbs.	61.00	115.00	40"

CUSTOM CONE BOTTOM TANKS

Available in diameters of 5', 6', 7', 8', 10' and 12' with cone angles of 60 deg., 45 deg. and 30 deg. (measured from horizontal). Can be mounted on legs or skirt and have a variety of plumbing options. Call for sizing pricing information.

CIRCULAR RACEWAY TANK

MODEL	OUTSIDE DIA.	INSIDE DIA.	WIDTH	DEPTH	CAPACITY(GALLONS)	PRICE
CRW-1	20'	12'	4'	3'	4,500	$3,100.00

DEMAND FISH FEEDERS *

MODEL	CAPACITY (IN EXTRUDED FEEDS)	CONE ANGLE	DIA.	HEIGHT	PRICE
DFF-1	45 lbs.	45 deg.	16"	24"	$ 79.00
DFF-2	120 lbs.	45 deg.	24"	36"	115.00
DFF-3	60 lbs.	45 deg.	18"	25"	89.00

* Units come with stainless steel hardware, a fiberglass lid and are adjustable for feed size and sensitivity.

MODIFIED NICHOLSON FEEDER: (For live brine shrimp, rotifers, algae)

MNF-12 - 12 gallons, 16" dia., 24" deep with air fitting, solenoid dump valve and hanging eyes - $225.00

MNF-TIMER - Cycling Timer for feeder (will operate multiple units) 2-1/2 sec. to 5 min. intervals - $ 98.00

AIRSTONES (SILICA SAND WITH 100 MICRON PORES)

MODEL	SIZE	FITTING	PRICE
AQAS-105	1-1/2" x 1-1/2" x 1-1/2"	3/16" HB	$2.35
AQAS-3	1-1/2" x 1-1/2" x 3"	1/4" HB	3.45
AQAS-6	1-1/2" x 1-1/2" x 6"	1/4" HB	5.15
AQAS-12	1-1/2" x 1-1/2" x 12"	3/8" HB	9.90

RACEWAY DIVIDER SCREENS

MODEL	WIDTH	HEIGHT	SCREEN SIZES AVAILABLE
RWDS-1	6'	[illegible]	1/8", 1/4", 1/2", 3/4" - $142.00
RWDS-2	6'	3'	1/8", 1/4", 1/2", 3/4" - $155.00
RWDS-3	3'	2'	1/8", 1/4", 1/2", 3/4" - $155.00
RWDS-4	3'	3'	1/8", 1/4", 1/2", 3/4" - $166.00
RWDS-5	10'	[illegible]	1/8", 1/4", 1/2", 3/4" - $166.00
RWDS-6	10'	[illegible]	1/8", 1/4", 1/2", 3/4" - $175.00
RWDS-7	8'	4'	1/4", 1/2", 3/4" - $175.00
RWDS-8	4'	3'	1/8", 1/4", 1/2", 3/4" - $143.00
RWDS-9	4'	4'	1/4", 1/2", 3/4" - $155.00

TANK FITTINGS

1. PVC PLUMBING KITS (include SxS elbow glassed to bottom of tank, stand pipe and screen).

MODEL	SIZE	PRICE
PVC-Kit 2	2"	$ 58.00
PVC-Kit 3	3"	90.00
PVC-Kit 4	4"	125.00

2. PVC ELBOW OR COUPLING GLASSED TO BOTTOM.

MODEL	SIZE	PRICE
PVC-El 2	2"	$ [illegible].00
PVC-El 3	3"	30.00
PVC-El 4	4"	40.00
PVC-El 6	6"	95.00
PVC-El 8	8"	135.00

POLYESTER FILTER MATERIAL

AQ-P-4..............1-1/2" thick x 4' wide..............$2.22/linear foot....& ....$90.00/50 ft. roll.

VINYL TUBING *

	INSIDE DIAMETER	OUTSIDE DIAMETER	PRICE PER FOOT
AQ-1P640	1/4"	3/8"	$.15
AQ-1P641	3/8"	1/2"	.22
AQ-1P642	1/2"	5/8"	.31
AQ-1P643	5/8"	3/4"	.36
AQ-VT-007	3/4"	1"	.95
AQ-VT-1	1"	1-1/4"	1.20

* Discounts available on 100' rolls.

PINCH CLAMPS FOR VINYL TUBING

AQ-PC-1	(for 1/2" O.D. max. tubing)	$ .55
AQ-PC-2	(for 3/4" O.D. max. tubing)	1.10

PLASTIC NETTING *

	MESH SIZE	WIDTH	PRICE PER LINEAR FOOT
AQ-N1/8	1/8"	39"	$ .54
AQ-N1/4	1/4"	48"	1.29
AQ-N1/2	1/2"	48"	1.62
AQ-N3/4	3/4"	48"	1.30

* Discounts available on rolls of 100' or more.

* STACK TANKS FOR WATER STORAGE

MODEL	GALLONS	DIAMETER	HEIGHT (WITH LID)	PRICE
ST-500 +	500	52"	72"	$ 595.00
ST-1000 +	1000	74"	72"	795.00
ST-1500	1500	87"	76"	1,095.00
ST-2000	2000	89"	95"	1,295.00
ST-3000	3000	106"	100"	1,495.00

ALL STACK TANKS ARE EQUIPPED WITH 2 THREADED BULKHEAD FITTINGS AND A REMOVABLE LID WITH MANWAY.

* TANK SIDEWALLS ARE TAPERED TO NEST FOR ECONOMICAL SHIPPING OF MORE THAN 1 TANK.

+ CAN BE SHIPPED MOTOR FREIGHT TRUCK.

PVC BULKHEAD FITTINGS (THRU-WALL) *

PART NO.	SIZE	PRICE
BF10050SXT	1/2"	$ 7.50
BF10075SXT	3/4"	8.50
BF10100SXT	1"	9.50
BF10125SXT	1-1/4"	[illegible]
BF10150SXT	1-1/2"	[illegible]
BF10200SXT	2"	18.50
BF10300SXT	3"	34.00
BF10400SXT	4"	57.00

HAYWARD PVC BALL VALVES **

PART NO.	SIZE	PRICE
QV10050	1/2"	$ 8.24
QV10075	3/4"	10.24
QV10100	1"	[illegible]
QV10125	1-1/4"	[illegible]
QV10150	1-1/2"	[illegible]
QV10200	2"	23.36

* ALSO AVAILABLE - INQUIRE ON SIZE AND PRICE.

** AVAILABLE WITH TXT OR SXS CONNECTIONS.

1. Fiberglass Water Storage Tanks (500 to 42,000 gallons). Accessories include 1/2" to 12" fittings, sight gauges, ladders, top or side manways, level gauges.

2. Airblowers - High quality regenerative air blowers ranging from 1/8" to 50 Hp (1 or 3 phase). Inquire for size and price information.

3. PVC Fittings - 3/4" to 6" sizes with elbows, couplings, nipples, tees, hose barbs, flanges, reducer bushings and more available in slip or thread connections.

4. Nylon Air Fittings - 1/4" to 1" fittings with male pipe thread by female hose barb.

5. Stainless Steel and Zinc Plated Bolts - Available in 1/4" to 3/4" dia. and a variety of lengths in stock.

6. Inquire for prices on water hauling tanks, transfer pumps, filter plates for gravel filters and other filter material.

7. Prices available on custom made fiberglass fish hauling tanks. Call for quotations.

8. Red Ewald, Inc. can custom fabricate most any tank for your operation. Call for information.

THIS PRICE LIST REPLACES ALL OTHERS AS OF JULY 13, 1990. PRICES, MATERIALS AND/OR SPECIFICATIONS SUBJECT TO CHANGE WITH OR WITHOUT NOTICE. WARRANTY ON TANKS LIMITED TO REPAIR OR REPLACEMENT OF TANKS ONLY. SHIPPING AND CRATING SERVICES ARE CHARGED SEPARATELY.
DISCOUNTS AVAILABLE ON CERTAIN ORDERS IN COMBINATION WITH NUMBER OF TANKS ORDERED AND DOLLAR VALUE INVOLVED.

RED EWALD INC.
P. O. BOX 519
KARNES CITY, TX 78118
512-780-3304

RED EWALD, INC.

1-800-531-3606 US
1-800-242-3524 TX
FAX: 512-780-4272
TELEX: 767685

TAA ★ Texas Aquaculture Association ★

ANNOUNCEMENT

The Texas Aquaculture Association is pleased to announce the availability of the Texas Inland Aquaculture Handbook. This handbook was originally prepared by the Texas Agricultural Extension Service for use by County Extension Agents in our State. Sufficient copies were printed to distribute to these agents. Many people have asked how to receive copies of this very informative handbook covering all aspects of inland aquaculture. With this in mind, we have printed copies of this handbook for sale to interested aquaculturists, investors, lake managers, state and federal biologists.

Included in this manual are sections on catfish (8 fact sheets), crawfish (5 fact sheets), sport and forage fish (11 fact sheets), and from one to ten fact sheets on such topics as tilapia, pond design and construction, pond management, water quality, water use and conservation, parasites and diseases, food and nutrition, pest management, transport and handling, etc. with over 20 sections in all. Every aquaculturist that has seen an advance copy of this publication indicates that this is a "must" for their shelf.

If you are interested in receiving a copy of this handbook, fill out the form below and mail it soon. Please make checks payable to Texas Aquaculture Association.

Please forward ______ copies of the Inland Aquaculture Manual ($25.00 per copy) to:

Name ______________________________
Address ____________________________
City _______________________________
State ______________ Zip ___________
Amount Enclosed ____________________

For Inquiries Contact:

Texas Aquaculture Association
P. O. Box 13285
Capitol Station
Austin, TX 78711
(512-474-4600)

RED EWALD, INC.
P.O. Box 519
Karnes City, TX 78118-0519
(512) 780-3304

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BROODFISH SPAWNING TANKS

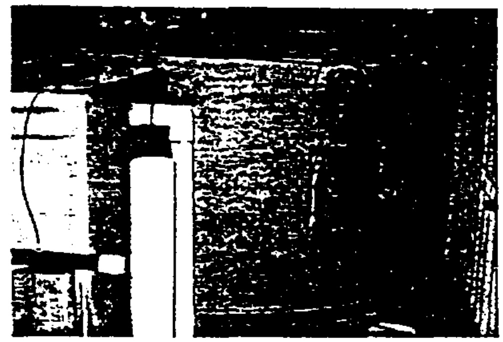
Red Ewald, Inc. now manufactures tanks for broodfish-spawning applications. These tanks were originally designed for and are being used in several redfish spawning applications. Its simple, functional design allows for use in spawning or holding applications.

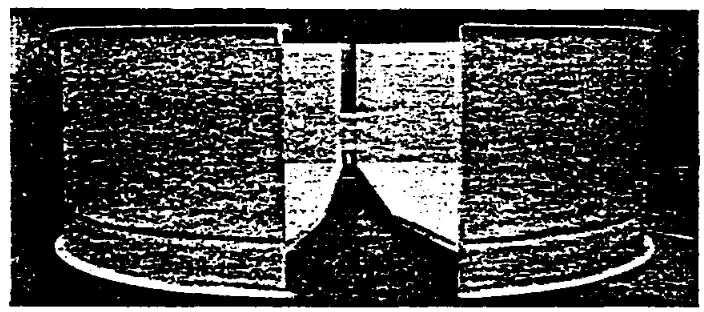
This tank is a 12' diameter by 5' overall height fiberglass tank. This high quality tank comes in two (2) pieces, has a smooth molded gel-coat finish inside, has a built-in skirt and a sloped bottom. The 2-piece construction allows for legal load transportation and a smaller access door in your building.

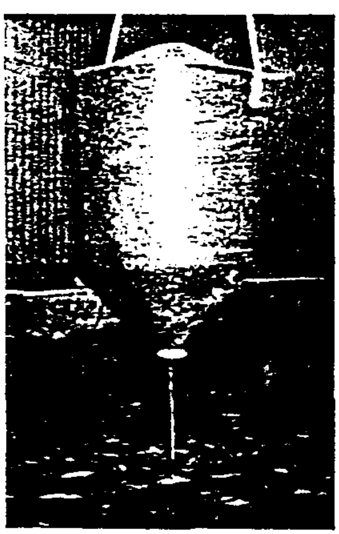
The sloped bottom has several distinct advantages over a flat bottomed tank. The sloped bottom allows complete drainage for cleaning and aids in carrying debris during usage to a center standpipe. In handling fish, especially large broodfish, draining the tank down a few inches above the sloped area leaves the fish in the bottom center where they are easily captured and cannot hurt themselves banging into the sidewalls.

Also available is a 12' x 5' deep panel tank. This cost efficient tank is made up of five (5) side panels and a one-piece bottom allowing the tank to be carried through a standard 3' doorway and assembled inside.

Both tanks come complete with stainless steel bolts and fiberglass materials for field assembly.







DEMAND FISH FEEDERS

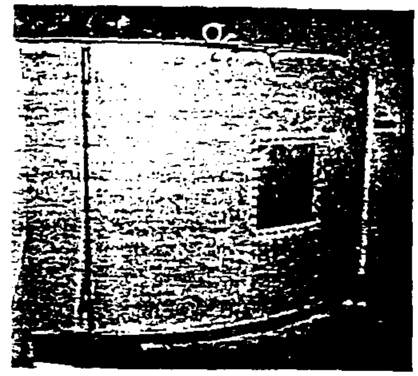
Red Ewald, Inc. now produces several sizes of demand fish feeders. These feeders are manufactured with a clear resin allowing for visual observation of your feed level without having to look inside the feeder. The units come equipped with a fiberglass lid, stainless steel trigger rod and mounting hardware, and a fiberglass feed plate with an adjustable washer for different fish and feed sizes. The cone shaped tank allows for good feed flow and minimum blockage.

These feeders have been successfully used with trout, catfish, *Tilapia* and redfish with fish ranging in size from 2" to 8lbs. Fish using demand feeders generally waste less feed, gain more weight at faster rates with a better conversion rate than do their mechanically fed counterparts.

"A NOTE ABOUT ALL RED EWALD, INC. AQUACULTURE TANKS"

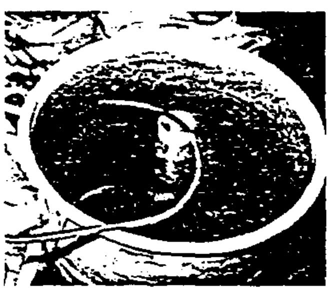
All Red Ewald fish culture tanks are manufactured using top quality materials and all our resins and gel coats are FDA approved for food grade use, and are therefore, safe for your fish or shrimp. Our company has been in business for twenty-five (25) years and with it's experienced personnel, Red Ewald, Inc. has consistently manufactured quality products at competitive prices.

RED EWALD, INC. AND STELLMAN RANCH



Red Ewald, Inc. and Stellman Ranch have combined to design and construct a large indoor redfish hatchery-growout system for fingerling and food fish production. This unique completely enclosed facility is one of the first of it's kind in the United States.

Installed near Aransas Pass, Texas for access to saltwater, this facility will produce some 80,000 lbs. of food sized redfish (1 lb. plus) per year and sell excess fingerlings to other fish farmers. The Stellman redfish farm was designed by Red Ewald, Inc. personnel (including professionally trained engineers and biologist) and was equipped with Red Ewald fish culture tanks.

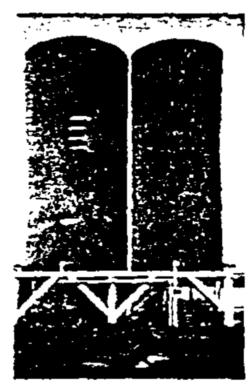


The Facility

This redfish farm is equipped with four (4) broodfish—spawning rooms. Each room contains a 12′ diameter by 5′ deep fiberglass spawning tank with a lexan viewing window and an efficient vertical screen filter tank. All four rooms are photoperiod and temperature controlled for maximum control of the redfish spawning cycle.

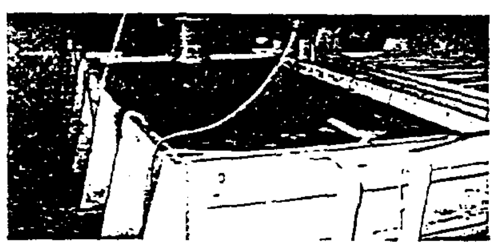
The hatchery area is set up with a variety of tank sizes and shapes for several functions. Round culture tanks with overhead light banks are used in algae-rotifer culture. A row of cone bottom tanks are used in rotifer and brine shrimp production and for hatching redfish eggs and larval feeding. These smooth, gel-coated tanks are very practical for redfish fry feeding because they take minimum circulation to keep the food organisms in suspension in the water for the redfish fry.

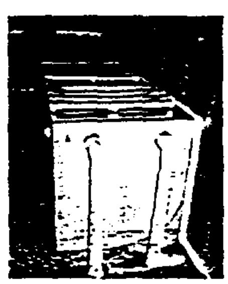
A series of rectangular troughs provide area for initial growout of the fingerlings.



The growout section consists of eight recirculating systems, each consisting of a 10,000 gallon Raceway and a 16′ Vertical Screen Filter. These tanks are capable of raising and supporting fish densities approaching 1 lb. per gallon.

The entire facility is powered by regenerative air blowers which provide air for aeration and water circulation. A backup generator provides standby electricity to prevent fish loss in the event of a power failure. Two (2) large water storage tanks provide fresh and salt water to the fish farm facility.





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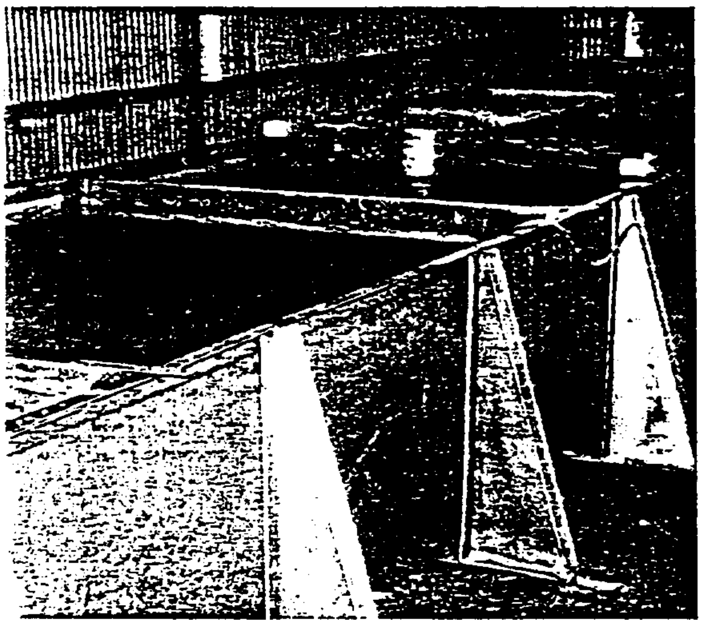
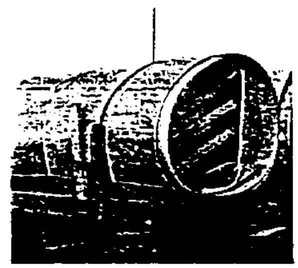
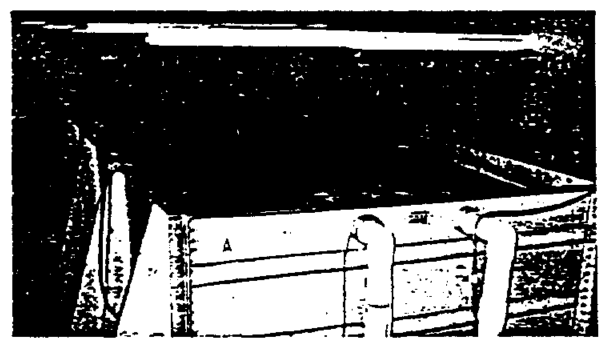
Fish Culture Tanks

At Red Ewald Inc. we have been making fiberglass tanks since 1962 that have been used extensively as culture and crop tanks. We have a series of standard mold tanks, with a smooth gel coated interior, that serve the needs of most enterprises. In addition, we can build tanks to the customer's needs.





Tank breaks down for economical transport.



Fiberglass Raceway Tanks

U.S. Patent No. 4,244,486

The New Red Ewald Fiberglass "Raceway" Tank is unique in design and has several outstanding features and applications over other design tanks. The tank is constructed entirely of fiberglass which offers the advantages of light weight, no rusting or corrosion problems, flexibility, exceptional strength, can be easily moved, altered or repaired, and requires no painting.

The tank's sidewalls and bottom are formed from a single, continuous, flexible, fiberglass sheet having a smooth interior finish without seams, offsets, or joints. The tank maintains its U-shape merely by virtue of its connection to the two ends of the tank and its support by struts along both side which conform to the tank's sidewalls. The struts are arranged in oppositely facing pairs along the sides of the tank and are connected by a fiberglass strip underneath the tank. The struts are not attached to the sidewall or bottom of the tank and may be placed at any desired location along the bottom and side edges permitting the bolts to extend through parts of the tank which are not exposed to the tank's contents thus avoiding possible corrosion and contamination problems and also leaving the interior of the tank smooth. Fiberglass angles are bolted to the top of both sides of the tank to prevent the sidewalls of the tank from bowing outward. The unique design, eliminates top cross braces, which is especially important in the fish culture industry where an open span tank is desirable to facilitate the use of dip nets, strainers, and separators.

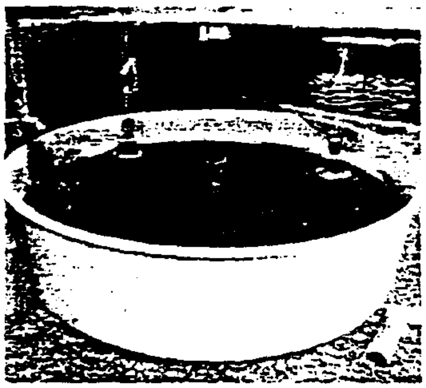
The tank is designed to completely break down for economical transportation. The sides and floor are formed with one flexible fiberglass sheet. This sheet can be rolled up into a 3' to 5' (depending on tank size) diameter roll for shipping. The struts nest inside each other and can be shipped along with the ends, support angles, bolts, gaskets, and options inside the rolled sheet. No additional fiberglass materials or special tools are required.

This design tank has been used successfully for many years and has given our customers excellent service. Raceways are commonly used in fish and shrimp growout, for high density culture, and offer more control in culture operations than does the older pond method. This design is especially desirable where a limited amount of space is available, such as inside a building.

Quality • Pride • Experience

RED EWALD, INC.

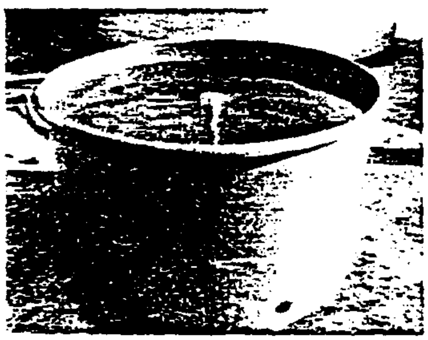
Round Fish Culture Tanks

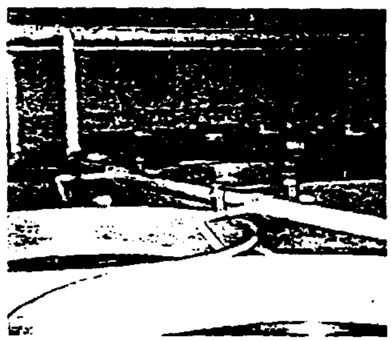


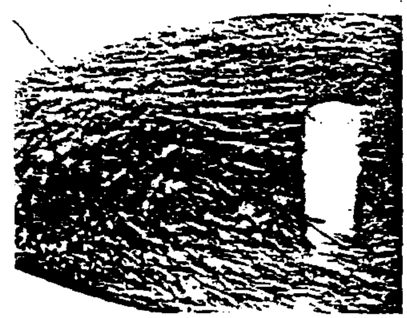
These round fish culture tanks are ideal for rearing fish due to their smooth gel coated interior. Tanks are available in many sizes up to 8' in diameter to fill the needs of any size operation. These tanks are economical to build, yet are strong enough for years of dependable service. A reinforced top lip gives the tank additional strength. The tanks are nested for shipping, giving you a tremendous freight savings.

These tanks are commonly used for fingerling growout, isolation of individual or small groups of fish, temporary holding tanks, and are used in both shrimp and algae culture. They may be adopted to many other uses depending upon your operation.

Many extras are available to include a variety of PVC drain fittings, PVC stand pipe plumbing kits, and fiberglass skirts which allow the bottoms of the tanks to deflect up to 3" for efficient cleaning of organic matter.



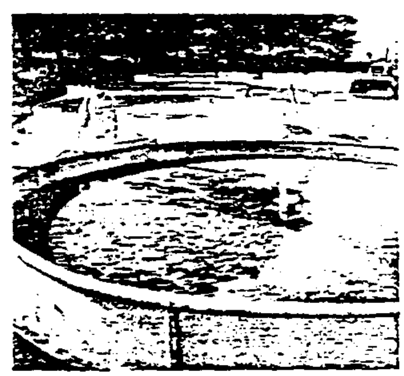


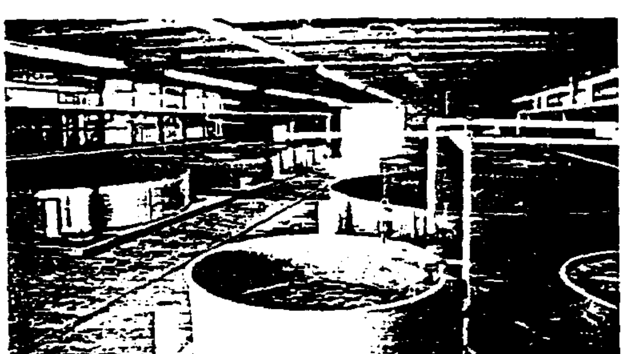


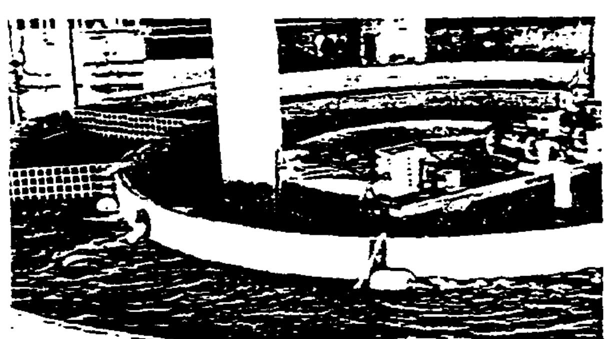
Panel Tanks

These large diameter tanks are ideal for fish raising. The 10', 12', 20', 30', and 40' diameter tanks are available in 24", 36", 48", and 60" heights. This design allows these tanks to be shipped in a package of several side panels and a one piece bottom, allowing us to ship a large quantity on a truck load for a tremendous freight savings. The floor and panels are bolted together in the field with stainless bolts and the seams are glassed, forming a rigid one piece tank. All bolts, nuts, washers, and fiberglass materials are furnished with the unit. After field assembly, the tanks become a permanent one piece tank but can be recut at the seams, taken apart, transported, and reassembled at a new location.

This tank is commonly used with a self-cleaning stand-pipe kit which allows for an automatic cleaning of waste materials in the tank. The panel tank is ideal where a large volume tank is needed inside an existing building with a limited size entrance. The sections and floor can be moved through a standard door and assembled inside.







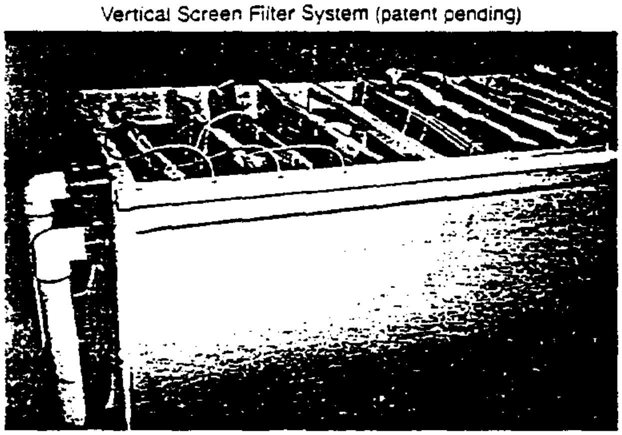
Recirculating Culture Systems

Red Ewald, Inc. can design and manufacture recirculating culture systems to fit your aquaculture operation. These systems can be designed for broodfish spawning, larval rearing, high density growout for fingerlings and food fish, live holding systems and more. Many species of fish, shrimp and other shellfish are being used in Red Ewald Recirculating Systems.

These systems can be designed around raceways, panel tanks, small troughs, round tanks and cone bottom tanks and are used in conjunction with Red Ewald's efficient **Vertical Screen Filter System** (patent pending). Complete aeration and circulation capabilities can be built into system design.

Filters

Vertical Screen Filter System (patent pending)



US PATENT 4806237

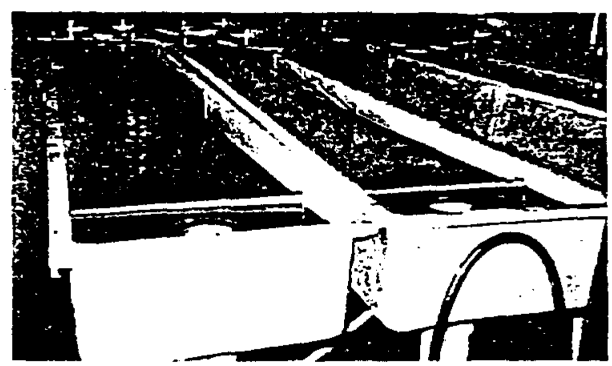
Red Ewald, Inc. manufactures a line of filters for your aquaculture operation. These include the **Vertical Screen Filter System** (patent pending) and fiberglass plates for undergravel filters. In addition, Red Ewald, Inc. can custom manufacture filters and tanks to customer specifications.

The **Vertical Screen Filter System** (patent pending) is a complete filtration system utilizing a high density polyester screen that traps sediments and trash and provides maximum amounts of surface area for bacterial growth and biological removal of ammonia, nitrites and other dissolved organics. By utilizing these screens in the vertical position, the entire water column is filtered with a minimum amount of floor space. The water passes horizontally through the screens. Aeration increases the efficiency of the filter many times. The screens are easily removed and sprayed off with a hose if clogged, and all the screens have overflow bypass in case of clogging.

Red Ewald now produces a series of filter plates for sand-gravel type filters. These filter plates can be adapted to all our round and rectangular culture tanks to fit most any filtration need. Used in combination with 1/4 x 1/8 gravel, these filters provide for very efficient filtration of ammonia and other dissolved substances. Various plumbing options are available including back flush hookups for cleaning of the filter and airlifts for increased filter efficiency.

Cone Bottom Tanks

Cone bottom tanks are excellent for the rearing of saltwater and freshwater shrimp. They are also commonly used to hatch red drum and other fish eggs and in larval rearing. Brine shrimp are hatched in cone bottom tanks. These tanks have a smooth molded, gel coated interior. Molded sizes are available from 12 to 500 gallons and mandrel wound sizes are available 6' to 12' in diameter with several cone angles and many sidewall depths. These larger sizes are very common in commercial shrimp operations as larval rearing tanks. All cone bottom tanks are available with legs or a fiberglass skirt, a reinforced top lip, and with a variety of plumbing options.



Fish Rearing Troughs

Rectangular fiberglass troughs are available in many sizes ranging from 6" to 36" deep, 12" to 60" wide and 48" to 216" long. These troughs are fabricated on a waxed mold giving the interior a smooth mirror finish. A top lip for extra strength and durability is standard on all tanks. A stiffener rib is standard on larger tanks to prevent bowing in the sidewalls.

These troughs serve many needs in the culture business. These needs include uses in fish fry growout and as holding tanks in the crab and lobster industry.

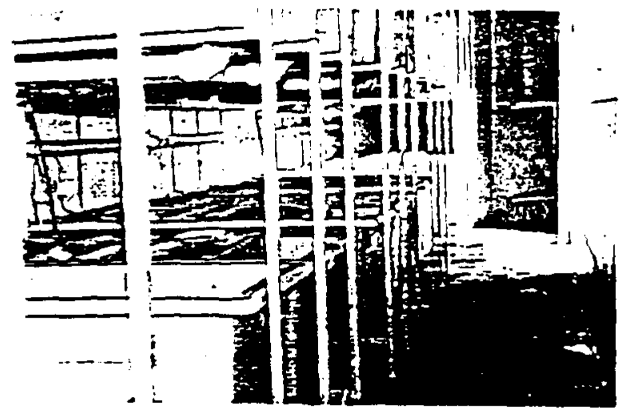
Fish rearing troughs are very popular due to their high versatility, many available sizes, and a variety of plumbing options. They are economically priced and are nested for a tremendous freight savings.

PORTABLE MODULAR FISH HATCHERY SYSTEMS

(U.S. PATENT # 4,738,220)

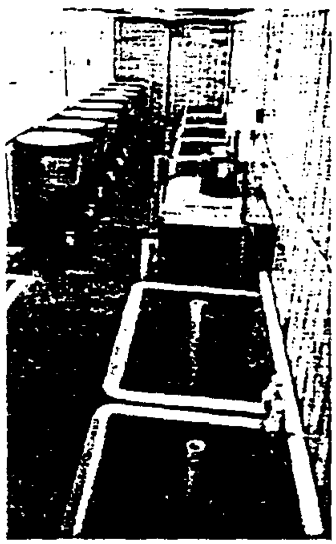
Red Ewald, Inc. manufactures a series of portable modular fish hatchery and lab systems. Utilizing insulated trailer vans, these trailer systems are easily moved from one location to another. In the event of abnormally high tides and storms, the trailers can be moved to high ground and safety until the danger is past.

These Modular Systems can be designed to facilitate broodfish spawning, hatching and rearing of larval fish and fingerlings, and live feed rearing (algae, rotifers, brine shrimp, nematodes). As a mobile wet lab, these modular systems can be used as an on-site laboratory for field studies and research. System designs can include recirculating or flow-through capabilities, heating and cooling capabilities, aeration, lighting and more. Units are currently being used with *Tilapia*, red drum, rotifers and algae, and as a mobile wet lab.



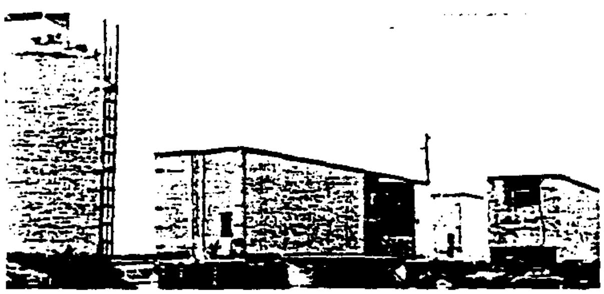
FRY-FINGERLING-BRINE SHRIMP TRAILER

The module is equipped with a series of culture tanks for egg incubation and hatching, fry rearing and fingerling culture with size and shape of the tanks depending upon the type of fish being cultured. This trailer can also be equipped with cone bottom tanks for brine shrimp culture. An air blower and heater-air conditioner are standard.



BROODFISH TRAILER

The trailer includes two large independent tanks for broodfish with filter tanks through which the water is recirculated. An air blower provides air for aeration and water circulation along with heating and cooling equipment for environmental control. Lighting is time clock controlled.



MOBILE WET LAB

This trailer option provides tanks and systems for research and experimental studies. Equipped with tanks, aeration, lighting, heating and cooling equipment, a complete work area can be set up at remote sites or can have a permanent home base. These trailers are designed and built to customer specifications. All that is needed at each jobsite is water and electricity. At remote sites, the trailer can be powered with a portable generator. One current trailer has been used in research work on sea urchins, crabs, octopi, spiny lobster and more.

ALGAE-ROTIFER TRAILER

This module has a series of tanks for the culture of algae, rotifers, or other live food organisms used in fish culture. An air blower provides aeration and a combination heater-air conditioner provides temperature control. High intensity light banks provide light for algae culture.

RED EWALD, INC.

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APPENDIX E

WATER WELL QUOTATION
(R. DeMARCY, B&J WATER WELL SERVICES)

B & J Water Well Service
419 East First Street
Kaplan, La. 70548

Eaton Industries
1240 Blalock
Suite 100
Houston, Texas 77055

Attention: Mr. Doug Graham

This well will be between 400 ft. and 500 ft. deep.

The well will comply with the rules of the Department of Transportation and Developement of Baton Rouge La.

The well will be cemented from the top of the water producing sand to ground surface.

The well will produce 600 G.P.M. with pressure setting of 30# - 50# pressure.

The well will be connected to your wire at well site.

Sincerely,

Ray A DeMarcy

Ray DeMarcy
B & J Water Well Service

RD:al

RECEIVED
JUL 16 1990
PROCUREMENT DIV.

CC: BEN LUNIS - EG&G - ID

B & J Water Well Service
419 East First Street
Kaplan, La. 70548

Eaton Industries

Attention Mr. Doug Graham

This is a copy of what I quoted over the phone.

400' 10" steel casing welded
50' 6" steel casing
120' 6" steel threaded pipe
50' 6" PVC W.O.P. screen .016
1 6" cap
1 air compressor to hold air in tank
1 6" check valve
1 6" gate valve
1 10" X 6" well seal
1 ½" steel vent
160 lb drilling mud
86' stainless cable
2 stainless V bolts
100' 10-3 sub cable
1 600 G.P.M. sub pump @50'
30-50 ft pressure setting
460 volt motor
cement well to 400 ft outside casing
1 10" X 6" sand seal

Cost of well $23,620.00 Plus Tax

10,000 gal. steel painted tank $13,482.00 plus tax

$2,000.00 installation plus tax

10,000 gal. coded tank $20,436.00 plus tax

Installation $2,000.00 plus tax

APPENDIX F

COMPARATIVE PERFORMANCE ANALYSIS: COMMERICAL CUT-FLOWER PRODUCTION
(J. WHITTIER, SOUTHWEST TECHNOLOGY DEVELOPMENT INSTITUTE)
SEATTLE TIMES EDITORIAL

COMPARATIVE PERFORMANCE ANALYSIS:

COMMERCIAL CUT-FLOWER ROSE PRODUCTION

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Comparative Performance Analysis: Commercial Cut-Flower Rose Production

5. AUTHOR(S)

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6. NAME AND ADDRESS OF PERFORMING ORGANIZATION

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7. ABSTRACT

A comparative performance analysis has been conducted to examine the various factors associated with establishing and operating a commercial rose cut-flower greenhouse in ten different locations across the United States. Plant productivity, defined as net blooms produced per plant per year, is largely dependent upon local climatic conditions and technological improvements. Regional variations in productivity have been explicitly analyzed. The greenhouse operation is assumed to be four acres in size and the facilities utilize current technologies. The operation is designed as a professionally-organized company with an owner/manager, grower, and salesperson. The primary product is a red hybrid tea rose for sale at wholesale. Selling markets vary by location, but in general they are large metropolitan areas. The analysis strongly indicates that new installations for cut-flower rose production are profitable in several areas in the U.S. Southwest, particularly in New Mexico, Arizona, and Texas. No one area stands out as a favored location. Las Cruces, New Mexico, has the highest net present value and return on investment results.

8 KEY WORDS

Economic analysis, commercial greenhouse, rose production, feasibility, production costs.

9. AVAILABILITY

Copies of this report are available from the New Mexico Research Development Institute, Communications Office, Suite M, 457 Washington SE, Albuquerque, NM 87108, (505) 277-3661. Please inquire as to price.

EXECUTIVE SUMMARY

A comparative performance analysis has been conducted to examine the various factors associated with establishing and operating a commercial rose cut-flower greenhouse in ten different locations across the United States. The purpose of this study is to compile a consistent, unbiased, and meaningful comparison of commercial greenhouse industry costs, the variables affecting those costs, the implications of altering key variables, and the financial returns associated with the business operation. The results of this study will provide prospective business ventures with important data for planning and decision making.

The intent of the analysis is to examine various geographic regions within the United States to determine sites with greater profitability for a new business operation. Because profitability is greatly influenced by a wide diversity of competing factions, great care was taken to collect accurate information on each region. Plant productivity, defined as net blooms produced per plant per year, is largely dependent upon local climatic conditions and technological improvements. Regional variations in productivity have been explicitly analyzed.

In this report a hypothetical rose cut-flower operation is placed in ten geographic regions throughout the nation. The greenhouse operation is assumed to be four acres in size and the facilities utilize current technologies. The operation is designed as a professionally-organized company with an owner/manager, grower, and salesperson. The primary product is a red hybrid tea rose for sale at wholesale. Selling markets vary by location, but in general they are large metropolitan areas.

An economic model has been created to estimate various cash flow, financial, and profitability issues that are important to a greenhouse operation. It is assumed that a new greenhouse business venture is established at a new location, because the intent of the model is to compare the ten sites on a start-up basis. No allowance or consideration is made for existing greenhouse operations that may be associated with a business expansion in an already-established location. Estimates and assumptions were developed for the following items: greenhouse capital costs, economic factors, utility costs, cash flow, operating costs, and profitability. Each of these categories, among others, is fully discussed in Appendix A.

The selection criteria for the ten sites included the following considerations: presence or absence of an existing industry, market, climate, availability of pertinent data, and geographic diversity. The ten locations chosen for the study are: Tucson, Arizona; San Diego, California; Denver, Colorado; Boston, Massachusetts; Flint, Michigan; Kansas City, Missouri; Las Cruces, New Mexico; Columbus, Ohio; Scranton, Pennsylvania; and Dallas, Texas. The geographic diversity of the ten sites allows for the calculation of differing production levels, operating costs, and selling prices to help evaluate profitability in different regions.

The analysis strongly indicates that new installations for cut-flower rose production are profitable in several areas in the United States Southwest, particularly in New Mexico, Arizona, and Texas. No one area stands out as a favored location. Las Cruces, New Mexico, has the highest net present value and return on investment results. Two areas outside of the Southwest, Scranton, Pennsylvania, and Columbus, Ohio, also show a positive investment opportunity. Both of these areas are favored with low electricity rates that help reduce annual operating costs. Both Scranton and Columbus are vulnerable to electricity price increases to an extent not shared by the Southwest locations.

The level of uncertainty in critical assumptions precludes absolute statements of which location is the "best," or most profitable. A new firm will wish to carefully evaluate individual sites on a case-by-case basis before selecting a location. See Table 1a for a comparison of the various sites.

Table 1a. Comparative Financial Performance

Location	NPV ($)	ROI (%)	BE Price ($)	Total Sales Revenue ($/ft^2)	Net Cash Inflow (AT) ($/ft^2)
Tucson	218,991	8	0.27	6.43	1.00
San Diego	-1,167,935	-1	0.32	6.00	-0.09
Denver	-391,875	4	0.34	7.64	0.63
Boston	-728,530	3	0.47	9.38	0.54
Flint	-575,487	3	0.44	8.81	0.56
Kansas Cty	-102,268	5	0.37	7.88	0.86
Las Cruces	352,470	9	0.27	6.60	1.09
Columbus	218,204	7	0.39	8.44	1.17
Scranton	286,600	6	0.41	8.81	1.05
Dallas	282,942	8	0.30	6.56	1.00

NPV - Net Present Value
ROI - Return on Investment
BE Price - Breakeven Selling Price

The reasons for estimated profitability for Southwest-based firms are varied, but they are directly attributable to one major operating factor that controls the industry. Greenhouse space represents a fixed production area. There are few options, within reason, for increasing annual production from the greenhouse floor area. High intensity discharge (H.I.D.) lighting is one accepted means for increasing production, but it is not readily feasible to plant more rose bushes per square foot or coax additional blooms from a plant. Because production is fixed, annual revenue is also similarly fixed. Bloom prices do not change dramatically, and no single producer within a region is able to receive substantially higher prices than another producer. Therefore the opportunities for increasing profitability come from lowering operating costs.

The Southwest offers, relative to the rest of the U.S., less expensive annual operating costs. Overall utility costs are low, land prices are competitive, and labor is both less expensive and available at the lower wage rates. Despite the situation that Midwest and East Coast growers are closer to the major markets and receive higher product prices than the Southwest growers, the lower operating costs in the Southwest offset the other regions' advantages.

The examples from Scranton and Columbus illustrate the precarious advantage of H.I.D. lighting. Both areas show estimated profitability, both with respect to the Southwest and to other domestic locations. The incentive afforded by low electricity rates allows for profitable operation of the H.I.D. lighting. However, slight increases in electricity rates, on the order of only $0.002-0.005/kWh, dramatically shift profitability to a negative position. Prospective growers will want to carefully evaluate the stability of the local utility and its rate policies before committing to H.I.D. lighting.

Some of the points brought out in this analysis may be considered as elements necessary for a successful venture. A primary consideration is that high levels of quality bloom production are absolutely required. The high annual solar radiation in the Southwest, particularly in the winter time when the crop is growing for holiday sales, is a natural resource benefit that has considerable financial rewards. By not having to invest in and operate H.I.D. lighting, the Southwest grower saves on financing and annual operating costs to an enormous degree relative to the other regions.

A second necessary element is a skilled labor force that is both willing and able to work for competitive wage rates. Annual costs for labor, expressed as a percentage of the total operating budget, range between 40 to 50%. Labor costs represent the single largest expenditure for a grower. Opportunities for enhanced automation, the substitution of capital for labor, appear to be limited. Therefore the grower will have to attract labor at rates that are both sufficient for the worker and competitive for a profitable enterprise. Because the overall cost of living tends to be considerably lower in the Southwest, labor rates also tend to be lower, particularly for agriculture-based labor. It is likely that the relative cost-of-living indices will continue to be lower in the Southwest, therefore contributing to a long-term economic advantage for the grower.

In summary, it is estimated in this report that a cut-flower rose operation may be established and operated in a Southwest location at a profitable level. Because of the lower real estate prices in the Southwest, less capital is required to start a new greenhouse business. In addition, no special incentives are necessary for the operation. Rather, the Southwest offers natural resource and cost of living advantages that make the region an economically-preferred location. U.S. growers, seeking expansion or relocation sites, should consider the opportunities afforded by a Southwest location. New growers to the industry should consider the Southwest as the primary location for their business planning.

Appendix A
Financial Model Description

SECTION 1. ASSUMPTIONS FOR OPERATING ANALYSIS

Greenhouse Assumptions

LAND COST: Land cost estimations are based on known prices of existing and likely possible locations. Commercial real estate brokers were contacted in the selected locations, given a brief explanation of the study, and asked to estimate a price for a ten-acre plot of land suitable for commercial greenhouse operations.

ROSE PLANTS PER ACRE: The figure given for the number of rose plants per acre is based upon averages cited by various experienced growers.

TOTAL NUMBER OF ROSE PLANTS: The total number of rose plants is determined by multiplying the number of rose plants per acre by the number of acres in production.

ROSE PLANT COSTS: Rose plant costs are approximations based on price lists distributed by plant wholesalers.

AVERAGE BLOOM SELLING PRICE: The bloom selling price is an annual weighted average selling price that will vary with the grower's location. The grower's market is usually a function of the location of his operations, and because transportation costs are assumed by the wholesaler, these costs become an important factor in determining the bloom selling price.

BLOOM PRODUCTION: The number of blooms produced by one Royalty plant per any given year is an approximation cited by a number of experienced rose growers in the selected areas and varies by location and/or the presence of H.I.D. lighting. Bloom production rates are calculated to vary by the amount of sunshine that a location receives.

EMPLOYEES PER ACRE: The number of people employed to work a one-acre area of production varies depending on the degree of automation in any particular greenhouse operation. A low level of automation is assumed for this study.

PRODUCTION LOSSES: With any type of production there will be shrinkage or production losses due to stem quality and/or the quality of post-harvest handling. The figure cited for production losses is an estimate suggested by experienced rose growers. A dry climate is expected to have fewer losses than a humid climate because of generally lower disease-related problems.

BLOOMS SOLD PER YEAR: The total estimated number of blooms sold per year is arrived at by multiplying bloom production by the number of rose plants by the number of acres in production, then subtracting the allowance for production losses.

GREENHOUSE SIZE: It is assumed that four acres is a reasonable size for a startup commercial operation.

ACRES: A ten-acre plot is assumed. Six of the ten acres will be used for warehouse/office facilities, parking, supply storage, and will also allow for future expansion.

H.I.D. LIGHTING: The assumed cost of H.I.D. lighting is $200 per lamp and includes installation.

H.I.D. LAMPS/ACRE: It is assumed that 785 four-hundred watt H.I.D. lamps are required per acre of greenhouse.

Economic Assumptions

STATE TAX RATE: Corporate state rates are calculated assuming a base tax rate in order to simplify calculations. Rules for the period of time tax losses may be carried forward vary by state; however, in order to simplify calculations, tax losses are carried over and back for a one-year period. Tax credits and special incentives are not considered in this analysis.

FEDERAL TAX RATE: Federal tax calculations are based on a flat rate and remain constant across the United States. The I.R.S. allows tax losses to be carried over for up to five years and carried back for three years. However, in order to simplify calculations, tax losses are carried over and back for a one year period. Tax credits and other special deductions are not considered in this study.

F.I.C.A. (Social Security) TAX RATE: F.I.C.A. taxes are calculated based on the current flat rate and remain constant across the U.S.

S.U.T.A. (State Unemployment) TAX RATE: Unemployment taxes are calculated based on the standard rate for new employers and will vary by state. New employers are assessed the standard rate until such time that they establish individual experience rates.

WORKERS' COMPENSATION RATE: Workers' Compensation rates were obtained by contacting the appropriate state offices. The rates apply to greenhouse workers in a newly-established greenhouse operation. Actual future rates will be determined by each individual greenhouse's experience rate after a certain time period.

VEHICLE FEE: It is assumed that greenhouse operators will use a van for local delivery and miscellaneous errands. The fee refers to the estimated cost per mile that operating a vehicle requires.

VEHICLE MILES DRIVEN PER YEAR: The delivery vehicle will be driven a given number of miles per year.

GENERAL INFLATION RATE: The financial model allows for the projection of costs and revenues adjusted for inflation. A zero inflation rate implies a constant dollar analysis over the given time horizon.

LABORER WAGE RATE: Labor costs include all wages paid to workers except administrative and marketing personnel. The laborer wage rate cited is computed using the American Chamber of Commerce Researchers Association "Inter-City Cost of Living Index, Third Quarter, 1988."

WORK WEEK: The work week is assumed to be six, eight-hour days. Workers are not compensated at a higher overtime rate unless they work over forty-eight hours per week.

PROPERTY TAX RATE: Real property tax rates for each location were obtained by contacting respective local and state government offices.

Utility Assumptions

ELECTRICITY ENERGY RATE: Electricity rates were determined by contacting local electric utility companies and are calculated in terms of dollars per kilowatt hour. The rates for greenhouses typically fall under the "Commercial User" category. Cost calculations are based on flat base rates with no allowances for factors such as deposits, minimum monthly customer charges, taxes, or different meter sizes.

ELECTRICITY DEMAND RATE: Electricity demand rates were determined by contacting local electric utility companies and are calculated in terms of dollars per kilowatt per month. Not all electric companies assess demand charges.

H.I.D. ELECTRICITY ENERGY RATE: Electricity rates for H.I.D. lighting were determined by contacting local electric utility companies and are calculated in terms of dollars per kilowatt hour. Some electric companies offer "Off-Peak" reduced rates. It was assumed that H.I.D. lighting would not be used unless an off-peak rate or relatively low electricity rates were available. Cost calculations are based on flat base rates with no allowances for factors such as deposits, minimum monthly customer charges, taxes, or different meter sizes.

H.I.D. ELECTRICITY DEMAND RATE: Electricity demand rates for H.I.D. lighting were determined by contacting local electric utility companies and are calculated in terms of dollars per kilowatt per month.

NATURAL GAS RATE: Natural gas rates were determined by contacting local private and municipal gas companies and are calculated in terms of dollars per million BTU.

WATER RATE: Water rates were determined by contacting local private and municipal water companies and are calculated in terms of dollars per thousand gallons.

HEATING FUEL INFLATION RATE: The financial model allows for the projection of costs and revenues adjusted for inflation. A zero inflation rate implies a constant dollar analysis over the given time horizon.

ELECTRICITY INFLATION RATE: The financial model allows for the projection of costs and revenues adjusted for inflation. A zero inflation rate implies a constant dollar analysis over the given time horizon.

HEATING LOAD: The heating load is calculated with a computer-assisted energy simulation model for each location, and the load is reported in terms of millions of BTU for a four-acre greenhouse complex. A printout of the computer inputs is included in Appendix C.

ELECTRICITY LOAD: The electricity load is computed by summing the total annual hours of sunlight for each location, which was obtained from the "Facility Design and Planning Engineering Weather Data," published by the Departments of the Air Force, the Army, and the Navy. Both kilowatt hours per acre per year and kilowatts per acre are calculated.

H.I.D. ELECTRICITY LOAD: The H.I.D. electricity energy load is based on the total number of H.I.D. lights operating sixteen hours per day, seven months per year. Both kilowatt hours per acre per year and kilowatts per acre are calculated.

WATER CONSUMPTION: An estimate of the number of gallons of water per acre of covered area per year per location is assumed, based on data obtained from "Greenhouse Roses," published by Roses Inc., and from individual greenhouses. It is assumed that greenhouses in locations that do not utilize evaporative cooling use approximately one-half the amount of water utilized by greenhouses using evaporative cooling.

BOILER EFFICIENCY: Because a natural gas burner/boiler has combustion inefficiencies, the boiler is assumed to be 75% efficient.

CO_2: The approximate square footage cost to generate carbon dioxide was obtained from the Ball Red Book. CO_2 will only be used from October to April.

Amortization Assumptions

PRINCIPAL: A debt-to-assets ratio of approximately 70% is typical for this industry segment (Bedding Plants, Inc., 1988 Greenhouse Operating Performance Report). Total capital costs were multiplied by 70% to obtain the principal.

INTEREST RATE: A given interest rate is assumed. The interest rate is 8.5%, which may be somewhat low for a current market rate. However, the authors believe 8.5% reflects a high interest rate since no inflationary effects are incorporated into the model. Thus, the 8.5% rate reflects a real or true rate and, in this case, is a conservative figure. This rate is used for the calculation of the loan payment and for the net present value calculation.

YEARS: The loan is amortized for the given time period.

ANNUAL LOAN PAYMENT: The annual loan payment is a sum of the principal and interest calculated for the specific year. Annual interest is calculated by multiplying the total loan balance at the beginning of the year by the interest rate. The principal is calculated by subtracting the interest from the annual payment.

DEPRECIATION: Total capital building and equipment costs are depreciated for a given time period, based upon the straight line depreciation method.

Cash Flow Assumptions

DEBT: It is assumed that 70% of total capital costs will be debt financed.

PERCENTAGE OF CASH AVAILABLE FOR OPERATIONS ABOVE CAPITAL COSTS: It is assumed that 30% of total capital costs are owner financed. An additional contingency allowance of 15% of total capital costs is included for operations.

CASH AVAILABLE FOR OPERATIONS: Total cash available for operations is the sum of total capital costs and contingency funds.

BEGINNING CASH: The beginning cash amount is the sum of the owner's contribution and the contingency funds.

SECTION 2. GREENHOUSE CAPITAL COSTS

Capital cost estimates for the greenhouse were obtained either from conversations with local growers and wholesalers, or from published reports.

Capital Outlay

LAND: The land cost estimation is for a ten acre plot amortized for a twenty-year period along with other capital costs.

PLANTS: The initial purchase of rose plants are amortized for a seven-year period. The rose plants must be replaced every seven years. The replacement of rose plants takes place at the end of the seventh year, and the cost of the new plants is also amortized for seven years.

Greenhouse

STRUCTURE: The total covered area is 174,000 square feet. The design will be quonset-style bays connected at the gutters.

COVER: The roof cover is double poly that will be replaced every two years.

SOIL PREPARATION: It is assumed that the grower will have to manage the local soil with a variety of medium conditioners. The plants will be grown directly in the local soil.

COOLING SYSTEM: A pad-and-fan evaporative cooling system will be installed in most locations, however a basic fan-cooling system with side vents is used where appropriate.

HEATING SYSTEM: The use of a natural gas-fired boiler with hydronic distribution is assumed.

THERMAL CURTAIN: Use of thermal sheets for either heat retention or light reduction will depend on the location of the greenhouse. These differences are included in the model.

H.I.D. LIGHTING: Natural lighting conditions in some areas of the country make the need for H.I.D. lighting necessary.

FREIGHT: A freight cost for incoming supplies is assumed.

IRRIGATION SYSTEM: The use of automatically-operated perimeter watering systems is assumed.

ENVIRONMENTAL CONTROLS: Environmental computer controls are used for monitoring and controlling temperature, ventilation, and humidity.

FERTILIZER INJECTOR: The use of centralized fertilizer injectors is assumed.

SORTING MACHINE: The use of an automatic sorting machine is assumed.

CO_2 GENERATOR: The use of a CO_2 generator is assumed. CO_2 will only be used from October to April.

CONCRETE WALKS: The cost of laying concrete walks is included.

Other Capital Equipment

METAL BUILDING: Estimated costs for a metal building to include office space and a headhouse area is is included.

OFFICE EQUIPMENT: It is assumed that office equipment includes a copier, computer, software, timeclock, and other miscellaneous supplies.

PLANT COOLING STORAGE UNIT: The use of a storage unit to refrigerate or cool flowers is assumed.

DELIVERY VEHICLE: The use of a van for local pick-up and delivery purposes is assumed.

MISCELLANEOUS: An additional allowance for miscellaneous items not included elsewhere is assumed.

SECTION 3. OPERATING BUDGET CASH FLOW

The third section shows a projected cash flow on a yearly basis for the first ten years of greenhouse operation. It is anticipated that it will take approximately five months to construct the greenhouse, another month to plant the roses, and an additional six to seven months before the rose plants are expected to produce saleable blooms.

Sales

SALES VOLUME: The volume of roses sold is calculated by subtracting the production losses from the blooms sold per year (see Assumptions).

SALES PRICE: The average bloom selling price is obtained from Assumptions.

SALES REVENUE: Sales revenue is calculated by multiplying the sales volume by the selling price. No sales occur in the first year, and no revenue is expected until year two.

Outlay for Production

Operating costs are typically separated into fixed and variable categories. However, annual rose production is basically constant. That is, the same number of rose plants yield approximately the same number of roses every year, and the operating requirements for those rose plants remain constant. Therefore, this study refers to what are normally variable expenses as production expenses. Fixed operating expenses continue to be referred to as fixed expenses.

PRODUCTION EXPENSES: Production expenses for both regular and H.I.D. electricity (where applicable), heat, water, CO_2, chemicals, and fertilizer are based on the assumed rates of usage. Estimates for year one are for six months of production; estimates for the remaining years are based on twelve full months of production.

FIXED OPERATING EXPENSES: Administrative salaries including the owner/manager, grower, sales, legal/accounting, and maintenance positions are assumed to be fixed annual salaries. Because planting and production will not begin until after the sixth month, year one salary estimates are lower than those of later years. Allowances for annual salary increases are not included in this study.

Hourly wages are assumed for laborers and are estimated to begin in the sixth month. Hourly wages are also assumed for delivery personnel. These costs are not incurred until year two.

F.I.C.A. and S.U.T.A. costs are incurred in direct proportion to both fixed and hourly annual wages paid. Workers' Compensation costs are based on annual wages paid to laborers and to delivery and maintenance personnel.

Cost estimates for trash disposal, crop insurance, property insurance, overhead, repairs and maintenance, and vehicle operation and maintenance were obtained either from conversations with local growers or from published reports. These costs are pro-rated for year one, and it is assumed that they will remain constant for the following nine years.

OTHER FIXED EXPENSES: Other fixed expenses include the breakdown of principal and interest in the total annual loan payment.

TAXES: Federal and state income taxes are calculated based on the tax rates (see Note 1).

CASH FLOWS: Year-end cash flows are determined by subtracting net cash inflow after tax balances from beginning cash flow balances. The year-one beginning cash flow amount is obtained from the "Assumptions" section.

SECTION 3a. NOTE 1

NET CASH INFLOW FOR TAX CALCULATION: The net cash inflow for tax calculations is determined by subtracting the tax deductible interest and depreciation allowances from the net cash inflow from operations. Depreciation is assumed to be straight line for a seven year period. The simplified allowance for tax loss carryover and carryback is for one year only.

BALANCE: The balance determines the tax loss carryover or carryback.

SECTION 4. FINANCIAL CALCULATIONS

Profitability

AVERAGE BLOOM SELLING PRICE: The average bloom selling price is given in the "Assumptions" section.

NET PRESENT VALUE (NPV): The NPV is calculated based on annual after tax cash flows for a twenty year period and discounted at the interest rate given.

INTERNAL RATE OF RETURN (IRR): The IRR is the rate that equates the present value of expected future after tax cash flows to the initial cost of the project. The calculation is for a projected twenty-year period.

RETURN ON INVESTMENT (ROI): The ROI is calculated for year two by dividing the year-two net cash inflow after taxes by the total capital costs.

PROFIT MARGIN: Profit margin for year two is calculated by dividing net income after taxes by year-two annual sales.

Breakeven Analysis

ANNUAL SALES: The amount given for annual sales revenue is for year two.

ANNUAL PRODUCTION EXPENSES: The amount given for annual production expenses is for year two.

ANNUAL FIXED EXPENSES: The amount given for annual fixed expenses is for year two and is the sum of total fixed operating expenses and total other fixed expenses.

NET INCOME: Net income is calculated as the annual sales less the sum of annual production expenses and annual fixed expenses for year two.

SALES REQUIRED FOR BREAKEVEN: Breakeven sales dollars represent the volume of sales at which total costs equal total revenues. The calculation is based on year two costs and revenues.

BREAKEVEN AVERAGE BLOOM SELLING PRICE: The breakeven average selling price is determined by dividing the breakeven sales dollars (the sum of annual production expenses and annual fixed expenses) by the annual total sales volume.

Effects of Changes in Average Bloom Selling Price

The effects of changes in average bloom selling price on firm profitability is indicated. Five-cent increases in the bloom selling price are used to illustrate the effect on profit margins.

Greenhouse

INSTALLED COST: The installed cost is the sum of the costs per square foot for the greenhouse and greenhouse installation. Other capital equipment costs are not included in this calculation.

PRODUCTIVE AREA: The productive area is calculated by dividing the number of rose plants per acre by the number of square feet per acre.

Utilities

HEATING COSTS: Heating costs per square foot are calculated by dividing the annual heating expenses by the total of 174,000 square feet.

ELECTRICITY COSTS: Electricity costs per square foot are calculated by dividing the annual electricity expenses by the total of 174,000 square feet.

Revenue

DOLLARS PER SQUARE FOOT (TOTAL SALES REVENUE): Revenue dollars per square foot ($/sq. ft.) is determined by dividing total sales by 174,000 square feet.

DOLLARS PER SQUARE FOOT (NET CASH AFTER TAXES):
Revenue dollars per square foot ($/sq. ft.) is also calculated in terms of net cash inflow after taxes and is determined by dividing net cash inflow after taxes by 174,000 square feet.

Operating Budget

The operating budget category includes various key operating costs expressed in terms of percentage of total expenses and provides a convenient method to compare costs at different locations. It is based on year two costs and revenue.

TABLE B-25. ASSUMPTIONS FOR THE LAS CRUCES AREA

Greenhouse Assumptions	
Land cost ($/acre)	$12,500
Rose plants per acre	31,500
Total # of rose plants	126,000
Rose plant costs ($/plant)	$3.00
Average bloom selling price	$0.32
Bloom production (blooms/plant/year)	30
Production losses	5%
Net blooms (plant/year)	29
Blooms sold per year	3,591,000
Employees per acre	7
Greenhouse size (acres)	4
Acres (total)	10
Square feet/acre	43,500
Warehouse/Office (sq. ft.)	7,000
Economic Assumptions	
State tax rate	4.8%
Federal tax rate	34%
F.I.C.A. rate	14%
S.U.T.A. rate	2.7%
Workers' Compensation/$100	$4.50
Vehicle fee ($/mile)	$0.30
Vehicle miles driven per year	20,000
General inflation rate	0%
Laborer wage rate	$4.50
Work week (hours)	48
Property tax rate ($/1,000, 1/3 valuation)	$20.95
Utility Assumptions	
Electricity energy rate ($/kWh)	$0.075
Electricity demand rate ($/kW/Mo)	$14.00
Natural gas rate ($/MMBTU)	$3.25
Water rate ($/1,000 gal)	$1.00
Heating fuel inflation rate	0%
Electricity inflation rate	0%
Heating load (MMBTU/4 acres)	16,217
Electricity load (kWh/year/acre)	120,000
Electricity load (kW/acre)	15
Water consumption (gal/acre/year)	4,888,500
Boiler efficiency	75%
CO_2 ($/sq. ft. to generate)	$0.20

Assumptions Cont.

Amortization Assumptions-Initial Outlay	
Principal	$1,507,730
Interest rate	8.5%
Years	20
Annual loan payment (P & I)	$159,323
Depreciation (# years, straight line basis)	7

Cash Flow Assumptions	
Debt (% of total capital costs)	70%
% of cash avail. for op. above capital costs	15%
Cash available for operations	$2,476,985
Beginning cash	$969,255

TABLE B-26. GREENHOUSE CAPITAL COSTS FOR THE LAS CRUCES AREA

Capital Outlay	*$*	*$/sq ft*
Land	$125,000	
Plants - roses (years 1 & 7)	$378,000	
Greenhouse		
Structure	$391,500	$2.25
Cover (replace every two years)	$26,100	$0.15
Soil Preparation	$25,000	$0.14
Pad & Fan Cooling	$139,200	$0.80
Heating System	$278,400	$1.60
Freight	$17,400	$0.10
Concrete Walks	$15,000	$0.09
Greenhouse Installation		
Structure	$174,000	$1.00
Pad & Fan	$26,100	$0.15
Heating	$17,400	$0.10
Electrical Wiring	$69,600	$0.40
Plumbing	$43,500	$0.25
Irrigation System	$121,800	$0.70
Environmental Controls	$60,900	$0.35
Fertilizer Injector	$8,700	$0.05
Sorting Machine	$25,000	
CO_2 Generator	$26,100	$0.15
Total Greenhouse only	*$1,465,700*	*$8.28*
Other Capital Equipment		
Metal Building (includes office)	$65,800	
Office Equipment	$30,000	
Concrete Pad (Metal bldg. only)	$29,400	
Plant Cool Storage Unit	$30,000	
Cool Storage Installation	$5,000	
Delivery Vehicle (van)	$15,000	
Miscellaneous	$10,000	
Total other	*$185,200*	
TOTAL	*$2,153,900*	

Table B 27. Operating Budget Cash Flow, Las Cruces, Years 1-10

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
SALES (volume sold)	0	3,562,875	3,562,875	3,562,875	3,562,875	3,562,875	3,562,875	3,562,875	3,562,875	3,562,875
Sales Price ($/bloom)		$0.320	$0.320	$0.320	$0.320	$0.320	$0.320	$0.320	$0.320	$0.320
SALES REVENUE	$0	$1,140,120	$1,140,120	$1,140,120	$1,140,120	$1,140,120	$1,140,120	$1,140,120	$1,140,120	$1,140,120
OUTLAY FOR PRODUCTION										
Production Expenses										
Electricity	$23,040	$46,080	$46,080	$46,080	$46,080	$46,080	$46,080	$46,080	$46,080	$46,080
Heat	$35,137	$70,274	$70,274	$70,274	$70,274	$70,274	$70,274	$70,274	$70,274	$70,274
Water	$9,777	$10,554	$10,554	$10,554	$10,554	$10,554	$10,554	$10,554	$10,554	$10,554
CO2	$20,300	$20,300	$20,300	$20,300	$20,300	$20,300	$20,300	$20,300	$20,300	$20,300
Chemicals/Fertilizer	$12,000	$24,000	$24,000	$24,000	$24,000	$24,000	$24,000	$24,000	$24,000	$24,000
Total Production Expenses	$100,254	$171,208	$171,208	$171,208	$171,208	$171,208	$171,208	$171,208	$171,208	$171,208
GROSS PROFIT	($100,254)	$968,912	$968,912	$968,912	$968,912	$968,912	$968,912	$968,912	$968,912	$968,912
Fixed Operating Expenses										
Owner/Manager	$20,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Grower	$15,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000
Sales	$12,500	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Legal/accounting	$10,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000
Maintenance	$10,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000
Laborers	$157,248	$314,496	$314,496	$314,496	$314,496	$314,496	$314,496	$314,496	$314,496	$314,496
Delivery	$0	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
FICA	$32,139	$64,278	$64,278	$64,278	$64,278	$64,278	$64,278	$64,278	$64,278	$64,278
Workers' Compensation (maint/labor/delivery)	$7,526	$15,277	$15,277	$15,277	$15,277	$15,277	$15,277	$15,277	$15,277	$15,277
SUTA	$6,068	$12,136	$12,136	$12,136	$12,136	$12,136	$12,136	$12,136	$12,136	$12,136
Greenhouse cover replacement	$0	$0	$26,100	$0	$26,100	$0	$26,100	$0	$26,100	$0
Trash disposal	$1,500	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000
Crop Insurance	$5,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Property Insurance	$10,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Overhead	$7,500	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000
Repairs & Maintenance	$0	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Vehicle Operation & Maintenance	$3,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000
Miscellaneous Tax	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Inventory tax	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Franchise tax	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Ad valorem tax	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Property Tax	$15,039	$15,039	$15,039	$15,039	$15,039	$15,039	$15,039	$15,039	$15,039	$15,039
Total Fixed Operating Expenses	$312,521	$620,227	$646,327	$620,227	$646,327	$620,227	$646,327	$620,227	$646,327	$620,227
NET CASH INFLOW FROM OPERATIONS	($412,775)	$348,685	$322,585	$348,685	$322,585	$348,685	$322,585	$348,685	$322,585	$348,685
Other Fixed Expenses										
Principal	$31,166	$33,815	$36,690	$39,808	$43,192	$46,863	$50,847	$96,888	$105,124	$114,059
Interest	$128,157	$125,508	$122,634	$119,515	$116,131	$112,460	$108,477	$136,285	$128,049	$119,114
Total Other Fixed Expenses	$159,323	$159,323	$159,323	$159,323	$159,323	$159,323	$159,323	$233,173	$233,173	$233,173
NET CASH INFLOW AFTER OTHER EXPENSES	($572,098)	$189,362	$163,262	$189,362	$163,262	$189,362	$163,262	$115,513	$89,412	$115,513
Taxes (See Note 1)										
Federal Income Tax	$0	$0	$0	$0	$0	$0	$0	$22,035	$47,782	$59,694
State Income Tax	$0	$0	$0	$0	$0	$0	$0	$3,111	$6,746	$8,427
Total Taxes	$0	$0	$0	$0	$0	$0	$0	$25,146	$54,528	$68,122
NET CASH INFLOW AFTER TAXES	($572,098)	$189,362	$163,262	$189,362	$163,262	$189,362	$163,262	$90,368	$34,884	$47,391
BEGINNING CASH FLOW	$969,255	$397,157	$586,519	$749,781	$939,144	$1,102,406	$1,291,768	$1,455,030	$1,545,397	$1,580,281
YEAR END CASH FLOW	$397,157	$586,519	$749,781	$939,144	$1,102,406	$1,291,768	$1,455,030	$1,545,397	$1,580,281	$1,627,672

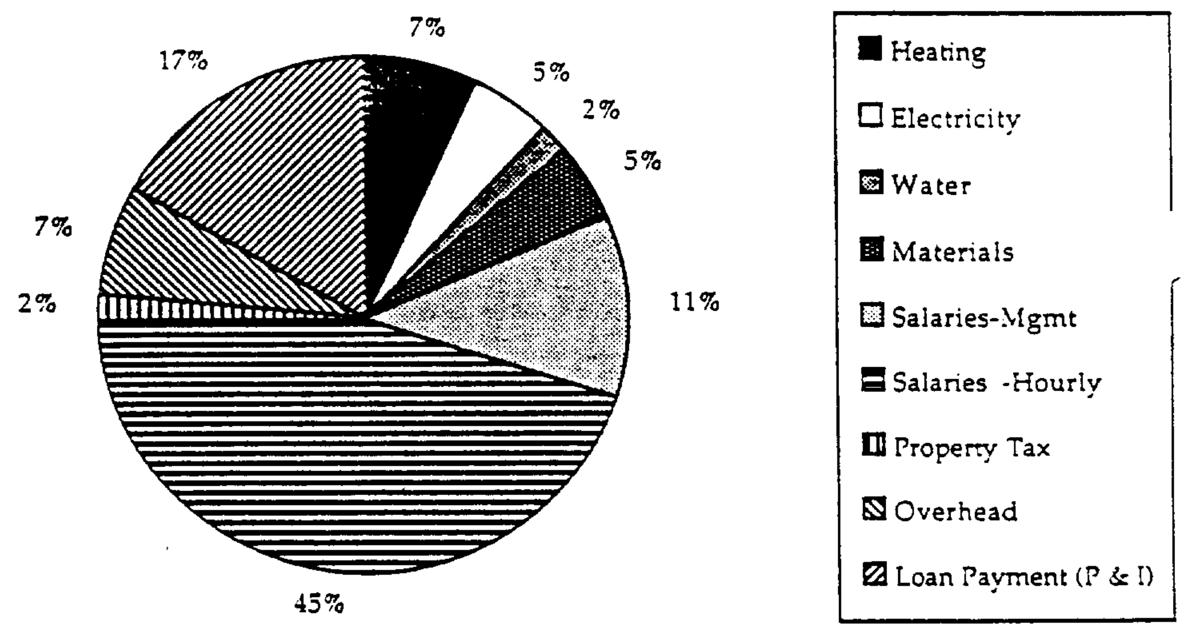
Table B 27a Net [illegible] , Years 1 10

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
NET CASH INFLOW FROM OPERATIONS	($412,774)	$348,685	$322,585	$348,685	$322,585	$348,685	$322,585	$348,685	$322,585	$348,685
Interest	$128,157	$125,508	$122,634	$119,515	$116,131	$112,460	$108,477	$136,285	$128,049	$119,114
Depreciation Amortization (Straight Line)	$307,700	$307,700	$307,700	$307,700	$307,700	$307,700	$307,700	$54,000	$54,000	$54,000
Total	$435,857	$433,208	$430,334	$427,215	$423,831	$420,160	$416,177	$190,285	$182,049	$173,114
NET CASH INFLOW FOR TAX CALCULATION	($848,631)	($84,522)	($107,748)	($78,530)	($101,246)	($71,475)	($93,591)	$158,401	$140,536	$175,572
Taxes										
Federal Income Tax	$0	$0	$0	$0	$0	$0	$0	$22,035	$47,782	$59,694
State Income Tax	$0	$0	$0	$0	$0	$0	$0	$3,111	$6,746	$8,427
Total Taxes	$0	$0	$0	$0	$0	$0	$0	$25,146	$54,528	$68,122
Balance	($848,631)	($84,522)	($107,748)	($78,530)	($101,246)	($71,475)	($93,591)	$133,255	$86,008	$107,450
Tax loss carryover or carryback	($848,631)	($84,522)	($107,748)	($78,530)	($101,246)	($71,475)	($93,591)	$64,810	$205,346	$380,918

TABLE B-28. FINANCIAL CALCULATIONS FOR THE LAS CRUCES AREA

Price ($)	Sales ($)	Annual Production Expenses ($)	Annual Fixed Expenses ($)	Total Expenses ($)	Net Income ($)	Profit Margin (%)
0.25	897,750	180,208	779,550	959,758	-62,008	-7
0.30	1,077,300	180,208	779,550	959,758	117,542	11
0.35	1,256,850	180,208	779,550	959,758	297,092	24
0.40	1,436,400	180,208	779,550	959,758	496,642	33
0.45	1,615,950	180,208	779,550	959,758	656,192	41

Figure B-7
Operating Budget Distribution, Las Cruces



APPENDIX E

APPENDIX E

Support Calculations

These calculations, in support of the projected quantities of GP/GT Energy in the forms E(B), E(G) and E(P), are based on well known relationships between the common energy and power units, specifically the following:

Energy Units	Power Units
1 KW Hour = 3,413 B.T.U.	3,413 BTU/hr. = 1.0 KW
1 HP Hour = 2,545 B.T.U.	1.0 KW = 1.34 HP
	1.0 HP = 0.746 KW

Further, the relationships that 1.0 B.T.U. is the amount of heat energy required to raise the temperature of 1.0 lb. of water by 1.0 °F; 1.0 SCF of natural gas contains 1,000 B.T.U.'s; and that the gas consumption of a gas-driven engine of the type to be applied herein = 6.3 SCF/HP hour.

Support calculation have been prepared for the values of the E(B), E(G), and E(P) energy parameters associated with the "Maximum" case for the East Sand for purposes of example, and are presented as follows:

E(B): Based on an assumed total temperature differential of 100°F

$$\#\text{B.T.U.'s per hour} = \frac{25{,}000 \text{ BPD x } 42 \text{ gal/bbl. x } 8.34 \text{ lbs./gal. x } 100°\text{F.}}{24 \text{ hrs.}}$$

$$= 36{,}487{,}500 \text{ B.T.U.'s per hour}$$

#KW = 36,487,500/3,413 = 10,690.7 KW

#HP = 10,690.7 x 1.34 = 14,325.6 HP

E(G): For Gas Turbine Power

Flow Rate/hour = 600,000 SCF/day divided by 24 hours = 25,000 SCF/hr.

#HP = 25,000 SCF/hr. divided by 6.3 SCF/HP hr. = 3,968 HP

#KW = 3,968 HP x 0.746 = 2,960 KW

#B.T.U.'s/hr. = 2,960 KW x 3,413 = 10,103,563 B.T.U.'s per hour

E(P): For Hydroturbine Power

#HP = flowrate (SCF/sec. x Hydrostatic Head, Ft. x Efficiency) x Constant Flowrate, SCF/sec.

$$= \frac{25{,}000 \text{ BPD x } 42 \text{ Gal/bbl.}}{(84{,}600 \text{ sec./day}) (7.48 \text{ gal./cu.ft.})} = 1.625 \text{ SCF/sec.}$$

$$\text{Hydrostatic Head} = \frac{950 \text{ psi}}{0.933 \text{ psi/ft of head}} = 2{,}194 \text{ Ft. of head}$$

Assumed Efficiency = 0.90

Constant = 0.1135 (converts weight of water to energy terms)

#HP = (1.625 SCF/sec. x 2,194 ft. x 0.9 x 0.1135) = 364.2 HP

#KW = (364.2 x 0.746) = 271.7 KW

#B.T.U.'s/hr. = 271.7 x 3,413 = 927,289 B.T.U.'s/hr.

Note (1): Identical calculations using the appropriate values for the other sands and the minimum case have been utilized to obtain the values shown under the heading entitled: "Order-of-Magnitude Projected Quantities"

APPENDIX F

EVALUATION OF AUTO DESALINATION

As with all process feasibility evaluations, background information must be obtained which determines the feasibility of the various process units. In the case of the GP/GT application, the following wellhead information was provided by the Project Manager, based upon historical data from the McAllen Ranch wellfield:

• Wellhead Temperature:	265°F
• Entrained Gas	25 ft^3/bbl
• Daily Feed	1.0 MGD
• Chemical Analysis	see attached
• Brine Disposal	Via Injection Well (others)
• Minimum System Recovery	75%
• Wellhead Pressure	1000 PSI
• Produce Water Quality	SDWA Standards

Based upon the temperature, pressure, and entrained gas information, all membrane systems can be precluded from further consideration without significant additional process equipment to cool and degas the streams. The elevated pressure can be reduced by the utilization of an energy recovery system to both recover the GP energy and depressurize the stream.

Immediately after depressurization, a single-staged flash unit without a condenser can be applied to remove the entrained (miscible and immiscible) gases from the stream. This energy source can be recovered or utilized for other energy production on-site.

Based upon standard thermodynamic design, the heat loss from wellhead, depressurization, through these units is estimated to be 15-20°, resulting in a flow to the desalination system at a temperature of approximately 245-250 °.

The basic concept of the autodesalination system has been to utilize the GT aspect of the flows. Instead of the usual system of heat sources and exchangers throughout the process, the stream arrives at an elevated temperature, which then provides the thermal energy to drive the multi-effect unit.
Prior to the actual design of a multi-effect distillation system, attention must be made to the feedwater chemistry, the brine chemistry, and the number of effects. The physical chemistry of the flows across the various effects determines the performance, scale deposition, and corrosivity of the system.

A thermodynamic review of the system indicates the number of effects to be between twelve and sixteen, based upon the water recovery. The implementation of freon (or CFC-free refrigerant) charged condensers instead of product water charged condensers will optimize the performance and reduce the actual number of stages required. It should be noted that there is an approximate 3.0-5.0 ° F temperature drop across each stage, based upon the vacuum applied and system insulating capacity. For the purposes of this review, a 5.0° F temperature drop was considered in the preliminary design.

With a basic concept of the most applicable type of system to utilize, an evaluation of the system feedwater was performed. Utilizing a modified commercially available physical-chemistry saturation computer model (Dh-SAT, French Creek Software), the system was first modeled at the wellhead parameters, at a pressure of 1000 PSI. Following this evaluation, an evaluation was performed of the brine (reject) stream at the 75% water recovery level (concentration factor 4.0), at a pressure of 0 PSI.

The results of both were evaluated, with graphical representations attached in Appendix A. The Dh-SAT program calculates indicators of scale potential for the following:

• barium sulfate	Barite
• barium carbonate	Witherite
• calcium carbonate	Calcite
• calcium sulfate	Gypsum
• strontium sulfate	Celestite
• calcium phosphate	Hydroxyapatite and Tricalcium Phosphate
• iron hydroxide	Amorphous Iron Hydroxide
• iron phosphate	Strengite
• iron carbonate	Siderite
• silica	Amorphous Silica
• calcium fluoride	Fluorite
• magnesium hydroxide	Brucite

In addition, several scaling indices are calculated, including the following:

- Langelier Index
- Stiff-Davis Index
- Ryznar Index
- Oddo-Tomson Index

A review of the data for the wellhead stream immediately finds several problems in the form of scale forming salts. The Langelier Index finds that for all conditions in excess of pH 7.0, scale will form. The elevated total dissolved solids level of this stream (>9,800 mg/l TDS) indicates the Stiff-Davis Index should perhaps apply. A review of the Stiff-Davis plot for these conditions finds significant scale formation at pH greater than 7.0 and at temperatures less than 233° F.

A review of the plots for several constituents finds immediate problems in scale formation with Silica at all pH conditions at temperatures less than 183° F, Aragonite at all temperatures at pH conditions greater than 7.0, Barite under 183° F, Calcite at all temperatures at pH greater than 7.0, Siderite at all conditions, and Strontianite at all temperatures at pH greater than 7.5.

In summary, the scaling potential of the feedwater source precludes the implementation of a multi-effect desalination process without significant additional process control systems for pH and temperature management.

In an effort to further understand the performance of the GP/GT feedwaters under the McAllen Ranch operational conditions, a second run was made at 75% water recovery, a concentration factor of 4.0.

A review of the data for the 75% recovery stream again immediately finds several problems in the form of scale forming salts. The Langelier Index finds that for all conditions in excess of pH 6.33, scale will form. The elevated total dissolved solids level of this stream (>36,500 mg/l TDS) indicates the Stiff-Davis Index should perhaps apply. A review of the Stiff-Davis plot for these conditions finds significant scale formation at all pH greater than 6.0 and at all temperatures less than 250° F.

A review of the plots for several constituents finds immediate problems in scale formation with Silica at all pH conditions at all temperatures less than 233° F, Amorphous Iron Hydroxide at all temperatures when the pH is greater than 6.5. Anhydrite under all conditions, Aragonite at all temperatures at all pH conditions greater than 5.5, Barite under 217° F, Calcite at all temperatures at all pH levels greater than 6.0, Siderite at all conditions, and Strontianite at all conditions.

In summary, the scaling potential of the brine reject stream will result in significant scale formation and deposition within the system, with what appears to be significant deposition (as noted in the Momentary Excess plots) in effects after Effect No. 6. Even with the addition of significant additional process control systems for pH and temperature management, the implementation of the multi-effect distillation system on the GP/GT feedwaters in technically unfeasible at this time.

EVALUATION OF AUTO DESALINATION

As with all process feasibility evaluations, background information must be obtained which determines the feasibility of the various process units. In the case of the GP/GT application, the following wellhead information was provided by the Project Manager, based upon historical data from the McAllen Ranch wellfield:

•	Wellhead Temperature:	265°F
•	Entrained Gas	25 ft^3/bbl
•	Daily Feed	1.0 MGD
•	Chemical Analysis	see attached
•	Brine Disposal	Via Injection Well (others)
•	Minimum System Recovery	75%
•	Wellhead Pressure	1000 PSI
•	Produce Water Quality	SDWA Standards

Based upon the temperature, pressure, and entrained gas information, all membrane systems can be precluded from further consideration without significant additional process equipment to cool and degas the streams. The elevated pressure can be reduced by the utilization of an energy recovery system to both recover the GP energy and depressurize the stream.

Immediately after depressurization, a single-staged flash unit without a condenser can be applied to remove the entrained (miscible and immiscible) gases from the stream. This energy source can be recovered or utilized for other energy production on-site.

Based upon standard thermodynamic design, the heat loss from wellhead, depressurization, through these units is estimated to be 15-20°, resulting in a flow to the desalination system at a temperature of approximately 245-250 °.

The basic concept of the autodesalination system has been to utilize the GT aspect of the flows. Instead of the usual system of heat sources and exchangers throughout the process, the stream arrives at an elevated temperature, which then provides the thermal energy to drive the multi-effect unit.

Prior to the actual design of a multi-effect distillation system, attention must be made to the feedwater chemistry, the brine chemistry, and the number of effects. The physical chemistry of the flows across the various effects determines the performance, scale deposition, and corrosivity of the system.

J. McNutt & Associates, Inc.
McAllen Ranch Well Analysis
November, 1993

WELL	DEPTH	Na	K	Li	Ca	Mg	Sr	Ba
B-16	3983.00	3258.00	308.00	6.00	163.00	2.00	21.00	5.00
B-21	4113.00	2741.00	288.00	6.00	57.00	1.00	8.00	4.00
B-22	4085.00	2837.00	318.00	5.00	164.00	2.00	22.00	6.00
B-20	4135.00	2023.00	181.00	4.00	84.00	1.00	13.00	4.00
B-15	4082.00	2657.00	290.00	5.00	147.00	1.00	13.00	2.00
B-24		3327.00	360.00	6.00	165.00	2.00	23.00	5.00
AVERAGE	4080	2807	291	5	130	2	17	4

CF-1	4080	2807	291	5	130	2	17	4
CF-2	4080	5614	582	11	260	3	33	9
CF-3	4080	8422	873	16	390	5	50	13
CF-4	4080	11229	1163	21	520	6	67	17

WELL	DEPTH	Zn	Fe	Mn	Cl	H4SIO4	Br	B	T. Alk
B-16	3983.00		5.20	0.20	5090.00	377.00	20.00	90.00	701.00
B-21	4113.00	1.20	9.00	0.10	4170.00	432.00	16.00	75.00	804.00
B-22	4085.00	0.50	6.60	0.20	4470.00	272.00	17.00	61.00	553.00
B-20	4135.00	0.30	3.00	0.10	3210.00	249.00	12.00	55.00	628.00
B-15	4082.00	0.90	12.60	0.60	4120.00	401.00	16.00	93.00	582.00
B-24		0.10	14.70	0.20	5218.00	404.00	21.00	99.00	318.00
AVERAGE	4080	0.5	8.5	0.2	4380	356	17	79	598

CF-1	4080	0.5	8.5	0.2	4380	356	17	79	598
CF-2	4080	1.0	17.0	0.5	8759	712	34	158	1195
CF-3	4080	1.5	25.6	0.7	13139	1068	51	237	1793
CF-4	4080	2.0	34.1	0.9	17519	1423	68	315	2391

NOTE: Water analyses based upon data from L.S. Land, UT-Austin Department of Geology

DownHole SAT(tm)
SURFACE WATER CHEMISTRY INPUT

McAllen Ranch	Geothermal Formation
4X (75% Recovery)	4080 ft. Avg. Depth
Report Date: 12-01-93	Sampled: 12-01-93
Sample ID#: 0	at 1818

CATIONS		ANIONS	
Calcium(as Ca)	520.00	Chloride(as Cl)	17519
Magnesium(as Mg)	6.00	Sulfate(as SO4)	200.00
Barium(as Ba)	17.00	"M" Alkalinity(as CaCO3)	2391.0
Strontium(as Sr)	67.00	"P" Alkalinity(as CaCO3)	0.00
Sodium(as Na)	11229	Silica(as SiO2)	1423.0
Potassium(as K)	1163.0	Phosphate(as PO4)	0.00
Lithium(as Li)	21.00	H2S (as H2S)	0.00
Iron(as Fe)	34.10	Fluoride(as F)	100.00
Ammonia(as NH3)	0.00	Nitrate(as NO3)	0.00
Aluminum(as Al)	0.00		
Boron(as CaCO3)	315.00		

RAMETERS

pH	7.00		
Temperature(Deg F)	250.00	Pressure(psia)	0.00
Calculated T.D.S.	36528	P-CO2(Bars)	3.16E-4
Molar conductivity	35082	Density(g/ml)	1.00

DownHole SAT(tm)
SURFACE WATER DEPOSITION POTENTIAL INDICATORS

McAllen Ranch	Geothermal Formation
4X (75% Recovery)	4080 ft. Avg. Depth
Report Date: 12-01-93	Sampled: 12-01-93
Sample ID#: 0	at 1818

SATURATION LEVEL

Calcite	CaCO3	11.18
Aragonite	CaCO3	8.75
Witherite	BaCO3	0.09
Siderite	FeCO3	238.45
Magnesite	MgCO3	0.15
Strontianite	SrCO3	0.15
Anhydrite	CaSO4	0.04
Gypsum	CaSO4*2H2O	0.01
Barite	BaSO4	0.35
Celestite	SrSO4	0.08
Tricalcium phosphate	Ca3(PO4)2	0.00
' 'roxyapatite	Ca5(PO4)3(OH)	0.00
engite	FePO4*2H2O	0.00
Brucite	Mg(OH)2	< 0.001
Amorphous Iron	Fe(OH)3	1108.1
Amorphous Silica	SiO2	2.04
Fluorite	CaF2	5.55
Halite	NaCl	0.00
Thenardite	Na2SO4	< 0.001
Iron sulfide	FeS	0.00

COMMON INDICES

Langelier	1.62
Ryznar	3.76
Practical	0.81
Stiff-Davis	3.51
Oddo-Tomson	2.27
Larson-Skold	9.55

BOUND IONS	TOTAL	FREE
Calcium	520.00	211.12
Barium	17.00	3.31
Carbonate	279.76	4.62
Phosphate	0.00	0.00
Sulfate	200.00	132.16

FRENCH CREEK SOFTWARE, INC.
KIMBERTON & HARES HILL ROADS, KIMBERTON, PA 19442

DownHole SAT(tm)
SURFACE WATER MOMENTARY EXCESS

McAllen Ranch	Geothermal Formation
4X (75% Recovery)	4080 ft. Avg. Depth
Report Date: 12-01-93	Sampled: 12-01-93
Sample ID#: 0	at 1818

PRECIPITATION TO EQUILIBRIUM		mg/l	lbs/1000 Barrels
Calcite	$CaCO_3$	7.01	2.44
Aragonite	$CaCO_3$	6.81	2.37
Witherite	$BaCO_3$	-19.43	-6.77
Siderite	$FeCO_3$	2.35	0.82
Magnesite	$MgCO_3$	-7.12	-2.48
Strontianite	$SrCO_3$	0.14	0.05
Anhydrite	$CaSO_4$	-1377.3	-479.92
Gypsum	$CaSO_4*2H_2O$	-3183.6	-1109.3
Barite	$BaSO_4$	-9.90	-3.45
Celestite	$SrSO_4$	-467.50	-162.90
calcium phosphate	$Ca_3(PO_4)_2$	-0.00	>-0.001
roxyapatite	$Ca_5(PO_4)_3(OH)$	-135.01	-47.05
Strengite	$FePO_4*2H_2O$	>-0.001	>-0.001
Brucite	$Mg(OH)_2$	-16.47	-5.74
Amorphous Iron	$Fe(OH)_3$	< 0.001	< 0.001
Amorphous Silica	SiO_2	701.16	244.32
Fluorite	CaF_2	104.12	36.28
Halite	NaCl	-6.6e+5	-2.3e+5
Thenardite	Na_2SO_4	-1.6e+5	-5.5e+4
Iron sulfide	FeS	-0.40	-0.14

DownHole SAT(tm)
SURFACE WATER CHEMISTRY INPUT

McAllen Ranch
Water Analysis

Geothermal Formation
4080 ft. Avg. Depth

Report Date: 12-01-93
Sample ID#: 0

Sampled: 12-01-93
at 1818

CATIONS		ANIONS	
Calcium(as Ca)	130.00	Chloride(as Cl)	4380.0
Magnesium(as Mg)	2.00	Sulfate(as SO4)	50.00
Barium(as Ba)	4.00	"M" Alkalinity(as CaCO3)	598.00
Strontium(as Sr)	17.00	"P" Alkalinity(as CaCO3)	0.00
Sodium(as Na)	2807.0	Silica(as SiO2)	356.00
Potassium(as K)	291.00	Phosphate(as PO4)	0.00
Lithium(as Li)	5.00	H2S (as H2S)	0.00
Iron(as Fe)	8.50	Fluoride(as F)	25.00
Ammonia(as NH3)	0.00	Nitrate(as NO3)	0.00
Aluminum(as Al)	0.00		
Boron(as CaCO3)	79.00		

.RAMETERS

pH	7.00		
Temperature(Deg F)	250.00	Pressure(psia)	1000.0
Calculated T.D.S.	9152.2	P-CO2(Bars)	3.16E-4
Molar conductivity	12680	Density(g/ml)	1.00

FRENCH CREEK SOFTWARE, INC.
KIMBERTON & HARES HILL ROADS, KIMBERTON, PA 19442

DownHole SAT(tm)
SURFACE WATER DEPOSITION POTENTIAL INDICATORS

McAllen Ranch
Water Analysis

Geothermal Formation
4080 ft. Avg. Depth

Report Date: 12-01-93
Sample ID#: 0

Sampled: 12-01-93
at 1818

SATURATION LEVEL

Calcite	$CaCO_3$	2.09
Aragonite	$CaCO_3$	1.64
Witherite	$BaCO_3$	0.03
Siderite	$FeCO_3$	20.32
Magnesite	$MgCO_3$	0.05
Strontianite	$SrCO_3$	0.05
Anhydrite	$CaSO_4$	0.01
Gypsum	$CaSO_4*2H_2O$	0.00
Barite	$BaSO_4$	0.17
Celestite	$SrSO_4$	0.02
Tricalcium phosphate	$Ca_3(PO_4)_2$	0.00
'roxyapatite	$Ca_5(PO_4)_3(OH)$	0.00
.engite	$FePO_4*2H_2O$	0.00
Brucite	$Mg(OH)_2$	< 0.001
Amorphous Iron	$Fe(OH)_3$	283.22
Amorphous Silica	SiO_2	0.48
Fluorite	CaF_2	0.26
Halite	NaCl	< 0.001
Thenardite	Na_2SO_4	< 0.001
Iron sulfide	FeS	0.00

COMMON INDICES

Langelier	0.63
Ryznar	5.73
Practical	3.68
Stiff-Davis	2.34
Oddo-Tomson	1.60
Larson-Skold	10.12

BOUND IONS	TOTAL	FREE
Calcium	130.00	76.91
Barium	4.00	1.65
Carbonate	24.84	0.96
Phosphate	0.00	0.00
Sulfate	50.00	41.17

FRENCH CREEK SOFTWARE, INC.
KIMBERTON & HARES HILL ROADS, KIMBERTON, PA 19442

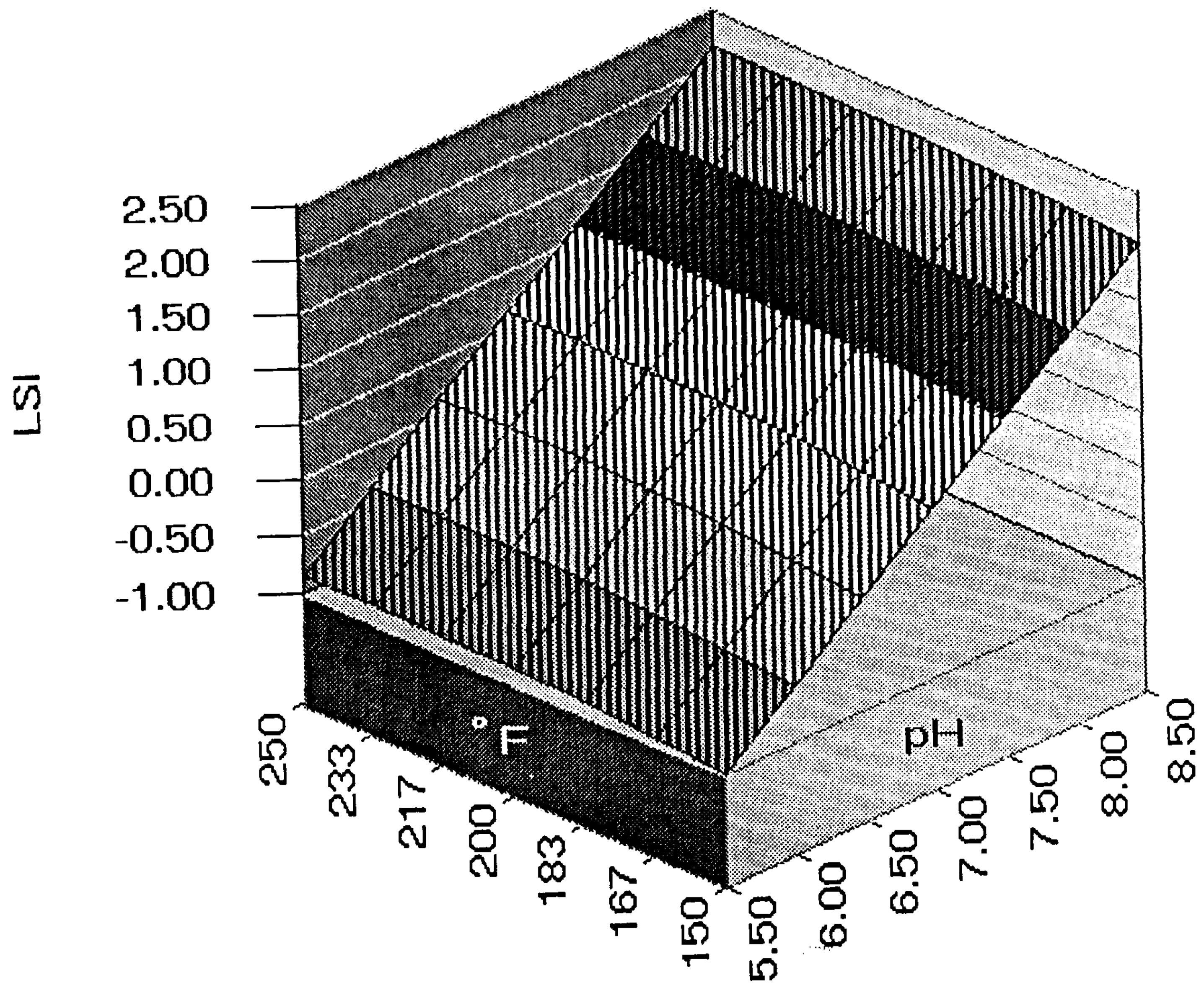
DownHole SAT(tm)
SURFACE WATER MOMENTARY EXCESS

McAllen Ranch	Geothermal Formation
Water Analysis	4080 ft. Avg. Depth
Report Date: 12-01-93	Sampled: 12-01-93
Sample ID#: 0	at 1818

PRECIPITATION TO EQUILIBRIUM		mg/l	lbs/1000 Barrels
Calcite	$CaCO_3$	0.83	0.29
Aragonite	$CaCO_3$	0.62	0.22
Witherite	$BaCO_3$	-14.22	-4.96
Siderite	$FeCO_3$	0.35	0.12
Magnesite	$MgCO_3$	-6.15	-2.14
Strontianite	$SrCO_3$	-9.16	-3.19
Anhydrite	$CaSO_4$	-949.58	-330.89
Gypsum	$CaSO_4*2H_2O$	-2069.9	-721.27
Barite	$BaSO_4$	-11.79	-4.11
Celestite	$SrSO_4$	-316.16	-110.17
calcium phosphate	$Ca_3(PO_4)_2$	-0.00	>-0.001
.roxyapatite	$Ca_5(PO_4)_3(OH)$	-82.53	-28.76
Strengite	$FePO_4*2H_2O$	>-0.001	>-0.001
Brucite	$Mg(OH)_2$	-13.33	-4.64
Amorphous Iron	$Fe(OH)_3$	< 0.001	< 0.001
Amorphous Silica	SiO_2	-368.39	-128.37
Fluorite	CaF_2	-37.85	-13.19
Halite	$NaCl$	-6.1e+5	-2.1e+5
Thenardite	Na_2SO_4	-1.3e+5	-4.7e+4
Iron sulfide	FeS	-0.55	-0.19

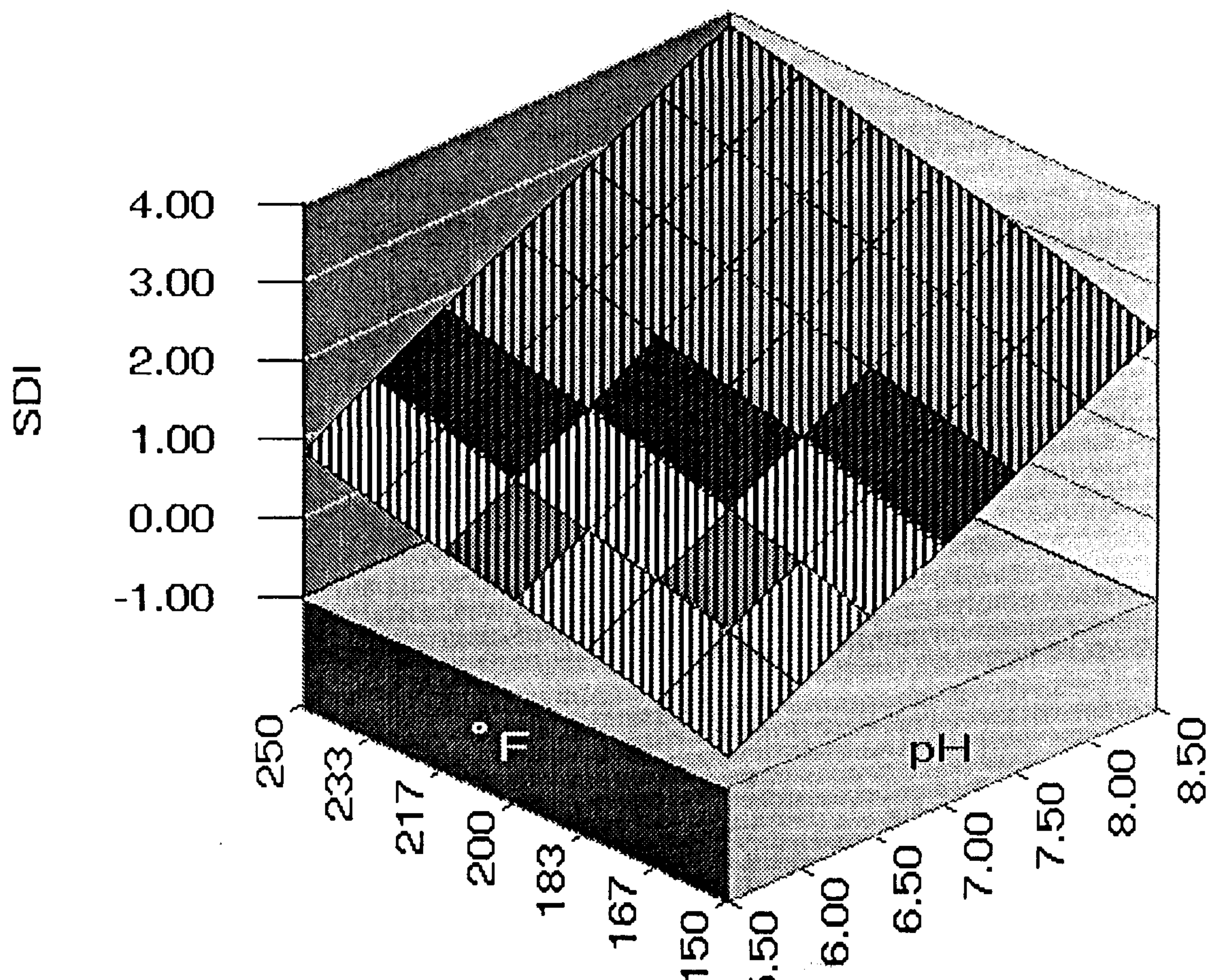
McAllen Ranch, Wellhead Conditions

Langelier Saturation Index



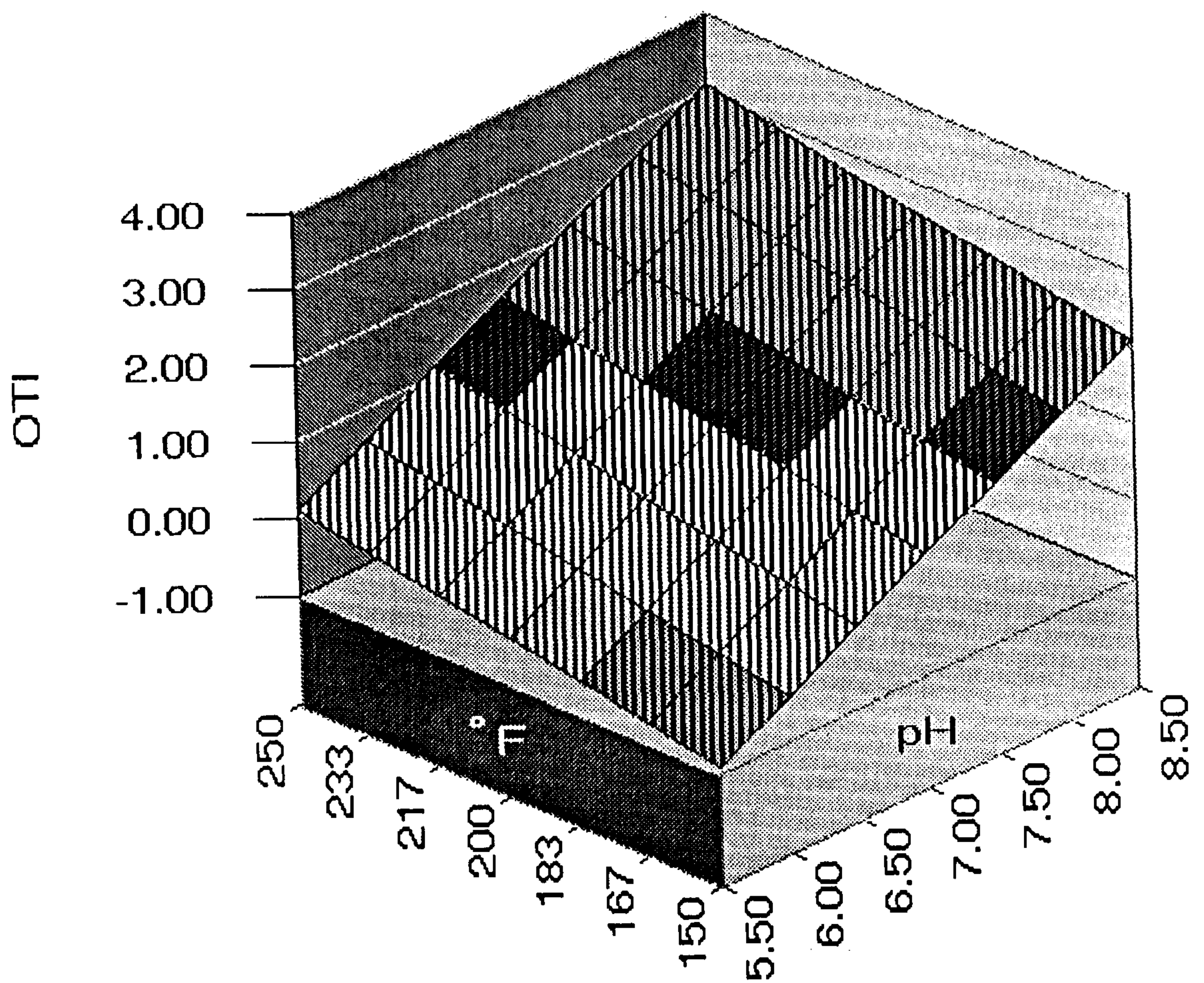
McAllen Ranch, Wellhead Conditions

Stiff-Davis Index



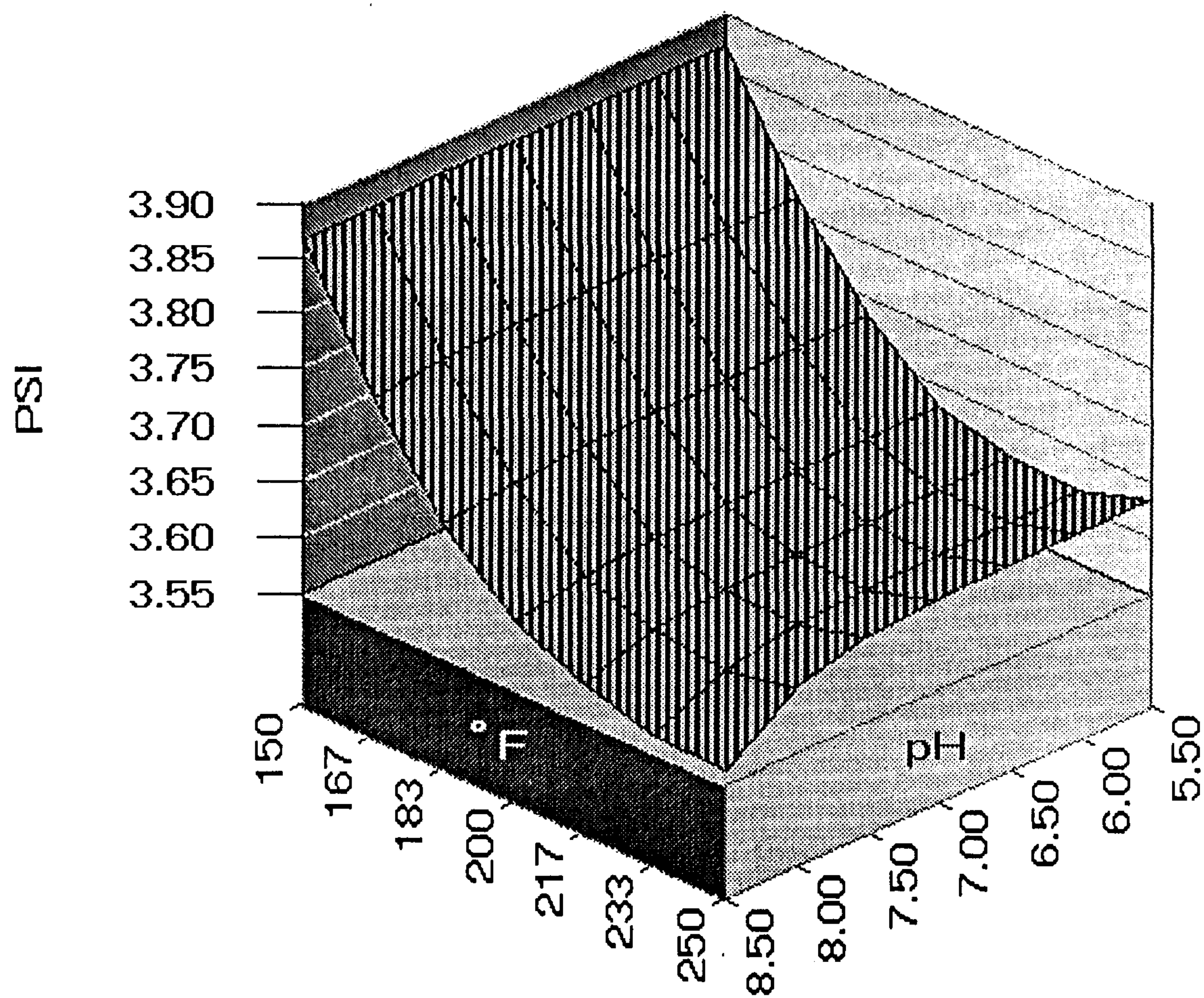
McAllen Ranch, Wellhead Conditions

Oddo-Tomson Index



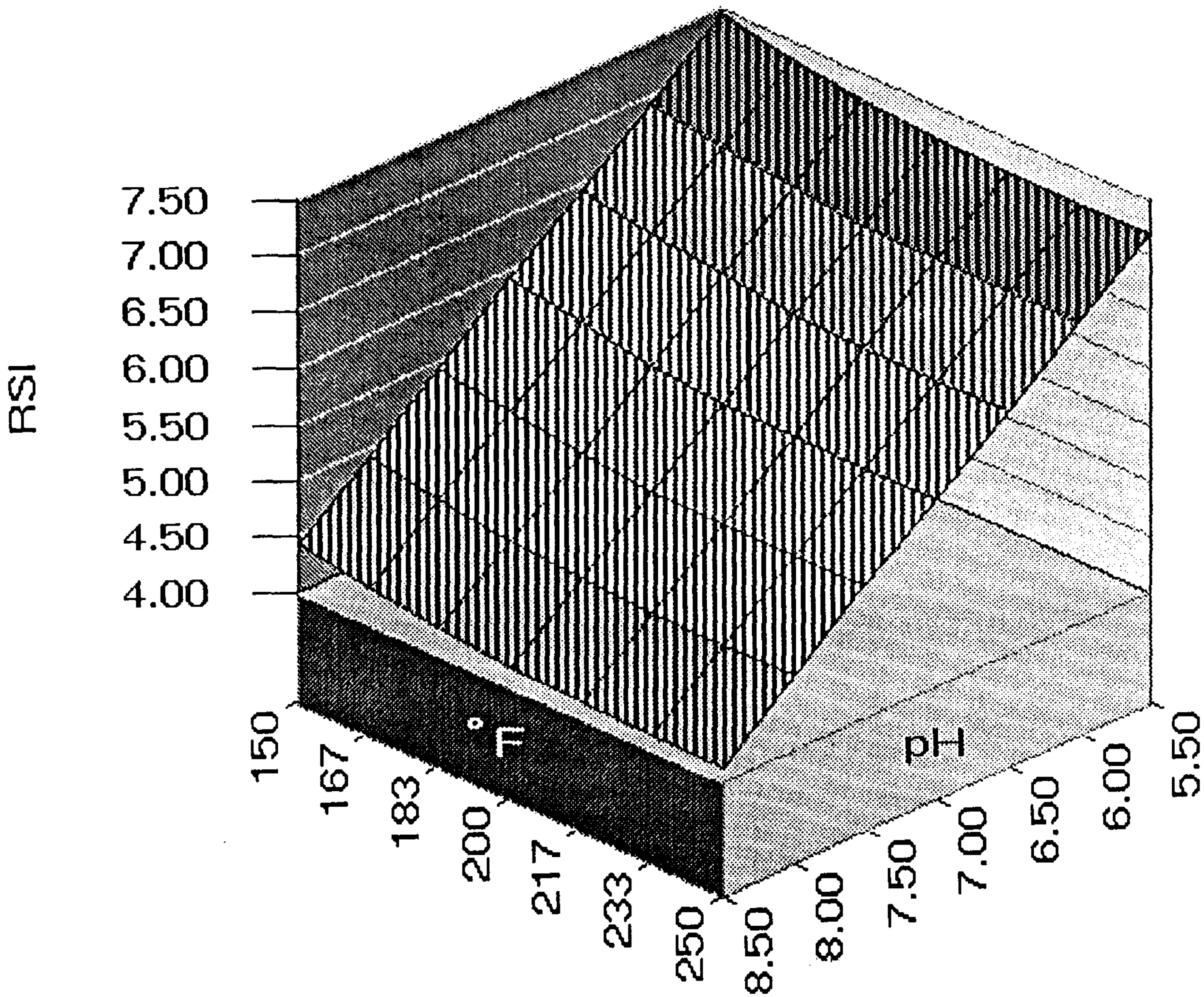
McAllen Ranch, Wellhead Conditions

Practical Equilibrium Index



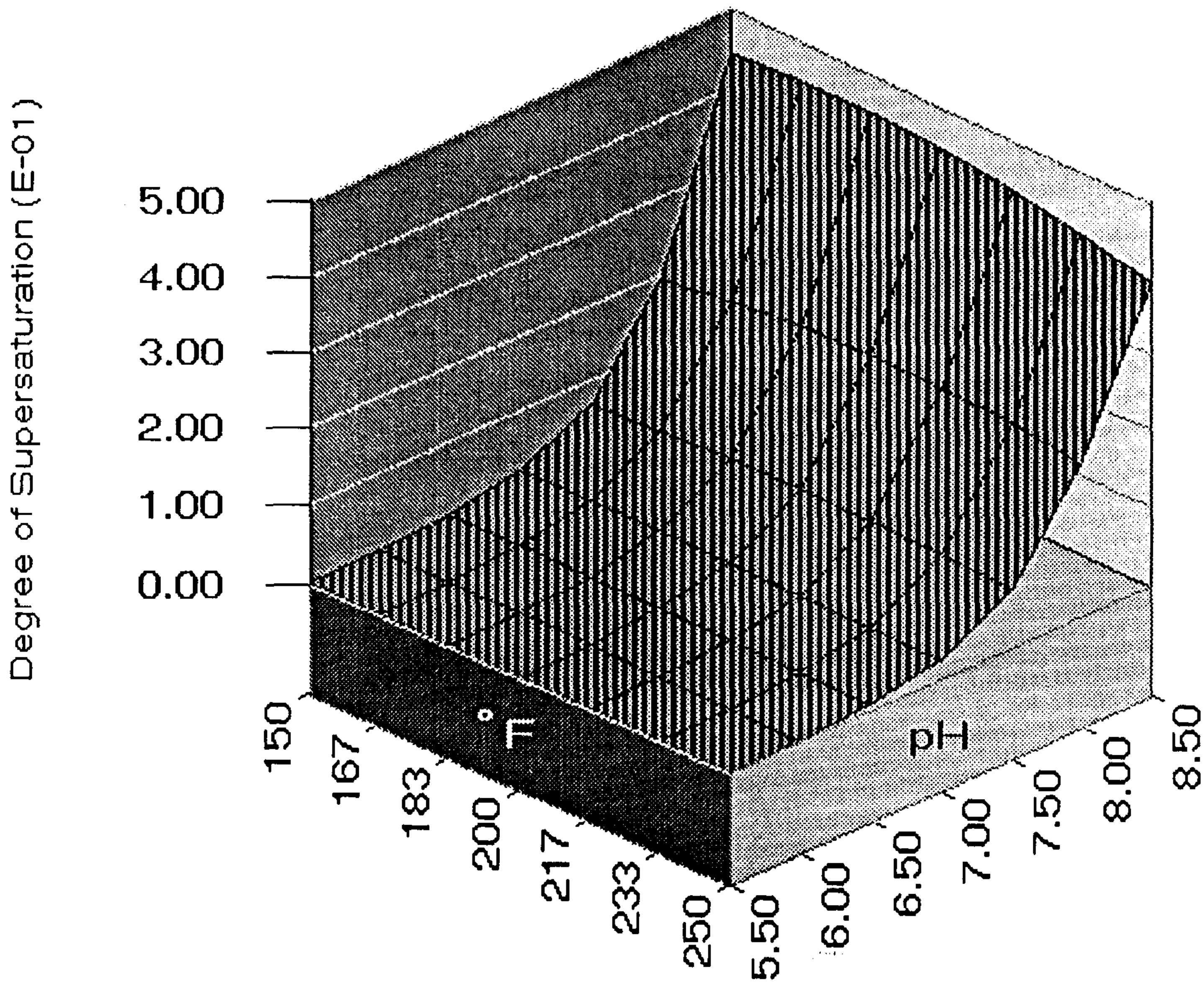
McAllen Ranch, Wellhead Conditions

Ryznar Stability Index



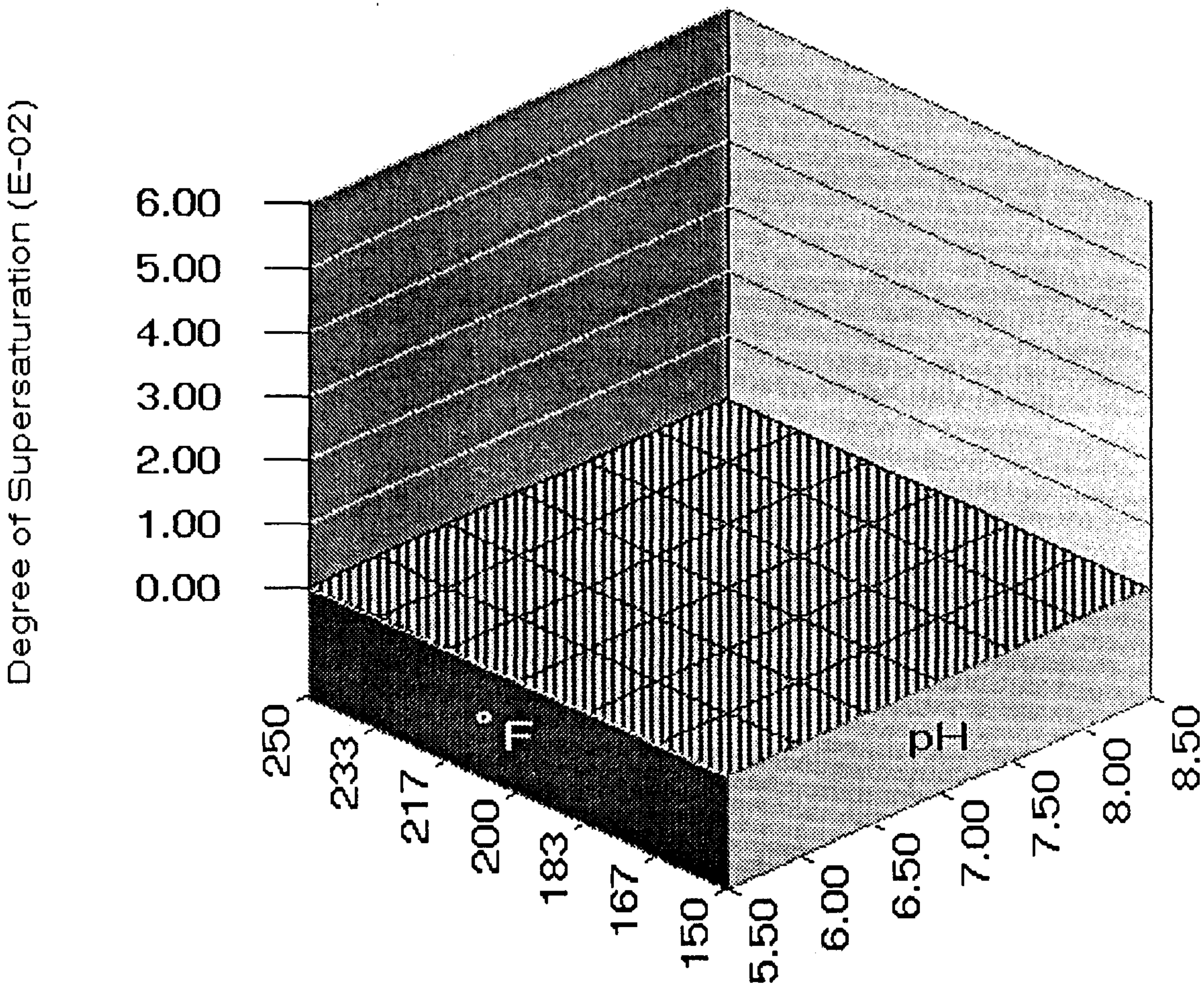
McAllen Ranch, W llhead Conditions

Witherite Saturation Level



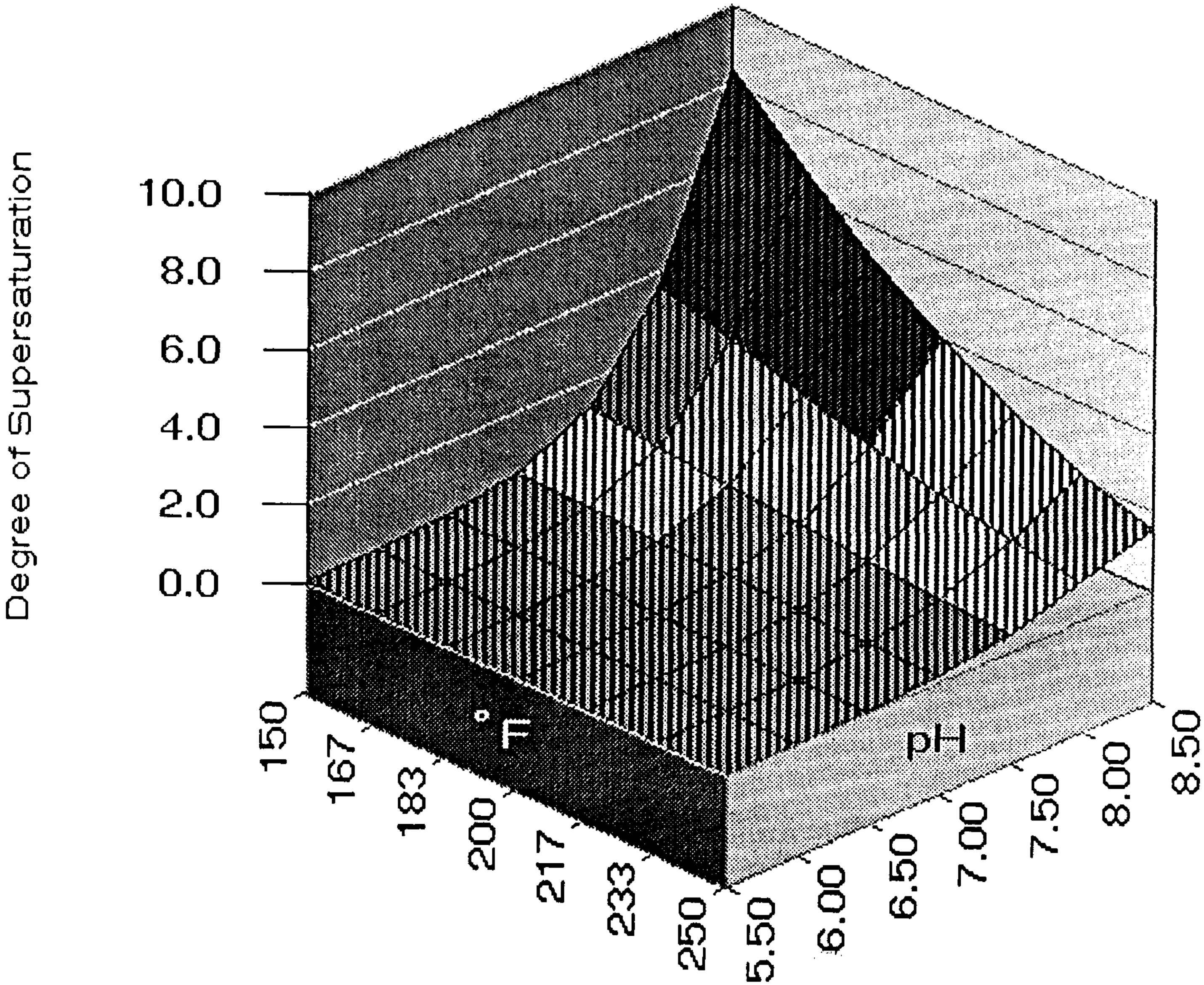
McAllen Ranch, Wellhead Conditions

Thenardite Saturation Level



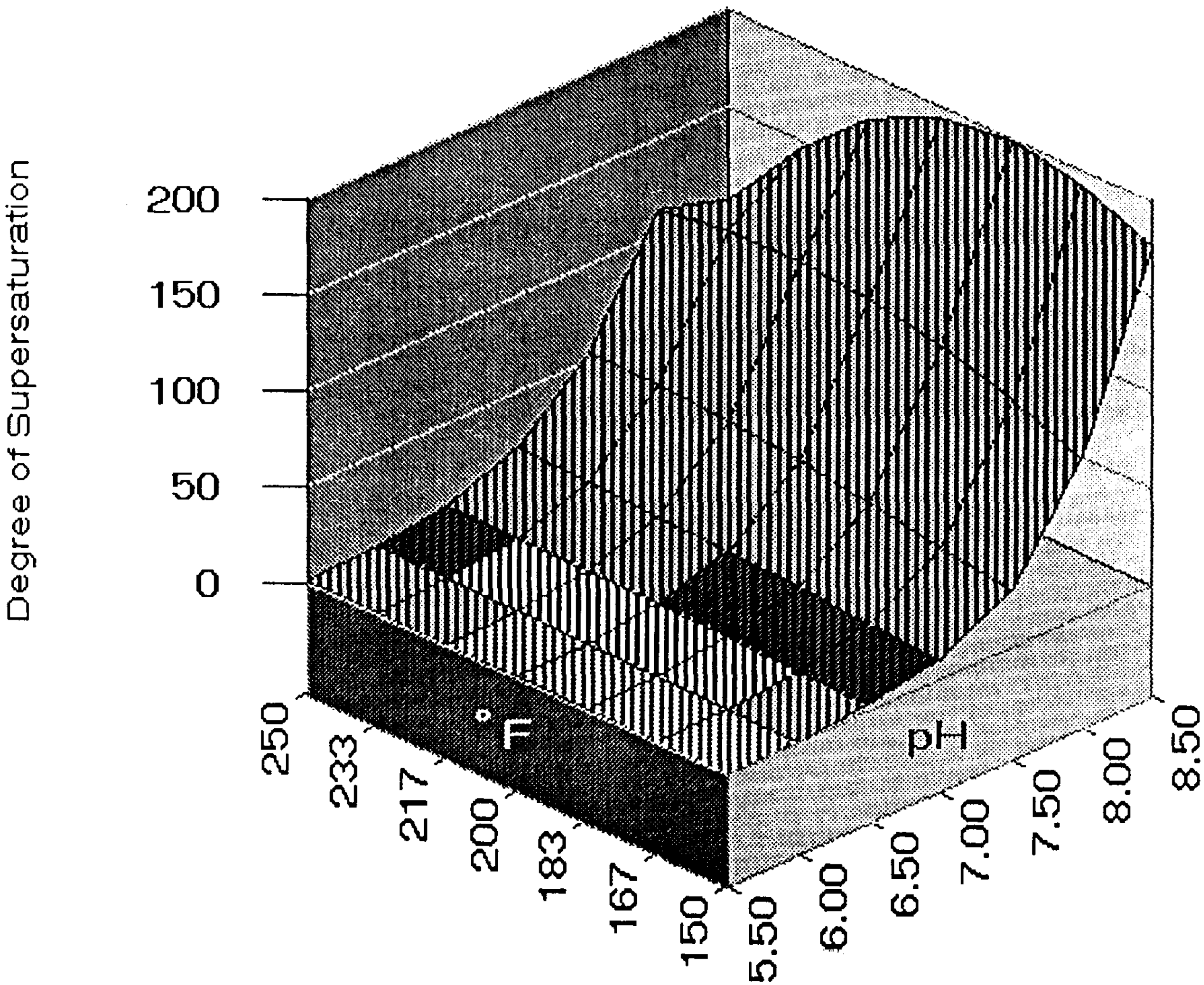
McAllen Ranch, Wellhead Conditions

Strontianite Saturation Level



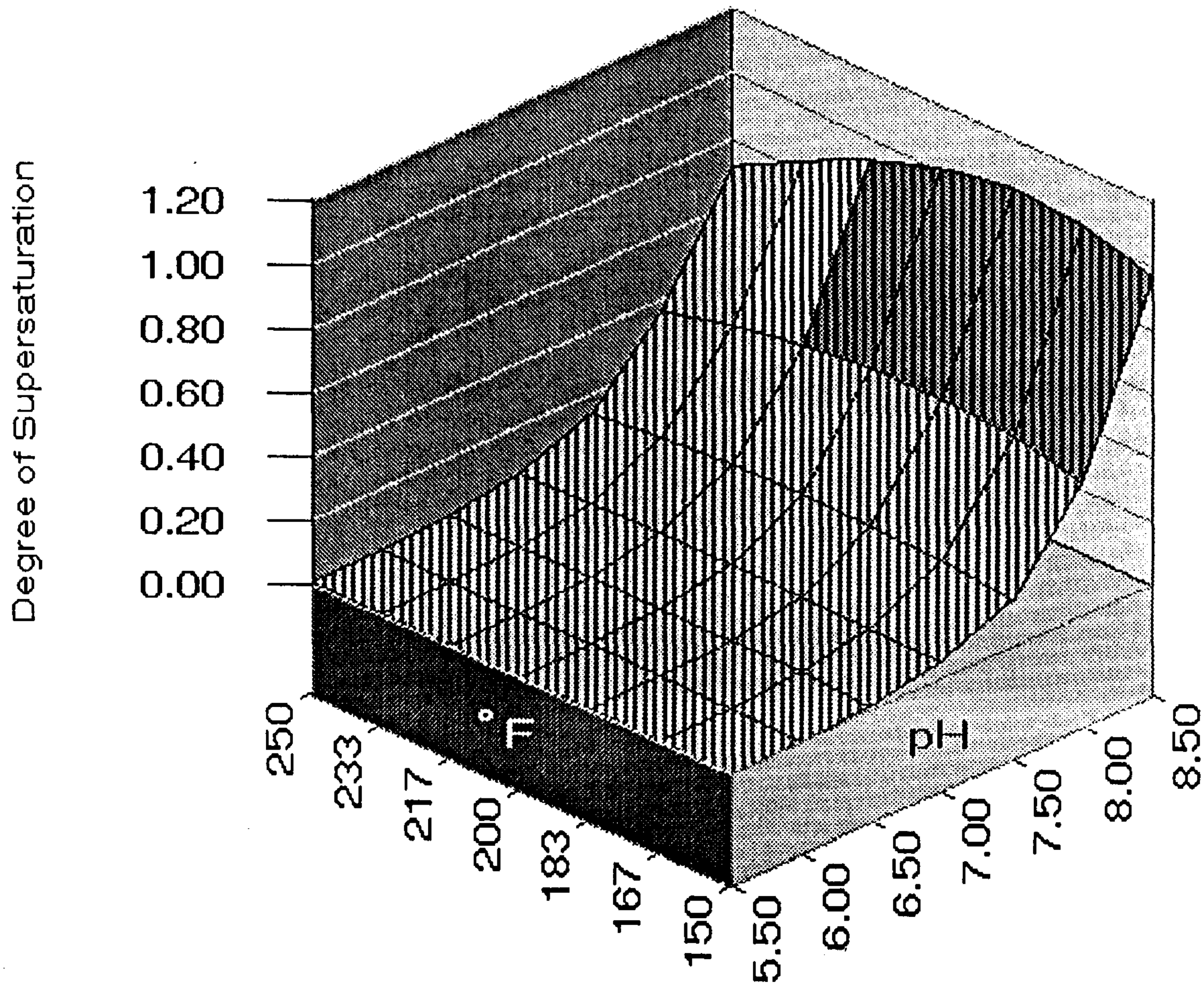
McAllen Ranch, Wellhead Conditions

Siderite Saturation Level



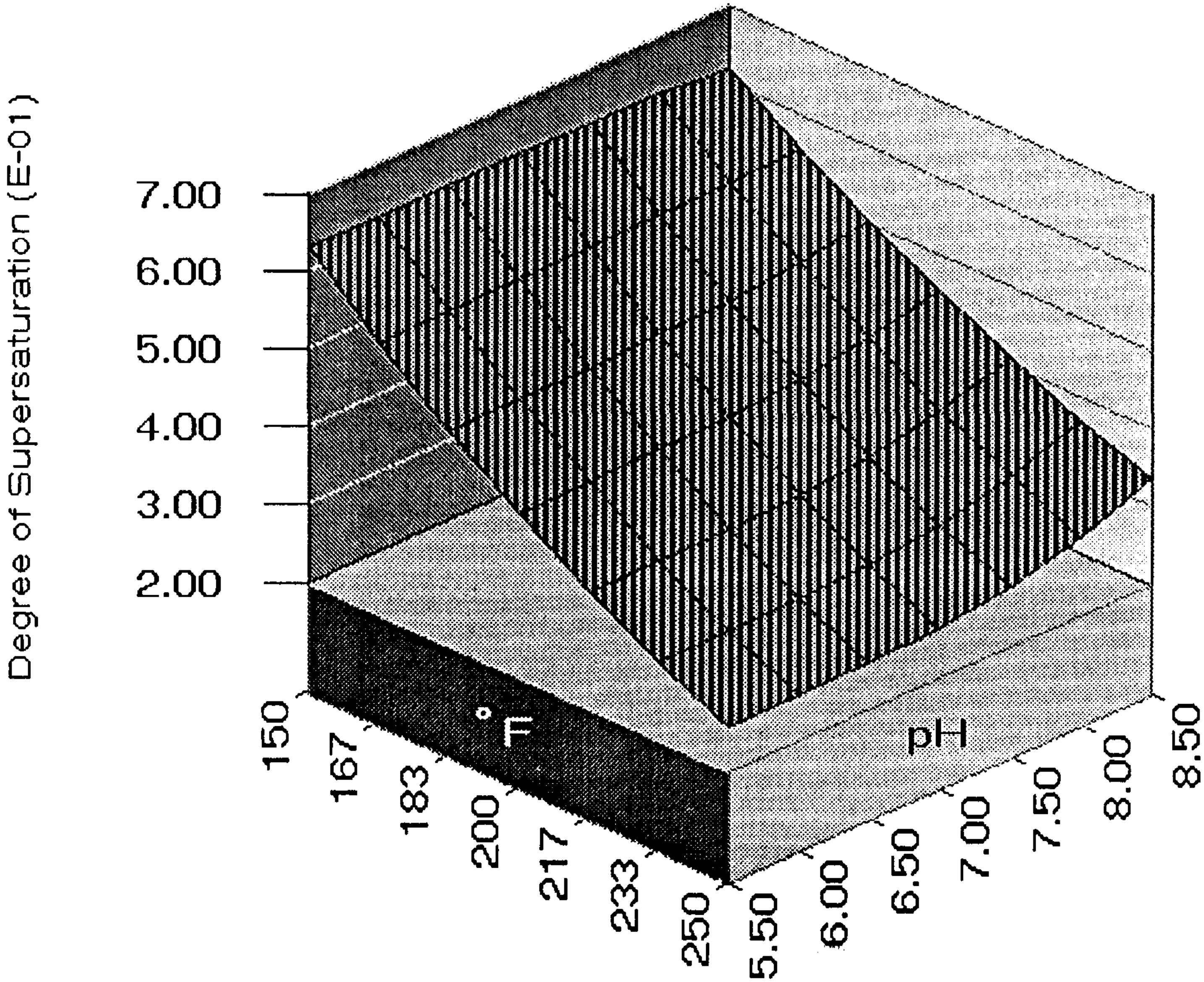
McAllen Ranch, Wellhead Conditions

Magnesite Saturation Level



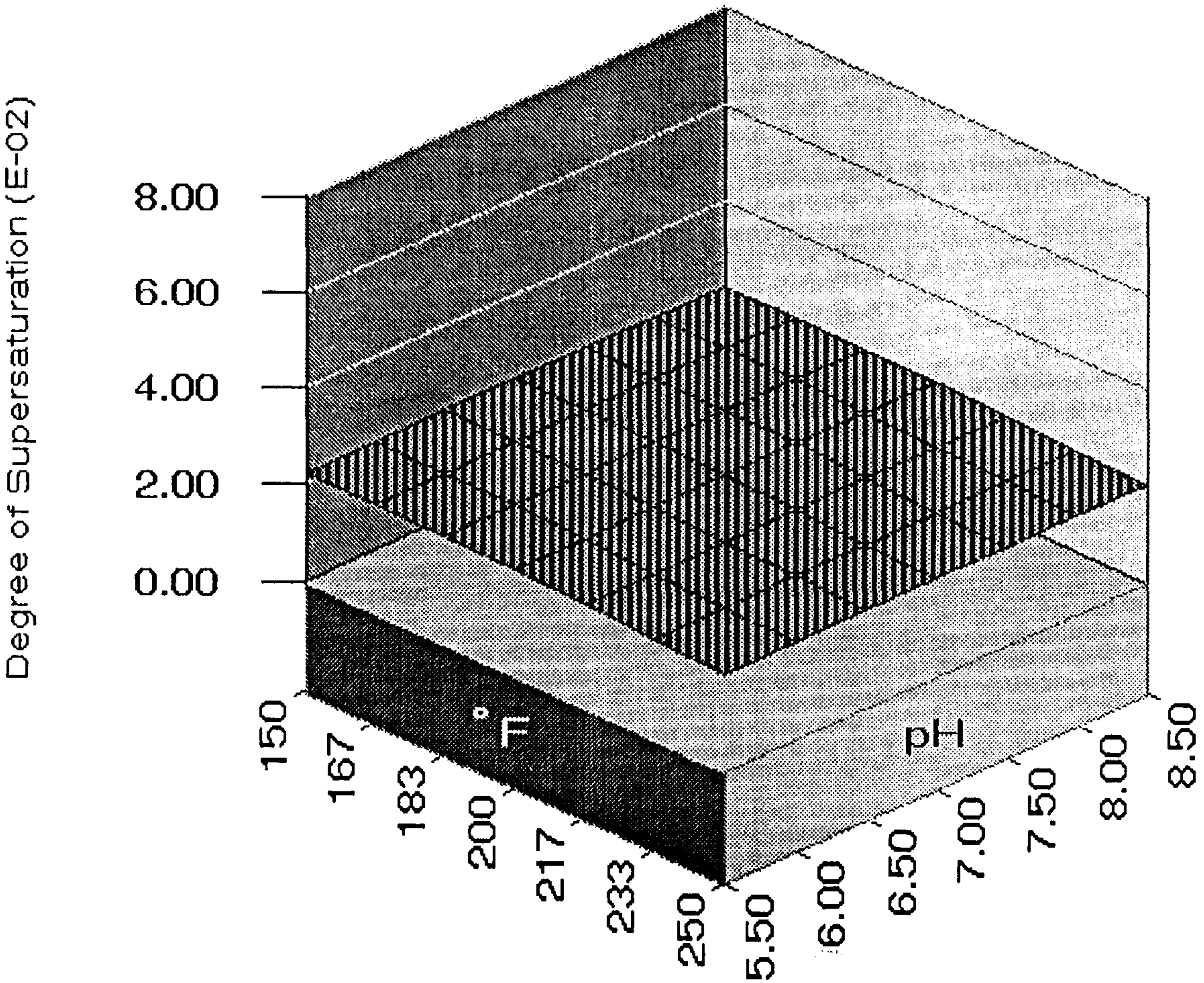
McAllen Ranch, Wellhead Conditions

Fluorite Saturation Level



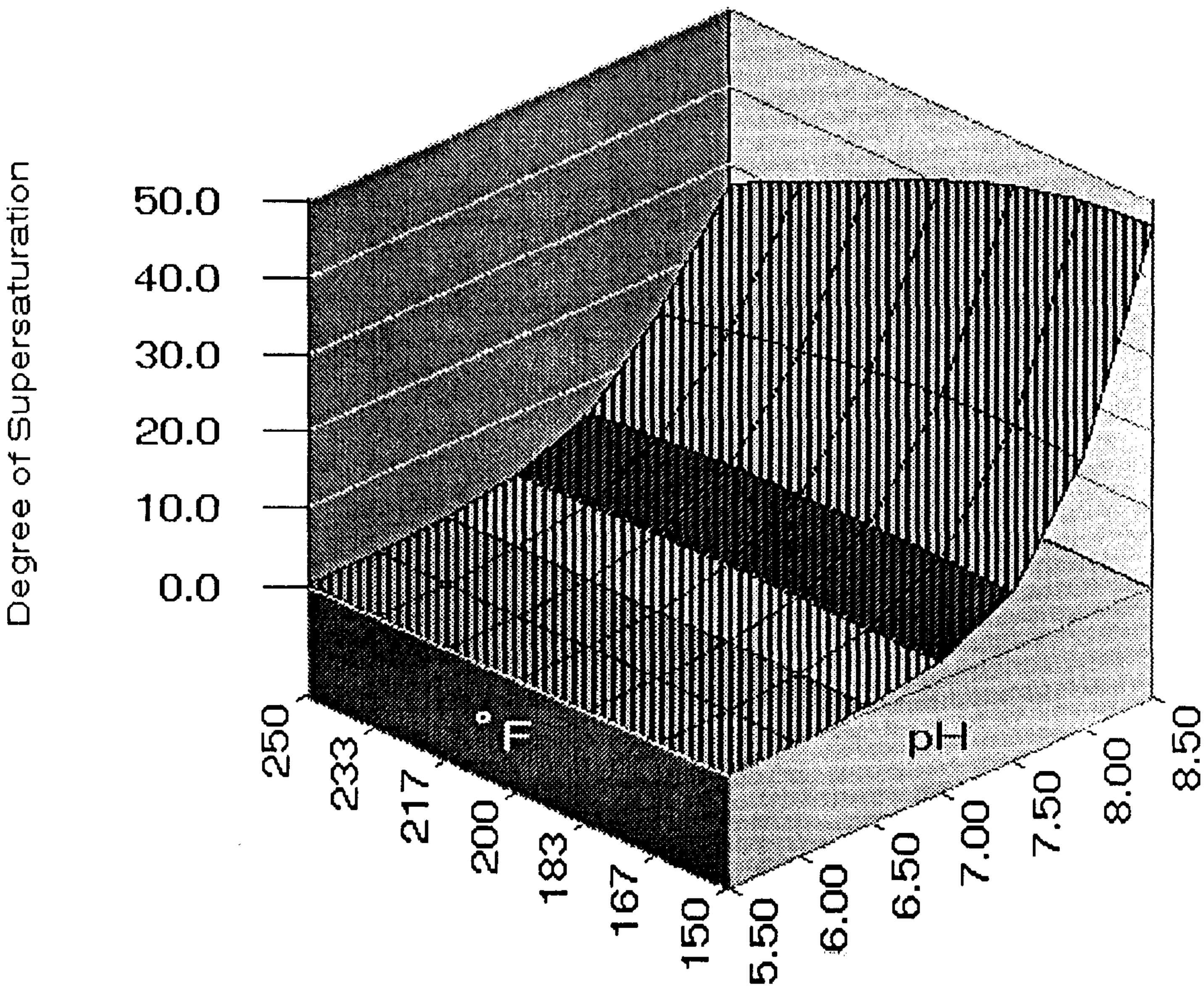
McAllen Ranch, W. llhead Conditions

Celestite Saturation Level



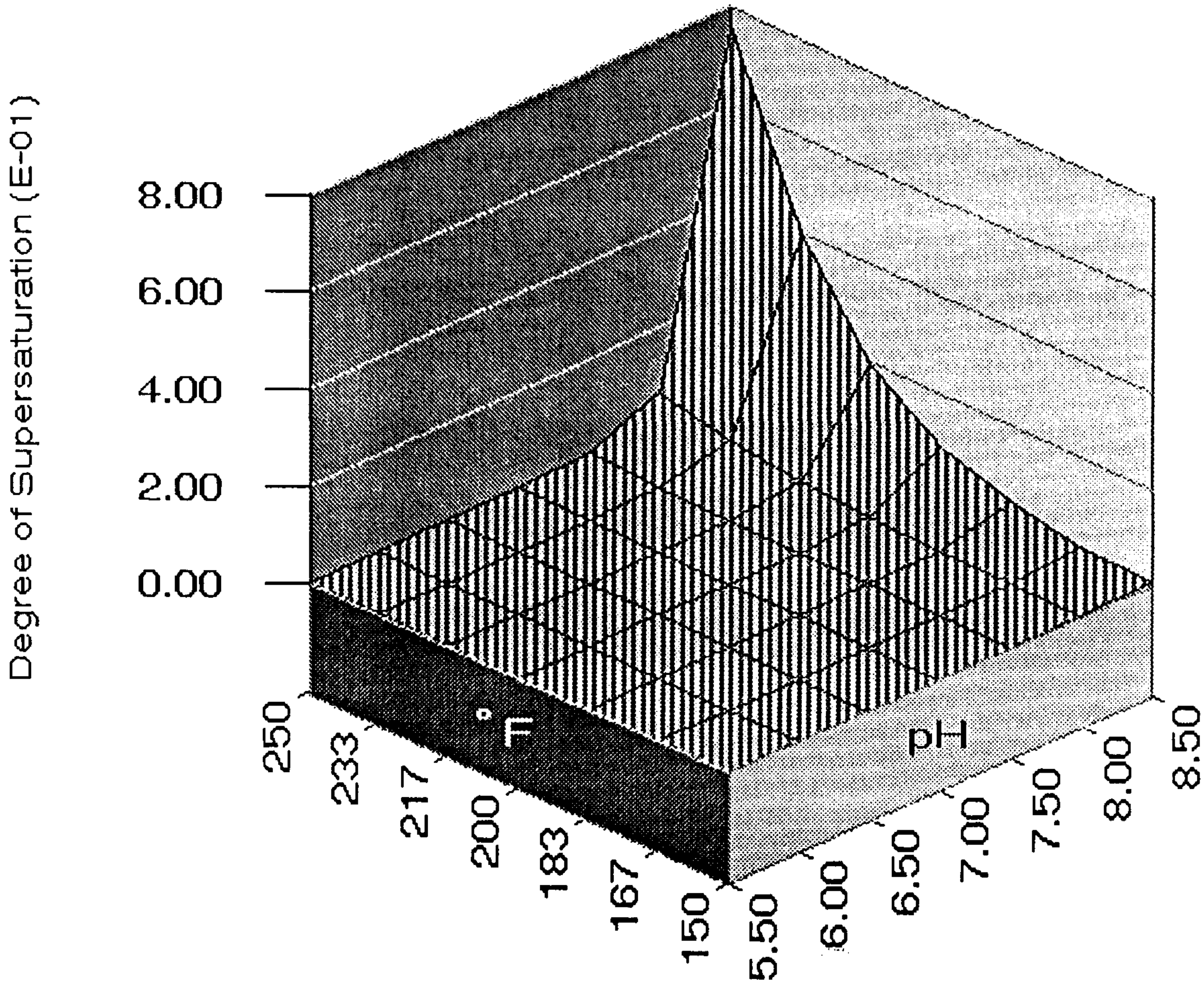
McAllen Ranch, Wellhead Conditions

Calcite Saturation Level



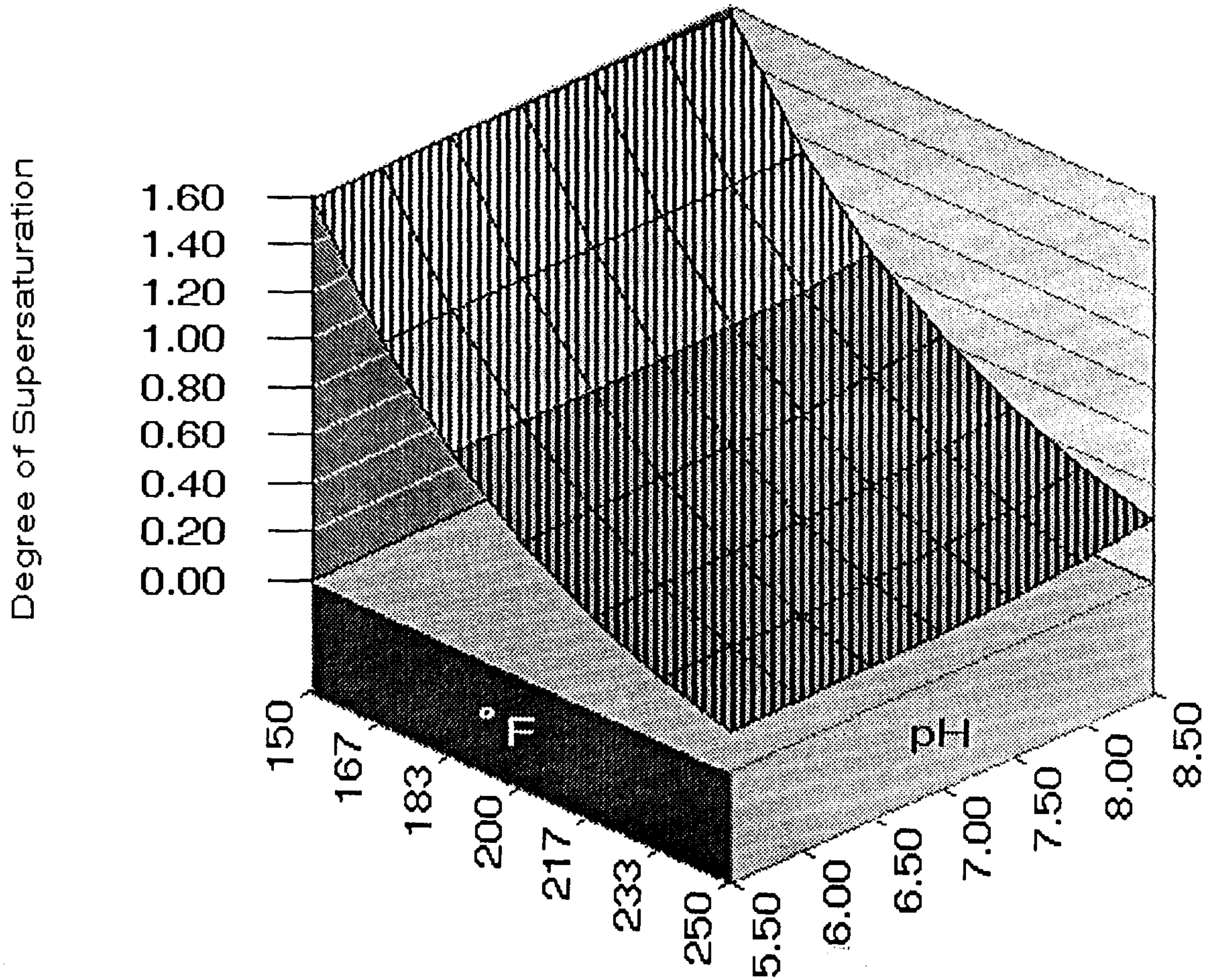
McAllen Ranch, W.ilhead Conditions

Brucite Saturation Level



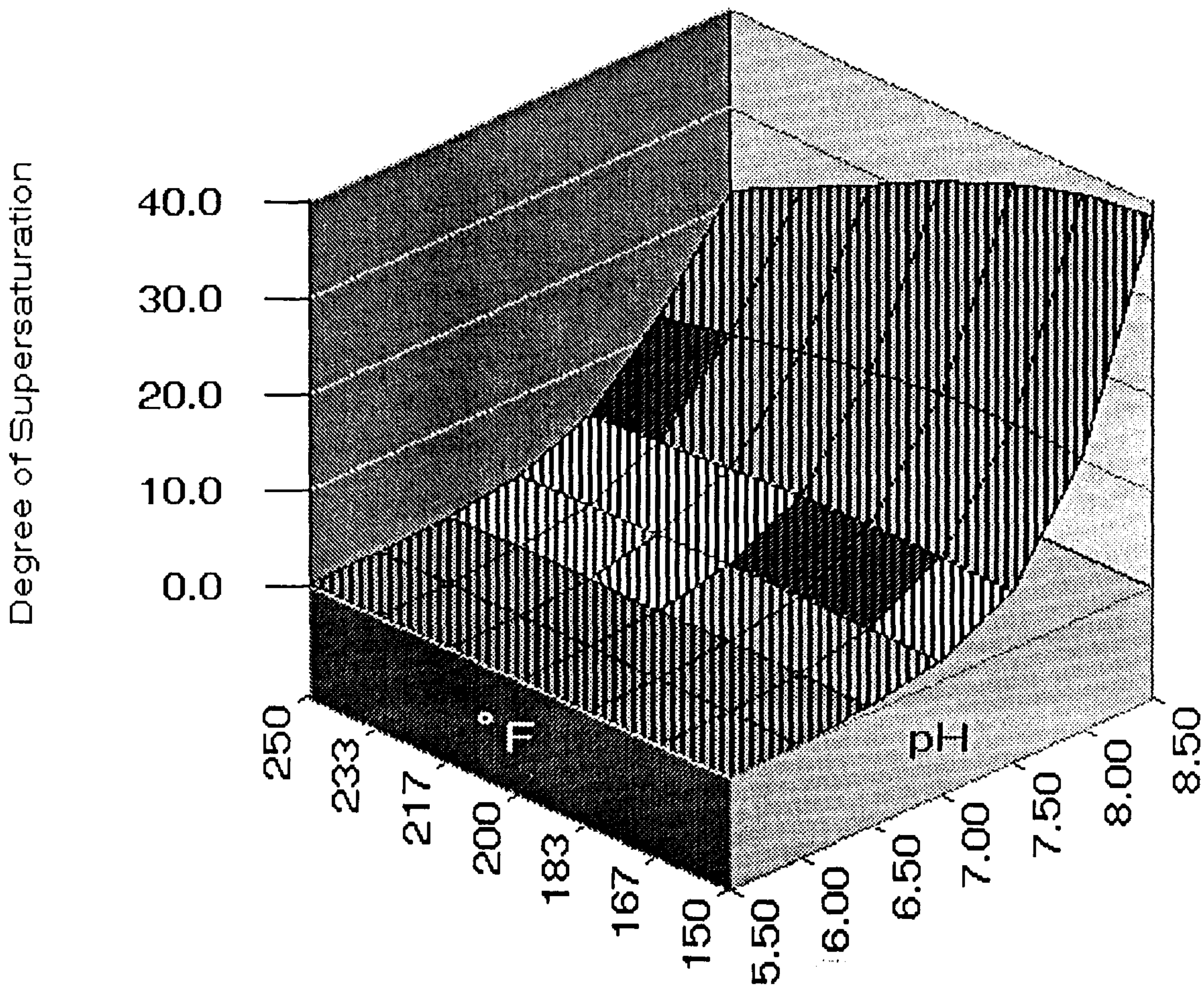
McAllen Ranch, Wellhead Conditions

Barite Saturation Level



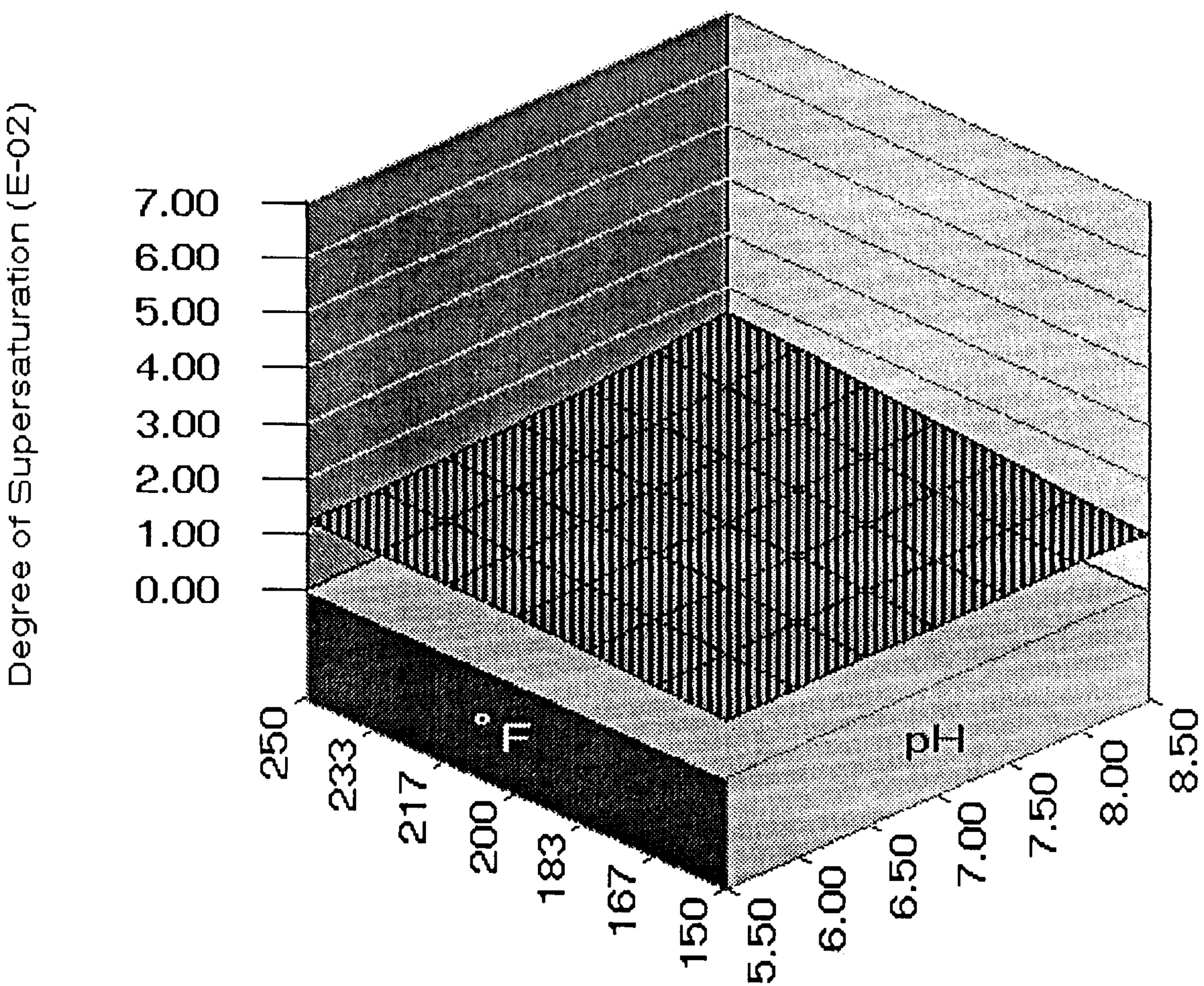
McAllen Ranch, W llhead Conditions

Aragonite Saturation Level



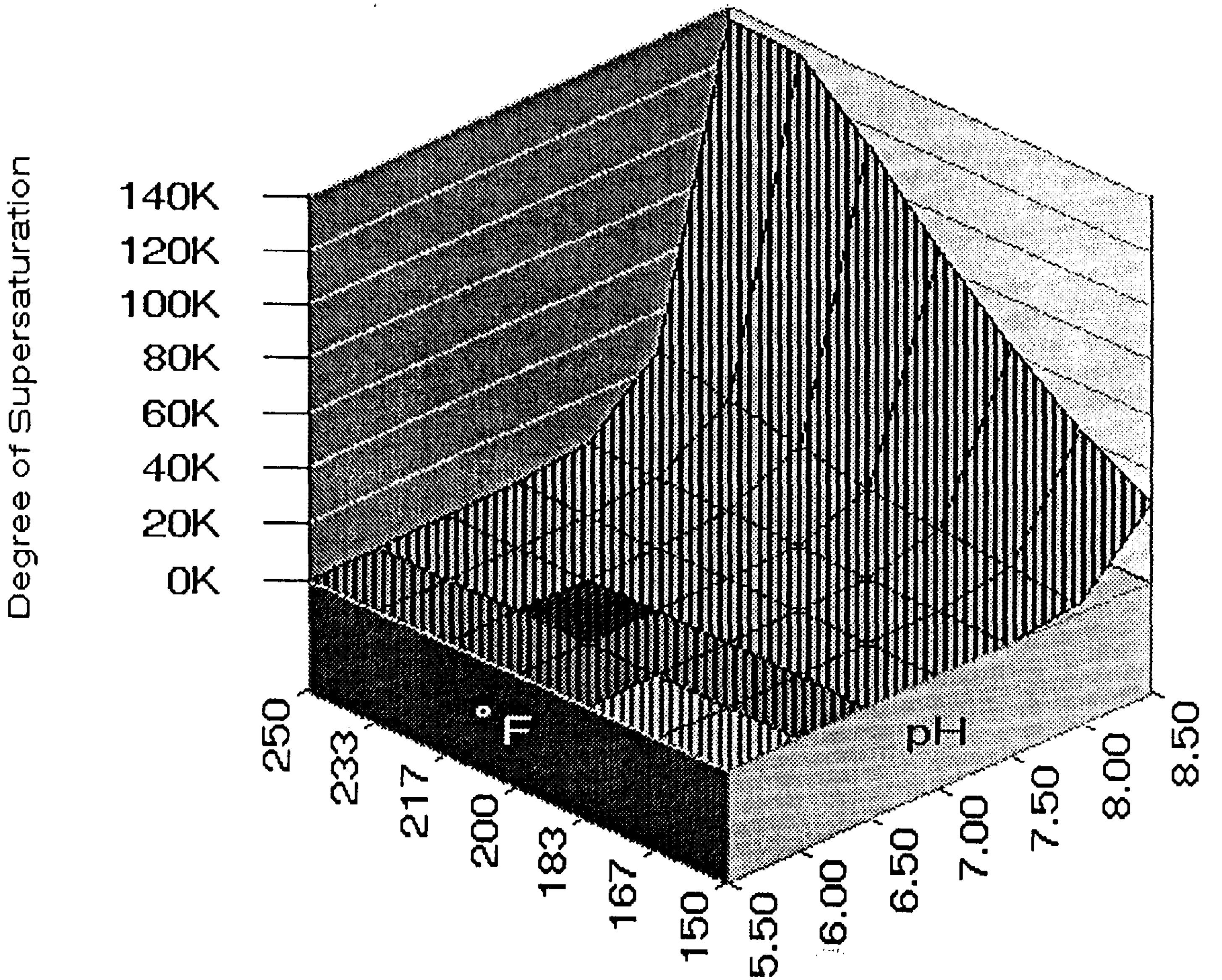
McAllen Ranch, Wellhead Conditions

Anhydrite Saturation Level



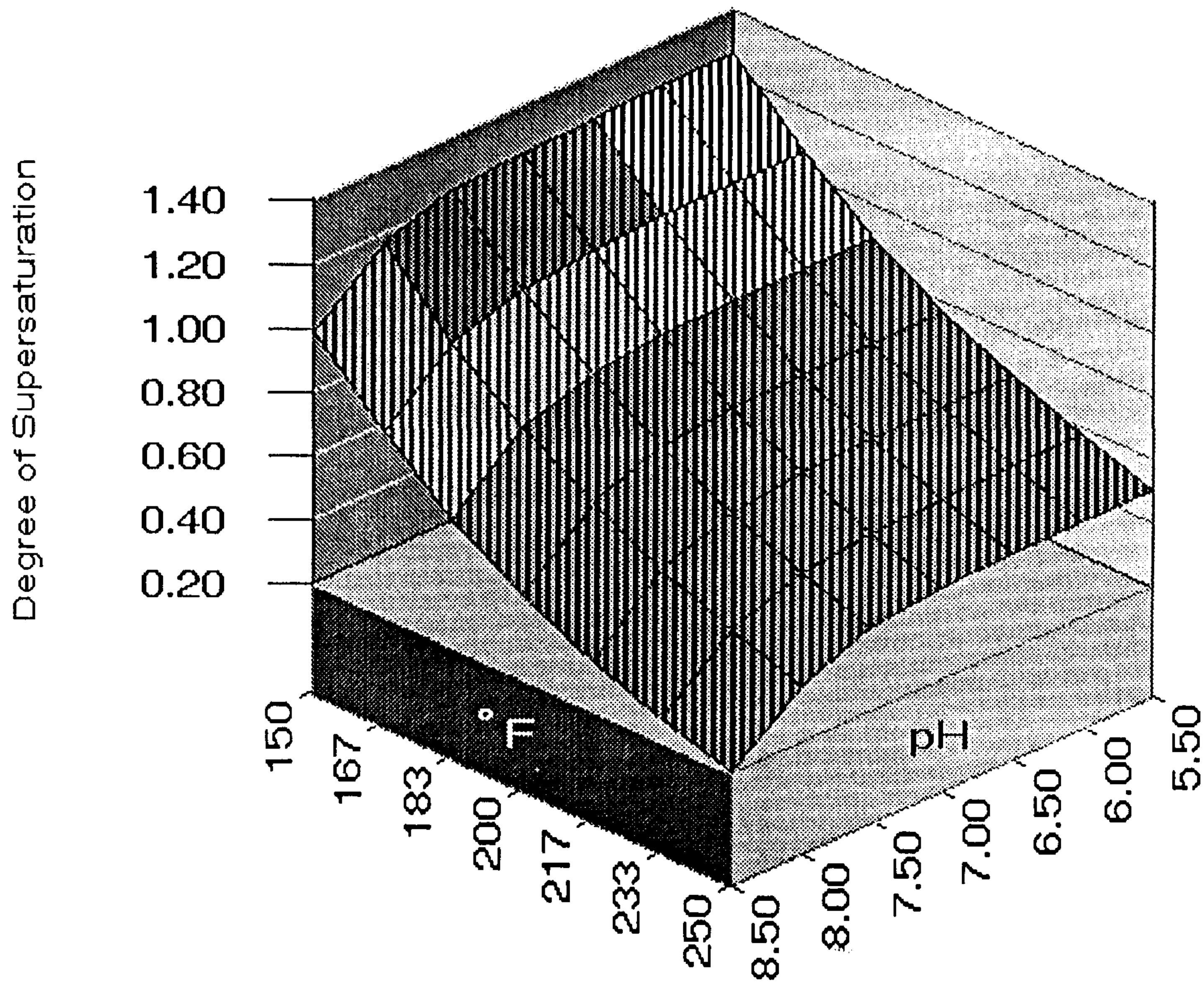
McAllen Ranch, Wellhead Conditions

Amorphous Fe(OH)3 Saturation Level



McAllen Ranch, Wellhead Conditions

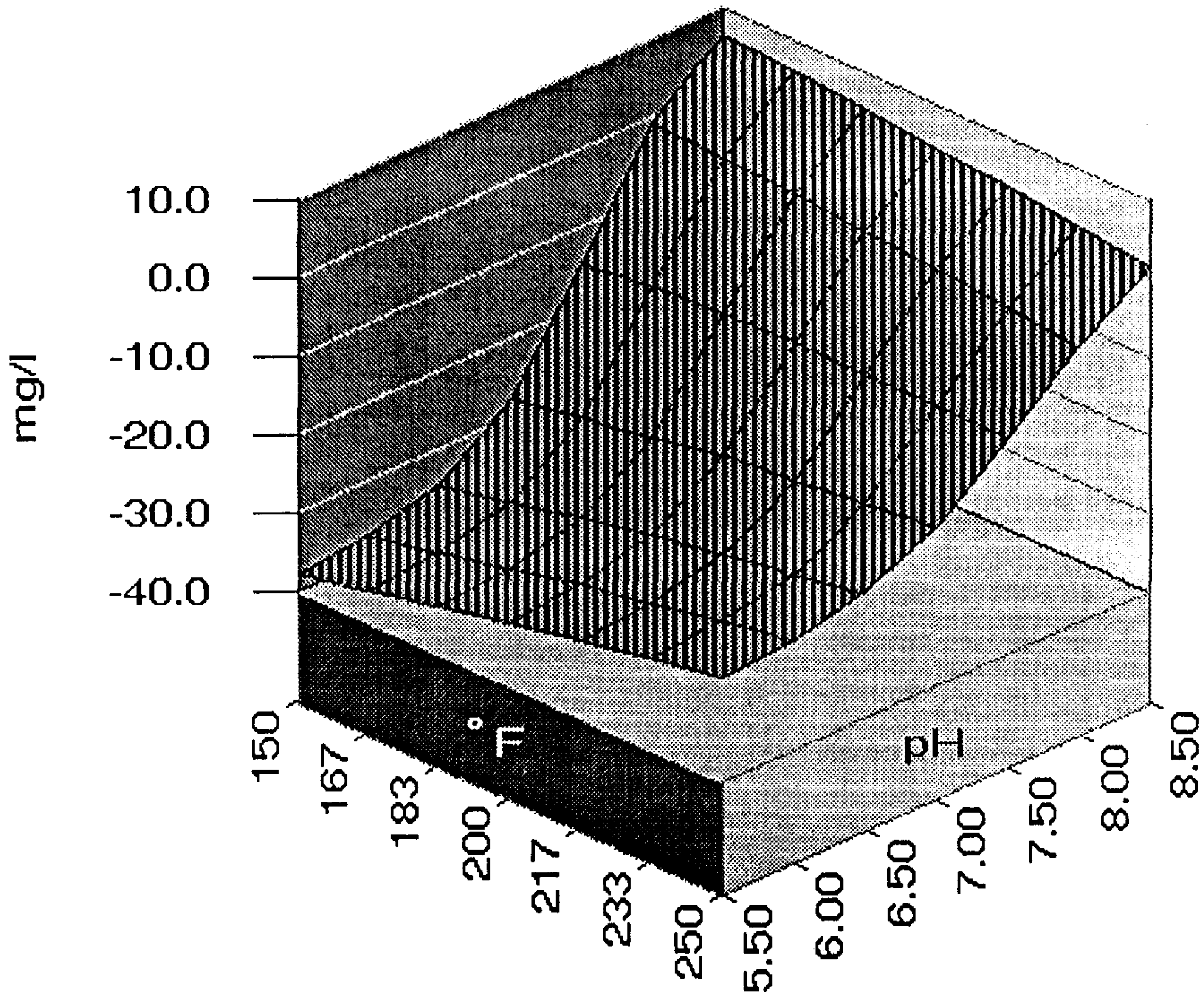
Amorphous Silica Saturation Level



APPENDIX G

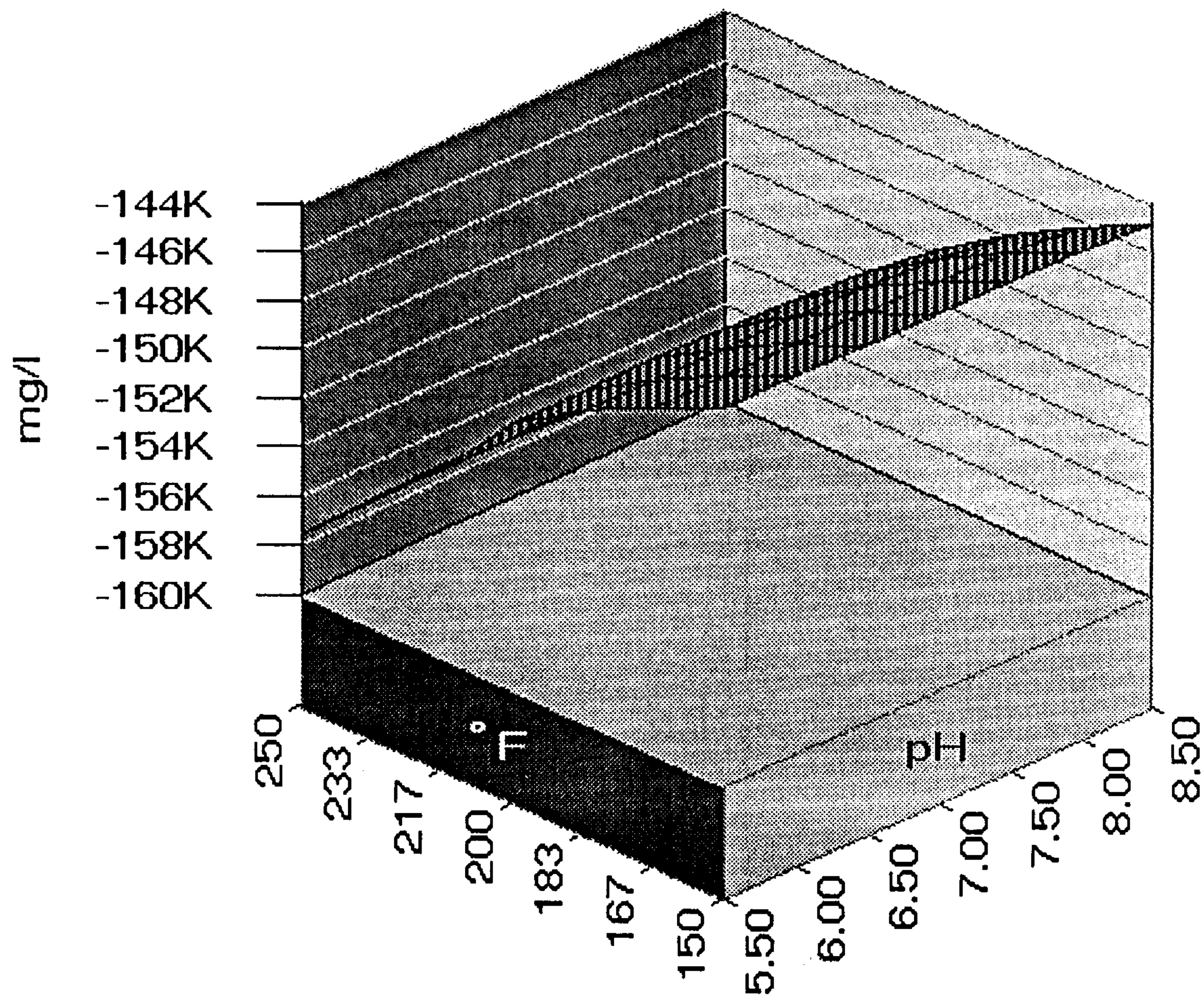
McAllen Ranch, 75 ˒ Water Recovery

Witherite Momentary Excess



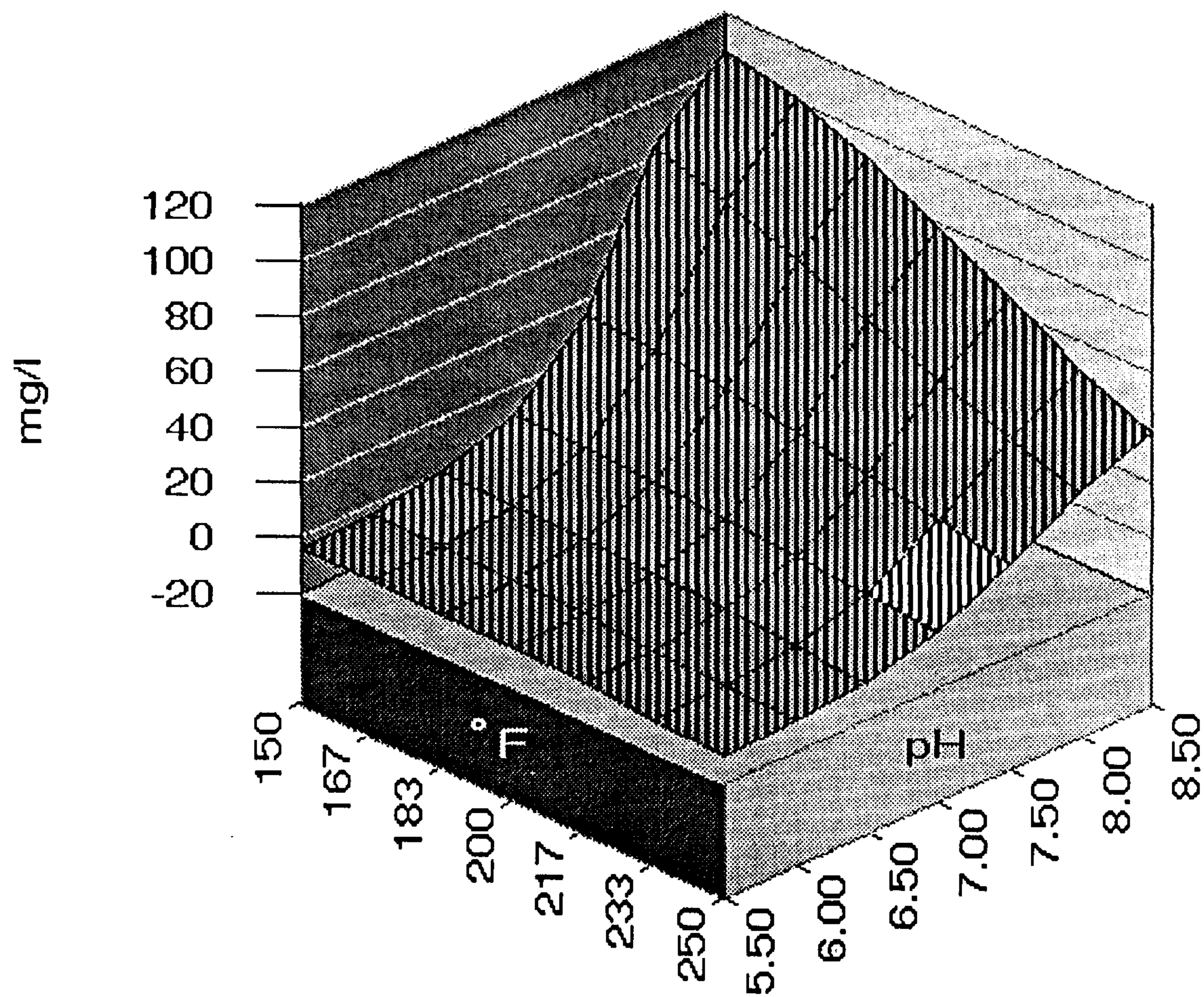
McAllen Ranch, 75 5 Water Recovery

Thenardite Momentary Excess



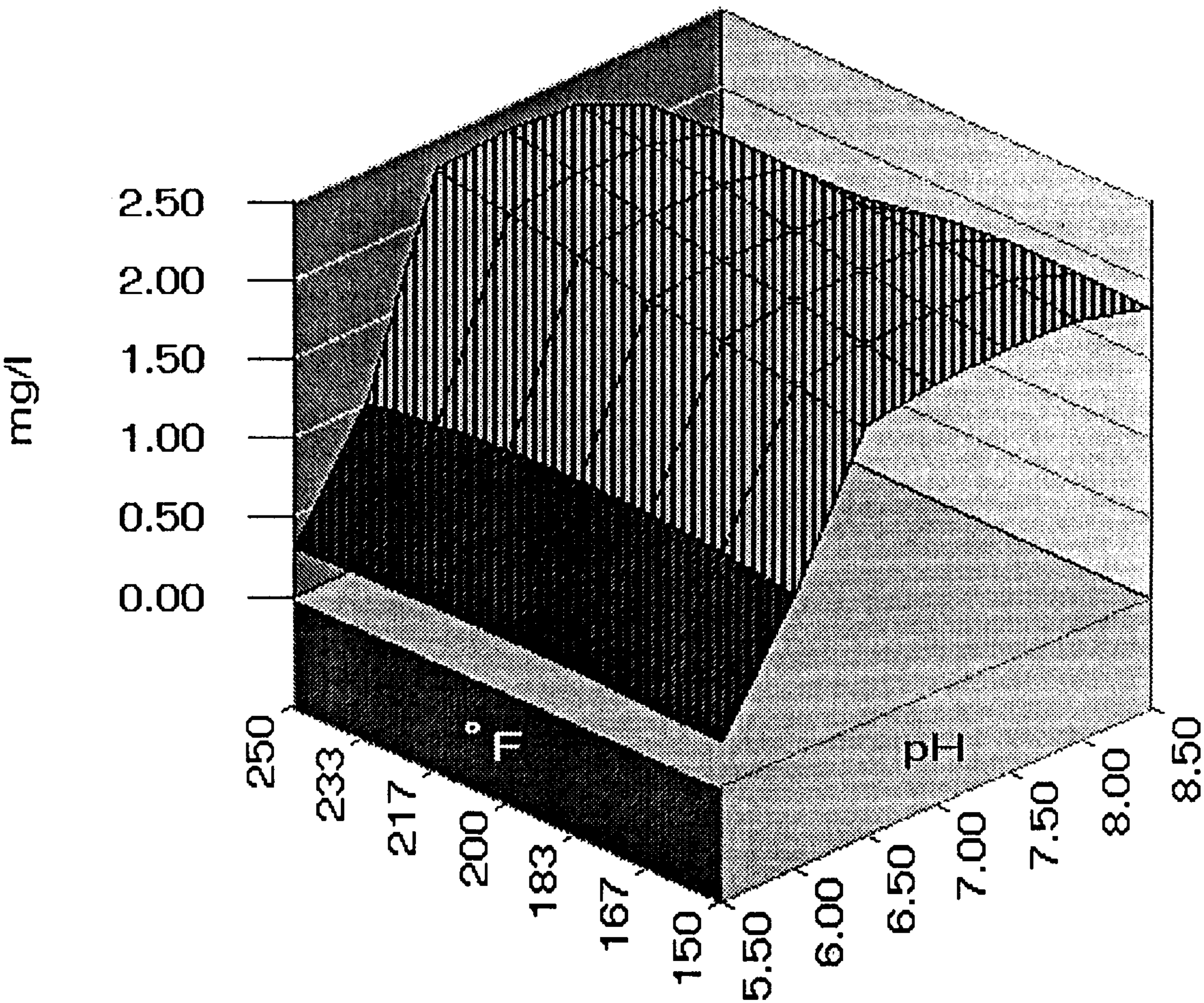
McAllen Ranch, 75% Water Recovery

Strontianite Momentary Excess



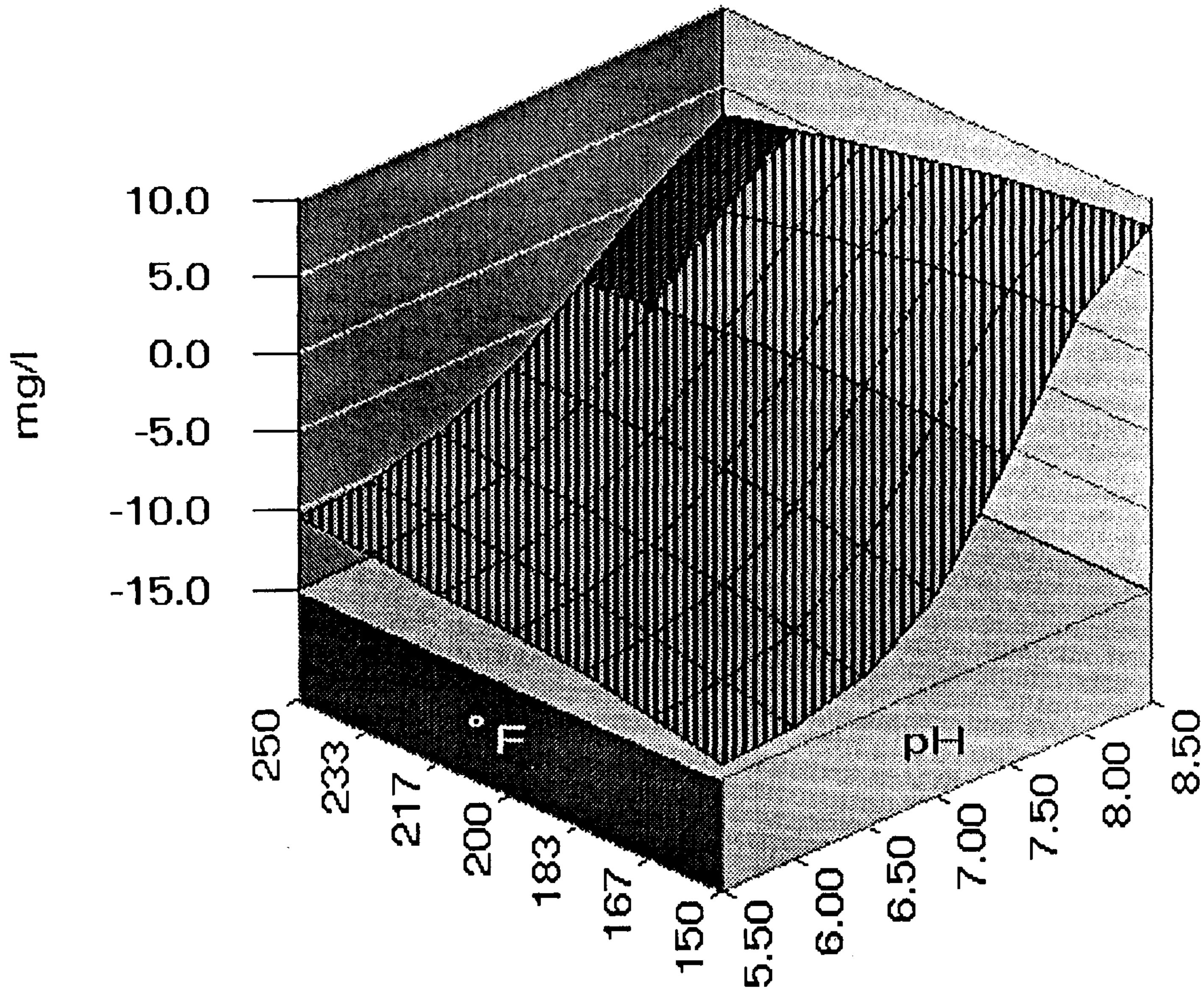
McAllen Ranch, 75 % Water Recovery

Siderite Momentary Excess



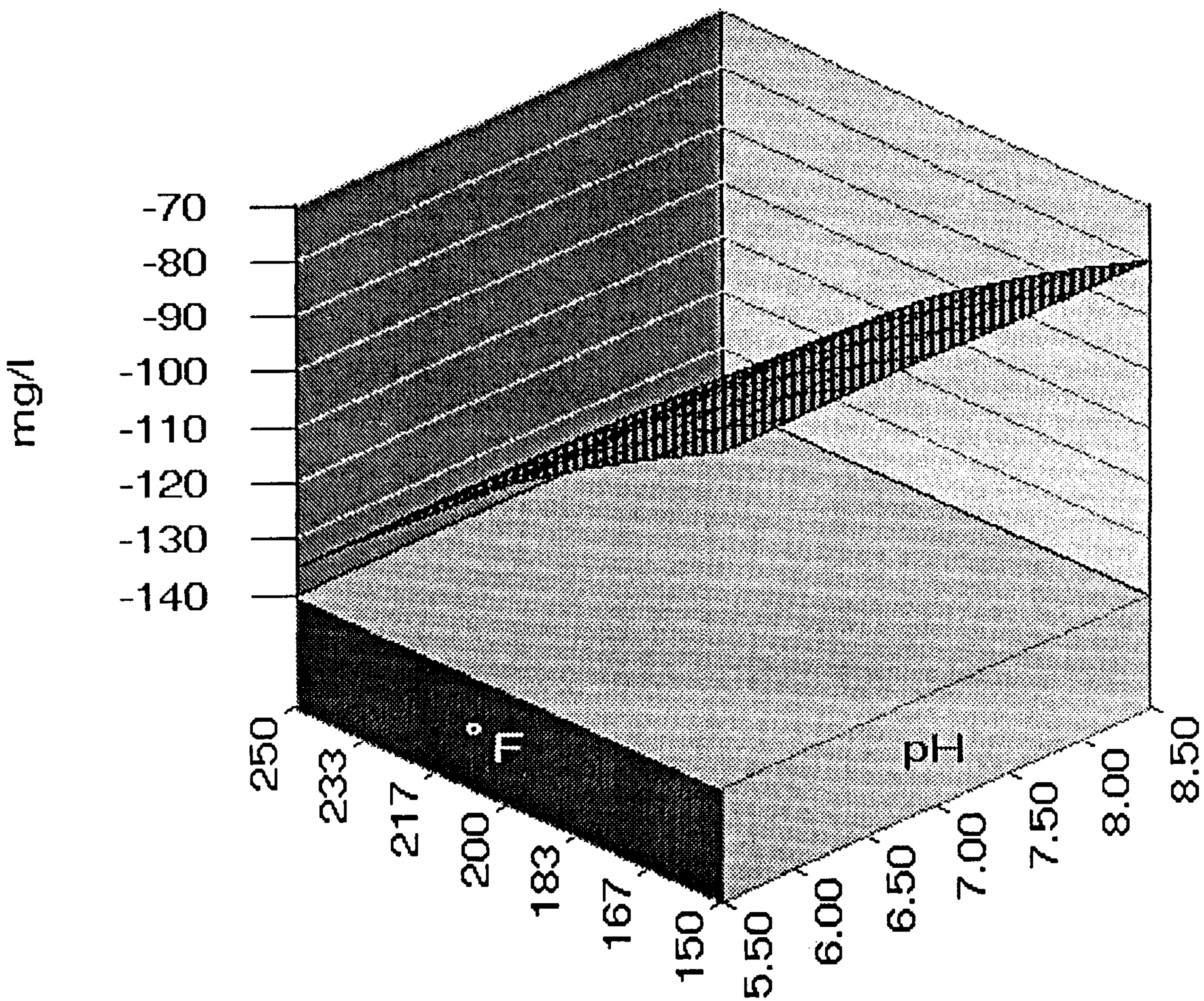
McAllen Ranch, 75. Water Recovery

Magnesite Momentary Excess



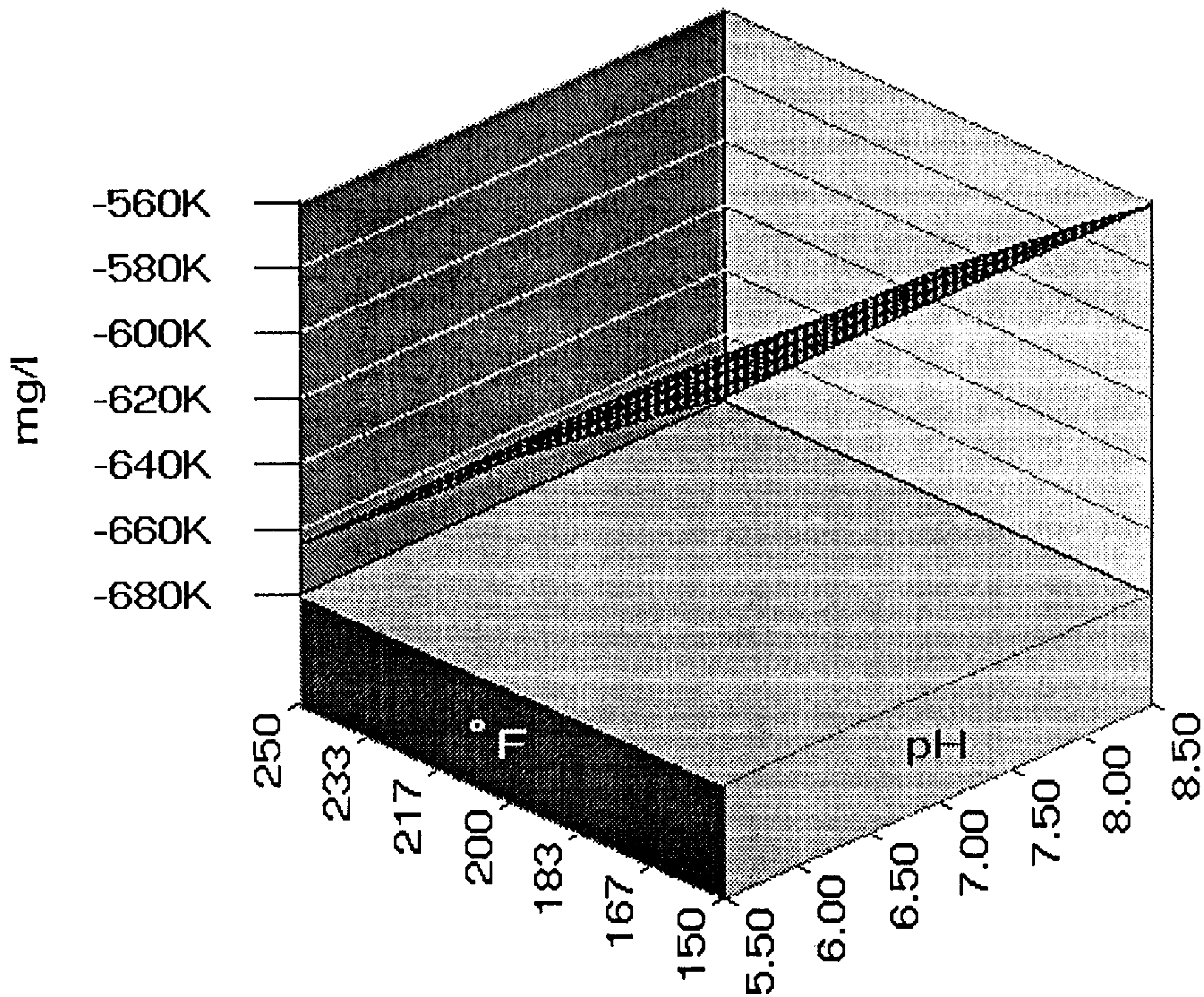
McAllen Ranch, 75% Water Recovery

Hydroxyapatite Momentary Excess



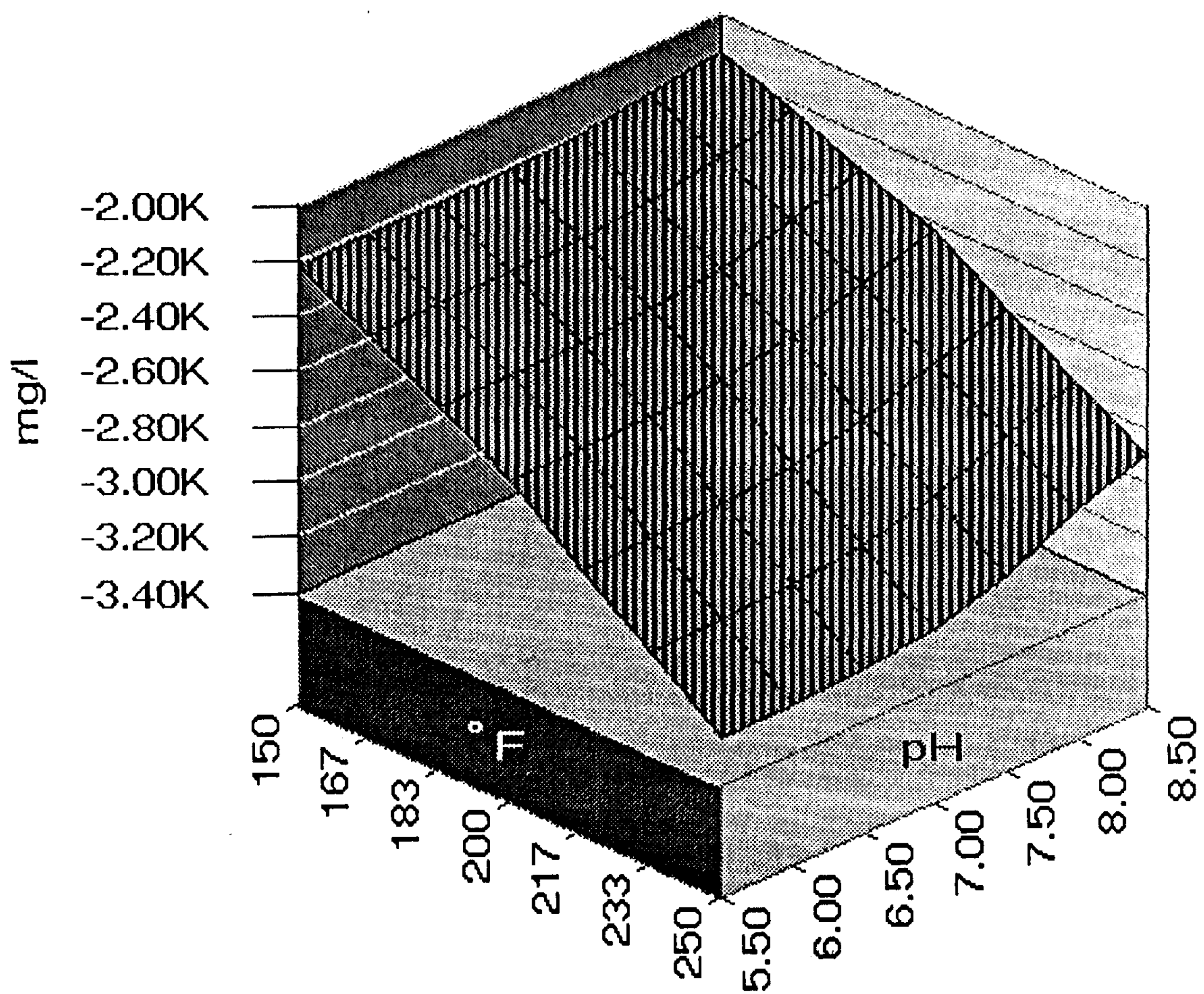
McAllen Ranch, 75% Water Recovery

Halite Momentary Excess



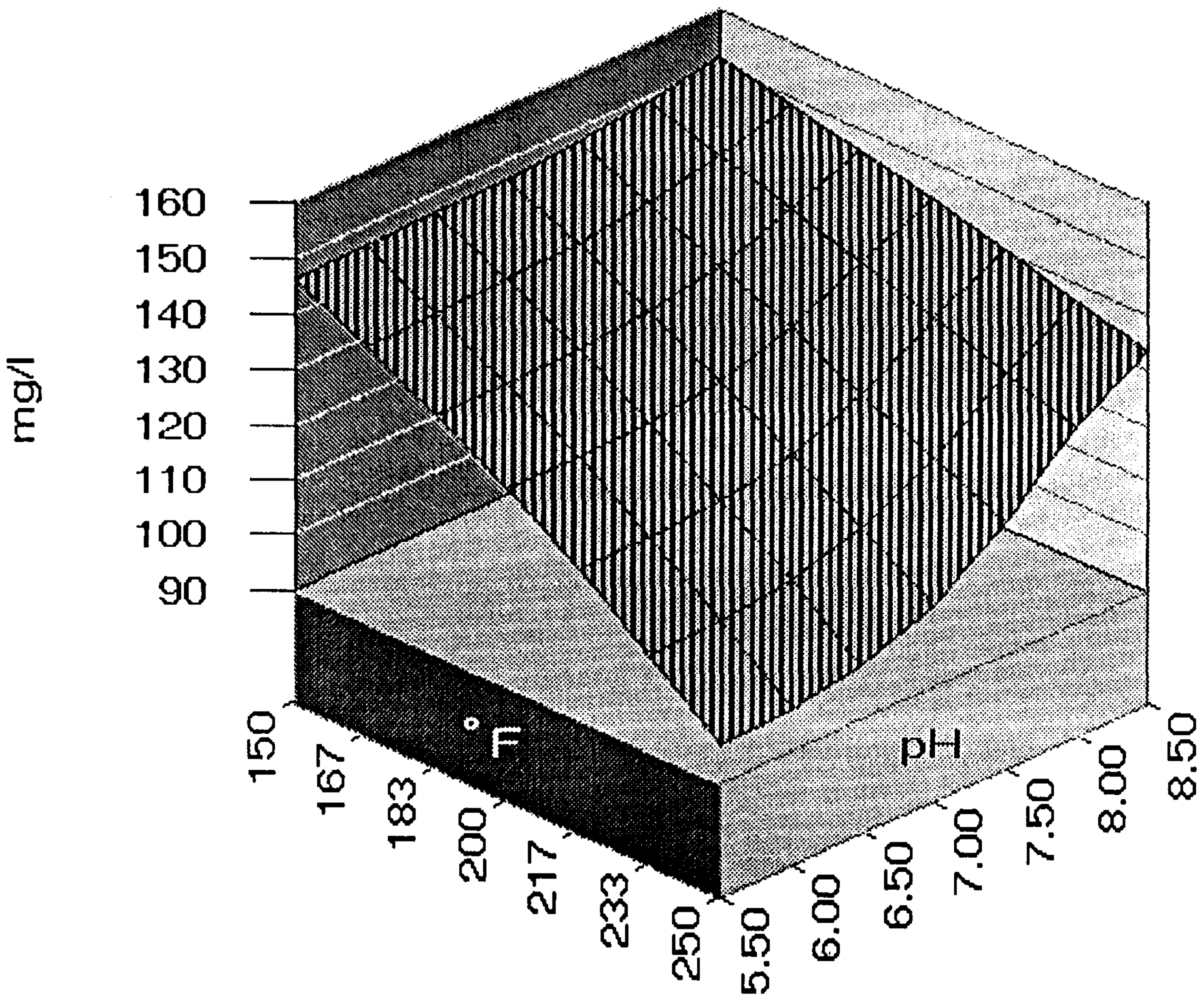
McAllen Ranch, [illegible]% Water Recovery

Gypsum Momentary Excess



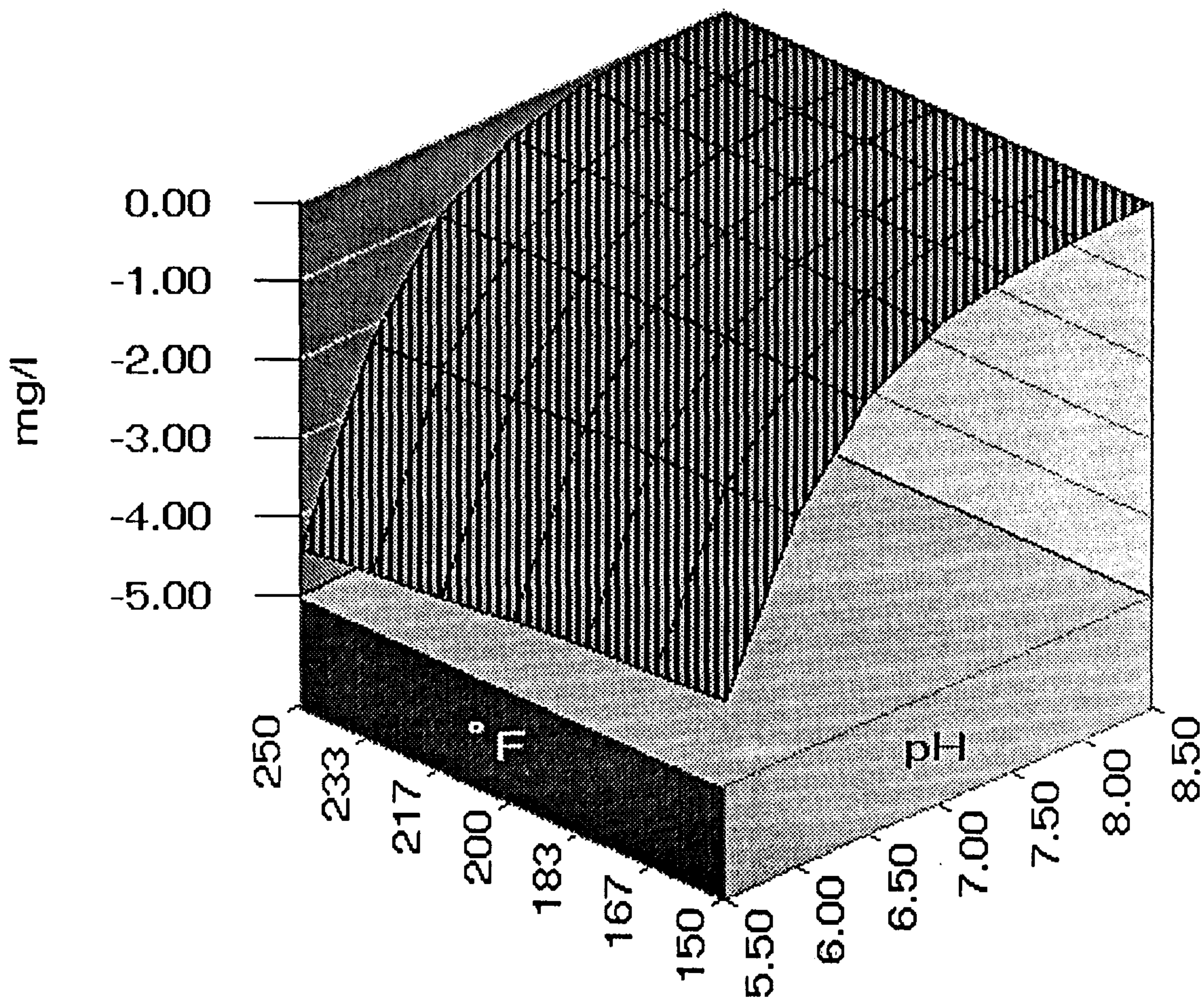
McAllen Ranch, 7[illegible] % Water Recovery

Fluorite Momentary Excess



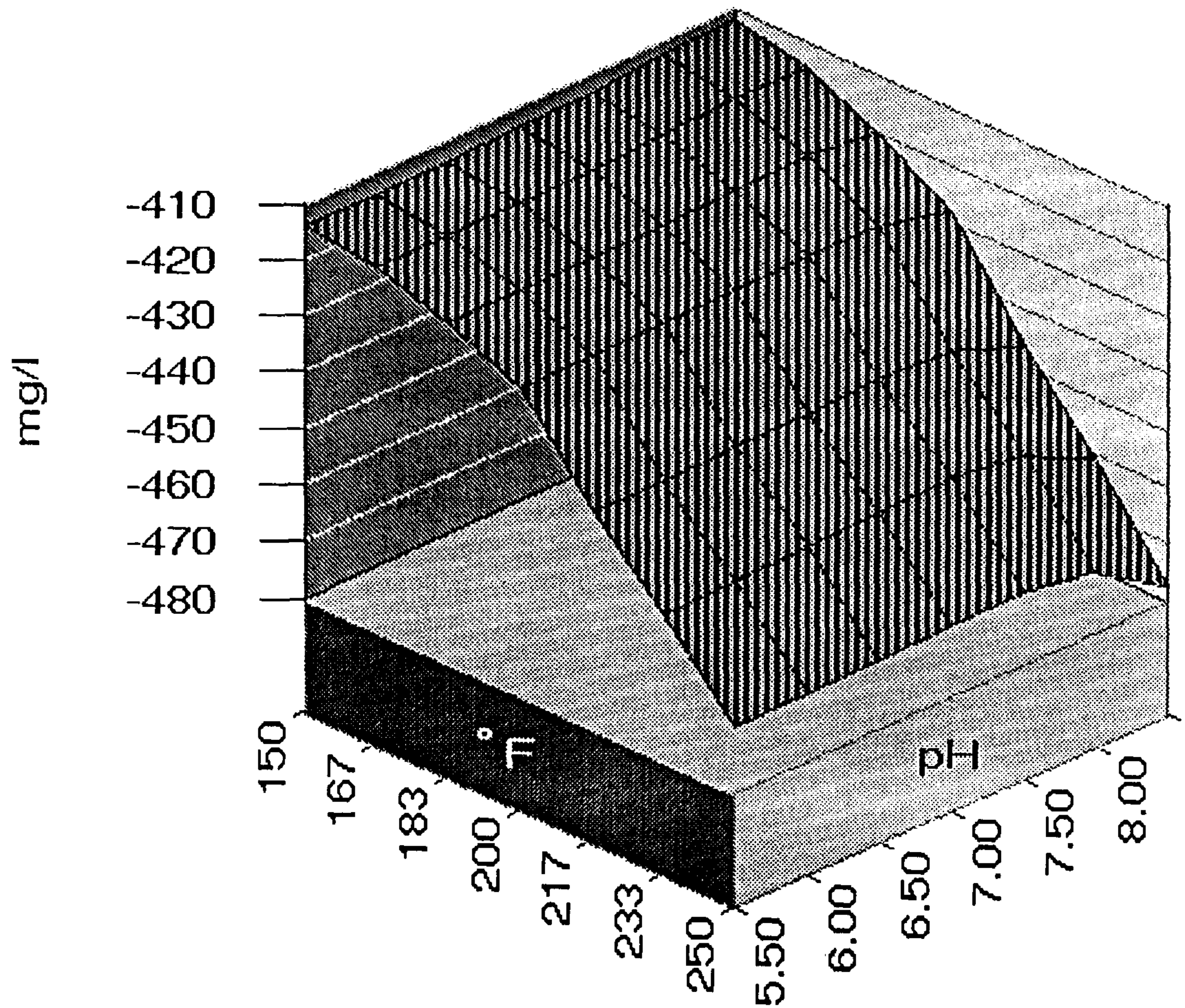
McAllen Ranch, 75 , Water Recovery

Iron sulfide Momentary Excess



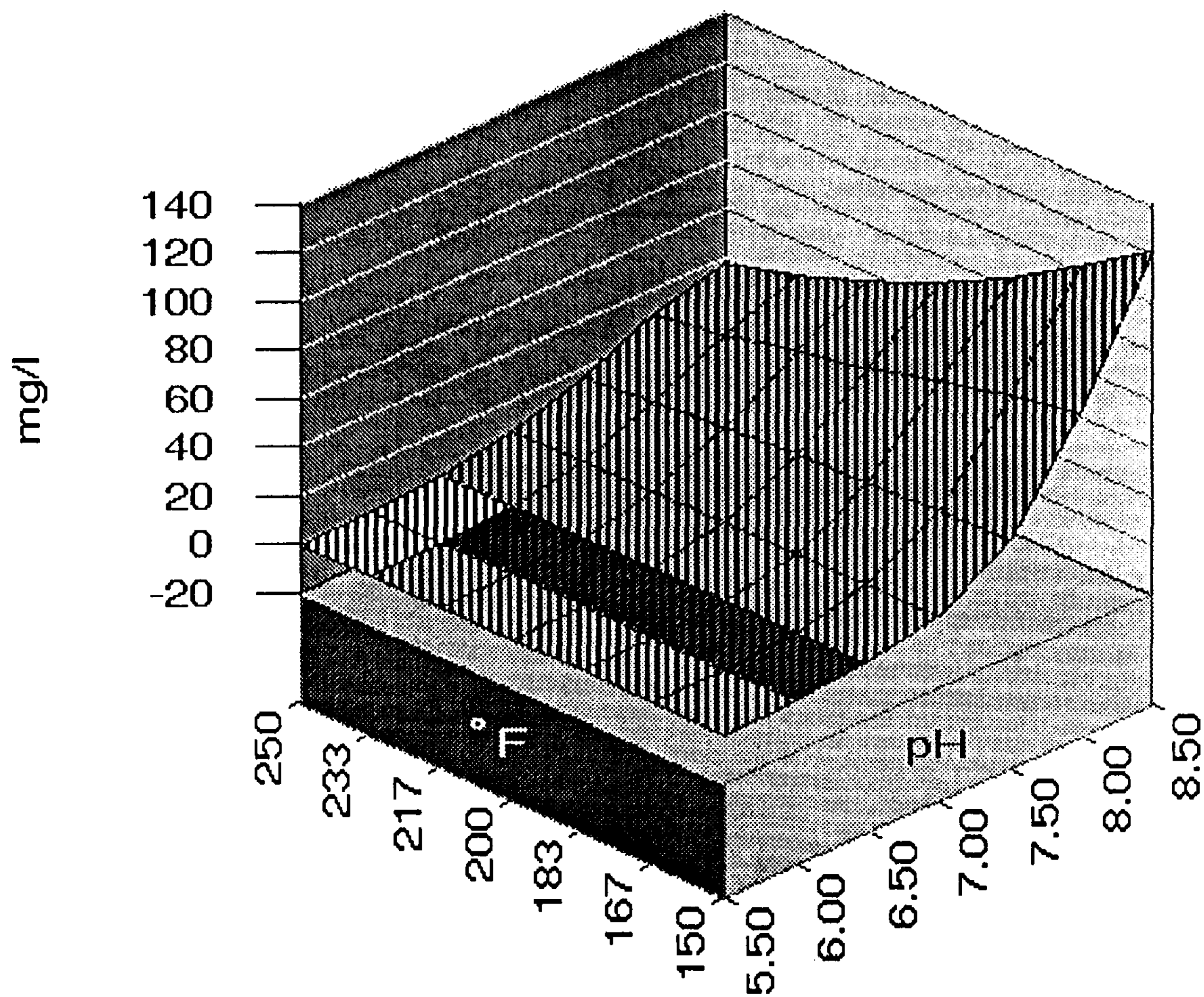
McAllen Ranch, 75% Water Recovery

Celestite Momentary Excess



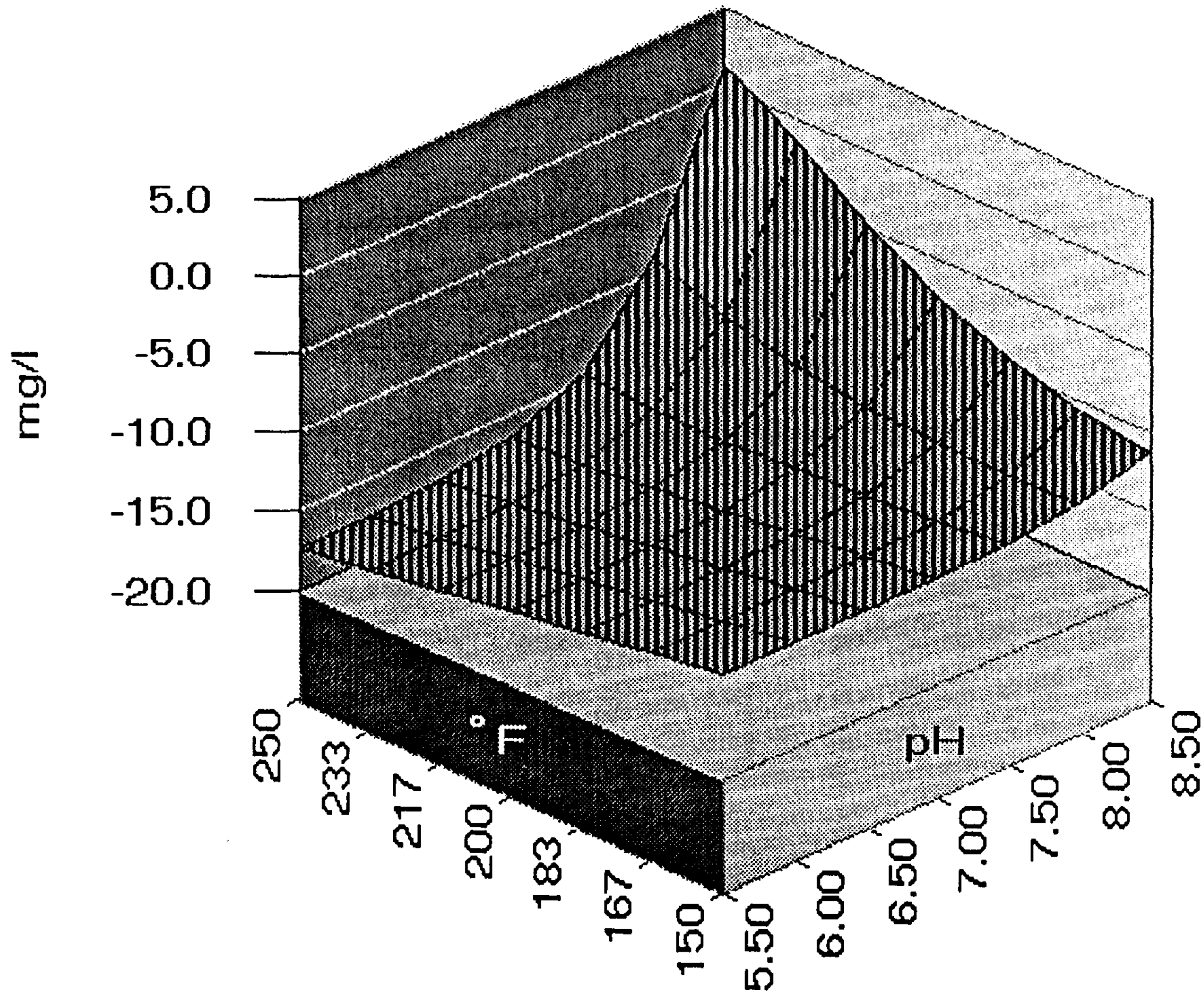
McAllen Ranch, 75 % Water Recovery

Calcite Momentary Excess



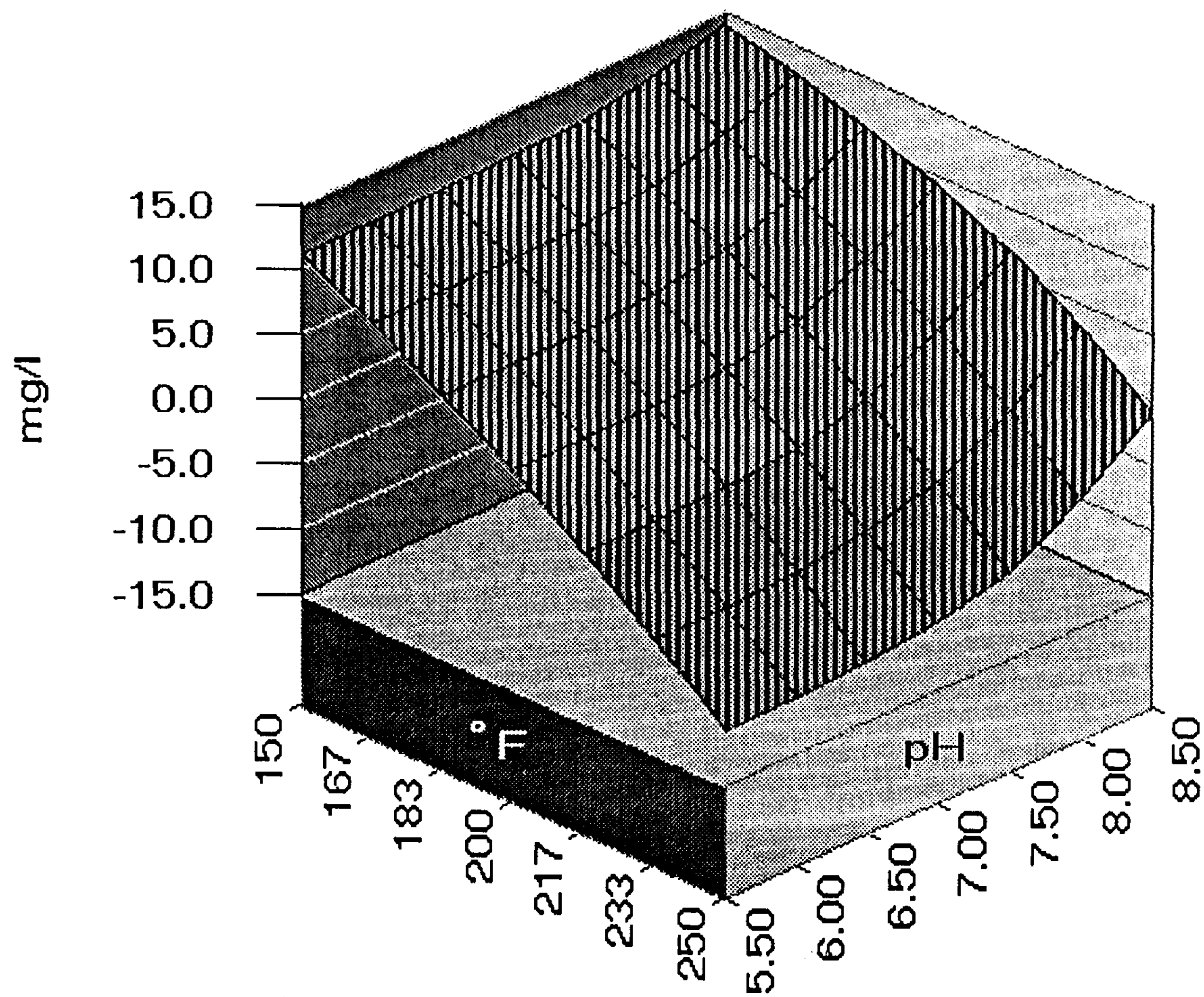
McAllen Ranch, 7[illegible] % Water Recovery

Brucite Momentary Excess



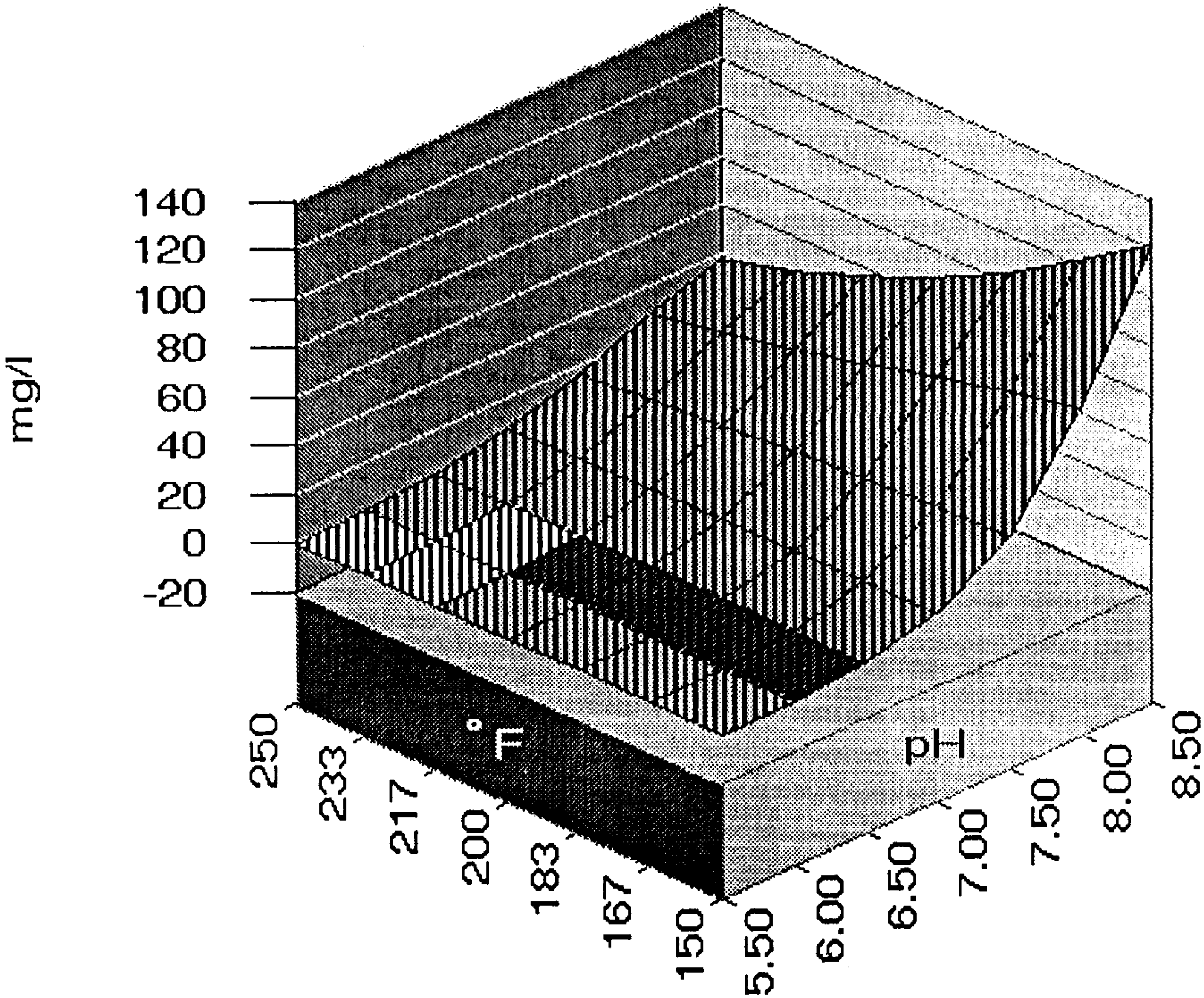
McAllen Ranch, [illegible]% Water Recovery

Barite Momentary Excess



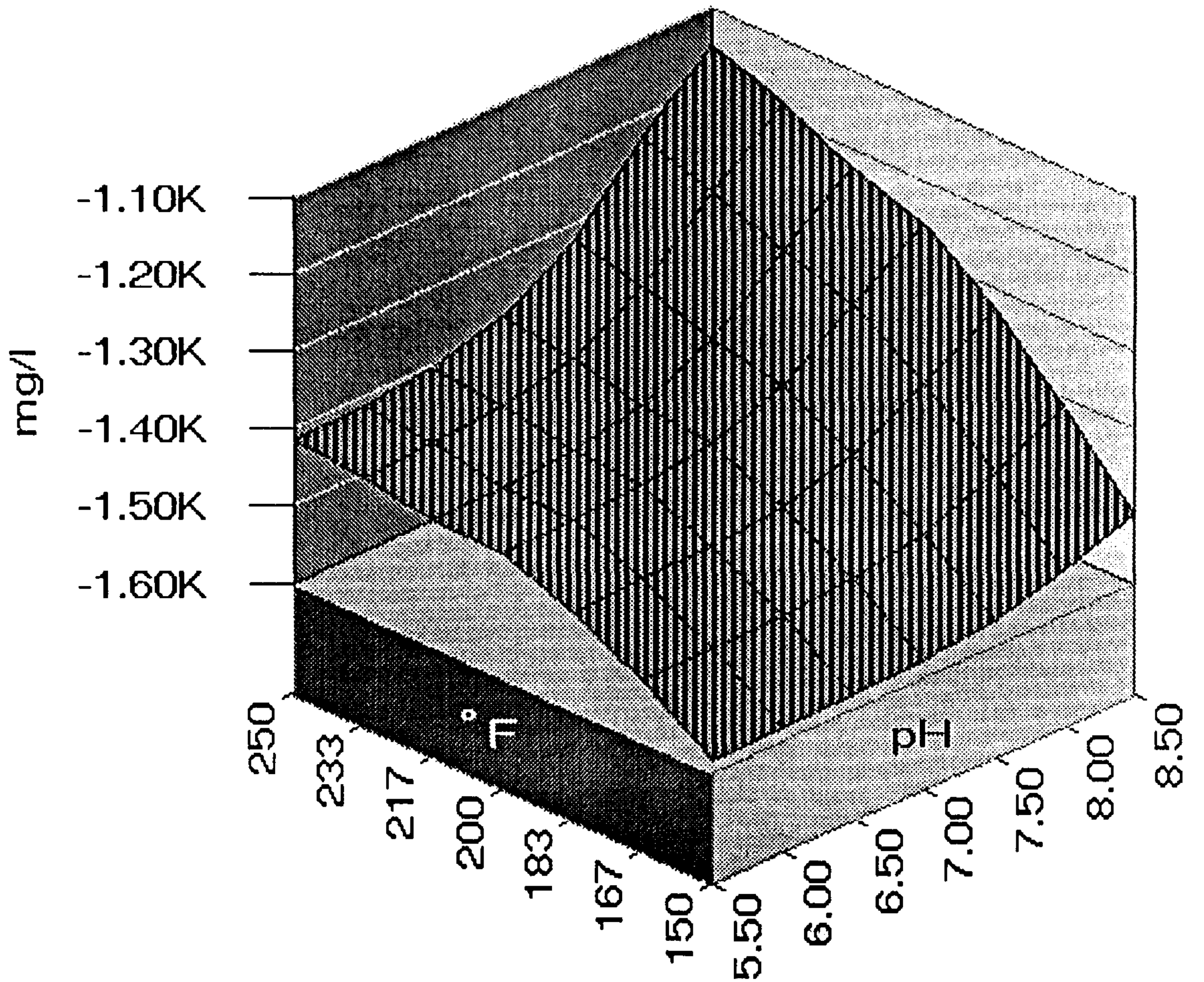
McAllen Ranch, 7[illegible]% Water Recovery

Aragonite Momentary Excess



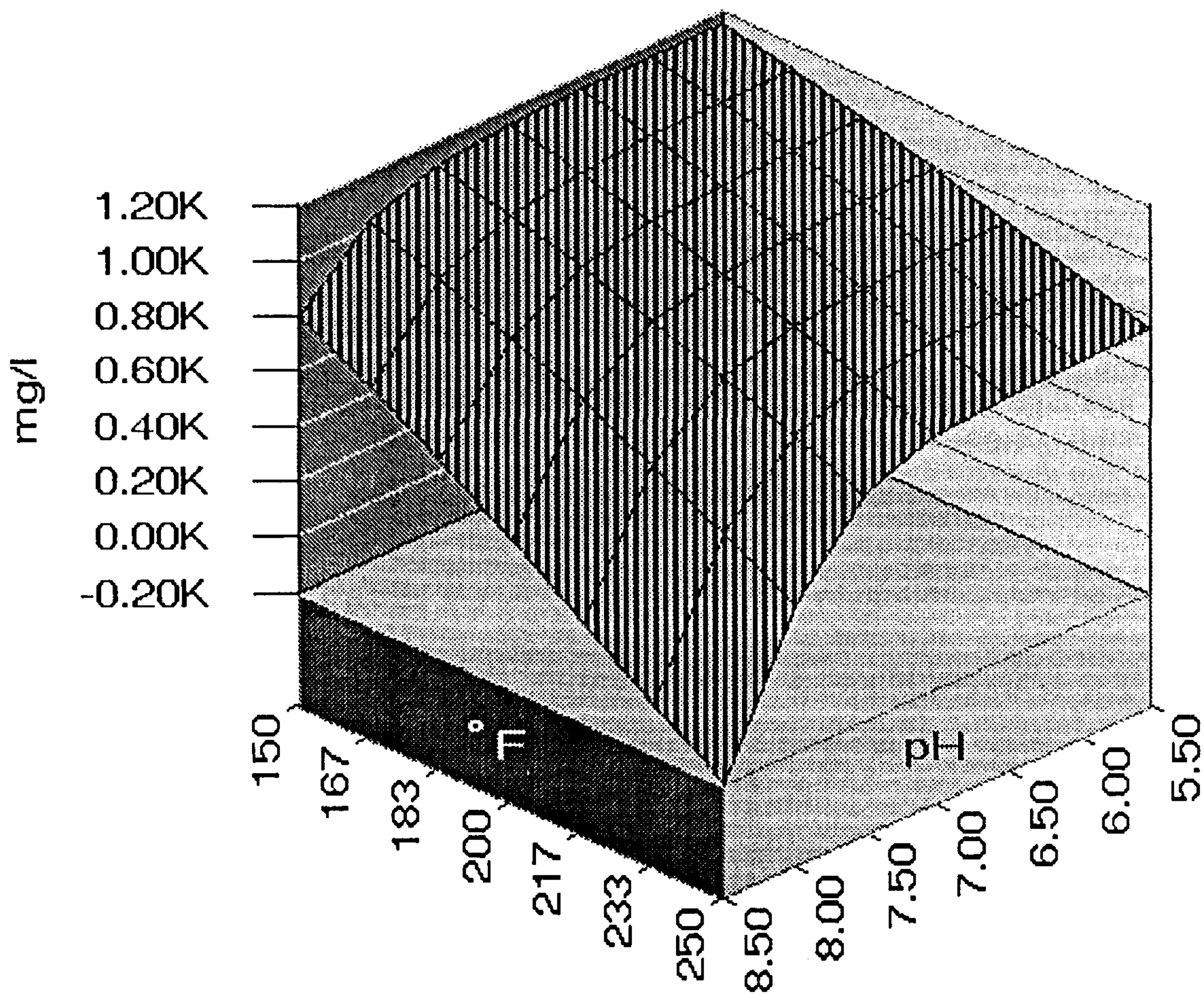
McAllen Ranch, 75 % Water Recovery

Anhydrite Momentary Excess



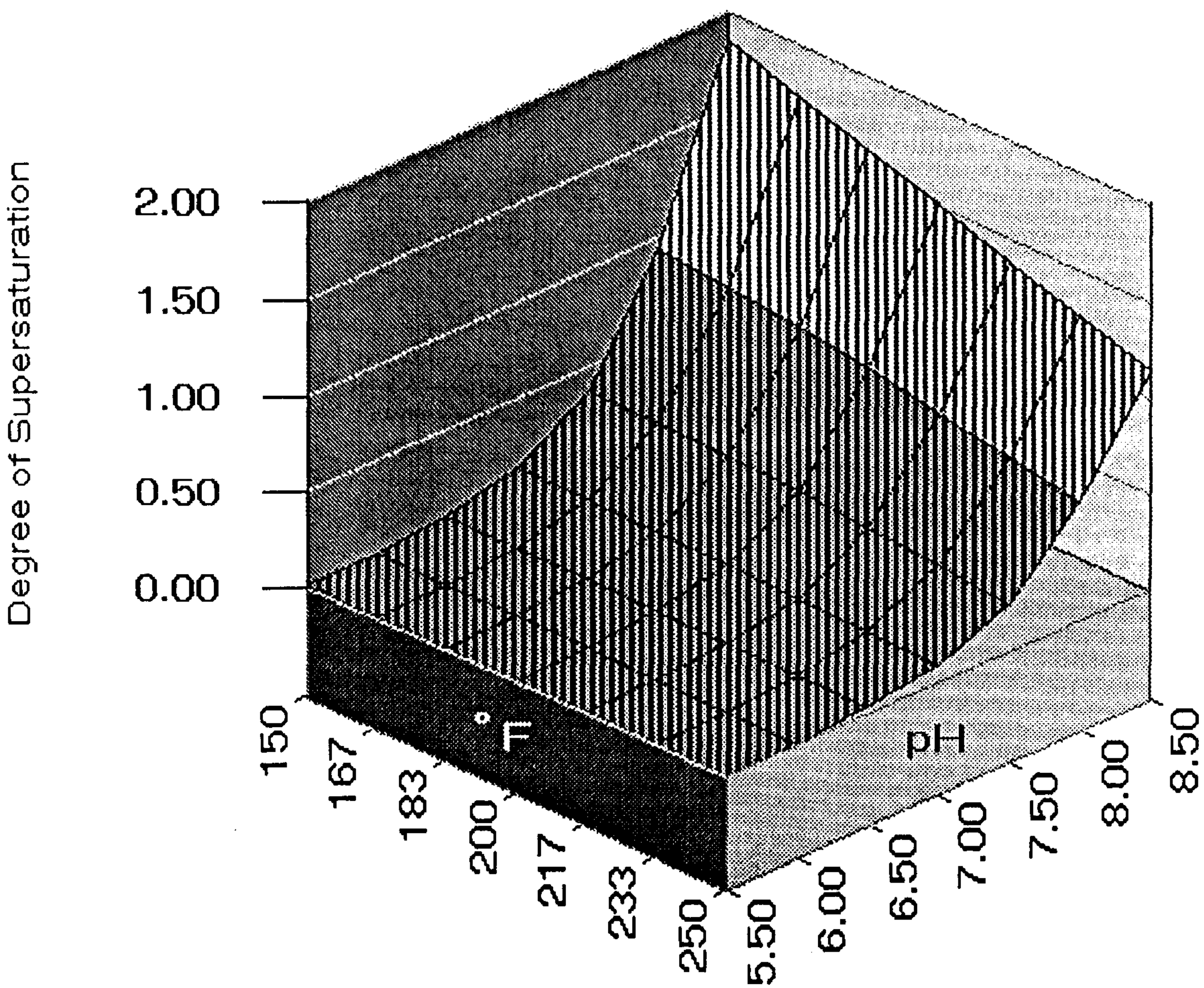
McAllen Ranch, 75% Water Recovery

Amorphous Silica Momentary Excess



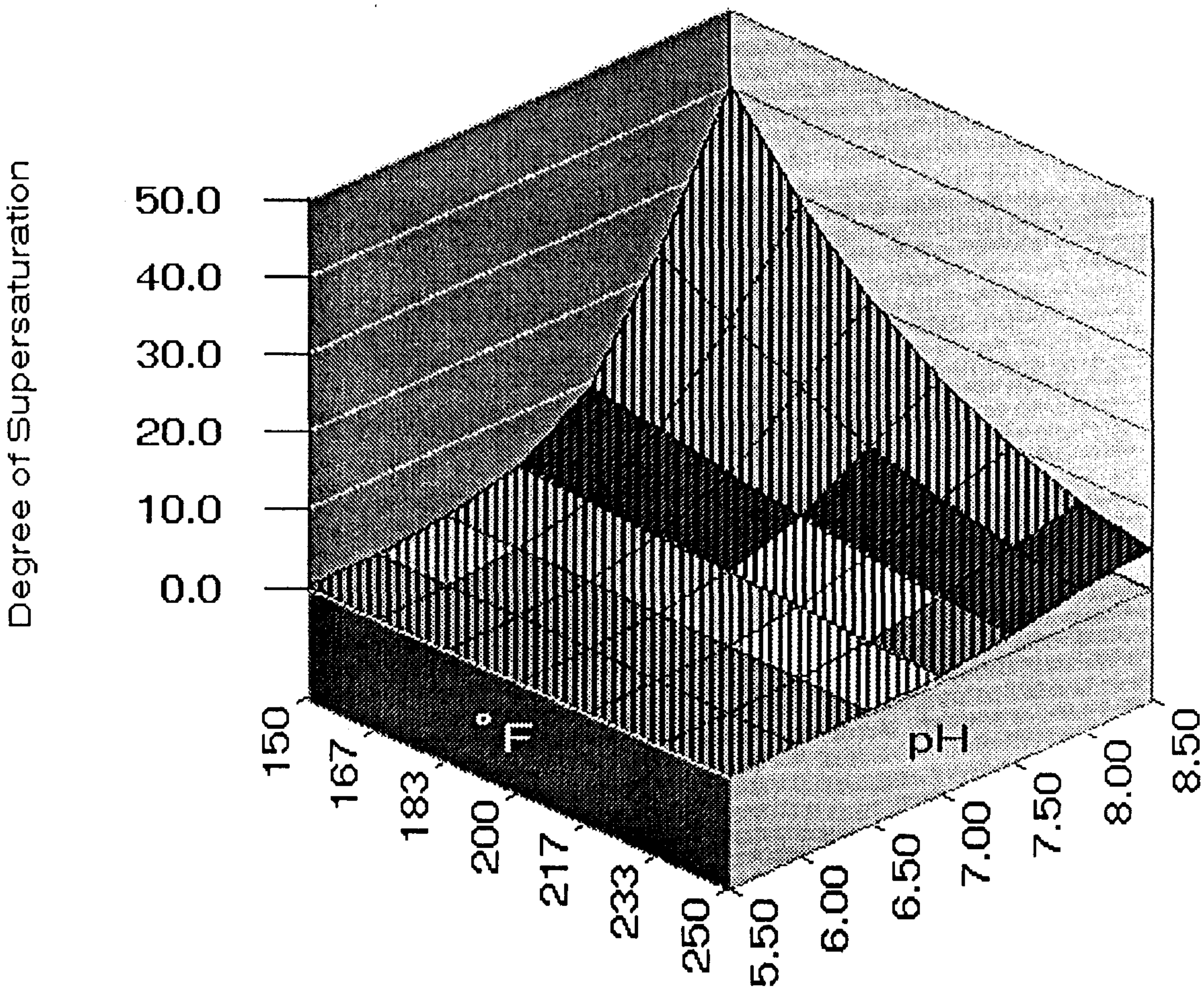
McAllen Ranch, /· % Water Recovery

Witherite Saturation Level



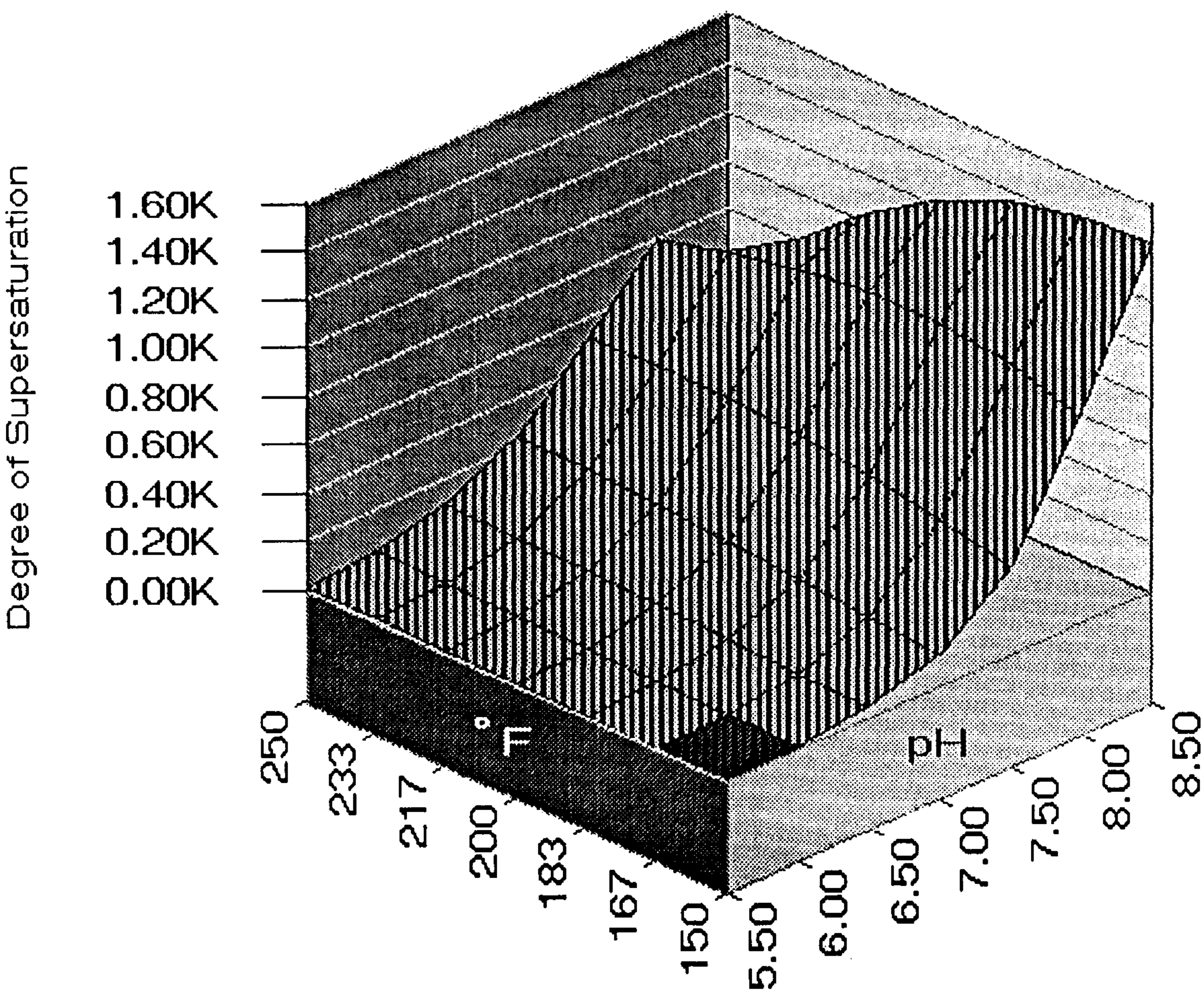
McAllen Ranch, [illegible] % Water Recovery

Strontianite Saturation Level



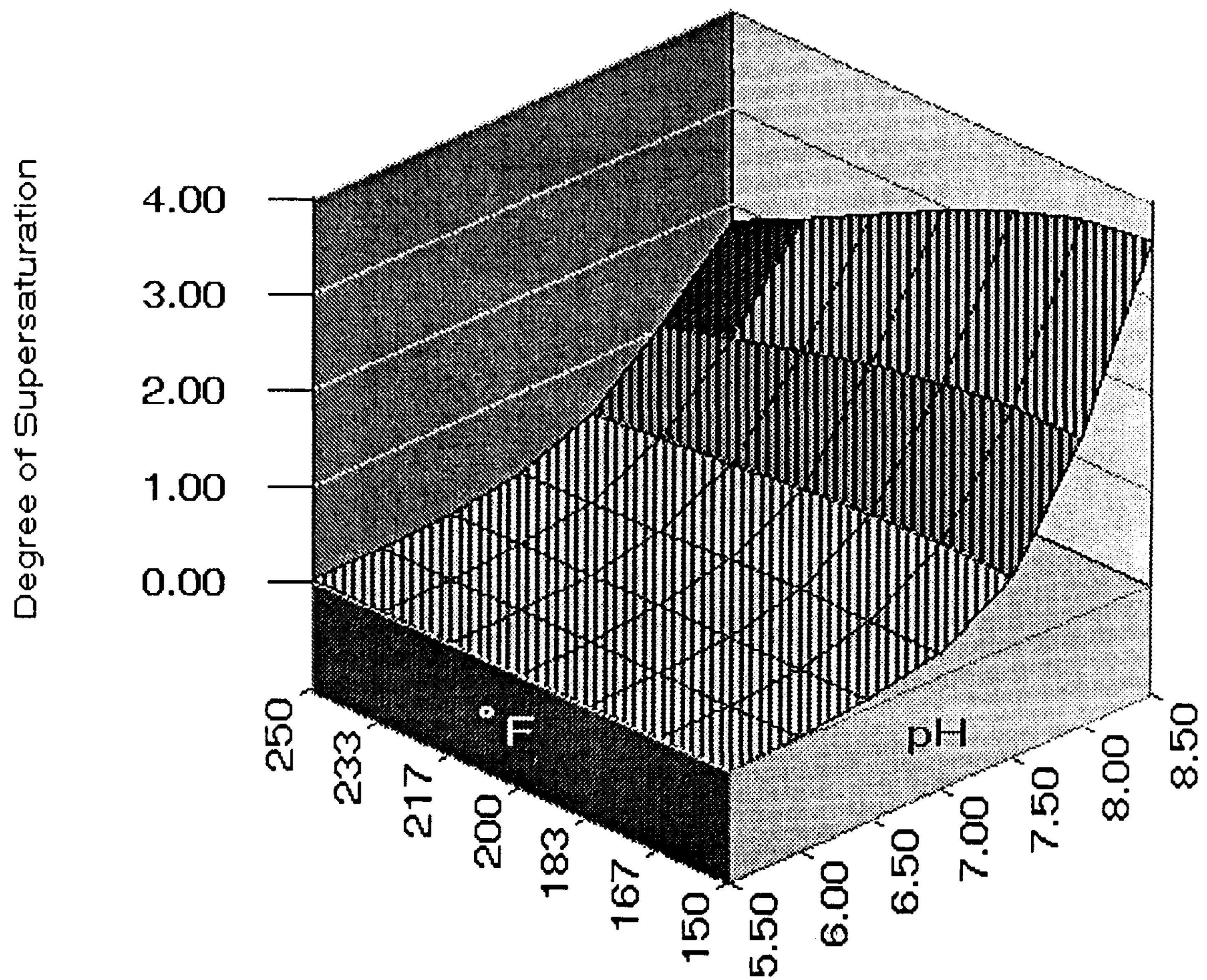
McAllen Ranch, 7. % Water Recovery

Siderite Saturation Level



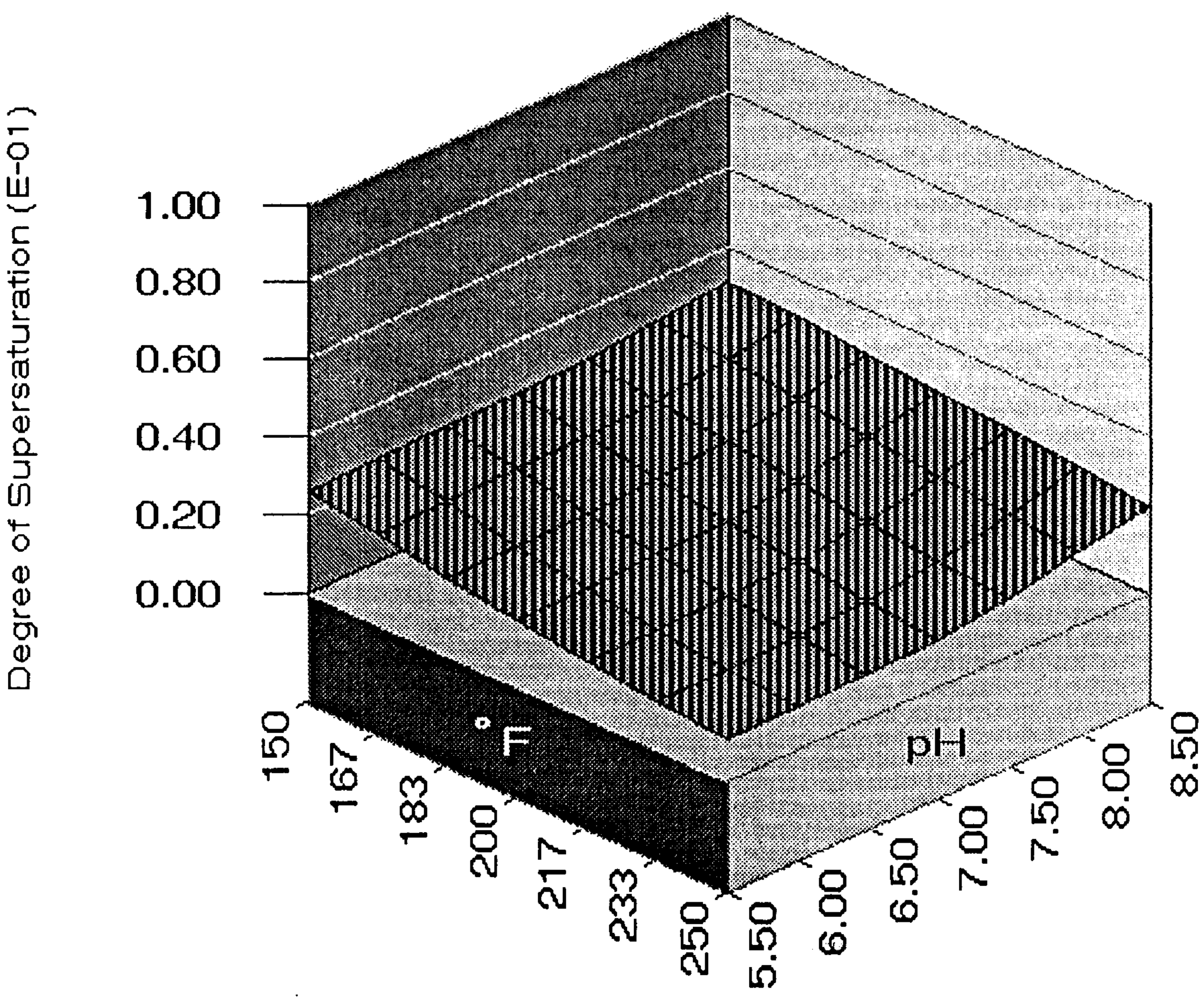
McAllen Ranch, 7 % Water Recovery

Magnesite Saturation Level



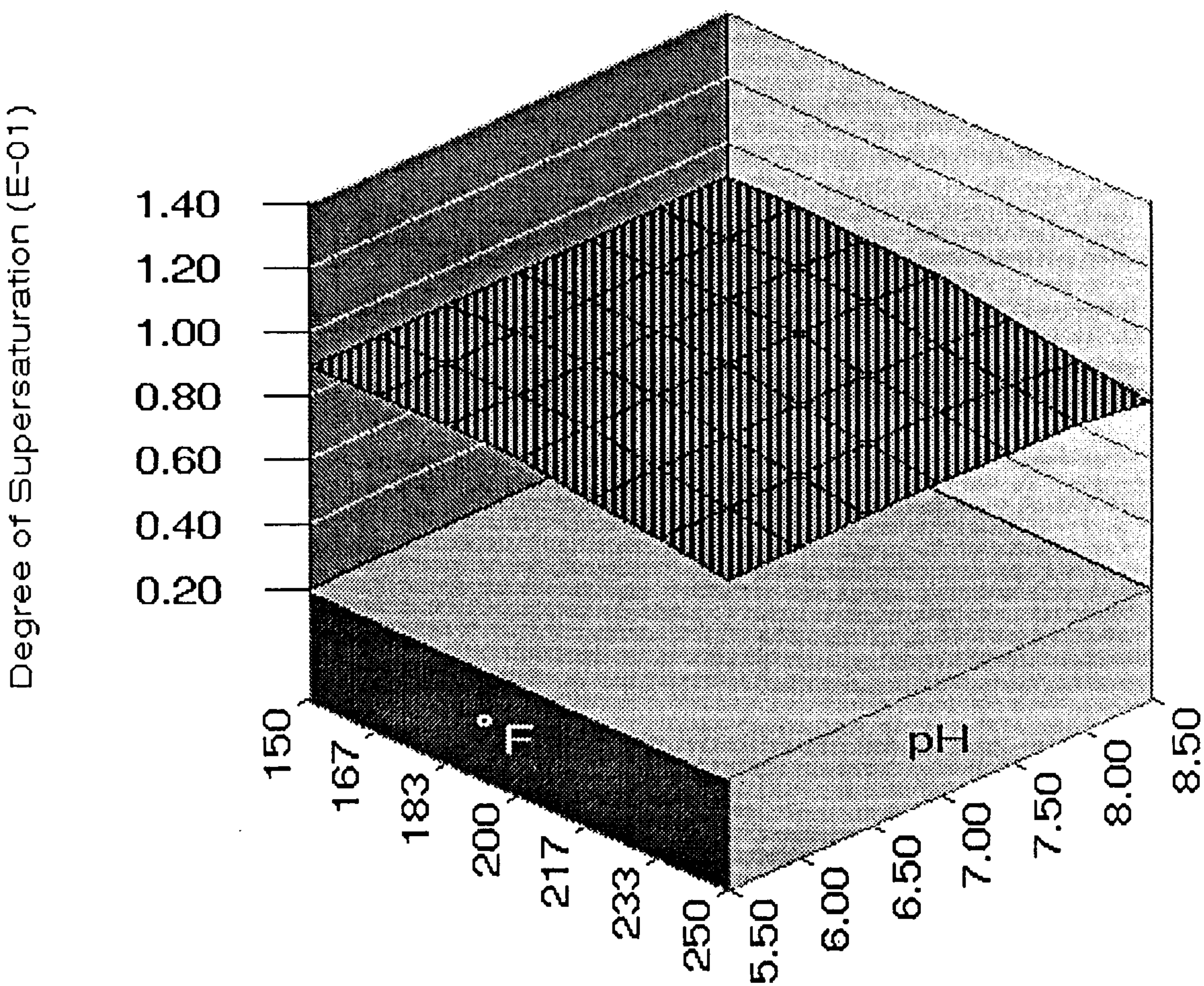
McAllen Ranch, 7 % Water Recovery

Gypsum Saturation Level



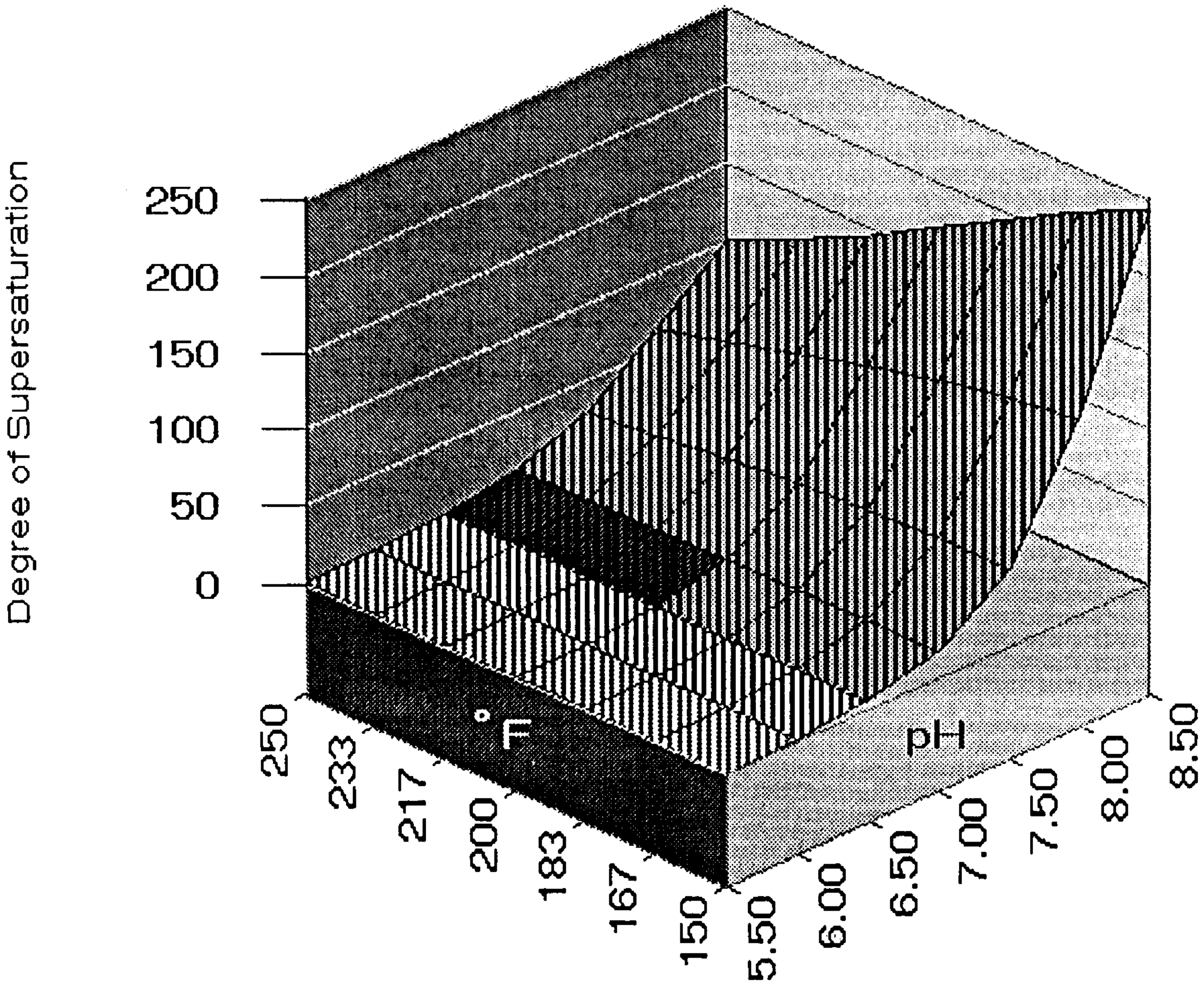
McAllen Ranch, 7. % Water Recovery

Celestite Saturation Level



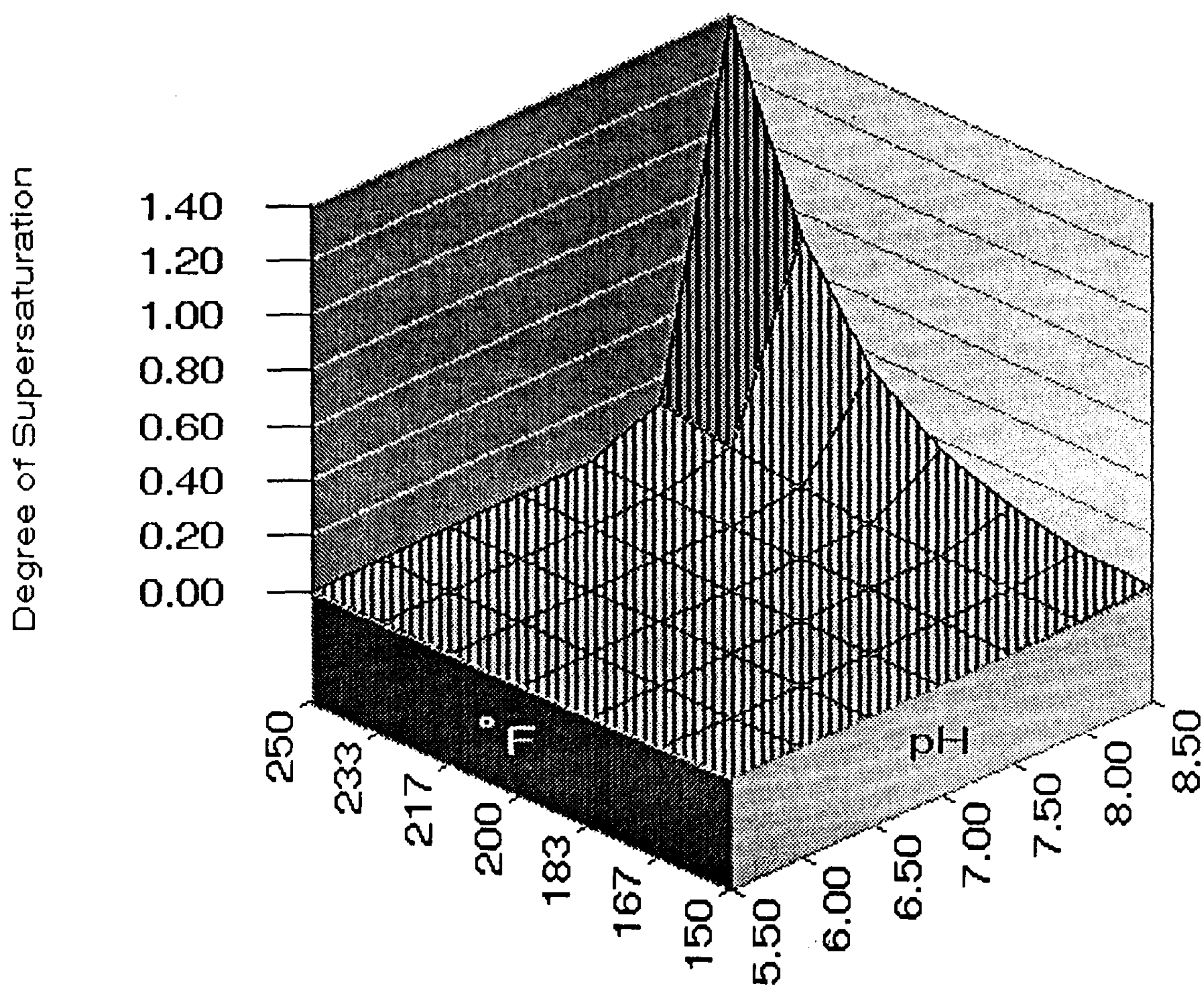
McAllen Ranch, 7\ % Water Recovery

Calcite Saturation Level



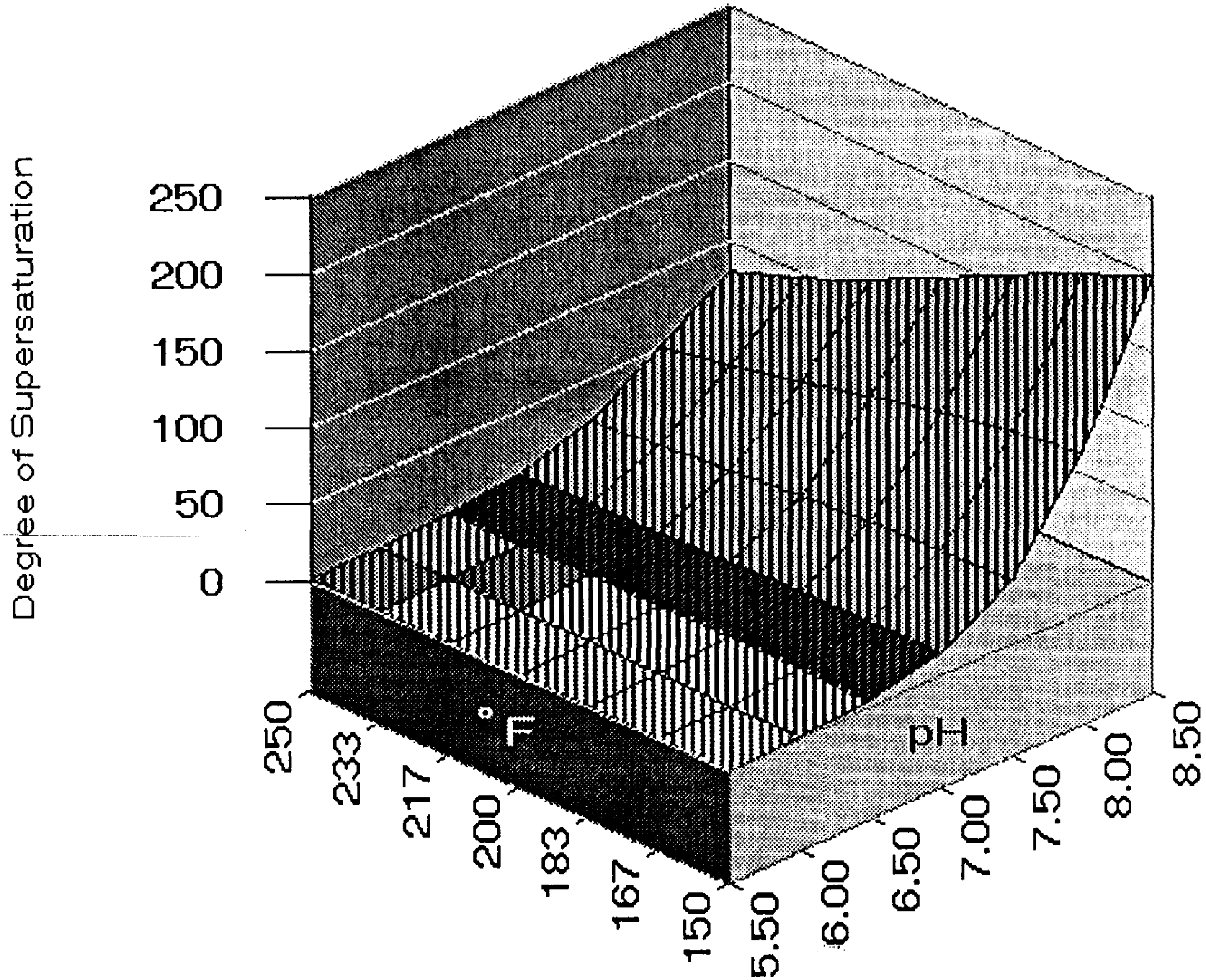
McAllen Ranch, / % Water Recovery

Brucite Saturation Level



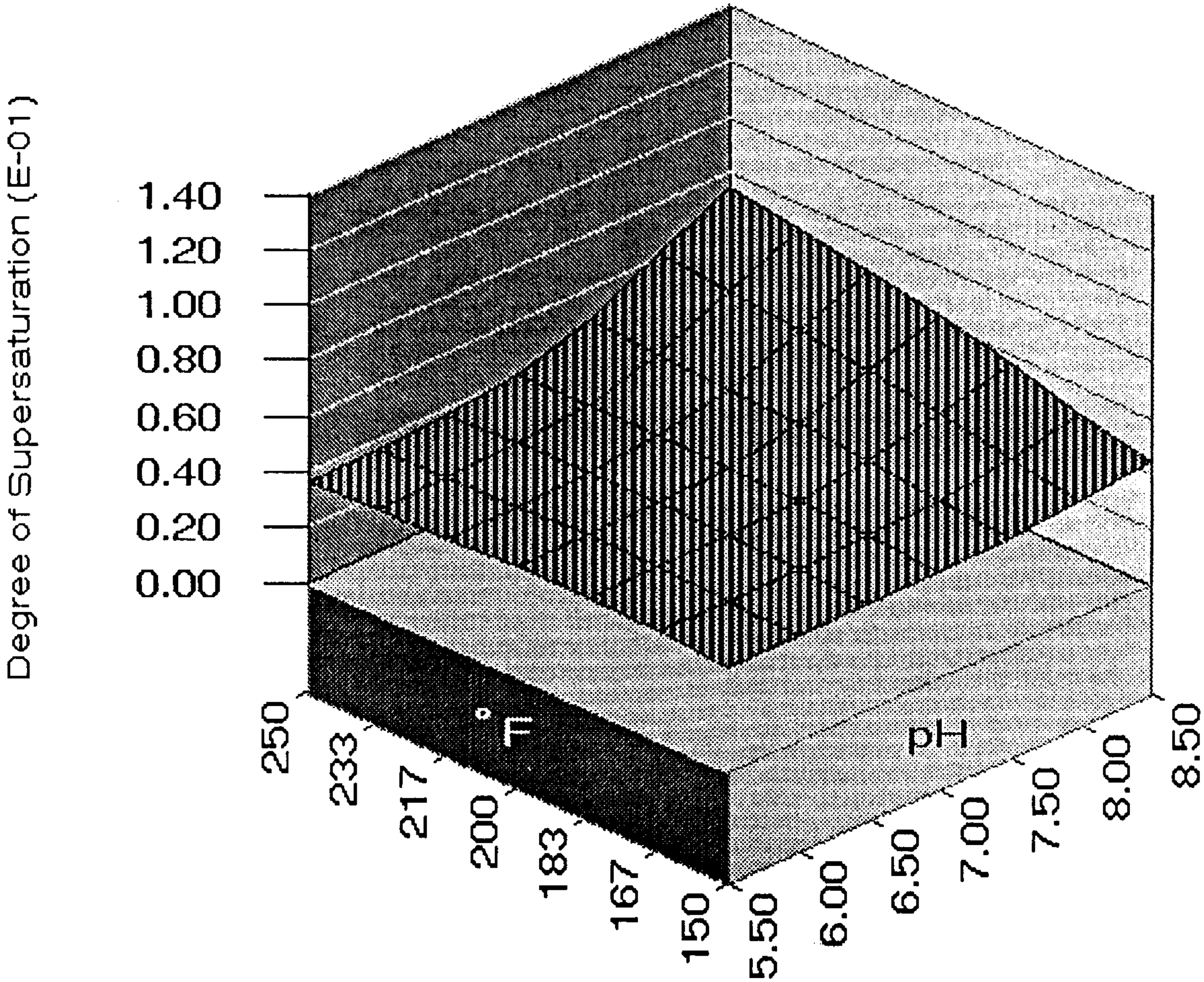
McAllen Ranch, 7. % Water Recovery

Aragonite Saturation Level



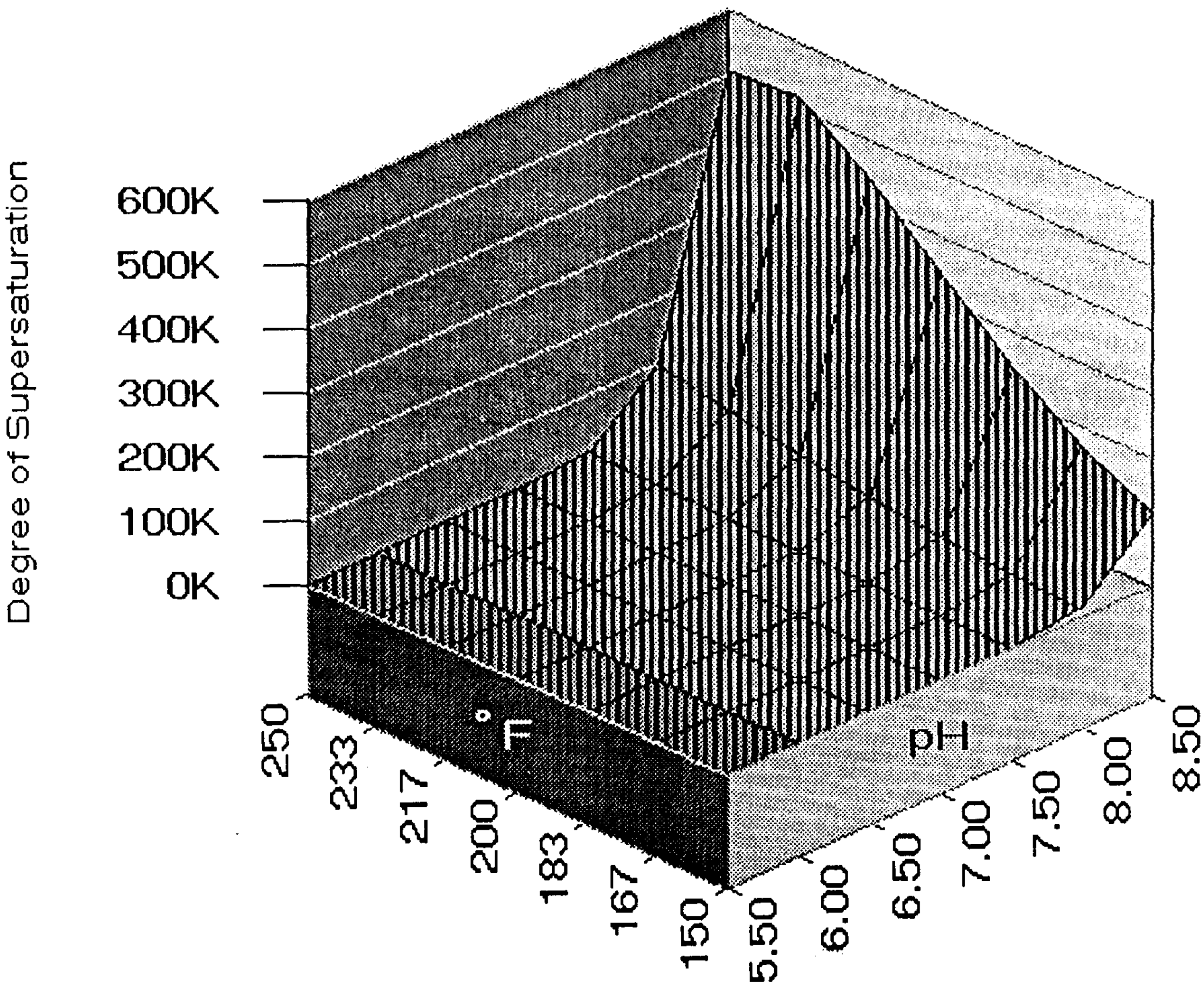
McAllen Ranch, 7 % Water Recovery

Anhydrite Saturation Level



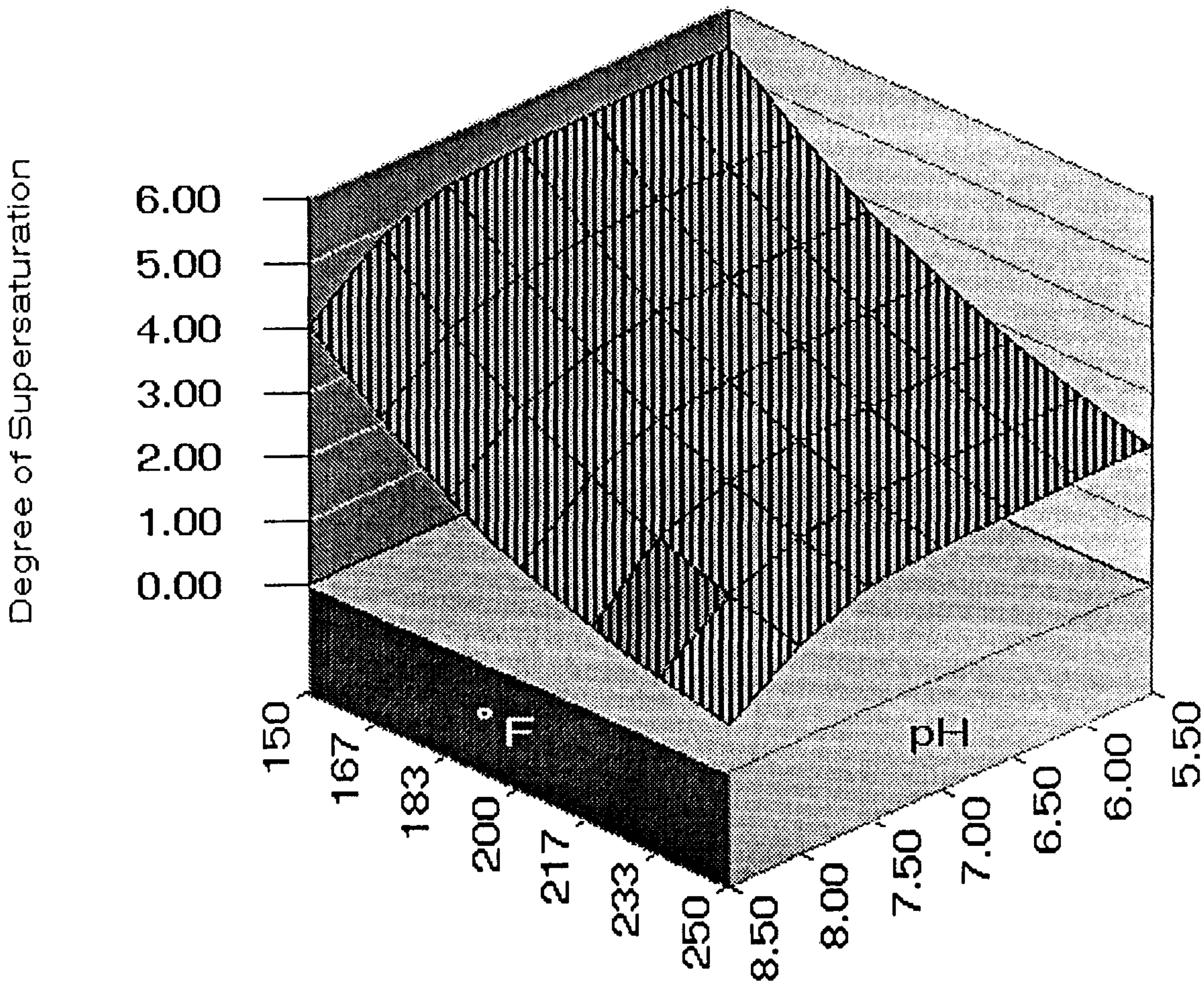
IVICAllen Kancn, /\ % VVater Kecovery

Amorphous Fe(OH)3 Saturation Level



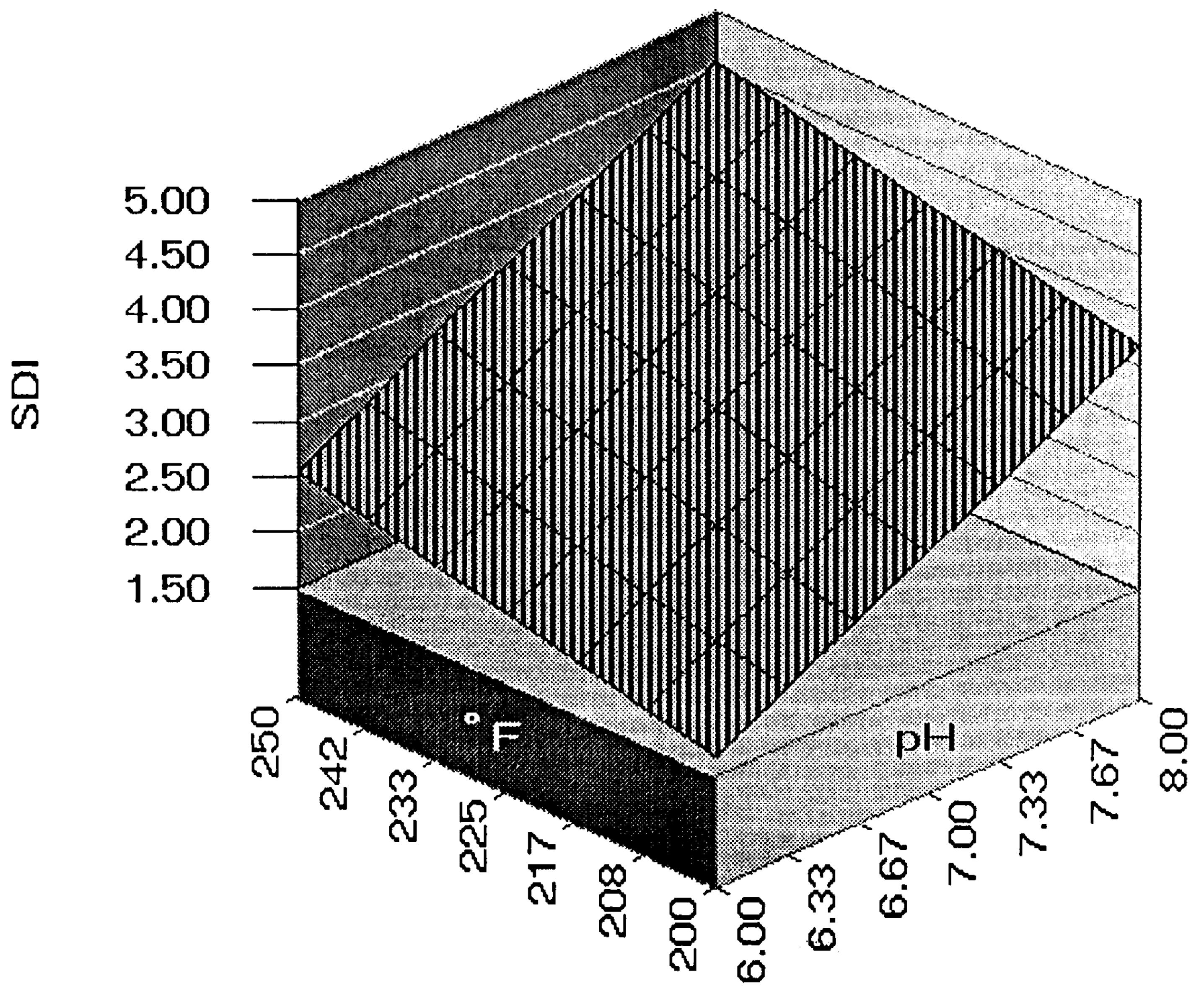
McAllen Ranch, / % Water Recovery

Amorphous Silica Saturation Level



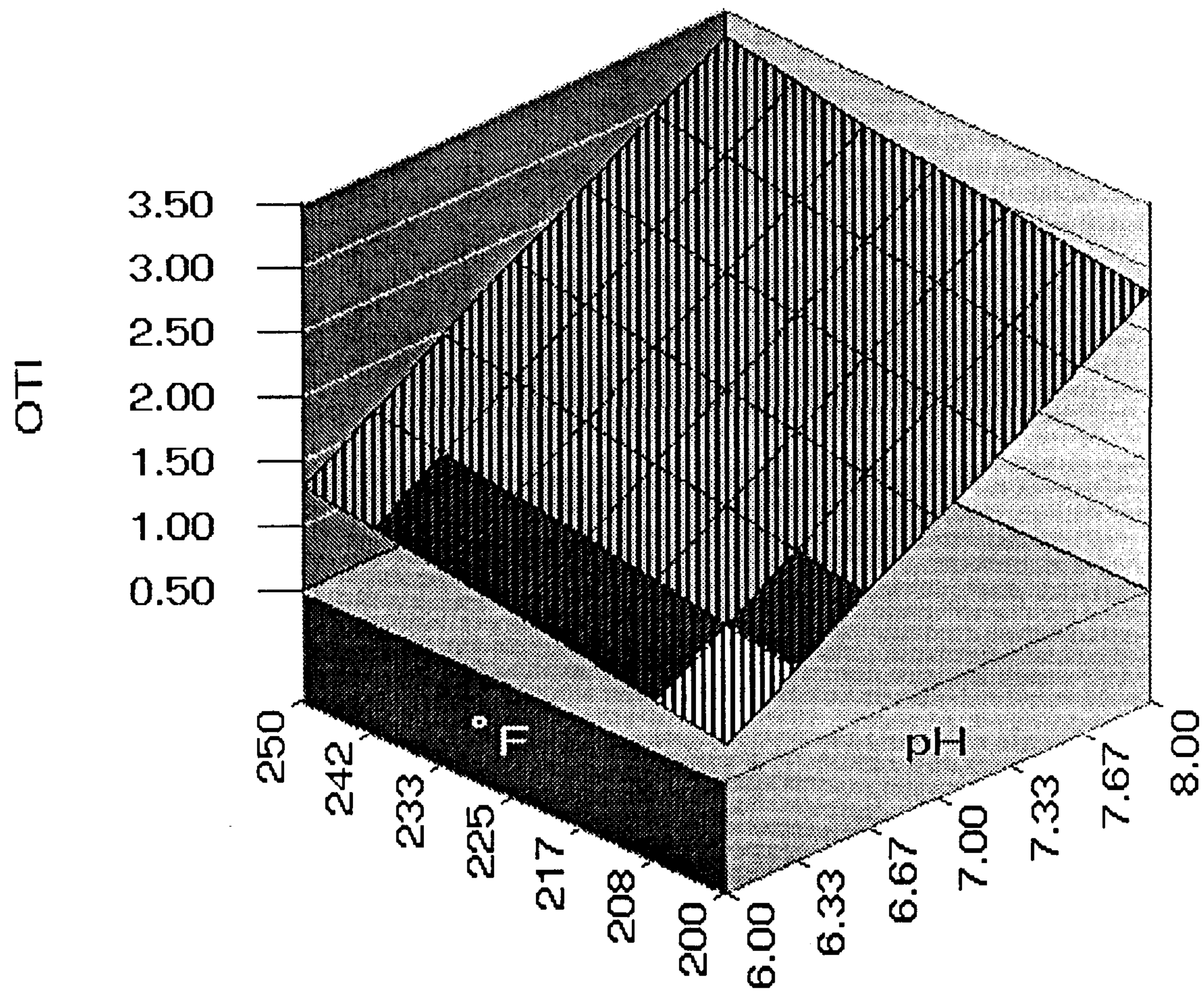
McAllen Ranch, / % Water Recovery

Stiff-Davis Index



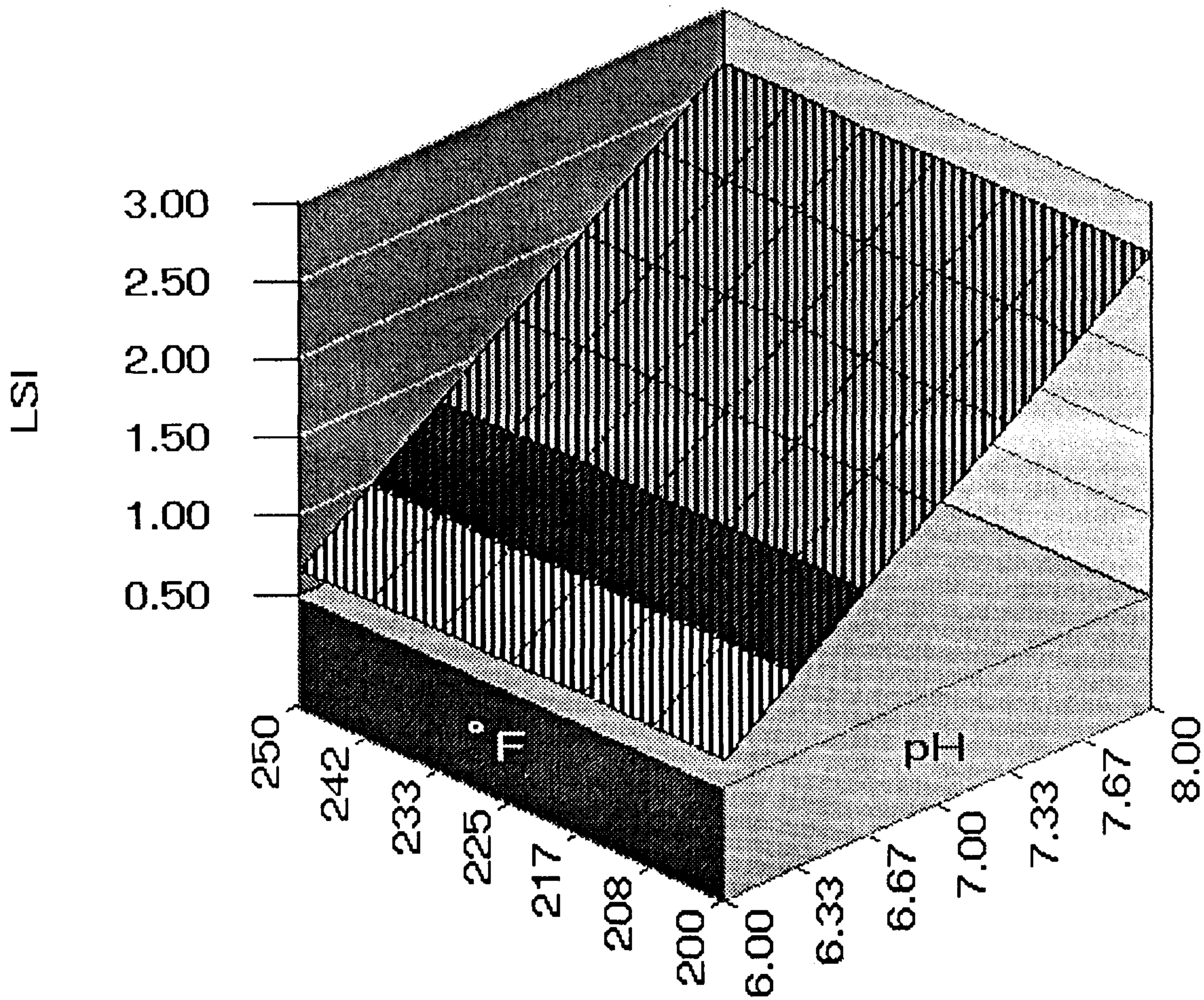
McAllen Ranch, 7[illegible] % Water Recovery

Oddo-Tomson Index



McAllen Ranch, /. % Water Recovery

Langelier Saturation Index



J. McNutt & Associates, Inc.
McAllen Ranch Well Analysis
November, 1993

WELL	DEPTH	Na	K	Li	Ca	Mg	Sr	Ba
B-16	3983.00	3258.00	308.00	6.00	163.00	2.00	21.00	5.00
B-21	4113.00	2741.00	288.00	6.00	57.00	1.00	8.00	4.00
B-22	4085.00	2837.00	318.00	5.00	164.00	2.00	22.00	6.00
B-20	4135.00	2023.00	181.00	4.00	84.00	1.00	13.00	4.00
B-15	4082.00	2657.00	290.00	5.00	147.00	1.00	13.00	2.00
B-24		3327.00	360.00	6.00	165.00	2.00	23.00	5.00
AVERAGE	4080	2807	291	5	130	2	17	4
CF-1	**4080**	**2807**	**291**	**5**	**130**	**2**	**17**	**4**
CF-2	**4080**	**5614**	**582**	**11**	**260**	**3**	**33**	**9**
CF-3	**4080**	**8422**	**873**	**16**	**390**	**5**	**50**	**13**
CF-4	**4080**	**11229**	**1163**	**21**	**520**	**6**	**67**	**17**

WELL	DEPTH	Zn	Fe	Mn	Cl	H4SIO4	Br	B	T. Alk
B-16	3983.00		5.20	0.20	5090.00	377.00	20.00	90.00	701.00
B-21	4113.00	1.20	9.00	0.10	4170.00	432.00	16.00	75.00	804.00
B-22	4085.00	0.50	6.60	0.20	4470.00	272.00	17.00	61.00	553.00
B-20	4135.00	0.30	3.00	0.10	3210.00	249.00	12.00	55.00	628.00
B-15	4082.00	0.90	12.60	0.60	4120.00	401.00	16.00	93.00	582.00
B-24		0.10	14.70	0.20	5218.00	404.00	21.00	99.00	318.00
AVERAGE	4080	0.5	8.5	0.2	4380	356	17	79	598
CF-1	**4080**	**0.5**	**8.5**	**0.2**	**4380**	**356**	**17**	**79**	**598**
CF-2	**4080**	**1.0**	**17.0**	**0.5**	**8759**	**712**	**34**	**158**	**1195**
CF-3	**4080**	**1.5**	**25.6**	**0.7**	**13139**	**1068**	**51**	**237**	**1793**
CF-4	**4080**	**2.0**	**34.1**	**0.9**	**17519**	**1423**	**68**	**315**	**2391**

NOTE: Water analyses based upon data from L.S. Land, UT-Austin Department of Geology

APPENDIX G

4 DEC 1993

TO: MR. KLEBER DENNY
Terra Associates, Inc.
Houston, Texas

cc: EPG, JWArnold, R. Johnson, file

tel: 713-993-0333
fax: 713-993-0743

FM: EUGENE R. REAHL
Ionics, Inc.
5455 Garden Grove Blvd
Suite 321
Westminster, CA 92683

tel: 714-893-1545
fax: 714-892-1592

SUB: PRELIMINARY EDR / RO COSTS & PERFORMANCE STUDY

REF: State of Texas Water Development Board Grant
Ionics M-10 (TX)

Reviewed your water data for GROUP 1 thru GROUP 4 conditions. We used the "mean" water analysis for each group for the EDR vs RO comparisons. We also used the range of feedwater pH's for each group and then took the average (high + low) / 2 plus about 20% for our calculations. We used 24 degrees C as the feed temp in all cases.

(1) Per our discussion, rough data indicates GROUP 1 thru GROUP 4 waters contain levels of Boron (above 1.4 ppm) which will cause severe problems for fruits, plants, and other growing things. Although Bo causes problems for plants, you and I can drink same up to 45 ppm with no problem!! EDR does not remove boron at normal pH. RO requires elevated pH, as well, for effective reduction. As discussed, we've ignored boron removal in this study. Keep in mind though, if Bo reduction is required, both EDR and RO could reduce same by having the feed water pH raised to 8.5 - 9.5. This requires a presoftening system installation (either lime or lime-soda clarification or softening RO membranes) - so that 2nd phase EDR or RO system will not suffer catastrophic membrane scaling due to high pH.

(2) Since you asked for high water recovery to minimize brine disposal via injection wells - this was our overriding objective in the study. The RO design pushed water recovery to a limit of 180 to 5 ppm SiO_2 in the brine for GROUP 1 thru GROUP 3. For GROUP 4 (because SiO_2 is low), we used 85% as a normal upper limit. Due to the level of Calcium and Bicarbonate in the "mean" water analysis for each GROUP, RO requires the feeding of sulfuric acid to feedwater in each case, to control the level of $CaCO_3$ scaling in RO brine.

⁻DR system water recovery is also limited by $CaCO_3$ and $CaSO_4$ (calcium ılfate). At high water recovery EDR electrical energy (primarily DC power used within EDR membrane stacks) also rises.

Two important points:

(a) for any actual/eventual installation, a cost-benefit analysis would be made comparing the overall effects of operating a desalter plant at various water recovery (ie O&M costs) vs the costs of deep well injection. This study uses the highest recovery for RO and EDR - based on "mean" water analysis'.

(b) there's a broad range of salinities & water qualities in each GROUP - any actual desalter system built (RO or EDR) could have significantly different capital and O&M numbers.

(3) Attached are flow schematic diagrams showing EDR & RO GROUP 1 thru GROUP 4 operations. PLEASE NOTE: EDR's GROUP 4 design should be based on 90% recovery - not the 92% illustrated. In each case EDR puts less wastewater down hole than RO. This is very significant. Also significant is the fact that the O&M spread between RO and EDR (see attached GROUP 1 O&M + a review for all 4 cases) will be REDUCED or ELIMINATED when the effects of EDR's reduced well pumping, reduced ɔst-treatment chemical addition PLUS reduced deep well injection .sposal are included into the O&M evaluation. We'll let you add in the cost of raw water and brine discharge pumping. Also - if ELECTRICAL COSTS are less than \$.08/KWHr the gap is further closed.

(4) Also attached are two (2 ea) pages indicating typical RO & EDR capital costs. These costs indicate that EDR is more expensive than RO - this is due to the fact that EDR produces 500 ppm water directly, while RO blends to 500 ppm. Consequently, the RO system is smaller (typically 80% of total flow). With EDR, the counterbalance will be a smaller deep injection well!!

(5) Finally, we generated these capital and O&M costs in increments of 1.00 mgd product water. Since it's likely that plants larger than 1 mgd would be built, we generated our estimates based on 5.00 mgd installations, broken down into 1 mgd increments.

We hope this info package gets you up to speed on the initial RO and EDR process comparison - please call us to discuss further.

EUGENE R. REAHL

FM: EUGENE R. REAHL
Ionics, Inc.
5455 Garden Grove Blvd
Suite 321
Westminster, CA 92683
tel: 714-893-1545
fax: 714-892-1592

SUB: CORRECTION TO DATA

REF: State of Texas Water Development Board Study
Ionics memo dated 4 DEC 93
Ionics M3-27260

Your call to me yesterday discussed two topics. First, the EDR brine TDS values illustrated in our DEC memo. Yes, these do need to be orrected, as does the 2nd item - our O&M number.

(1) CORRECTED EDR BRINE TDS VALUES:

Overall performances of EDR and RO indicated on original flow schematic diagrams were correct, in terms of water recovery, product quality, etc. RO brine qualities were correct - EDR brine qualities need to be amended. Some originally indicated EDR brine TDS values were too low, while some were high. Have marked up the original GROUP 1 - GROUP 4 flow schematics to indicate corrected EDR brine qualities. Have also attached 2 pages of computer generated water qualities. These indicate the "mean" raw water quality used for GROUP 1 thru GROUP 4 designs, as well as EDR product, steady-state brine and averaged brine TDS. I would think you could easily change these figures on your report via PLC/computer.

(2) CORRECTED EDR O&M COST:

Your right again - the EDR O&M numbers don't add up correctly. I checked all the calculations made for RO and EDR. Problems were used by an errant hand held calculator which was replaced late last ,ear. Since all calc's were checked, we also talked further yesterday with RO membrane manufacturers to have them comment on original designs/costs generated by this writer.

Have attached two new data sheets to replace the O&M breakout originally indicated for GROUP #1 water case, and to replace the

Review of O&M Costs for all 1-4 cases.

2nd new sheet corrects two erroneous hand held calculator mistakes which were included in your original data: EDR GROUP #1 O&M has been lowered, while EDR GROUP #2 O&M has been increased. All of the RO O&M costs have been slightly raised to account for what will be a higher "averaged" RO feed pump pressure over 5 year membrane life.

This new sheet reflects ACCURATE RO and EDR O&M costs.

(3) OTHER FACTORS:

Normally, groundwaters are clean and present no problem to EDR or RO systems - with disposable cartridge filters being the only pretreatment required. However, as we've been finding in So California recently, wells drilled down into old/ancient riverbeds are producing raw waters with high Silt Density Index (SDI) numbers. This means that high enough amounts of very fine silt are coming up in raw waters to be a problem for RO. Additional prefiltration (multi-media filters with coagulant chemical feed) are being "designed" into RO costs. EDR will not require this type of filtration, as unlike RO, EDR membranes are not used as super filters, since with EDR, water is not pushed through the membranes.

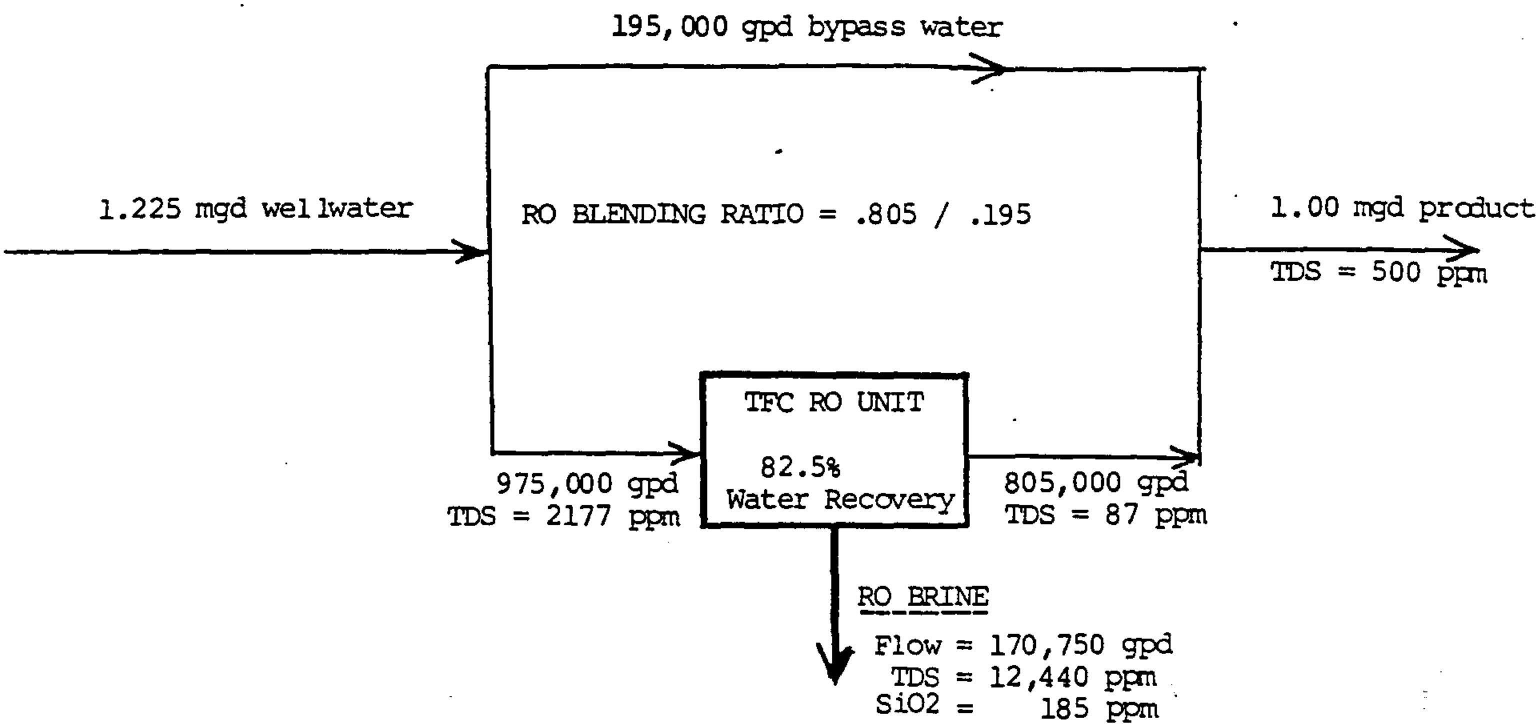
From our experience in areas West of Corpus Christi (in towns like Hebbronville) uranium mining was accomplished by pumping ammonia based chemicals down into wells which bisected ancient riverbeds. From our understanding of Texas geology, your area of interest (GROUP #1 thru GROUP #4) may have similar conditions. This would mean that additional pretreatment maybe be required - particularly for RO.

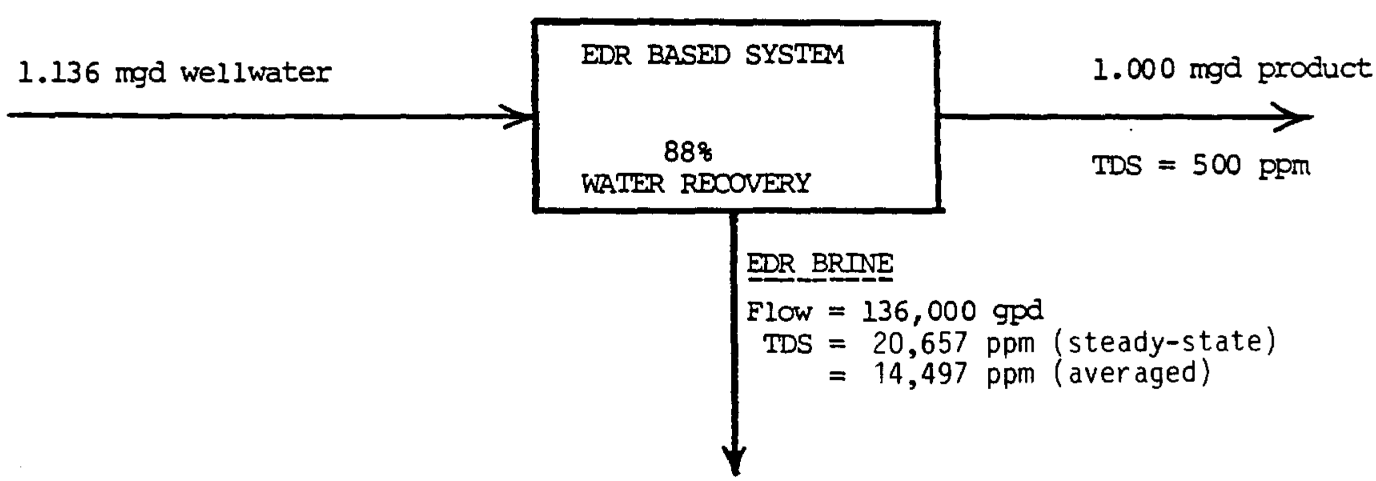
The bottom line to all this is, that in addition to considering the extra groundwater pumping with RO (vs EDR), and the extra deep injection well volume with RO, additional capital and O&M costs could be incurred with RO - over and above what we've indicated in our memos to you. Only after test wells have been drilled at a specific site, and only after all raw water data is collected/analyzed, will a final determination of ACTUAL RO costs/performances be possible. The same could be said for EDR - but to a much lesser extent, since compared to RO, EDR is far less susceptible to "surprises".

(4) The changes indicated in this memo will make your original study more accurate. Hope we have not confused you too much - please call us after you've reviewed this latest input.

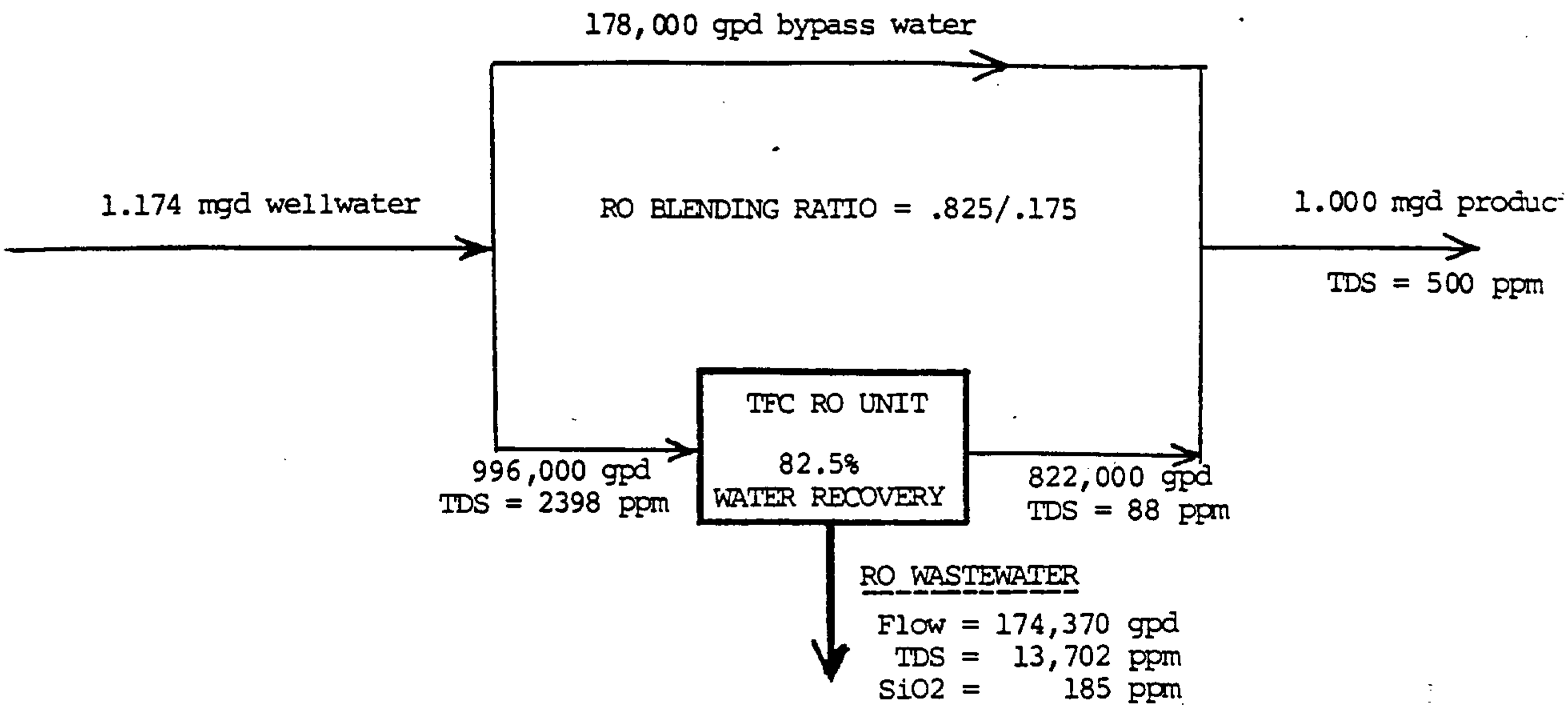
EUGENE R. REAHL

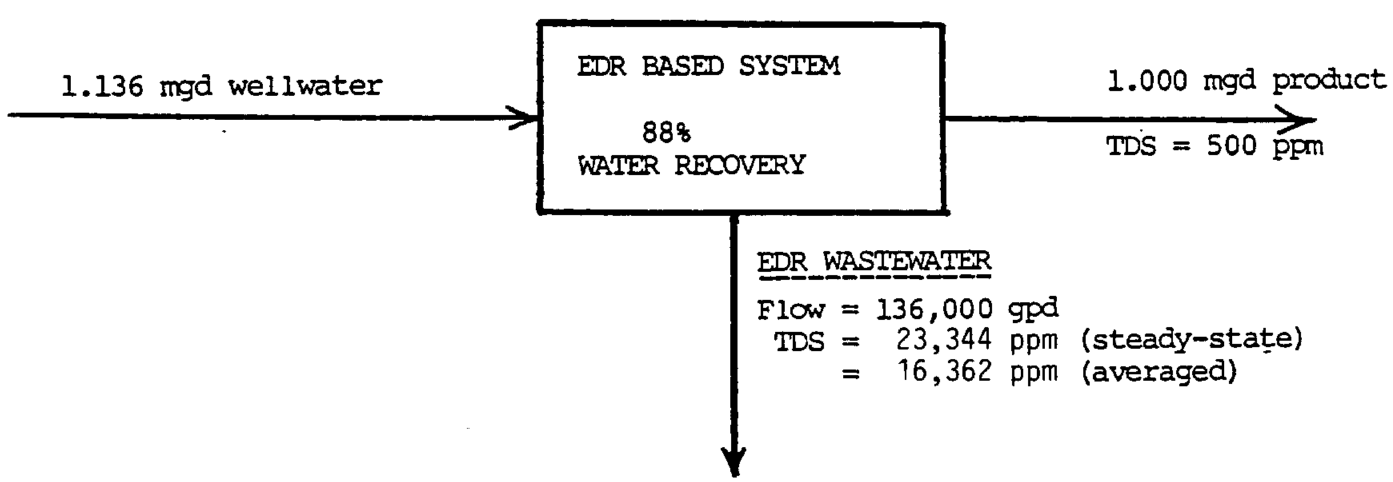
GROUP 1 CONDITIONS



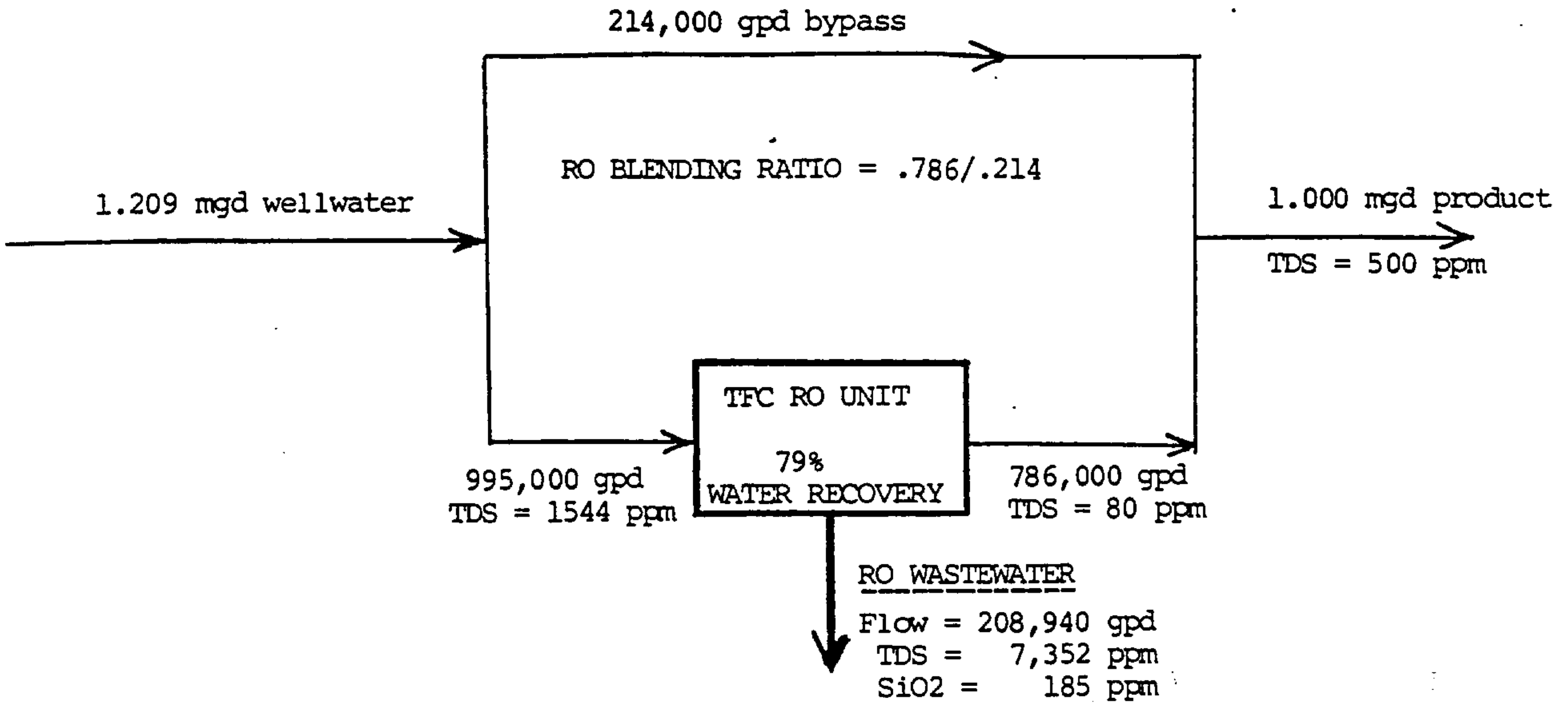


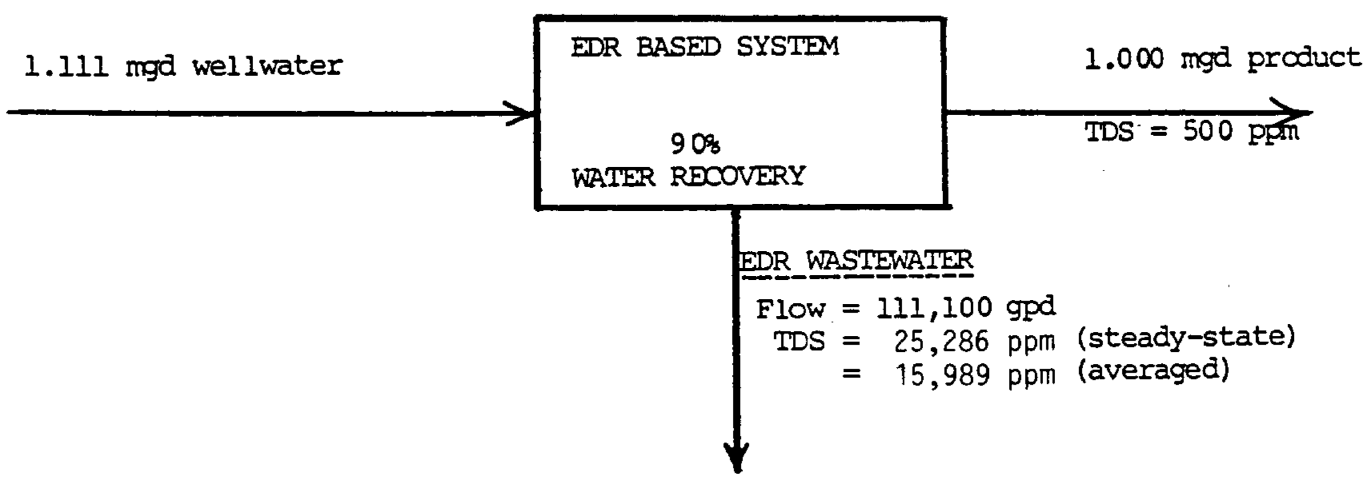
GROUP 2 CONDITIONS



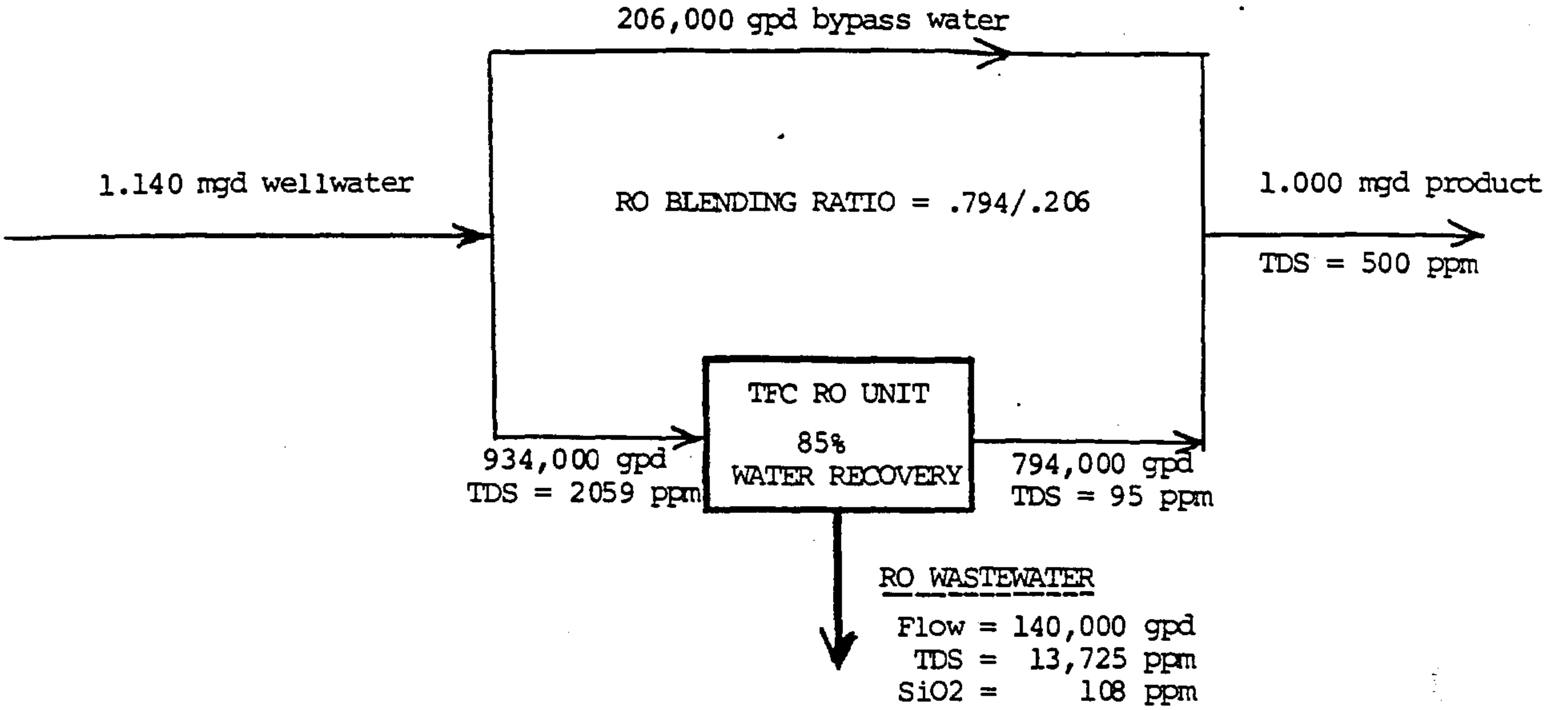


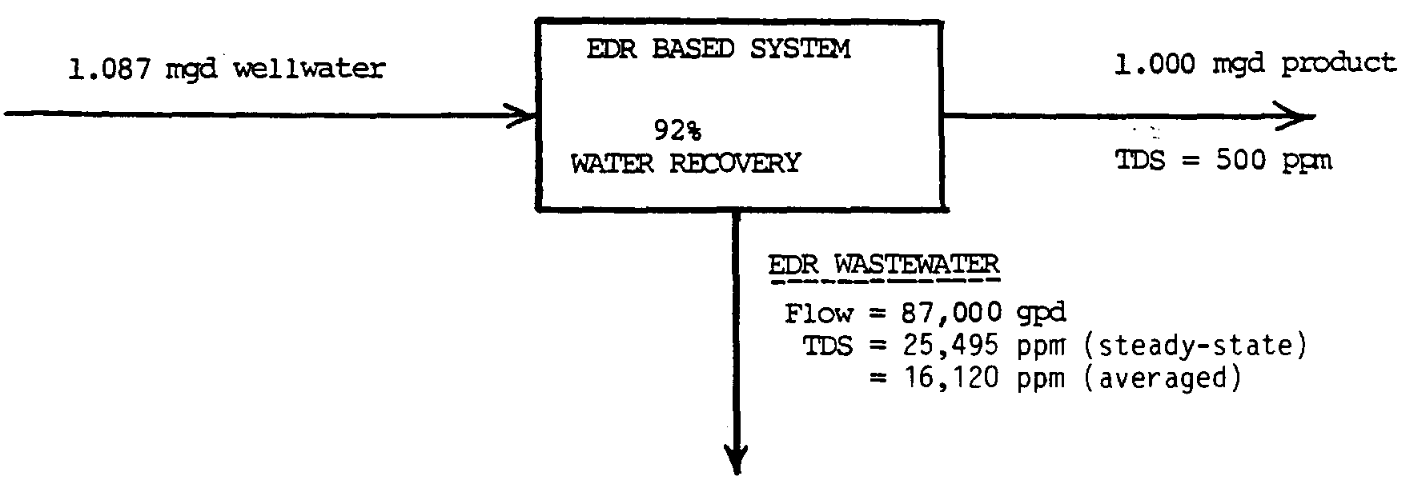
CASE 3 CONDITIONS





CASE 4 CONDITION





BUDGET CAPITAL COST REVIEW

---costs measured in thousands of dollars---

	GROUP 1	GROUP 2	GROUP 3	GROUP 4
REVERSE OSMOSIS BASED SYSTEM	$ 665	$ 685	$ 655	$ 660
⌐R BASED SYSTEM	$ 940	$ 940	$ 930	$ 935

` above capital costs include all essential elements of desalter process - membrane systems, freight, installation, and building. costs DO NOT INCLUDE raw water wells, piping to desalter, brine transfer to deep injection wells, nor deep injection wells. costs DO NOT INCLUDE taxes, permits, eng'ring, architectural fees, etc

.0H16D

ESTIMATED O&M COSTS IN DOLLARS PER 1000 GALLONS

	RO	EDR
(1) TOTAL OPERATING COSTS:		
A. Electr Power ($.08/KWHr) **(1)	$.323	$.3155
B. Total Chemicals Used		
(RO FLOCON 200)	$.010	-none-
(RO H2SO4 to feed)	$.028	-none-
(RO/EDR membr cleaning)	$.010	$.010
(EDR acid to feed)	-none-	$.010
(EDR FLOCON to brine)	-none-	$.0025
C. Replace Filter Cartridges	$.060	$.040
TOTAL OPERATING COSTS:	$.431	$.378
(2) LONG-TERM REPLACEMENTS:		
A. RESERVE: Membrane Repl	$.090	$.090
B. RESERVE: All Other Parts	$.055	$.030
TOTAL REPLACEMENTS COST:	$.145	$.120
(3) TOTAL ALLOCATED LABOR ($25/Hr):		
A. Daily Amortized Labor	$.033	$.025
B. Amortized Maint Labor	$.042	$.027
TOTAL ALLOCATED LABOR:	$.075	$.052
(4) TOTAL SPECIFIC PROCESS COST:	$.651	$.550
(5) RO BLENDING RATIO: (no blend with EDR)	.805/.195	
(6) FINAL O&M COST WATER: **(2)	$.524	$.550

**(1) above electr power DOES NOT include well pump or product repressurization, nor deep injection well pumping
(2) final cost DOES NOT include post-treatment chemicals

0H16D

REVIEW OF O&M COSTS ***(1)

includes costs of electricity, chemicals, filters, long-term replacements and labor - all measured in $/1000 gallons of final 500 ppm TDS drinking water

	GROUP #1	GROUP #2	GROUP #3	GROUP #4
REVERSE OSMOSIS (with blend)	$.520	$.538	$.496	$.470
EDR (no blend)	$.550	$.600	$.550	$.544

process electrical energy consumption in
(1) KWHr/1000 gallon **(2)
&
(2) total KWHr/day per 1 mgd product flow

		GROUP #1	GROUP #2	GROUP #3	GROUP #4
REVERSE OSMOSIS	(1)	4.0/3.22	4.1/3.37	3.85/3.03	3.9/3.09
	(2)	3220	3370	3030	3056
EDR	(1)	3.95	4.3	3.9	3.9
	(2)	3950	4300	3900	3900

**(1) O&M costs DO NOT INCLUDE well pumping, product repressurization, deep injection well pumping, and other costs.

(2) RO KWHr/KGal numbers represent specific RO energy/blended O&M cost, based on each cases RO product blending ratio (see flow schematic diagrams).

APPENDIX H

CANYON INDUSTRIES, INC.
5346 MOSQUITO LAKE RD.
DEMING, WA 98244

December 1 1993

Bob Young
Robert Young & Associates, Inc.
10101 Fondren, Ste 480
Houston, TX 77098

Dear Mr Young.

Thank you for your call and faxed data on the planned Geo-Pressure Hydroelectric project. Attached is a sketch showing typical layout of a similar sized system.

Equipment is described as follows:

<u>Turbine</u> Single variable nozzle impulse (Pelton) type turbine, 1800 RPM shaft speed.

<u>Generator</u> Induction type, 1800 RPM 480 VAC three phase, with power factor correction.

<u>Controls</u> Operational and protective switchgear to comply and interface with the utility grid.

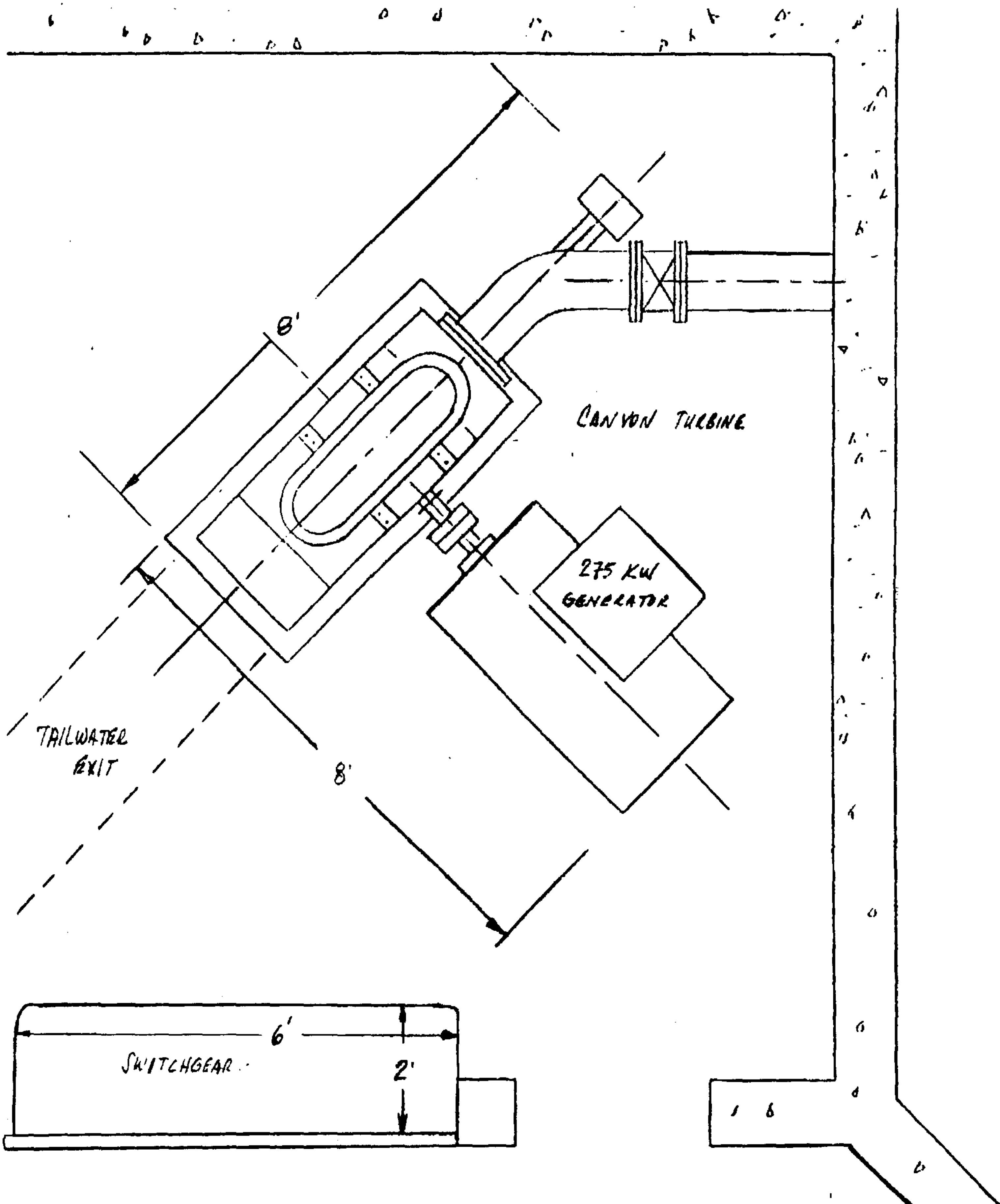
Budget estimate, equipment as described..$ 66,000.00.

I trust this will assist you in further planning, but give me a call as you have questions

Sincerely

Daniel A. New

DAN pan
Encl.



CANYON INDUSTRIES
5346 Mosquito Lake Road
DEMING, WASHINGTON 93244

TENTATIVE POWERHOUSE PLAN
GEO-PRESSURE HYDRO PROJECT