- Final Report -

DISPOSAL/RECOVERY OPTIONS FOR BRINE WATERS FROM OIL AND GAS PRODUCTION IN NEW YORK

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submitted to

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ABSTRACT

Produced water from oil and gas operations, or brine as it is typically referred, may be characterized as being highly saline, with total dissolved solids greater than 100 g/L. If these brines are disposed improperly there may be severe adverse environmental effects. Thus, it is important that brine be disposed using environmentally sound methods. Unfortunately, costs for the disposal of brine water are a significant burden to oil and gas producers in New York State. These costs and the relatively low market price of oil and natural gas have contributed to the decline in gas and oil production in New York State during the past 10 years.

The objectives of this study were to evaluate new and existing options for brine disposal in New York State, examine the technical and economic merits of these options, and assess environmental impacts associated with each option. Two new disposal options investigated for New York State oil and gas producers included construction of a regional brine treatment facility to treat brine prior to discharge into a receiving water and a salt production facility that utilizes produced water as a feed stock. Both options are technically feasible; however, their economic viability depends on facility size and volume of brine treated.

KEY WORDS

produced water, brine, treatment, reclamation, New York State, oil and gas production

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EXECUTIVE SUMMARY

There are presently approximately 5,500 active gas wells and 3,800 oil wells owned by about 600 operators in New York State. The majority of active oil wells are in Allegheny and Cattaraugus Counties, and the majority of active gas wells are in Chautauqua County. In 1990, 0.42 MMBBL (million barrels) of crude oil and 25,400 MMCF (million cubic feet) of natural gas were produced with an estimated market value of New York State's 1990 oil and gas production of $66.2 million.

During oil and gas production, a highly saline by-product water is generated with total dissolved solids greater than 100 g/L. Once brought to the surface, brine constitutes an environmental threat to fresh surface water and potable ground water supplies if disposed improperly. The latest (1990) annual brine generation rates, estimated by the New York State Division of Mineral Resources (DMN), are about 300,000 BBL (12.6 million gallons) from gas production and about 2.1 MMBBL (88.2 million gallons) from oil production.

In the past (prior to 1984) brine was generally disposed in a brine pit adjacent to the well. Separated brine was placed in the brine pit and allowed to infiltrate into soil and/or evaporate. However, brine pits are no longer environmentally acceptable due to potential groundwater contamination, and are not allowed for disposal. There are currently three brine disposal methods that are acceptable to the New York State Department of Environmental Conservation (DEC): road spreading of brines for deicing and road stabilization, discharge to surface waters through permitted facilities, and underground injection.

Although these methods are currently acceptable, costs for the disposal of brine water add a significant burden to oil and gas producers in New York State. These costs and the relatively low market price of oil and natural gas have contributed to the decline in gas and oil production in New York State during the past 10 years. Thus, there is a need to explore and develop brine disposal alternatives that are more cost effective than those presently available.

In addition, because preparation of a generic environmental impact statement (GEIS) is the key step in developing criteria for recommending changes in existing regulations, it is anticipated that new regulations related to brine disposal may be proposed in the future. Any new proposed regulations may affect the acceptability of the current brine disposal methods.

Therefore, in anticipation of possible future changes in brine disposal regulations and the need for a more cost effective brine disposal enterprise to service the oil and gas producers in New York State, the New York State Energy Research and Development Authority (Energy

Authority) and the Gas Research Institute (GRI), in conjunction with the State University of New York at Buffalo, have conducted this study.

OBJECTIVES AND SCOPE

The objectives of this study were to:

- Define the scope of the brine disposal problem in southwestern New York State, both for the present and for the future.
- Develop options (strategies) for treatment/disposal of present and future gas (and oil) brines generated in southwestern New York State.
- Perform technical and economic feasibility analysis of treatment/disposal options. Identify key constraints to the implementation of any treatment/disposal option.
- Develop options (strategies) for reclamation/reuse of present and future gas (and oil) brines generated in southwestern New York State.
- Perform technical and economic feasibility analysis of reclamation/reuse. Identify key constraints to the implementation of any reclamation/reuse option.
- Recommend best alternative for brine reclamation/disposal and include a preliminary economic analysis.

In conjunction with the development of options to reclaim brines a marketing study was conducted to potential use/demand for recovered brine salt products.

To accomplish the objectives of the project, information was collected from various governmental and industry agencies. In addition, laboratory work analyzed brine water and evaluated the effectiveness of proposed treatment processes to remove undesirable impurities. All laboratory work was performed in the Environmental Engineering Laboratories at the State University of New York at Buffalo. Preliminary design for the facility used guidelines from government manuals and equipment vendors. Site selection used criteria developed during this study and supporting information obtained from county municipal agencies and personal visits to the area.

MAJOR RESULTS AND CONCLUSIONS

Existing Situation

Due to low market prices for oil and gas, the profit margin for oil and gas production in New York State is limited. From 1986 to 1991, the volume of brine generated in New York State from oil and gas production has steadily decreased from 8.8 to 2.4 million bbl., primarily due to the cessation of a large portion of oil produced by waterflooding operations. An added burden to oil and gas producers is the cost for disposing of brine waters generated during oil and gas recovery.

Approximately 600,000 to 400,000 bbl. of the more the 2.2 million bbl. of oil/gas brines generated must be disposed by DEC-approved methods. The majority of the highly saline brines requiring disposal by approved methods is generated in Chautauqua, Cattaraugus, and southern Erie counties.

These highly saline brines are disposed using one of three methods: road spreading, underground injection, or discharge into a surface water after treatment at a commercial brine or municipal wastewater treatment plant. The DEC estimates that in 1990, approximately 30 percent of the highly saline gas associated brines was roadspread, 50 percent was discharged through treatment plants, and 20 percent was injected into disposal wells.

Roadspreading is the least costly of the available disposal methods. Highway departments use brines for road stabilization and deicing. Oil and gas producers are not charged a fee for brine disposal using roadspreading. The only cost of brine disposal by roadspreading is transportation to the roadspreading site. The fees presently levied for brine disposal using underground injection and surface water discharge after treatment are similar. The primary difference in costs is transportation. Current costs for brine disposal by these methods range from $1.80 to $3.50 per bbl.

Regulatory changes limiting and/or requiring treatment of brines prior to roadspreading would severely limit that option and result in an added economic hardship for oil and gas producers.

Three commercial brine treatment facilities are operating in Pennsylvania. No such facility is located in New York State, although some municipal wastewater treatment plants accept a limited amount of brine for disposal. The transportation costs to brine treatment facilities in Pennsylvania are significant. Transportation costs may be equal to, or greater than, the fees levied by the brine treatment facilities for disposal, about $400,000 annually based on 50 percent of the highly saline brines being shipped to these facilities.

There are five existing underground injection wells in New York State. The aggregate approved capacity of these wells is greater than 1.2 million bbl. per year. However, despite the seemingly favorable economics for disposal wells, less than 10 percent of the total capacity is used. Thus, there are other factors, economic or technical, that control the use of these wells. Unfortunately, none of these factors was clearly identified in this study. It is hypothesized that poor geological conditions and poor fluid characteristics (e.g. high suspended solids) primarily contribute to this situation.

Brine Disposal Alternatives

One alternative brine disposal method that was evaluated was construction of a commercial brine treatment facility to treat 600,000 bbl. of brine per year. This facility would have an estimated capital cost of about $2.5 million with an annual cost $814,000. Treated brine would be discharged into Cassadaga Creek, near the Town of Levant in Chautauqua County. Assuming that $0.0325 per gallon of brine discharged is charged (similar pricing to that of the closest Pennsylvania facilities), a facility could be constructed with a payback period of about 8.1 years and an internal rate of return of about 11 percent. The payback period decreases and the internal rate of return increases as the fee for brine disposal is raised. If the capacity of the treatment plant and the volume of brine increases commensurably, the economics also become more favorable. This latter scenario is unlikely unless there is a significant increase in oil and gas production in New York State.

Construction of an underground injection facility was also evaluated as a brine disposal alternative. Capital cost and annual cost estimates for constructing and operating an underground injection facility are $1.34 million and $525,000, respectively. Assuming that $0.0325 per gallon of brine disposed is charged, an underground injection facility could be constructed with a payback period of about 3.7 years and an internal rate of return of about 37 percent.

Reclamation of Salt Products from Brine

The third brine disposal alternative investigated was treating brine and reclaiming marketable salt products, sodium and calcium chloride, using a vacuum pan evaporative method. The proposed reclamation process would include pretreatment of the brine to remove suspended and dissolved impurities; preliminary heating and storage of brines using solar ponds as an energy source; and recovery of salt products from the pretreated, preheated brine using a multiple-effect vacuum pan evaporator. The total capital costs for such a facility are estimated at $5 million. Total annual costs are estimated at $1.8 million. The net annual revenue projected from the sale of the reclaimed salt products and brine disposal fees is from $750,000 to $820,000. The payback period would be about four years with an internal rate of return from 25 to 27 percent.

Salt production, a mature industry with limited capacity for future growth, is dominated by a few large producers. More than 75 percent of the sodium chloride market is controlled by three companies. A single primary calcium chloride supplier has more than 60 percent of the market.

The projected volume of sodium chloride to be produced by the salt reclamation facility would be less than 1 percent of the amount of sodium chloride consumed in New York State in 1989. However, the projected volume of calcium chloride to be produced by the salt reclamation facility would be nearly 28 percent of the estimated amount of calcium chloride consumed in New York State. This, and other significant factors, will make direct entry into the salt consumer market difficult.

RECOMMENDATIONS

Recommendations for future handling of oil and gas production brine waters are outlined in this section. The first set of recommendations assumes that there will be no future changes in regulations that would restrict roadspreading or require pretreatment prior to road spreading, and the present volume of brine generated will remain steady or decline.

The second set of recommendations assumes new regulations will be imposed that would restrict roadspreading or require pretreatment prior to road spreading, and the present volume of brine generated will increase such that brine disposal needs are equal to or greater than 600,000 bbls. per year.

No Regulatory Changes, Steady or Declining Brine Generation

The following recommendations minimize the cost of disposing oil/gas production brines for New York State producers.

- Dilute brines generated from oil recovered by waterflooding should continue to be directly discharged into surface waters whenever possible.
- Highly saline brines generated from oil (primary recovery) and gas production should be disposed by roadspreading whenever possible. Definitive agreements, preferably long-term, should be established with municipal highway departments. Presently, brine that is disposed by roadspreading is "given" to the highway departments. This type of arrangement should be maintained. It benefits both oil/gas producers and highway departments.
- A detailed field study should be conducted to investigate the feasibility of using the Theresa formation (7,000+ feet around Chautauqua Lake) as a receptacle for an underground disposal well. Preliminary analyses in this present study indicate disposal costs could be reduced by as much as 40 percent, not including

transportation savings. Highly saline brine that could not be roadspread should be disposed by this method, if feasible.

- If development of the aforementioned underground injection well is not feasible, or the existing disposal wells in New York State cannot be rehabilitated to handle larger flows without significant cost increases, highly saline brine that is not roadspread should be disposed at the closest treatment facility willing to treat the brine. The closest existing commercial brine treatment facility is located in Warren, Pennsylvania.
- A commercial brine treatment facility could be developed in New York State and built and operated profitably only if the amount of brine treated in the facility is 600,000 bbl/yr or greater. (The brine treatment facility in Warren, Pa. has a capacity of nearly 1,800,000 bbl/yr.). This scenario is unlikely as long as roadspreading is permitted and cost effective.

Roadspreading Restricted and/or Treatment Required, Increasing Brine Volumes

Implementing the following recommendations would minimize the cost of disposing oil/gas production brines to New York State producers.

- Dilute brines generated from oil recovered by waterflooding should continue to be directly discharged into surface waters whenever possible.
- A detailed field study should be conducted to investigate the feasibility of using the Theresa formation (7,000+ feet around Chautauqua Lake) as a receptacle for an underground disposal well. Preliminary analyses in this present study indicate disposal costs could be reduced by as much as 40 percent, not including transportation savings.
- If development of an underground injection well is not feasible, or the existing disposal wells in New York State cannot be rehabilitated to handle larger flows without significant cost increases, a salt reclamation facility (see Section 5) should be developed in New York State, as a partnership with one of the current principal salt producers. Direct entry into the salt supply market will be difficult otherwise.
- If developing a joint venture with a principal salt producer fails, a commercial brine treatment facility should be built. If the amount of brine treated in the facility is 600,000 bbl/yr or greater, a brine treatment facility could be built and operated to compete with the facility in Warren, Pa.. For New York State oil and gas producers, the primary advantage would be reducing transportation costs.

1. INTRODUCTION

New York State is a relatively minor producer of oil and gas. There are presently approximately 5,500 active gas wells and 3,800 oil wells owned by about 600 operators in New York State. The oil and gas industry is concentrated in the southwest corner of the state, primarily in Allegheny, Cattaraugus and Chautauqua counties (Charnow, 1986). The majority of active oil wells are in Allegheny and Cattaraugus Counties, and the majority of active gas wells are in Chautauqua County. In 1990, 0.42 MMBBL (million barrels) of crude oil and 25,400 MMCF (million cubic feet) of natural gas were produced with an estimated market value of New York's 1990 oil and gas production of $66.2 million.

During oil and gas production, a highly saline by-product water is generated. (Hereafter, this by-product will be referred to as brine or brine water.) This water is highly saline, with total dissolved solids greater than 100 g/L, and is trapped with the oil and gas in the geological formations (DEC, 1988a). Brine is brought to the surface as oil and gas are brought to the surface. Once brought to the surface, brine constitutes an environmental threat to fresh surface water and potable ground water supplies if disposed improperly. The latest (1990) annual brine generation rates, estimated by the New York State Division of Mineral Resources (DMN), are about 300,000 BBL (12.6 million gallons) from gas production and about 2.1 MMBBL (88.2 million gallons) from oil production.

In the past (prior to 1984) brine was generally disposed in a brine pit adjacent to the well. Separated brine was placed in the brine pit and allowed to infiltrate into soil and/or evaporate. However, brine pits are no longer considered to be environmentally acceptable due to the high potential for groundwater contamination, and are no longer allowed for disposal. In a draft generic environmental impact statement (GEIS) on the oil, gas, and solution mining industry prepared by the New York State Department of Environmental Conservation (DEC) in 1988, three acceptable brine disposal methods (that are in current use) were identified: 1) road spreading brines for deicing and road stabilization, 2) discharge to surface waters through permitted facilities, and 3) underground injection.

Although these methods are acceptable currently, the costs for the disposal of brine water add a significant burden to oil and gas producers in New York State. These costs and the relatively low market price of oil and natural gas have contributed to the decline in gas and oil production in New York State during the past 10 years. Thus, there is a need to explore and develop more cost effective brine disposal alternatives.

In addition, because preparation of a GEIS is the key step in developing criteria for recommending changes in existing regulations, it is anticipated that new regulations related to brine disposal may be proposed that may affect the acceptability of current brine disposal methods.

Therefore, in anticipation of possible future changes in brine disposal regulations and the need for a more cost effective brine disposal enterprise to service the oil and gas producers in New York State, the New York State Energy Research and Development Authority (Energy Authority) and the Gas Research Institute (GRI), in conjunction with the State University of New York at Buffalo, conducted this study.

OBJECTIVES

The objectives were to:

- Define the scope of the brine disposal problem in southwestern New York State, both for the present and for the future.
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- Perform technical and economic feasibility analysis of reclamation/reuse. Identify key constraints to the implementation of any reclamation/reuse option.
- Recommend best alternative for brine reclamation/disposal and include a preliminary economic analysis.

In conjunction with the development of options to reclaim brines a marketing study was conducted to potential use/demand for recovered brine salt products. In addition, several heat energy sources, including solar ponds, were investigated for the evaporative portion of the proposed brine reclamation facility.

SCOPE OF PROJECT

To accomplish the objectives of the project, information was collected from various governmental and industry agencies. In addition, laboratory work was conducted to analyze brine water and to evaluate the effectiveness of proposed treatment processes in removing undesirable impurities. All laboratory work was performed in the Environmental Engineering Laboratories at the State University of New York at Buffalo. Preliminary design of the facility was prepared using guidelines from government manuals and equipment vendors. Site selection for a brine treatment/salt reclamation facility was based on criteria developed during this study and supporting information obtained from county municipal agencies and personal visits to the area.

ORGANIZATION OF REPORT

This report is organized into six major sections. In Section 1 an introduction into the nature and scope of the project is presented. Section 2 discusses the status of oil/gas production in New York State and the current brine disposal methods. Potential development of a brine treatment/disposal with a surface water discharge is reviewed in Section 3 and the feasibility of an underground injection facility for brine disposal is outlined in Section 4. In Section 5, the marketability of reclaimed salt products from oil/gas brines and the design of a salt recovery system in New York State is discussed. Finally, in Section 6 conclusions and recommendations from the project are presented.

2. STATUS OF OIL/GAS PRODUCTION AND BRINE DISPOSAL IN NEW YORK STATE

This section describes the current status of oil/gas production and brine disposal practices in New York State.

OIL, GAS, AND BRINE PRODUCTION IN NEW YORK STATE

Statistics for oil and gas production in New York are compiled annually by the New York State Department of Environmental Conservation's (DEC) Division of Mineral Resources (DMN). These statistics, published in a yearly report entitled ***New York State Oil and Gas Drilling and Production***, provided the primary source of information for this report.

All drilling activity associated with oil and gas production and solution mining must be permitted through the DMN. As part of these permits, the status and productivity of each well must be reported each year to the DMN. This requirement, plus purchasers' and transporters' reports, supply the DMN with the statistical information for their annual report on oil and gas productivity.

Oil, gas, and brine production levels are summarized in several ways: as a statewide total, by town in each county, and by oil/gas producing formations.

A summary of oil, gas, and brine production for the years from 1984 to 1990 is presented in Table 2.1. As can be seen, oil production has decreased more than 50 percent from 1,071,000 to 417,000 bbl/yr. Gas production has also decreased steadily from 33.0 to 25.4 billion cubic feet per year, about 25 percent, during the same period. Brine generation has decreased nearly 75 percent, from 8,809,000 to 2,378,000 bbl/yr.

The largest drop-off in brine generation between 1989 and 1990 was due primarily to the cessation of operations by Pennzoil Products Co., shutting down 629 shallow water-flooded oil wells (DEC, 1990).

During this project, a series of meetings with DMN personnel was held. Based on conversations with DMN personnel, brine production values are probably underestimated in their annual report. Inaccuracies in annual well status and production reporting procedures are believed to exist. Thus, the reported totals for brine production may be considered to be low estimates of actual values.

Table 2.1
OIL, GAS, AND BRINE PRODUCTION TRENDS

Year	Oil Production, bbls	Gas Production, BCF	Brine Production, bbls
1984	NA	NA	NA
1985	1,071,000	33.0	NA
1986	853,000	34.2	8,809,000
1987	710,000	29.4	7,178,000
1988	566,000	27.7	7,085,000
1989	496,000	25.5	5,622,000
1990	417,000	25.4	2,378,000

Source: DEC 1986, 1987, 1988b, 1989, 1990

SPECIFIC ASPECTS OF BRINE GENERATION IN NEW YORK STATE

In assessing the brine treatment/disposal needs for New York State, it was necessary to examine the available information regarding not only the quantity of brine generated, but also its quality.

Although 2.4 million barrels of brine were generated in 1990, the majority of brines was generated from oil wells in older fields where waterflooding operations were conducted. Waterflooding is a technique, developed in the early 1900's, where water is forced into an oil-producing formation to force out oil (DEC, 1988a). The formations that generate brine from waterflooding operations are: Bradford, Chipmunk, Clarksville, Fulmer Valley, Glade, Penny, Penny and Fulmer Valley, Richburg, Scio, and Waugh and Porter.

Brines from waterflooded fields are extremely dilute compared to brines generated from formations where waterflooding is not practiced. These highly diluted brines may be discharged directly into receiving surface waters under the State Pollution Discharge Elimination System (SPDES) program, or recycled as part of the waterflooding operation. Thus, there is little need for a treatment/disposal alternative for these brines. Only those brines that are highly concentrated require special considerations for treatment/disposal.

Highly saline brine is generated from eight oil/gas producing formations: Bass Island, Black River, Helderberg, Medina, Onondaga, Oriskany, Queenston, and Salina. Of these eight formations, the Bass Island and Medina formations generate the majority of highly concentrated brines. From latest DEC compilation, 1987, the total quantity of highly saline brine generated in New York State is estimated to be about 600,000 bbl., 180,000 bbl from primary oil recovery (non-waterflooded wells) and 420,000 bbl from gas wells.

Oil from the Bass Island trend is from deep formations. The average depth of the wells in this trend is 3,000 ft (900 m). The Bass Island trend fields, Clymer, Harmony, North Harmony, Ellery and Gerry-Charlotte are located in Chautauqua County, and the Dayton field is located in Cattaraugus County. These fields start around the Town of Clymer in the southwest corner of Chautauqua County and proceed in a northeastern direction toward the Town of Sinclairville bisecting, Chautauqua Lake.

Brine from the Bass Island wells is highly saline and contains a number of undesirable impurities. They cannot be discharged to surface water bodies without treatment. Using the field names and the DEC Production Data, Bass Island brine production trends were obtained and are summarized in Table 2.2.

Table 2.2
BASS ISLAND TREND BRINE PRODUCTION IN CHAUTAUQUA AND CATTARAUGUS COUNTIES

Year	Brine generated by county, bbls			Total gallons
	Chautauqua	Cattaraugus	Total	
1984	NA	NA	NA	NA
1985	NA	NA	NA	NA
1986	30,411	129	30,540	1,282,680
1987	152,878	99	152,999	6,425,034
1988	44,517	7	44,524	1,870,008
1989	47,075	4	47,079	1,977,318
1990	33,335	0	33,335	1,400,070

Source: DEC 1986, 1987, 1988b, 1989, 1990

Brine generation from the Bass Island formations peaked in 1987 at 152,999 barrels and has steadily declined, to 33,335 barrels in 1990. This trend corresponds directly to the decreasing oil production previously described.

The majority of wells drilled in New York during the last few years have been in the Lower Silurian Medina Group. These wells have a projected life of 30 years. The Medina Group dips from a shallow depth in northern Erie County to deep depths in southern Chautauqua County.

Like brine from the Bass Island trend, brines from the Medina formation are an environmental concern and cannot be discharged to a surface receiving water without treatment. From the annual ***New York State Oil and Gas Drilling and Production*** reports, brine production trends were determined for the Medina formation in Chautauqua and Cattaraugus Counties and summarized in Table 2.3.

Table 2.3
MEDINA TREND BRINE PRODUCTION IN CHAUTAUQUA AND CATTARAUGUS COUNTIES

	Brine generated by county, bbls			
Year	Chautauqua	Cattaraugus	Total	Total gallons
1984	NA	NA	NA	NA
1985	NA	NA	NA	NA
1986	43,412	573	43,985	1,847,370
1987	136,177	1,805	137,982	5,795,240
1988	94,306	493	94,799	3,981,558
1989	85,767	904	86,671	3,640,182
1990	125,114	2,193	127,307	5,346,894

Source: DEC 1986, 1987, 1988b, 1989, 1990

Brine production in these counties has fluctuated over the last five years from a low of 43,985 barrels in 1986 to a high of 137,982 barrels in 1987. Brine production decreased in 1988 and 1989 but rebounded to 127,307 barrels in 1990.

As part of this study the geographic distribution of the generated brines was evaluated. To do this, oil, gas, and brine production values were collected from the DMN database on an individual well basis. Each well location, denoted by longitude and latitude, was also obtained.

Data from the DMN computerized database, were then entered into the Geographic Information System (GIS) housed in the Department of Geography at the State University of New York at Buffalo. Using the GIS, the location of all wells was mapped onto political boundary maps of New York State. Well locations in each county were also formulated.

Using these well location maps and production data from the DMN, contour maps were generated, showing the annual oil, gas and brine production rates. These contour maps give a general geographical distribution of oil, gas, and most importantly brine production.

A map showing the oil and gas fields in New York State is shown in Figure 2.1. The gas fields cover all of Chautauqua and the western end of Cattaraugus County. The gas fields also stretch to the northeast and are scattered throughout Erie, Genesee and Wyoming Counties. Two major oil fields are in Chautauqua County. One field runs from the southwest corner of the county and goes in a northeastern direction while the other field in the southwest corner of the county. Cattaraugus County has oil fields in the southeastern part of the county. In the southwest corner of the county is Allegheny State Park. There is little or no oil or gas drilling in the park in this area. In Allegheny County the oil fields are located in the southern part of the county.

The majority of the gas fields are in Chautauqua while the majority of the oil fields are in Cattaraugus and Allegheny Counties. Most of the brine from the oil fields in Cattaraugus and Allegheny Counties are from waterflooding operations.

The Bass Island trend oil and gas fields are shown in Figure 2.2. The fields are in Chautauqua County and correspond to the oil field that runs from the southwest corner in a northeasterly direction.

The Medina Gas fields, along with a list of field names, are shown in Figure 2.3. The largest field, called Lakeshore, covers all of Chautauqua County and the western end of Cattaraugus County. Numerous smaller fields are found in Erie, Genesee, Wyoming, and northern Livingston counties. The remaining fields are scattered throughout the counties of Monroe, Livingston, Ontario, Allegheny, and Cattaraugus counties.

Oil and gas well locations in Chautauqua and Cattaraugus Counties are shown in Figure 2.4. As seen, numerous oil and gas wells are located throughout Chautauqua County. All the oil and gas wells in Cattaraugus County are located in the western part, near the border with Chautauqua County. Based on the number of wells, it is apparent that brine production is concentrated in Chautauqua County. Oil productivity contours for Chautauqua County in 1989 are shown in Figure 2.5. The production contours correspond to the Bass Island Trend fields (seen from Figure 2.2).

Gas production contours for 1989 are shown in Figure 2.6 for Chautauqua County. Unlike oil, gas production is scattered throughout the county with the highest concentration of gas production in the southern half of the county. Predominant areas of gas production are southwest and east of Chautauqua Lake, and near Jamestown which is near the southern end of Chautauqua Lake.

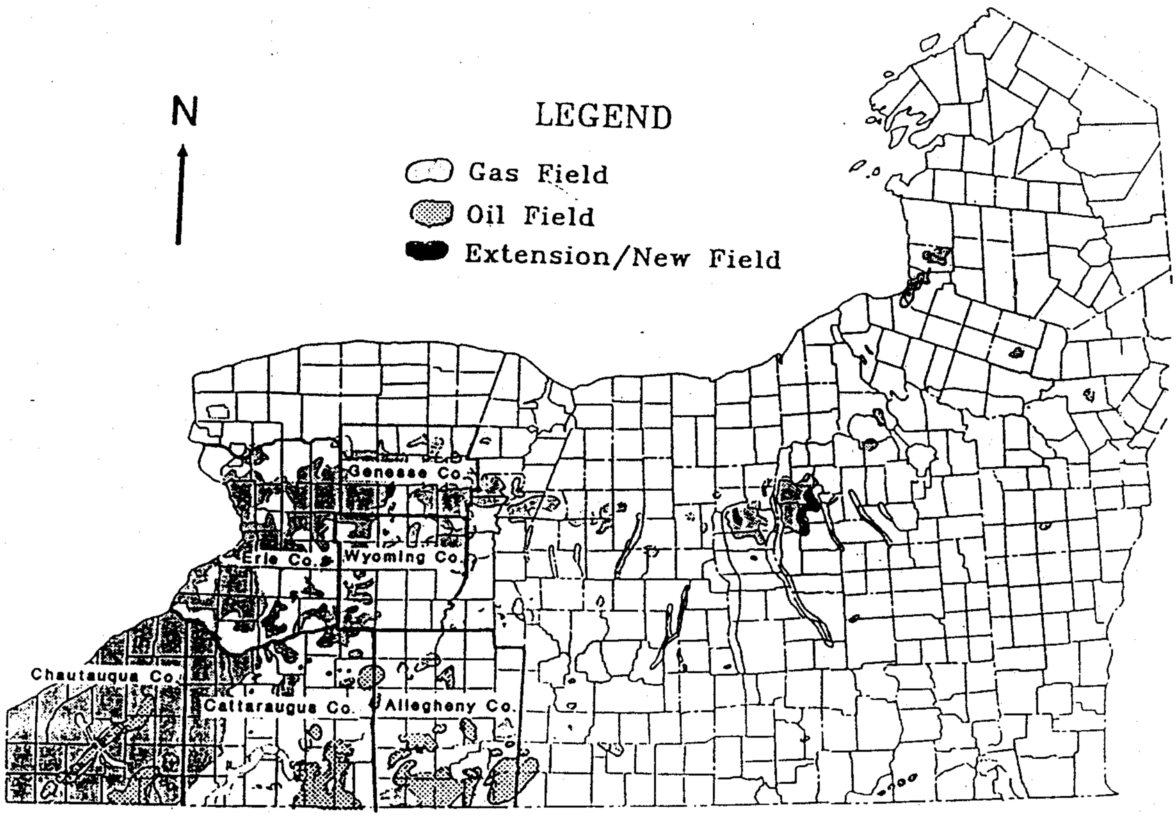


Figure 2-1. NEW YORK STATE OIL AND GAS FIELDS

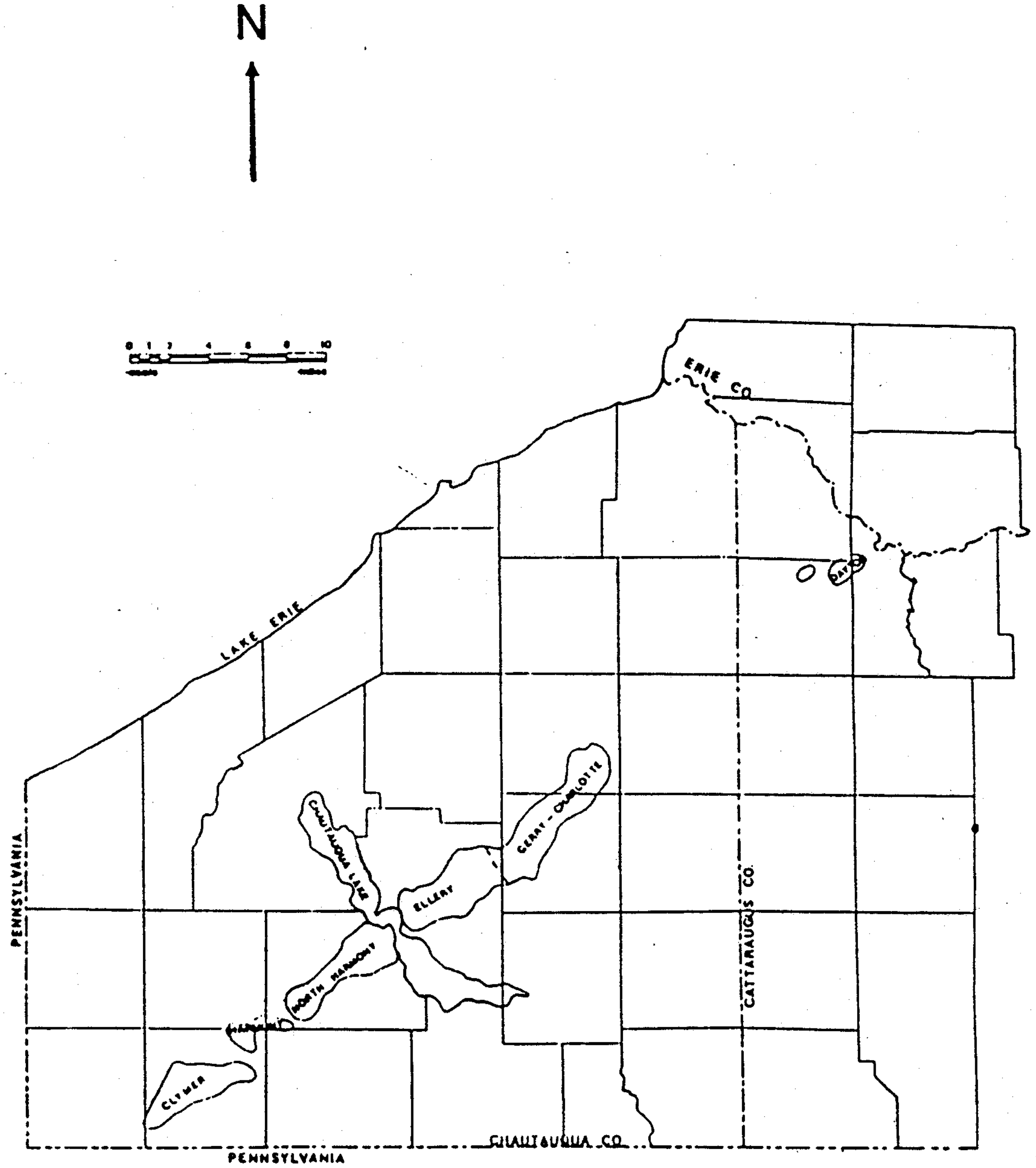
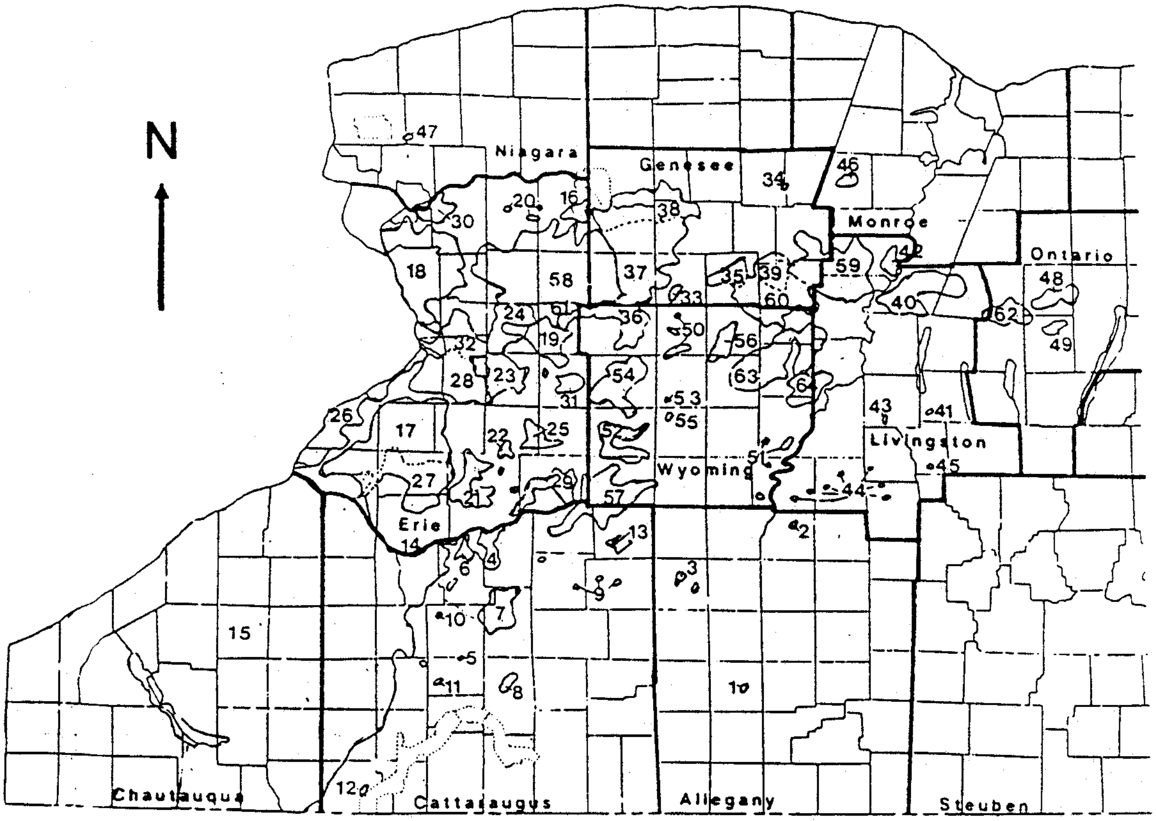


Figure 2-2. BASS ISLAND TREND OIL AND GAS FIELDS



MEDINA FIELDS IN NEW YORK STATE

ALLEGANY

1. Friendship
2. Rush Creek
3. Rushford

CATTARAUGUS

4. Ashford
5. Dublin Hollow
6. East Otto Pools
7. Ellicottville
8. Great Valley
9. Hog Hollow Pools
10. Jersey Hollow
11. Little Valley
12. Onoville
13. Pigeon Hill
14. Utley Brook

CHAUTAUQUA

15. Lakeshore

ERIE

16. Akron
17. Brant-Eden
18. Buffalo
19. Buffalo Creek
20. Clarence Pools
21. Concord
22. Concord Pools
23. East Aurora
24. Elma
25. Glenwood
26. Lakeview
27. North Collins
28. Orchard Park-Hamburg
29. Sardinia
30. Tonawanda
31. Wales
32. West Seneca

GENESSEE

33. Alexander
34. Bergen
35. Bethany
36. Danley Corners
37. Huron Creek
38. Indian Falls
39. Roanoke

LIVINGSTON

40. Avon
41. Conesus
42. Finnegan Hill
43. Groveland
44. Hunt Hollow Pools
45. Sparta

MONROE

46. Churchville

NIAGARA

47. Sanborn

ONTARIO

48. East Bloomfield
49. Vincent

WYOMING

50. Attica Pools
51. Castile Pools
52. Java
53. Orangeville
54. Sheldon
55. Wethersfield
56. Wyoming

CATTARAUGUS, ERIE, WYOMING

57. Chaffee-Arcade

ERIE, GENESSEE, WYOMING

58. Alden-Lancaster

GENESSEE, LIVINGSTON

59. Uhley Corners-Caledonia

GENESEE, LIVINGSTON, WYOMING

60. Pavilion

ERIE, WYOMING

61. Cowlesville

LIVINGSTON, ONTARIO

62. West Bloomfield

LIVINGSTON, WYOMING

63. Leicester
64. Silver Lake

Figure 2-3. MEDINA GAS FIELDS IN NEW YORK STATE

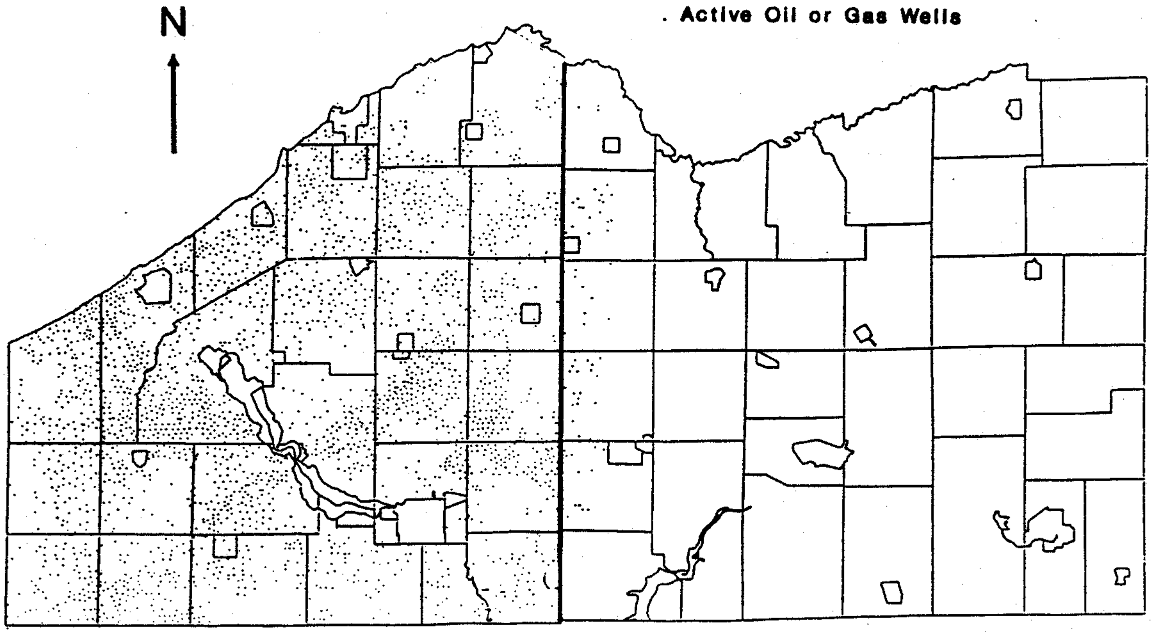


Figure 2-4. OIL AND GAS WELLS IN CHAUTAUQUA AND CATTARAUGUS COUNTIES

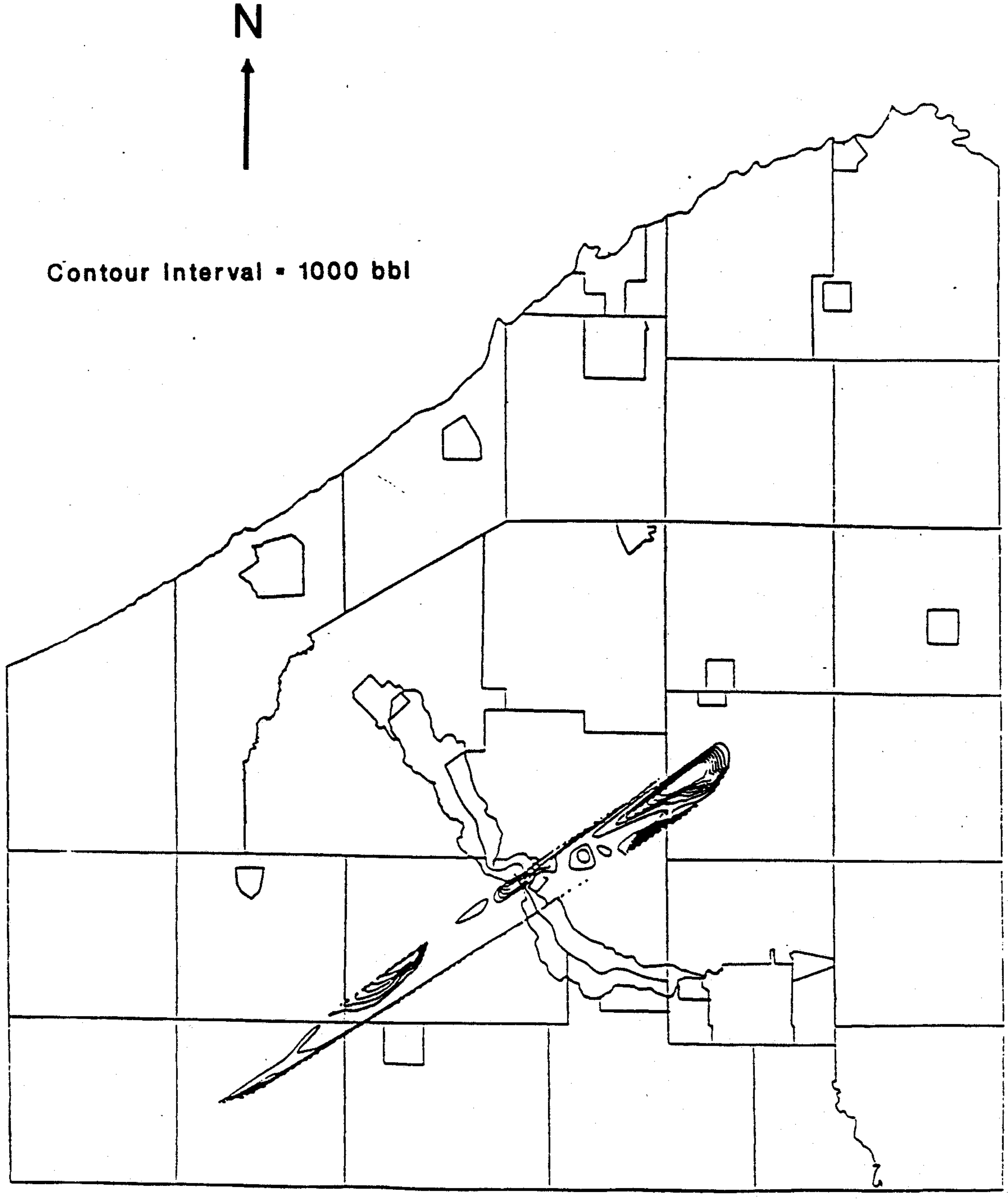


Figure 2-5. 1989 CHAUTAUQUA COUNTY OIL PRODUCTION CONTOURS

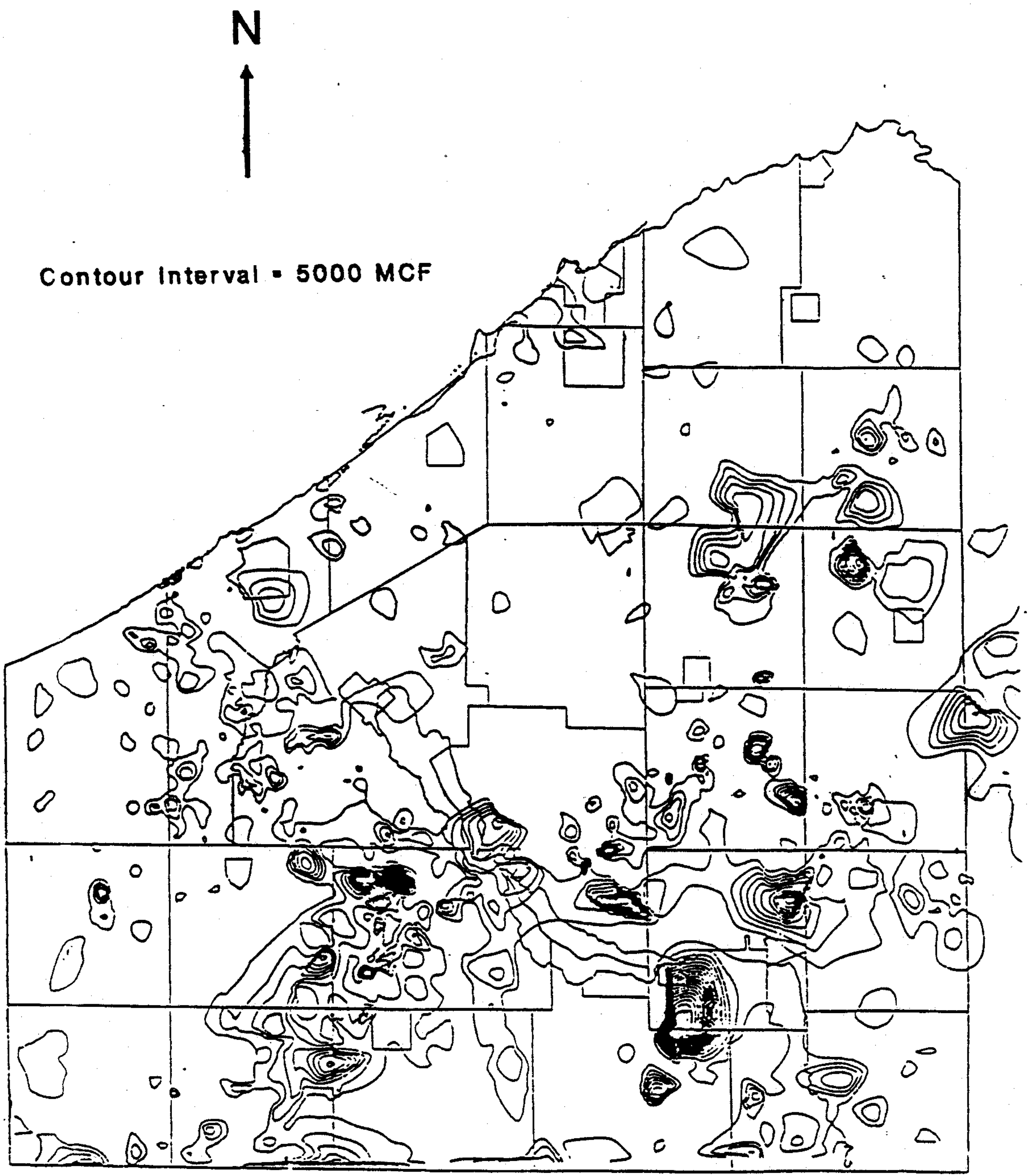


Figure 2-6. 1989 CHAUTAUQUA COUNTY GAS PRODUCTION CONTOURS

Brine production contours for 1989 are shown in Figure 2.7 for Chautauqua County. As expected, based on oil and gas production contours, the majority of the brine production is in the southern half of the county around Chautauqua Lake.

From Figures 2.1 it is evident that the major oil and gas production activity reserves are in the southwestern portion of New York State. From Figures 2.4 it is evident that the major oil and gas production activity is in Chautauqua County, and that the majority of the brine generated is centered around Chautauqua Lake (see Figure 2.7).

BRINE QUALITY CHARACTERIZATION

Brine quality data from DMN reports were reviewed and summarized (see Table 2.4). As can be seen, brines from the major oil and gas producing formations contain very high amounts of dissolved solids. Because the majority of brine generation comes from oil and gas production in the Medina group and because the characteristics of the brine from this formation are typical of the other formations, brine from the Medina formation was considered to be representative of brine that would be received at a treatment/reclamation facility. On this basis to confirm the reported characteristics, brine from the Medina formation was collected and analyzed. Brine was analyzed for dissolved solids, heavy metals, and other specific ions.

Brine was collected from Gypsum Energy in Darien Center, New York on March 1, 1991 and on July 11, 1991. The March 1 brine sample was collected from a steel 30,000 gallon brine storage tank owned by Gypsum Energy. The brine was a composite from various gas wells from the Medina formation throughout Genesee County. The brine sample of July 11 was collected from a single gas well in Genesee County. The brine was collected from a fiberglass 5,000 gallon storage tank at the well site.

A total solids analysis was performed on the brine. The analysis included (TS) total solids, (TDS) total dissolved solids and (TSS) total suspended solids. The volatile and fixed components of the solids were also investigated. In addition the characterization of the brine included pH, turbidity, density, and the chloride and specific ion concentrations. The specific ions determined were chloride, copper, sodium, calcium, magnesium, potassium, iron, manganese, nickel, lead, zinc and strontium. Analytical methods outlined in ***Standard Methods for the Examination of Water and Wastewater*** (APHA, 1989) were employed.

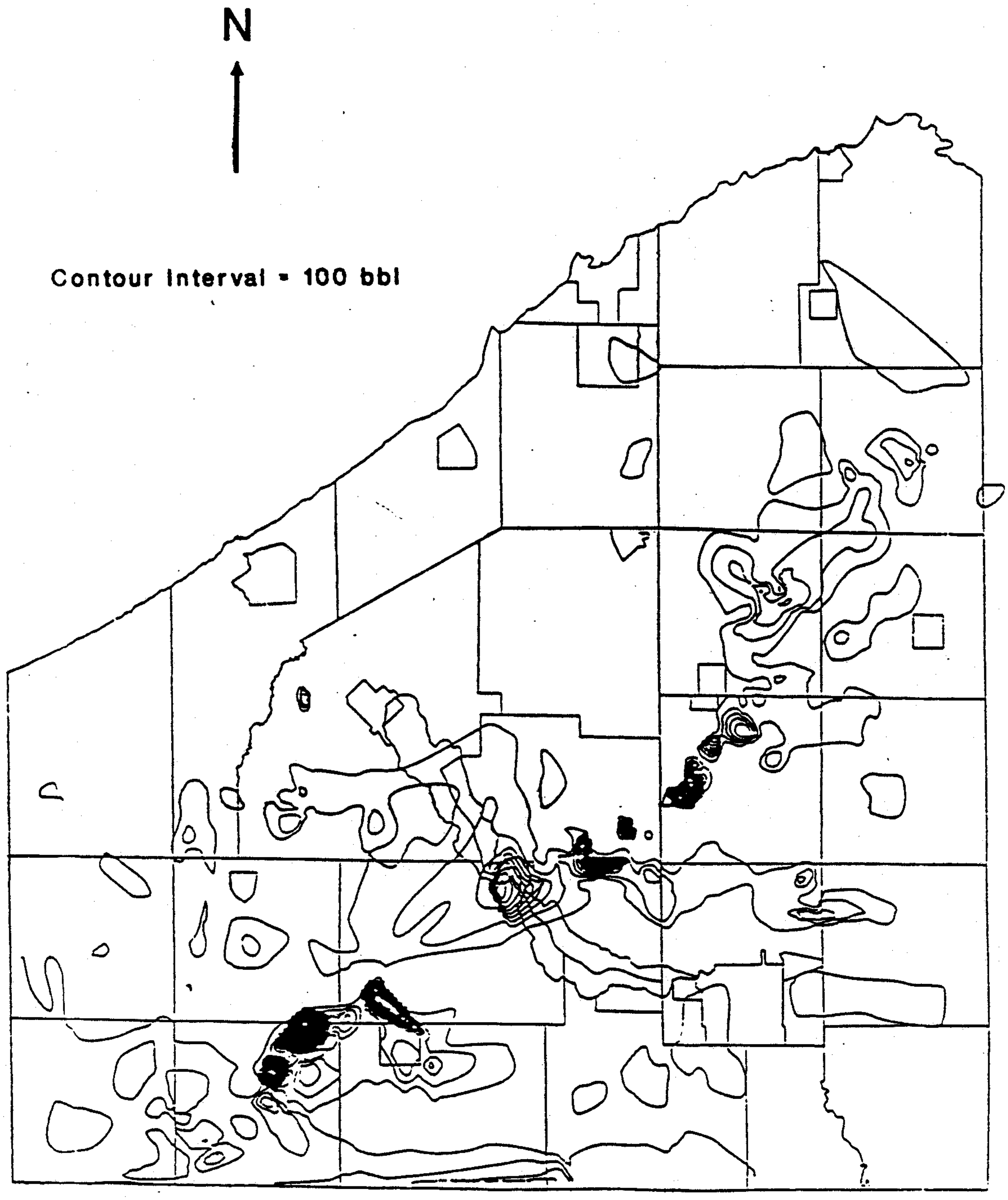


Figure 2-7. 1989 CHAUTAUQUA COUNTY BRINE PRODUCTION CONTOURS

Table 2.4
BRINE QUALITY DATA FROM NEW YORK'S GAS AND OIL PRODUCING ZONES[1]

Parameter (mg/L)	Potsdam/ Theresa	Queenston	Medina	Oriskany	Bass Island	Upper Devonian Oil Zones
Sodium (Na)	76,712	73,500	69,893	45,457	60,750	36,367
Calcium (Ca)	31,256	36,603	37,124	33,684	56,400	16,467
Magnesium (Mg)	4,499	2,887	2,766	5,168	3,160	2,733
Strontium (Sr)	--	0	--	--	--	107
Barium (Ba)	750	0	--	--	--	8
Potassium (K)	3,367	1,124	--	1,307	--	71
Iron (Fe)	17	195	676	215	18	189
Manganese (Mn)	0	--	84	--	0	7
Chloride (Cl)	183,701	187,418	181,298	145,442	203,000	92,167
Bromide (Br)	1,417	1,120	1,721	1,687	--	860
Sulfate (SO_4)	18	--	736	57	180	619
Bicarbonate (HCO_3)	89	--	25	203	50	0
Iodine (I)	9	11	18	10	--	200
Lithium (Li)	54	--	--	--	--	--
Trace Metals	--	--	--	--	--	0.74
Hydrocarbons	--	--	--	--	--	107.5
Measured TDS	300,763	298,358	292,121	231,836	323,500	156,267
Calculated TDS	299,187	302,869	292,727	232,743	323,558	149,582
IONIC RATIOS						
Na/Ca	2.4	2.01	1.89	1.42	1.08	2.24
Ca/Mg	9.75	12.76	15.90	6.93	34.17	6.04
Mg/K	1.07	2.64	--	4.00	--	47.03
Cl/Br	142.84	255.07	102.49	104.86	--	104.60
No. of Analyses	9	2	8	4	2	3

[1] As reported in DEC, 1988a.

High total dissolved solids concentrations interfere with atomic absorption analysis. For metals with high concentrations like sodium, calcium, magnesium, potassium, iron, manganese and strontium, the interferences are eliminated by dilution. However, for metals like zinc, lead, nickel and copper which have low concentrations, matrix interferences cannot be eliminated through dilution. Thus, the method of standard additions was used to determine the metal concentrations.

Results of the TS, VS, and FS solids analyses performed on the brine samples are summarized in Table 2.5. Composite sample results are the average of five analyses. The individual well sample solids concentrations are the average of two analyses. Dissolved solids concentrations (TDS, VDS, FDS) on the composite brine were the average of seven analyses, while those for the individual well brine results were averaged from two analyses.

Table 2.5
BRINE WATER SOLIDS ANALYSIS

Parameter	Medina Brine	
	Composite	Individual Well
TS measured (mg/L)	270,400	276,250
VS (mg/L)	36,400	16,000
FS (mg/L)	233,600	260,250
VS/TS Ratio (%)	13.1	5.7
TDS (mg/L)	245,800	292,500
VDS (mg/L)	18,400	10,000
FDS (mg/L)	229,000	282,500
VDS/TDS Ratio (%)	6.9	3.4
TSS (mg/L)	174	64
VSS (mg/L)	64	34
FSS (mg/L)	110	27.5
VSS/TSS Ratio (%)	37.2	55.2
TS calculated (mg/L)	245,960	292,580

Suspended solids analyses (TSS, VSS, FSS) for the composite and individual well brine were determined from nine and four analyses, respectively.

As can be seen the total solids (TS) measured for both samples were very high around 270,000 mg/L. The ratio of the volatile solids to the total solids (VS/TS) gives a rough approximation of the fraction of organic matter in the solids. The VS/TS ratios were 13.1 percent and 5.9 percent for the composite and individual well brine, respectively. While these ratios suggest that the organic portion is not the major portion of the total solids, this small percentage of the total solids could be significant, since the total solids are high.

The total dissolved solids (TDS) were found to contribute 91 percent of the total solids for the composite brine and 94 percent for the individual well brine. Again, the volatile fraction of the total dissolved solids was low with a TDS/VDS ratio of 6.9 percent and 3.4 percent, respectively.

The total suspended solids (TSS) for both samples was found to be less than 1 percent of the total solids. However, the volatile portion in the total suspended solids is considerably higher than in the other solids analysis. The VSS/TSS ratios were 37.2 percent and 55.2 percent for both the composite and individual samples, respectively. Thus, a major portion of the suspended matter in the brine is organic, probably due to the presence of oils and grease.

The total solids calculated from the sum of the measured total dissolved solids and total suspended solids did not correspond to the measured total solids. For the composite brine the measured total solids concentration was more than 24,000 mg/L higher than the calculated total solids. For the individual well brine the measured total solids concentration was more than 16,000 mg/L less than the calculated total solids. Because the brine solids are very hygroscopic, as the solids dry water molecules can be trapped within the solids structure. Thus, errors in both total and dissolved solids measurements can occur. Differences between measured and calculated total solids concentrations for both samples were less than 10 percent, which is within the accuracy of the tests.

In addition to solids analyses, the composite and individual well brine water samples were characterized for pH, density, turbidity and chloride concentration. These results are shown in Table 2.6.

Table 2.6
BRINE WATER CHARACTERIZATION

	Medina Brine	
Parameter	Composite	Individual Well
pH	2.7	3.7
Density (kg/L)	1.17	1.18
Turbidity (NTU)	190	62
Chloride (mg/L)	141,700	161,700

The pH of both samples was acidic, around 3. Thus, heavy metals are likely to be in the brine if they are present in the gas producing geologic zones. By raising the pH heavy metals present should precipitate.

The density measure was 17 to 18 percent heavier than that of pure water giving an indication that the water is highly mineralized. The turbidity of the composite brine was much higher than the turbidity of the individual well brine. A possible reason for this difference could be the different storage vessels employed. The composite well brine was stored in a steel storage tank. At pH < 3, the tank lining may be dissolving into the water, adding solids to the water. The individual well brine was stored in a fiberglass storage tank at the well site which does not experience the corrosive effects of a steel tank. In either case both samples of brine have considerable turbidity which must be removed prior to disposal or reclamation. As expected, the chloride concentration was found to be very high for both samples.

Specific constituent analyses were performed on both samples. Specific constituents measured were sodium, calcium, magnesium, strontium, potassium, iron, manganese, nickel, lead, zinc and copper. Results of these analyses are summarized in Table 2.7.

Table 2.7
BRINE WATER METALS ANALYSIS

Parameter (mg/L)	Medina Brine	
	Composite	Individual Well
Sodium	58,800	66,800
Calcium	21,000	23,200
Magnesium	3,000	3,360
Strontium	1,760	1,780
Potassium	1,080	1,040
Iron	130	129
Manganese	70	85
Nickel	3.6	3.1
Lead	2.5	2.2
Zinc	1.2	0.6
Copper	0.6	0.6

From the metal analysis it is evident that the majority of the solids are sodium and calcium with concentrations of 50,000 to 60,000 mg/L, and 21,000 to 23,000 mg/L, respectively. The magnesium, strontium and potassium contribute significant amounts to the solids but are an order of magnitude less than the sodium and calcium. Iron and manganese concentrations are high, around 130 and 80 mg/L, respectively, but their concentrations are one order of magnitude less than the magnesium, strontium and potassium concentrations, or two orders of magnitude less than the sodium and calcium concentrations. The nickel, lead, zinc and copper concentrations were low and constitute a very small fraction of the dissolved salts in the brine.

Due to the high concentration of chloride, sodium, and calcium the reclamation of sodium chloride and calcium chloride may be possible. The reclamation of magnesium chloride, strontium chloride and potassium chloride may also be possible. However, their volume would be small and would add considerable cost to a reclamation process.

Data from Tables 2.5, 2.6, and 2.7 are summarized in Table 2.8. Also listed in Table 2.8 are results reported by the DMN data base. Values for the pH value and the copper concentration were obtained from the DEC Oil and Gas Production Brine-Region 9 Results/Summary for 1983-85 Sampling.

Overall the characterization of the composite and individual well brine compares favorably to the characterization data reported by the New York State Department of Environmental Conversation (DEC). However, there were some exceptions. The pH for both the composite and individual well brine was lower than the reported DEC data. The pH's were 2.7 and 3.3 for the brine samples while the DEC range was 4 to 7.6. The reason for this is unclear. The strontium concentration for both samples was almost double the values reported by the DEC. However, other investigators have reported strontium concentrations that were similar to the concentrations measured for this study (Moody and Associates, 1989).

CURRENT DISPOSAL METHODS USED BY OIL/GAS PRODUCERS IN NEW YORK STATE

Currently acceptable brine disposal alternatives available to oil and gas operators, as stated by the DEC, are: road spreading, discharge to surface waters with or without treatment under a SPDES permit, and underground injection.

Oil and gas producers in New York State dispose of brine within New York State using one of the above alternatives, or transport the brine out of state to either Ohio or Pennsylvania for underground injection, road spreading, or for treatment at NPDES permitted facilities. To transport brine, transporters must obtain a waste transporters permit issued by the DEC Division Solid and Hazardous Waste (DSHW) under 6 NYCRR Part 364.

Under the current regulatory and economic situation facing oil and gas producers in New York State, the general order of preference for brine disposal is: surface water discharge with no prior treatment, applicable only to very dilute brines generated during waterflooding operations; road spreading with no treatment; surface water discharge with treatment; and underground injection. Preference is primarily based on cost.

Due to the varying nature of the chemical composition of brines, not all the disposal options are available for specific brines. Diluted brines from waterflooding operations can be surface discharged without treatment provided that a SPDES permit is obtained. Diluted brines, however, are undesirable for road spreading and are not used. Concentrated brines from deep formations cannot be surface discharged unless they are treated by a permitted

Table 2.8
BRINE ANALYSIS RESULTS

Parameter	Medina Brine		Typical values as reported to DEC
	Composite	Individual Well	
pH (pH units)	2.7	3.3	4 - 7.6
TS (mg/L)	270,400	276,250	NA
TDS (mg/L)	244,800	292,500	253,000 - 281,000
TSS (mg/L)	174	64	NA
Density (kg/L)	1.17	1.18	NA
Turbidity (NTU)	190	62	NA
Chloride (mg/L)	141,700	161,700	136,000 - 146,000
Sodium (mg/L)	58,800	66,800	57,200 - 62,400
Calcium (mg/L)	21,000	23,200	24,200 - 26,100
Magnesium (mg/L)	3,000	3,360	2,510 - 2,710
Strontium (mg/L)	1,760	1,780	530 -720
Potassium (mg/L)	1,080	1,040	730 - 1,070
Iron (mg/L)	130	129	113 - 232
Manganese	70	85	44 - 73
Nickel	3.6	3.1	0.02 - 2.6
Lead	2.5	2.2	0.01 - 3.4
Zinc	1.2	0.6	0.5 - 1.2
Copper	0.6	0.6	0.06 - 0.21

facility prior to discharge. These concentrated brines are well suited for road spreading purposes, however. Both diluted and concentrated brines can be underground injected.

Of the available disposal alternatives for the highly saline brines, road spreading is the least expensive. The primary cost in road spreading is transportation to the road-spreading site. Surface discharge through a SPDES permitted facility, either a municipal or industrial wastewater treatment plant, or a designed brine treatment facility, is the next most economical disposal alternative. Transportation and treatment/disposal charges are the major costs involved in this disposal alternative. Although the cost of brine disposal by underground injection does not differ significantly from that of surface discharge through a SPDES permitted facility, the least desirable of the alternatives is underground injection. Regulatory concerns, permitting requirements, and the lack of adequate injection wells in the vicinity of the oil/gas producing areas of New York State are the principal reasons (Cook, 1987).

Road Spreading

Sodium chloride (NaCl) and calcium chloride ($CaCl_2$) are widely used for highway maintenance. Sodium chloride is used more extensively for snow and ice control operations due to its lower costs; while calcium chloride, which is also good for ice control, is used primarily for dust control and as a road stabilization agent.

The chemical characteristics of the more concentrated brines compare favorably to chemical characteristics of commercial road salt, making brine attractive to local highway departments for road maintenance. Additional factors stimulating their use are the relatively low cost of brines (the materials cost to highway departments are free) and the producers' need for a means to properly dispose of these fluids (DEC, 1988a).

Approximately 30 percent of the highly saline brine generated in New York State is disposed by road spreading. The majority of brine used for road spreading is from deep gas well production. Brines from waterflooding oil fields are too dilute for roadspreading.

Under current state regulations, a 6 NYCRR Part 364 permit is required from the DEC to spread brines on paved or unpaved roads. Part 364 permit requirements include written approval from the owners of the road-spreading site, the local highway superintendent, and minimal monitoring requirements (no visible oil or grease in the brine).

The primary problem with road spreading is its seasonal nature. The imbalance between brine production and use on roads means that brines must either be stored between periods of use or alternative disposal means found (DEC, 1988a).

Environmental concerns stem from the fact that brine is a liquid. If improperly applied, potential runoff and spills may occur polluting underlying groundwater and damaging roadside vegetation. Oil and gas brines contain lower concentrations of calcium chloride than the commercial solutions used in dust control. As a result, additional applications of brine are needed for dust control, increasing the possibility of runoff and spill problems.

Brines are also less desirable than solid salt for road deicing. Refreezing of the liquid brine during snow and ice control may result in slippery and icy surfaces. Solid granules from commercial road salt are thought to be more effective in penetrating through the ice to break the ice bond with the pavement.

Discharge to Surface Waters

Brine may be discharged directly into a receiving water provided that a SPDES permit is obtained. Permit conditions for such discharges include limitations of total dissolved solids (TDS), oil and grease, and any other pollutants of water quality concern as determined by the DEC. At the present time, SPDES permits for direct surface water discharge are confined to brines from waterflooding operations, which comprise the large majority of brines generated in New York State (DEC, 1988a).

Another possible method of disposal for brines is processing at a SPDES permitted municipal or industrial wastewater treatment plant. Brines are blended with the normal wastewater, and co-treated together. The volume of brine treated per unit volume of normal wastewater treated is quite low, less than one gallon of brine per 1,000 gallons of wastewater, to provide a high level of dilution for the dissolved solids. The brine goes through the same treatment processes as the normal wastewater. Oil and grease are removed by flotation and biological treatment. Turbidity and heavy metals are removed by bioadsorption and flocculation/sedimentation in the secondary treatment processes.

One major concern for SPDES-permitted facilities that use biological treatment is the potential disturbance of the biological process. As a precaution, brine must be introduced very slowly to prevent a sudden change in the osmotic pressure. For this reason, use of existing municipal and industrial wastewater treatment plants as a disposal alternative is unreliable. Such facilities can only be relied on as a short-term alternative for a small volume of high-strength oil and gas brines.

Two wastewater treatment facilities specifically designed and operated to treat brines are located in northwestern Pennsylvania, within 100 to 150 miles of the major brine generating regions in New York State. These facilities treat only oil and gas production fluids and do not employ any biological processes. Both of these facilities are NPDES permitted with discharge limits on total suspended solids (TSS), pH, oil and grease, and total dissolved solids (TDS). There are additional monitoring requirements for heavy metals, although discharge limits have not been established. Based on conversations with NYS DEC officials, a SPDES permit from New York State would regulate the same parameters as the Pennsylvania NPDES permits, but may set lower discharge levels. DEC policy does not allow them to issue any specific permit levels until an application for a permit is submitted to their office and reviewed at their headquarters in Albany.

Underground Injection

Although underground injection has been widely used in other states to dispose of brine water, use of this technique has been discouraged in New York State. A SPDES permit from the DEC is required for an injection disposal well in New York State, along with a federal Underground Injection Control (UIC) permit.

The federal UIC permit requires certain monitoring requirements. Monitoring injection pressure, rate of injection, annular pressure and accumulative volumes injected is recorded on a daily basis (Cook, 1987). In addition, a groundwater monitoring program must be established to ensure that contaminants are not migrating toward potable aquifers.

There are five permitted injection wells in New York State. Two of the injection wells are located in Chautauqua County; other wells are in Steuben, Livingston, and Wyoming Counties.

The primary environmental consideration for approval of an injection permit application is protection of groundwater resources. If the injected brine were to escape from the well due to mechanical failure, significant environmental impact may occur before detection. Protection is achieved through stringent controls on the casing and cementing of the injection well.

Although it is common to consider the brines "disposed of", they are actually stored in an underground formation. Due to geological changes or mechanical failures, these reserves could cause future environmental problems. Failures within the disposal system are extremely difficult to detect and correct (Cook, 1987).

The porosity and permeability of the receiving zone is a significant factor for a disposal well. If too high a pressure is necessary to move water into the formation, or if the formation will not accept water quickly enough, the well is undesirable for injection purposes. Most formations in New York State are relatively "tight" and do not readily accept injected fluids (DEC, 1988b). This is a primary reason why there are so few underground injection wells in New York.

Wells require an injection pump as part of the surface equipment. Depending on the depth of the well and the injection pressures, the power requirements may be very substantial.

Not only is deep well injection expensive, the well can quickly be damaged without adequate and proper treatment of the injection fluid.

Operation of a disposal well usually follows three steps. The first step is to off-load the brine from a truck into a holding tank. This allows time for any oil to separate and move to the top of the tanks, and any settleable solids to drop to the bottom. The second step of the treatment is filtration. A washable 25-micron filter followed by a 5-micron filter helps protect the injection zone from suspended solids buildup. The last step is chemical treatment. The use of a biocide protects against bacterial activity in the well. Bacterial slime can plug the receiving formation, thus shutting down the well. A corrosion inhibitor is also used to prevent tubing deterioration (Cook, 1987).

Due to these various difficulties - tight formations, operating costs, and concern for groundwater resources - underground injection is not currently a favorable option for the disposal of brine. Although the permitted capacity of the five injection-well sites in New York State is greater than 1,200,000 bbls/yr., less than 120,000 bbls/yr. are injected for disposal. A listing of the injection wells permitted for oil/gas brine disposal is given in Table 2.9 along with their 1989 injection volumes. Data received from the DEC for 1990 injected volumes are similar to those for 1989; 110,000 bbls.

Table 2.9
PERMITTED BRINE DISPOSAL WELLS IN NEW YORK

Well	Permitted rate, bbl/year	1989 volume injected, bbl
Ewell #1 121-13965 Covington, Wyoming Co.	50,000	2,567
H-229 101-00033 Greenwood, Steuben Co.	219,000	39,800
Marapeg #3 013-16813, Chautauqua, Chautauqua Co.	146,000	57,656
Ranous #1 051-16133, Caledonia, Livingston Co.	146,000	1,957
Tecroney #1 013-18798, Clymer, Chautauqua Co.	730,000	0

Source: DEC, 1989b

NEED FOR BRINE DISPOSAL ALTERNATIVES IN NEW YORK STATE

Average wellhead prices paid for natural gas in 1990 was $2.23 per thousand cubic feet (MCF) and $23.00 per barrel of oil. A natural gas price between $3.00 to $3.50 per thousand cubic feet (MCF) is needed for most gas producers to drill and develop new gas reserves in New York State economically (DEC, 1988a).

The current production of natural gas in New York State represents approximately 5 percent of the state's natural gas energy needs (DEC, 1988b). If wellhead prices increase and an economical disposal option found, it is expected that production of oil and gas in New York State would increase. The Medina formation alone has estimated gas reserves of more than 2 trillion cubic feet (Van Tyne and Copley, 1984). Thus, there are still significant gas reserves in New York State and gas production from the Medina formation will be the predominant gas production and development area for the foreseeable future (DEC, 1988b). However, due to current pricing drilling new gas wells has been declining rapidly, decreasing overall production.

Due to the disparity in market price and production costs, which include the brine disposal costs, many of the marginal producing wells in New York State also are being shut down. To help maintain current production levels and the economic benefits of the oil and gas industry in New York State, it is evident that an economical disposal alternative is highly desirable for the State's oil and gas producers.

The costs to the oil and gas producers to dispose of brine water can be broken down into two categories: disposal and transportation. Disposal costs do not vary considerably among the various methods. The primary factor affecting the overall disposal costs for brine is transportation. At current transportation rates of about $60.00 per hour, hauling costs are a predominant factor when selecting a disposal alternative. Transportation of brine to a brine treatment facility such the Warren Brine Treatment Plant in Warren, Pennsylvania (see Section 3) can make up more than 50 percent of the total disposal cost.

According the GEIS report prepared by the DEC in 1988, because of the very high transportation costs to out-of-state disposal facilities, an important factor in encouraging continued oil and gas development in New York State would be the availability of a brine disposal facility proximate to the oil/gas production areas. If a centrally located brine treatment facility was constructed in New York State, the transportation distances would be reduced, and this disposal facility would be the economical choice for New York's oil and gas producers.

In the following sections, the feasibility of developing a brine treatment, reclamation, and/or disposal facility in New York State is explored.

3. BRINE TREATMENT/DISPOSAL FACILITY DEVELOPMENT

In this chapter, environmental concerns associated with oil/gas brines and the development of a brine treatment facility are discussed. In addition, descriptions of existing brine treatment facilities that discharge to surface waters available to New York oil and gas producers are presented.

ENVIRONMENTAL CONCERNS

It is difficult to predict the extent of the environmental impacts that may result from an accidental spill, leak, or improper disposal of brine water from oil/gas production. The environmental impacts will depend on the composition of the brine, volume of the spill or leakage, the flow and quality of the receiving water or the natural attenuating capabilities of the soil, the proximity of sensitive resources, and the success of cleanup operations (DEC, 1988a). Based on chemical analyses of the brines generated in New York State (see Section 2), chlorides, heavy metals, and total dissolved solids (TDS) have been identified as the primary contaminants of concern. Other contaminants found in brines that are of concern are oil and grease, and turbidity. Each of these contaminants is discussed below.

Any brine treatment facility that is developed must address these concerns, either by removing the contaminants from the waste stream (i.e. treatment) or ensuring that minimal impact occurs when released to the environment.

Chlorides

Chloride levels of 200,000 mg/L and higher are not uncommon for brine waters generated by oil and gas production. Fortunately, chloride is a relatively non-toxic chemical. Therefore, the impact of chloride from a single accidental leak or spill of brine water poses little long term threat to ground or surface drinking water quality, assuming ample dilution of the brine with fresh water. However, chloride levels in both ground and surface waters will increase in areas subjected to frequent and prolonged additions of chloride, whether from road salting or chronic contamination by chloride-bearing wastewaters. If chloride concentration increases in an aquifer, little can be done to remediate the situation. There currently are no economically feasible methods to remedy the situation in any reasonable period of time (DEC, 1988a). Dilution of the chloride as the result of groundwater recharge with high quality (low chloride) water, naturally or artificially, is the only means of remediation.

Acute effects of chloride on plants and fish may occur due to a sudden change in osmotic pressure. Excessive concentrations of sodium chloride osmotically inhibit the ability of plants to absorb water (Miller, 1978). Spillage of brine or other waste fluids high in sodium chloride almost always kills vegetation and sterilizes the soil until the salts are flushed from the soil. In the Northeast, however, soil salt toxicity is short lived due to the high rainfall and rapid leaching of the sodium and chloride salts.

Roughly one-third of the freshwater consumed in New York State comes from groundwater supplies. In upstate New York more than 2 million people receive drinking water from small private water wells (DEC, 1985). Many of the groundwater supplies in the western portion of New York State are located in the same vicinity as oil and gas operations (DEC, 1988a). As a result, the prime concern of the DEC is the protection of groundwater drinking supplies from contamination with brine.

New York State's public drinking water standard for chloride is 250 mg/L, which is the taste threshold of sodium chloride in water. Considering the chloride concentration of the brine it is evident that substantial dilution of the brine is necessary to reduce the chloride concentration to the State's drinking water standard.

Heavy Metals

Brine has measurable concentrations of several soluble metals including strontium (Sr), lead (Pb), manganese (Mn), copper (Cu), zinc (Zn), iron (Fe), nickel (Ni), cadmium (Cd), and chromium (Cr). Most of these substances are known to pose an environmental threat to humans, animals, and plants if they are present in elevated concentrations in drinking water, surface water, ground water, and/or the soil. Recommended levels for the above constituents in soil and drinking water are listed in Table 3-1.

The environmental impact of heavy metals from brine spilled onto soil depends on a number of factors including soil pH, alkalinity, cation exchange capacity, organic content, degree of water saturation and other chemicals present. In general, heavy metal mobility and the threat of groundwater contamination increases as the soil pH decreases. In the Northeast, acid rains increase the possibility of heavy metal mobility. In addition, low pH soils increase the likelihood of metals uptake by plants. Plant uptake is a concern because it is the metal's primary route into the animal and human food chains. Cadmium is the most likely metal to pose a threat to human health through plant accumulation. It is particularly dangerous because of its severe effect on the kidneys (DEC, 1988a). Copper, nickel, and zinc are other

Table 3-1
RECOMMENDED LEVELS FOR HEAVY METALS IN SOIL AND DRINKING WATER

Constituent	Drinking water standard[a], mg/L	Tolerable soil concentration[b], mg/kg
Cadmium	0.010[c]	3
Chromium	0.05[c]	100
Copper	1[d]	100
Iron	0.3[d]	N/A[e]
Manganese	0.05[d]	1,000
Nickel	N/A	50
Lead	0.05[c]	100
Strontium	N/A	N/A
Zinc	5[d]	300

[a] U.S. EPA Drinking Water Standards (40 CFR)
[b] World Health Organization (Alloway, 1990)
[c] Primary standard (health concerns)
[d] Secondary standard (aesthetic concerns)
[e] Not applicable

metals that could pose the serious threats to plant life. Plants require several of these metals in traces amounts for their own growth. However, excessive amounts of metals, particularly zinc or copper, can reduce plant yields or even cause their death.

Total Dissolved Solids

The high total dissolved solids (TDS) concentration of brine water, >250,000 mg/L, could affect aquatic life significantly if released randomly into a receiving stream. The combined effect of the TDS levels from the dissolved sodium, calcium, magnesium and chloride, and sulfate could result in fish-kills, deformation of fish larvae and other problems (DEC, 1988a). For this reason, the DEC sets stricter regulations on well siting around surface waters and known aquifers to prevent spills.

Oil and Grease

Oil and grease are not definitive chemicals, but rather general designations for thousands of organic compounds with varying physical, chemical, and toxicological properties. They may be volatile or non-volatile, soluble or insoluble, persistent or easily degraded. However, oil and grease found in brines may be generally described as being primarily made up of long-chain hydrocarbons, which are fairly insoluble and non-volatile.

Aesthetic degradation is the primary concern associated with oils and grease. When released to a surface water, oils and grease float on the surface, giving the water a "sheen". In addition, because they are insoluble, oils and greases readily attach to surfaces and will accumulate along the shoreline. The EPA has established a criterion that surface waters should be virtually free of oils and grease, especially from petroleum products that impart taste.

Turbidity

Turbidity interferes with recreational use and aesthetic enjoyment of water. The less turbid the water the more desirable it becomes for swimming and other water-related sports such as fishing.

With regard to environmental and health effects, increased turbidity can adversely affect fish and fish food populations. Turbidity reduces light penetration into the water body, reducing the depth of the photic zone (depth of photosynthetic activity in the water column). This reduces primary production and decreases fish food. Additionally, the near surface waters are heated more because of the greater heat absorbency of the particulate matter associated with the turbidity, which tends to stabilize the water column and prevent vertical mixing. Such mixing reductions decrease the dispersion of dissolved oxygen and nutrients to lower portions of the water body. The EPA has recommended that the depth of light penetration not be reduced by more than 10 percent as result of a wastewater discharge.

EXISTING BRINE TREATMENT FACILITIES WITH SURFACE WATER DISCHARGES

Two brine water treatment facilities currently operate in Pennsylvania, Cabot Oil and Gas Corp. Franklin Brine Treatment Plant in Franklin; and Environmental Development Corp. Warren Brine Treatment Facility in Warren. Both facilities treat brine generated by oil and gas producers from western Pennsylvania and southwestern New York State. The Franklin Brine Treatment Plant is about 89 miles southwest of Jamestown and the Warren Brine Treatment Facility is 22 miles south of Jamestown.

These facilities use a series of chemical and physical unit processes to treat the brine and discharge and discharge their effluent into the Allegheny River. The process is designed to remove oil and grease, turbidity, and heavy metals, and to adjust the pH of the effluent to an acceptable level before discharge. The Franklin Brine Treatment Plant design capacity is

205,000 gallons per day, while the Warren Brine Treatment Facility operates at 150,000 gallons per day. Both facilities currently (1991) charge $0.0325 per gallon ($1.37/bbl) to treat the brine water.

The Hart Chemical Company operates another brine processing plant in Creekside, PA., about 40 miles east of Pittsburgh. Their processing plant is a resource recovery facility designed to produce several marketable products using gas-well brine as a raw material. Products produced by the plant are sodium chloride crystals and calcium chloride/magnesium chloride solution. Ninety percent of the brine processed, comes from oil and gas producers who operate wells within a fifty-mile radius of the processing plant.

Hart Chemical's brine processing involves separating the various components of the brine prior to evaporation. The first separation removes crude oil by using a conventional oil/water separator. The second separation removes ferric chloride and barium by increasing the pH of the brine which precipitates the iron as ferric hydroxide and the barium as barium sulfate. Sodium hydroxide ($NaOH$) or calcium hydroxide ($Ca(OH)_2$) is used to increase the pH of the brine. The remaining aqueous solution of sodium chloride, calcium chloride, and a small amount of magnesium chloride is then evaporated to crystallize the sodium chloride from solution.

The crystallizer operated by the Hart Chemical Company is capable of processing 40,000 gallons of brine per day to produce 22 tons of sodium chloride crystals and 3,400 gallons of 40 percent calcium chloride/magnesium chloride solution. The products are sold to various chemical companies. The current cost to oil and gas producers to process their brine water is $0.08 per gallon of brine ($3.36/bbl), which is more than twice the fee charged for treatment and surface water discharge at the Franklin and Warren facilities.

BASIC FLOWSHEET OF TREATMENT FACILITY

The two Pennsylvania brine treatment/disposal facilities with surface discharge use similar process flowsheets for treatment. The proposed facility in New York State will use the same treatment system (see Figure 3-1). This treatment plant could be used to treat brine either for discharge into a receiving water or as a preprocessing step to reclaim marketable salt products.

Brine is typically transported in 2,000 or 5,000 gallon tanker trucks and unloaded into a storage tank prior to processing. Flotation is the first treatment step and is used to separate

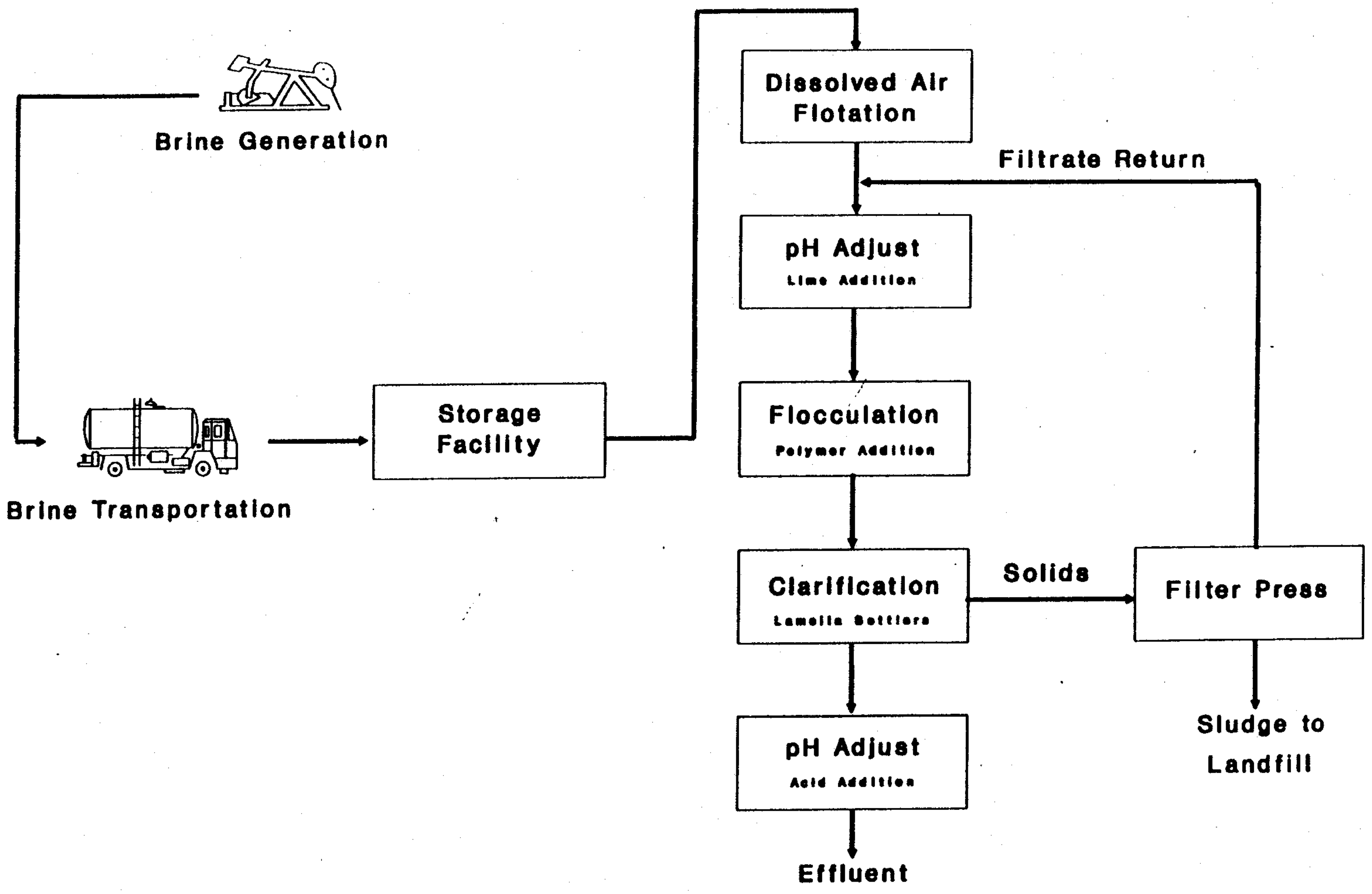


Figure 3-1. FLOWSHEET FOR PROPOSED BRINE TREATMENT FACILITY

any oil or grease before treatment. The remainder of the treatment process consists of a chemical feed system which adds lime to rapid-mix tank at the beginning of the coagulation process. An anionic polymer is added during the subsequent flocculation process to help agglomerate small coagulation solids and micro-flocs into larger, more settleable solids (Singlex, 1981). Following the flocculation process the solids are settled in a clarifier employing lamella tube settlers. The effluent from the clarification process is monitored for pH and adjusted with acid as needed before discharging into a receiving water. Solids separated during the clarification process are dewatered using a filter press with the dewatered solids going to a DEC-approved landfill and the filtrate returning to the head of the plant.

Gas production throughout a year fluctuates due to seasonal variation. During the winter months more gas is produced and as a result, more brine than during the summer months. Brine treatment facility operators estimate that 80 percent of the brine received for treatment is produced during the winter. Assuming a five-month winter period, and using the latest brine production from the Medina and Bass Island formations, (see Tables 2.2 and 2.3), a 60,000 gallon per day facility would meet the current needs. Because it is unlikely that a brine treatment facility would operate a 24-hour per day continuous basis and because of the diminishing returns of such a small facility, a treatment plant with a higher capacity, 75,000 gallons per day, was selected for study. A facility of this size would also allow for increases in gas production, if and when gas prices increase. A storage facility to hold twice the plant's daily treatment capacity (150,000 gallons) was also included in the design.

BENCH-SCALE STUDIES

Bench-scale studies were conducted for the design of the proposed treatment facility. Parameters studied included lime dosage for optimum turbidity/metals removal; polymer dosage for optimum suspended solids removal; acid dosage of final pH adjustment; estimated sludge production; and settling velocity.

Jar tests were conducted to optimize the lime and polymer dosage. The apparatus employed in the jar tests was a Phipps and Bird six paddle stirrer, Model No. 300. Lime, in the form of calcium hydroxide $Ca(OH)_2$, (Fisher Scientific Company), and the Westo-Floc 2411P, an anionic polymer, was supplied by Western Water Management, Inc. of North Kansas City, Missouri.

Optimum lime dosage was determined using turbidity, final pH, and total suspended solids measurements of the supernatant from a series of jar tests. Metals analyses were then performed on the supernatant using the optimum lime dosage to determine the metals removal potential.

When the optimum lime dosage was determined, additional jar tests were run to determine the optimum polymer dosage. In these tests, pH was adjusted to the optimum value with lime, then polymer in varying dosages was added. Optimum polymer dosages were defined based on turbidity and total suspended solids measurement of the supernatant. Metal analyses were also performed to determine if additional metal removal was achieved with polymer addition.

Using supernatant from the lime study, the acid dosage required to lower the pH of the supernatant to comply with SPDES discharge permit conditions was determined. The desired pH range for the effluent was between six to nine. Technical grade concentrated sulfuric acid (H_2SO_4) was diluted to a 1:100 solution, and titrated to the desired pH.

A mass balance was used to estimate the amount of sludge that the treatment process will produce.

Lime Study

During a jar test experiment, up to six one-liter beakers were filled with 800 ml of brine and placed under the jar test apparatus. Rapid mixing was initiated by setting the stirring apparatus at 100 RPM. Lime was added into the beakers and rapid mixed for two minutes. Initially, a three percent lime slurry was made, and the desired volume was added to the beaker. However, becuase the lime dosages required were large, uniform suspension of the lime slurry was difficult. Therefore, for all subsequent jar tests, lime was added in a powder form. After the lime addition, the solution was flocculated for 30 minutes at 30 RPM. The stirring apparatus was then turned off and the solutions were allowed to settle for one hour. After the settling period, 200 mL of supernatant were withdrawn with a pipet. The supernatant was then measured for pH, turbidity and TSS (total suspended solids). The remaining supernatant was preserved with concentrated nitric acid at a pH less than two for later metals analyses.

The analytical procedures used for pH, turbidity, TSS and metal analysis were the same as those used in the characterization of the brine.

Effluent characteristics from the lime study jar tests are presented in Table 3.2. The parameters listed in Table 3.2 are average values. The number of analyses at each lime dosage is also listed.

Table 3.2
JAR TEST RESULTS

Lime dosage, mg/L	No. of trials	Final pH	Turbidity, NTU	TSS	VSS	VSS/TSS, %
0	2	3.1	213	88	33	37.1
100	1	8.0	22	43	22	50.1
200	1	8.3	52	117	40	34.3
500	2	8.1	58	114	48	41.7
1,000	3	8.3	51	93	32	34.7
2,000	1	8.8	28	80	33	41.6
2,500	1	8.7	65	145	45	31.0
5,000	3	8.9	26	107	40	37.5
7,500	4	9.2	20	121	33	27.2
10,000	7	9.5	12	82	31	38.2
12,500	2	10.7	5.9	58	28	49.4
15,000	3	11.2	9.7	130	55	42.3
17,500	2	11.1	15	178	77	43.0
20,000	2	11.4	11.8	38	12	31.9
25,000	1	11.3	12.5	NA	NA	NA
50,000	1	11.3	11	55	22	39.5

In Figure 3.2, solution pH as a function of lime added is plotted. As can be seen, the brine is heavily buffered in the pH range from 8 to 11. Copious amounts of lime must be added to raise the pH above nine, the pH range where heavy metal precipitation is greatest.

The initial average turbidity during the lime jar tests was 213 NTU. At a lime dosage of 12,500 mg/L, the supernatant turbidity was reduced to 5.9 NTU. Higher lime dosages produced slightly higher turbidities around 12 NTU. In general, the turbidity steadily decreased from 213 NTU to 5.9 NTU, except for a lime dosage of 2,500 mg/L. The turbidity of 65 NTU when 2,500 mg/L of lime was added was measured one day after sampling and re-suspension was observed. Thus, this turbidity reading is erroneous due to experimental error and should be eliminated.

From Figure 3.3, a plot of pH versus final turbidity, it is evident that a pH range between 9.5 and 11.5 results in the lowest turbidity readings and is the optimum pH range. The corresponding lime dosage for this pH range is from 10,000 to 15,000 mg/L.

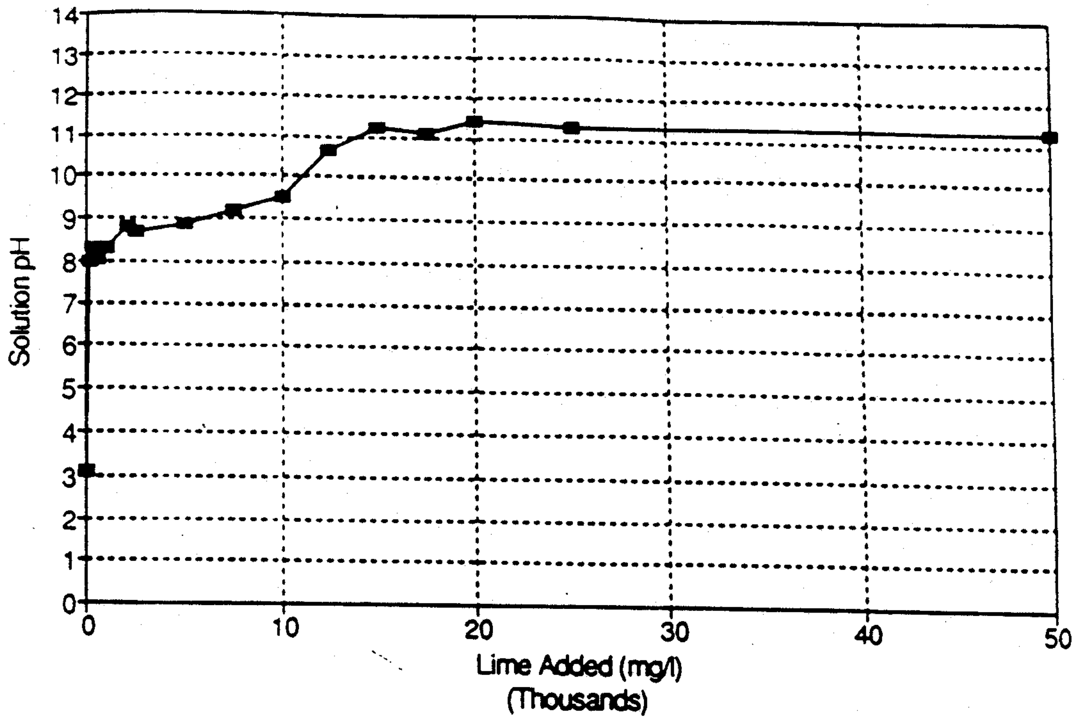


Figure 3.2. SOLUTION pH VERSUS LIME ADDED

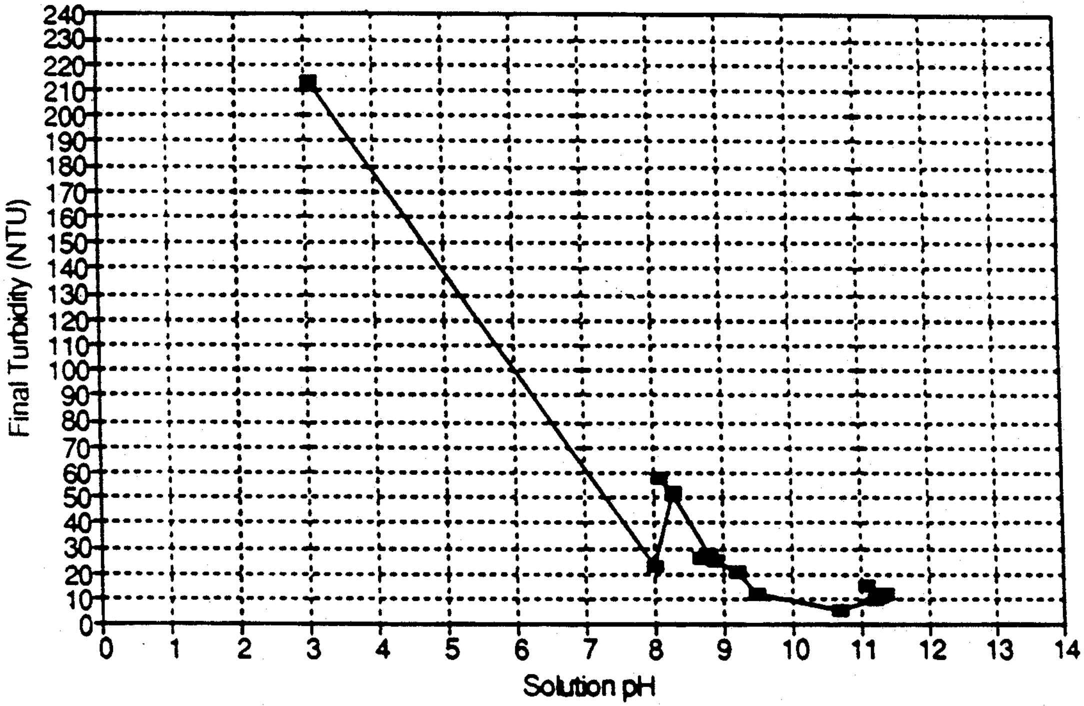


Figure 3.3. SOLUTION pH VERSUS FINAL TURBIDITY

Total suspended (TSS) and volatile suspended solids (VSS) concentration varied with increasing lime dosage. No apparent trend was evident. The TSS averaged 87.5 mg/L initially and increased to 114 mg/L at a lime dosage of 500 mg/L, but was 80 mg/L at 2,000 mg/L lime dosage.

Metals analyses and chloride concentration of the untreated brine and supernatant from six different lime additions are shown in Table 3.3. Lime dosages between 7,500 and 20,000 mg/L are presented.

Table 3.3
METALS AND CHLORIDE ANALYSIS

	Lime Dosage mg/L						
Parameter, mg/L	0	7,500	10,000	12,500	15,000	17,500	20,000
Chloride	141,700	151,700	153,100	161,700	155,030	151,700	141,700
Sodium	58,800	62,000	62,290	63,600	60,400	57,400	52,000
Calcium	21,000	24,650	25,340	28,200	25,870	24,400	21,000
Magnesium	3,000	1,245	613	15	9.3	8.9	6.6
Strontium	1,760	1,675	1,749	1,840	1,790	1,740	1,630
Potassium	1,080	1,060	1,054	1,050	1,040	1,020	990
Iron	130	18.1	16.1	12.1	12.7	12.2	12.5
Manganese	70	2.0	1.5	1.1	1.3	1.2	1.2
Nickel	3.6	3.6	3.3	3.1	3.2	3.3	3.5
Lead	2.5	2.5	2.7	2.8	2.6	3.4	3.5
Zinc	1.2	0.5	0.4	0.3	0.5	0.6	0.6
Copper	0.6	0.7	0.7	0.8	0.9	0.8	0.6

Lime precipitation removed little or no chloride, calcium, sodium, strontium, potassium, nickel, lead, or copper. Significant removal of only magnesium, manganese, iron, and zinc was achieved. At a lime dosage of 12,500 mg/L magnesium, manganese, iron, and zinc removals were 99.5, 98.4, 90.7, and 75 percent, respectively.

Polymer Study

As previously noted, the existing brine treatment facilities use polymer in their precipitation process to aid in flocculation process. Jar tests were also used to determine the optimum polymer dosage. The polymer used was an anionic polymer in a one percent solution as specified by Western Water Management, Inc.. Jar tests were conducted similar to the lime precipitation tests, with some exceptions. An optimum lime dosage, 12,500 mg/L was added to the beaker and rapid mixed for two minutes. The pH was measured to make sure that an optimum pH was achieved. If an optimum pH was not reached, additional lime was added until an optimum pH was achieved. After the rapid mixing cycle, the solutions were flocculated. At the start of the flocculation cycle polymer was added to the beakers. After 30 minutes of flocculation, the solutions were settled for one hour.

After the settling period, samples of the supernatant were withdrawn from the beakers with a pipet. The turbidity, TSS, and metals concentrations were determined as explained in the lime study. Results from the polymer jar tests are shown in Table 3.4.

Table 3.4
POLYMER STUDY DATA

Parameter	Polymer dosage, mg/L					
	0	1	3	4	5	6
Final pH	10.4	10.2	10.4	10.5	10.5	10.5
Turbidity (NTU)	2.4	2.9	1.7	1.6	2.2	1.6
TSS (mg/L)	31.1	33.3	32.2	23.3	23.4	28.4
VSS (mg/L)	11.1	8.9	8.9	8.9	8.9	12.2
VSS/TSS (%)	35.4	35.0	26.4	38.7	26.6	32.9
Chloride	161,700	161,700	161,700	161,700	161,700	161,700
Sodium	67,520	66,120	66,000	66,360	65,480	66,040
Calcium	36,600	34,600	35,500	34,800	34,800	34,800
Magnesium	7.4	10.2	7.8	6.6	6.8	6.2
Strontium	2,360	2,300	2,280	2,300	2,300	2,300
Potassium	840	820	820	820	820	820
Iron	4.0	4.0	3.8	3.5	3.7	3.5
Manganese	1.5	1.5	1.5	1.5	1.5	1.5
Nickel	4.5	4.5	4.3	4.3	4.3	4.3
Lead	2.8	2.7	2.5	2.5	2.5	2.5
Zinc	0.1	0.1	0.1	0.1	0.1	0.1
Copper	0.4	0.4	0.4	0.4	0.4	0.4

With the addition of the anionic polymer to the treatment process very little additional dissolved solids were removed. The turbidity was initially low and decreased slightly with increasing polymer dosage. However, the difference between the reactors with polymer and without polymer was minimal. The addition of the anionic polymer in the treatment process is questionable at this stage. However, because polymer addition is known to improve solids settleability, polymer addition was included in the treatment plant design. A polymer dosage of one mg/L was used as the optimum dose.

A plot of turbidity versus polymer dosage is presented in Figure 3.4. The turbidity was initially 2.4 NTU and increased to 2.9 NTU with the addition of 1 mg/L of the polymer. The turbidity reduced with increasing polymer dosage except for polymer dose 5 mg/L, which experienced a slight increase.

Figure 3.5 is a plot of total suspended solids (TSS) and volatile suspended solids (VSS) versus polymer dosage. Both the total suspended solids (TSS) and volatile suspended solids (VSS) remained relatively constant over the polymer test range.

Acid Neutralization Study

In order to discharge the brine treatment facility's effluent to a receiving water, the effluent's pH must be adjusted to between six to nine. An acid titration was performed on the supernatant from the lime study jar tests. The acid used was a technical grade sulfuric acid (H_2SO_4) in a one percent solution. Samples of 100 mLs of supernatant were titrated with the acid in increments of one pH unit from the initial pH to a pH of six. The volume of the acid required to reduce the pH was recorded for each pH increment. Results from the acid neutralization tests are shown in Table 3.5.

Table 3.5
ACID NEUTRALIZATION STUDY RESULTS

Sample no.	Sample vol., mL	Initial pH	mL of acid titrant to reach desired pH						
			11	10.5	10	9	8	7	6
1	100	11.5	5.3	6.4	7.0	7.9	8.1	8.3	8.4
2	100	11.6	5.5	6.3	6.8	7.7	8.1	8.2	8.3
3	100	11.6	5.2	6.3	6.9	7.7	8.0	8.2	8.3

To reduce the pH from the initial pH of 11.6 to the optimum pH of 10.5, about 6.3 mLs of acid was required. It is interesting to note that to reduce the pH from the optimum pH to the end of the desired pH range of six, requires just an additional two mL of acid. Only 0.5 or 0.6 mL of the acid reduced the pH from the high point to the low point of the desired pH range for the effluent. Most of the brine buffering capacity is from the initial pH to a pH of 10. This buffering is most likely due to hydroxide (OH^-) buffering. The brine is poorly buffered between a pH of six to nine.

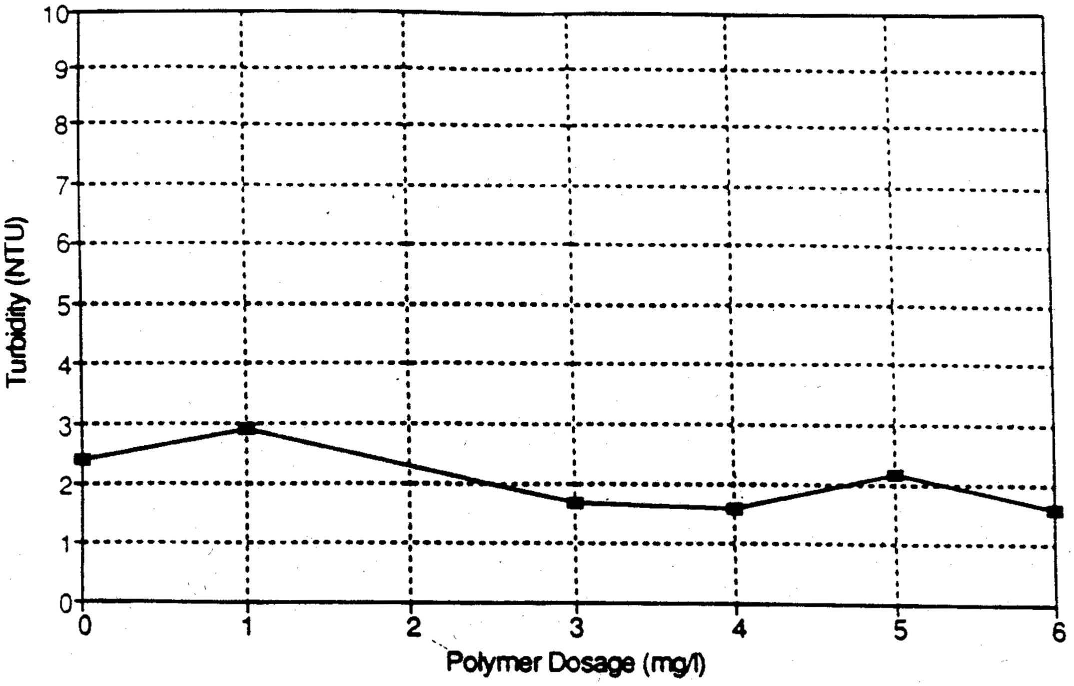


Figure 3.4. TURBIDITY VERSUS POLYMER DOSAGE

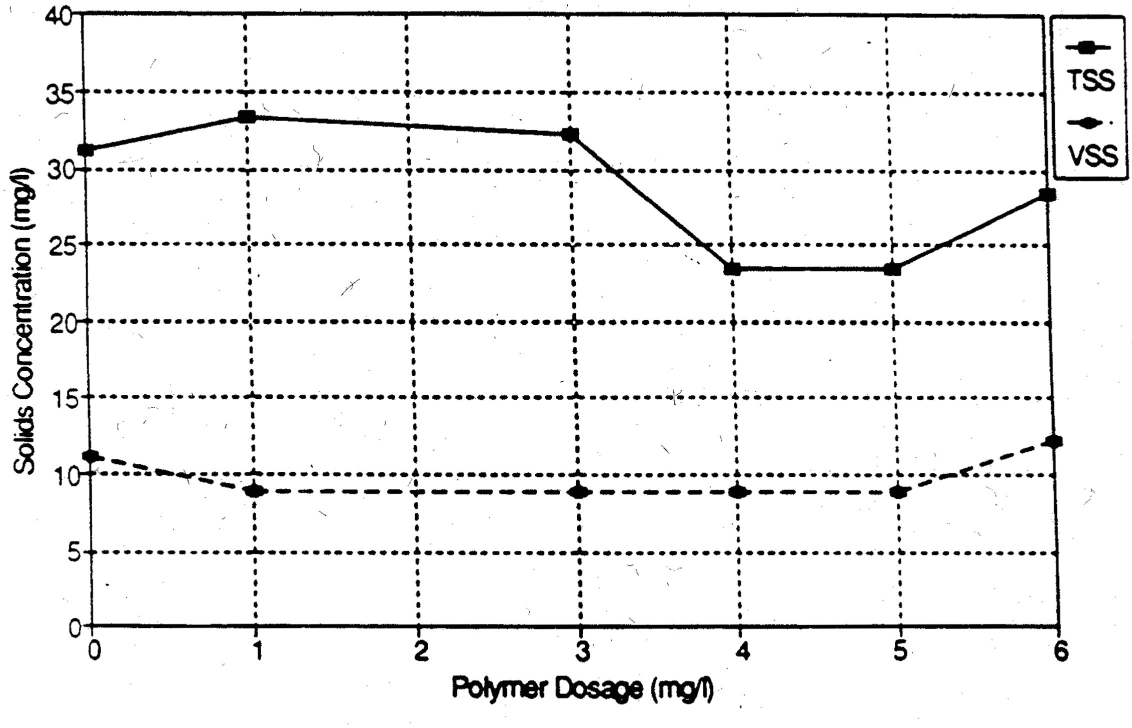


Figure 3.5. TSS AND VSS VERSUS POLYMER DOSAGE

From the results of the acid neutralization study about 1.7 mL of the acid will be needed to reduce the pH from the optimum pH of 10.5 to a pH around eight. This corresponds to a acid dosage of 170 µL (0.17 mL) of the technical grade sulfuric acid (H_2SO_4) per liter of effluent.

Sludge Analysis

Sludge collected from the lime studies was analyzed for solids content and total volume. The solids percentage of the sludge and an estimate of the amount of sludge produced by the process were determined. The solids percentage of the sludge was determined using *Standard Methods 2540 G* (APHA, 1989). The estimated sludge volume was determined by comparing the effluent constituents concentrations to the concentrations determined in the brine characterizations. The difference between their concentrations, plus the added lime, gave an estimate of the mass of sludge per volume of brine treated using lime precipitation.

A percent total solids analysis was performed on the sludge from the jar tests. Four total solids analyses were performed on the sludge generated at the 10,000 mg/L lime dosage and two analyses were performed at the 12,500 mg/L lime dosage. Two of the four samples from the 10,000 mg/L lime dosage were duplicated while both samples from the 12,500 mg/L were duplicated. Results from the percent solids analyses are shown in Table 3.6.

Table 3.6
PERCENT SOLIDS ANALYSIS ON THE SLUDGE

Reactor/Lab No.	Lime dose, mg/L	Solids, %
R2/L9	10,000	29.7
	10,000	29.7
R3/L9	10,000	30.1
	10,000	30.1
R1/L8	10,000	32.0
R6/L8	10,000	32.3
R5/L9	12,500	28.5
	12,500	28.5
R4/L9	12,500	28.8
	12,500	28.7

The percent solids determined from the sludge analyses was about 30 percent in each test. Typical solids percentages for wastewater treatment sludges range between 2 and 10 percent. As a comparison, the required percent solids for sludge disposal in a landfill is usually 20 percent. Thus, the 30 percent sludge solids fraction seems very high. High solids content is probably not a true reflection of the actual solids content, and is probably caused by the hygroscopic nature of the lime sludge. The highly mineralized solids in the sludge rapidly absorbs moisture from the atmosphere, giving a false positive reading. Water molecules trapped in the solid matrix also could contribute to a false positive measurement.

For the design of a full-scale treatment process, the percent solids in the sludge is needed to size the sludge pumps properly. Because of the uncertainty, the values determined in the lab were not used in the design. Design manuals report typical range of percent solids in various sludges. For the purposes of design in this study the highest value from the typical range was used when sizing the sludge pumps.

Estimate of Sludge Amount

A mass balance was performed to estimate the amount of sludge that will be produced. The amount of dissolved constituents removed by the treatment process plus the amount of lime added provided an estimate of the sludge produced. Average untreated brine was compared to effluent from the 12,500 mg/L lime dosage and one mg/L polymer dosage. The difference between the constituent concentrations gives an approximate amount of solids that the process will remove. Untreated brine and effluent constituent concentrations with the resulting difference for each are presented in Table 3.7. The lime dosage of 12,500 mg/L was then added to this difference to give an estimate of the sludge produced per liter of waste.

The total amount of dissolved solids removed by the treatment process is about 3,500 mg/L. With the additional lime concentration the estimated amount of sludge that the treatment process will produce is approximately 15,950 mg of sludge per liter of brine treated. For design purposes 16,000 mg of sludge per liter of brine was used. This value was used to estimate the amount of sludge production and the cost of disposal.

Table 3.7
ESTIMATED SLUDGE PRODUCTION

Constituents	Metals concentration, mg/L		
	Waste	Effluent	Removed
Sodium	63,600	66,120	No Change
Calcium	28,200	34,600	No Change
Magnesium	3,000	10.2	2989.8
Strontium	1,760	2,300	No Change
Potassium	1,080	820	260
Iron	130	4	126
Manganese	70	1.5	68.9
Nickel	3.6	4.5	No Change
Lead	2.5	2.7	No Change
Zinc	1.2	0.1	1.1
Copper	0.6	0.4	No Change
Total Dissolved Solids Removed, mg/L			3,445.8
Lime Dosage, mg/L			12,500.0
Estimated Sludge Produced, mg per L of brine treated			15,945.8

Settling Velocity

To determine the optimum polymer dosage the settling velocity, was investigated. The settling velocity is a measurement of how fast the floc settles. The sludge interface depth as a function of time is summarized in Table 3.8.

Table 3.8
POLYMER JAR SETTLING VELOCITY

Time, minutes	Distance settled (cm) at indicated polymer dose					
	0 ppm	1 ppm	3 ppm	4 ppm	5 ppm	6 ppm
0	0	0	0	0	0	0
15	2.1	2.9	1.7	1.8	1.8	2.0
30	4.2	5.2	3.4	3.5	3.6	3.5
45	5.3	5.8	4.6	4.8	4.7	4.8
60	5.8	6.1	5.2	5.4	5.1	5.2
Velocity, cm/min	0.14	0.17	0.11	0.12	0.12	0.13

The settling velocity for the reactor without the polymer was 0.14 cm/min, while the settling velocity with 1 ppm of polymer had the highest velocity at 0.17 cm/min. A polymer dose of three ppm produced the lowest settling velocity at 0.11 cm/min. Polymer dosages of four ppm and five ppm generated similar settling velocities of 0.12 cm/min. The six ppm polymer dose had a settling velocity of 0.13 cm/min.

From Figure 3.6, the graph of distance settled versus time, it can be seen that the one ppm polymer dose produced the steepest slope. The addition of 1 ppm of polymer would appear to aid in the settling of the floc. However, the addition of polymer above three ppm reduced the settling velocity of the floc. The dosage of polymer that was used for the treatment facility design was one ppm. This corresponds to one mg of polymer per liter of brine.

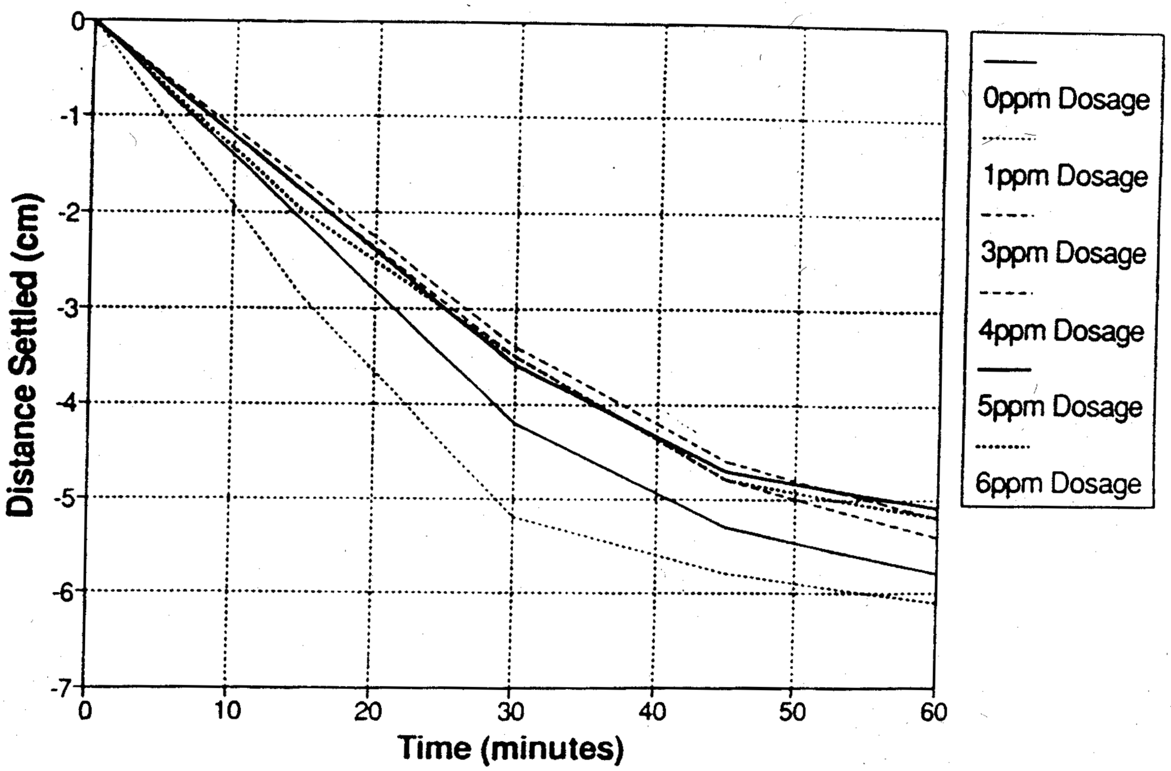


Figure 3.6. SETTLING VELOCITY FROM POLYMER STUDY

PROPOSED SITE LOCATION FOR BRINE TREATMENT FACILITY

The criteria used to evaluate potential sites for the proposed brine treatment facility were: proximity to the major brine generation areas; proximity to a receiving stream with sufficient year-round flow to accommodate the discharged dissolved solids; tanker truck accessibility; and suitable land area to house the treatment facility and also a reclamation facility (solar ponds plus evaporator) if determined to be feasible. In this chapter, each of these criteria is discussed. In addition, a proposed location for the brine treatment facility is described. Potential environment impacts on the receiving water stream as a result of discharging treated brine are also evaluated.

Proximity to Major Brine Generation Areas

As noted in Section 2, the Bass Island and Medina formations generate the majority of the highly concentrated brines. These fields are located primarily in Chautauqua, and Cattaraugus counties and extend into parts of Erie, Genesee, and Wyoming counties. Based on DEC data brine generation rates are highest currently in Chautauqua County. In recent discussion with personnel at U.S. Energy Corp., when gas prices become more favorable, the concentration of new well drilling is likely to be highest in Cattaraugus County. Thus, a brine treatment facility within Chautauqua County close to Cattaraugus County would be central to the majority of brine generated currently and in the future.

On this basis, the search for potential sites for a brine treatment facility was focused in the eastern half of Chautauqua County, closer to Cattaraugus County.

Proximity to a Suitable Receiving Stream

The DEC uses a number of primary references to determine if a wastewater treatment facility will be able to discharge into a receiving stream and what the SPDES permit conditions will be. The ***Official Compilation of Codes, Rules, and Regulations of the State of New York, Title 6, Chapter X*** is used to determine the classifications and standards for all rivers and streams in New York State. Also listed in this document is the "beat usage of waters" description of the classifications and standards. The ***SPDES Permits Water Quality Application of Regulatory and Guidance Criteria*** and ***Low-Flow Frequency Analysis of Streams in New York*** are used in establishing the maximum allowable pollutant loading during periods of low flow for a receiving stream once its classification has been determined.

In selecting a potential site for the location of a brine treatment facility, these references were consulted for appropriate guidelines and are discussed in subsequent subsections.

The steps taken to select a suitable location for the proposed brine treatment were:

- Determine the most likely contaminants of concern based on the brine characteristic analyses and NPDES permit conditions of the two commercial brine treatment facilities in Pennsylvania.
- Identify streams with sufficient flow volume in Chautauqua County to receive treated brine.
- Identify potential sections of these streams which are not classified as being a potential drinking water source or overly environmentally sensitive.
- Identify land areas in these sections which are not located in flood plains and have truck accessibility.
- Determine potential environmental impacts of treated brine water discharge based on historical water quality and flow volume data.

Contaminants of Concern. Both commercial brine treatment facilities in Pennsylvania discharge into the Allegheny River and have similar NPDES permit discharge limitations. Parameters for which concentration limits are set are total suspended solids (TSS), oil and grease, and dissolved iron (Fe) with limits of 30, 15, and 7 mg/L, respectively. Other parameters which must be monitored include aluminum, strontium, cadmium, chloride, and total dissolved solids (TDS). These parameters are monitored only to determine whether limits should be placed on these parameters at a later time.

Based on the bench-scale testing and operating data from the two commercial brine treatment facilities, effluent concentrations for each of the three parameters with limits should be obtained readily. Assuming that a receiving stream in Chautauqua County can be identified that has similar water quality and use to the Allegheny River, DEC SPDES conditions are expected to be similar to those issued by the Pennsylvania Department of Natural Resources (DNR). (The DEC does not issue tentative SPDES permits until an application is submitted.)

To determine other potential contaminants of concern in the absence of definitive limitations it was assumed that any stream receiving treated brine water would be a potential drinking water source. Thus, drinking water standards were not to be exceeded as a result of treated brine water discharge.

Of the parameters for which drinking water standards exist, chloride (Cl) was considered to be the limiting constituent for the treated brine water. The U.S. EPA sets a secondary drinking water standard (aesthetics) of 250 mg/L for chloride. For this study, therefore, it was assumed that treated brine water could not be discharged to a receiving stream, if the resultant mixture exceeded the 250 mg/L chloride limit.

Brine chloride concentrations in the DEC database range from 4,200 to 200,000 mg/L for brines from the Medina and Bass Island trends. Chloride concentrations measured during this study were between 150,000 and 162,000 mg/L. Little, if any, chlorides were removed during treatment. To insure that the 250 mg/L chloride limit is not exceeded, a dilution factor of at least 800 will be needed which means that the flow of the receiving stream should be at least 800 times greater than that of the treated brine discharge flow.

Potential Receiving Streams (based on flow volume). The ***Low-Flow Frequency Analysis of Streams in New York*** was prepared by the U.S. Geological Survey (USGS), in cooperation with the DEC in 1979. The document lists data on the lowest flows at specific gage stations (flow volume measurements) for rivers and streams throughout New York State. Low flows are reported as the statistically determined minimum seven-day flow with an average ten-year recurrence level, or MA 7 CD ten-year flow. More simply, this flow is the low flow which will occur during any one week period, on average, during a 10-year period. Stream flows will be higher 99.8% of the time. The MA 7 CD ten-year flows were used as a guide to help determine potential receiving streams. Only streams which had MA 7 CD ten-year flows greater than ten times the maximum design flow of the brine treatment facility (75,000 gpd) were considered.

From ***Low-Flow Frequency Analysis of Streams in New York*** three rivers were identified that could possibly accept treated brine water: Cassadaga Creek, Conewango Creek, and Chadakoin River. The flows of all other rivers and streams around Chautauqua Lake were considered too low to accept treated discharge. Flows were measured in Chadakoin River and Conewango Creek from the late 1930's to the mid-1970's. Flows were measured in Cassadaga Creek from the mid-1950's to the mid-1960's. Although the measurement period is shorter for the Cassadaga Creek, according to Mark Jackson, a Water Resources Engineer with the DEC (Region 9), flows for the Cassadaga Creek are conservative due to dry weather.

Referring to Figure 3.7, the three major rivers are highlighted. The Cassadaga Creek starts at Cassadaga Lake in the town of Cassadaga and meanders 28 miles, meeting the Chadakoin

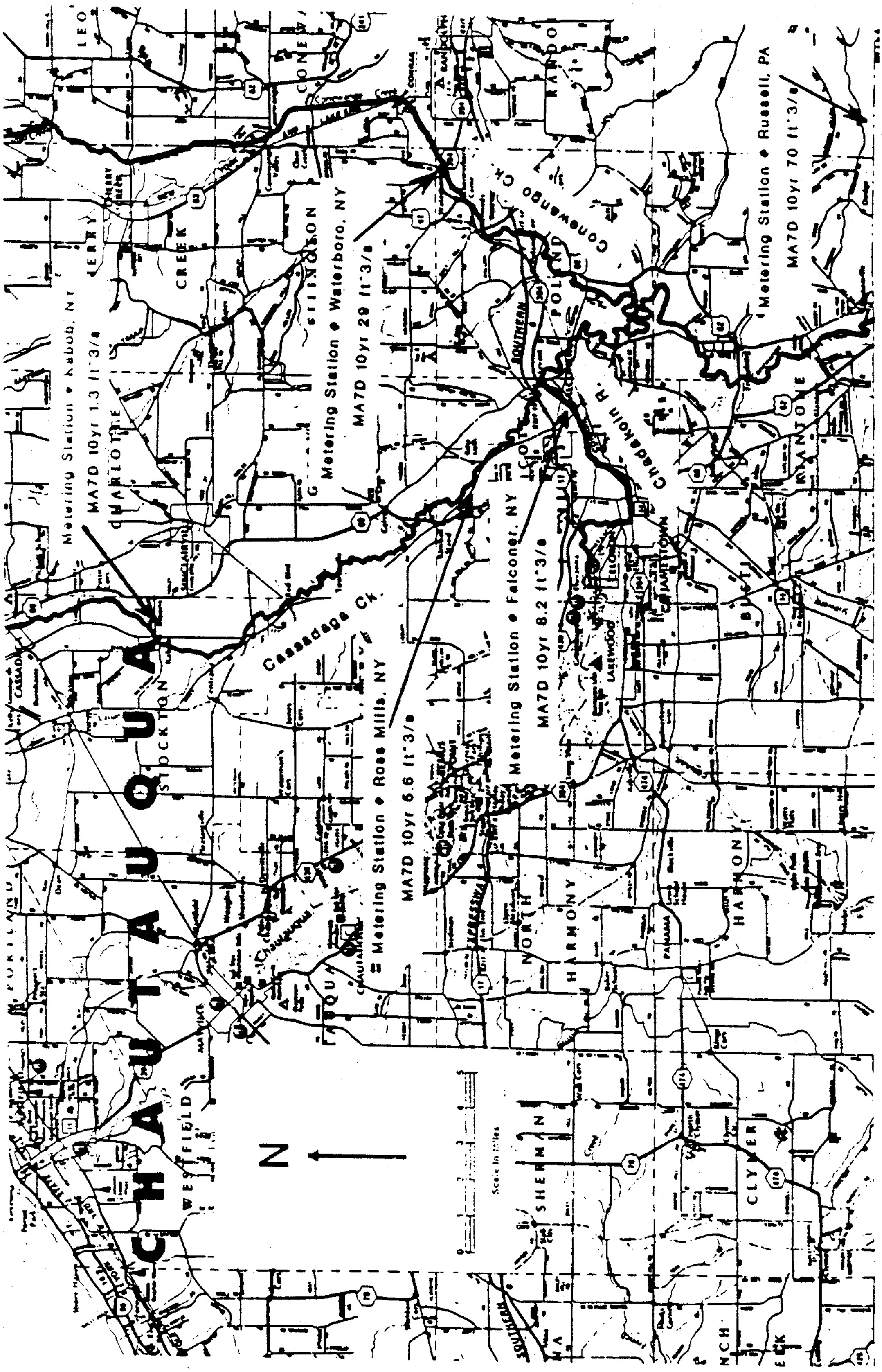


Figure 3-7. LOCATIONS OF FLOW METERING STATIONS IN MAJOR STREAMS OF CHAUTAUQUA COUNTY

River around the Levant area north of Falconer. The Chadakoin-Cassadaga then flows eight miles and joins the Conewango Creek about 3.5 miles east of Jamestown. The Chadakoin River connects Chautauqua Lake and Cassadaga Creek. The river flows through the city of Jamestown and the village of Falconer for a total distance of about 8.5 miles. The Conewango originates in Cattaraugus County around New Alboin. The creek flows in and out of Chautauqua County two times and finally exits the state into Pennsylvania around Fentonville, 8 miles south of Jamestown. The Conewango continues south to the town of Warren, Pennsylvania and flows into the Allegheny River.

The location of the flow metering stations is also shown in Figure 3.7. Flows were measured at two locations on the Cassadaga and Conewango Creeks and at one location on the Chadakoin River. Flows are measured on Cassadaga Creek at Kabob and Ross Mills. The MA 7 CD ten-year flows were 1.3 ft^3/sec (cfs) at Kabob and 5.6 cfs at Ross Mills. The Chadakoin's flows are measured at Falconer. The MA 7 CD ten-year flow there was 8.2 cfs. The Conewango's flows are measured at Waterboro and at Russell, Pennsylvania. The MA 7 CD ten-year flows were 29 cfs and 70 cfs, respectively.

Based on the MA 7 CD ten-year flow of the Cassadaga at Ross Mills, 5.6 cfs, any location upstream of this station probably would not be able to receive a treated brine flow of 75,000 gal/day (0.12 cfs). The combined MA 7 CD ten-year flow of the Cassadaga and Chadakoin at Falconer is 8.2 cfs, high enough to consider this river as a possible receiving water for the treated brine flow. MA 7 CD ten-year flows are not known for locations upstream of Waterboro on the Conewango. Thus, potential sites will be limited to locations downstream of Waterboro. The MA 7 CD ten-year flow measured at Waterboro, 29 cfs, is sufficiently high to be considered as a receiving stream.

Stream Classifications. Title 6, Chapter X of the ***Official Compilation Codes Rules and Regulations of the State of New York*** lists best usage categories, water quality standards and purity for each section of surface water in New York State. The state is broken down into ten major river drainage basins. The two major river drainage basins that cover the area of concern in Chautauqua County are the Allegheny River Basin Series and the Lake Erie-Niagara River Drainage Basin Series.

The three best usage classifications of interest for this study are C, C(T), and B. Best usage for Class C streams is defined as being suitable for fishing and fish propagation. The water quality is to be suitable for primary and secondary contact recreation even though other factors may limit the use for that purpose.

Primary contact recreation is an activity where the human body comes in direct contact with the water such as swimming, diving, or water-skiing. Secondary contact recreation is an activity where contact with the water is minimal and ingestion of water is not probable such as fishing and boating.

Class C(T) is similar to Class C, except that trout spawning areas are prevalent. These stream sections are more fragile. Thus, more stringent water quality limits are set by the DEC than for Class C waters.

Best usage of Class B water is primary contact recreation and any other uses except as a source of water supply for drinking, culinary or food processing. Generally, more stringent water quality limits are set by the DEC for Class B waters than for Class C waters. For siting the brine treatment facility, a stream section with a Class C rating will be desired to minimize environmental impact.

The three streams of interest are shown again in Figure 3.8. Cassadaga Creek is a Class C stream, except for a quarter-mile section around point A, where the Cassadaga has a Class B designation. From the source of the Cassadaga creek to point B, the section is designated Class C(T).

The Chadakoin River is Class C from Chautauqua Lake to its juncture with Cassadaga Creek. Conewango Creek is Class C from the Pennsylvania state line to a point five miles from its source, where it is Class C(T).

Brine Treatment Facility Siting. The three potential receiving streams are shown on a Chautauqua County road map in Figure 3.9. Also, projected onto this map are the major brine generation areas from Figure 2.7. As can be seen, the closest stream to the brine generation areas is Cassadaga Creek. The Cassadaga runs through the northern portion of the brine generation field. From points A to B the flow in Cassadaga Creek was evaluated as being too low for discharging the projected treated brine water flow. In addition with trout spawning areas, Class C(T) and Class B designation areas, this section would be undesirable for the proposed facility anyway.

The section of Cassadaga Creek, south of point B, to point D, is a potential area for a brine treatment facility, especially when the added flow from the Chadakoin at point C is considered. The usage classification from point B to point D is Class C. As further evidence

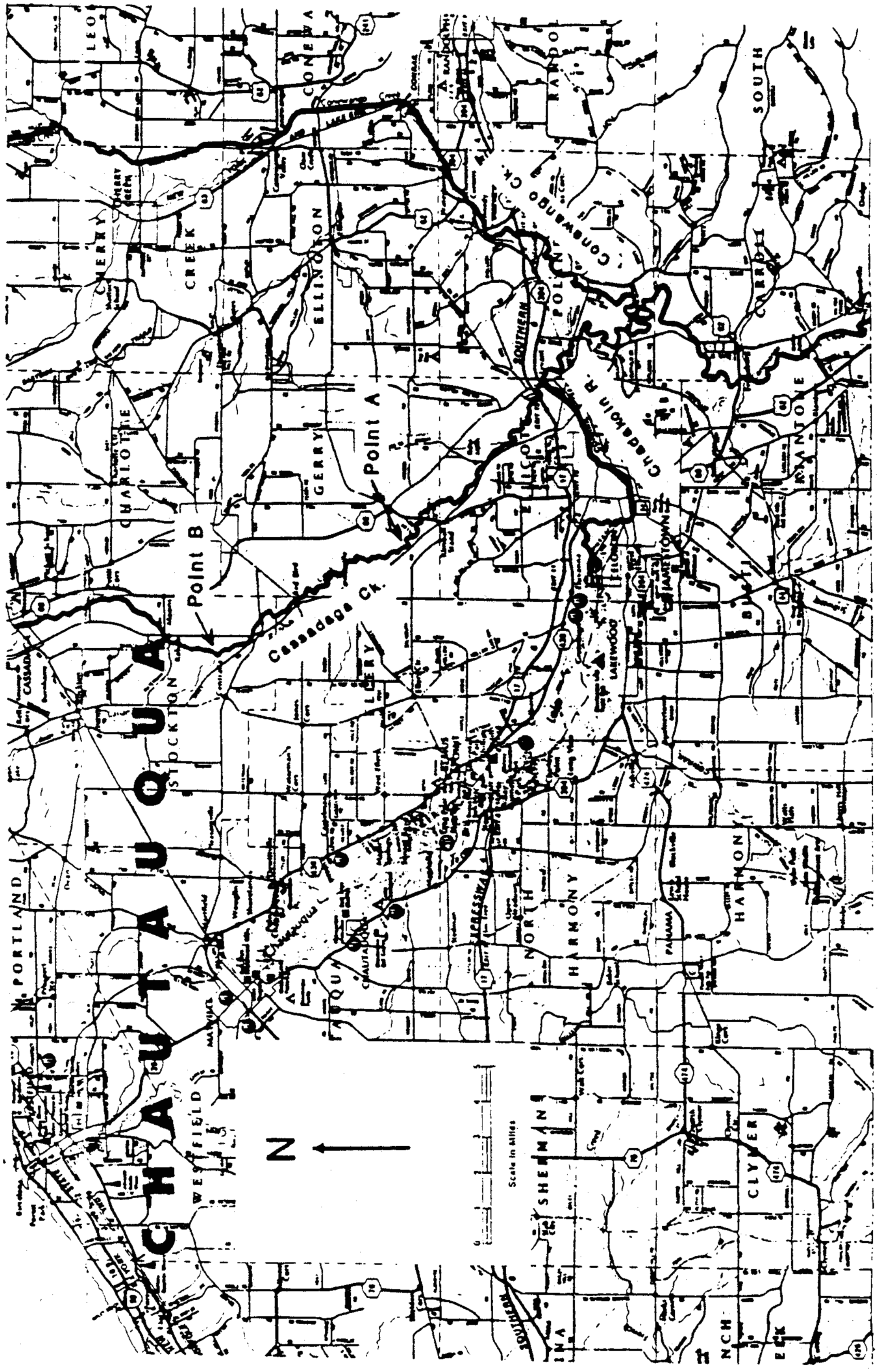


Figure 3-8. REFERENCE MAP FOR STREAM CLASSIFICATIONS IN CHAUTAUQUA COUNTY

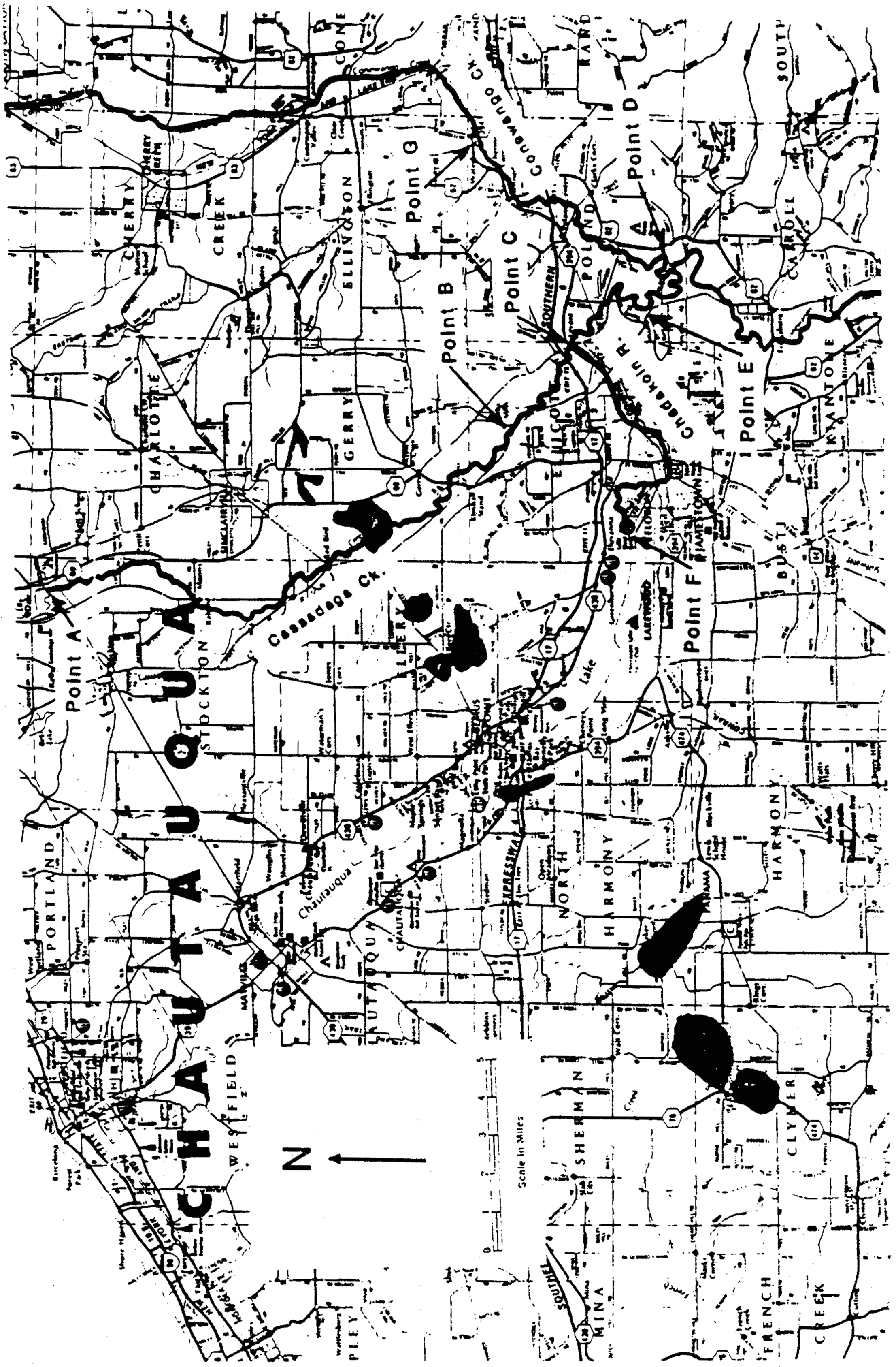


Figure 3-9. MAJOR BRINE GENERATION IN RELATION TO STREAMS OF INTEREST

for the possibility of treated brine water discharge, the Jamestown Wastewater Treatment Plant is located at point E.

Although the flow would be large enough in this stream section, the land around the wastewater treatment plant is generally woody and swampy, requiring higher capital expense to develop this land.

Another possible area for the brine treatment facility is around the convergence of the Chadakoin River and Cassadaga Creek. The Chadakoin River flows through the city of Jamestown and the village of Falconer. The classification of the Chadakoin from point F to point C is Class C. Any facility along the Chadakoin would have to be close to the junction with Cassadaga Creek due to development along the river in Jamestown and Falconer. One significant advantage of this area is that the Southern Tier Expressway (NY 17) has three exits close to this area, providing good access for trucks.

Along the Conewango Creek, any location upstream of point G is considered to be unsuitable due to unknown flow volumes. Locations south of point G may be suitable based on the flow and stream classification. Conewango Creek from point G to the state line is Class C. Of the three possible sections for locating a brine treatment facility, the Conewango Creek has the highest flows. However, a significant disadvantage of locating a brine treatment plant close to the Pennsylvania border is the distance from the areas of highest brine generation in New York state to this site. Because transportation costs are a large portion of the overall cost of brine disposal, locations south of point G are less desirable.

Other possible sites include locations around the merger of the Cassadaga and the Conewango at point D, and locations south of point D. However, the area around where the Cassadaga and Conewango meet is swampy which makes this location unsuitable due to the capital costs required. Locations south of point D are not swampy, but truck access and, once again, distance makes this location less desirable.

As noted previously, officials at U.S. Energy project the concentration of future gas drilling to be in west central Cattaraugus County. Thus, the farther east and north the facility is located the better the brine treatment facility would be in serving future production needs. A facility along the Conewango Creek around point G would meet this desirability. In contrast to this condition, however, is the fact that a large quantity of gas is being produced from fairly new wells south of Jamestown (see Figure 2.6) and brine generated from this area is likely to increase, making the area south of point D desirable.

As a compromise between these two locations, and considering all the other factors, a site around the convergence of Cassadaga Creek and the Chadakoin River has been determined to be best suited for a brine treatment facility. After surveying the area, two possible site locations have been identified. These two possible sites for the brine treatment facility are shown in Figure 3.10. Site No. 1 is located along Cassadaga Creek, just north of Levant and the merger with the Chadakoin River. Site No. 2 is on the Chadakoin River, outside of Falconer before the merger with Cassadaga Creek.

Site No. 1 is four miles downstream from the Ross Mills metering station and is less than half a mile from the junction of the Chadakoin. The MA 7 CD ten-year flow of the Cassadaga Creek at Ross Mills is 5.6 cfs. The MA 7 CD ten-year flow of the Chadakoin River at Falconer is 8.2 cfs. Based on these two flows, the total MA 7 CD ten-year flow at the merger of the two streams (a half mile downstream of Site No. 1) would be expected to be at least 13.8 cfs.

Site No. 1 is located off the Gerry-Levant Road. Access to the site from the Gerry-Levant Road can be accomplished by exiting the Southern Tier Expressway at Exit 13 and proceeding east on State Highway Rt. 394. The proposed site is 70 acres and is between the Gerry-Levant Road, the New York State Department of Transportation equipment storage site, and Cassadaga Creek.

As noted earlier in this report, another option being explored for brine disposal is salt reclamation in which solar ponds will be used for heating and storing brine (see Section 4). The treatment plant proposed in this report would be the pretreatment step for salt reclamation. To insure that the contents of the solar ponds are not swept away during heavy rains, the brine treatment facility should not be located within the 100-year flood plain. Flooding into the solar ponds would pose an environmental hazard and could seriously affect the water quality of the river.

Flood maps were prepared by the Federal Emergency Management Agency for the National Flood Insurance Program. Flood Insurance Rate Maps for the Town of Ellicott Chautauqua County, New York (Community-panel Number 361073 0014A) were acquired from the New York State DEC Division of Water. These maps outline the boundaries for a 100-year flood for the river in question.

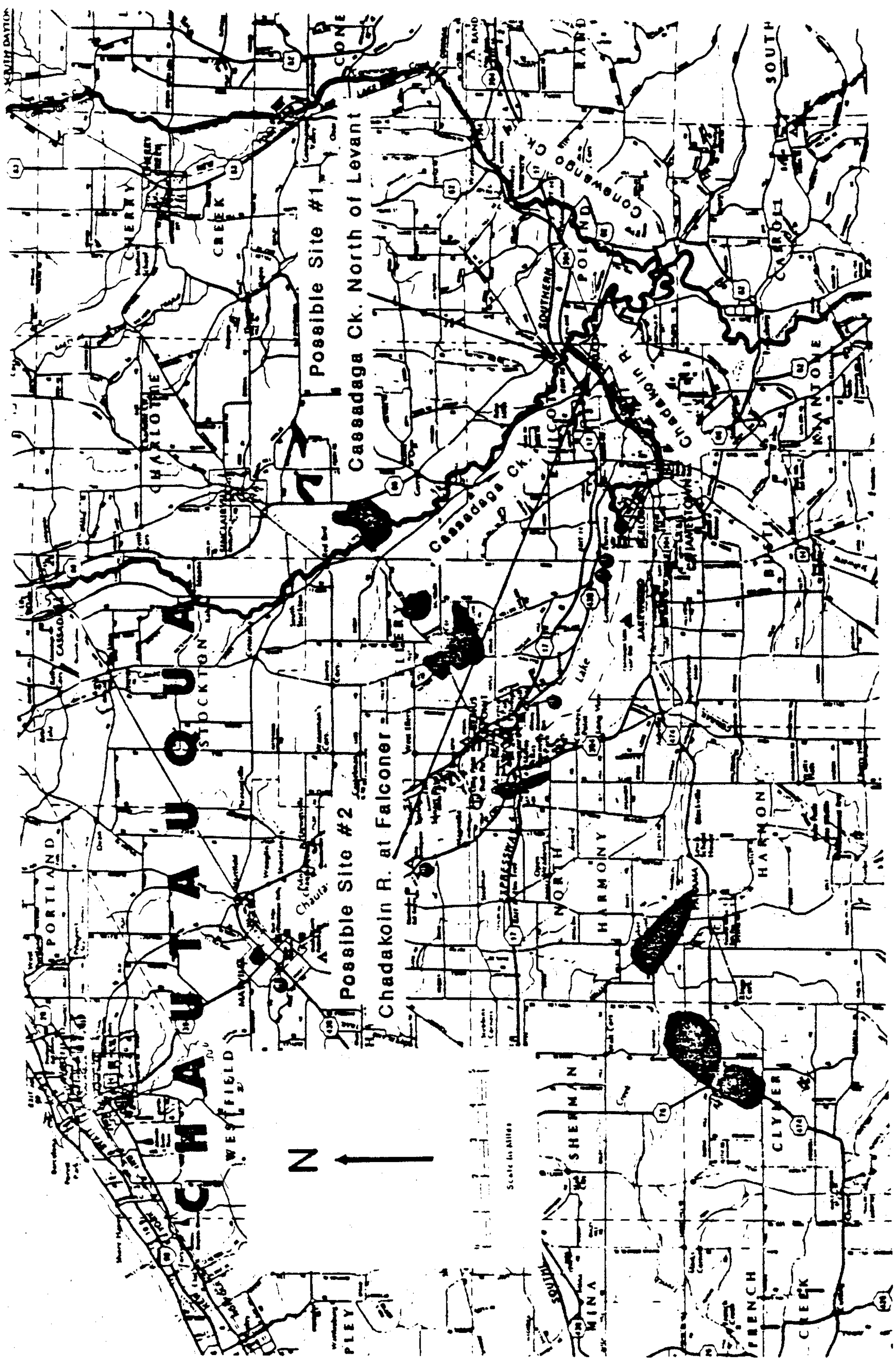


Figure 3-10. POSSIBLE SITE LOCATIONS FOR BRINE TREATMENT FACILITY

The 100-year flood plain for the proposed site is shown in Figure 3.11. As can be seen, Site No. 1 is outside the 100- year flood plain. Thus, Site No. 1 would be a good choice for a salt reclamation facility as well.

Site No. 2 is located on the Chadakoin River, near the merger of the Chadakoin and the Cassadaga. As noted above, the MA 7 CD ten-year flow of the Chadakoin measured at Falconer is 8.2 cfs and the combined MA 7 CD ten-year flow at the merger is expected to be 13.8 cfs.

Site No. 2 is between State Highway 394 and Elmwood Avenue. Access to the site can be accomplished by exiting the Southern Tier Expressway at Exit 13, proceeding east on State Highway Rt. 394, proceeding south on Quaint Road, then proceeding west on Elmwood Avenue and entering the site.

The 100-year flood plan around Site No. 2 is shown in Figure 3.12. As can be seen, the proposed site would be completely flooded during a 100-year storm event. If solar ponds are to be considered as future possibility, this site should not be considered.

Therefore, after considering all of the pertinent criteria for site selection, Site No.1 is considered to be the best choice for locating a brine treatment facility. It is centrally located to current brine generated in New York and will be beneficial for future gas production operations. This site is also suitable for locating a salt reclamation facility with solar ponds.

Environmental Impact Assessment (Site No. 1). As part of the evaluation to determine the potential impact of discharging treated brine water to the receiving stream at Site No. 1, constituent-by-constituent mass balance analyses were conducted using a simple case scenario, where complete mixing of the treated brine water with the Cassadaga is assumed to occur shortly after discharge. The merger of Cassadaga Creek and the Chadakoin River is less than one half mile from the proposed site. Thus, for the mass balance analyses, the combined flow from Cassadaga Creek and the Chadakoin River was used.

To determine the water quality of Cassadaga Creek at Site No. 1, a grab sample was collected from Cassadaga Creek. The water sample was analyzed for parameters similar to those performed for the brine used in the bench-scale studies. These analyses were performed in the Environmental Engineering Laboratories at the State University of New York at Buffalo. Procedures were the same as those earlier in this section.

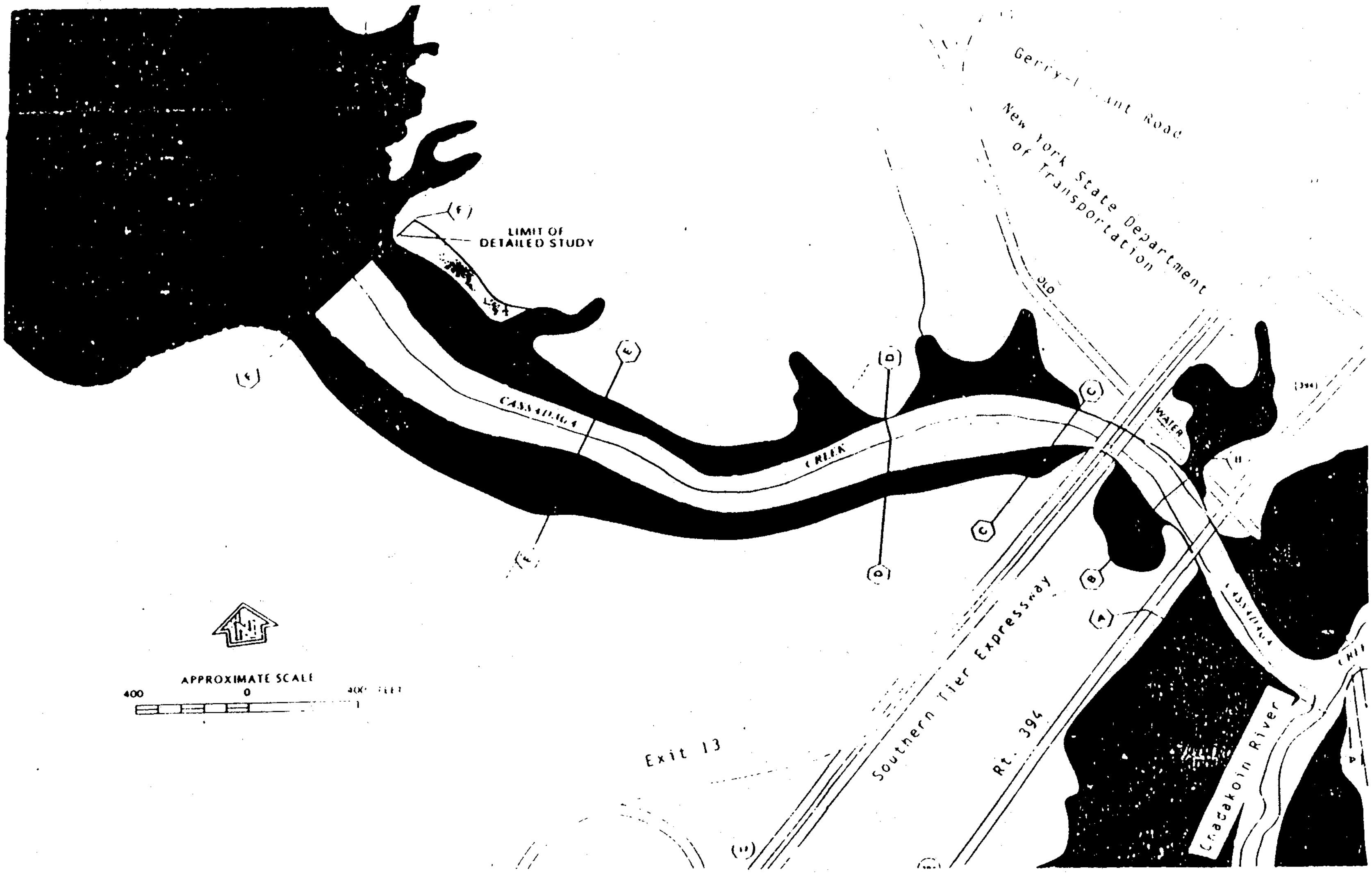


Figure 3-11. 100-YEAR FLOOD PLAIN NEAR PROPOSED SITE NO. 1

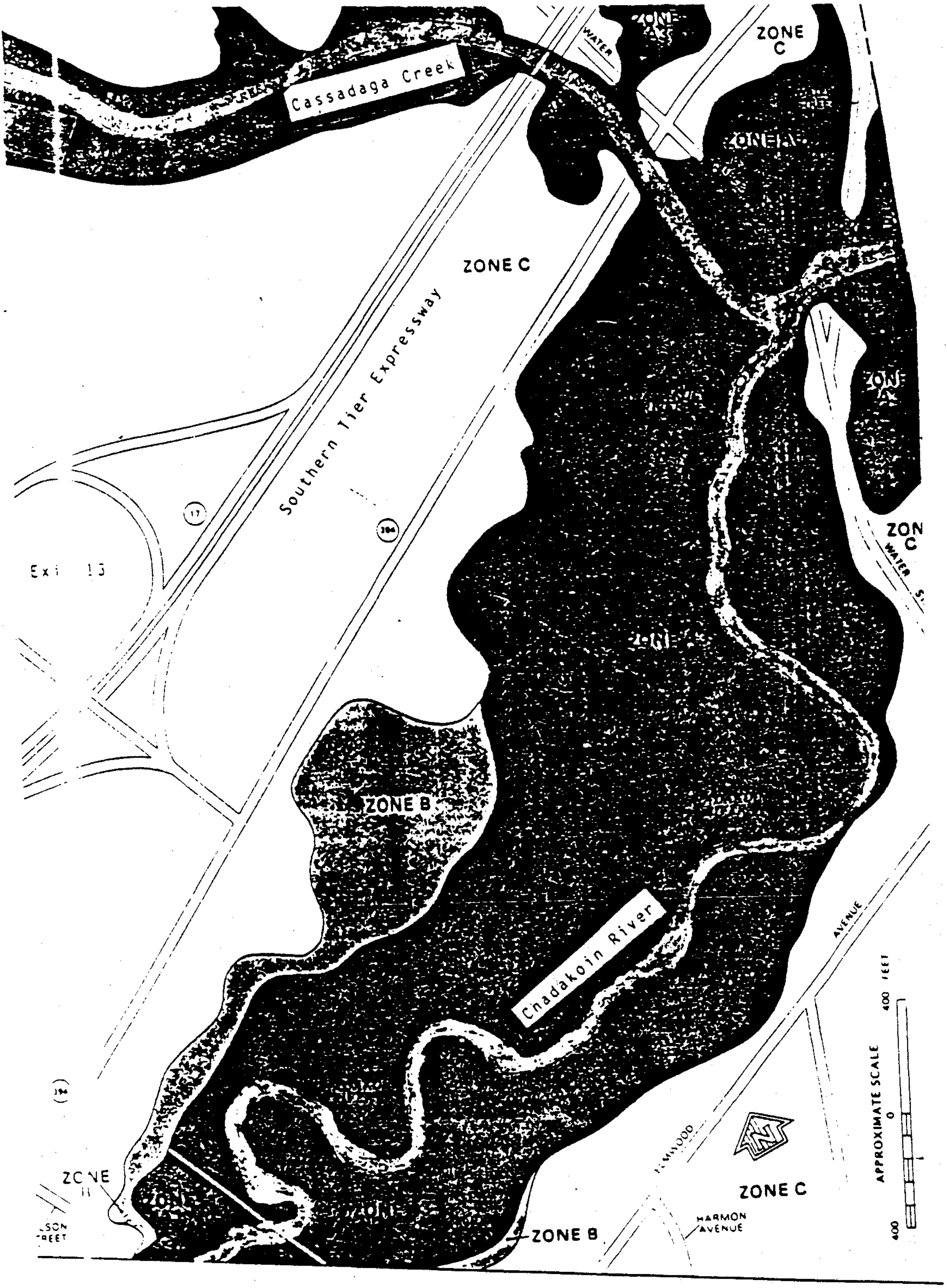


Figure 3-12. 100-YEAR FLOOD PLAIN NEAR PROPOSED SITE NO. 2

Water quality data was also obtained for the Chadakoin River and the Conewango Creek, using the ***Earthinfo Inc., Fast Access to Environmental Data***. Earthinfo provides access to a library of environmental and natural resource databases. The USGS Quality of Water, Surface Water and Ground Water Database (Watstore) was used to obtain typical metals and chloride concentrations in the Chadakoin River and Conewango Creek. The Watstore database lists observations from 215,000 metering stations and the measurement of 5,000 parameters. No data were available for the Cassadaga Creek from the Earthinfo system.

Parameter concentrations in Cassadaga Creek, the Chadakoin River and Conewango Creek are shown in Table 3.9, along with effluent concentrations expected from the brine treatment facility. The effluent characterization is based on a one ppm polymer dosage.

Table 3.9
WATER QUALITY DATA FOR POTENTIAL RECEIVING STREAMS

Parameter	Cassadaga Creek*	Chadakoin River**	Conewango Creek**	Treated brine*
pH, units	7.3	7.4	7.5	7.0
Turbidity, NTU	NA	NA	NA	2.9
Chloride, mg/L	15.0	20	12.2	161,700
Sodium, mg/L	10.5	16	6.0	66,120
Calcium, mg/L	34.1	25	33.0	34,600
Magnesium, mg/L	8.6	4.3	6.1	10.2
Strontium, mg/L	0.2	NA	NA	2,300
Potassium, mg/L	1.8	1.3	1.1	820
Iron, mg/L	0.5	0.017	0.1	4.0
Manganese, mg/L	0.2	0.007	0.045	1.5
Nickel, mg/L	0	0.001	0.01	4.5
Lead, mg/L	0	0.005	0.001	2.7
Zinc, mg/L	0	0.006	0.013	0.1
Copper, mg/L	0	0.001	0.01	0.4

* Laboratory analysis
** From ***Earthinfo Inc. Fast Access to Environmental Data***

It was expected that all the rivers and streams in the area of the proposed site would have similar water quality characteristics. As expected, the laboratory analysis of the Cassadaga Creek compares favorably with the data obtained through the Earthinfo database for the Chadakoin River and Conewango Creek.

As previously noted, and from the data in Table 3.9, chloride concentration is the major contaminant of concern. The chloride concentration is about 2.5 times the concentration of sodium, 4.7 times the concentration of calcium, and 70 times the concentration of strontium. If the chloride concentration is diluted to acceptable levels (drinking water standards), it is expected that the remaining contaminants will be sufficiently diluted.

The MA 7 CD ten-year flow for Cassadaga Creek at Ross Mills, as determined from the ***Low Flow Frequency Analysis of Streams in New York State*** is 5.6 cfs, and 8.2 cfs for the Chadakoin River. The maximum design flow capacity of 75,000 gpd for the proposed brine treatment facility corresponds to a flow of 0.12 cfs. Using the Cassadaga Creek MA 7 CD ten-year flow, 5.6 cfs and the initial chloride concentration, 15 mg/L, the resulting chloride concentration in the receiving stream after treated brine water discharge can be determined. For a 75,000 gpd treated brine flow, the resulting chloride concentration would be 3,410 mg/L under MA 7 CD ten-year flow conditions; 6,390 mg/L for a 150,000 gpd treated brine flow. This load would be detrimental to freshwater aquatic life in the stream around the proposed site. Using the MA 7 CD ten-year flow for the combined Cassadaga Creek and Chadakoin River, the resulting chloride concentration is still 1,410 mg/L for the 75,000 gpd flow and 2,670 mg/L for the 150,000 gpd flow. Clearly, under the MA 7 CD 10-year flow the resulting chloride concentration could be too high, and the treated brine should not be discharged under the MA 7 CD 10-year low flow conditions. However, since the MA 7 CD 10-year flow only occurs 0.2% of the time, on average, during a ten-year period, determination of the frequency that the Cassadaga Creek's flow is too low for discharge should be determined before eliminating Site No. 1 as a potential discharge location.

The minimum flow in Cassadaga Creek needed to dilute the chloride concentration can be determined using the drinking water standard for chloride concentration, 250 mg/L, as a guideline for the maximum limit that the receiving stream chloride concentration can be. Back calculating to determine the minimum flow necessary in Cassadaga Creek yields 77 cfs and 147 cfs for a 75,000 and 150,000 gpd treated brine discharge flow, respectively.

To determine the average amount of time that the actual flow in Cassadaga Creek is above the aforementioned minimum levels, flow frequency data were needed. Unfortunately, flow frequency data, other that found in the ***Low Flow Frequency Analysis of Streams in New York***, was unavailable for Cassadaga Creek. However, an estimate of flow frequency for Cassadaga Creek could be made using flow data from the ***Earthinfo Inc. Fast Access to Environmental Data***. The Earthinfo Inc. uses the USGS Watstore database containing historical flow data dating from 1850. Metering station data can be indexed by state, station name, and station ID number. Daily values and peak values are listed along with calculated summary statistics for all existing stations.

Daily average flows are available from the database for three stations in the study area. One on the Chadakoin River at Falconer, NY and two on Conewango Creek at Waterboro, NY and at Russell, PA. The daily average flows are calculated over the entire period of record. For the metering station at Falconer, NY on the Chadakoin River, the period of record ranges from 1936 to 1990. For the metering station at Waterboro, NY on Conewango Creek, the period of record is 1939 to 1990, while for the metering station at Russell, PA the period of record is from 1940 to 1989. The locations of the metering stations are shown in Figure 5.1.

Using a mass balance, the flow for Cassadaga Creek can be estimated. The Chadakoin River feeds into Cassadaga Creek and thereafter, Cassadaga Creek flows into the Conewango Creek. The Waterboro metering station on the Conewango River is upstream from the junction of Cassadaga Creek and the Conewango River. The Russell, PA metering station is downstream from this junction. Using the Russell, PA metering station as the outflow and the metering stations at Waterboro, NY and Falconer, NY as inflow, the flow in the Cassadaga Creek can be estimated. The daily average flows for each month over the last 30 years are listed in Table 3.10. Flows from the metering stations at Falconer and Waterboro are subtracted from the flow at the metering station at Russell, Pa. to give an approximate flow in Cassadaga Creek.

Table 3.10
DAILY AVERAGE FLOWS (CFS) OVER THE LAST 30 YEARS

Stream	Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Conewango	Russell	823	1,541	2,161	1,913	2,082	3,283	2,806	1,330	883	465	410	590
Conewango	Waterboro	285	561	742	657	767	1,208	983	471	302	155	141	203
Chadakoin	Falconer	204	358	506	502	522	690	644	309	211	116	102	148
Cassadaga Creek		334	622	913	754	793	1,386	1,179	550	371	194	167	239

The estimated flows in Cassadaga Creek are maximum during spring, with flows of 1,386 and 1,179 cfs during the months of March and April, respectively. Low flow conditions are expected during the summer months of July, August and September. Estimates for low flows are 194, 167, and 239 cfs during these months, respectively. These low flows are above the minimum flows needed to dilute the chloride concentration below 250 mg/L.

It should be clearly understood, that the foregoing analysis is only an estimate of the average flow in Cassadaga Creek. It is likely that small tributaries and loss/gain of water to the groundwater will occur between the metering stations. The actual flow in Cassadaga Creek may be higher or lower than the estimate given; however, in the absence of a metering station and long-term historical data, the flow estimate is reasonable.

Flow frequency estimates for Cassadaga Creek were needed to predict the amount of time that discharge of treated brine may not be possible due to flow conditions less than 77 cfs. Again, unfortunately, flow frequency data for Cassadaga Creek are not available. Therefore, as a conservative estimate, flow frequency data for the Chadakoin River were assumed to represent the flow frequency data for Cassadaga Creek.

Average flows in the Chadakoin are lower than those in Cassadaga Creek. In general, flow in the Chadakoin River is about 65% of the flow in Cassadaga Creek (see Table 3.10).

Using the ***Earthinfo Inc. Fast Access to Environmental Data***, flow frequency data for the Chadakoin River were obtained. Average monthly flows for the last 30 years were accessed. The average monthly flow is the average of the daily flows for each month. Figure 3.13 is a flow frequency distribution of monthly averages over the last 30 years. Although the recorded flows occur over a wide range, there are a number of readings below 100 cfs. A cumulative frequency plot is shown in Figure 3.14. As can be seen, flows below 150 cfs and 77 cfs occurred about 30% and 16 percent of the time, respectively. These flows represent the minimum flows needed to discharge 150,000 and 75,000 gpd, respectively.

Thus, it appears that, depending on the size of the treated brine flow, it may not be possible to discharge into the receiving at full design capacity for a portion of the year.

However, this flow frequency analysis is for the Chadakoin River, not Cassadaga Creek. As noted previously, flow in Cassadaga Creek is significantly higher than that in the Chadakoin River. Therefore, it is probable that the amount of time that the brine treatment facility will not be able to discharge at its design capacity will be small, if any.

Low flows in the Chadakoin River and Cassadaga Creek streams usually occurs during the summer months. Gas production is reduced during this time and as a result brine production is reduced. In addition, use of brine for road spreading is highest during the summer. The flow of treated brine will be lower during summer, coinciding with low flows in the receiving water. High flows in the river and streams occur in winter, which coincides with increased gas and brine production.

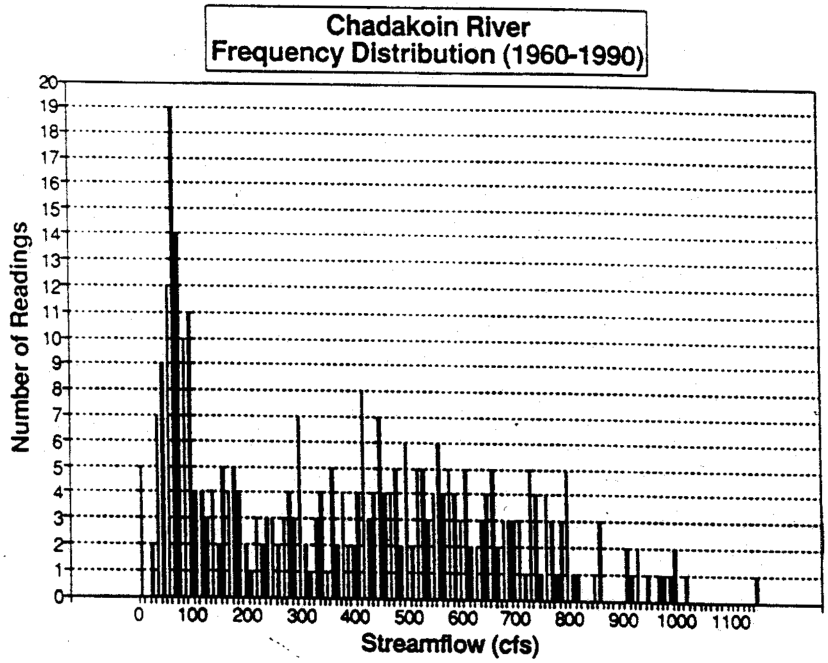


Figure 3.13. **CHADAKOIN RIVER FLOW FREQUENCY DISTRIBUTION**

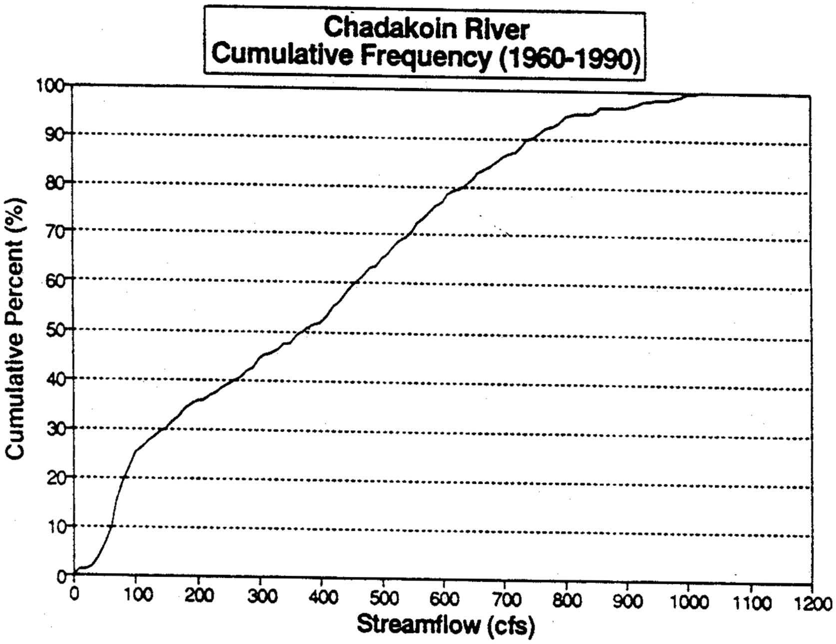


Figure 3.14. **CHADAKOIN RIVER CUMULATIVE FLOW FREQUENCY**

To insure that chloride levels do not exceed 250 mg/L, it is recommended that the treatment facility sample and analyze water from Cassadaga Creek and the Chadakoin River during the low flow periods. If chloride levels increase above 200 mg/L, the volume of discharge will then be reduced. Excess treated brine will then be stored on site in storage tanks or in the solar ponds until the flow in the receiving stream is sufficient to maintain the chloride level below 250 mg/L.

ECONOMIC COST ASSESSMENT

Figure 3.15 is a schematic diagram of the proposed brine treatment facility. The facility consists of four principal components: brine unloading/storage area; chemical feed systems; brine treatment processes; and solids (sludge) handling and disposal.

Costs were determined for components within the storage area and the treatment scheme. Components within the storage area consist of a containment area, pumping facilities for unloading brine, storage tanks, flotation, and raw water pumping facilities to the head of the treatment scheme. Equipment required to treat the brine consists of a rapid mix tank followed by a flocculator and clarifier. Lime, polymer, and acid feed systems are also included along with a filter press. Costs were also determined for the appropriate pumping equipment for the clarifier sludge, wastewater return, effluent pumping, as well as for the main building to house the treatment facility.

An economic cost comparison between 75,000 gpd and 150,000 gpd facilities is listed in Tables 3.11 through 3.13. The construction, and operation and maintenance costs for the components of the two treatment facilities are shown in Table 3.11. It is interesting to note that the cost to install the components for the 150,000 gpd facility ($1.73M) is only 33 percent ($430,000) more than the installation cost for the 75,000 gpd facility ($1.3M). The difference in costs of the annual operation and maintenance of the components of the larger facility is estimated to be just 13 percent or $17,000 per year more than the smaller facility. However, the energy requirements for the 150,000 gpd facility are anticipated to be almost double the 75,000 gpd facility energy requirements.

The non-component costs and the total capital costs for both facilities are listed in Table 3.12. The total capital costs for the 75,000 gpd facility is $2.47 million while the 150,000 gpd facility is $3.23 million. For an additional $0.76 million, or a 31 percent increase, in the capital costs the 75,000 gpd facility's capacity could be doubled.

Table 3.11
DESIGN COST COMPARISON OF COMPONENT ITEMS FOR THE BRINE TREATMENT FACILITY

	Facility Size, gal/day					
	Construction Costs ($)		O & M Costs ($/yr)		Electrical Usage (kwh/yr)	
Component	75,000	150,000	75,000	150,000	75,000	150,000
1. Raw water unload pump	33,000	42,300	310	390	8,200	15,700
2. Storage Tanks (100,000 gal ea)	150,000	225,000	--	--	--	--
3. Oil/Grease Storage Tanks	5,000	10,000	--	--	--	--
4. Flotation	158,000	198,000	16,800	19,600	27,000	55,000
5. Raw Water Pumping Facilities	25,900	30,000	230	270	7,200	14,000
6. Containment Area	75,000	100,000	--	--	--	--
7. Rapid Mix/Flocculation/Plate Settler	93,500	187,000	1,870	3,740	13,100	26,200
8. Sludge Pumping	4,600	5,600	8,700	8,900	4,100	8,200
9. Lime Feed System	139,000	202,000	2,780	2,940	14,000	40,000
10. Polymer Feed System	15,200	15,800	12,800	12,800	7,500	7,500
11. Acid Neutralization System	15,200	15,800	12,800	12,800	7,500	7,500
12. Filter Press	217,400	247,100	37,600	37,600	5,000	7,500
13. Wastewater Return Pump	20,400	20,400	400	400	680	1,305
14. Wastewater Clearwell Tank	3,500	29,750	--	--	--	--
15. Effluent Clearwell Tank	8,800	8,800	--	--	--	--
16. High Service Pumping Station	22,400	24,000	260	280	8,000	18,000
17. Dewatered Sludge Transport	187,800	187,800	45,500	59,300	--	--
18. Main Building	100,000	150,000	--	--	--	--
SUBTOTAL	1,274,700	1,699,350	140,050	159,020	102,280	200,905
Adjusted Const. Cost for Locality	**1,300,194**	**1,733,337**	--	--	--	--
Adjusted O & M Costs for Locality	--	--	**121,844**	**138,347**	--	--

Table 3.12
DESIGN COST COMPARISON OF NON-COMPONENT ITEMS FOR THE BRINE TREATMENT FACILITY

	Costs ($) for Indicated Facility	
Non-Components	75,000 gpd	150,000 gpd
Site Work	65,010	86,667
Electrical	104,016	138,667
Instrumentation	65,010	86,667
Piping	130,019	173,334
General Contractors Profit	199,710	266,241
Engineering	186,396	248,491
Contingencies	279,594	372,737
Land Acquisition	140,000	140,000
Total Non-Component Costs	1,169,755	1,512,804
Total Component Costs	1,300,194	1,733,337
Total Capital Costs	2,469,949	3,246,141

Table 3.13
ANNUAL OPERATING COST FOR THE BRINE TREATMENT FACILITY

	Annual Costs ($)	
Item	75,000 gpd	150,000 gpd
Amortized Capital Costs	233,145	306,412
Electrical Costs	11,251	22,100
O & M Costs	121,844	138,347
Lime Costs	263,068	525,913
Polymer Costs	75,240	150,480
Acid Costs	8,400	16,806
Disposal Costs	101,300	202,575
Total Annual Costs	814,248	1,362,633
Cost/Gallon of Brine Treated	**$0.0298**	**$0.025**
Payback Period @ $0.0325/gallon	8.1 yrs	4.5 yrs
Payback Period @ $0.035/gallon	6.6 yrs	3.8 yrs
Payback Period for 150,000 gpd facility operated at 50% @ $0.0325/gallon	10.6 yrs	
Payback Period for 150,000 gpd facility operated at 50% @ $0.035/gallon	8.7 yrs	

The projected annual operating costs for both facilities are listed in Table 3.13. The annual costs to operate the 75,000 gpd facility ($0.82 million) is $0.55 million less than the costs to operate the 150,000 gpd facility ($1.37 million). A doubling of capacity is estimated to require only a 67 percent increase in annual costs for the facility.

The unit cost to treat brine is shown in Table 3.13. By doubling the size of the facility the projected cost to treat the brine was reduced by almost $0.005 per gallon. Using a current disposal fee of $0.0325 per gallon, a profit of $75,440 per year for the 75,000 gpd facility and $416,740 per year for the 150,000 gpd facility is anticipated. If $0.035 per gallon of brine treated is charged the potential profit for the facilities is increased to $143,880 and $553,600 per year for the 75,000 gpd and 150,000 gpd facilities, respectively.

The payback period for the 75,000 gpd facility is 8.1 years at current disposal rates and decreases to 6.6 years if the costs to dispose of the brine is increased from $0.0325 to $0.035 per gallon. Corresponding internal rates of return are 11 and 16 percent, respectively. The payback periods for the 150,000 gpd facility are 4.5 years at current disposal costs and 3.8 years at future costs. Corresponding internal rates of return are 22 and 26 percent, respectively.

The current volume of highly concentrated brines generated in New York State would require a 75,000 gpd facility. Annual costs associated with constructing a 150,000 gpd facility and operating under the 75,000 gpd conditions were also investigated. The minimum cost to treat a gallon of brine for this facility is projected to be $0.0324. Thus, the facility would break-even or experience a minimal profit at $0.0325/gallon brine treated and would require a payback period of 10.6 years. At $0.035/gallon brine treated, a profit of $68,585 per year is possible with a payback period of 8.7 years. The internal rates of return for both conditions are less than 2 percent.

The costs outlined in Tables 3.11 through 3.13 are believed to be conservative estimates of the costs, and some items should be examined more closely for more accurate pricing. The cost of the land acquisition for the proposed facility is very conservative. The cost for the proposed facility was determined for the acquisition of a 70-acre parcel of land, based on having a facility that would include a reclamation facility (solar ponds). If a reclamation facility is not included considerably less land would be required and hence lower the acquisition land costs. This would reduce the total capital cost.

Polymer costs were calculated based on a one ppm dosage. If polymer dosages of four ppm are required in the full-scale operations, the facility would not be able to operate at a profit at current disposal costs.

The costs to disposal of the sludge generated by the treatment process were determined based on the distance to the closest municipal landfill to the proposed facility. The Ellery Landfill in Chautauqua County is within ten miles from the facility and has tipping charges of $25/ton. This cost is considerably less than privately owned landfills (e.g. CID Landfill in Chaffee) that have tipping charges up to $80/ton and are more than 60 miles from the facility. These conditions would increase the disposal costs along with the operation and maintenance costs of transporting the sludge

In general, the profitability of a brine treatment facility is highly linked to the size of the facility needed and the amount of brine that will be treated on a yearly basis. A treatment plant that is designed and operated to treat over 100,000 gpd is needed to be considered worthy of investment by a private industry. It is clear from the foregoing analysis that the design of the two commercial brine treatment facilities in Pennsylvania are designed to treat 200,000 gpd and require significant brine volumes to remain profitable.

One advantage that a brine treatment facility in New York would have compared to the commercial brine treatment facilities in Pennsylvania is the shorter transportation involved. Transportation time could be reduced an average of one hour, resulting in a savings of about $0.0125 per gallon of brine. Thus, it would be possible to charge a higher price for treatment at a New York facility and still reduce overall brine disposal costs to the state's oil and gas producers. However, as the price charged for disposal is increased, producers will become more likely to shut down wells that generate high volumes of brine.

4. UNDERGROUND INJECTION WELLS

Underground injection of liquid wastes has been widely practiced in the United States for many years (Wentz, 1989). Generally, during underground injection, wastes are placed in well-confined geological formations deep below the surface. With proper planning and maintenance, underground injection does not present an unreasonable risk to human health and the environment.

The major environmental concern associated with underground disposal of wastes is potential contamination of drinking water. Regulations stemming from the Safe Drinking Water Act of 1974 were developed to protect underground drinking water sources from contamination that may be caused by disposal of liquid wastes by underground injection.

The EPA has established five classifications for injection of various types of liquid waste: Classes I, II, III, IV, and V. Brines may be disposed in only Class I or Class II disposal wells. A SPDES permit from the DEC and a federal underground injection control (UIC) permit is required to operate a brine disposal well. Other permits required include a well drilling permit from the DMN and a Part 364 Hauler's Permit to bring brines to the injection site. Financial security documentation is also needed to unsure proper plugging and abandonment of injection wells.

The primary environmental consideration in approving an injection well permit is protection of the groundwater resources by ensuring that the injection well is constructed and operated to prevent movement of injected fluids into or between potential drinking water aquifers.

Stringent controls are required on the casing and cementing of the injection well, as well as the injection pressures permitted during operation. Testing, monitoring and reporting is also mandated. Specific details on UIC regulations may be found in the ***Code of Federal Regulations,*** Title 40, Parts 124, 144, 146, and 147.

BASICS OF INJECTION WELLS

Injection wells for waste disposal usually are dug into limestone or sandstone formations below any underground drinking water sources, and are 2,000 feet or more beneath the surface. These injection zones are normally located between layers of impermeable layers of shale or clay, preventing migration of injected fluids upward.

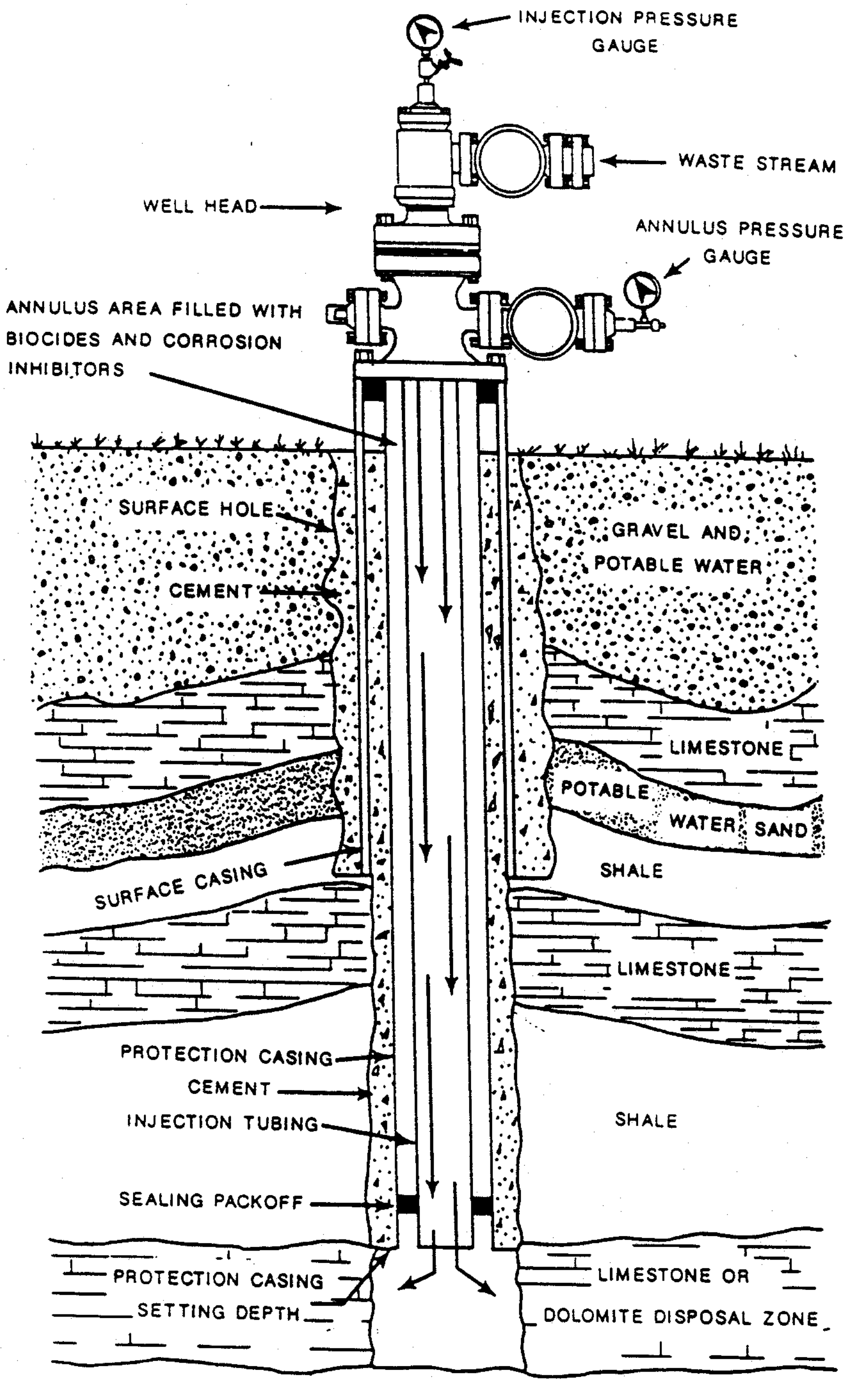


Figure 4.1 SCHEMATIC OF A TYPICAL CLASS I WASTE DISPOSAL WELL

deep and their combined permitted capacity is 876,000 bbl/yr. However, during 1989 only 58,000 bbls. of brine were injected, less than 10 percent of the designed capacity.

There are a number of factors for this. First, because the Akron formation is relatively "tight", injection fluids are not readily accepted. Thus, higher pressures and lower flows result. Costs of injection per unit volume of waste volume are high. Second, only fluids that are very low in solids content may be injected. Plugging of the injection well may result if the solids content of the brine is too high. Therefore, pretreatment is required before brines can be injected, or the types of brines that can be injected must be limited.

To overcome the problems encountered when using the Akron formation, the much deeper Theresa formation is a possible alternative. This formation is "looser" and should readily accept injection fluids. Unfortunately, the Theresa formation around Jamestown is at a depth more than 7,000 feet. Thus, injection wells into the Theresa formation must be nearly three times deeper than the existing injection wells in Chautauqua County.

ECONOMIC ASSESSMENT

For this study, a four-inch injection well at a depth of 7,200 feet was evaluated. This well should be sufficient to accommodate a maximum disposal rate of 75,000 gallons per day. Components for the underground injection facility consisted of a containment area, pumping facilities for unloading brine, storage tanks, flotation, and injection pumping facilities.

An economic cost analysis for an injection well with a 75,000 gpd capacity is outlined in Tables 4.1 and 4.2. The construction costs for the components of the underground two treatment facilities are shown in Table 4.1. Non-component costs are listed in Table 4.2.

The total capital cost for the underground injection facility is projected to be $1.34 million, or about half of the capital cost of the treatment facility with surface discharge. It must be noted, however, that this cost does not include the cost of any pretreatment system that may be required if brine solids must be removed prior to injection, nor does it include the costs for a leak monitoring system. The project life for an injection well is uncertain. For this analysis a five-year well life was assumed.

Pretreatment, if required, may be accomplished using a system similar to that developed in Section 3, or by activated carbon adsorption to remove colloidal particles. The costs for the former alternative would not be different than that previously outlined. The total annual costs for an activated carbon facility designed to treat 75,000 gal/day of brine reported in the

Table 4.1
COMPONENT COSTS FOR UNDERGROUND INJECTION WELL

Component	Cost, $
Drilling	$159,000
Casing	55,400
Cementing	9,100
Testing	60,000
Screens and packing	35,000
Casing and packing installation	7,700
Subtotal - Well installation	$326,200
Storage tanks	150,000
Unloading pumps	33,000
Oil/Grease separator	10,000
Transfer pumps	26,000
Containment area	75,000
Building	100,000
Subtotal - Above ground facility	$394,000
Total Component Costs	$720,200

literature (Breton et al., 1988) as high as $100 per 1000 gallons treated. However, a more reasonable estimate for the total annual cost (capital and O & M) of adsorption is about $3.00 per 1000 gallons treated, or about $77,000 per year.

Table 4.2
NON-COMPONENT AND TOTAL CAPITAL COST FOR UNDERGROUND INJECTION WELL SYSTEM

Piping	31,500
Electrical	19,700
Instrumentation	19,700
Site work	14,400
Contractor O&P	96,600
Engineering	90,200
Contingencies	135,300
Monitoring wells and permits	200,000
Land acquisition	10,000
Total Non-Component Costs	617,400
Total Component Costs	720,200
Total Capital Costs	1,337,600

It is difficult to estimate the total annual costs for an underground injection well. Operation and maintenance costs and costs associated with monitoring are uncertain. These costs are highly dependent on the characteristics of the specific well. However, based on a five-year life and a seven percent discount rate, the amortized capital costs would be $326,240 per year, which is nearly $100,000 more than the treatment facility with surface discharge. The primary reason for this difference is the assumed projects lives, five years for the injection well versus 20 years for the treatment plant.

Annual costs for operation and maintenance include electrical costs, chemical costs (for maintaining porosity of the well), and maintenance for pumps and storage facilities. Other costs include monitoring costs (testing and reporting), and pretreatment costs, if required. Based on a conservative estimate of 10 percent of the component cost for operation and maintenance, $77,000 per year for carbon adsorption pretreatment, and a monitoring cost of $50,000 per year, the total annual cost for the injection well is estimated to be approximately $525,000 per year. This estimate is nearly $300,000 per year less than that for the treatment facility with surface discharge.

Using the estimated total annual cost of $525,000 to dispose of brine by underground injection, the unit cost to treat brine would be about $0.0192 per gallon. Assuming that a disposal fee of $0.0325 per gallon could be charged (the current market price), a profit of $364,700 per year could be anticipated. If $0.035 per gallon of brine treated is charged the potential profit for the facilities is increased to $432,500 per year.

The payback period for the underground facility would be 3.7 years at $0.0325 per gallon charge for disposal and decreases to 3.1 years when a $0.035 per gallon is charged. The corresponding internal rates of return are 37 and 43 percent, respectively. Thus, it would seem that an underground injection well could be operated profitably and may be worthy of private investment.

Based on the foregoing analysis, underground injection wells appear to be a cost effective alternative for brine disposal. There are presently five permitted injection wells (see Section 2) in New York State that have a combined design capacity to meet the disposal needs of the oil and gas producers in New York adequately. However, the amount of brine injected into these wells is less than 10 percent of their permitted capacity. Clearly, there are more factors that affect the use of injection wells for brine disposal than were considered in this analysis; otherwise greater use of these wells would occur.

5. BRINE TREATMENT/SALT RECOVERY FACILITY DEVELOPMENT

From strictly an environmental management viewpoint, resource recovery is a much more desirable alternative than direct disposal into the environment. However, under the current regulatory situation in New York, there is little incentive for producers to consider this alternative and little research has been conducted to assess this possibility. For this reason, a major emphasis of this study was to investigate the technical and economic feasibility of developing a salt reclamation facility using production waters as a feedstock.

Production waters contain a number of inorganic salts which can be used for industrial, municipal or agricultural purposes. The principal constituents with marketable value are sodium chloride (NaCl) and calcium chloride ($CaCl_2$). Based on an average characterization of brines (see Table 2-4), produced waters (other than those from waterflooding operations) contain approximately 14 percent NaCl and seven percent $CaCl_2$. Based on 600,000 bbl. of highly saline brine generated annually, the salt content is about 16,000 tons of NaCl and 8,000 tons of $CaCl_2$.

MARKETABILITY OF RECLAIMED BRINE PRODUCTS

This section of the report concerns the marketability of sodium chloride and calcium chloride reclaimed from by-product brine waters resulting from oil and gas production. The focus is on the competitive supply markets for the products, the demand for the products in end-use applications, the buying behavior among user segments, and the appropriate marketing strategy in each market.

Supply and Demand for Sodium Chloride

Data on the supply and demand for sodium chloride are available from numerous sources. These sources include: the U.S. government (Bureau of Mines, Bureau of Census), industry sources (trade associations such as the Salt Institute), non-governmental statistical reports, and other marketing surveys and reports. Because data reported in this document are taken from various estimates, the numbers in one table might not be exactly the same as in another table. These variations are due the resistance of companies to disclose proprietary production and pricing information, and the difficulty of estimating the volumes held in inventory or distribution centers. The data which are believed to be most accurate are always used and all sources of data are noted at the bottom of each table.

Production of Sodium Chloride. Sodium chloride, or "common table salt," exists naturally and is mined or recovered by several means. Salt is obtained either from underground deposits or from brine solutions at, or near, the earth's surface (including the ocean). The diagram in Figure 5-1 shows the various mining or recovery methods.

Rock salt is mined by conventional room-and-pillar techniques similar to those used to mine coal. Solution mining, in which a saturated brine is obtained, involves the injection of pressurized freshwater into a sunk well. When the water dissolves the salt, the brine is removed from a second, adjacent well. Occasionally, however, natural brine deposits are found underground and simply pumped to the surface. Solid salt may be obtained through the mechanical evaporation of brines from solution mining or from brines that occur near the surface or ocean brines. The process uses heat alone or in combination with vacuum. Solar evaporation is an effective alternative method in areas of high evaporation and low precipitation. The saline water is collected and allowed to evaporate in specially constructed ponds that are separated to isolate the brine during different stages of fractional crystallization.

The United States accounts for 18 percent of the world's salt production, making it the world's largest salt producer. U.S. salt production for 1985 to 1989 by mining or recovery method is given in Table 5-1.

Table 5-1
U.S. SALT PRODUCTION BY TYPE
(Thousand Short Tons)

Year	Vacuum Pans and Open Pans	Solar	Rock	Brine[a]	Total[b]
1985	3,613	2,549	13,990	19,065	39,217
1986	3,637	2,679	13,333	17,633	37,282
1987	3,776	3,120	12,230	17,817	36,943
1988	3,824	3,379	12,750	19,218	39,170
1989	3,975	3,140	13,979	18,184	39,278
Capacity	4,615	4,375	16,795	18,184[c]	43,969

[a] Weight of brine is based on anhydrous salt content.

[b] Data may not add to totals shown because of independent rounding.

[c] Brine capacity is assumed to be the same as production.

Source: Minerals Yearbook, 1989.

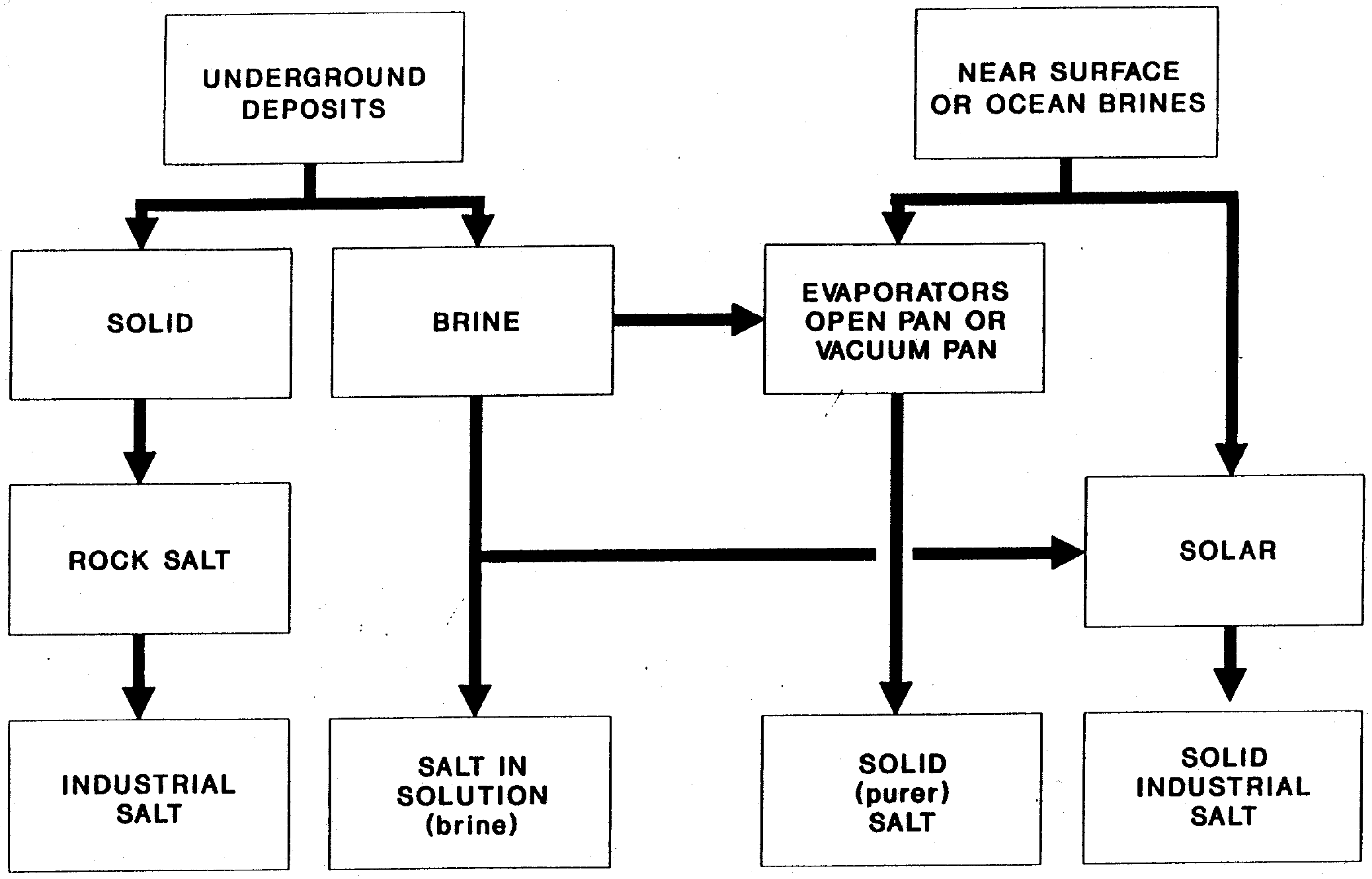


Figure 5-1. VARIOUS MINING AND RECOVERY METHODS TO PRODUCE SALT

U.S. salt production declined 1.5 percent per year from 1970 to 1986 and has been relatively stable in recent years. Brine salt accounted for most of the decline during that time. This decline was due to the reduced use of salt to make synthetic soda ash (none has been produced in the U.S. since 1986) and the declining production of chlorine and caustic soda by the electrolysis of salt. Brine production reached a high of 26.2 million short tons in 1970 and a low point in 1986. (More discussion of these issues is given in the section on the chlor-alkali end-use segment.)

Salt in the form of brine accounts for the largest portion of annual production being just over 46 percent of the 1989 total. The figures for brine production include that for sale and for captive use. Rock, solar, and vacuum pan types accounted for 36, 8, and 10 percent, respectively, of the annual total.

The known capacity for each type of salt (as of December 1988) is given in Table 5-1 along with the production figures. Each type of salt involves a unique set of processing, operational, and marketing characteristics. Capacity for rock salt mining is generally a function of the hoisting capabilities of the mines. Mechanical evaporation depends on the number and size of the vacuum crystallizers operating in series. Solar evaporation, on the other hand,depends on climatic conditions and geographic location. Rated capacity for solar salt is based on historical evaporation patterns. Brine capacities are assumed to be the same as production levels because they are based on the injection rate and solubility rates of underground deposits. Capacities are therefore not meaningful to derive for solution mining. Other than brine, the industry is operating at close to 82 percent of capacity.

The most recent published source (Bureau of Mines Survey, 1989) states that the U.S. salt industry is made up of 31 companies operating 69 facilities in 13 states. Three major suppliers account for 76 percent of industry capacity as follows:

- Akzo Salt Inc. - 38 percent
- Morton Salt Co. - 24 percent
- Cargill Inc. - 14 percent

Concentration has been occurring in this industry since 1982 when 40 suppliers operated at 80 production sites. The closing or consolidation of salt facilities is blamed on market competition, energy and labor costs, less expensive imports, and excess production capacity.

In addition to the known suppliers of salt for purchase, there are numerous chlorine facilities that produce their own brine for "captive" use. Brine producers have historically been lumped together with only aggregate data being available. Recently, however, data on the brine sources and usage of U.S. chlorine facilities have been made available. The total salt requirements (both purchased and captive) for all chlorine facilities is 22.2 million short tons at 100 percent capacity. Fifty-one percent of that chlorine facility capacity uses captive brines. The chemical companies that captively produce their own brines are listed in Table 5-2 along with an estimate of the brine each must produce to operate at 100 percent capacity.

Table 5-2
U.S. SALT-BASED CHLORINE FACILITIES THAT USE CAPTIVE BRINE
(Thousand Short Tons)

	Salt Requirements at 100% Capacity	
Company/Facility Location	Per Plant	Total
Dow Chemical, USA		6,743
Freeport, TX	4,998	
Plaquemine, LA	1,745	
PPG Industries, Inc.		2,502
Lake Charles, LA	2,012[a]	
Natrium, WV	280	
Olin Corp.		999
Augusta, GA	201	
McIntosh, AL	639	
Niagara Falls, NY	159	
Vulcan Chemicals		478
Wichita, KS	478	
LaRoche Chemicals		383
Gramercy, LA	383	
LCP Chemicals & Plastics, Inc.		159
Moundsville, WV	159	
Syracuse, NY[b]	0	
R.M.I. Co.		65
Ashtabula, OH	65	
TOTAL	11,329	11,329

[a] Combination of captive and purchased brines

[b] Closed June 1988

Source: Mineral Industry Surveys, 1989, U.S. Bureau of Mines; Minerals Yearbook, 1989; Chlorine Institute, Pamphlet 10, January 1990.

For 1989, the U.S. salt-based chlorine industry operated at approximately 90 percent of capacity, according to the Chlorine Institute. Captive brine production therefore accounted for approximately 56 percent of U.S. brine production in 1989 (captive brine facilities at 100 percent capacity times 0.90 utilization rate divided by total 1989 U.S. production of brine). The remainder of the required salt is purchased from domestic sources or imported. Only one chlorine facility in New York State is known to use captive brines. Another, LCP Chemical's plant in Syracuse, closed in June 1988.

New York is one of the leading states in salt production. The top five are Louisiana 34 percent, Texas 20 percent, New York 14 percent, Ohio 11 percent, and Kansas 5 percent. The salt production facilities located in New York State are given in Table 5-3.

Table 5-3
SALT PRODUCTION FACILITIES IN NEW YORK STATE

Company	Plant Location	Production Method	Product Form	Production Capacity[a]
AKZO Salt Corp.	Retsof Watkins Glen	Room and pillar Brine wells[b]	Rock Solid	4,000 335
Cargill, Inc.	Lansing Watkins Glen	Room and pillar Brine wells[b]	Rock Solid	1,300 250
Morton International, Inc.	Silver Springs	Brine wells[b]	Solid	275
LCP Chemicals	Solvay	Brine wells	Brine	N/A
Texas Brine Corp.	Wyoming Dale	Brine wells Brine wells	Brine Brine	N/A N/A

[a] Thousand short tons

[b] Vacuum pan evaporation

Source: Mineral Industry Surveys, 1989; Chemical Economics Handbook, 1988.

The three industry leaders have salt production facilities in New York State. In addition, two brine producers, LCP Chemicals and Texas Brine, operate facilities in New York State. (It is believed, however, that LCP Chemicals was phasing out its brine production in 1989.) The capacities for the brine producers were not obtainable.

Prices for sodium chloride are difficult to summarize due to fluctuations in prices during any given year and the lack of information on actual prices paid versus quoted list prices. The

Bureau of Mines estimates prices paid through an analysis of the value of shipments in Table 5-4.

Table 5-4
U.S. UNIT VALUE OF SHIPMENTS FOR VARIOUS TYPES OF SALT[a]
(Average annual value and 1989 constant dollars[b], Dollars per short ton)

	Salt in Brine		Rock Salt		Solar Salt		Vacuum Pan and Open Pan Salt	
Year	Annual Value	Adjusted to 1989 Dollars	Annual Value	Adjusted to 1989 Dollars	Annual Value	Adjusted to 1989 Dollars	Annual Value	Adjusted to 1989 Dollars
1985	6.14	6.99	15.15	17.25	23.10	26.31	92.66	105.53
1986	5.15	5.72	14.51	16.10	23.76	26.37	91.27	101.30
1987	4.93	5.30	14.34	15.43	25.40	27.33	94.21	101.35
1988	3.58	3.73	14.46	15.06	26.59	27.69	97.71	101.74
1989	5.67	5.67	16.38	16.38	27.88	27.88	92.73	92.73

[a] Values are based on the average of all salt producers' valuations reported to the Bureau of Mines of the finished salt in bulk, compressed pellets, and packaged, f.o.b. plant, and includes all processing costs, depreciation of equipment, taxes, and profit.

[b] From final 1989 implicit price deflators for gross national product, by the Council of Economic Advisors, based on 1982 = 100.

Source: Salt Minerals Yearbook, 1989, p. 871.

Variations in prices across forms generally reflect processing cost differences (i.e, energy, mechanical processing). The average price of evaporated salt is considerably higher than rock salt or salt in brine.

Because salt has relatively low production costs and high-bulk density, shipping costs are usually a large part of the selling price. Moreover, salt is ill-suited for international trade. U.S. Imports and Exports for the years 1985 through 1989 are given in Table 5-5.

In 1989, the U.S. imported nearly four times the quantity of salt that it exported. Imports reached a high of 7,545 thousand short tons in 1984 but are likely to remain stable at the level of 6,000 to 7,000 thousand short tons or 13 to 16 percent of U.S. consumption. Costs for imported salt were often lower than for domestic salt because of lower production costs and favorable currency exchange rates. Most salt is imported by foreign subsidiaries of major U.S. salt producers. Except for rock salt from Canada, the imports are almost all solar salt. Exports averaged two to three percent of U.S. production in recent years. Most of the exported salt came from eight domestic companies and was sent to Canada.

Table 5-5
U.S. SALT PRODUCTION, IMPORTS, EXPORTS, AND CONSUMPTION

(Thousand Short Tons)

	1985	1986	1987	1988	1989
Production	39,217	37,282	36,943	39,170	39,278
Sold or Used	40,067	36,663	36,493	38,940	38,856
- Exports	904	1,165	541	884	1,567
+ Imports	6,207	6,665	5,716	5,474	6,084
Consumption	45,370	42,163	41,668	43,530	43,373

Source: Minerals Yearbook, 1989.

Consumption of Sodium Chloride (NaCl). More than 43 million tons of domestic and imported salt were consumed in the United States in 1989. The value of this market is more than $650 million. Calculations of consumption for 1985 to 1989 were given in Table 5-5. The 43,473,000 short tons of salt consumed in the U.S. in 1989 is virtually the same amount consumed in 1988.

New York State is the largest consumer of salt (other than salt in brine) in the U.S. (2,655,00 tons in 1989) followed by Ohio (2,153,000), Illinois (1,937,000), Pennsylvania (1,635,000), Michigan (1,626,000) and Wisconsin (1,211,000) due mostly to the weather conditions in these states and the usage of sodium chloride for deicing. The breakdown of salt usage in New York State is given in Table 5-6.

Table 5-6
SALT CONSUMED IN NEW YORK STATE BY TYPE

(Thousand Short Tons)

	Year				
Type	1985	1986	1987	1988	1989
Vacuum Pans and Open Pans	243	248	256	266	249
Solar	a	a	97	75	61
Rock	2,415	a	2,092	2,172	2,345
TOTAL	N/A	N/A	2,445	2,513	2,655

[a] Withheld to avoid disclosing company proprietary data.

Sources: Minerals Yearbook, 1986, 1988, 1989.

The major uses of salt are the inorganic chemical industry for the production of chlorine and caustic soda, for snow and ice removal, as a mineral in animal diets, and as a food preservative and flavoring agent for human consumption. The use of salt by the various end-use segments are given in Table 5-7.

Table 5-7
DISTRIBUTION OF DOMESTIC SALT BY END USE AND TYPE
(Thousands of Short Tons)

End Use	Vacuum Pans & Open Pans	Solar	Rock	Salt in Brine	TOTAL[a]
Chemical	786	562	1,711	16,897	19,957
Food-processing industry	877	184	339	2	1,404
General industrial	352	777	686	342	2,155
Agricultural	394	334	615	[b]	1,341
Water treatment	44	186	277	11	517
Ice control and/or stabilization	11	291	11,146	13	11,461
Distributors	1,938	1,180	1,284	4	4,408
Other[c]	122	230	1,247	967	2,566
TOTAL	4,524	3,744	17,305	18,236	43,808

[a] Includes imports

[b] Less than 1/2 unit

[c] Includes exports

Source: Minerals Yearbook, 1989.

The chemical industry is the largest consumer (46 percent of all consumption) of salt, mostly brine. About 93 percent of the salt in brine is used by the chemical industry, with almost 100 percent going to chlor-alkali producers. Those producers manufacture chlorine and its co-product, sodium hydroxide or "caustic soda." Ice control and/or road stabilization accounts for another 26 percent of all consumption of salt in the U.S. Most rock salt (64 percent) is used for this application.

General industrial uses include leather tanning, textile dyeing, soap making, pulp and paper manufacturing, ceramics manufacturing, rubber manufacturing, refrigeration, oil-well operation, and pigment and dry-detergent formulation. These are all small-use applications but, in total, consume almost 5 percent of all salt and are the largest consumers of solar salt. The next largest end-use segment is the food-processing industry which uses 3.2 percent of total consumption. Salt from mechanical evaporation is used most heavily in the food-processing industry.

The annual growth rate of demand in the U.S. is expected to be one to three percent during the period from 1986 to 1991 (compared to -0.5 percent for the period 1981 to 1986). The trend in demand, however, varies somewhat by end-use segment. The forecasted growth rates of consumption for some end-use segments are given in Table 5-8.

Table 5-8
FORECASTED GROWTH RATES FOR SALT BY END USE, 1986-1992

End Use	Average Annual Growth Rate
Chemicals	
Caustic soda and chlorine	0-1.3%
Other chemicals	2%
Snow and ice control	0.0%
Food processing	0.0%
Feed dealers, mixers	1-2%
Industrial	1-2%
Miscellaneous	0-2%

Sources: Minerals Yearbook, U.S. Department of the Interior, Bureau of the Mines; CEH estimates.

The forecasts for growth are near zero or slight. The factors influencing the flat forecast for chlor-alkali and deicing are discussed in a later section. The food processing and agricultural uses tend to move with GNP, however, the pressure to reduce salt in human diets will mitigate that growth in food processing. In previous years, when petroleum and natural gas drilling were increasing, the use of industrial salt grew by 5 percent per year, but that growth has leveled off. Overall, domestic consumption is expected to rise, on average, 1.5 percent per year through 1995.

Supply and Demand for Calcium Chloride

In-depth information on the calcium chloride industry is sparse and difficult to obtain because the industry is small, and the one dominant supplier (68 percent of the market) is reluctant to disclose data that may be proprietary. Most of the data in this section were obtained from government agencies and trade associations that survey end-users and then "back-in" to the industry-level estimates.

Production of Calcium Chloride ($CaCl_2$). The calcium chloride produced in the U.S. comes from both natural and synthetic sources. Brines are the sources of natural calcium chloride. Synthetic calcium chloride is produced by reacting hydrochloric acid with calcium carbonate. (Prior to 1986, calcium chloride was also produced as a by-product of the reaction of calcium hydroxide with ammonium chloride in Solvay (synthetic) soda ash production). Today, most calcium chloride produced domestically comes from natural brines. The precise breakdown of natural versus synthetic quantities produced, however, has never been made available to avoid disclosing company proprietary data. Table 5-9 gives the total quantity figures for U.S. calcium chloride production (in thousand metric tons) for 1985 through 1988 (the latest year for which complete data are available).

Table 5-9
U.S. PRODUCTION AND APPARENT CONSUMPTION OF CALCIUM CHLORIDE
(Thousand Short Tons[a])

Year	Production	Imports	Exports	Apparent Consumption
1985	584	39	23	600
1986	419	82	15	486
1987	462	157	24	595
1988	467	154	16	605

[a] 100% CaCl2 Equivalent

Source: Chemical Economics Handbook, 1990.

Calcium chloride is usually produced as a solution with a concentration of 30 to 45 percent. It can undergo further evaporative processes to produce an anhydrous form (pellets or flakes) of up to 97 percent calcium chloride concentration.

Five companies operating in either Michigan or California produce natural calcium chloride from brines. Dow Chemical Co. and Wilkinson Chemical Corp. are the leading producers of calcium chloride from natural brines. Both use Michigan brines. Dow produces calcium chloride solutions, flakes, and pellets while Wilkinson produces solutions only. U.S. suppliers, production capacities and available product forms are listed in Table 5-10.

Table 5-10
U.S. SUPPLIERS, PRODUCTION CAPACITY, AND PRODUCT FORMS OF CALCIUM CHLORIDE (100% $CaCl_2$)
(Thousands of Short Tons)

Supplier	Annual Production Capacity	Type	Product Form	Location of Production Facilities
Dow Chemical	545	Natural	Solutions, Flake, Pellet	Michigan
Tetra Technologies, Inc.	121	Synthetic	Solutions, Pellet	Louisiana
Allied-Signal, Inc.	50	Synthetic	Solutions	Louisiana
The Wilkinson Corp.	19	Natural	Solutions	Michigan
Hill Brothers Chemicals Co.	16	Natural	Solutions, Flake	California, Utah
Cargill, Inc. - Leslie Scott Co., Sub.	15	Natural	Solutions	California
Lee Chemical, Inc.	12	Natural	Solutions	California
National Chloride Co.	11	Natural	Solutions	California
Occidental Chemical Corp.	7	Synthetic	Solutions	Washington
Standard Chlorine Chemical Co., Inc.	5	Synthetic	Solutions	Delaware
TOTAL CAPACITY	801			

Source: Chemical Economics Handbook, 1990.

Although actual production of each company is not available, it is clear that Dow Chemical is the dominant supplier with more than 68 percent of total industry capacity. The industry is highly concentrated with the top three suppliers accounting for more than 80 percent of industry capacity. None of the production facilities is located in New York State.

Prices for calcium chloride vary widely based on grade, geography and logistics. For these reasons, prices are difficult to estimate or project. Moreover, actual prices are negotiated and usually discounted. Table 5-11 lists the year-end 1989 published (list) prices and specifications.

Recent trends in prices can be viewed in Table 5-12. Projections are for stable prices over the next several years.

Data for Imports and Exports were given in Table 5-9 along with production figures. Most U.S. trade in calcium chloride takes place with Canada although trade with Mexico has increased in recent years. Very little calcium chloride is exported by the U.S. (3.4 percent of production in 1988) and almost all of it goes to Canada. Most exports are believed to be in pellet form. Imports from Canada are primarily 77 percent flake form but solutions are also imported. Most of this is synthetic calcium chloride, produced in Ontario.

Table 5-11
YEAR-END PUBLISHED PRICES FOR CALCIUM CHLORIDE, 1989

Products and Specifications	Value per Short Ton
Calcium chloride concentrate, regular grade, 77%-80%, flake, bulk, carload, works	$153
100-pound bags, carload, same basis	196
Anhydrous, 94% to 97%, flake or pellet, bulk, carload, same basis	217
80-pound bags, carload, same basis	279
Brining grade, 80-pound bags	285
Calcium chloride, liquid, 100% basis, tank car, tank truck, barge	113
45% same basis	134
Calcium chloride, United States Pharmacopeia, granular, 275-pound drums, truck load, freight equalized	1,580

Source: Chemical Marketing Reporter, V. 237, No. 1, Jan 1, 1990, p. 33.

Table 5-12
HISTORICAL PRICE DATA FOR CALCIUM CHLORIDE, 1985-1989
(Dollars per Short Ton)

Year	Flake[a]	Pellets[b]	Solution[c]
1985	196.00	279.00	108.00
1986	182-205	275-320	104-118
1987	196.00	279.00	118.00
1988	196.00	279.00	118.00
1989	180-230	260-320	105-150

[a] 77-80%, 100-pound bags

[b] 94-97%, 80-pound bags

[c] 40-50% CaCl2, 100% basis

Source: Chemical Economics Handbook, 1990.

Consumption of Calcium Chloride ($CaCl_2$). As indicated previously in Table 5-9, the total volume of calcium chloride consumed in U.S. in 1988 was 605,000 short tons. Using average end-use prices, this market is about $85 million per year.

The uses of calcium chloride are related to its hygroscopicity (ability to absorb water vapor), high solubility, high heat solution, and low freezing point. Table 5-13 shows the major uses for calcium chloride domestically.

Table 5-13
CALCIUM CHLORIDE USES
1988 U.S. Consumption

Use	Volume[a] (Thousand Short Tons)	Percent of Total
Highway De-icing	212	35%
Dust Control/Stabilization	133	22%
Industrial Processing	121	20%
Oil Recovery	61	10%
Concrete Treatment	30	5%
Tire Ballasting	24	4%
Other (Food processing, desiccants, food additives, etc.)	24	4%
Total	605	100%

[a] All data were reported as 100% $CaCl_2$

Source: Report by Chemical Economics Handbook - SRI, 1990, Chemical Marketing Reporter, CEH estimates and Bureau of the Census Data Report.

The principal use of calcium chloride is to melt snow and ice from roads. Calcium chloride is also used for stabilizing road bases and controlling dust. Industrial uses include the manufacture of various calcium compounds, to coagulate latex emulsions in the manufacture of rubber, to remove water from petroleum fractions, freezeproofing of coal, as an additive to pelletized ore in steel industry blast furnaces, to increase the web strength of corrugated media in the manufacture of paper, and by a variety of industries for wastewater treatment.

Application in oil recovery are in drilling muds, cementing operations, and workover/completion fluids. For the concrete industry, calcium chloride shortens the setting time of cement and provides early strength. In tire ballasting, calcium chloride lowers the freezing point and increases the weight of water added to off-road tires to improve traction. Other uses are numerous, small-volume applications.

The U.S. consumption of calcium chloride is tied closely to its use in deicing and dust control. Thus, demand is often erratic since it is dependent on weather conditions from year to year. Environmental and economic issues related to this use are discussed in the next section on end-use segments. Because of the problems related to rust and corrosion and the relatively higher cost of calcium chloride over rock salt, government agencies are seeking alternatives for deicing materials. Consumption for dust control is expected to be stable over the next five years.

Overall, consumption of calcium chloride has been declining slowly for many years, approximately 0.2 percent per year from 1980 to 1989. Projections are for a growth rate of zero to two percent per year for the near future.

End-Use Segments

An analysis of the supply and demand for sodium and calcium chloride shows that there are a few dominant end-use segments in each product/market and several other segments with small, but significant product usage. For sodium chloride, the most important end-use segments are chemical production and ice control/stabilization. For calcium chloride, ice control and dust control are the major end-use markets. While these dominant end-use segments require a closer examination simply because of the large volumes of product usage, the other segments were screened for potential viability as outlets for the products of a brine reclamation facility. The reasons for eliminating these segments from further evaluation are given in the final (discussion) section. This section provides information on the chlor-alkali industry and the ice control-stabilization-dust control segment.

Chlor-Alkali Industry. Chlor-alkalis are known as basic chemicals because they are used both as building block materials, and as processing aids and catalysts in the production of other chemical and non-chemical products. The sodium chloride industry is a primary upstream supplier to the chlor-alkali industry. In turn, the chlor-alkali industry produces chlorine, caustic soda, and soda ash for use by other manufacturers. Chlorine and caustic soda are co-products resulting from the electrolysis of salt brine. The process requires 1.75 tons of salt to produce one ton of chlorine and 1.1 tons of caustic soda. Changing demand for either product therefore effects the other. Since soda ash production is unrelated to sodium chloride, it will not be considered here.

Chlorine's primary uses are as a raw material in the production of polyvinyl chloride resin (24 percent), other chemicals (20 percent), and in pulp bleaching and paper production (14 percent). Other uses include water and sewage treatment and metal extracting. Because of its use in polyvinyl chloride, the demand for chlorine is closely tied to the housing and automotive industries.

Caustic soda is used primarily in the production of other chemicals (50 percent) and in pulp and paper manufacturing (25 percent). Other important markets are aluminum, soaps and detergents, textiles, petroleum and gas processing, and water treatment. Caustic soda reacts more slowly than chlorine to fluctuations in the economy.

From 1976 to 1986, there was no growth in the chlorine-caustic soda industry. Due to downsizing among many important end markets and increased world competition, some 20 plants closed in the early 1980's due to weak demand. Although the industry went through this restructuring, it has now stabilized. Since 1986, the industry has seen healthier business conditions. There are presently 24 companies operating 52 chlor-alkali plants in the U.S. The major producers and their share of U.S. capacity is given in Table 5-14.

Table 5-14
U.S. CHLOR-ALKALI PRODUCERS

Firm	Percent of U.S. capacity
Dow Chemical	27
Occidental	26
PPG	13
Olin	7
Vulcan Chemicals	5
Georgia Gulf	4
LCP Chemicals	4
Pioneer Chlor Alkali Co.	2
Penwalt	2
Niachlor	2
DuPont	4
Others	8

Source: <u>Chemical Profiles</u>, 1989.

The two largest U.S. chlor-alkali producers are Dow Chemical and Occidental Chemical. These two companies account for more than half the total U.S. capacity. Several chlor-alkali producers are located in New York State -- all are located in Niagara Falls. Their capacities are listed in Table 5-15.

Table 5-15
CHLOR-ALKALI INDUSTRY IN NEW YORK STATE

Company	Location	Chlorine capacity[a]
Occidental	Niagara Falls	885
Olin	Niagara Falls	250
Niachlor (Olin/DuPont)	Niagara Falls	660
DuPont	Niagara Falls	165

[a] tons per day

Source: CPI Purchasing, July 1989.

Information related to the operations of the chlor-alkali producers is proprietary. It is therefore not possible to know the suppliers of brine to those plants. While it may be possible to infer which brine suppliers are meeting the needs of the chlor-alkali producers, the capacities and volumes of the brine suppliers are also not available. From discussions with government statisticians at the Bureau of Mines and other industry experts some knowledge of industry activity could be developed. It is thought that Olin supplies most of its Niagara Falls plant requirements with captive brine sourced through direct pipelines from the source well. Niachlor is also known to obtain feedstock through a pipeline operated by Texas Brine. Thus, Niachlor obtains 100 percent of its brine from Texas Brine, but it is unclear as to which company actually owns the pipeline. DuPont sources half of its requirements from Morton and the other half from Akzo. Occidental obtains about 10 percent of its requirements from captive brines sourced through its own wells and then splits the remainder between two outside suppliers, about 30 percent to one, and 60 percent to the other. This information is anecdotal, however, and may not be accurate.

It make sense therefore to consider the trends and outlook for the chlor-alkali industry in an effort to evaluate the likelihood of a successful entry as a sodium chloride supplier.

In 1989, the chlor-alkali industry was experiencing its best performance in more than a decade. This was a result of strong demand from domestic end-markets and strong exports due to the weakened U.S. dollar. Rising output for 1987-1989 reflected, in part, the start-up of a new 660 ton per day plant built by Olin and DuPont in Niagara Falls. The increased demand, however, is spurred by strong demand for caustic soda. While chlorine demand is strong in polyvinyl chloride (growth rate of 2.7 percent), this growth in demand is being negated by the enormous pressure to reduce the use of chlorine by the pulp industry, and to reduce emissions of chlorine-based compounds (such as those in chloroflourocarbons). On the other hand, caustic soda raises little concern over environmental impacts.

Chlorine demand has traditionally grown faster than caustic soda, but the trend reversed in the late 1980's as environmental concerns caused chlorine demand to slow while industry demand for caustic soda continued to grow. As such, U.S. caustic soda output will be constrained by chlorine production. Chlorine is both dangerous and expensive to store and the supply of caustic soda is likely to be short. Moreover, prices of caustic soda have been rising drastically relative to chlorine. Consequently, the industry is looking into methods for making caustic soda that will add to that being produced by the electrolysis of sodium chloride but that will not produce additional chlorine. In light of these economic and environmental conditions, the chlor-alkali industry is projected to grow at a meager zero to two percent per year.

Roadway Uses: Ice Control, Stabilization, and Dust Control. There are three "roadway" uses of salt and calcium chloride: ice control, stabilization, and dust control. In addition to unpaved roads, calcium chloride is also used to control dust in the bulk shipment of mined materials. This use is grouped with roadway dust control for this analysis.

Sodium chloride is the primary deicing chemical in the U.S. Calcium chloride is the second largest deicing chemical and is preferred in severe weather conditions. Sodium chloride is highly corrosive and loses its effectiveness below 25°F, but is significantly less expensive than calcium chloride. Mixtures of both chemicals are popular.

Because the consumption of deicing chemicals is dependent on the severity of the winter, the consumption often varies by 20 percent or more from year to year. Overall, sales of deicing chemicals have been flat over the last several years due to mild winters in the U.S.

Concerns have been raised in recent years about the corrosive effects of salt on vehicles and roadway structures and because of the degradation of water supplies and vegetation near where the salt is applied. Concern about the corrosive effects has prompted the development of specialty deicing products containing salt or calcium chloride in conjunction with anticorrosion additives. While these products are effective in reducing corrosion, they are significantly more expensive and have had difficulty penetrating the market. Calcium magnesium acetate, produced by Chevron Corporation since 1987, is priced at $500 per short ton and requires twice as much product for application than sodium chloride. It is unlikely that this product, or others, will have a noticeable effect on sodium chloride consumption for snow and ice control.

While there seems to be little hope for an economical substitute, attention has focused on more efficient management and procedures for road spreading. Most studies indicate that 500 pounds of salt per lane-mile of roadway is most effective, but this rate varies with temperature, snowfall, and other conditions. By altering the spreading rates, variations in equipment, and the addition of abrasive, more efficient use of deicing chemicals can be achieved.

The properties of calcium chloride make it uniquely effective in dust control and stabilization operations. It dissolves readily by attracting moisture from the air and other sources. Also, in solution it retards the rate of moisture evaporation, and acts as a compaction aid. Consequently, it retains fine particles in the unpaved surface and base, and contributes to the stability of the structure.

Almost all highway deicing in New York State is accomplished by using crushed rock salt or a mixture of rock salt and abrasives (generally sand). A large portion of the salt is purchased through collective State bids. The estimated usage for the 1990-1991 season for the political municipalities and state agencies was 611,187 tons. The usage by county and the ranges of prices in the bid award are listed in Table 5-16.

The New York State Department of Transportation solicits separate bids for its requirements. Their usage estimates are given in Table 5-17.

Approximately 100,000 tons are used by the New York State Thruway Authority. The total usage for the political subdivisions, state agencies, Department of Transportation, and New York State Thruway Authority is 1,220,287 tons. This total is <u>not</u> the same as total usage in New York State. Additional usage by political subdivisions that choose not to buy on state bid and private road deicing would have to be added. However, those estimate are not obtainable.

Table 5-16
NEW YORK STATE POLITICAL SUBDIVISIONS AND AGENCIES ESTIMATED SALT REQUIREMENTS
(1990 to 1991)

County	80-lb. bags, (tons)	Price, $/ ton	Bulk, tons	Price, $/ton	Total Usage
Albany	72	87.62	36,195	28.78-31.40	36,267
Allegheny	-	-	1,688	29.77-31.55	1,688
Bronx	-	-	50	38.36	50
Broome	-	-	6,178	36.13-38.36	6,178
Cattaraugus	22	80.18	650	29.22-29.27	672
Cayuga	-	-	16,044	24.03-24.19	16,044
Chautauqua	-	-	154	33.12-34.60	154
Chemung	-	-	1,900	37.23	1,900
Chenango	-	-	8,300	31.70	8,300
Clinton	144	100.10	15,878	28.16-34.23	16,044
Columbia	-	-	158	42.54-42.62	158
Cortland	-	-	6,635	26.70-26.77	6,635
Delaware	-	-	575	40.42-40.59	575
Dutchess	44	91.57-93.88	834	31.08-43.93	878
Erie	132	75.49-76.75	39,439	21.84-25.97	39,571
Essex	-	-	15,260	31.05-37.23	15,260
Franklin	-	-	1,462	27.95-34.65	1,462
Genesee	-	-	350	34.50	350
Greene	-	-	4,486	34.86-35.07	4,486
Hamilton	-	-	3,554	36.79-36.98	3,554
Herkimer	-	-	140	32.88	140
Jefferson	-	-	75	34.72	75
Kings	62	90.04-91.64	-	-	62
Livingston	-	-	7,800	32.55-33.23	7,800
Madison	-	-	12,662	31.07-32.48	12,662
Monroe	-	-	72,499	25.10-27.10	72,499
Montgomery	-	-	3,900	32.59-32.69	3,900
Nassau	150	94.64	7,840	31.72-33.31	7,990
New York	30	94.74	40	33.03	70
Niagara	86	78.06	26,049	23.87-27.38	26,135
Oneida	68	78.06-78.84	30,000	25.03-28.41	30,068
Onondaga	66	87.37	566	32.59	632
Ontario	-	-	24,412	21.44-25.31	24,412
Orange	-	-	1,207	39.11-39.18	1,207
Orleans	-	-	7,148	29.91-32.11	7,148
Oswego	22	90.11	250	31.03	272
Ostego	-	-	4,998	33.35-33.50	4,998
Putnam	-	-	1,800	39.39	1,800
Rensselaer	-	-	30,060	29.61-32.91	30,060
Richmond			70	35.83	70
Rockland	46	95.42-97.72	22,879	32.78-34.30	22,925
St. Lawrence	-	-	1,855	27.58-40.01	1,855
Saratoga	-	-	2,105	33.33-33.42	2,105

Table 5-16
(continued)

Schenectady	22	91.49	15,989	29.59-32.21	16,011
Schoharie	-	-	3,807	33.88-34.00	3,807
Seneca	-	-	2,420	25.50-25.54	2,420
Steuben	-	-	32,647	20.74-25.25	32,647
Suffolk	-	-	30,017	33.11-41.09	30,017
Sullivan	-	-	60	40.85	60
Tioga	-	-	6,972	31.94-32.00	6,972
Ulster	-	-	1,456	34.71-34.86	1,456
Warren	-	-	2,000	35.90	2,000
Washington	-	-	8,956	34.95-37.67	8,956
Wayne	-	-	20,500	22.81-25.74	20,500
Westchester	66	97.06-98.84	47,090	30.17-33.64	47,156
Wyoming	-	-	16,096	25.65-29.31	16,096
Yates	-	-	4,000	27.65-27.75	4,000
TOTAL	1,032	75.49-110.10	610,155	21.48-42.62	611,187

[a] All prices are dollars per short ton, delivered

Sources: "Notice of Contract Award," Bid Number 2485-Z, Office of General Services, Standards and Purchase Group, Executive Department, State of New York, September 15, 1990-May 31, 1991.

Table 5-17
NEW YORK STATE DEPARTMENT OF TRANSPORTATION ESTIMATED SALT REQUIREMENTS
(1990-1991)

Region Number	Estimated Quantity[a], tons	Price Range, $/ton
1	66,200	29.35-37.60
2	47,500	24.20-33.85
3	63,900	19.30-26.00
4	40,300	25.42-28.92
5	65,100	22.56-28.31
6	37,700	18.45-27.50
7	67,350	24.44-30.88
8	60,300	30.19-36.30
9	49,450	24.35-38.14
10	11,300	31.14-37.91
TOTAL	509,100	18.45-38.14

[a] All product was purchased in bulk

Source: "Notice of Contract Award", Bid Number 2490, Office of General Services, Standards and Purchase Group, Executive Department, State of New York, September 15, 1990-May 31, 1991.

For roadway de-icing, calcium chloride can be used by itself in pellet form or as an additive to rock salt in pellet or liquid form. Because of the higher cost, many highway departments use rock salt that is pre-wet with liquid calcium chloride or mixed with calcium chloride pellets. Used in conjunction with rock salt it achieves faster road deicing, extends the salt's temperature range, and reduces the amount of deicer per mile thus reducing spreading time as well.

The relative usage of calcium chloride to sodium chloride for deicing is difficult to estimate. According to Duane Amsler of the Department of Transportation, about 4.2 million gallons of 32 percent calcium chloride is used in New York State each year (6,000 tons). The solution is sprayed on the loads of salt prior to application. In addition, about 200 tons of calcium chloride flakes are used by the Department of Transportation to thaw drainage structures. George Stipanovich states that Erie County used about 40,000 tons of sodium chloride in 1989-90, but used less than 250 tons of calcium chloride, and much of that was used on construction jobs for dust control.

There is frequent debate about the precise economics of using sodium chloride versus calcium chloride for deicing. Some highway departments use virtually no calcium chloride. Others believe there is always a need for calcium chloride wherever snow and ice are a problem based on recommendations in trade publications (i.e., Public Works). The difficulty arises from efforts to attach economic estimates to the benefits of calcium chloride mixtures. It is widely known that calcium chloride makes the rock salt work faster and at lower temperatures. Indirect benefits of mixing in pellets or pre-wetting the rock salt include: less deicer required per mile; crews treat more miles in less time; abrasives are more manageable; melts more ice; leaves no powdery residue; and less threat of concrete damage. These benefits are difficult to quantify; therefore, most highway superintendents base their decisions on cost per ton of deicing chemical.

Estimates for the total use of calcium chloride for road deicing in New York State have not been obtainable. A reasonable estimate would be 29,000 tons based on the assumption that New York State's use of calcium chloride as a portion of total U.S. volume (for highway deicing) is the same proportion as its use of total U.S. rock salt (13.8 percent). There seems to be no reasonable basis on which to estimate the total use of calcium chloride in New York State for dust control and road stabilization.

Study of Buyer Behavior

To better understand the potential customers for reclaimed brine minerals and to provide guidance for the development of marketing strategies, a survey of end-users was conducted. Since the demand in the end-use segments can be estimated from industry data, the purpose of the survey was to examine the buying decision process in each of the end-use segments. This section describes the survey procedures and reports the results.

Research Method. During the earlier stages of the project, numerous personal interviews were conducted with decision makers in each of the end-use segments. These revealed general themes that were useful for structuring a quantitative mail survey of potential customers. The analysis of secondary data reported in the previous sections indicated that the chlor-alkali producers and Departments of Transportation were the end-use segments with the greatest volume usages. The survey was therefore designed to understand the buying behavior of those two segments. In addition, buyers from a wider variety of end-use segments were included as a basis for comparison. The results provide a description of the types of purchases transacted, buying criteria of the decision makers, sources of information used in the decision process, and the substantive content (topics) of that information.

The three sources for the names and addresses of potential buyers were the National Association of Purchasing Management, American Feed Industry Association, and New York State Superintendents of Highways. A total of 1,055 questionnaires was mailed to potential respondents in the end-use segment, as summarized in Table 5-18.

A personalized cover letter asked respondents to fill out the questionnaire if they were responsible for buying salt or calcium chloride; or pass the questionnaire along to a person who has responsibility for buying those products for the organization. If the organization did not purchase either product, the respondents were asked to return the questionnaires unanswered. The questionnaire asked for information about the organization, respondent, "last" purchase of sodium and/or calcium chloride, characteristics of the decision process, and the annual use of the products. Thus, the results give a close look at some recently made decisions.

Table 5-18
SAMPLING FRAME AND RESPONSE

Industry	SIC Code	Source of Names and Addresses	Q's Mailed	Response
Oil & Gas Extraction	1300	National Association of Purchasing Managers	49	1
Food & Kindred Products	2000		50	10
Animal Feed	2048	American Feed Industry Association	91	8
Textile Mill Products	2200	National Association of Purchasing Managers	50	2
Paper & Allied Products	2600		50	
Chemicals & Allied Products	2800		87	2
Chloralkali Producers	2821			5
Petroleum Refining & Related Industries	2900		50	2
Rubber & Miscellaneous Plastics Products	3000		50	
Leather & Leather Products	3100		21	
Stone, Clay, Glass and Concrete Products	3200		50	
Primary Metal Industries	3300		50	
Fabricated Metal Products, Except Machinery & Trans. Equip.	3400		49	
Machinery, Except Electrical	3500		50	1
Transportation Equipment	3700		50	
Other Industry	n.e.c.			1
Road Spreading (Gov't)	9621	State of New York, Department of Transportation; Directory of Town Superintendent of Highways		37
Albany			9	
Allegheny			29	
Cattaraugus			32	
Cayuga			21	
Chautauqua			27	
Commis			57	
Cortland			15	
Erie			25	
Franklin			19	
Genesee			13	
Monroe			20	
Niagara			12	
Onondaga			19	
Orleans			10	
TOTAL			1055	68

There are several plausible explanations for the relatively low response rate in this particular survey. In the segments for which there was no response, most are small-volume applications which decreased the likelihood that the questionnaire would reach the primary decision maker in the organization. For others, such as chlor-alkali producers, the information requested in the questionnaire is considered proprietary. Although we assured the anonymity of the respondents, their concerns may not have been resolved. Finally, there was some informal feedback (handwritten comments on the back of the returned questionnaires) that the questionnaire was difficult to fill out. These reasons, in addition to the lack of pre-notification and follow-up, likely caused the low response rate.

The small sample size precludes the use of any sophisticated statistical tests on the data. Nonetheless, the data are still useful for understanding the buying decision process of sodium and calcium chloride buyers. A description of the organizations and their product usage provides a clearer view of the sample characteristics. Because of the wide variation in the units of measure, purity levels, and forms of the products, a summary of the volumes and types is not possible. Therefore, a description of each respondent organization is given in Table 5-19. The descriptions recorded in this table use the exact words of the respondents.

For analysis purposes, the responses were grouped as highway departments, chlor-alkali producers, and all "other industries." Table 5-20 shows the mix of responses in the three segments according to the reported size of the organization (relative to others).

Grouping the respondents into the three industry segments permits a comparison of the buying process in each. The remainder of the analysis provides averages and/or frequencies for the three segments and the total sample. Table 5-21 first provides descriptive information on the "last" purchase of sodium and/or calcium chloride.

An examination of these data leads to the following summarization of the nature of the transactions:

> **Highway Departments**. This segment is most likely to use a competitive bidding process (84 percent) for the purchase of these products. Competitive bidding is commonly used by governmental agencies (it is often required). In fact, most of these product purchases are made through a State-wide bidding procedure. The purchases are therefore frequently part of a previously negotiated contract and few suppliers are available or need to be contacted. Consistent with this situation, little information is required to make the purchase decision and an average of only two decision participants are involved.

Table 5-19
DESCRIPTIONS OF ORGANIZATIONS AND REPORTED PURCHASES

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
018	SIC 1300 - oil & gas exploration and production	sodium chloride (evaporated) 99% pure 21 kilograms (46.3 pounds) calcium chloride (natural), 99.9% pure 4 cases of 500 cm bottles	small quantities for laboratory use	not given	
011	SIC 2000 - manufacture of dry seasoning blends	sodium chloride (evaporated), purity level not given (food grade assumed), 129,660 pounds (64.8 tons)	base for dry seasoning	2,656 tons sodium chloride price not given	
013	SIC 2000 - corn wet milling (corn oil and specialty foods and soy products)	calcium chloride (natural) 32% purity level 3,000,000 pounds (1500 tons)	added to starch slurry before glucose molecules are broken down to retain calcium levels	1,000 tons calcium chloride @ $96 per ton	reported volume of last purchase is higher than annual usage
030	SIC 2000 - food processing (ketchup, soups, baby food, sauces, vegetables)	calcium chloride (natural) food grade (fine) 70,000 pounds (35 tons)	pickle packing	35 tons calcium chloride @ $.51 per pound	reported price is equal to $1020 per ton
033	SIC 2000 - industrial manufacture of spices and seasonings	sodium chloride (evaporated) 99.9% pure 45,000 pounds (22.5 tons)	ingredient in manufacturing of various seasonings	3,000 tons sodium chloride @ $120 per ton	
041	SIC 2000 - manufacture of food ingredients	sodium chloride (evaporated) 99.9% pure quantity not given	food preservation and flavoring	350 tons sodium chloride @ $90 per ton	
049	SIC 2000 - manufacture of Ramen noodles for grocery sales	sodium chloride (rock) 99% pure 44,100 pounds (22.05 tons)	food manufacturing ingredient	1.6 tons sodium chloride price not given	last purchase amount is greater than annual usage

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
054	SIC 2000 - sugar, beet pulp by-products	sodium chloride (solar) purity level not given 40,000 pounds (20 tons) calcium chloride (natural) purity not given 40,000 pounds (20 tons) magnesium chloride brine 30% purity level 35 tons	water softeners, ion exchange recharging	400 tons sodium chloride price not given 1200 tons brine price not given	magnesium chloride brine is not relevant to this study
056	SIC 2000 - process canned foods: soups, dry beans, salsa, catsup, green beans, tomatoes, hominy, sauces	calcium chloride (synthetic) 93% pure 5,500 pounds (2.75 tons)	firm-up dry beans and tomatoes	8 tons calcium chloride @ $950 per ton	
063	SIC 2000 - processed/packaged meats (wieners, bacon, boneless ham, smoked sausage)	sodium chloride (evaporated) purity not given 50,000 pounds (25 tons)	seasoning of meats	500 tons sodium chloride @ $30 per ton	
012	SIC 2048 - feed mill	sodium chloride (type not given) 99% pure 20 tons	mixed into feed	1000 tons sodium chloride @ $32 per ton	
015	SIC 2048 - specialty animal feed manufacturer (aquaculture, research diets for labs, zoos, pet diets)	sodium chloride (evaporate) 100% pure 2000 pounds (1 ton)	ingredient in animal feeds	12 tons sodium chloride @ $136 per ton	
016	SIC 2048 - animal feed manufacturing	sodium chloride (solar) >98% purity 7000 tons	feed	7000 tons sodium chloride @ $48 per ton	reported last purchase is equal to annual usage
017	SIC 2048 - manufacturer of food products, personal care products, animal feed ingredients	sodium chloride (evaporated) 99.9% pure 24000 pounds (12 tons)	carrier in food products	150 tons sodium chloride @ $75 per ton	
023	SIC 2048 - farmer's cooperative (feed, fertilizer, petroleum, farm supplies)	sodium chloride (rock) 96% pure 24 tons	feed ingredient	600 tons sodium chloride @ $30-$50 per ton	
024	SIC 2048 - private label blender of mineral and vitamin pre-mixes for animal feed and pet foods	sodium chloride (rock) purity not known 25 tons	ingredient in mineral mixes, re-packaging bulk salt in private label packages	3000 tons sodium chloride @ $40 per ton 1 ton calcium chloride @ $360 per ton	

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
037	SIC 2048 - manufacture and sales of animal feeds	sodium chloride (solar) 98% pure quantity not given calcium chloride (synthetic) 98% pure quantity not given	part of feed and mineral mixes	annual usage not given	
064	SIC 2048 - farm cooperative that manufactures livestock feeds	sodium chloride (evaporated) purity not known 25 tons	livestock feed production	1050 tons sodium chloride @ $50.34 per ton	
004	SIC 2200 - textile processing (bleaching, dying, printing, finishing)	sodium chloride (type not given) 99% pure 2500 pounds (1.25 tons) calcium chloride (natural) purity not given 2500 pounds (1.25 tons) brine purity not given 2500 pounds	sodium chloride used for dying calcium chloride and brine beads used to clean boiler	annual usage and prices not given	brine "bead" used as a cleaning agent
036	SIC 2200 - manufacturer of textiles and chemicals	not specified (stated only that they buy "con contract")	dying of textiles, water softening	1870 tons sodium chloride @ $80 per ton	
065	SIC 2800 - petrochemical company (gasoline, olefins, polyethylene, polypropylene, ethylene, specialty chemicals)	calcium chloride (natural) purity not known 675 tons	H-F acid neutralization	675 tons sodium chloride @ 120 per ton 1200 tons brine @ $60 per (dry salt) ton	
067	SIC 2800 - chemical manufacturer (Cl_2, NaOH, vinyl chloride, chlorinated solvents)	products and quantities not given	for laboratory use	annual usage not given	
014	SIC 2812 - chemical manufacturer producing chlorine, caustic and specialty, intermediate and commodity chemicals	calcium chloride (synthetic) 77% pure 6300 pounds (3.15 tons)	used with water to form brine and is used as a refrigerant for caustic process	500,000 tons brine @ $1.63 per ton	
022	SIC 2812 - manufacturer of industrial chemicals	sodium chloride (solar and evaporated) 99.4 - 99.99% pure 400,000 tons	manufacture of chlor-alkali products	400,000 tons sodium chloride @ $40 per ton	
050	SIC 2812 - major chemical producer of basic (industrial) and performance products	sodium chloride (rock) 98.5% pure 400,000 tons	produce chlorine and caustic	400,000 tons sodium chloride price not given	

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
053	SIC 2812 - manufacturer of chemicals and plastics (inorganic and agricultural chemicals at this location)	sodium chloride (solar) 98% pure 3500 tons	chlor-alkali	annual usage and prices not given	
057	SIC 2812 - major producer of glass, coatings, fiberglass and chlorine/caustic	sodium chloride (rock) 98.9% pure 150,000 tons	chlorine/caustic production	150,000 tons price not given	reported purchase was a year-long contract with monthly releases
021	SIC 2900 - refiner of petroleum products	sodium chloride (rock) 90% pure 50,000 pounds (25 tons)	water treating	300 tons sodium chloride @ $620 per ton	reported price seem out-of-line with industry prices
060	SIC 2900 - refining of crude into various petroleum products	calcium chloride (natural) 38% pure 2,160,000 pounds (1080 tons)	water treatment, product treatment	10,764 tons calcium chloride @ $72.64 per ton	
068	SIC 3500 - manufacturer of earthmoving equipment and diesel engines	sodium chloride (rock) purity not known 40,000 pounds (20 tons)	ice control	40 tons sodium chloride price not given 5 tons calcium chloride price not given	
001	SIC 9621 - town highway department	sodium chloride (rock) purity not known 100 tons	salt roads - snow, ice removal on highways	1000 tons sodium chloride @ $26.32 per ton	
002	SIC 9621 - town government, road maintenance	calcium chloride (type not known) 33% pure 4,000 gallons	ice control	4,000 gallons calcium chloride @ $.49 per gallon	
003	SIC 9621 - highway department, road maintenance (summer and winter)	sodium chloride (rock) purity not known 400 tons	snow and ice control	400 tons sodium chloride @ $29.00 per ton	
005	SIC 9621 - town highway department	sodium chloride (rock) purity not known 250 tons	ice control	300 tons sodium chloride @ $26.00 per ton	
006	SIC 9621 - highway department, snow removal and road maintenance	sodium chloride (rock) purity not known 100 tons	ice and snow removal	1000 tons sodium chloride @ $20.00 per ton	
007	SIC 9621 - town highway department, build and maintain roadway system	sodium chloride (rock) purity not known 50 tons	roadway deicer	500 tons sodium chloride @ $29.00 per ton	
008	SIC 9621 - highway maintenance and repair	sodium chloride (rock) purity not known 2500 tons	snow and ice removal on highways	2500 tons sodium chloride @ $25.78 per ton	

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
009	SIC 9621 - complete maintenance of roads within municipality, vegetation control, drainage maintenance, traffic control signs	sodium chloride (rock) 80% pure 300 tons calcium chloride (synthetic) 65% pure 40 50-lb bags (1 ton)	(blank)	45 tons sodium chloride @ $26.47 per ton 1 ton calcium chloride @ $175.00 per pallet of 40 50-lb bags	
010	SIC 9621 - department of public works	sodium chloride (rock) purity not known 100 tons	de-icing	2750 tons sodium chloride @ $30+ per ton 1000 gallons calcium chloride @ $.68 per gallon	
019	SIC 9621 - maintain town highways and road, winter and summer	sodium chloride (rock) 80% pure 120 tons calcium chloride (natural) 51% pure 4000 gallons	salt and calcium chloride used to keep sand from freezing in stockpile, bulk of calcium chloride used for dust control and stabilization	120 tons sodium chloride @ $30.00 per ton 4000 gallons calcium chloride @ $.51 per gallon	
020	SIC 9621 -maintenance of roads and bridges	sodium chloride (rock) 100% pure 25 tons	clear parking lots of ice	250 tons sodium chloride @ $31.00 per ton	stated 100% purity level may not be accurate
025	SIC 9621 - highway maintenance	sodium chloride (rock) 96% pure 100 tons	snow and ice control on highways, stabilization of gravel road surfaces	500 tons sodium chloride @ $22.00 per ton 5000 gallons calcium chloride @ $.24 per gallon	
026	SIC 9621 - town highway department	sodium chloride (rock) purity not known 100 tons calcium chloride (synthetic) 32% pure 2,000 gallons	ice control	1720 tons sodium chloride @ $26.00 per ton 4000 gallons calcium chloride @ $.49 per gallon	
027	SIC 9621 - maintenance of county highways and bridges	sodium chloride (rock) purity not known 40 tons calcium chloride (natural) 80% pure 1,000 gallons	deicing, dust control	7,000 tons sodium chloride @ $12.50 per ton 14,800 gallons calcium chloride @ $.58 per gallon	

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
028	SIC 9621 - administer county highway infrastructure and a county solid waste disposal system	sodium chloride (rock) purity not known 300 tons calcium chloride (natural) purity not known 100 tons	de-icing material mixed with sand	2500 tons sodium chloride @ $30.00 per ton 150 tons calcium chloride @ $70.00 per ton	
029	SIC 9621 - maintenance and up-keep of roadway	sodium chloride (rock) 100% pure 500 tons calcium chloride (natural) 100% pure 3,500 gallons	de-icing of roadways, also dust control and stabilization	3,000 tons sodium chloride @ $39.50 per ton 5,000 gallons calcium chloride @ $.45 per gallon	
031	SIC 9621 - municipal highway maintenance	sodium chloride (rock) purity not known 60 tons	snow and ice control	3,000 tons sodium chloride @ $35.00 per ton	
032	SIC 9621 - maintenance of town owned roads	sodium chloride (rock) 100% pure 750 tons calcium chloride (synthetic) 71% pure 15,000 gallons	rock salt used for snow and ice control calcium chloride used for road base stabilization	volume of sodium chloride not given, price stated as $26.62 per ton volume of calcium chloride not given, price stated as $.72 per gallon	
034	SIC 9621 - highway, maintenance and water repairs for a small town	last purchase not stated	incorporate into gravel roads	5,000 gallons brine @ $.50 per gallon	
035	SIC 9621 - highway department	sodium chloride (rock) purity not known 1400 tons calcium chloride (type not given) purity not known 3,000 gallons	de-icer on highways	1400 tons sodium chloride price not given 3000 gallons calcium chloride price not given	
038	SIC 9621 - plow and sand roads, maintain roads in summer	sodium chloride (rock) 100% pure 125 tons calcium chloride (natural) purity not given 3,500 gallons	mix with grit for sanding roads	1500 tons sodium chloride @ $25.00 per ton 2500 gallons calcium chloride @ $.98 per gallon	last purchase of calcium chloride exceeds stated annual usage

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
039	SIC 9621 - town highway department	sodium chloride (rock) purity not known 5000 tons calcium chloride (natural) 60% pure 2 tons brine 30% pure 1000 gallons	95% used for deicing roads 5% for dust control	5000 tons sodium chloride @ $24.00 per ton 2 tons calcium chloride price not given 1000 gallons brine @ $.54 per gallon	
040	SIC 9621 - construction and maintenance of county road system	sodium chloride (rock) 100% pure 800 tons calcium chloride (natural) 100% pure 20 tons	snow and ice control	4800 tons sodium chloride @ $33.50 per ton 20 tons calcium chloride @ $198.00 per ton	
042	SIC 9621 - highway service	sodium chloride (rock) purity not known 12,000 tons	de-icing	12,000 tons sodium chloride @ $28.00 per ton	
043	SIC 9621 - town highway work	sodium chloride (rock) 100% pure 80 tons	snow and ice control	700 tons sodium chloride @ $30.00 per ton	
044	SIC 9621 - county public works	calcium chloride (natural) purity not known quantity not given	liquid calcium chloride to pre-wet salt and sand	11,604 tons sodium chloride @ $30.00 per ton 80 tons calcium chloride @ $250.00 per ton 3000 gallons brine @ $.80 per gallon	
045	SIC 9621 - public works department	sodium chloride (rock) 85% pure 200 tons	road treatment - snow and ice	10,000 tons sodium chloride @ $24.00 per ton	

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
059	SIC 9621 - highway maintenance	sodium chloride (rock) 100% purity 500 tons calcium chloride (natural) 32% pure 1000 gallons	ice control	4000 tons sodium chloride @ $26.00 per ton 100 tons calcium chloride @ $50.00 per ton	
061	SIC 9621 - government services	sodium chloride (rock) minimum 97% purity 2,400 tons	mix with abrasive sand for melting snow	24,000 tons sodium chloride @ $24.50 per ton	
062	SIC 9621 - highway and grounds maintenance	sodium chloride (rock) purity not known 12,000 tons	snow and ice control	12,000 tons sodium chloride @ $34.00 per ton 100 tons calcium chloride @ $120.00 per ton	
066	SIC 9621 - municipal highway department	sodium chloride (rock) purity not known 3500 tons calcium chloride (natural) purity not known 2800 pounds (1.4 tons)	pavement de-icer	3500 tons sodium chloride @ $25.89 per ton 1.5 tons calcium chloride @ $300.00 per ton	
046	SIC could not be determined from response	sodium chloride (evaporated) 39.4% purity 7200 pounds (3.6 tons)	as a carrier	95 tons sodium chloride @ $125 per ton	

ID#	TYPE OF ORGANIZATION	LAST PURCHASE	USE	ANNUAL USAGE	REMARKS
047	SIC 9621 - maintenance, snow and ice control of roads	sodium chloride (rock) 100% purity 30 tons calcium chloride (synthetic) 80% pure 1 ton brine purity not given 5000 gallons	sodium chloride for snow and ice removal calcium chloride and brine for dust control	60 tons sodium chloride @ $27.00 per ton 1 ton calcium chloride @ $150.00 per ton 15,000 gallons brine @ $.18 per gallon	
048	SIC 9621 - maintenance and repair of roads and bridges	sodium chloride (rock) purity not known 700 tons	snow and ice control	700 tons sodium chloride @ $24.00 per ton	
051	SIC 9621 - public works	sodium chloride (rock) 90% purity 6000 tons calcium chloride (synthetic) 95% pure 40 tons	sodium chloride for snow and ice removal calcium chloride for dust control	6000 tons sodium chloride price not given 40 tons calcium chloride price not given	
052	SIC 9621 - maintain highway system	sodium chloride (rock) purity not known 100 tons brine purity not known 4000 gallons	rock salt for snow and ice control brine for dust control	500 tons sodium chloride @ $28.00 per ton 10,000 gallons brine @ $.26 per gallon	
055	SIC 9621 - town highway repair and maintenance	calcium chloride (natural) 35% pure 1500 gallons	dust control and new-road surface stabilization	8000 gallons calcium chloride @ $.577 per gallon	
058	SIC 9621 - town highway department	sodium chloride (rock) purity not known 50 tons calcium chloride (natural) 33% pure 100 gallons	mix with sand to de-ice roads	400 tons sodium chloride @ $20.50 per ton 1 ton calcium chloride @ $55.00 per ton	

Table 5-20
INDUSTRY SEGMENTS BY SIZE OF ORGANIZATION

Industry Segment	Non-Response	Reported Size			Total
		Small	Medium	Large	
Highway Departments	0	14	20	3	37
Chloralkali Producers	0	1	1	2	4
Other Industries	1	5	6	15	27
Total	1	20	27	20	68

Table 5-21
CHARACTERISTICS OF THE PURCHASE TRANSACTION

	Highway Departments	Chlor-Alkali Producers	Other Industries	Total Sample
Competitive bidding process:				
Was used	31 (84%)	4 (80%)	10 (38%)	45 (66%)
Not used	6 (16%)	1 (20%)	16 (62%)	23 (34%)
Type of contract:				
No contract	5 (16%)	1 (20%)	9 (36%)	15 (24%)
Part of previously negotiated contract	21 (66%)	2 (40%)	15 (60%)	38 (61%)
New contract established	6 (19%)	2 (40%)	1 (4%)	9 (15%)
Purchase was made from:				
Distributor	11 (33%)	1 (20%)	10 (38%)	22 (34%)
Manufacturer	22 (67%)	4 (80%)	16 (62%)	42 (66%)
Average number of available suppliers	2.1	6.8	3.1	2.8
Average number of suppliers contacted	1.6	3.0	2.1	1.9
Efforts to search for information related to the purchase (Average of two items scaled from 1 = little to 5 = much)	1.9	2.4	1.9	1.9
Average number of decision participants	2.0	3.8	1.9	2.1

Chlor-Alkali Producers. Most purchases by this segment are made through a competitive bidding procedure. This is common for a high-volume, commodity-type product. The chlor-alkali buyers are more likely than highway departments, however, to be negotiating their own contracts. Likewise, they have a greater number of suppliers available, contact more suppliers, search for the most information, and involve the most decision participants of the three segments studied.

Other Industries. This segment includes a wide variety of end-uses. Some are small-volume uses and most involve more stringent purity requirements than the other two segments. Consequently, competitive bidding is less likely to be used (only 38 percent of the time) and there are more frequent purchases outside of any contractual agreements. The need to seek information is low, although at least two suppliers are contacted. Few decision participants are involved.

Along with these variations in purchase transaction characteristics, the relative buying criteria are also likely to vary across segments. This can be seen by the relative rankings by importance of the different buying criteria displayed in Table 5-22.

Table 5-22
RANKING OF BUYING CRITERIA
(Average Importance Ratings, 1 = Not Important, 5 = Very Important)

Highway Departments		Chlor-Alkali Producers		Other Industries		Total Sample	
Supply availability	4.74	Product suitability	4.40	Supply availability	4.88	Supply availability	4.77
Product suitability	4.68	Supply availability	4.40	On-time delivery	4.88	Product suitability	4.65
On-time delivery	4.56	Price	4.20	Product suitability	4.65	On-time delivery	4.64
Vendor reliability	4.38	On-time delivery	4.00	Vendor reliability	4.65	Vendor reliability	4.43
Price	4.24	Relationship with supplier	4.00	Price	4.19	Price	4.22
Environmental requirements	4.00	Environmental requirements	4.00	Relationship with supplier	3.92	Environmental requirements	3.92
Customer service/ support	3.27	Vendor reliability	3.60	Environmental requirements	3.81	Relationship with supplier	3.55
Relationship with supplier	3.21	Customer service/ support	3.40	Customer service/ support	3.73	Customer service/ support	3.47

Supply availability and product suitability are the most importance criteria for the highway departments and chlor-alkali producers. For "other industries", on-time delivery was rated the most important along with supply availability. Price seems to be more important to chlor-alkali producers than to the other segments, which makes sense given the high proportion of direct costs accounted for in the production process by sodium chloride. The relationship with the supplier is also most highly valued by the chlor-alkali producers, probably for the same reason. Customer service and support is one of the least important criteria to all segments. This is consistent with the commodity nature of the product and the lack of technical assistance required.

Because any marketing efforts would need to communicate with the end-use buyers, questions were included about the sources of information that were used to purchase sodium and calcium chloride. In addition, the topics on which the information was sought are included. Table 5-23 lists the average reliance on each source of information.

Table 5-23
SOURCES OF INFORMATION USED TO MAKE PURCHASE DECISIONS

	Segment			
Sources of Information	Highway Departments	Chlor-Alkali Producers	Other Industries	All
Sales representative	2.83[a]	2.75	2.77	2.80
Your top management	2.30	1.83	1.31	1.81
Technical specialists (vendor)	2.24	2.75	1.81	2.08
Users	2.43	2.04	1.82	2.11
Product literature	1.41	1.08	1.24	1.31
Purchase history records	2.68	3.17	2.57	2.67
Advertising	1.46	0.50	0.93	1.14
Trade shows	1.34	0.25	0.65	0.93
Articles in trade publications	1.53	0.75	0.87	1.16
Colleagues at other firms	2.77	0.75	0.99	1.81

[a] Average rating of each source on a scale anchored at 0 = provided no information and 5 = provided a great deal of information.

From the description of transactions it was seen that very little information is sought to make these purchase decisions. The information that is used, however, comes primarily from the vendor's sales representative, the organization's own purchase history records, the "users," and technical specialists employed by the vendor. The least used sources of information are trade shows, advertising, and articles in trade publications. But, this varies somewhat across the three segments.

The decision makers at the highway departments rely on the users as a source of information, more so than the other two segments. In addition, the highway departments' information search involved a relatively greater reliance on colleagues at other firms (organizations).

Total depth is usually about 3 m (10 ft) and is divided into the three sections shown in Figure 5-3. The bottom convecting zone serves as a combination collector and storage unit. Solar radiation reaching this layer warms the water there, which is prevented from convecting upwards by the overlying density gradient in the gradient zone, provided by salinity stratification. The stabilizing effect of the added salt on density is much greater than the destabilizing effect of the adverse temperature gradient and this is the main operating principle of the solar pond. An upper convecting zone exists near the top of the pond. Though it is desirable to minimize the depth of this layer to increase collection efficiency, it is impossible to eliminate this layer completely; a small mixed region will always exist because of external factors such as wind-mixing, convective mixing and possibly through-flow and diffusion (Atkinson and Harleman, 1987). Although the theoretical mechanics are not completely understood, practical experience from a number of ponds in the U.S., Israel and Australia has shown that surface mixing may be controlled with the installation of a floating grid of plastic netting. These and other aspects of solar ponds are reviewed in some detail by Hull and Nielsen (1986).

Heat is extracted from the pond either by pumping a working fluid through a heat exchanger at the bottom of the pond or by withdrawing fluid from the hot bottom layer, passing it through an external heat exchanger and re-injecting into the lower layer. Both of these options have been used successfully, though the latter option is usually preferable for larger ponds where the size of an internal heat exchanger may be unmanageable. An external exchanger is used in the large Israeli pond and also in the pond operated by the University of Texas at El Paso (UTEP). The UTEP pond is the first pond in the U.S. to be used for electrical generation (by driving an organic Rankine cycle engine). This pond also supplies process heat for a canning plant and powers a desalination unit producing 5,000 gal/day of potable water.

Solar ponds are relatively simple to install and are considerably less expensive than other solar energy collection systems, depending on availability of land, water, salt and costs for a bottom liner (it is assumed that a liner will be needed for the present application). One of the main reasons for this low cost is the advantage of combining the collection and storage processes in a single unit. However, there are also several potential drawbacks that should be considered when designing a system with a solar pond.

Perhaps the most significant problem of a solar pond is its relatively low collection efficiency. Depending on water clarity, depth, bottom/edge losses and meteorology, the collection efficiency is typically on the order of 20 percent. Thus, large areas are needed.

The topic of least interest to the chlor-alkali producers was user needs. To the contrary, along with product specifications, user needs and environmental issues were high on the list of buyers from the highway departments.

Discussion

The production of sodium chloride and calcium chloride from oil/gas brines represents a new source of these products for the market. To evaluate the potential for marketing these products, this section first assumes that a new independent organization would enter these markets as a competitive supplier. Later in this section several alternative scenarios are considered.

The end-use segments related to the use of sodium or calcium chloride for general industrial applications, industrial processing, oil recovery, tire ballasting, and animal feed-mix share some characteristics that may hinder market entry. These end-use segment characteristics can be characterized as follows:

- Existence of entrenched market leaders

  Akzo, Morton and Cargill are large and diversified suppliers with more than 75 percent of salt industry capacity. Dow Chemical dominates the calcium chloride industry.

- In-depth knowledge of derived demand for each market

  Due to the complexity and diversity of the end-uses for these products, any competitor requires extensive knowledge of buyers' requirements. The competitors in the sodium and calcium chloride industries are long-time players who have built up substantial knowledge of end-use for industrial applications.

- Research and development base

  The large and diversified competitors are on the cutting-edge of new product research and are likely to develop better applications and possible substitute products.

- Strong reputation and brand-name recognition

  The strength of brand-names in differentiating products and companies in the marketplace is more prevalent in consumer markets. For industrial uses, brand-names may be powerful when the product is a small-dollar purchase, but the product's quality is critical. The industry leaders have created a competitive advantage by branding products in those markets. For example, Akzo sells salt for water conditioning under the "Sun Gems" brand name. Dow Chemical sells 32% calcium chloride as "Liquidow" for roadspreading. Other Dow Chemical brand names for calcium chloride are "Dowflake" and "Peladow." Although these products are commodities, the strong brand-name recognition assures buyers of supplier credibility and reliability.

- Comprehensive distributor network

  The entrenched competitors gain an additional competitive edge through an established marketing influence. Often there is carry-over from their efforts to sell and distribute other products. This barrier to entry is important in terms of access to the distribution channels. Distributors will be reluctant to stock another item. Often there is intense loyalty between distributors and manufacturers and close relationships may have developed over the course of many years.

The end-use segments of food-processing and concrete admixtures share these characteristics in addition to forecasts of declining usage. Increased concern over salt intake in the human diet has reduced U.S. consumption of salt an average of 6.9 percent per year since 1972. Likewise, demand for calcium chloride for concrete treatment has declined due to concerns over its corrosive effects. Decreasing demand in an already highly competitive industry closes the door to a successful entry attempt.

The chlor-alkali industry is also characterized by many of the same factors that paint a gloomy picture of the prospects for a new supplier of sodium chloride. The same is true of calcium chloride for ice control and stabilization. The analysis reveals end-use markets that are both mature and facing critical environmental concerns. Sales of the products to the chlor-alkali producers or for road spreading would have to be at the expense of one of the competitive suppliers, rather than from industry growth. Even if the reclaimed minerals can be sold at lower than market prices, the large and powerful competitors are likely to retaliate with price cuts.

By all indications then, a direct market entry strategy does not have strong support. There are two possibilities, however, which might prove feasible if a brine reclamation facility could produce products at below current industry costs. The first possibility is for the facility to enter a sole-source relationship with an end user. Under this scenario, the end user would purchase all the output from the brine reclamation plant.

A second possibility is the establishment of a "strategic alliance" or joint venture relationship with one of the entrenched suppliers. Traditional management assumptions always dictated arm's-length relationships characterized by adversarial relationships, limited communication, and narrow scope of dealings. More recently, firms have recognized the benefits of developing strategic alliances or partnerships for mutual benefit. These "modern" concepts may be applicable to the marketing strategy of the brine reclamation facility. Rather than competing head-to-head with market leaders, it would be mutually beneficial to develop a long-term relationship that could deal with both the increasing costs to oil and gas drillers for brine disposal, and desires to protect the environment.

Such a strategy requires that only one market relationship needs to be developed. Therefore, with plant design and specifications in hand, a skilled marketing specialist (with perhaps a chemical engineering background) could work to develop a strategic alliance with one of the industry players. The primary focus of the negotiations would be on the "assets" that each player brings to the party. In this case, the plant designers would bring the technical expertise, patents, access to raw materials, and etc. The competitive supplier would bring the reputation, marketing capabilities, customer relationships, and so on.

This strategy cannot be assessed further until a plant can be designed that provides a cost advantage over current methods and products. Until then, the competitive suppliers are unwilling, and rightly so, to discuss proprietary marketing information.

As reported, depending on the final product form, prices for sodium and calcium chloride vary considerably, from $5 to $100 per ton for sodium chloride and $110 to $280 per ton for calcium chloride. For the forms of product that are projected from a proposed brine reclamation facility, vacuum pan salt and calcium chloride solution, average market prices are $90 per ton for delivered bulk salt, $130 per ton for 40 percent calcium chloride solution. Assuming that the quality of the salt products reclaimed from produced waters will meet buyer criteria in a variety of end-user segments for evaporated sodium chloride salt and 45 percent calcium chloride solution, and that these products can be sold at 70 percent of the market price, it is estimated that the revenue potential is about $1,736,000 per year. Thus, after an initial analysis it would seem that resource recovery may be economically feasible.

RESOURCE RECOVERY FACILITY DEVELOPMENT AND DESIGN

For the reclaimed products to be marketable, they must be of high quality, free of oil/grease, potentially toxic impurities (heavy metals), and aesthetic impurities (suspended matter). To produce a product that is of the highest quality possible, a preprocessing system to remove these impurities is required. A treatment system identical to that described in Section 3 is necessary to provide the desirable preprocessing.

The recovery of commercial salts from brines is a well-developed practice. Vacuum pan evaporation is the most commonly used technique for producing salt products. Vacuum pan evaporators are either the calandria (internal heating surface) type, or the forced-circulation (external heat-exchanger) type.

The vacuum pan method produces an extremely high quality salt with minimum expenditure for energy and manpower. Two persons can operate an evaporator which produces 200 tons of salt per day. Energy efficient quadruple-effect evaporators can produce one kg of salt using the energy in only one kg of steam.

Due to the relatively small source of the proposed processing facility, the decreased need for heat energy, and lower maintenance costs, a triple-effect evaporator with subsequent post-processing equipment, (filter, dryer and screens). has been designed. A simple flow diagram of the salt recovery process is shown in Figure 5-2. Various pumps, recycle tanks and piping are also necessary, as well as a packaging/storage facility for the final products. As previously noted, it is anticipated that two primary products will be reclaimed from the production waters, medium coarse rock salt (NaCl) with a minimum purity of 99.5 percent and a concentrated calcium chloride solution (40+ percent) with a 95 percent purity.

Design conditions used to develop a preliminary design and conduct an economic assessment of the salt recovery system were a capacity to process 600,000 bbl/yr of brine. Both year-round and half-year operation to coincide with conjunctive use of a solar pond (see later discussion) was considered.

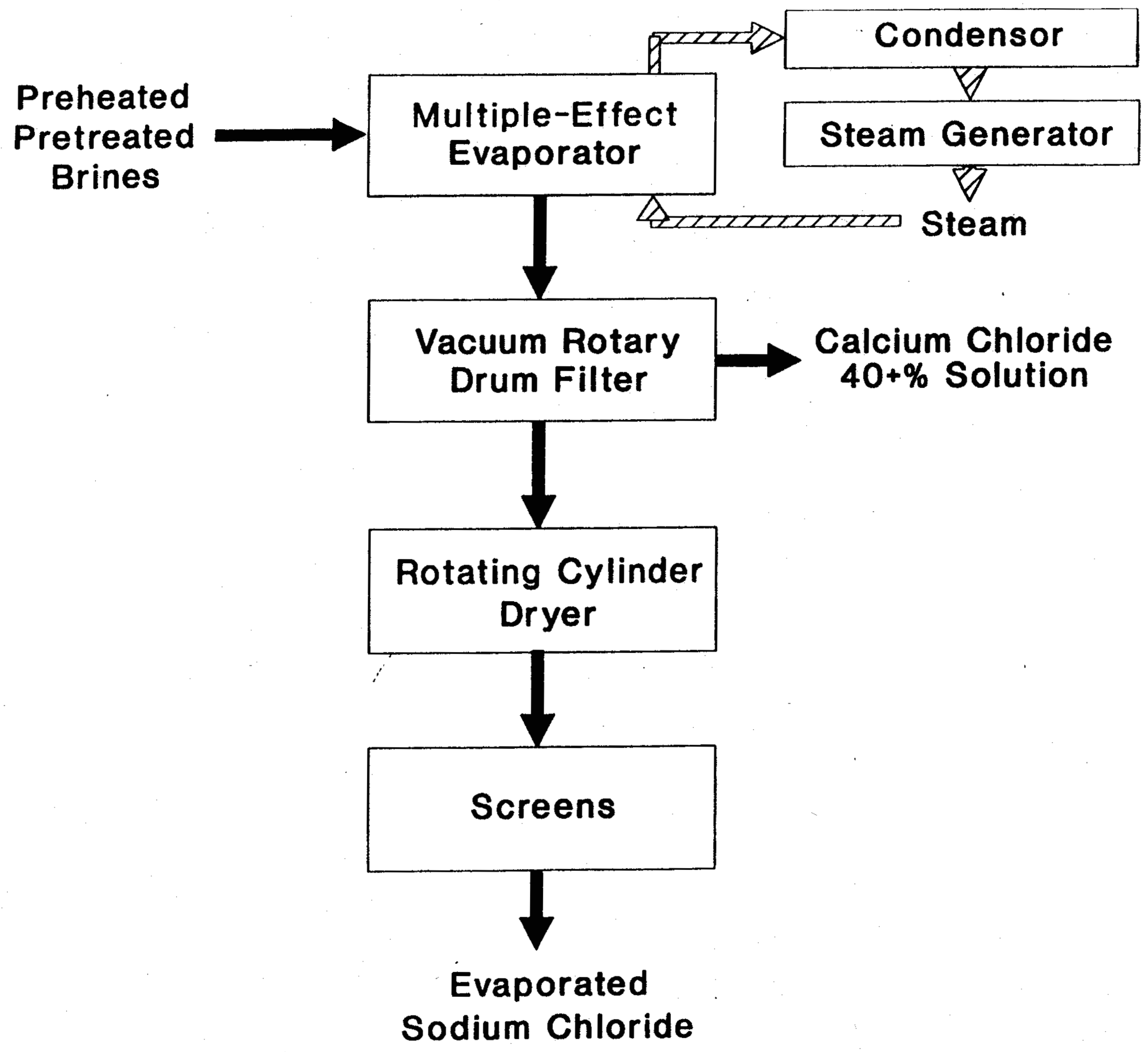


Figure 5-2. PROCESS FLOWSHEET FOR SALT RECOVERY SYSTEM

Costs were determined for the components of the salt recovery system. Components consisted of the evaporators, dryers and filters, condenser (for steam recovery), pumps, and screens. A summary of the estimated component costs are shown in Table 5-25. Non-component costs are listed in Table 5-26. Estimate of the annual costs are presented in Table 5-27.

The total capital costs for a salt recovery facility is projected to be $1.70 million for a year-round operation facility, or $2.33 million for a half-year operation facility. Thus, the capital cost for a salt recovery facility for year-round operation is about 25% less than the treatment facility with surface discharge and nearly the same when half-year operation is considered.

Based on a 20-year life and a seven percent discount rate, the amortized capital costs would be $160,100 per year and $220,250 per year for the year-round and half-year facilities, respectively. Annual costs for operation and maintenance include electrical costs, steam costs, labor, and maintenance for the equipment and pumps. Based on a conservative estimate of 15 percent of the component cost for operation and maintenance, $7.00 per 1000 lb. of steam (50 percent of the cost of the steam is for natural gas), and $0.11/kwh for electricity, the total annual cost for the year-round operating salt recovery is estimated to be approximately $899,070 per year. Total annual costs for the half-year operating facility are estimated to be approximately $948,790. Electrical and steam costs for both systems are similar since their estimates are based on brine volume processed. Thus, the difference in total annual costs is less than $50,000.

Steam requirements are based on the assumption that the steam provides all the heat energy to satisfy the latent heat of evaporation for the entire volume of brine. Heat energy needed to raise the temperature of the brine to the boiling point was not included in this calculation, but is considered in a later section.

Using the estimated total annual costs to reclaim salts from brine by vacuum pan evaporation, the unit cost to recover salt products would be about $0.0357 per gallon of brine for the year-round facility and $0.0377 per gallon for the half-year facility. Including the cost of pretreatment for turbidity, suspended solids, and heavy metal removal, $0.0298 per gallon, the total cost of recovering salt products is $0.0655 and $0.0675 per gallon for the year-round and half-year operating facilities, respectively. The combined value of sodium chloride and calcium chloride recovered from one gallon of brine is about $0.0697.

Table 5-25
ESTIMATED COMPONENT COSTS FOR SALT RECOVERY SYSTEM

Component	Estimated cost, $	
	Year-round operation	Half-year operation
Evaporator and condenser	$400,000	$600,000
Dryers and filters	200,000	245,000
Pumps	30,000	40,000
Screens	5,000	7,000
Total Component Costs	$635,000	$892,000

Table 5-26
NON-COMPONENT AND TOTAL CAPITAL COST FOR SALT RECOVERY SYSTEM

Item	Estimated cost, $	
	Year-round operation	Half-year operation
Piping	$185,000	$259,700
Electrical	114,300	160,600
Instrumentation	82,600	116,000
Steam generation	120,000	120,000
Site work, building, & utilities	95,300	133,800
Contractor O & P	196,800	276,500
Engineering	139,700	196,200
Contingencies	127,000	178,400
Total Non-Component Costs	$1,060,700	$1,441,200
Total Component Costs	635,000	892,000
Total Capital Costs	$1,695,700	$2,333,200

Table 5-27
ESTIMATED ANNUAL COSTS FOR SALT RECOVERY SYSTEM

Component	Estimated cost, $	
	Year-round operation	Half-year operation
Operation and maintenance	$95,250	$133,800
Electricity	43,250	43,250
Steam	600,470	551,490
Amortized Capital Cost	160,100	220,250
Total Annual Costs	$899,070	$948,790

As noted in Section 3, the Hart Chemical Company operates a resource recovery/brine processing plant in Creekside, PA., about 40 miles east of Pittsburgh. The crystallizer operated by the Hart Chemical Company is capable of processing 40,000 gallons of brine per day (340,000 bbl/yr) to produce 22 tons of sodium chloride crystals and 3,400 gallons of 40 percent calcium chloride/magnesium chloride solution per day. The current cost to oil and gas producers to process their brine water is \$0.08 per gallon of brine (\$3.36/bbl), which is similar to the projected cost of producing the salt product determined in this project. Thus, their primary profit for operating their facility seems to be primarily the result of product sales. Their charge to producers covers the cost of production.

PREHEATING BRINE PRIOR TO EVAPORATORS

The salt recovery system is designed to work with an incoming brine temperature of 55 to 60°C. If it is assumed that brine is delivered to the facility at an average temperature of 15 C, then sufficient heat must be provided to raise the temperature by about 45°C (81°F). In the following calculations, a heat capacity for concentrated salt solution is assumed to be 3,350 J/kg C (0.81 Btu/lb F) and a specific gravity of 1.2. Thus, in 600,000 bbl. of brine the weight is 1.2×10^8 kg (2.7×10^8 lb), requiring 5.03×10^6 kWh (1.77×10^{10} Btu) for heating to 60 C.

There are a number of options for energy sources for heating the brines to the desired temperature of 60°C. These include: (1) electrical heating, (2) oil or gas boilers, (3) use of geothermal brines, (4) co-generation, (5) vent gas, or (6) solar ponds. The first option is easily shown to be the most expensive. If electricity costs \$0.11/kWh, it would cost more than \$550,000/year, excluding the cost of the heating devices or any maintenance costs. The energy costs for option 2 may be estimated by assuming a heat value of 5.8×10^6 Btu/bbl of oil and cost of \$20/bbl, and 1020 Btu/ft^3 of natural gas and associated cost of \$3.5/1000 ft^3. The annual energy cost for either oil or gas is then about \$61,000.

Options 3 through 5 require siting the facility near the appropriate source of energy. The geothermal option involves drilling a pumping well. One advantage of the geothermal option is that the geothermal brines have similar characteristics to the production brines and might be used to supplement the source flow for the salt recovery plant. However, depending on the amount of geothermal brine needed, the size of the salt recovery plant and ancillary facilities (possibly including the pretreatment plant) would have to be increased significantly, nearly double. Alternatively, most of these brines would be reinjected, involving drilling a second well.

Preliminary estimates for the costs for these alternatives can be obtained by examining the costs for constructing and operating an underground injection well (Section 4) and by looking at the salt recovery plant with half year operation. The methods and costs for constructing an geothermal well are similar to those for an underground injection well. Based on a geothermal well generating 50 gpm of 70°C brine, the total annual costs will approximately by $525,000 per year, not including the cost for brine disposal. Building a second well for disposal would double the year cost, or about $1 million per year. It is obvious that this option would not be favorable compared to using gas or oil for heating energy.

The cost for increasing the size of the salt recovery plant to accommodate the geothermal brine can be estimated by assuming that the plant designed to run half of the year, would be operated year-round. The size of the facility would not change. However, the electrical and steam costs would approximately double, increasing the annual costs by about $600,000. Thus, the total cost increment would be at least $1.25 million per year ($600,000 + $525,000). This increment could be higher if the geothermal brine must be pretreated prior to salt recovery. The estimated cost for this pretreatment can be calculated as the difference between the total annual costs for the 150,000 gpd and 75,000 gpd treatment plants described in Section 3. This total is $550,000 per year. In this case, the total cost increment would be $1.80 million.

One advantage of this alternative is that the salt recovered from the geothermal brine could be sold for revenue. Assuming that the composition of the geothermal brine is similar to that of the highly saline oil/gas brines, then the total amount of salt recovered from the geothermal brine would be similar to the oil/gas brines, 16,000 tons of sodium chloride and 8,000 tons of calcium chloride. The revenue potential for these amounts, as previously described, is about $1.74 million. Thus, the revenue generated by recovering salt from the geothermal brine could nearly be offset the cost for obtaining energy from the geothermal brine.

Option 4 requires that the facility be located close to a large power station in order to take advantage of its waste heat. This siting requirement is a fairly restrictive condition since there are only a small number of power plants in the area. Because this location would not necessarily be conveniently located for producers, transportation costs will be increased and they would be less likely to bring their brines to the facility. In order to be attractive for producers, it is felt that the facility must be located as centrally as possible, and this option is not considered further here. Another significant consideration that would discourage this option is the corrosive nature of the brine. Power utilities are unlikely to agree to having a brine handling facility near the power generating facilities, fearing that the brine could decrease the life of their facility and/or increase maintenance costs.

Option 5 involves using waste or vent gas from an oil well or wells which is usually flared off. Based on a heating value of 1020 Btu/ft^3 of natural gas, about 20 million ft^3 of gas per year will be needed. As with Option 4, this requires siting the facility near an oil well which could assure a sufficiently steady source of gas for the process. There are several factors which argue against serious consideration of this option. First, as with Option 4, the facility must be centrally located for gas producers and this restricts the areas in which an appropriate oil producer might be identified. Secondly, oil production has been steadily declining in New York state and it appears risky to expect that a sufficient source of vent gas could be assured. For these reasons this option is also not considered further at this time.

Option 6 involves construction of a series of ponds to be used as solar collectors. These serve a dual purpose of providing storage capacity, and providing a built-in heating source for the brine stream to the evaporation plant. These solar/storage ponds are characterized by having a strong salinity gradient through roughly the middle third of their depth, as shown in Figure 5-3. This salinity gradient provides a strong density gradient which prevents thermal convection and allows the lower convecting layer of the pond to heat up. Fresh water, probably from a nearby stream, will have to be used to initially set up the necessary gradient.

The basic concept of the solar pond is not new. The phenomenon of relatively warm water being generated at the bottom of a shallow body of water was described near the turn of the century by Kaleczinsky (1902), though it was not until much later that this concept was proposed for development as a useful solar energy collector (Tabor, 1963). There are several collector designs which are known generally as solar ponds, but the one which has received the most attention is the salt gradient solar pond and this is the design which was considered.

The pond surface area should be large enough to avoid excessive edge losses and not so large that piping and pumping considerations are a problem. Most ponds are from 0.5 to 1 acre in size; however, larger ponds have been constructed. One pond in Israel has a surface area of about 50 acres (Tabor and Doron, 1990) and even larger ponds have been proposed, notably for the Salton Sea in southern California (French and Meitlis, 1980), but with the total area divided into a number of smaller sections, or modules. This sort of division is desirable for several reasons, including greater ease of cleaning and maintenance and the ability to shut down a module completely if necessary, while still allowing the others to work.

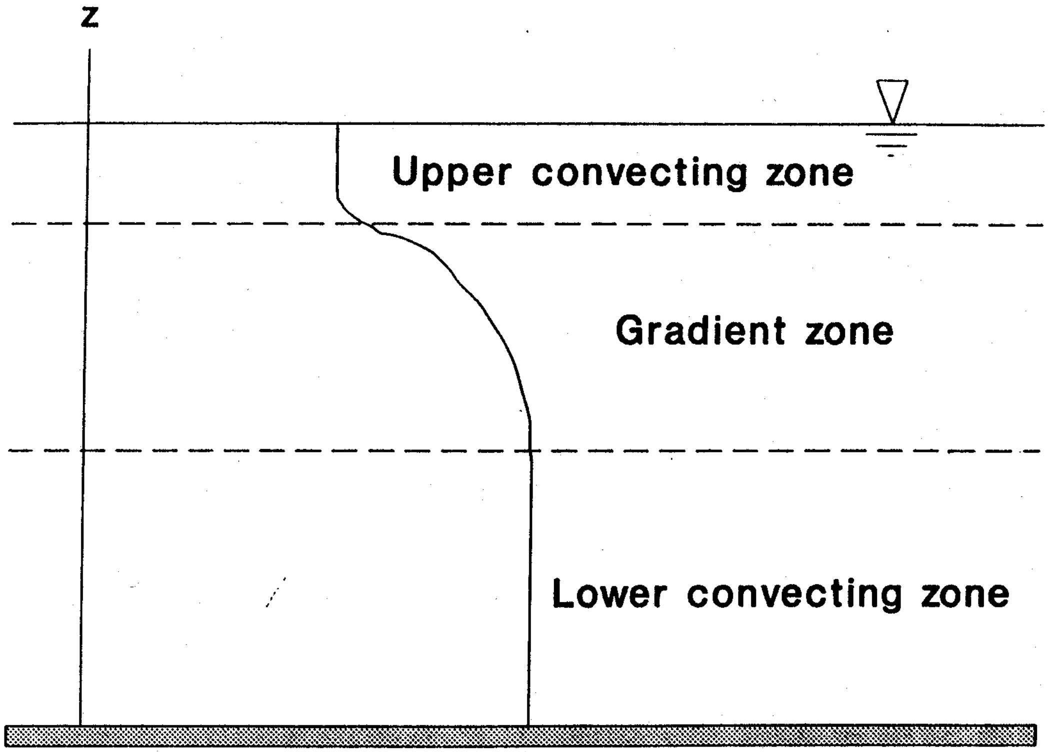


Figure 5-3. TYPICAL SALT DENSITY GRADIENT STRATIFICATION IN SOLAR PONDS

Total depth is usually about 3 m (10 ft) and is divided into the three sections shown in Figure 5-3. The bottom convecting zone serves as a combination collector and storage unit. Solar radiation reaching this layer warms the water there, which is prevented from convecting upwards by the overlying density gradient in the gradient zone, provided by salinity stratification. The stabilizing effect of the added salt on density is much greater than the destabilizing effect of the adverse temperature gradient and this is the main operating principle of the solar pond. An upper convecting zone exists near the top of the pond. Though it is desirable to minimize the depth of this layer to increase collection efficiency, it is impossible to eliminate this layer completely; a small mixed region will always exist because of external factors such as wind-mixing, convective mixing and possibly through-flow and diffusion (Atkinson and Harleman, 1987). Although the theoretical mechanics are not completely understood, practical experience from a number of ponds in the U.S., Israel and Australia has shown that surface mixing may be controlled with the installation of a floating grid of plastic netting. These and other aspects of solar ponds are reviewed in some detail by Hull and Nielsen (1986).

Heat is extracted from the pond either by pumping a working fluid through a heat exchanger at the bottom of the pond or by withdrawing fluid from the hot bottom layer, passing it through an external heat exchanger and re-injecting into the lower layer. Both of these options have been used successfully, though the latter option is usually preferable for larger ponds where the size of an internal heat exchanger may be unmanageable. An external exchanger is used in the large Israeli pond and also in the pond operated by the University of Texas at El Paso (UTEP). The UTEP pond is the first pond in the U.S. to be used for electrical generation (by driving an organic Rankine cycle engine). This pond also supplies process heat for a canning plant and powers a desalination unit producing 5,000 gal/day of potable water.

Solar ponds are relatively simple to install and are considerably less expensive than other solar energy collection systems, depending on availability of land, water, salt and costs for a bottom liner (it is assumed that a liner will be needed for the present application). One of the main reasons for this low cost is the advantage of combining the collection and storage processes in a single unit. However, there are also several potential drawbacks that should be considered when designing a system with a solar pond.

Perhaps the most significant problem of a solar pond is its relatively low collection efficiency. Depending on water clarity, depth, bottom/edge losses and meteorology, the collection efficiency is typically on the order of 20 percent. Thus, large areas are needed.

The pond is also limited in the maximum temperatures that may be obtained, depending on the boiling point of the solution. In a hot climate heat must be extracted to prevent boiling. Boiling is probably not a major problem in western New York, but has occurred in a pond in New Mexico, causing excessive mixing and effectively destroying the gradient (Weeks and Bryant, 1981). This temperature limitation affects heat exchange efficiency and limits the theoretical efficiency of any heat engine that may be driven by the pond. However, these limitations will not be a problem for the suggested scheme of operation of a pond for the brine reclamation facility, as described further below. It is also important to design a good match between the thermal output of the pond and the end use, which usually means that the pond should be operated primarily during periods when it is receiving the greatest amount of solar radiation.

To optimize the output of a solar pond it is necessary to maintain the density gradient in the gradient zone. This process usually involves a periodic adjustment by selectively withdrawing and/or injecting fluid of desired density at specific locations using a thin diffuser plate. This procedure was originally proposed by Zangrando (1980) for initially filling large ponds and has since been adopted in almost every current solar pond for gradient maintenance. Practical experience with these diffusers has shown that it is possible to maintain the gradient under closely controlled conditions. However, except under high heating or high wind conditions, the relatively low diffusivity of salt allows a pond to be operated with only occasional adjustments in the gradient necessary.

Some very recent experiments at Tel Aviv University (Tsinober, personal communication, 1992) indicate that certain salts have very large negative Soret coefficients, meaning that diffusion may be driven by a temperature gradient and that diffusion proceeds in the direction of higher temperature. The implication of this result for solar ponds is that the pond would be self-stabilizing. It happens that $CaCl_2$ is one of the salts with this property, so that a pond made up of production brines may in fact require no gradient maintenance. Unfortunately, the information is not now sufficient to determine precisely how the pond will behave. Thus, it will be assumed that periodic adjustments in the gradient will still be necessary.

Most solar ponds in the U.S. have been built for basic research on the fundamental chemico-physical processes of importance. These have provided some important operating experience over the past 10 to 15 years. Several ponds have also been developed for practical use, notably the UTEP pond already mentioned. A pond in Miamisburg, Ohio was built to heat a municipal swimming pool (Wittenburg and Harris, 1981), ponds have been used for agricultural purposes such as grain drying and greenhouse heating (Short et al., 1979) and ponds have been built in California to drive desalination units (Engdahl, 1984). In addition, a number of ponds in Israel, Australia, Italy, India and other countries have been built for similar purposes and have operated satisfactorily (a recent international solar pond conference in Rome, in 1990, attests to the international interest in solar ponds).

As envisioned for the brine reclamation facility, a series of three-acre ponds, each about 3 m (10 ft) in depth, would be constructed. Each pond would have the capacity to provide enough heat to process approximately 100,000 bbls of brine per year, based on computer simulations. Initially, treated brines would be used to create the dense saline layer at the bottom of the ponds. Enough brine will be added to bring the total depth to about 1.5 m; mixtures of fresh water and brine will then be used to establish the gradient. The initial brine requirement for one pond is about 40,000 bbl., or about 25 days of average production. Assuming another week will be required to establish the gradient, it will be about a month after operations are started before the first pond is filled. As this pond starts to collect solar radiation and warm up, the remaining ponds can be filled. Based on the climatic conditions in western New York, it is expected that solar pond heating will be effective for about six months each year, from the beginning of May to the end of October. For the remaining months of the year brine will have to be stored until the next heating season. The storage capacity in the six ponds will be adequate for this purpose. Due to the large volumes needed to fill these ponds, only one or two of the six is expected to provide sufficient heat during the first year, though this will depend on when the salt recovery facility starts operation. For instance, if brine collection begins in the fall, most of the ponds should be ready for operation the following summer.

Three different operating schemes have been examined for heating pretreated brines using solar ponds. In the first scheme hot water from the lower layer of the pond is withdrawn and sent through an external heat exchanger to preheat pretreated brines before they are sent on to the evaporator. Saline water from the solar pond passing through the heat exchangers is returned to the pond. As previously noted, this is the most common method of heat extraction from a pond.

In the second heating scheme, pretreated brine is introduced directly into the bottom layer of the pond. Heated brine is then withdrawn from the bottom layer and sent to the evaporator. There are two significant advantages of this scheme: first, no external heat exchanger is needed and second, by allowing the depth of the saline layer to fluctuate, winter storage can be provided within the solar ponds themselves, eliminating the need for separate storage facilities.

The third heating scheme involves use of geothermal brines. There is a significant geothermal brine source in western New York State. Brines with a temperature of about 75°C are available in the general area where the brine reclamation facility is proposed. For this heating scheme, geothermal brines are sent through an external heat exchanger to heat the pretreated production brines before they are introduced to the solar pond. As previously noted, the geothermal brines are similar in quality to the production brines and may be processed similarly to generate additional salt product. Higher operating temperatures can be obtained using the geothermal source, but the size of the evaporator would have to be increased to accommodate the higher flows. This option also involves higher costs for drilling the geothermal well (and possibly a reinjection well).

To determine expected temperatures, the operation of a solar pond for the proposed system was simulated using the numerical model described by Atkinson and Harleman (1987) and recently modified by Atkinson (1990) to include surface ice growth. This model considers primarily one-dimensional (vertical direction) processes, though it also incorporates horizontal flows. It solves the basic conservation equations for heat, salt and momentum and includes a detailed evaluation of surface heat exchange and heat loss to the ground.

Simulations were carried out for a two-year period, using 30-year daily-averaged meteorological data for the Buffalo, New York area. Solar radiation data were not available and these were obtained from solar radiation charts. Each simulation starts January 1 with a constant pond temperature of 10°C (50°F). Due to transient start-up responses, second year results are of greater interest since they indicate conditions more representative of steady state. Each of the three brine-heating schemes was simulated to determine their effect on the pond operating temperatures. In addition, a control condition, in which heat extraction or brine inflow/outflow was not considered, was simulated. These simulations for a three-acre pond are shown in Figure 5-4. Each of the cases indicated on Figure 5-4 is designated as follows:

- Case 1: Control condition, no heat extraction or flows;
- Case 2: Scheme 1, heat is extracted through an external heat exchanger to preheat the process stream, 100,000 bbl. heated from May 1 to October 31;

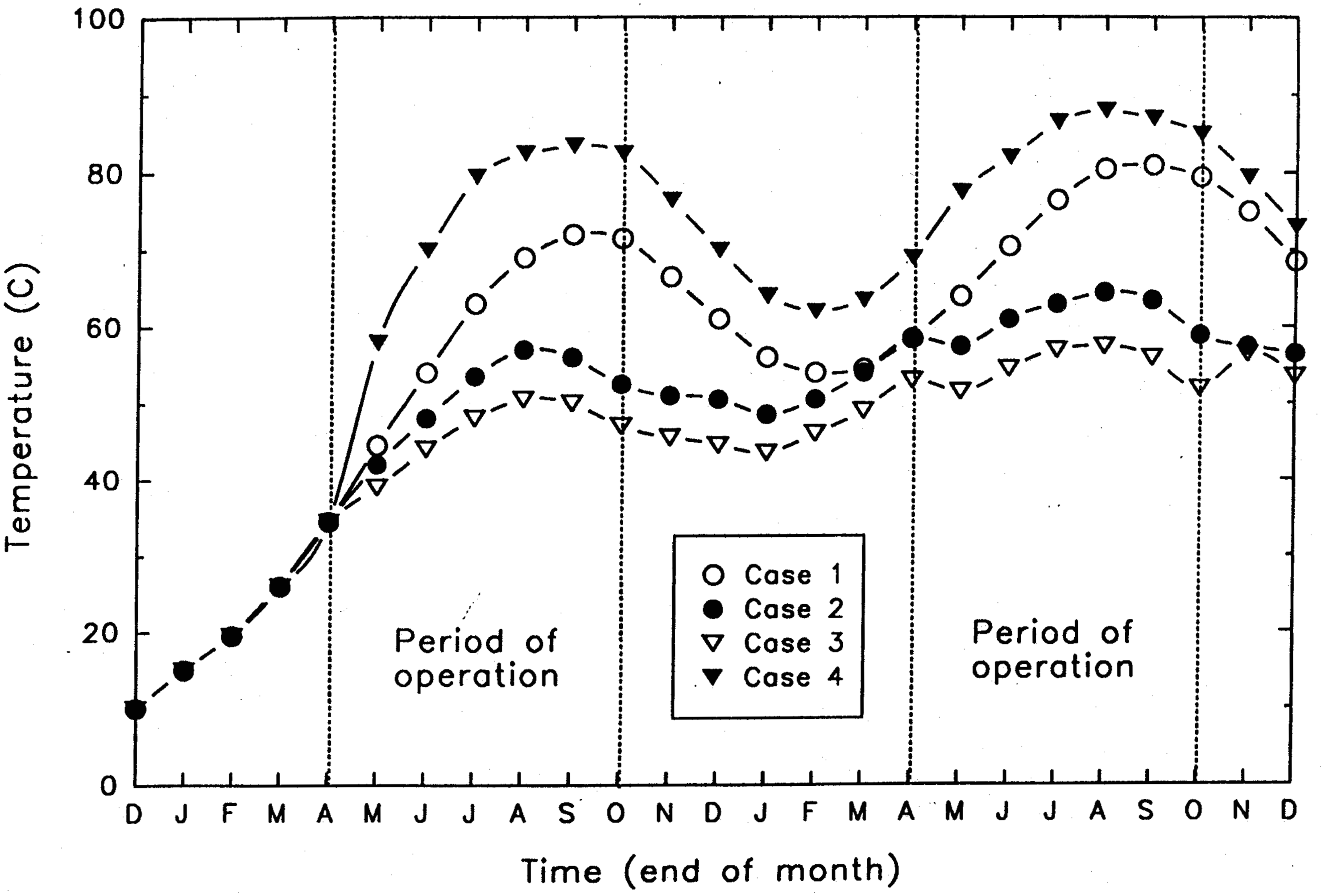


Figure 5-4. COMPUTER SIMULATION OF TEMPERATURE IN SOLAR POND BOTTOM LAYER

- Case 3: Scheme 2, pretreated brine is directed directly into the pond, brine inflow temperature assumed to be 10 C;
- Case 4: Scheme 3, brine inflow is heated with geothermal brine before being introduced to the pond, additional geothermal brine also introduced, though total flow is still assumed to be 100,000 bbls, geothermal brine temperature assumed to be 75 C, with a flow rate of 40 gal/min.

The first twelve months of the simulation represent the start-up of the solar pond and are probably not representative of long-term operation. The second twelve months are more representative of expected long-term operation. The difference in temperature between the control condition (Case 1), and the Case 2 and Case 3 heating schemes is proportional to the amount of energy that will be extracted from the pond to preheat the brines. The difference in temperature between Case 1 and Case 4 is reflective of the net heat gained from the geothermal brines.

As can be seen in Figure 5-4, the Case 3 heating scheme produces the lowest temperatures. However, these temperatures, between about 55 to 60°C, are sufficient for the solutions introduced to the evaporator. As long as the solution temperatures are above about 50 C, the temperature at which evaporation occurs is primarily controlled by the application of a vacuum. Of course, higher solution temperatures reduce the vacuum pressure required.

Because more energy is needed to increase solution temperature, rather than in generating the required vacuum, little energy savings is achieved using the Case 2 or Case 4 heating schemes. For this reason, and also the previously discussed advantages, Case 3 will be the most appropriate of the three heating schemes and this set-up is assumed in further discussion of the solar pond.

The main costs for the ponds include excavation, earth work and a liner. There are also costs associated with piping and pumping. Nielsen (1980) estimated costs for a solar pond in the Columbus, Ohio area. These included earth moving at $1.50/m^3, a liner at $4 to $8/m^2, installed, and a surface wave control net at $1.50/m^2, installed. Other costs included heat exchangers, salt and possibly wall insulation or covering with concrete, but these are not needed here.

Earth moving involves digging out about half the total depth of the pond, using the excavated material to form side berms to provide sufficient height for the total desired depth of the pond. For each three-acre pond, assuming a three m (10 ft) depth, about 6,500 m^3 must be moved, resulting in a cost of $10,000. For the liner, a more recent figure of

$7.10/m^2, installed, which is reported for the Beit Ha'Arave pond in Israel (Tabor and Doron, 1990) was used. This site used a double liner made of high temperature polyethylene, with a layer of clay sandwiched between the plastic layers. For each three-acre pond, this implies a cost of $31,000. Surface wave and wind protection is advisable and, using Nielsen's figure, this adds another $6,500 to the cost for each pond. Finally, costs for pumping and piping for each pond are estimated at $50,000, so that the total installed cost for each pond is $97,500, or $7.50/m^2. The total capital cost for all six ponds is then $585,000. Operation and maintenance costs are minor, involving occasional cleaning and gradient maintenance. Annual operating costs are estimated at $40,000 for all ponds.

The benefit derived from the construction of these ponds is obtained from the displacement of oil or gas supplies that would otherwise be needed for heating the brine to 60°C. As previously noted, the economic worth of this energy is about $61,000 per year, although it could be higher if oil/gas prices rise.

To compare the economics of using the solar ponds with a gas- or oil-fired system, it is necessary to consider also the cost of the boiler for gas/oil. This is estimated at $150,000, with average maintenance costs of $30,000. If capital costs are amortized over an expected 20-year life-time, assuming a 7 percent interest rate, then the total annual cost for the solar pond system is $95,220. The corresponding cost for a gas- or oil-fired system is $105,160.

These figures are similar enough that a definite choice is not possible. However, the solar pond costs are probably conservative, while there is considerable uncertainty in the prices for oil and gas over the next 20 years. This uncertainty, along with the environmental advantages of the solar pond system, suggests that the ponds provide the more attractive alternative for pre-heating the production brines.

MOST ECONOMIC SALT RECOVERY FACILITY ALTERNATIVE

In Figure 5-5, a proposed flowsheet for the most economic salt recovery system is shown. The overall system consists of the brine pretreatment facility, the solar heating/storage ponds, and the vacuum pan evaporation system. Each of these major components was considered earlier in this report. Total cost estimates for the entire proposed facility are summarized in Table 5-28. Design conditions for this proposed plant were as follows:

- Design flow = 600,000 bbl/yr;
- Preprocessing treatment system operation = year round; and

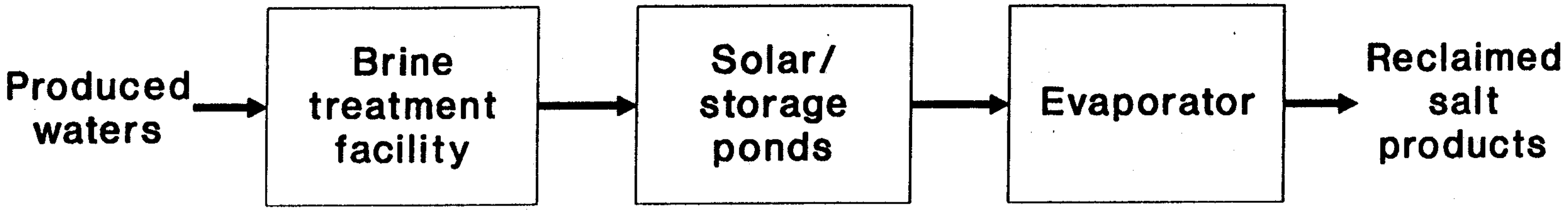


Figure 5-5. PROPOSED FLOWSHEET FOR MOST ECONOMICAL SALT RECOVERY SYSTEM

Table 5-28
COST ESTIMATES FOR BRINE RECLAMATION FACILITY BASED ON PRELIMINARY DESIGN

Item	Capital Cost, $	Annual Operating Cost, $
Component Costs		
Preprocessing Treatment	1,300,200	581,100
Solar Ponds (Storage/Heating)	585,000	40,000
Salt Recovery System	892,000	728,540
COMPONENT SUBTOTAL	2,777,200	
Non-Component Costs		
Land acquisition	140,000	
Site work	160,310	
Electrical and instrumentation	365,930	
Piping	315,020	
Miscellaneous	120,000	
Contractor	199,710	
Engineering	326,100	
Contingencies	406,590	
NON-COMPONENT SUBTOTAL	2,033,660	
TOTAL CONSTRUCTION COSTS	$ 4,810,860	$ 454,150(a)
ANNUAL OPERATING COSTS		$ 1,349,640
TOTAL ANNUAL COST		$ 1,803,790
Annual Revenue from Salt Products		$ 1,736,000
Annual Revenue from Disposal Charges(b)		$ 819,000
Annual Revenue from Disposal Charges(c)		$ 882,000
NET ANNUAL LOSS POTENTIAL (with no disposal charges)		($ 43,790)
NET ANNUAL PROFIT POTENTIAL (@ 0.0325/gal disposal charge)		$ 751,210
NET ANNUAL PROFIT POTENTIAL (@ 0.0350/gal disposal charge)		$ 814,210

(a) 20 year project life, 7% interest

(b) Disposal charge = $0.0325/gal

(c) Disposal charge = $0.0350/gal

- Solar pond/evaporator system operation = 6 months/year, Case 3 heating scheme.

Based on the proposed preliminary designs and cost analyses, the payback period for a reclamation facility using solar ponds as the primary energy source for the multiple effect evaporators will be on the order of 3.7 to 4 years, depending on the charge for brine disposal imposed by the reclamation facility owner/operators. The internal rate of return would be from 25 to 27 percent. Thus, the entire project would seem to be economically feasible and would provide the best internal rate of return.

SUMMARY

To determine if a facility to reclaim salt products from oil and gas brines is feasible from technical, marketing, and economic aspects, a detailed study was conducted. A reclamation process involving pretreatment of the brine to remove suspended and dissolved impurities; preliminary heating and storage of brines using solar ponds as an energy source; and reclamation of salt products from the pretreated brine using vacuum pan multiple effect evaporators appears to be cost effective.

Analyses indicate that such a facility could generate a net revenue from sales of reclaimed salt products and brine disposal fees from $750,000 to $820,000 per year. An initial investment of about $5 million would be required and would have a payback period of about four years. The internal rate of return is projected from 25 to 27 percent.

Unfortunately, most oil and gas producers in New York State are small; the average size is less than 20 wells. Thus, it is uncertain if such a facility could be developed by a single producer. However, if a reclamation facility could be developed by a separate entrepreneur or consortium of producers in a location that is central to the oil and gas fields in New York State, significant cost savings to the producers could be achieved due to a reduction in transportation costs, which are from 20 to 50 percent of the brine disposal costs at existing commercial brine disposal facilities.

6. CONCLUSIONS AND RECOMMENDATIONS

Presented in this section are conclusions derived from this study and a discussion of recommendations regarding the disposal of oil and gas production brines in the future.

CONCLUSIONS

Conclusions as a result of the investigative work done for this study are:

- Due to low market prices for oil and gas, the profit margin for oil and gas production in New York State is limited. An added burden to oil and gas producers is the cost for disposing of brine waters generated during oil and gas recovery.
- During the period from 1986 to 1991, the volume of brine generated in New York State from oil and gas production has steadily decreased from 8.8 to 2.4 million bbl. caused primarily by the cessation of a large portion of oil produced by waterflooding operations.
- The majority of brine generated in New York State is relatively dilute and is discharged directly to surface waters without treatment or it is recycled in the waterflooding operations.
- Approximately 600,000 to 400,000 bbl. of highly saline brines, generated primarily from gas production and primary recovery oil production, are generated in New York State. These brines must be disposed by DEC approved methods. The majority of highly saline brine is generated in Chautauqua, Cattaraugus, and southern Erie counties.
- These highly saline brines are disposed using one of three methods: road spreading, underground injection, or discharge into a surface water after treatment at a commercial brine or municipal wastewater treatment plant. The DEC estimates that in 1990, approximately 30 percent of the highly saline gas associated brines were roadspread, 50 percent was discharged through treatment plants, and 20 percent was injected into disposal wells.
- Roadspreading is the least costly of the available disposal methods. Highway departments use brines for road stabilization and deicing. Oil and gas producers are not charged a fee for brine disposal using roadspreading. The only cost of brine disposal by roadspreading is transportation to the roadspreading site.
- The fees presently levied for brine disposal using underground injection and surface water discharge after treatment are similar. The primary difference in costs is transportation. Current costs for brine disposal by these methods range from $1.80 to $3.50 per bbl.

- Regulatory changes limiting and/or requiring treatment of brines before roadspreading would severely limit that option and result in an added economic hardship on oil and gas producers in New York State.

- Three commercial brine treatment facilities are operating in Pennsylvania. There is no facility located in New York State, although some municipal wastewater treatment plants accept a limited amount of brine for disposal. The transportation costs to brine treatment facilities in Pennsylvania are signficant. Transportation costs may be equal to, or greater than, the fees levied by the brine treatment facilities for disposal, about $400,000 annually based on 50 percent of the highly saline brines being shipped to these facilities.

- One alternative brine disposal method that was evaluated was the construction of a commercial brine treatment facility, designed to treat 600,000 bbl. of brine per year. This facility located within New York State is estimated to have a capital cost of about $2.5 million and an annual cost $814,000. Treated brine would be discharged into Cassadaga Creek, near the Town of Levant in Chautauqua County. Assuming that $0.0325 per gallon of brine discharged is charged (similar pricing to that of the closest Pennsylvania facilities), a facility could be constructed with a payback period of about 8.1 years and an internal rate of return of about 11 percent. The payback period decreases and the internal rate of return increases as the fee for brine disposal is raised. If the capacity of the treatment plant and the volume of brine increases comensurately, the economics also become more favorable. This latter scenario is unlikely unless there is a significant increase in oil and gas production in New York State.

- Construction of an underground injection facility was also evaluated as a brine disposal alternative. Capital cost and annual cost estimates for constructing and operating an underground injection facility are $1.34 million and $525,000, respectively. Assuming that $0.0325 per gallon of brine disposed is charged, an underground injection facility could be constructed with a payback period of about 3.7 years and an internal rate of return of about 37%.

- There are five existing underground injection wells in New York State. The aggregrate approved capacity of these wells is greater than 1.2 million bbl. per year. However, despite the seemingly favorable economics for disposal wells, less than 10 percent of the total capacity is used. Thus, there are other factors, economic or technical, that control the use of these wells. Unfortunately, none of these factors were identified in this study. It is hypothesized that poor geological conditions and poor fluid characteristics (e.g. high suspended solids) are key factors that have contributed to this situation.

- The third brine disposal alternative investigated was treating brine and reclaiming marketable salt products, sodium and calcium chloride, using a vacuum pan evaporative method. The proposed reclamation process would include three major processing steps: pretreatment of the brine to remove suspended and dissolved impurities; preliminary heating and storage of brines using solar ponds as an energy source; and recovery of salt products from the pretreated, preheaated brine using a multiple-effect vacuum pan evaporator. The total capital costs for such a facility are estimated to be about $5 million. Total annual costs are estimated to be about $1.8 million. The net annual revenue projected from the sale of the reclaimed salt products and brine disposal fees is between $750,000 and $820,000. The payback period would be about 4 years with an internal rate of return from 25 to 27 percent.

- Salt production is a mature industry with limited capacity for future growth. The salt industry is dominated by a few large producers. More than 75 percent of the sodium chloride market is controlled by three companies. There is a single primary calcium chloride supplier, with more than 60 percent of the market.
- The projected volume of sodium chloride to be produced by the salt reclamation facility would be less than one percent of the amount of sodium chloride consumed in New York State in 1989. However, the projeced volume of calcium chloride to be produced by the salt reclamation facility would be nearly 28 percent of the estimated amount of calcium chloride consumed in New York State. This, and other significant factors, will make direct entry into the salt user market difficult.

RECOMMENDATIONS

Two sets of recommendations are outlined. The first set are applicable assuming that there will be no future changes in regulations that would restrict roadspreading or require pretreatment prior to road spreading, and that the present volume of brine generated will remain steady or decline.

The second set of recommendations assumes that new regulations will be imposed that would restrict roadspreading or require pretreatment prior to road spreading, and that the present volume of brine generated will increase so that brine disposal needs are equal to or greater than 600,000 bbls. per year.

No Regulatory Changes, Steady or Declining Brine Generation

The purpose of these recommendations is to minimize the cost of disposing oil/gas production brines to New York State producers.

- Dilute brines generated from oil recovered by waterflooding should continue to be discharged into surface waters directly whenever possible.
- Highly saline brines generated from oil (primary recovery) and gas production should be disposed by roadspreading whenever possible. Definitive agreements, preferably long-term, should be established with municipal highway departments. Presently, brine that is disposed by roadspreading is "given" to the highway departments. This

type of arrangement should be maintained. It benefits both oil/gas producer and highway department.

- A detailed field study should be conducted to investigate the feasibility of using the Theresa formation (7,000+ feet around Chautauqua Lake) as a receptable for an underground disposal well. Preliminary analyses in this present study indicate disposal costs could be reduced by as much as 40 percent, not including transportation savings. Highly saline brine that could not be roadspread should be disposed by this method, if feasible.

- If development of the aforementioned underground injection well is not feasible, or the existing disposal wells in New York State cannot be rehabilitated to handle larger flows without significant cost increases, highly saline brine that is not roadspread should be disposed at the closest treatment facility willing to treat the brine. The closest existing commercial brine treatment facility is located in Warren, Pennsylvania.

- A commercial brine treatment facility could be developed in New York State could be built and operated profitably only if the amount of brine treated in the facility is 600,000 bbl/yr or greater. (The brine treatment facility in Warren, Pa. has a capacity of nearly 1,800,000 bbl/yr.). This scenario is unlikely as long as roadspreading is permitted and cost effective.

Roadspreading Restricted and/or Treatment Required, Increasing Brine Volumes

The following recommendations based on this study are forwarded. The purpose of these recommendations is to minimize the cost of disposing oil/gas production brines to New York State producers.

- Dilute brines generated from oil recovered by waterflooding should continue to be discharged into surface waters directly wheneever possible.

- A detailed field study should be conducted to investigate the feasibility of using the Theresa formation (7,000+ feet around Chautauqua Lake) as a receptable for an underground disposal well. Preliminary analyses in this present study indicate disposal costs could be reduced by as much as 40 percent, not including transportation savings.

- If development of the aforementioned underground injection well is not feasible, or the existing disposal wells in New York State cannot be rehabilitated to handle larger flows without significant cost increases, a salt reclamation facility (see Section 5) should be developed in New York State. This venture should be conducted in partnership with one of the current principal salt producers. Direct entry into the salt supply market will be difficult otherwise.

- If it appears that marketing reclaimed salt products will be difficult due to the failure of developing a joint venture with a principal salt producer, a commercial brine treatment facility should be developed in New York State. If the amount of brine treated in the facility is 600,000 bbl/yr or greater, a brine treatment facility could be built and operated to compete favorably with the brine treatment facility in Warren, Pa.. For New York oil and gas producers, the primary advantage would be reduction of transportation costs.

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