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GEOTHERMAL APPLICATIONS ON THE MADISON (PAHASAPA) AQUIFER SYSTEM IN SOUTH DAKOTA

FINAL REPORT
OCTOBER 1, 1976 - SEPTEMBER 30, 1977

J.P. GRIES

September 1977

South Dakota School of Mines and Technology

IDAHO OPERATIONS OFFICE

MASTER

IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

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Principal Investigator

South Dakota School of Mines and Technology
Rapid City, South Dakota 57701

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TABLE OF CONTENTS

<u>Section</u>	<u>Title</u>	<u>Page No.</u>
I	Introduction	1
	Objectives	1
	Organization and Management	2
	Summary and Conclusions	2
II	Geology	4
	The Madison Formation	4
	Structure	4
	Porosity and Permeability	4
	Hydrology	5
	Recharge	6
	Potentiometric Surface	6
	Hydrologic Characteristics of the Madison	7
	Well Yields	8
	Well Interference	8
	Temperature	8
	Well Completions	9
III	Water Quality	17
	General	17
IV	Water Treatment	21
	General	21
	Scaling Tendencies	21
	Corrosion Tendencies	22
	Summary	23
V	Corrosion and Scaling Studies	24
	General	24
	History of Geothermal Applications	24
	Midland	24
	Philip	25
	Corrosion and Scaling Predictions	30
	Calcium Carbonate	30
	Calcium Sulfate	31
	Silica	31
	Corrosion and Scaling Experiments	31
	Philip	33
	Edgemont	36
	Bar-N Ranch	36
	Recommendations and Conclusions	40
	Acknowledgments	41

TABLE OF CONTENTS (continued)

<u>Section</u>	<u>Title</u>	<u>Page No.</u>
VI	Geothermal Applications	42
	General	42
	Central Heating System Design Concept	43
	Heat Exchangers	44
	Site-Specific System Studies	48
	Midland, South Dakota	48
	Economic Analysis	56
	Cheyenne River Sioux Reservation	60
	Cherry Creek, South Dakota	61
	Red Scaffold, South Dakota	64
	Potable Water Use of the Madison	
	Aquifer on the Reservation	67
	Other	70
	Possible End Use Application of the	
	Madison Water	71
	Irrigation	71
	Stock Watering	74
	Livestock Building Heating	74
	Greenhouse Use	75
	General Concepts for Future	
	Consideration	76
	Central Absorption Refrigeration	
	System	76
	Supplemental Heating by Solar Energy	80
	Heat Pump Assisted Geothermal System	82
	Grain Drying	82
	Wool Washing	83
	Ultimate Disposal of Geothermal Water	83
	Surface Discharge	83
	Well Injection	84
	Evaporation Lake	84
	Guidelines for Future Applications	84
	General Considerations	84
	Specific Findings	85
VII	Legal Considerations	87
	References	
	Appendix A	
	Appendix B	

LIST OF TABLES

<u>Table No.</u>	<u>Title</u>
III-1	Madison Water Wells in South Dakota and Western Wyoming
III-2	Water Quality
III-3	Sulfide Ion and Dissolved Oxygen Concentrations in Selected Madison Aquifer Waters
IV-1	Calcium Carbonate Scaling Tendencies of Madison Aquifer Water
V-1	Estimated Corrosion Rates for Copper from the Philip Water Plant Heat Exchangers
V-2	Scaling and Ryznar Indices for Selected Madison Waters
V-3	Corrosion Rates for Philip
VI-1	Madison Aquifer Water Quality.
VI-2	Grain and Silage Yields -- Comparison of Heated and Unheated Soils

LIST OF PLATES

<u>Plate No.</u>	<u>Title</u>
II-1	Thickness of Madison Formations
II-2	Structure On Top Of Madison
II-3	Depth To Top Of Madison
II-4	Areas Of Favorable Porosity Madison Limestone
II-5	Potentiometric Surface Madison Artesian System
II-6	Isothermal Map Madison Formation
II-7	Total Dissolved Solids In Madison River

LIST OF FIGURES

<u>Figure No.</u>	<u>Title</u>
V-1	Philip Water Plant Forced Air Heat Exchanger
V-2	Philip Water Plant Forced Air Heat Exchanger Core
V-3	Philip Water Plant Heat Exchanger Cross Section Of A Copper Tube
V-4	Philip Water Plant Sections From Forced Air Heat Exchanger Cores
V-5	Corrosion Test Rack
V-6	Edgemont, South Dakota Aluminum 3003 After Six Weeks Exposure to Madison Water
V-7	Edgemont, South Dakota Carbon Steel 1020 After Six Weeks Exposure to Madison Water
V-8	Edgemont, South Dakota Glass Plate After Six Week Exposure to Madison Water
VI-1	Typical Plate Type Heat Exchanger
VI-2	Distribution Flow Diagram Midland, South Dakota
VI-3	Midland, South Dakota District Heating System
VI-4	Typical Control System
VI-5	Typical House Control System
VI-6	Midland, South Dakota Geothermal vs Conventional Fuel Cost
VI-7	Cherry Creek, South Dakota Flow Diagram
VI-8	Cherry Creek, South Dakota District Heating System
VI-9	Red Scaffold, South Dakota Flow Diagram
VI-10	Red Scaffold, South Dakota District Heating System
VI-11	Conceptual Ammonia Absorption Geothermal System
VI-12	Conceptual Ammonia Absorption Geothermal System
VI-13	Conceptual Solar Assisted Geothermal System

ABSTRACT

Pertinent geologic, hydrologic, and chemical data for the Madison Formation underlying western South Dakota are presented in text and in graphic form. A temperature anomaly in west central South Dakota makes 130 to 160°F water available at depths of less than 3500 ft.

A central geothermal space heating system designed for Midland, South Dakota indicates that by 1980 geothermal heat will be competitive with existing energy sources.

Preliminary tests indicate the superiority of 304 or 316 stainless steel for fabrication of equipment to utilize the warm, corrosive Madison water.

South Dakota has no statutes governing geothermal resources; under existing water law, geothermal water would be classified as a top priority domestic use. Suggestions are made for state legislation pertaining to the development of geothermal energy.

SECTION I INTRODUCTION

Although warm artesian waters from Cretaceous sandstones were observed as early as the 1880's in eastern South Dakota, the drilling of the first deep water well (2983 feet) at Edgemont, Fall River County, in 1910-13, demonstrated the potential of the upper Paleozoic sandstones and carbonates. The flow of this well attracted attention because of its volume (515 gpm), its abnormally high temperature (130°F), and its high shut-in pressure (94 psi).

Subsequent drilling of a few municipal, military, and industrial water wells, and a few hundred deep oil tests in western South Dakota, resulted in the accumulation of information on the quantity, quality, depth, temperature, and pressure head of these artesian flows. Schoon and McGregor (1974) have calculated geothermal gradients throughout the state, and have summarized the existing applications for geothermal energy.

Various uses for the warm waters have been suggested, notably for wool washing plants, for elaborate hot water baths, for space heating, and for a variety of agricultural uses. To date, the only practical applications for warm Madison water have been for space heating at Midland and Philip, in Haakon County. In each case, existing municipal wells have been used as the heat source. Preliminary studies have been started for space heating of the school buildings in Edgemont and at St. Mary's Hospital in Pierre.

The success of the installations at Midland and Philip, coupled with the attendant corrosion and scaling problems which are characteristic of all installations where deep Madison water is used for domestic or industrial purposes, prompted the proposal which resulted in funding of the present project by the Division of Geothermal Energy, Energy Research and Development Administration. This paper constitutes the final report on work performed under Contract No. EY-76-S-07-1625.

Objectives

Objectives of the study fall into three broad groups:

1. A study of the geology, hydrology, temperatures, and chemistry of the Madison Formation and its contained fluids.
2. Design of a central space-heating installation for small towns, military installations, or Indian settlements, including corollary study of materials, water treatment, comparative cost as compared to existing and projected energy sources, and practical uses for the water from which the heat has been partly extracted.

3. Investigation of legal aspects of geothermal development in South Dakota, including existing state and federal laws, and the possible place of rural electric cooperatives in the financing or operation of small central geothermal installations.

Sixteen separate items are listed in the original proposal. Each has been addressed, although the emphasis placed on various aspects has changed as the investigation progressed. Only one topic -- development of geothermal energy at Ellsworth Air Force Base -- was eliminated, as it was learned after the proposal was submitted that the two deep Madison wells at that base had been plugged and abandoned due to structural and mechanical failure.

Organization and Management

Responsibilities for the project followed closely the organization outlined in the original proposal.

The Department of Geology and Geological Engineering compiled data on the Madison reservoir, and has submitted the information in the form of maps, tables, and text discussion. Porosity studies on the reservoir rock were made by Mr. Sherwin Artus, Denver consultant reservoir engineer.

Water quality was examined by Dr. Dan Carda of the Mining Experiment Station at the School of Mines and Technology. Possible water treatment was considered by Sheppard T. Powell Associates, Baltimore consultant to R. W. Beck and Associates. Corrosive effects of water from individual wells was determined by Dr. Stanley Howard of the Department of Metallurgy, assisted by Dr. Carda.

Comparative costs of present-day energy sources in western South Dakota were compiled by the associated Rural Electric Cooperatives under direction of Mr. Harvey Malon of Rushmore Generating and Transmission Cooperative. Mr. Gene LeBrun, attorney for the cooperatives, investigated the legal facets of proposed central heating installations, and organizations for operating the same. Possible sources of funding under existing state and federal laws were examined by Mr. LeBrun and Mr. Malon.

R. W. Beck and Associates investigated the feasibility of a geothermal heating installation for the town of Midland, South Dakota, and for two settlements on the Cheyenne River Sioux Reservation. The study included design, materials, costs, and possible uses for the spent water.

All teams cooperated in preparation of the final report.

Summary and Conclusions

The present study supports an original assumption that adequate warm water is available from the Madison Formation to supply small-scale geothermal space heating installations in western South Dakota

communities. Geothermal wells would be 3000 to 7000 feet deep, temperatures would range from 120 to 170°F, and individual wells could be expected to yield 300 to 500 gpm over the life of a geothermal installation. Yield in some areas will be by free flow; in others, pumping with standard submersible pumps will be required. In water-hungry South Dakota, it is believed that gainful use can be made of waters from which heat has been extracted, and that prohibitively expensive reinjection into either the Dakota or Madison aquifer will not be necessary.

Total dissolved solids vary between 1000 and 2700 parts per million. The water is generally superior to that now available from shallower aquifers in the same areas. The Madison water contains no dangerous levels of any toxic elements, but the total mineral content obviously exceeds recommended EPA standards.

No significant scaling has been observed in Madison waters which have remained unexposed to the atmosphere. Corrosion is the primary problem encountered. Preliminary studies indicate that water from each well may present its own peculiar problems. In some waters tested, 304 or 316 stainless steel appears entirely satisfactory as a construction material for geothermal installations. Where chloride concentrations are greater than 100 ppm, copper and copper-base alloys may serve as well as or better than stainless steel.

Geothermal application of the Madison water in western South Dakota will most likely be in the form of central space heating systems for small farming communities. End-use applications for the Madison water will be domestic or agriculture-related.

The economics of a central geothermal heating system for the community of Midland indicates that in the very near future such a system will be more economical than conventional heating systems.

South Dakota has no existing statutes relating to geothermal resources. Under existing South Dakota water law, hot water for heating homes would fall under domestic use, which carries the highest priority, subject only to the stipulation that the water may not be wasted or that its withdrawal must not interfere with existing users.

South Dakota municipalities have the authority to construct, operate, and maintain a system to provide heat from geothermal sources, and to finance the same with revenue bonds. South Dakota rural cooperatives do not at present have authority to operate a system to provide heat from a hot water source, nor does the Rural Electrification Administration have authority to make loans for heating systems using only geothermal water. It is recommended that South Dakota prepare and enact legislation governing the development of geothermal energy.

SECTION II GEOLOGY

The Madison Formation

The Madison, or as it is locally known in the Black Hills, the Pahasapa Formation, is generally referred to as a limestone, although as has been demonstrated by Andrichuk (1955), Gries and Mickelson (1964), and others, much of the formation is actually a clean, crystalline dolomite.

The Madison carbonates, and their time equivalents elsewhere in the Rocky Mountain region, were deposited in a broad seaway which covered much of the area now occupied by the Rocky Mountains of the United States and Canada. South Dakota lies on the eastern edge of that former seaway (Plate II-1). The formation thickens from zero along the eastern edge of the subcrop to over 1300 feet in northwestern Harding County. Farther to the north and northwest, it thickens to about 2700 feet in the center of the Williston Basin in North Dakota, and to over 2800 feet in the central Montana trough (Craig, 1972 p. 103).

The Madison is divisible into three lithologic units, which are in ascending order the Lodgepole Member, the Mission Canyon Member, and the Charles Member. In the deeper parts of the Williston Basin, and extending into northwestern South Dakota, the Charles contains evaporite units which profoundly affect the quality of the Madison water.

Structure

As a result of later structural movements, the Madison has been down warped into the Williston Basin to the north, and uplifted and eroded over the Black Hills. Plate II-2 shows structure contours on the top of the Madison Formation, while Plate II-3 may be used to determine the approximate depth of the Madison below the present land surface. However, depth may be determined more reliably when the known surface elevation is used in conjunction with Plate II-2.

Porosity and Permeability

Porosity in the Madison Aquifer is a combination of three types: 1) normal intergranular porosity, particularly in the dolomites, 2) joint and fracture porosity, and 3) solution openings ranging in size from slightly enlarged joints to caverns in which the drill bit may drop several feet. Permeability is affected also by the types of openings present in the aquifer. It is not surprising that well yields vary widely.

In an effort to locate favorable areas for obtaining high yields, Mr. Sherwin Artus, Reservoir Engineer consultant of Denver, was asked to make electric log analyses of about 150 wells into the Madison Aquifer

of South Dakota (Plate II-4 and Appendix B). For each log, he determined average porosity for each stratigraphic interval where the porosity exceeded 7 percent. For each interval thus delineated, the average porosity (ϕ) was determined, and multiplied by the length of that interval (h) to give ϕh , an equivalent length of void space. Artus did this separately for each of the three members of the Madison. For the present summary, the figures for the Charles, Mission Canyon, and Lodgepole members were totalled and are presented on Plate II-4. Bearing in mind that all wells did not penetrate the entire thickness of the formation, and that the formation thicknesses vary widely (Plate II-1), it is obvious that these figures have little comparative value. The randomness of the figures indicates that porosity is not directly related to thickness, and that good wells may be expected in areas where the total thickness of the formation is not great. A few better-than-average areas are shaded on Plate II-4.

Hydrology

The Madison limestone is noted throughout its areal extent for large flows of water under high artesian pressures, and for the attendant drilling problems of well control and lost circulation.

Two episodes in the postdepositional history of the Madison Aquifer are pertinent to the understanding of its water-yielding potential. Following the retreat of the early Mississippian sea, the newly deposited carbonate terrain remained slightly above sea level for a long period of time. As a result of groundwater solution on this carbonate terrain, caverns were formed. Their ultimate collapse resulted in the formation of sinkholes, and a widespread karst topography was developed over the entire area of outcrop. Sufficient limestone was removed by solution and erosion to produce a surface relief of many tens of feet, and the insoluble clays and chert within the formation remained behind as a blanket of red residual soil. Part of this clay was washed into the underground passages as it was formed; more was reworked and distributed over the low spots on the surface when the sea next returned to the area. Deposition of more red muds effectively sealed the top of the Madison, and much of the old solution network remained open or only partially filled with clay. Slow circulation of groundwater through these openings has continued to the present time.

The second episode pertinent to the hydrologic behavior of the Madison occurred when the Black Hills were uplifted during the Laramide Orogeny. As soon as the overlying sediments were removed by erosion, surface water was again able to enter the cavern system. Much water filters down through bare outcrops, but more spectacular infiltration occurs where streams cutting down through the limestone lose large volumes of water to sinkholes in the limestone along the creek bed. This water has sometimes carried recent alluvial material down into the old openings, but more often it has tended to remove the old clay filling from the upper part of the old cave network, and to redeposit it at lower elevations. The cleaned-out openings are then enlarged by further solution.

Recharge

Because water now entering the limestone cannot all be accepted by the hydrologic system, some of it breaks back to the surface to form artesian or resurgent springs. Although the position of these springs has shifted somewhat as erosion progressed, the present-day sinkholes and springs are descendants of the earlier system.

The relationship between stream losses to sinkholes in the Madison Formation and the discharge from resurgent springs has been verified by researchers at the South Dakota School of Mines during ten years of stream gaging across the Madison outcrops and at various springs (Crooks, 1968; Gries and Crooks, 1968; Gries, 1971; Gries, Niven, and Crooks, 1968). These records have been summarized by Rahn and Gries (1973), who have confirmed that the resurgent springs do serve as escape valves, returning to the surface water which cannot move into the Madison artesian system. Their calculations also show that the amount of water returned to the surface in this manner is greater than that lost to the sinkholes along stream channels. It is concluded that an important part of the recharge to the Madison artesian system is derived from rain and snowmelt which infiltrate the outcrop area.

In addition to the visible evidences cited above, two other lines of approach indicate that the outcrops around the Black Hills constitute the recharge area for South Dakota and for the eastern Powder River Basin in Wyoming. The potentiometric map Plate II-5 shows the highest head to be at and adjacent to the outcrops, and the total dissolved solids map Plate II-7 shows the greatest dilution of the water to be close to the outcrops.

Very little is known about the movement of the water once it enters the Madison artesian system. Except close to the outcrop area, the potentiometric surface becomes nearly flat, and no definite directions of movement can be inferred. Limited age-dating of the Madison water gives contradictory estimates of the rate of movement downward from the outcrop (P. H. Rahn, personal comm.). Swenson (1968) postulated that the Madison water escapes from the system by upward leakage into the Cretaceous sandstone aquifers. Support for this hypothesis is found in the anomalous quality of Dakota water in the north central part of the state.

Potentiometric Surface

Potentiometric maps published by Gries (1971), Mancini (Wyoming State Engineer's Office, 1974), and Konikow (1976) are all based on the same scanty information. The map shown on Plate II-5 is based, where possible, on producing water wells, with either a direct measurement of the static level, or a level calculated from the shut-in pressure of flowing wells. Latkovich (1960) concluded that static levels calculated from drill-stem test data, if combined with surface measurements, result in a very erratic and unsatisfactory model of the potentiometric surface. In the present study, only a few isolated drill-stem test

figures have been used to give broad control in the northwestern part of the state. The most remarkable feature of the present map is that, except for an initial steep gradient away from the outcrop area, the potentiometric surface is nearly flat. Except for a small anomalous area in Mellette County, it seems safe to say that a flowing Madison well can be anticipated at any point where the formation is present and the surface has an elevation of less than 2400 feet.

Hydrologic Characteristics of the Madison

Very little information is available on transmissivities, storage coefficients, or specific capacities of Madison wells in South Dakota.

The first Madison well drilled at the Rapid City Air Force Base in 1942 reported a specific capacity of 10.6 gpm/ft drawdown at a pumping rate of 426.5 gpm. At the Ben French Station of Black Hills Power and Light Co., the No. 3 Well, completed in the Madison, had a specific capacity after a small acid treatment of 0.187 gal/ft drawdown. After a second acid treatment, the specific capacity improved to 0.28 gal/ft drawdown. The well was subsequently abandoned.

On the Wyoming side of the Black Hills, where conditions within the Madison may be presumed to be similar, the following information is given by the Wyoming State Engineer's Office (1974, p. 51) for the Powder River Basin:

<u>Area</u>	<u>Transmissivity</u>	<u>Storage Coefficient</u>
North, near outcrop in Bighorn Mountains	8,000-89,000 gpd/ft	3.2×10^{-4} to 4.3×10^{-4}
South, near Laramie Range near Douglas	500-1,000 gpd/ft	10^{-4} (est)
South, near Hartville Hills	1,000-3,000 gpd/ft	5×10^{-5} to 1×10^{-4}
Newcastle Area	5,000-15,000 gpd/ft (est)	10^{-4} (est)

In the 3200-foot Madison test wells drilled by Energy Transmission Systems, Inc. (ETSI) in Niobrara County, Wyoming, only a few miles from the South Dakota border, the specific capacities, even after acid treatment, were only on the order of 0.1 gal/ft drawdown, and the transmissivities were about 400 gpd/ft.

Specific capacities have been compiled for municipal and industrial wells in Weston County, Wyoming, on the southwest flank of the Black Hills. The specific capacities range from 0.7 to 3.6 gal/ft of drawdown. Figures for five of the better wells in Weston County are given below:

<u>Owner</u>	<u>Location</u>	<u>Specific Capacity</u>
Terra Resources	19-46N-64W	3.2
Terra Resources	20-46N-65W	2.2
Terra Resources	23-46N-65W	3.0
Terra Resources	25-46N-66W	1.7
City of Upton	25-48N-65W	1.9

Well Yields

Recorded well yields in the Black Hills area range from 80 gpm on the pump to over 1000 gpm free flow (Table III-1). It would appear from study of the randomly distributed wells in South Dakota that a discharge of 500 gpm, either natural flow or pumping, can be considered an average for a properly constructed and developed Madison well. Some wells would require acid fracturing to reach this rate of production.

Well Interference

The question of interference between closely spaced limestone wells has not been adequately studied. Virtually no change in flow is noted at the No. 1 Madison well of the Black Hills Power and Light Co. at Osage, Wyoming when the No. 2 Well, a mile away, is heavily pumped. A test run on the two city wells at nearby Upton in June 1972 showed a drawdown on the observation well one mile away of 0.60 feet after 4 hours of pumping at 150 to 160 gpm, and a drawdown of 44.14 feet on the pumping well. There is some evidence that neither well had entirely recovered from pumping on the previous day.

It would seem advisable to maintain a distance of half a mile between Madison wells when a well field is planned; a mile would be better if engineering considerations permit.

Temperature

The Madison temperature map Plate II-6 is instructive. A distinction has been made between temperatures obtained directly from flowing or pumping wells, and data from bottom-hole temperature recorders on resistivity log sondes run in oil tests.

Surface water temperature is slightly lower than formation temperature if the water movement to the surface is slow, and wells in long service frequently yield water a few degrees warmer than the figures obtained on the initial production tests.

Few deep oil tests in South Dakota bottom in the Madison; most continue to deeper sedimentary strata or to the Precambrian basement rocks. Hence, most bottom hole temperatures have been recorded deeper than the Madison Formation. Temperatures have been corrected back to the top of the Mission Canyon Member of the Madison. This has been done by assuming

a mean annual temperature (surface) of 45 degrees, subtracting that from the recorded bottom hole temperature (BHT), and determining a gradient in feet per degree of depth. That gradient -- which ranged from 45 to 80 feet per degree Fahrenheit (averaging very close to 60 feet per degree) -- divided into the interval in feet from the top of the Mission Canyon to the bottom of the hole, gives a figure in degrees to be subtracted from the BHT to arrive at an approximate temperature at the top of the Madison. A separate symbol has been used on Plate II-6 to indicate temperatures derived by this method. Since most water wells would be drilled at least 200 feet into the Madison, actual water temperatures might be 3 degrees higher than indicated by the map.

Comparison of Plates II-2 and II-6 shows that basically, the temperatures reflect the depth to the aquifer, and are due entirely to the normal geothermal gradient in the earth's crust. The highest temperatures occur in the northwestern part of the state, where the Madison lies at depths of over 7000 feet.

The large warm-water area in the west-central part of the state is an anomaly for which there is no satisfactory explanation at present. Carda (1975) has noted that the Philip, Midland, and Bar-N Ranch wells in Haakon County are the only three Madison wells within the state in which he detected Radium 226, and all three lie within the warm-water anomaly.

Well Completions

Madison wells are sometimes difficult to complete properly. If the red shale cap which generally overlies the Madison karst surface were always underlain by relatively solid limestone, it would be relatively simple to drill a few feet into the top of the limestone to set and cement casing. But in karst topography, mud-filled fractures and caverns may be encountered several feet or even several tens of feet below the first apparently solid limestone. These red zones may cause trouble by permitting the well to throw out chunks of red shale. The chunks may wedge in the casing, where they restrict flow and usually cause the well to yield water with a reddish cast. Generally, setting a perforated liner after determining the extent of the cavernous area will solve the problem.

Because drillers anticipate a large flow when the first cavernous porosity is encountered, they are prone to set casing at the first sign of Madison limestone, and to take their chances on later cavern fillings.

Fortunately, limestone wells respond to acid stimulation. Acid injected under high pressures not only fractures the rock hydraulically, but enlarges the fractures as the acid is held in the rock under hydrostatic pressure. Acidizing at selected intervals, after examination of porosity logs (gamma ray and bulk density), permits placing the acid in relatively tight areas rather than having it all pass into the most open passages. Successive injections of small amounts of acid (3000-5000 gal) in carefully selected intervals is generally more effective than one large "shotgun" treatment.

PLATE II-1
THICKNESS OF MADISON FORMATION
Sept. 1977

PLATE II-2
STRUCTURE ON TOP OF MADISON
Sept. 1977

PLATE II-3
 DEPTH TO TOP OF MADISON
 Sept. 1977

PLATE II-4
AREAS OF FAVORABLE POROSITY
MADISON LIMESTONE
 Sept. 1977

PLATE II-5
 POTENTIOMETRIC SURFACE
 MADISON ARTESIAN SYSTEM
 Sept. 1977

PLATE II-6
ISOTHERMAL MAP MADISON FORMATION
Sept. 1977

PLATE II-7

TOTAL DISSOLVED SOLIDS IN MADISON AQUIFER
 Sept. 1977

SECTION III WATER QUALITY

General

Chemical analyses of the waters from the Madison Aquifer were conducted on wells of specific interest by approved methods outlined in either the 13th edition of Standard Water and Waste Water Methods of Analysis or the EPA Manual of Methods for Chemical Analysis of Water and Wastes. A complete description of methodology is found in Appendix A. Previously analyzed and compiled data on mineral contents of other Madison waters also is given in Tables III-1 and III-2.

Water quality varies widely within the Madison Aquifer. It can generally be said that the water quality is best close to the Black Hills perimeter and decreases radially outward, with the lowest quality occurring to the north of the Black Hills. The northernmost counties in South Dakota have the worst quality, at the greatest depths and some of the highest temperatures, but have the lowest population. This water in most cases exceeds recommended EPA levels for human consumption on several parameters; however, people have been known to drink it with few ill effects, notably in Midland and Edgemont.

The Madison waters observed, when permitted to cool and evaporate in the atmosphere, will produce a heavy white deposit composed primarily of gypsum and amorphous silica. However, this deposit did not seem to occur in the transmitting pipes inspected. This water is far superior to most water from the shallower Inyan Kara group and is highly prized by the ranchers.

The gas contained within the water is composed largely of nitrogen, carbon dioxide, traces of oxygen, and hydrogen sulfide. The sulfide concentration was determined on-site colorimetrically by the methylene blue method and was measured spectrophotometrically (Table III-3). The hydrogen sulfide is apparently the cause of the corrosion, and is discussed in subsequent sections of this report.

There are no dangerous levels of any toxic elements in the waters tested. This would permit the water to be used for irrigation in arable soils or as a livestock water. Secondary utilization or disposal of cooled Madison Aquifer water should not present any major problems.

TABLE III-1

Madison Water Wells In South Dakota And Western Wyoming

Reference Number	State	County	Well Name	Well Number	Date Drilled	Location--Sec., Township, Range	Elevation (Ft. Above Sea Level)	Total Depth	Top of Madison (Ft. Depth)	Base of Madison (Ft. Depth)	Static Level (Ft. Above Sea Level)	Well Discharge (GPM)	Well Specific Capacity (GPM/Ft.)	Temp. (°F)
1	S.D.	Butte	Delzer	1	1976	28-12N-3E	3210	4858				1000 Est.		134
2	S.D.	Butte	Harmon Olson	1	1952	27-9N-3E	3000	4016	2890	3575	3000+	1080		125
3	S.D.	Butte	Ken Bean	1	1976	28-9N-3E	3100	3510	3200		3100+	1050		108
4	S.D.	Custer	Palensky, Streeter	1	1949	15-6S-6E	3508	939						108
5	S.D.	Dewey	Eagle Butte City	1	1956	17-12N-24E	2422	4325	3953		2570	110 ⁺		128
6	S.D.	Fall River	B.H. Ord. Depot	1	1942	3-10S-2E	3665	4000	3600	3870	3665+		2.0	139
7	S.D.	Fall River	B.H. Ord. Depot	2	1943	3-10S-2E	3664	3855	3560	3780	3664+	800		113
8	S.D.	Fall River	Edgemont City	2	1936	2-9S-2E	3578	3183			3668			139
9	S.D.	Fall River	Edgemont City	4	1962	2-9S-2E	3565	3460	3050	3380	3565	300 Est.		130
10	S.D.	Fall River	Edgemont B-N RR	2	1946	1-9S-2E	3459	2955	2890		3205			125
11	S.D.	Fall River	Mines Development	1	1962	2-9S-2E	3450	3060	3806		3644	100 Est.		130
12	S.D.	Haakon	Bar-N Ranch	1	1959	31-5N-24E	2470	4112	3850		2470+	250 Est.		145
13	S.D.	Haakon	Midland City	2	1960	6-1N-25E	1945	3311	3300		2549 Est.	55		160
14	S.D.	Haakon	Philip City	1D	1962	1-1N-20E	2245	4010	3784		2245+	400		153
15	S.D.	Hughes	Pierre Airport	1	1942	35-111N-79W	1719	2370	2252	2340	1719+	200 Est.		110
16	S.D.	Jones	Murdo City Well		1976	36-1S-28E	2202	3622			2440	50		140
17	S.D.	Lawrence	Johnson, Warren		1971	23-7N-2E	3360	1498	1450			1100 Est.		55
18	S.D.	Lawrence	McNenny Fish Hatch.	19		21-7N-1E	3480	1306			3480	40		52
19	S.D.	Lawrence	Spearfish City		1962	15-6N-2E	3673	860	577	860	3670	540		56
20	S.D.	Lawrence	Spearfish City		1975	15-6N-2E	3689	750	610			600		
21	S.D.	Meade	Bear Butte	2	1956	19-6N-6E	3190	1350	902		3190+			55
22	S.D.	Meade	Black Hills Cem.	5		26-5N-5E		1100						82
23	S.D.	Mellette	Anderson (Nelson)		1964	32-42N-25W	2110	2690	2540		2188			141
24	S.D.	Mellette	Bachman		1952	21-42N-26W	2202	2730			2243			140
25	S.D.	Mellette	Koskan		1964	34-42N-26W	2174	2934	2825	2920	2248			149
26	S.D.	Pennington	B.H.P.&L. Co.	1	1959	34-2N-7E	3300	1275	889		3427	450 Est.	1.38	57
27	S.D.	Pennington	B.H.P.&L. Co.	3	1960	34-2N-7E	3340	1930	1300	1655	3340+	20	0.28	57
28	S.D.	Pennington	Ellsworth AFB	1	1942	18-2N-9E	3184	4645	4205		2641	380 Est.	9.2	129
29	S.D.	Pennington	Ellsworth AFB	2	1942	13-2N-8E	3210	4436	4205		2891		3.0	121
30	S.D.	Ziebach	Dupree City	1	1965	31-13N-21E	2359	4500	4268		2508			138
31	Wyo.	Crook	Sundance	3		25-52N-63W		1123						60
32	Wyo.	Niobrara	Etsi	0-1	1974	28-36N-62W	4247	3274	2870	3140	3725			46
33	Wyo.	Weston	Newcastle	1	1949	20-45N-61W	4355	2638	2612		4664	1450		76
34	Wyo.	Weston	Osage	1	1941	10-46N-63W	4380	2592	2580		4789	530		73
35	Wyo.	Weston	Upton	4	1964	25-48N-65W	4332	3161	2900		4200			78
36	Wyo.	Crook	Madison Test Well	1	1976	15-57N-65W	3604	4341	2285	3001	3721	250	6.8	108

TABLE III-2

WATER QUALITY*

Reference Number	Total Dissolved Solids (PPM)	Specific Conduct.	pH	Alk. (Ca CO ₃)	Al	HCO ₃ ⁻	SO ₄ ⁻⁻	Cl ⁻	F ⁻	NO ₃ ⁻	PO ₄	SiO ₂	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Sr ⁺⁺	Li ⁺	Total Fe	Mn ⁺⁺	B	SAR
1	2710		6.5	1425.6		121	1622	61				35.5	571.7	120	36	13			1.00	.20		
2	1894		6.7	950		129	1175	51				19.2	381	91	26	13			.20	.20		
3	896		7.7	415.8		154	489	18				3.3	167	67	12.9	5.7			.58	0		
4	198					103	9	25	.3			2	410	16	10	2						
5	2094		6.6	134		168	1325	65	4.4			32	405	95	49	22			1.4	.0		.13
6	1331																					
7	1070	1730	7.5	148	0.30	180	319	269	1.3	1.6	.04	30	110	30	203	18	2.2	.29	.05	.01		
8	1109					198	315	255	1.4			28	123	35	186	16			.9			
9	1140	1630	7.6	190		232	285	257	.92	2.2	6.7	33	130	33	180	14.3		.36	<.005	.015		
10	880	1080	7.7	195		238	180	125	.61	2.2	6.1	37	108	26	93	7.9		.17	<.005	.007		
11	836	1260	7.6	195		238	215	140	.74	5.3	6.2	35	114	26	107	5.8		.21	.334	.007		
12	2066		6.92	950		126	1087	185	2.4		.07	42	381	79	85	15			.14	.40	.43	
13	1462	1230	7.2	120	.023	146	736	28	2.8	.2	.02	36	272	68	18	10	5.5	.03	.28	.01	.07	.25
14	1172	1165	7.2	131	.026	160	633	21	2.3	.2	.05	34	221	51	15	7	5.4	.03	.12	.00	.07	.24
15	2318						1040	91	4				340	91	59							
16	1572	1490					896	57				36	309	57	37	12			4.7			.51
17																						
18	362	580	7.7	216	0	264	103	.6	.3	1.0	.08	12	87	24	2.1	1.4	.89	.00	.01	.00		
19	233	405	7.8	225	.054	274	8.2	.6	.2	.5	.06	10	52	23	2.1	1.1	.15	.00	.01	.00		
20																						
21	2080	2250	7.5	162	.015	198	1400	.9	1.2	.5	.05	11	462	96	3.9	2.5	4.2	.02	.02	.01		
22	230		8.13	128		224	12	2				11	51.5	27.6	2	2			.06	.00		
23	1270					152	672	42	1.7				246	47	35	13						
24	1270						620	53					252	70	48							
25	1180						630	2.5					268	24	39							
26	189																					
27	223						263	.7					31	22	8							
28	1210					204	214	3	.6			21	73	29	8	3						
29	461	678	7.7	167	.009	204	204	1.0	.6	.4	.05	21	91	33	4.9	3.7	.94	.01	.01	.00		
30	2521					183	1102	245	4.3				400	94	144	44						
31																						
32	455		7.3			232	110	74					85	24	42	61.2		.03	.13			
33	302	509	7.7	238	.044	290	47	1.2	.3	.8	.04	12	64	29	2.6	1.7	.38	.01	.00	.00		
34	311	526	7.7	244	.061	298	50	.7	.4	.9	.06	11	70	27	2.1	1.4	.32	.00	.02	.00		
35	456	698	7.7	226	.035	276	169	.8	1.2	.5	.04	12	88	41	2.6	2.2	2.9	.00	.18	.00		
36	1060	1345	6.6	176	.030	180	470	66	1.9		.01	25	180	40	70	9.2	4.5	.040	.31	.100	.21	1.2

*All data mg/l unless otherwise noted

TABLE III-3

Sulfide Ion and Dissolved Oxygen Concentrations
in Selected Madison Aquifer Waters

<u>Location</u>	<u>Dissolved Oxygen (ppm)</u>	<u>Sulfide Ion (ppm)</u>
Bar-N Ranch	0.3	0.20
Midland	0.4	0.04
Philip	0.5	0.03

SECTION IV WATER TREATMENT

General

When considering water, and specifically a geothermal water source, as a medium in a heat transfer application, due consideration must be given to the scaling and corrosion tendencies of the water. These tendencies must be controlled by some type of treatment, or scaling and corrosion will inhibit heat transfer system performance. The quality of the water dictates the best means by which to keep the scaling and corrosion tendencies under control.

The water analysis data on the existing wells into the Madison Aquifer have been compiled in Section III. Some generalizations with regard to scaling tendencies and corrosiveness, as well as suitability of construction, can be based upon these data. However, since the quality of the water varies within the aquifer, specific control must be designed for the tendencies existing at the point of use.

The services and expertise of Sheppard T. Powell Associates, water consultants, of Baltimore, Maryland, were used in this study.

Scaling Tendencies

Water quality data indicate that the scaling and mineral deposition tendencies of the Madison geothermal water can be in the form of calcium carbonate, calcium sulfate, silica, and iron. Each of these will be discussed separately.

Using the water analysis from the Midland, South Dakota well, the Langelier Saturation Indices (LSI) were calculated for calcium carbonate scaling tendencies at various temperatures between 160° and 110°F. The results of these calculations indicated that the water is supersaturated at 160°F, and saturated to a lesser extent at 110°F. These results are indicated on Table IV-1.

TABLE IV-1

Calcium Carbonate Scaling Tendencies of Madison Aquifer Water

<u>Temperature</u>	<u>Langelier-Powell Chart</u>		<u>Langelier-Larson and Buswell</u>		<u>Ryznar** Index</u>
	<u>S.I.</u>	<u>pH *</u>	<u>S.I.</u>	<u>pH *</u>	
160°F.	0.63	6.57	0.92	6.28	5.36
130°F.	0.37	6.83	0.70	6.50	5.80
120°F.	0.29	6.91	0.61	6.59	5.98
110°F.	0.19	7.01	0.53	6.67	6.14

*pH of saturation with respect to calcium carbonate.

**Ryznar Stability Index calculated with Larson-Buswell values.

Saturation indices of this order indicate a significant scaling tendency at the warmer temperatures and a lesser although still appreciable scaling potential as the water cools. The Ryznar Stability Indices (RSI) are also indicated. This index is an empirical relationship formulated on the basis of corrosion and scaling studies of various actual waters having different saturation indices. With a Ryznar Stability Index of less than 6.0, which is the case for all three of the above temperatures, it may be expected that scaling will occur and generalized corrosion would be minimal. When the RSI is 7.0, a protective film of calcium carbonate scale probably would not form, and corrosion would increase. Above an RSI of 7.5 or 8.0, corrosion would become progressively worse.

Another possible scale-forming compound in this water is calcium sulfate. It is generally accepted that a conservatively safe solubility product limit for this compound in water lies within the range of 400,000 or less. This value is obtained by multiplying the calcium (mg/l) present by the sulfate (mg/l). Using the analysis provided, the product is 213,000. Thus, it is felt that calcium sulfate probably would not constitute a problem.

The silica content of the water may be significant, and requires further study. Heavy scaling in one geothermal heating system in Iceland was found to result from silica and iron oxide. This scaling took place in those sections of the system where the heat had been reduced.

Although scaling is protective from a corrosion standpoint, it would interfere with heat exchanger function and should be kept to a minimum. To do this it would be desirable, we feel, to feed acid into this water and lower the actual pH to within 0.3 to 0.4 units of the pH at 160°F. This would probably be in the pH range of about 6.5-6.8. Concurrent with the acid feed, polyphosphate, an anti-scalant and corrosion inhibitor, could be metered in to achieve a concentration of about one to two parts per million. At such a pH in the presence of polyphosphate, scale formation would be minimized and corrosion held to an acceptable degree. Adjustments in pH and polyphosphate levels would best be made on the basis of actual practice to compensate for temperature differences across the heat exchanger. In this way, a treatment which balances corrosion control and scale inhibition can be developed. Such a balanced treatment would distribute a very thin, dense scale as uniformly as possible across the heat exchanger.

In determining the scaling tendency of this water and suitable means for control, the pH value of the water is of prime importance, as are the total alkalinity and other factors used in developing the saturation index.

Corrosion Tendencies

Internal corrosion of water systems is usually caused by dissolved oxygen and hydrogen sulfide. These elements are difficult to measure.

If hydrogen sulfide, high dissolved oxygen, or other substances such as arsenic are present, they could have considerable bearing on corrosion and, consequently, on the types of heat exchanger tubing which could be considered for this application. The internal deposits present on the heat exchanger cores or bundles from the Philip and Midland installations, which were analyzed by X-ray diffraction, indicate the presence of copper sulfide and Bornite (Cu_5FeS_4) as a black internal scale in association with severe internal corrosion. This indicates that hydrogen sulfide is present in the geothermal water in significant amounts. Just a trace or a fraction of a milligram per liter could do this type of damage in a heat exchanger application. Sulfide reacts with copper alloy tube materials and causes severe corrosion. The reaction product of sulfide and copper is a soft, porous black material which offers poor protection to the underlying metal. Usual water velocities can erode this layer, leaving fresh metal exposed for further reaction with sulfides in a continuing cyclic fashion, which results in severe corrosion characterized by thinning or severe pitting. Chlorination or hypochlorination with the feeder setting tied to well pump operation would effectively prevent these effects. The white external deposits at Midland were identified as gypsum, which is calcium sulfate. Scale found in pipes at Philip was similarly calcium based. Appropriate acidification and use of scale preventives are called for to control such white-to-yellow external deposits.

To further examine the corrosiveness of the water, studies are being conducted by the South Dakota School of Mines and Technology. The findings to date are discussed in Section V of this report.

Summary

In conclusion, it appears that pH control through mild acidification and use of a scale and corrosion inhibitor such as a polyphosphate would be required. From an analysis of the materials used in existing geothermal heating systems, it generally appears that corrosion has been the major problem. Water velocities in these systems has evidently been adequate to prevent major scaling problems. Section V, Corrosion and Scaling Studies, will cover this subject in more detail.

SECTION V CORROSION AND SCALING STUDIES

General

Corrosion and scaling studies were composed of three parts: 1) historical documentation of heat exchanger experience with Madison Aquifer water; 2) theoretical prediction of corrosion and scaling properties of Madison water; and 3) on-site corrosion and scaling investigations. Before the presentation of these three subjects, some general comments on the nature of Madison waters in comparison to commonly held ideas about geothermal waters are in order.

Geothermal waters have the reputation of being highly corrosive and saturated with dissolved solids which rapidly erode or plug heat exchanger equipment and connecting plumbing. This reputation emanates from the properties of geothermal brines, which have been reported to contain up to 300,000 ppm dissolved solids (Wehlage, 1976). Fortunately, geothermal Madison Aquifer waters do not conform to this reputation. The maximum concentration of dissolved solids from a South Dakota well into the Madison is 2710 ppm at the Delzer Well in Butte County. Also, unlike geothermal brines, Madison waters from South Dakota wells have relatively low chloride levels. One other characteristic of Madison geothermal waters which is also of major importance in regard to corrosion and scaling is temperature. Madison waters from South Dakota wells do not exceed the boiling point. Corrosion and scaling problems in these waters are very much different from corrosion and scaling problems in many geothermal brines.

History of Geothermal Applications

A survey of Madison well applications in South Dakota shows that wells at Philip and Midland have been and are continuing to be used for space heating as well as for municipal water supplies.

Midland

Independent School District 114 at Midland heats its two largest buildings with Madison Aquifer water. Each building is heated with recirculating water which has been heated by geothermal water in a primary heat exchanger. Both primary exchangers are conventional shell-and-tube units with the Madison water flowing through the tubes. According to school principal Richard Rockafellow, the steel shell in the older building has been replaced once in thirteen years, while two sets of copper tubes have been installed during the same period. The newer building's heat exchanger has continued to perform without failure since its installation 5 years ago. Failure of the older units resulted from corrosion rather than by scaling. X-ray analysis of the interior of the tubes showed the presence of a layer of copper (I) sulfide corrosion product.

Philip

The Philip water plant is heated by two forced-air heat exchangers, one of which is shown in Figure V-1, and one natural convection baseboard exchanger. Figure V-2 shows the core from one of the forced-air units. The tubing is all copper and all joints are soft-soldered. The cores fail due to corrosion of the small vertical tubes and have service lives ranging from five to eleven years. Likewise, the copper baseboard exchanger failed as a result of corrosion after eleven years of service. Sectioning of the tubing through the points of failure showed fairly uniform attack of the tubing walls, with no evidence of pitting. A black, loosely adhering crust of copper (I) sulfide was observed throughout the insides of the cores. Massive encrustations of calcium carbonate and sulfate were found on the exterior of the exchangers where leaks had developed, allowing evaporation of aquifer water.

Cross sections from six of the small vertical tubes, taken at regular intervals across the width of the core shown in Figure V-2, were mounted and polished for metallographic examination. Figure V-3 shows a micrograph of one of the tubing walls. The sulfide corrosion layer is clearly visible on the inside of the tube wall. The absence of significant variation in the tubing wall thicknesses of the six samples indicated no significant influence of velocity on corrosion rate. This conclusion is based on the assumption that velocities through the tubes near the center of the core exceeded the velocities through the tubes near the sides of the core.

Madison water for the exchangers at Philip is supplied through a 2-in. rigid copper pipe which has considerably greater wall thickness than the copper tubing used in the heat exchangers. No failure of the supply piping has occurred during the twelve years it has been in service. Supply piping performing satisfactorily was removed for destructive examination. The interior surfaces were found to be coated with a black copper (I) sulfide layer. No pitting or appreciable thinning was observed anywhere along selected sections, including highly turbulent locations such as elbows. A bronze valve body and its gate were found to be in good condition. Occasional points of leakage from the supply piping were found to be the result of poor soldering during installation. Polished samples of the cross sections of properly soldered joints showed no corrosion attack.

The corrosion rate of copper at Philip was estimated as described below for the forced-air unit cores, even though the original tubing thickness was unknown. Figure V-4 shows sections from two forced-air cores. The left section is from a unit in service 5 years, while the one on the right was in service 11 years. Since the ends of the small tubes terminating in the large supply tube were exposed to Madison Aquifer water from both sides, their walls were assumed to have corroded twice as quickly as the portions of the same tubes whose outsides were

PHILIP WATER PLANT
FORCED-AIR HEAT EXCHANGER

FIGURE V-1

**PHILIP WATER PLANT
FORCED-AIR HEAT EXCHANGER CORE**

FIGURE V-2

PHILIP WATER PLANT
HEAT EXCHANGER
CROSS-SECTION OF A COPPER TUBE

FIGURE V-3

5 YEARS

11 YEARS

SERVICE PERIODS

PHILIP WATER PLANT
SECTIONS FROM
FORCED-AIR HEAT EXCHANGER CORES

FIGURE V-4

not exposed to the Madison water. Therefore, by measuring the difference in a small tube's thickness before and after its entrance into the large supply tube, the net corrosion effect for one surface was obtained. Results of these measurements are presented in Table V-1.

TABLE V-1

Estimated Corrosion Rates for Copper from the
Philip Water Plant Heat Exchangers

<u>Exchanger</u>	<u>Corrosion Rate (mils/yr)</u>
Forced Air	
5-Year Service	1.57
11-Year Service	1.90
Baseboard	1.61

It should be noted that the core with a 5-year service life failed at a solder joint and not from general corrosion of the copper tubing. Nevertheless, the estimated corrosion rate in Table V-1 is still valid. Failure of the solder joint appeared to be unrelated to corrosion of any kind. However, attempts by water plant personnel to repair the core by resoldering it obscured the original failure.

A copper corrosion rate was also obtained from the Philip baseboard exchanger by assuming the original thickness of the core to be the same as the core flange soldered onto the supply tube. At this location, the inside core surface was protected from the Madison water by the solder. This thickness was accurately measured by examining a mounted and polished section of a solder joint from the baseboard exchanger. The corrosion rate determined by this method is also shown in Table V-1 and is in excellent agreement with the estimated rates from the forced-air cores.

Corrosion and Scaling Predictions

Scaling could result from the formation of calcium carbonate, calcium sulfate, or silica. Each of these compounds is discussed below. The method of predicting calcium carbonate formation involves the calculation of a scaling index (S.I.), which is also used to predict corrosivity. Therefore, the subject of corrosion is included in the discussion of calcium carbonate.

Calcium Carbonate

When accurate water quality data are available, scaling and corrosion tendencies can be predicted reasonably well using the scaling index, S.I., developed by Langelier (1946) and later refined by Powell (1954) and by

Larson and Buswell (Permutit, 1949). The scaling index is the difference between the pH of the water and the pH at which precipitation of calcium carbonate occurs. Therefore, a positive S.I. indicates scaling by calcium carbonate while a negative S.I. indicates a corrosion tendency. The Ryznar Index (Ryznar, 1944), which equals twice the saturation pH minus the water's pH, is also frequently used to determine the level of corrosivity or carbonate scale tendency. On this index, less than 6.0 indicates scale formation, while 7.5 or greater indicates corrosion.

Table V-2 gives the S.I. calculated using the Langelier-Powell chart, the S.I. calculated using Larson and Buswell values, and the Ryznar Index for selected Madison waters. No index for any site or temperature indicates that corrosion is a significant concern. Conversely, scaling is predicted to be severe at Philip, Midland, and the Bar-N Ranch. These results are contrary to observed behavior at Philip and Midland and indicate incorrect water quality values used in the calculation of the indices. Values used are pH, total alkalinity, calcium ion concentration, and total dissolved solids. The values to be used in determining the indices are on-site values at the temperature of interest. Since most of the water quality values reported and used for index calculation were established by laboratory analysis of water samples, significant errors in the indices are not unexpected. Therefore, the use of scaling indices based on laboratory analyses of field samples is of little or no value in predicting the calcium carbonate scaling behavior of Madison waters. Extensive field water analyses would be required to achieve reliable prediction.

Calcium Sulfate

Scaling by calcium sulfate precipitation is expected when the solubility product is exceeded. When the concentrations of sulfate and calcium ions are expressed in ppm, the solubility product is 400,000. Since nearly all Madison wells are considerably below this value, scaling by calcium sulfate precipitation is expected to be a rarely encountered problem.

Silica

Silica scaling has been observed in Icelandic geothermal waters having silica concentrations of 70 ppm (Chesney, 1977). Although no Madison water has reported silica concentrations this high, silica analyses are frequently low because it plates out onto container walls while in transit for laboratory analysis. Therefore, unless specific evidence is available which indicates silica formation is not a problem, accurate on-site analysis for silica should be made at each location considered for geothermal development.

Corrosion and Scaling Experiments

Because of the complexity of Madison waters and the difficulties encountered in using scaling indices to predict corrosion and scaling tendencies, an experimental program was undertaken to provide reliable

TABLE V-2

Scaling and Ryznar Indices for Selected Madison Waters

<u>Location</u>	<u>Temperature (F)</u>	<u>Scaling Index</u>		<u>Ryznar* Index</u>
		<u>Langelier-Powell</u>	<u>Langelier-Larson & Buswell</u>	
Philip	160	0.95	0.99	5.22
Midland	160	0.63	0.92	5.36
	110	0.19	0.53	6.14
Edgemont	113	0.54	0.58	6.34
Eagle Butte	128	0.23	0.12	6.36
	100	-0.04	-0.12	6.84
Bar-N Ranch	145	1.48	1.52	3.88

* Calculated using Larson-Buswell values

information on 1) the corrosion behavior of commonly used heat exchanger metals and alloys and 2) the probability of scaling. Both of these goals were achieved with the corrosion test rack shown in Figure V-5. Each test rack had (26) 2-in. diameter samples of the following thirteen materials:

Carbon Steel	1020
Stainless Steel	304
Stainless Steel	316
Monel	400
Admiralty Brass	443
Copper	801
Copper Alloy	715
Copper Alloy ¹	958
Copper Alloy	958 (weld rod)
Copper Alloy ²	613
Copper Alloy	613 (weld rod)
Aluminum*	3003
Glass, Plate*	

¹Ampcoloy 483^R

²Ampco 8^R

*Not shown in Figure V-5

The test rack was placed inside the 4-in. diameter PVC enclosure through which Madison water flowed. Periodic observation of the disks permitted evaluation of the corrosion and scaling properties of the Madison water. The glass disks were used as a sensitive means of visually assessing the occurrence of scaling. Test racks were installed at Philip, Bar-N Ranch, and Edgemont, because these locations provided waters of widely different temperatures and chloride and sulfate concentrations.

Philip

The first test rack was installed at the Philip Water Plant on April 5, 1977. Flow rate through the test chamber was 7.5 gal/min, and the discharge temperature was 157°F. Several weeks after installation, the rack was found to be coated with the same powdery black copper (I) sulfide observed in copper heat exchangers in the water plant. On September 1, 1977, half of the disks (one of each material) were removed and examined for corrosion.

No scale was found on the glass disks. Both of the copper alloy 613 specimens, copper, Admiralty brass, copper alloy 715, and the stainless steels showed very minor, uniform attack. Both of the copper alloy 958 specimens and Monel showed general etching. Carbon steel and aluminum were heavily attacked, with the steel having a rough etched surface and the aluminum showing some shallow pitting. Dealloying was not observed in any specimens or in the brass nuts used to secure the disks (which were mounted on Teflon collars and washers to preclude galvanic corrosion).

CORROSION TEST RACK

FIGURE V-5

The rate of corrosion was determined by cleaning the corrosion products from the samples and weighing to determine total weight loss. With the exception of copper alloy 613, the samples were cleaned easily by dipping into a hot 1:1 HCl solution, rinsing, and then scrubbing with a cleanser. Unexposed blanks cleaned in this fashion showed negligible weight loss. Table V-3 shows the calculated corrosion rates.

TABLE V-3

Corrosion Rates For Philip

<u>Specimen</u>		<u>Corrosion Rate</u> <u>(mils/yr)</u>
Carbon Steel	1020	4.72
Stainless Steel	304	0.019
Stainless Steel	316	0.025
Monel	400	0.40
Admiralty Brass	443	0.12
Copper	801	0.13
Copper Alloy	715	0.32
Copper Alloy	958	0.51
Copper Alloy	958 (weld)	0.60
Copper Alloy	613	0.24
Copper Alloy	613 (weld)	0.43
Aluminum	3003	4.43

These results show that 304 or 316 stainless steel would serve well in Madison waters similar to those at Philip. Also, most of the copper alloys, copper, and Admiralty brass would provide approximately 50-year service with wall thicknesses of 0.025 inch. Since most heat exchanger cores would normally have walls of this thickness for structural purposes, factors other than corrosion rates could well determine the selection of heat exchanger materials.

Sulfide ion can cause and is probably responsible for much of the corrosion of copper and copper-base alloys in the water found at Philip. If such is the case, much lower corrosion rates in such materials could be achieved through oxidation of the sulfide ion to sulfate by chlorination. The quantity of chlorine required to achieve this protection equals the stoichiometric amount plus enough to maintain a 0.5 to 1.0 ppm excess. For sulfide levels in the range of the waters at Midland and Philip, such treatment would require approximately 500 lb of chlorine per year for a community with the heating demand of Midland (approximately 3×10^{10} Btu/yr).

The marked difference between the corrosion rate determined in these experiments and the copper corrosion rates estimated from failed exchanger cores recovered from the Philip Water Plant warrants discussion. The estimated rates exceed the test rack rate by a factor of approximately twelve. The difference in the rates probably arises from the different conditions prevailing in each case. The test rack specimens were exposed only to oxygen-deficient water which was continuously flowing. On the

other hand, since the heat exchangers were not in operation during the summer months, the copper cores may have been exposed to prolonged periods of stagnant water or perhaps moist air rich in oxygen, depending on the procedures used to place the heat exchangers on summer standby. In consideration of the difference in the corrosion conditions, it appears as though special attention should be given to idle heat exchange equipment to prevent unduly high corrosion rates.

Edgemont

The corrosion test rack was installed July 29, 1977 at the Edgemont City Well No. 2, drilled in 1936. Periodic inspection of the specimens has shown that the aluminum 3003 and the carbon steel 1020 are severely attacked. Figures V-6 and V-7 show these two disks after 6 weeks of exposure. X-ray diffraction analysis of the white deposit on the aluminum specimen showed it to be amorphous. All of the remaining specimens appeared to resist corrosion.

Noticeably absent from the test rack assembly was the fine dispersion of copper sulfide so prevalent at Philip and Midland. At Edgemont, the PVC tube and most specimens were discolored with a yellowish-brown deposit probably high in iron although the deposit was too thin to allow collection for X-ray analysis. This deposit was also observed on the glass disks as shown in Figure V-8.

Because of the short exposure times of the samples, no attempt was made to determine corrosion rates by weight loss measurements. However, the South Dakota School of Mines and Technology will continue to operate the corrosion test rack and publish the results in the open literature.

Bar-N Ranch

A corrosion test rack was installed on August 16, 1977 at the Bar-N Ranch Well. Inspection of the specimens after three weeks' exposure showed the familiar black copper sulfide deposit throughout the assembly. Aluminum 3003 was corroding in the same fashion as the aluminum sample at Edgemont with large deposits of a white amorphous material covering severe pits. Carbon steel was also severely etched. This rapid attack of aluminum and carbon steel at Edgemont and the Bar-N Ranch is attributed to high chloride concentrations. Disks of 304 and 316 stainless steel appeared least affected by exposure.

As with Edgemont specimens, no attempt was made to determine corrosion rates by weight-loss measurements. When sufficient exposure time for reliable weight-loss measurements has elapsed, South Dakota School of Mines and Technology personnel will report those results in the open literature.

EDGEMONT, S.D.
ALUMINUM 3003 AFTER SIX WEEKS
EXPOSURE TO MADISON WATER

FIGURE V-6

EDGEMONT, S.D.
CARBON STEEL 1020 AFTER SIX WEEKS
EXPOSURE TO MADISON WATER

FIGURE V-7

EDGEMONT, S.D.
GLASS PLATE AFTER SIX WEEKS
EXPOSURE TO MADISON WATER

FIGURE V-8

Recommendations and Conclusions

The following recommendations are made with respect to minimization of scaling and corrosion:

1. In systems with a primary heat exchanger, 304 or 316 stainless steel is recommended as a construction material. In Philip-type water where chloride concentrations are less than 100 ppm, the service life of stainless steel is expected to be indefinite.
2. In systems without a primary heat exchanger, stainless steel is recommended over copper and copper-base alloys on the basis of corrosion resistance. However, factors such as the high cost of stainless steel exchangers for individual users may make thick-walled (0.050 in.) copper or copper-base alloy exchangers more economical. Service life of such exchangers is expected to be at least 50 years. Substantial extension of this life or reduction in required wall thickness might be achieved by chlorination of sulfide ion.
3. In waters with chloride concentrations greater than 100 ppm, copper and copper-base alloys might serve as well as or better than 304 and 316 stainless steels. Quantitative corrosion rates for such waters will be reported in the open literature as they become available from continuing studies.
4. Since corrosion rates in copper exchangers appear to be substantially higher in stagnant geothermal water than in flowing water, a corrosion control program should be established for heat exchangers during prolonged periods of idleness.
5. Prediction of scaling tendency by the Langelier and Ryznar indices using currently available water quality data is unsatisfactory. A study to obtain accurate, on-site water analyses should greatly improve the value of the indices as a predictive tool.
6. No significant scaling has been observed in geothermal Madison waters which have remained unexposed to the atmosphere. Corrosion is the primary problem to be overcome in the recovery of heat from Madison Aquifer waters.

ACKNOWLEDGMENTS

Project personnel wish to thank John Cieslewicz and Robert Mehring of Ampco Metal, Milwaukee, Wisconsin, for contributing a corrosion test rack, numerous corrosion specimens, and technical corrosion analyses and advice. Also, the project personnel thank the employees of the cities of Philip, Midland, and Edgemont and the personnel of the Diamond Ring Ranch (formerly Bar-N) for their cooperation in fulfilling the objectives of this project.

SECTION VI GEOTHERMAL APPLICATIONS

General

In order to determine which potential heating applications would be practical in the area of South Dakota overlying the Madison Aquifer, commercial, residential, and industrial development must be considered. The thermodynamic characteristics of the aquifer must also be known in order to judge the practicality of potential and known applications.

The following circumstances form the basis for considering potential heating applications:

1. The western area of South Dakota is dotted with small farming communities.
2. The major businesses and industries in the area are related to agriculture, or support the agricultural business. Cattle ranching and winter wheat are the primary sources of income to the area.
3. Population density is low.
4. There is no major natural gas pipeline in this part of the state. Therefore, home heating systems in the small communities are primarily using the more expensive energy sources, namely fuel oil and propane. Some all-electric heating systems have been installed in recent years.
5. No major rail service passes through the state; thus, no commercial centers of any size exist.
6. Water for both domestic and agricultural use is a limited resource. Therefore, potable water in the area is perhaps as important as the potential geothermal heat value in the Madison Aquifer. Consequently, attention must be paid to both local water use and the geothermal aspects of the Madison Aquifer in future utilization studies.

Accordingly, the following matters must be given special consideration in future studies:

1. Development must be suitable for small communities.
2. Development must be oriented to agriculture-related industries.
3. The possibility of using geothermal water for domestic purposes must be considered.
4. Drawdown rates on the aquifer must be acceptable within recharge rates.

5. Basic economics will be related to the depth of well or wells.

In light of these conditions, the most fruitful initial area of investigation appears to be use of the geothermal source as the energy supply for a small municipal heating system. The feasibility of such a system, both technical and economic, would involve considerations of population size and density, community needs, and end-use of the geothermal water supply. The cost and advantages of a geothermal heating system would then be evaluated against the cost of heating homes and businesses with fuel oil or propane. From a technical standpoint, the physical and chemical characteristics of the Madison Aquifer water will determine materials required for a reliable system, and a system concept to satisfy the local demands would be developed.

Other potential applications of geothermal heating would be related to the agricultural industry. These could include livestock watering, irrigation, warm-bed heating, and greenhouse farming. The other known industrial applications have been discounted, except for general industrial building heating, due to the fact that little industry exists and the energy level of the geothermal source is too low for process heating, curing, cooking, drying, and present absorption refrigeration systems. Therefore, the practical applications for geothermal heating to be considered for this area of South Dakota will be limited to heating systems and agricultural uses.

When considering the use of energy from any geothermal source, the most critical factor to examine is the quality of the water. Its physical and chemical properties must be analyzed, and utilization must be based upon controlling or inhibiting its scaling or corrosive tendencies. Therefore, the testing and analysis carried out by the South Dakota School of Mines and Technology must be carefully considered.

Central Heating System Design Concept

In order to properly evaluate the feasibility of geothermal heating systems for small communities based upon the agricultural industry, an initial system design concept must be developed. This concept should be directed toward the following goals:

1. System reliability, so that homes are assured of heat during the cold winter months
2. Minimization of maintenance requirements
3. Compatibility of the system with skill levels of local technicians so that the system can be locally maintained and repaired

4. Minimization of the amount of retrofitting required in local homes, in order to reduce economic burdens on home owners
5. Reduction of problems caused by scaling or corrosive tendencies of the geothermal water

Other factors which influence the formulation of a geothermal system design concept are the end uses of the geothermal water, which dictate the system size; the reliability factor, which determines the extent of standby or redundancy equipment needed; and the physical layout and density of the community, which control the extent of the distribution system.

Based upon the data gathered in this study, a central system appears to be the most logical and desirable concept for the communities involved.

The central system concept would consist of a heat exchanger or converter located at the geothermal source to transfer heating energy to a secondary closed-loop hot water distribution system for end use in community buildings. This concept confines to one area any potential fouling due to scaling or corrosion. Therefore, preventive maintenance and corrosion inhibitors can be used at a central facility to prevent problems. The secondary loop would also be closed and treated for corrosion and scale control. With such a system, standard piping and end-use heat exchangers can be used. Thus, mineral deposition, corrosion attack, and distribution system maintenance problems are minimized.

The primary reason for placing the heat exchangers in a central location rather than installing small geothermal heat exchangers in individual homes is that, in previous applications using the Madison water, small exchangers had to be replaced within eight to eleven years. It is felt, therefore, that system reliability will be greater with a large controlled central exchanger. In our opinion, the central heat exchangers should also be of different design and material than previously used in South Dakota. It is therefore tentatively suggested that plate-type heat exchangers using plates of 316 stainless steel be considered for any geothermal system application of the Madison Aquifer as hereinafter discussed. Outside of the material selection of the heat exchanger, all other design considerations are the same as for a standard hot water distribution system.

Heat Exchangers

A minimum of two full-size heat exchangers (3 half-size exchangers are also a possibility) should comprise the central heat transfer system. Each heat exchanger must be capable of transferring approximately 100 percent of the design heating requirements from the Madison Aquifer water to the heating system. The quality of this water is such that material selection is critical to the reliability of the system. Past experience in Midland and Philip, both located in Haakon County, South

Dakota, has shown the life expectancy of the heat exchangers that have been used is much too limited to consider for use in a central heating system. Copper sulfide and bornite deposits on the copper tubing of existing exchangers indicate progressive corrosion rates that cannot be tolerated in a central plant. Corrosive action has also been noted on the carbon steel shells of the shell-and-tube type heat exchangers, and was more rapid than the corrosion of copper tubing. The corrosion problem is further aggravated by the entrained 8 percent dissolved oxygen and 3 percent carbon dioxide gases found in water from the Madison Aquifer, as well as by the presence of hydrogen sulfide.

Although coupon sampling testing for corrosion rates of various materials is still going on, and hopefully will continue even after this project is complete, it is our opinion based on all data compiled to date, that 304 or 316 stainless steel should be considered as the heat exchanger material, unless results of tests underway at the South Dakota School of Mines and Technology indicate that another material selection would be more suitable for the conditions encountered. Also, from analysis of the water sampling and testing, mild acidification for scale control and a polyphosphate treatment of the aquifer water for scale and corrosion control are considered necessary. The extent of treatment depends on specific water conditions.

It will be necessary to decide upon the final design of the heat exchanger during final engineering on any project that develops from this initial study. The most commonly used heat exchangers are the shell-and-tube type, either straight or U-tube design. However, in this case, it is believed that shell-and-tube exchangers would not be the most desirable choice. Not only would stainless steel exchangers of this type be expensive, but system compatibility must also be considered, keeping in mind that the exchanger must be sized for the peak heating requirements, but must operate at average levels. The heat transfer rate is controlled primarily by controlling flow, which directly affects the velocity of the water as it passes through the exchanger. A water analysis by Sheppard T. Powell Associates, a nationally known group of water consultants, as well as studies of existing use in the area, indicate that low water flow conditions promote mineral precipitation and scaling. Extensive scaling means extensive maintenance in order to keep heat transfer surfaces clean, and results in a reduction in the heat transfer rate. A bypass and mixing arrangement on the secondary loop could also be a means by which temperature is controlled and flow remains constant, and be a solution to low flow potential problems.

Another major consideration is the expansion capability of the system, which must be expandable at a reasonable cost with a minimum of downtime. Community growth is a possibility if the energy cost advantage and availability become attractive considerations, as could be the case.

Based on these parameters, we feel that the plate type heat exchanger would be much more suitable for this application. This type of heat exchanger consists of a series of plates through which fluids flow in alternating directions, as shown in Figure VI-1 which follows. A plate type exchanger with countercurrent design has a better heat transfer rate per square foot of surface area than the shell-and-tube, is more compact, and has the following major advantages when considered for geothermal applications:

1. Plate type heat exchangers have been installed in geothermal heating systems in Iceland and France. Such exchangers are reported to be in service at the present time, and reportedly have worked well.
2. For maintenance and routine cleaning for scale removal, the compression bolts holding the plates together can be removed, so that the plates can be separated, washed down and bolted back together without removing the exchanger from the system. A conventional shell-and-tube heat exchanger would require at least head removal, possible tube removal, chemical cleaning, and possibly mechanical cleaning.
3. The number and type of plates in the plate exchanger module can be changed relatively easily. If future loads change, or if the temperature gradient or heat transfer rate needs to be modified after installation, plates can be added or deleted from the module to fit new heating demands, improve heat transfer, or increase velocity through the exchanger. With shell-and-tube heat exchangers, expansion of the system to keep up with growth would require installation of additional exchangers or replacement with larger ones, whereas the plate heat exchanger can be expanded to some extent for more capacity by adding more plates.
4. Use of 304 or 316 stainless steel as the exchange material should increase the expected economic life of the unit considerably over that obtained in the past using other materials. Replacement costs would be minimized, and hopefully the testing and analysis still underway at the South Dakota School of Mines and Technology will indicate up to a 30-year life expectancy, with only gasket material replacement necessary every 10 years.

Therefore, we will assume the use of plate type exchangers for economic analysis of geothermal heating systems in this investigation. The life expectancy, cleaning requirements, and expansion capability criteria appear to be best met by the plate type heat exchangers with stainless steel plates.

If this central facility concept were eliminated and a direct system installed, with special fabricated end-use coils, the cost of the central

This view illustrates the arrangement of alternating channels giving counter-current flow throughout for higher heat-transfer efficiency.

Corrugations stiffen the plates (permitting the use of thin-gauge material), increase the effective area and promote highly turbulent flow even at low liquid velocities. All these factors contribute to the efficiency of heat transfer.

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R. W. BECK and ASSOCIATES

ANALYTICAL AND CONSULTING ENGINEERS

Seattle, Washington

Denver, Colorado

**TYPICAL PLATE-TYPE
HEAT EXCHANGER**

SCALE NONE

FIGURE VI-1

REV.

facility would be eliminated. However the cost of the home heating coils would double. Therefore, based on the costs developed in the site-specific studies, elimination of the central facility would result in an investment savings of only about 4 percent. In some cases, this savings could be the deciding factor in determining whether or not a geothermal heating system is economically justified. However, the possible complications of distribution and end-use maintenance could more than offset this savings.

Site-Specific System Studies

Site-specific studies are necessary for a proper and realistic evaluation of the feasibility of a central geothermal municipal heating system. Specific site areas take into account actual Madison Aquifer water characteristics, equipment sizing requirements, retrofit conditions, and end-use application. From the theoretical application of a geothermal resource to a designated study site, some generalized conclusions can be drawn which can serve as parameters for other locations. These parameters can be modified according to the needs of a specific location.

Midland, South Dakota

It was decided to initially evaluate the feasibility of a central geothermal heating system for the community of Midland, South Dakota, which has a population of about 210 people. Midland was selected for three basic reasons: 1) Its population size is typical of many western South Dakota communities. 2) Midland already has a well drilled into the Madison Aquifer for domestic city water service. This well is an ideal source of sampling data and analysis information which are necessary for technical assessment of the proposed material selection, operating characteristics, and water quality. 3) Since the City of Midland has utilized the water from the Madison Aquifer to heat its schools, information on actual operating experience using this water as a heating medium is available. It is reported that the high school heating system, which has been in service since 1968, has served the school's needs reliably.

For sizing considerations, the design peak heating requirements and average seasonal demand for this study were based upon 1) the prevailing weather conditions at Midland; 2) the number, type, and typical size of homes and other buildings in the city; 3) the assumption that a standard internal building temperature will be maintained; and 4) an estimation of system losses. According to our survey, the community consists of 110 residential homes, 3 churches, and 14 commercial establishments. Climatological data available for the area indicate that the outside design winter temperature is -20°F , and it is assumed that all facilities would require a 70°F inside temperature, although this may later be modified by federal directives. Based upon this information as well as upon the average size of homes in the community, it is estimated that the peak seasonal demand for Midland would be approximately 11.3×10^6 Btu/hr. Therefore, any proposed central heating system must be sized for this capacity.

Using the design conditions established above, the average system loading and annual demand can be estimated by considering the duration of the heating season, average ambient outside winter temperature, and the design peak heating demand. Using these factors for western South Dakota, and specifically Midland, the average season demand for heating is estimated to be approximately 33×10^9 Btu/yr, including distribution heat losses. The calculated load was then verified by checking it against the 1976 energy consumption for Midland. Rushmore Electric Power Cooperative (called "Rushmore"), as a member of this investigative team, conducted a survey of all fuel suppliers for Midland to determine the amount of energy actually used in Midland during 1976. This survey indicated that 240,000 gallons of propane and 60,500 gallons of fuel oil were consumed. Converted to thermal units, this consumption equates to about 30.3×10^9 Btu/yr. Considering that distribution heat losses were taken into account, we feel this 10 percent variance is consistent with the calculated demands for Midland. Therefore, the size of the system can be established within reason, and will be used as the criterion for equipment sizing and economic analysis.

A flow diagram of the basic distribution system considered desirable for geothermal use in a community like Midland has been developed and is shown on Figure VI-2, which follows. One operating and one standby heat exchanger (plate type suggested for temperature approach, material, and expansion capability) would transfer the heat from the geothermal fluid to the secondary loop for distribution. One unit could be down for tube cleaning at any given time and the system would still be capable of meeting community demands.

Distribution of heat to the community is accomplished through a combination of two different sizes of pumps. As indicated on the flow diagram, five pumps have tentatively been selected -- three pumping 200 gpm and two pumping 425 gpm. Installation of two different pump sizes allows for optimum operation, and the economy of using less pumping power for average or low-load conditions. It is estimated that during about half of the heating season, one or two of the 200-gpm pumps will be more than adequate to serve the heating needs of Midland, with one serving as a standby, required only if one of the other pumps is down for repairs. The 425-gpm pumps are necessary for severe weather conditions occurring primarily in January, when the maximum demand is placed upon the system. Selection of smaller pumps thus reduces the initial capital investment and power consumption for normal operation.

Also included in the basic secondary distribution system is a 1000 gallon expansion tank, an air separator, necessary valves and manholes, and customer connections.

As is apparent from the flow diagram (Figure VI-2), no well pumps are indicated. This is because the existing well head pressure, which has also been recorded in the past, is 280 psig. Unless aquifer studies indicate that this pressurized condition is not typical or dependable, pumps are considered unnecessary, and will not be used in the economic analysis.

A proposed distribution piping system, sized and laid out for Midland, is illustrated on Figure VI-3, which depicts the layout of the town's proposed heating system. The design calls for a 10-inch main installed from a pumping and heat exchanger house located near the high school, and running east down the alley just north of the main street through town. Branch lines in each alley are sized for all potential consumers to be connected. Distribution piping is sized for equalization of pressure drops in each branch and main line in order to facilitate uniform flow throughout the system. This preliminary plan, of course, is subject to modification during final design, if this system is actually implemented.

The type of piping contemplated would be insulated PVC or asbestos cement pipe installed in a trench five feet underground (under the frost line in the area). This type of pipe material would work well in geothermal systems, if properly installed. Its corrosion-resistant properties make it ideal in this application.

The type of control system that is selected is a very important factor in system reliability. A schematic diagram of the proposed control system is shown on Figure VI-4. Basically, it is desirable to maintain a constant delivery temperature to the central heating system so that only water flow is modulated to satisfy demand. This is accomplished by regulating the flow of the geothermal water through each of the plate heat exchangers. The secondary loop, or distribution system flow, is controlled by the number and size of pumps selected for operation. An orifice flow measurement is integrated into the system, which by pre-set points selects the pumps to satisfy the flow requirements. Design of a lead/lag and numerical logic sequence is anticipated to streamline the control system. If necessary, hour meters can be added for maintenance purposes.

Other less complicated control system schemes could be considered. A final decision in this matter would be the responsibility of the utility or municipality and its engineering advisors or consultants if this system were selected for installation. The control system outlined herein is solely for the purpose of defining a scope for costing to be used in the economic analysis.

The general survey of Midland indicated that, of approximately 132 buildings, five or six have all-electric heating systems, about ten homes have hot water heating systems, and the remainder of the homes are using forced warm air furnaces burning propane or fuel oil.

In evaluating the application of the proposed system to the homeowner, it is felt that the following minimum-cost conversions would be required:

N

KEY

- - RESIDENCE
- - COMMERCIAL BUILDING
- ⊕ - CHURCH
- ⊙ - GAS STATION
- ⊗ - EXISTING WELL
- ⊕ - EXISTING WATER TOWER
- ⊗ - PROPOSED WELL
- ALLEYS
- SUPPLY HEADER
- RETURN HEADER

300 0 300 600 900
SCALE IN FEET

Rev.	Date	By	Ckd.	Approval	Description
R. W. BECK and ASSOCIATES					
ANALYTICAL AND CONSULTING ENGINEERS					
Seattle, Washington			Denver, Colorado		
GEOTHERMAL STUDIES					
MIDLAND, SOUTH DAKOTA					
DISTRICT HEATING SYSTEM					
Des. By	Eng.	Appr.	Post	Approval	
Rev. By	Chg.	Appr.			
File					

FIGURE VI-

FIGURE VI - 3

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				APPROVED
REVISIONS	DATE	OWN.	APP.	DATE

R. W. BECK and ASSOCIATES
 ENGINEERS AND CONSULTANTS
 Seattle, Washington Denver, Colorado

TYPICAL CONTROL SYSTEM

SCALE NONE
 FIGURE VI-4 REV.

1. No conversion is recommended for the all-electric homes, since these are the newer homes in the community and the homeowners would most likely be unreceptive to a new heating system.
2. The hot water heating systems would be directly cross-connected, with the option of the homeowner retaining his own boiler as a backup unit.
3. Forced warm air furnace systems would be adapted by inserting a hot water coil in the main return air duct just before the furnace and modifying the control system so that the coil would take care of most needs with the recirculating fan. We have made only a general assessment of the relative cost, based upon an average furnace for a home of average size. Each central air system would have to be evaluated individually to determine actual size and control modification requirements. The existing furnace system would basically be maintained, with the fuel oil or propane available as supplemental energy on extremely cold days, or as a backup system. The cost of this type of conversion is included in the economics analysis that follows.
4. Each residential system would have two-way motorized control valves regulated by a thermostat signal within the home. The typical home connection and control system contemplated and used in this study is illustrated on Figure VI-5.

Although the city of Midland already has a well installed into the Madison Aquifer, for purposes of this study it is proposed that the cost of a new well be considered in the economic evaluation, since a withdrawal rate of about 1200 gpm would be required (present well capacity has been estimated to be approximately 280 gpm). Also, the existing well is about 9 years old, and would not meet the life criterion for a central system. However, this well could be utilized as a backup to the proposed system, or be converted to a re-injection well, if deemed necessary.

The Madison Aquifer water might be discharged from the heat exchangers to the existing line supplying the domestic city water tower, to a truck station that is maintained for service to outlying farmers, or to a local irrigation system. If it were not used in one of these ways, the water could be reinjected. Excess water from the proposed system could be sent to an irrigation system. Approximately 600 ac-ft of water would be available annually. These systems, as well as other potential end-use applications, will be discussed later. However, since it is anticipated that the implementation of extensive end-use applications would most likely lag the proposed heating installation, either surface discharge or reinjection through a well into the shallower Dakota Aquifer should be considered for disposal of excess water. Costs of a re-injection well are not included in the economic analysis that follows.

DISTRICT
HEATING
SYSTEM

HOUSE
SYSTEM

1. MAIN SHUT-OFF VALVES
2. STRAINER
3. SEALED REGULATING VALVE
4. MOTORIZED CONTROL VALVES
5. GLOBE VALVE BY-PASS
6. SAFETY RELIEF VALVE
7. HOT WATER COIL / RADIATOR UNITS

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R. W. BECK and ASSOCIATES

ENGINEERS AND CONSULTANTS

Seattle, Washington

Denver, Colorado

**TYPICAL HOUSE
CONTROL SYSTEM**

SCALE **NONE**

FIGURE VI-5

REV.

Economic Analysis

The preliminary estimated cost for the central geothermal heating system just discussed has been developed in two ways: 1) as described heretofore, and 2) including Btu meters for each customer on the system. Using first quarter 1977 pricing information, the estimated installed cost of the system is:

<u>Item</u>	<u>(1)</u>	<u>(2)</u>
Underground Distribution System	\$371,870	\$371,870
Heat Exchanger, Pipe, Valves & Central Facility	78,400	78,400
Customer Connections	19,800	19,800
Btu Meters	-0-	81,180
Well Costs	170,000	170,000
Engineering, Financing, and Administration Costs	<u>61,700</u>	<u>61,700</u>
Total Estimated Cost of Project	\$701,070	\$782,250

In addition, the following estimated costs would be incurred or would be pro-rated to the customer, depending upon his specific type of heating system:

1. For existing hot water heating systems -
New thermostat and motorized controls \$140/unit
2. For forced warm air furnace systems -
hot water coil, motorized control valves,
home control system modification \$295/unit

Note: For our purposes, commercial customers are generally considered to cover their own cost of modification, or are assumed to have installations no more complex than those described above. Also, no primary home heating system is considered to be replaced.

Total cost for homeowner conversions is estimated to be as follows:

1.	(10) (\$140)	=	\$ 1,400
2.	(115) (\$295)	=	\$34,220
			<u>\$35,620</u>

Total Project Capital Cost:

1. Basic system - \$736,670
2. Basic system plus metering - \$817,870

An economic evaluation of these systems will be developed for consideration. The only difference between the two systems is the Btu meter cost differential. The advantages of Btu meters will be discussed later in this report.

In order to put the economics in a form for direct comparison with other types of energy presently utilized in South Dakota, the cost of the proposed heating system will be expressed in terms of \$/10⁶ Btu average over the life of the system. This comparison is made to determine the feasibility of a geothermal system in terms of present actual energy rates in the Midland area.

The basic criteria used in the economic analysis are as follows:

1. A twenty-five-year economic life is assumed for all major system components. Twenty-five years will also be taken as the amortization period for the capital investment required to complete the system.
2. All capital required for the installation of this system has been assumed to be borrowed at an 8-percent interest rate. (Whether the final entity will be an REA Cooperative operation or a municipal operation is not required knowledge for this study. Rushmore has investigated the legal ability of the Cooperative to finance, staff, and operate a combination heating and domestic water supply system as hereinafter discussed. Municipal bond funding at an estimated interest rate of 8 percent has been used for this study.)
3. A 2-percent annual cost for renewal and replacement credit has been used to figure annual fixed charge reserves.
4. Operation, maintenance, administrative overhead, and accounting costs have been estimated at 4 percent of the gross value of the facility, and escalated at an 8-percent annual rate. An established administrative system, either utility or municipality, has been assumed.

Therefore, the average annual cost of operation of this geothermal heating system can be itemized as follows (if in operation in 1977):

	<u>Basic System</u>	<u>Basic System Plus Metering</u>
Capital Investment (1)	\$736,670	\$817,870
Annual Debt Service Cost	69,011	76,618
(Capital Recovery Factor: 25 years @ 8% compound interest: 0.09368)		
Basic Renewal and Replacement Cost/Credit	14,733	16,357
O & M Admin. Costs (1st year) (To escalate 8% annually)	29,466	32,714
Total Cost (1st year only)	\$113,210	\$125,689

(1) Includes estimated costs of home conversions.

Based upon $30,350 \times 10^6$ Btu/yr as the annual product of the system to the consumer (no heat losses chargeable), the unit value or rate charge for this heating service would have to be:

1. Basic system only: $\frac{\$113,210}{30,350 \times 10^6 \text{ Btu}} = \$3.73/10^6 \text{ Btu}$
2. System Plus Meters: $\frac{\$125,689}{30,350 \times 10^6 \text{ Btu}} = \$4.14/10^6 \text{ Btu}$

Based upon the energy consumed in Midland during 1976, and using January 1977 rates of 37 cents/gallon for propane and 42.8 cents/gallon for fuel oil, the average composite unit cost of the fuels is $\$3.78/10^6$ Btu. This is used as a comparative figure to determine the present-day economic feasibility of a geothermal heating system.

Therefore, according to the above values based on today's cost of heating fuel in South Dakota, the geothermal heating system, including metering for billing purposes, is somewhat more expensive on the average unit basis to the citizens of Midland than present fuel costs. However, this situation should change in the near future. The basic charges for the geothermal energy source are fixed, with the exception of operation (electrical power), maintenance, and administration (personnel), which are influenced by inflationary pressure. In comparison, the propane and fuel oil costs have been rising faster than the inflationary rate in the last 4 years, and it is possible that this trend may continue. However, to illustrate the effect of rising costs, it is assumed that propane and oil costs may increase at 6 percent annually, and that cost of living increases continue at 8 percent per year. The annual unit cost to the consumers, required to operate the facility, is plotted on Figure VI-6, along with the fuel costs of existing system for the next 8 years. As can be noted, based on the above escalation and inflation factors, the cost of operating the geothermal heating system between 1978 and 1980 would be less than the average cost of conventional fuels.

The benefit/cost ratio, a means commonly used to evaluate alternatives, can be determined for this system. Using the sum-of-period payments method, with the escalation and inflationary factors utilized previously, the benefit/cost ratio is determined over a 10-year period:

1. Fuel (both propane and fuel oil): $(\$3.78/10^6 \text{ Btu})(\text{caf}^*-6\%-10) =$
 $(\$3.78/10^6 \text{ Btu})(13.18) = \$49.82/10^7 \text{ Btu}$
2. Geothermal System:
 - a. Administrative Increases
 $(\$32,714)(\text{caf}-8\%-10) = (\$32,714)(14.487) = \$473,927$
 - b. Fixed Costs
 $(\$92,975)(10) = \frac{929,750}{1,403,677}$

*caf = compound amount factor, used in interest tables for determining sum of payments over a given period, in this case 6% interest for a 10-year period.

**ASSUMED
AVERAGE ANNUAL UNIT ENERGY COSTS**

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				DRAWN _____ CHECKED _____ APPROVED _____ APPROVED _____ DATE _____			
REVISIONS	DATE	DWN.	APP.	DATE	MIDLAND, SOUTH DAKOTA		
					SCALE		
					FIGURE: VI-6		
					REV.		

For comparison to the fuel, the geothermal heating system must recover these costs through the sale of an average of $30,350 \times 10^6$ Btu annually.

$$\text{Then: } \frac{1,403,677}{30,350 \times 10^6} = \$46.25/10^7 \text{ Btu}$$

The benefit/cost ratio of the geothermal heating system is then:

$$\frac{49.82}{46.25} = 1.08$$

This 1.08 ratio means that over the time period analyzed, an annual average savings of 8 percent is realized.

Cheyenne River Sioux Reservation

Further investigation of potential applications of geothermal energy in South Dakota has centered upon possibilities in the territory under the jurisdiction of the Cheyenne River Sioux Tribe -- approximately 2 1/2 million acres with a population of 11,000. In determining the specific needs of the tribe, meetings and follow-up discussions were held during this period with the tribal chairman, Mr. Wayne Ducheneaux, and other leading tribe members. In general, interest in geothermal applications on the reservation, and particularly in water, is high. This interest is emphasized by the fact that a massive 12-million-dollar system is presently being designed to convey water from the Cheyenne River through Eagle Butte to many of the small communities in outlying areas of the reservation. It was expressed at the meetings, and it is evident, that lack of an adequate potable water supply has been a drawback to the development of the reservation. Therefore, any application of the geothermal water underlying the area should consider as a primary by-product a potable water supply meeting applicable standards. Due to the quality of the water in the Madison Aquifer in this area, such consideration necessitates evaluation of water treatment facilities.

From our discussions with the various leaders of the tribe, it was felt that the communities of Cherry Creek and Red Scaffold would be excellent subjects for evaluation. Therefore, our investigations of geothermal heating utilization on the reservation are centered upon these two communities and their respective needs.

Also, since no wells have been drilled in the Madison Aquifer in the vicinity of Cherry Creek or Red Scaffold, assumptions had to be made regarding its physical and chemical characteristics in these locations based upon known characteristics of the aquifer in Eagle Butte, Philip, Midland, Murdo, and Dupree. An analytical assessment of the Madison conducted in these areas by the South Dakota School of Mines and Technology was used in our consideration.

Cherry Creek, South Dakota

The community of Cherry Creek has a population of approximately 480 people. The central community consists of about 64 homes, a church, and a school. Most of the housing in Cherry Creek is newly constructed by the Housing and Urban Development Agency (HUD) and is classified as dense. Based on the prevailing weather conditions, type of construction, and density of population, it is estimated that a central geothermal heating system for Cherry Creek should be sized for a capacity of approximately 3.5×10^6 Btu/hr with a demand of about 11×10^9 Btu/yr. A system of this size, based upon the anticipated characteristics of the aquifer, would withdraw about 65 million gallons of water annually.

The basic concept underlying our analysis of the geothermal heating system has been developed through research into materials, equipment, water quality, and the specific needs of the community. Based upon this research, it is our opinion that the following system would be most suitable for a community of the type represented by Cherry Creek:

1. A deep well, capable of withdrawing 350 gpm from the Madison Aquifer.
2. Two 3.5 million Btu/hr (each) water-to-water stainless steel plate type heat exchangers, to be used for heat transfer from the aquifer to a closed-loop central heating distribution system.
3. Three nominally sized 150-gpm hot water pumps for the central closed-loop community system.
4. A distribution piping network supplying hot water to the homes in the community, complete with motorized control valves and control thermostats for each home.

The system just described is depicted on Figures VI-7 and VI-8. This system is similar to that developed for Midland, South Dakota. Basically, primary consideration has been given to system life and ease of maintenance. These are the reasons for the use of central heat exchangers and corrosion-resistant materials. The central heat exchanger concept, where the aquifer water would come into contact with heat exchangers only at the central facility and not in each home, would isolate any potential corrosion or precipitation problem from the individual homes. This is considered essential in central heating system concepts. Also, no special procedures for corrosion control would be required for the piping distribution system or home heating systems if central heat exchangers were used.

Although Cherry Creek was suggested for study by the Cheyenne River Sioux Tribe, it is noted at this point that the new HUD homes in the community have all-electric heating systems which cannot easily or economically be converted to hot water heating. However, for purposes of study, a community on the reservation similar in size but not electrically heated could utilize some of the basic information developed herein.

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REVISIONS	DATE	OWN.	APP.	DATE _____				
					CHERRY CREEK, S.D. FLOW DIAGRAM		SCALE	REV.
							FIGURE: VI-7	

N

KEY

- - RESIDENCE
- ⊞ - CHURCH
- ⊞ - SCHOOL
- ⊞ - PROPOSED WELL
- SUPPLY HEADER
- RETURN HEADER

300 0 300 600 900
SCALE IN FEET

Rev.	Date	By	Ckd.	Appr.	Description
R. W. BECK and ASSOCIATES ANALYTICAL AND CONSULTING ENGINEERS Seattle, Washington Denver, Colorado					
GEOTHERMAL STUDIES CHERRY CREEK, S.D. DISTRICT HEATING SYS.					
Des.	Eng.	Arch.	Inst.	Draw.	Appr.
File	Date	FIGURE: VI-25			

The estimated cost of a central heating and distribution system for a community the size of Cherry Creek, based on 1977 prices, can be broken down as follows:

Distribution System	\$40,000
Heat Exchanger Facility and Equipment	52,700
Customer Connections and Btu Meters	51,600
Well	180,000
Contingency	30,000
Engineering, Administration, and Construction Management	<u>35,000</u>
Total	\$389,300

Also required for implementation of this system, but not included in cost estimates, would be modification to the home heating systems. No definitive costs have been developed, since Cherry Creek was used only as an example for estimating purposes. Since most of Cherry Creek's home heating systems are electric, we did not investigate these systems to determine the extent of modifications required, because modification is considered too expensive.

Red Scaffold, South Dakota

The community of Red Scaffold had to be approached differently from Cherry Creek, due to the fact that any consideration of geothermal utilization would be in conjunction with new HUD housing, complete with a new potable water distribution system since none is presently available. Therefore, the home heating systems could more than likely be designed for compatibility with an available geothermal heating source. In this respect, our consideration is essentially for a "new community" of 16 homes, centrally located near the geothermal well. Such is the basis for the economic analysis that follows.

Red Scaffold is a small community of approximately 80 people, having one school in addition to the residences. Therefore, the cost of a system would be spread over a much smaller consumer market, and the required revenues would not be proportional to community size. This fact is evident in the estimated initial investment required.

The type of system anticipated for a community the size of Red Scaffold is depicted on Figures VI-9 and VI-10. The basic criterion from an engineering standpoint is identical to that for Cherry Creek, in that a central heat exchanger with pumping is considered desirable for reliability.

				R. W. BECK and ASSOCIATES ENGINEERS AND CONSULTANTS Seattle, Washington Denver, Colorado	
				RED SCAFFOLD, S.D. FLOW DIAGRAM	
				SCALE FIGURE: VI-9	
				REV.	

REVISIONS	DATE	DWN.	APP.	DATE

DRAWN	
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APPROVED	
APPROVED

- KEY**
- - RESIDENCE
 - Ⓢ - SCHOOL
 - ⓖ - GARAGE
 - ⊕ - EXISTING WELL
 - Ⓢ - PROPOSED WELL
 - SUPPLY HEADER
 - RETURN HEADER
 - - NEW HOUSING

300 0 300 600 900
SCALE IN FEET

Rev.	Date	By	Chd.	Approvals	Description		
R. W. BECK and ASSOCIATES							
ANALYTICAL AND CONSULTING ENGINEERS							
Seattle, Washington				Denver, Colorado			
GEOTHERMAL STUDIES							
RED SCAFFOLD, S.D.							
DISTRICT HEATING SYS.							
Des. By	Eng. By	Chd. By	Appr. By	FIGURE: VII-10			
Date	Date	Date	Date				

Community heating requirements have been calculated based upon design standards calling for R-31 ceiling insulation and R-16 wall insulation in new HUD construction, as well as upon prevailing weather conditions. Based upon these inputs, we have estimated the peak demand heating requirements (system losses included) to be about 800,000 Btu/hr, utilizing about 2.7×10^9 Btu/yr from the Madison Aquifer. Based upon the physical characteristics of the aquifer in this area, the anticipated water withdrawal rate would be about 15.5 million gallons annually.

The estimated cost, based on 1977 prices, for a system satisfying these parameters for Red Scaffold would be about \$295,300, broken down as follows:

Distribution Piping System	\$22,000
Central Heat Exchanger Facility and Required Equipment and Auxiliaries	35,900
Customer Connections and Btu Meters	13,400
Well into the Madison Aquifer	<u>180,000</u>
Contingency	20,000
Engineering, Government Adminis- tration, and Construction Management	<u>24,000</u>
Total	\$295,300

Also, it is mandatory for Red Scaffold to have a water treatment facility and a central potable water distribution system in order to qualify for HUD housing. This standard is not presently met. Therefore, the needed housing facilities are not eligible for government assistance.

Potable Water Use of the Madison Aquifer on the Reservation

Because of the critical need for and limited supply of adequate potable water, these geothermal heating systems should consider the practicality of potable end-use. The basis for evaluating the potential of Madison Aquifer water for potable use is the United States Environmental Protection Agency Interim Primary and Proposed Secondary Drinking Water Standards. The Primary Drinking Water Standards are final regulations published in the Federal Register (40 CFR 141). The Secondary Drinking Water Standards are currently in the public review stage, and have been published in the proposed form in 40 CFR 143. These regulations have been promulgated to supersede the 1962 U.S. Public Health Service Drinking Water Standards.

The primary standards, which are mandatory limitations for community water supplies, are presented on Table VI-1, with the exception of limitations for radioactivity and organic chemicals (pesticides). The secondary standards (also presented in Table VI-1) are nonmandatory recommended limits which apply to materials with deleterious, non-toxic health effects.

TABLE VI-1
MADISON AQUIFER WATER QUALITY

	<u>Primary Standard</u>	<u>Secondary Standard</u>	<u>Bar N Sample 1</u>	<u>Bar N Sample 2</u>	<u>Philip</u>	<u>Dupree</u>	<u>Midland</u>	<u>Eagle Butte</u>
Arsenic	0.05		.005 ¹					
Barium	1.0		1					
Cadmium	0.010		0.01					
Chromium	0.05		0.1					
Lead	0.05		0.02					
Mercury	0.002		0.002					
Nitrate (asN)	10.0		0.13				0.2	
Selenium	0.01		.005					
Silver	0.05		0.01					
Fluoride	2.2 ²		2.4		2.3	4.2	2.8	4.4
Chloride		250	185	183	21	245	28	71.0
Color (Units)		15						
Copper		1	0.02					
Corrosivity		None						
Foaming Agents		0.5						
Hydrogen Sulfide		0.05						
Iron		0.3	0.14		0.12		0.11	1.4
Manganese		0.05	0.40				0.01	0.0
Odor (TON)		3						
pH (Units)		6.5-8.5	6.92				7.2	
Sulfate		250	1087	984	633	1102	802	128
TDS		500	2066	2084	1172	2521	1310	2263
Zinc		5	0.05					
Turbidity (JTU)	1 avg 5 Max. ³		58 ⁴					
Boron			0.43		0.07			
TSS	-	-	10					
Total Hardness			1274					
Carbonate Hardness			126		160	183	146	168
Ortho Phosphate			0.06					
Total Phosphate			0.07		0.05		0.02	
Calcium			381	374	221	400	266	378
Magnesium			79	42	51	94	66	182
Sodium			85	82	15	144	25	97
Potassium			15	9	7	44	9.7	28
MO Alkalinity			126				120	
Silica			54		34		35	
Strontium					5.4		5.5	
Lithium					0.03		0.03	
Temperature (F)					129	138		128

1. Values shown as are at limit of detectability.
2. Based on an annual average of maximum daily air temperature (56.5 F.) for Sioux Falls, South Dakota. Reference NOAA Environmental Data Service Calendar year 1976.
3. Maximum for two consecutive days.
4. After cooling, due to precipitation of dissolved material at lower temperatures.

A summary of the available data regarding water quality in the Madison Aquifer in the vicinity of the reservation is also presented in Table VI-1 for comparative purposes. Water sample analyses from deep wells at Bar-N Ranch (two samples), Philip, Midland, Dupree, and Eagle Butte are represented, and compared with the Primary and Secondary Drinking Water Standards. Radioactivity and pesticide contamination were not included in this analysis due to the negligible potential of the deep well water for this type of contamination.

The primary standards are exceeded for fluorides and turbidity in water from the Madison Aquifer. A marked increase in turbidity and suspended solids occurs in this water as it is cooled, due to the precipitation of dissolved materials at lower temperatures. Mercury levels were detected at the primary standard, while data on chromium levels were insufficient. The secondary standards are exceeded for total dissolved solids, sulfates, and, based on limited data, possibly iron and manganese.

Following is a discussion of the problems resulting from the use of water not meeting primary and secondary standards and some methods of alleviating such problems.

1. Excessive fluoride levels in water result in mottled tooth enamel or permanent black or gray discoloration of enamel in persons using the water. Available defluoridation methods include reverse osmosis, distillation, and ion exchange using activated alumina or bone char as resins. These three methods are expensive and not very practicable for small communities due to their complex operational and maintenance requirements. Installation of defluoridation equipment at Cherry Creek and Red Scaffold is therefore not recommended for these reasons. EPA can issue variances from the fluoride limitation for small communities with this problem on a case-by-case basis.
2. The turbidity of the water is treatable to acceptable levels by granular media filtration or other clarification methods.
3. Total dissolved solids levels in the water can be effectively reduced by softening with lime and soda ash or by other softening methods. Iron and manganese levels can also be reduced to acceptable levels by lime/soda ash softening methods.
4. Excessive sulfates in water have a cathartic effect on users and may impart an odor to the water. Levels in the range of 500-1000 mg/l can be acclimated to by regular users but will affect the infrequent user. Higher sulfate levels will affect all users. The treatment methods available for sulfate removal include distillation, reverse osmosis, and electrodialysis. All three are expensive and very complex to operate and maintain and, therefore, are not recommended for use in this instance.

In conclusion, the Madison Aquifer water is marginally acceptable for potable use at Red Scaffold and Cherry Creek, assuming that a variance from the fluoride standard can be obtained from EPA. The use of the water, however, has a potential for deleterious (although not toxic)

health effects on users. Another water supply should be considered if available. Accordingly, an analysis will be carried out on these two systems for heating only. End-use possibilities are discussed in subsequent sections.

	<u>Cherry Creek</u>	<u>Red Scaffold</u>
1977 Cost for Central Geothermal Heating Systems	\$389,300	\$295,300
Annual Debt Service Cost (1)	36,470	27,664
Renewal and Replacement Cost/Credit	7,786	5,906
Operation, Maintenance and Administration Cost	<u>17,650</u>	<u>13,168</u>
Total	\$ 61,906	\$ 46,738
Unit Energy Rate for Geothermal Heating System \$/10 ⁶ Btu	5.63	17.31

(1) Capital Recovery Factor: 25 years at 8 percent compound interest: 0.09368

The present rate for propane, the conventional fuel used on the reservation (wood is also present) in Eagle Butte, was \$.315 per gallon in March 1977. This is equivalent to a unit rate of \$3.45 per 10⁶ Btu.

Using a benefit/cost ratio computation for Cherry Creek similar to that of Midland, the benefit/cost ratio is:

$$\frac{45.46}{64.36} = .71$$

Therefore, based on the assumptions used for this study, neither of these heating systems can be justified economically. If other financing arrangements are possible, the studies should be re-opened.

It is noted at this point that about half the cost of the geothermal system is tied up in the well, due to the depth to which the well would have to be drilled. From investigations into wells drilled to this depth, it may take 10 days to drill to 3000 feet, and a month to reach 5000 feet. Thus, the labor cost increases rapidly as the required well depth increases.

Other

Ellsworth AFB was going to be investigated for industrial applications, however the wells that the base did have into the Madison have been abandoned due to pluggage. Thus, insufficient current data was available to determine possible application.

Possible End Use Applications of the Madison Water

One of the initial possible end-use applications of the Madison water after heat extraction is as a potable water supply for a given community. As previously stated in the site-specific study, the City of Midland already utilizes the Madison water as its potable supply. Although the water quality does not meet the EPA Interim Drinking Water Standards in every category, it has served that community for many years without treatment. In Philip, South Dakota, about 20 miles west of Midland, this water is treated and used as the city water supply. However, as previously discussed, Madison water underlying the Cheyenne River Sioux Indian Reservation cannot be used as a drinking water supply without extensive treatment.

Due to the extent and importance of the agricultural industry in South Dakota, applications of geothermal water to support and assist this industry were undertaken. Potential applications investigated included:

1. Diversion of the Madison water for irrigation
2. Stock watering with warm water
3. Heating of livestock buildings
4. Utilization of geothermal water for heating greenhouses or other small businesses

The general economy of Haakon County, where the city of Midland is located, is based largely upon agricultural activity. Winter wheat is by far the predominant crop, although grain sorghum and corn sorghum are also common. Cow-calf ranching operations are common to the Midland area. These are generally classified as small to medium in size. Based upon this information, our investigation of applications to existing businesses of the Madison geothermal water was limited to three specific areas: irrigation, stock watering, and livestock building heating.

Irrigation

According to both the Soil Conservation Service and the County Agricultural Extension Agent of Haakon County, South Dakota, the soils in the Midland area generally can be classified as follows:

1. Quality is medium to poor.
2. Erosion conditions range from slight to severe.
 - a. Under slight erosion conditions, the erosion rate is less than 2.5 tons per acre per year.
 - b. Moderate erosion conditions are defined by an erosion rate between 2.5 tons and 5.0 tons per acre per year.
 - c. Under severe erosion conditions, the average erosion rate is generally over 5.0 tons per acre per year.
3. Soils within the severe erosion class generally have extremely hard subsoils, resulting in slow permeability and thus low fertility. Less than 10 percent of the soils in this class are suitable for crop cultivation.

4. Soils within the slight erosion class are generally characterized as fairly deep, well drained, and loamy, resulting in moderate permeability. Winter wheat is the primary crop grown in such soil, although some oats, sorghum, and alfalfa may also be grown.

Irrigation of soils within the slight erosion class is a physical possibility, although the economics of such a development remain unproven.

Along with the erosion classifications, considerations of topography and soil type are also necessary. The topography of the area is hilly with gentle slopes. Clay type soils are common throughout the county. This is classified as a tight soils condition. The presence of clay means that sprinkler or flood irrigation would result in very little flushing of the salts that would accumulate on the surface. However, if the soil were loose (e.g. sandy or gravel-like), flood irrigation would tend to flush salts away. But since flood irrigation is generally limited to lands with slopes less than 3 percent, it is anticipated that sprinkler irrigation would be the preferred method.

Soils which fall within the moderate erosion class are also potentially suited for irrigation. However, in order to confirm this, a more specific soils survey as proposed by the Soil Conservation Service would be required. Approximately 30 percent of this type of soil on land close to Midland is presently under cultivation, with wheat as the predominant crop. Oats, corn, and alfalfa might also be grown in soils of this association.

Based upon the prevailing soil conditions within a reasonable radius of Midland (i.e., 35 percent slightly erodible and 15 percent moderately erodible), irrigation use of the geothermal water does potentially exist for cultivation of wheat, oats, and alfalfa.

Irrigation with geothermal water from the Madison Aquifer might result in a wide range of short-term benefits to the farmer, including 1) prevention of damage related to temperature extremes, 2) extension of the growing season, 3) promotion of growth, and 4) improvement in crop quality. It should be noted, however, that the use of warm water irrigation (as opposed to cool water irrigation) appears to provide only a limited advantage to the farmer. Further study in this area is required before any real conclusion can be drawn.

There was very little farming in the area of the Cheyenne River Indian Reservation investigated. Most of the soils in this area are classified as heavy clays with moderate to poor permeability. Some of the bottom lands along the Cheyenne River are cultivated, but generally not for cash crops. Moreover, the quality of the Madison water underlying the reservation is unsuitable for irrigation, due to its heavy solids concentration.

Therefore, only limited consideration should be given to irrigation use of the Madison Aquifer water in the Cheyenne River Sioux Indian Reservation. The demand is not there, and soil and water conditions as well as topography are all unsuitable.

Since germination and early growth of crops are primarily a function of soil temperature, geothermal irrigation would lengthen the growing season, thus encouraging some double cropping and increasing the agricultural income to the area. In addition, achieving an earlier crop maturity gives the farmer a marketing advantage, particularly for high-value crops.

Basic information concerning the relationship of soil temperature to plant growth is limited, and, although some literature on the subject does exist, much of it is related to plant growth in the noneconomic sense. A series of field experiments conducted in 1969 near Corvallis, Oregon showed that grain and silage yields increased significantly when soil temperatures were warmed above their natural level. As Table VI-2 indicates, grain and silage productivity increased by 49 percent when irrigated with warm water.

TABLE VI-2

Grain and Silage Yields -- Comparison of Heated and Unheated Soil

<u>Crop</u>	<u>Yield (tons/acre)</u>		<u>Yield Increase (%)</u>
	<u>Unheated</u>	<u>Heated</u>	
Corn			
Silage	5.5	8.0	45
Grain	3.2	4.3	34
Tomatoes	32.1	48.3	50
Soybeans, silage	2.25	3.74	66
Bush beans			
First planting	6.44	7.80	21
Second planting	3.30 ¹	5.70	73
Total	9.74	13.50	30

¹Did not mature

Source: L. Boersma, 1970.

The quality of the Madison Aquifer water, based upon an analysis by Sheppard T. Powell Associates, as well as the analysis and comments by South Dakota State University, is such that it could possibly be used

for irrigation purposes. However, irrigation would be dependent upon the extent to which the soil allows relatively free movement of water. In Haakon County, much of the area around the river and streams is alluvial, and therefore the soil would fulfill the requirements for utilizing the Madison water for irrigation.

Stock Watering

As stated earlier, much of the land in the area is used for ranching purposes. From discussions with various individuals in the area, it was stated by most of the people that cattle lose less weight and remain generally healthier through the winter months if they are drinking warm water. The ranchers prefer Madison water over Dakota Aquifer water when they can obtain it. The Bar-N Ranch, in northern Haakon County, utilizes and maintains its well into the Madison Aquifer for this specific purpose. In fact, at the present time, ranchers are hauling stock water from the geothermal well in Midland to their ranches, and paying \$1/1000 gallons for the water. In addition to the general critical water situation in South Dakota, this represents a very strong, inelastic demand, which could be supplied by the Madison water. This water could still be warm enough for stock watering (100°F) after heat removal for the district heating system. In general, the cattle remain warmer and lose less weight, and their growth is not slowed by cold weather.

Therefore, if an irrigation pipeline were installed from the proposed Midland well to suitable tracts of land, some of the water from this pipeline would most likely be utilized for livestock water supplies.

Livestock Building Heating

Through a series of interviews with farmers and agribusinessmen in the Midland area, it became apparent that there is a general interest in utilizing the geothermal water in the area for animal husbandry. This use would primarily include the heating of barns, hog houses, and chicken coops. The interest was in general terms, in that no cost or economic considerations were discussed. Therefore, the actual demand for use would have to be calculated considering the cost ramifications.

However, there is evidence that a heated and controlled environment for livestock growth has certain merits. The results of a study conducted by M. M. Yarosh, et al., in 1972 indicate that proper temperature control can decrease the feed consumption of livestock and increase productivity, since the feed efficiency (pounds gained/pounds of feed) is largely dependent upon the environmental temperature. In smaller animals, this is even more evident.

For example, the optimum weight gain temperature for hogs varies from 73°F for a 100 pound pig to 65°F for a 250 pound pig. Marginal weight gains decreased very rapidly outside of this temperature zone.

For example, a 250 pound pig reaches an optimum level of feed efficiency at approximately 60°F. As stated previously, the optimum weight gain occurs at 65°F. If an original ambient hog house temperature of 50°F is raised to 60°F, tests have indicated that the feed efficiency is increased by more than 20 percent and the weight gain rate is increased by approximately 17 percent. It stands to reason that farmers and ranchers would be interested in the potential uses of the Madison water.

In summary, this limited study has revealed agricultural benefits that could be derived from use of geothermal water. Irrigation possibilities, stock watering and animal husbandry are just a few of the potential immediate benefits. These are reiterated as follows:

1. An irrigation system utilizing geothermal water at a temperature of about 120°F could be considered. This judgment is based on the general suitability of soils and the expressed interest of Midland area residents who were interviewed. Although the current state-of-the-art of open field use of warm water is limited, the results of research are encouraging. Extension of the growing season and improvements in crop quality are two examples of the benefits that could be realized from warm water irrigation.
2. The use of geothermal water for heating animal shelters could enhance farm productivity. As has been indicated, feed efficiency for swine growth has been shown to increase by over 20 percent with a 10°F rise in hog house temperature (from 50°F to 60°F).
3. Stemming from widespread drought conditions in South Dakota and much of the western United States, there exists a strong and growing demand for a dependable supply of stock water. Distribution of geothermal water for stock use could be developed in conjunction with an irrigation system or a tank truck transportation system.

However, further investigation into a system for bringing geothermal water to various farms would be necessary to define specifically the agricultural aspects, system cost, and economic benefits. Such an investigation should address 1) the desired system delivery temperature and volume required for heating livestock facilities; 2) the extent and type of distribution pipeline; 3) whether irrigation, stock watering, and heating needs can be served through a common system, maximizing the benefits to the fullest extent.

Greenhouse Use

Greenhouse heating and warm-bed heating represent a relatively proven and generally economical end use of the geothermal waters throughout the world. In both Hungary and New Zealand, as well as Iceland, the greenhouse industry and all-year land utilization are well established. In New Zealand, even orchids, pineapples, and flowers are grown in greenhouses, as well as the cash vegetable crops. Therefore, documentation of this geothermal application is relatively extensive.

However, it must be pointed out that there are many factors, aside from geothermal source availability, to consider in the establishment of a greenhouse, which is a commercial enterprise and must therefore be financially sound. A cost/benefit study considering such factors as the potential market area, investment level requirement, transportation, and site selection should be undertaken before an interested party decides to venture into this field.

The type of greenhouse operation which might have an economic potential in the Midland area would be the production of vegetables, such as tomatoes, beans, lettuce, cucumbers, and radishes. Labor, fuel, and initial capital cost are the major factors affecting the economics. Market demand is also of primary importance. An overview of the potential for greenhouses suggests that market areas may exist in Pierre and Rapid City. Vegetables presently have to be imported from other states to this area during the winter months.

General Concepts for Future Consideration

The investigation reported herein was based upon adaptation of present technology to the specific geothermal source and utility needs present in South Dakota. Work is currently underway in industry and the academic areas to expand the applications of a low-temperature geothermal source. Some of the promising possibilities that are applicable in South Dakota are discussed below.

Central Absorption Refrigeration System

The basic components of an absorption system are the evaporator, absorber, generator, and condenser sections. A soluble gas and a solvent liquid are used in the cycle.

Because of the level of thermal energy available from the Madison Aquifer (about 150°F), an ammonia-water absorption system appears to be the type that might merit consideration. However, commercially available ammonia-water systems presently use low-pressure steam as the energy source. Development of a way to use geothermal water as energy for a refrigeration system requires further investigation, but the possibilities look promising.

The Applied Physics Laboratory of the Johns Hopkins University (Taylor, Toth, and Stowe, 1977) has investigated application of the ammonia-water absorption process to a conceptual geothermal district heating and air conditioning system. The major advantage of such a system is the year-round utilization of the aquifer to furnish cooling as well as heating, and the availability of Madison Aquifer water, with heat removed, for both summer and winter end uses. These uses include potable city water and agribusiness applications.

Based upon the information developed by Johns Hopkins University, a conceptual application to South Dakota can be developed. A combined central heating and cooling system is possible. Modifications to the conventional ammonia-water refrigeration system cycle are necessary to deliver both heating and cooling to the community.

The generator in such a system would be at the geothermal source, distilling a high purity ammonia vapor. The gas would be delivered to individual absorber units during the winter, or to a central condenser during the summer. For heating, an absorber section would be installed in the return air system of each home. The absorber, where the ammonia vapor is absorbed by the water, forming a concentrated solution, would heat the home by releasing the heat of absorption. The evaporator and condenser sections of the basic cycle would be bypassed. For cooling, all components of the conventional system are utilized. The ammonia vapor from the generator is condensed to form a liquid and pumped to an evaporator coil in the return air system, where it is vaporized, extracting heat from the air, and returns to the central system. An absorber is installed in the central system to reject the heat as water absorbs the ammonia. The dilute solution is pumped to the generator, where the cycle begins again with distillation of the ammonia.

A diagrammatic sketch of the typical cycle and system components is shown on Figures VI-11 and VI-12. For the sake of economy, two 3-way valves can switch the individual home units from summer to winter, or vice versa. The ammonia gas line would flow to the home unit during the winter, and from the unit during the summer. The line carrying liquid ammonia during the summer would carry a dilute solution during the heating season. This eliminates two additional distribution lines between the central plant and the consumers. However, the central plant could be only in a heating or cooling mode.

Also, it is considered important that the home units be installed outside, with the return air system run to the unit since ammonia is dangerous and corrosive.

Heat rejection from the system would be required during the summer cooling season. A system of any magnitude would require the addition of a condenser water system consisting of a cooling tower.

It must be pointed out that absorption systems are chemical systems and are difficult to operate efficiently. The operating characteristics are based upon mixture ratios, pressures, and separation characteristics. The concentration of the solution is the variable which determines the amount of heat conveyed. An increase or decrease in concentration levels affects the heat transfer characteristics of the system.

SUMMER (COOLING) MODE

REVISIONS				DATE				DWN				APP				DATE			
DRAWN				CHECKED				APPROVED				DATE							

R. W. BECK and ASSOCIATES
ANALYTICAL AND CONSULTING ENGINEERS
Seattle, Washington Denver, Colorado

**CONCEPTUAL AMMONIA
ABSORPTION
GEOTHERMAL SYSTEM**

SCALE
NO.
FIGURE: XI-11

WINTER (HEATING) MODE

BRUNING 44-132 22523-1

				DRAWN		R. W. BECK and ASSOCIATES ANALYTICAL AND CONSULTING ENGINEERS Seattle, Washington Denver, Colorado		CONCEPTUAL AMMONIA ABSORPTION GEOTHERMAL SYSTEM		SCALE		REV.
				CHECKED						NO.		
				APPROVED						FIGURE: VI-12		
				APPROVED								
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The concept of this system is applicable to any central geothermal heating system using low energy levels. Further technical development and research are needed, and the economic ramifications are not presently known. More extensive study is recommended, including an actual pilot plant operation to determine if the 150-160°F geothermal source can efficiently operate an ammonia-water system.

Supplemental Heating by Solar Energy

There are two major drawbacks to widespread studies of geothermal applications of the Madison Aquifer: 1) the low level of the energy potential of the aquifer, and 2) the limited development of industry and various agricultural enterprises. The temperature level of the Madison Aquifer limits direct application as a heat source, thus eliminating direct use in meat, dairy, and food processing industries. Moreover, these industries are not prevalent in the area. Therefore, practical applications are limited.

The low energy level of the Madison Aquifer can be modified to a certain extent. For example, by supplemental heating, the temperature level of the geothermal source can be elevated to increase its energy potential. Supplemental heating may consist of a heat pump, solar assisted heating, or fossil fuel fired heat exchanger or boiler. Any of these techniques will increase the application possibilities of the aquifer. Cooking, pasteurizing, sterilizing, drying and blanching operations within the food and dairy products industries would then become potential end-users of a supplemental geothermal system. Another possibility is roasting of cereal grain for hog feed in order to break down the starch. By having an elevated heating source available, commercial and industrial development of the food products and associated industries might be enhanced in western South Dakota.

The feasibility of any scheme to elevate the water temperature would be affected by the aquifer flow and the thermal characteristics of the process to be served. To be of any benefit the percentage of geothermal heat used should be high with respect to any supplemental energy. The attainment of this objective may involve some technical problems that are beyond the scope of this report.

One source of supplemental heating to consider in conjunction with a primary geothermal heat source would be a solar assisted system. By using solar energy as the supplemental heat source, the dependence of the system upon a purchased source of fuel is reduced, thus improving the economic benefits.

Depending upon the specific process application and its needs, two different approaches could be considered: 1) installation of the supplemental solar heating components on the secondary side after the heat exchanger, or 2) installation of the solar assisted heating on the primary side, prior to the secondary loop heat exchanger.

If the only requirement for solar supplemental heating is to elevate the energy potential of the secondary loop, then the solar equipment should be placed in the secondary loop after the heat exchanger. An energy storage component should also be added to the system.

However, there are some advantages to installing supplemental solar heating in the primary loop (Figure VI-13). Through proper sizing and design of the heating system, the temperature of the geothermal source could be elevated so that some of the water can be boiled away through a vacuum distillation system off the main system, condensed, and collected as distilled water. This water could be used by itself or mixed with a given quantity of the Madison water to produce potable water which may satisfy the EPA drinking water standards. The balance of the geothermal water would go to a heat exchanger for transfer of heat to the secondary loop for distribution of heating to the homes. One major disadvantage of this approach is the increased solids and scaling tendency of the water on heat exchangers. Water treatment for scaling and corrosion control would be more critical to the performance and life of the system.

Before further study of a combined solar and geothermal system is undertaken, a specific process or application should be evaluated, so that practical considerations can be taken into account.

Heat Pump Assisted Geothermal System

Another potential means of adding supplemental energy to the overall system would be the application of a water-to-water heat pump cycle. The type of cycle contemplated would consist of a refrigeration type compressor, a condenser to transfer heat to the secondary heating fluid for distribution, and an evaporator using the geothermal fluid as the heat source. This type of system, which is available commercially, can "pump" heat from one fluid to another. However, there are limitations on the temperature level of the secondary fluid because of the pressures developed in the system. The heat transfer medium, in order to operate in the vapor-liquid phases at temperatures above 150°F, is under high pressure. This means that evaporator and condenser materials selections have to consider normal working pressures, and any system leaks or loss of pressure can present major operating problems. Material selection is also critical due to the potential corrosive nature of the water. Another point to consider is that the temperature approach controls the amount of energy transferred from the geothermal source to the system. This amount of energy may not be significant.

This application merits further study, which should be based on selected equipment and a specific location.

Grain Drying

Although winter wheat is the predominant cash crop in the area overlying the Madison Aquifer, and does not generally require drying, grain drying potential does exist in some areas. Corn and milo do require drying, especially if the summer has been wet.

- ① FLOW CONTROL VALVE
- ② SOLAR PANEL
- ③ RESTRICTING ORIFICE
- ④ FLASH CHAMBER
- ⑤ BRINE PUMP
- ⑥ CONDENSER; WITH AIR EJECTOR OR VACCUM PUMP.
- ⑦ CONDENSATE /DISTILLED WATER PUMP- FOR DELIVERY TO POTABLE WATER SYSTEM.
- ⑧ HEAT STORAGE

				DRAWN _____ CHECKED _____ APPROVED _____ APPROVED _____		R. W. BECK and ASSOCIATES ENGINEERS AND CONSULTANTS Seattle, Washington Denver, Colorado	
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						SCALE _____ NO. _____ FIGURE: VI-13	
						REV. _____	

SOLAR ASSISTED CONCEPT

The Pierre Farmer's Co-operative, in Pierre, South Dakota, has grain drying facilities. They presently dry the grain at temperatures between 180 to 200°F, the specific temperature depending upon the humidity and the amount of chaff present with the grain. Generally, the drying temperature will be inversely proportional to the amount of chaff. The drying system presently in use at Pierre has a 500-bushel capacity. After a 15-minute warm-up period, the system dries the grain in about 20 minutes, using continuous agitation.

Generally, very little wheat drying is done in western South Dakota. The possibility of utilizing a geothermal source for this application would have to be analyzed for a specific instance.

Wool Washing

Although sheep ranching is not a major industry, in some areas of northern South Dakota, the geothermal water could possibly be utilized for washing wool prior to transport. Transportation costs are based on freight weight. Thus removal of dirt and other foreign matter could be of economic benefit.

Ultimate Disposal of Geothermal Water

If end uses of the Madison Aquifer water do not consume all that is available, disposal or discharge of the water will be required. This can be accomplished by any of these methods: surface discharge, well injection, or routing to an evaporation lake.

Surface Discharge

In order to discharge to any surface waters, including dry or intermittent streams, a National Pollutant Discharge Elimination System (NPDES) discharge permit must be obtained. In South Dakota, this permit program is presently administered by the U.S. Environmental Protection Agency (EPA), Region VIII. The NPDES permit contains maximum limitations for discharge of pollutants, which are normally based on effluent guidelines developed specifically for certain types of industrial or municipal systems. No effluent guidelines have been developed for discharge from geothermal systems. Another factor which often governs permit conditions is water quality standards, since a discharge may not cause water quality standards in a receiving stream to be violated. An allowance is made for a reasonable mixing zone to allow dilution of the effluent by the receiving water. Water quality standards for South Dakota are assigned to receiving waters according to several classifications, ranging from stringent requirements for domestic water supplies to more flexible standards for commercial and industrial waters. Most likely, water quality standards will dictate the NPDES permit conditions for surface discharge of the geothermal water.

The major factor governing the ability to meet water quality standards is the volume of dilution water in the receiving body. Discharge of the geothermal water to a large river may be acceptable to the permitting agency, whereas discharge to a small stream may require pretreatment of the water in order to remove objectionable characteristics. Therefore, surface discharge of the geothermal water must be evaluated on a site-specific basis.

Well Injection

Subsurface injection of waste waters is currently unregulated. However, the EPA has drafted Underground Injection Control (UIC) program regulations for the states in 40 CFR, Part 146, as required by the Federal Safe Drinking Water Act. These regulations will govern underground injection programs.

The proposed UIC regulations are currently under revision to accommodate oil and gas drilling operations, and are expected to be republished in October 1977. These guidelines, as currently proposed, require each state to develop a permit program for well injection operators. Indian lands not subject to state jurisdiction are specifically exempt from this regulation.

Well injection permits will be issued to operators who can demonstrate that their operation does not endanger underground drinking water sources. The size of the receiving aquifer and its present or potential use as a drinking water supply will be critical factors in the well injection permit program.

Specifically in western South Dakota, any reinjection of Madison Aquifer water after heat extraction would be to the Dakota Aquifer, which is shallower than the Madison. Many complex and interreacting factors are involved in evaluating the ramifications of the re-injection possibility. A laboratory test mixing the two waters to observe the blending characteristics, and possible precipitation reactions, which could blind the interstices in the ground water soil formation, should be done on a case-by-case basis if and when a specific demonstration project is selected.

Evaporation Lake

Another means of ultimate disposal would be to establish an evaporation lake. As long as no overflow to a surface waterway exists, this means is currently unregulated. An evaporation lake would be a good option in South Dakota, considering its soil conditions and weather factors.

Guidelines for Future Applications

From our investigation of Geothermal Applications of the Madison Aquifer for South Dakota, some general guidelines can be established. These guidelines fall into two general categories: 1) general considerations, and 2) specific findings. In the general considerations category, the approach to analyzing for geothermal utilization is covered. The specific findings category covers direct guidelines based on conclusions from our study.

General Considerations

The following list of general considerations is deemed essential to the analysis of geothermal applications:

1. Define the end-use heat energy needs and requirements for the scope of investigation.
2. Determine the physical, chemical, thermodynamic, and water opacity characteristics of the geothermal source.
3. Determine the energy level and energy potential of the geothermal source.
4. Compare the heating needs with the available geothermal source to determine possible geothermal utilization.
5. Develop possible design concepts that may be considered for the application.
6. Determine the heat exchanger requirements for desired heat transfer rate, type of material to be utilized, and the type of exchange. Exchange medium is also a prime consideration.
7. Develop any end-use modifications required to best accept energy from the geothermal system.
8. Estimate the cost of the system concept(s).
9. Determine the savings in other energy sources attributable to the geothermal system.
10. Perform an economic evaluation.

Specific Findings

From our investigation on this project it appears that the following guidelines apply:

1. For application to Central Heating Systems, the geothermal source should have an energy level at or above 140°F, for both technical and economic reasons.
2. The end-use applications of the geothermal resource of the Madison Aquifer are limited, due to the relatively low energy level and to existing applications in the area.
3. The economic justification of any utilization is predicated on the cost savings effected by replacing the existing energy source. Therefore, the geothermal concept will be more attractive if it can replace a high-cost energy source rather than a low-cost energy source.

4. The end use of the Madison water after heat removal is limited by the mineral content of the water, soil conditions, and topography. Possible uses include irrigation, stock watering, and potable water.
5. The cost of the well, or both wells if re-injection is required, is a major economic factor.

From the economic study of the Midland system, based upon the physical conditions at Midland, the investment cost breakdown (without meters) can be analyzed to determine where the costs are allocated. From the investment costs developed in the Midland study, the breakdown is as follows:

Distribution System	50%
Central Facility	11
End-Use	7.5
Design, Engineering and	
Construction Management	8.4
Well	<u>23.1</u>
	100.0

SECTION VII LEGAL CONSIDERATIONS

This section covers the legal aspects of geothermal source utilization in the State of South Dakota, including federal legislation. Also covered are the entity and financial aspects as they apply to municipality and electric cooperative systems, and the means by which financing could be arranged.

The research presented below was done by Mr. Gene N. LeBrun, of Lynn, Jackson, Shultz, Ireland and LeBrun P.C., attorney for Rushmore Electric Power Cooperative, Inc.

GEOTHERMAL PROJECT
(LEGAL)

I.

SOUTH DAKOTA:

Although several states (Arizona, Idaho, California, Wyoming, Oregon, Colorado, Montana, New Mexico, Utah, Alaska) have statutorily addressed themselves to geothermal energy or geothermal resources, South Dakota has yet to adopt any legislation which specifically makes mention of this new energy resource, nor does there appear to be any case law in South Dakota wherein the Supreme Court has addressed itself to geothermal resources.

Given the definitions of minerals contained in South Dakota law, SDCL 5-7, Minerals on School and Public Land, or Title 45, Mining, Oil and Gas, it does not appear that geothermal resources, particularly that in the form of hot water, would be considered governed by mining statutes by the State of South Dakota. Rather, since the state's water and water right laws govern both surface and underground water, with no distinction between hot water or cold water, geothermal resources in the form of hot water would be governed by South Dakota's water laws. SDCL 46-1-1. Such water is declared by the legislature to be the property of the people of South Dakota but the right to use the water may be acquired by appropriation in the manner provided by law. SDCL 46-1-3.

Further, domestic uses of water have been given the highest priority in South Dakota.

"Domestic use" was redefined by the South Dakota legislature in 1973:

"Domestic use, the use of water by an individual, or by a family unit or household, for drinking, washing, sanitary, culinary purposes, and other ordinary household purposes; and irrigation of a family garden, trees, shrubbery or orchard not greater in area than one-half acre. Stock watering should be considered a domestic use. Use of ground water by municipal systems and, except for irrigation purposes, use by non-profit water supply companies as defined in §10-36A-1 and sanitary districts as defined in §34-17, shall be considered a domestic use except where ground water and water in flowing streams constitutes the same water supply source."

Therefore, in the absence of other legislation governing geothermal resources (hot water) and its uses, under present South Dakota law hot water used to heat homes would be considered a domestic use and given priority over non-domestic uses.

The State Water Resources Commission (Chap. 46-2) has the jurisdiction to regulate and control the development, conservation and allotment of waters of the state. SDCL 46-2-11.

Chapter 46-6 governs ground water and wells in South Dakota and in the absence of specific statutory enactments on geothermal resources, would presently govern geothermal hot water. That chapter defines vested rights in ground water, sets forth the requirements and procedures for appropriations of

90 90 90

ground water; governs the location and use of wells, both artesian and non-artesian, and prohibits and provides penalties for wrongful use and waste of water or interference with ground water and artesian wells.

II.

UNITED STATES (FEDERAL)

The Federal Government has recognized the potential of geothermal resources. In 1970 the Congress enacted the "Geothermal Steam Act of 1970", 30 U.S.C. 1001. Although the title would appear to limit the application of the Act to "geothermal steam", that is a misnomer in that the act defines geothermal steam and associated resources as:

"(i) all products of geothermal processes, embracing indigenous steam, hot water and hot brines; (ii) steam and other gases, hot water and hot brine resulting from water, gas, or other fluids artificially introduced into geothermal formations; (iii) heat or other associated energy found in geothermal formations; and (iv) any by-product derived from them;"

Since most of the geothermal resources in the United States are in federally owned lands in the western states, the Geothermal Steam Act of 1970 and its attendant regulations, 30 C.F.R. 270, provide the legal framework in which most geothermal resource exploration and exploitation occur. Strict control is exercised through the leasing provisions regulated by the Act. An excellent article appears in Vol. 12, No. 2, p. 188 of a

publication entitled "The Public Land and Resources Law Digest", published by the Rocky Mountain Mineral Law Foundation. There are geothermal lease suggestions contained in the same publication, Vol. 13, No. 2, p. 264.

In addition to federally owned and administrated lands, the act would also give authority to the government to issue leases for the development of geothermal resources on land that has been conveyed by the United States but which were subject to a reservation to the United States of geothermal steam and associated geothermal resources.

The Federal District Court for the Northern Division of California decided in 1973 in United States vs. Union Oil Company, 369 F.Supp. 1289, that geothermal resources were not "minerals" within the meaning of that term as used in the Stock Raising Homestead Act, reserving minerals to the Federal Government. It ruled that the government's argument that super-heated water was a mineral within the contemplation of Congress and of the meaning of the mineral reservation in the Act "will not hold water". That decision, however, did not "hold water" with the Ninth Federal Circuit Court of Appeals. In United States vs. Union Oil Company of California, 549 F.2d 1271 (9th Cir. 1977) the lower court's decision was reversed. The Appellate Court held that the reservations contained in the patents issued under the Stock Raising Homestead Act, reserved or retained subsurface resources, particularly sources of energy, for separate dis-

position and development in the public interest. Although that decision merely rules on the reservations contained in that particular Homestead Act of 1916, it no doubt sets a precedent of how other courts would rule on reservations contained in other patents issued under other acts. The reservation in the 1916 act in question reads as follows:

"Excepting and reserving, however, to the United States all coal and other minerals in the land so entered and patented, together with the right to prospect for, mine, and remove the same, pursuant to the provisions and limitations of the Stock Raising Homestead Act. 43 U.S.C. §291"

Although the Court in the Union Oil Company case did rely quite heavily on the apparent intention of Congress of granting patents for agricultural purposes, the case would appear to be strong precedent and authority for future courts to so hold whenever the patent reserved mineral rights to the federal government. Where there is no reservation of mineral rights, the geothermal resources would belong to the surface owner unless otherwise conveyed or leased.

III.

ENTITIES AND FINANCING:

Private individuals who have the legal right to the underground waters on their property and have complied with the appropriate laws and regulations governing underground water, would have the right to develop the geothermal resources on his property. If the minerals were reserved by the patent to the

federal government, or to the state, then, pursuant to the Union Oil Company case, the geothermal resources would be subject to the Geothermal Steam Act of 1970 in the case of federal land and the state's rights in the event of state patented land. (School Land)

A South Dakota municipality also would have the authority under South Dakota state law to construct, operate and maintain a system to provide heat from geothermal resources. SDCL 9-39-1. Such a municipality could, by vote of its electors, place the control of such a utility in the hands of the municipal utility board or manage it within the framework of their existing governing body. State law also provides the mechanisms and authorization for municipalities to finance its utility systems by the utilization of revenue bonds. SDCL 9-40. Such revenue bonding must be approved by the electors of the municipality.

South Dakota Rural Electric Cooperatives, under present law, SDCL 47-21, would not have the legal authority to operate a system which merely provided heat from a hot water geothermal resource. The statutory purpose and authority of Rural Electrics is for the "purpose of supplying electric energy and promoting and extending the use thereof". SDCL 47-21-2. That purpose and authority could be expanded by the Legislature if the Rural Electric Cooperatives desire to engage in the development of heating systems through geothermal resources.

The Rural Electrification Administration of the United States Department of Agriculture under present law, would not have authority to make loans for a strictly hot water geothermal heating system since their loans are limited to the generation, transmission or distribution of electricity and associated uses. Therefore, even if South Dakota Rural Electric Cooperatives were authorized, under a change in the state law, to develop and maintain a geothermal heat system, there would be no REA loan funds available under the present federal law. The Cooperative Financing Corporation, otherwise known as CFC, which is made up of member rural electric cooperative systems throughout the country, and acts as a subsidiary financing agent for its Rural Electric Cooperative members, does not have any such restriction on its loaning programs. If its Rural Electric Cooperative members were otherwise legally authorized to develop a geothermal heating system and CFC found that such a system was feasible and the member could provide the necessary security, and was otherwise eligible, CFC could loan money for such a geothermal heating system. (It is our understanding that the Raft River Rural Electric Cooperative of Malta, Idaho has either made application or received such a loan for some type of geothermal plant.

Private corporations or non-rural electric co-operatives would have the authority under South Dakota law to develop and operate a heating system utilizing geothermal resources, provided they meet all of the other legal requirements.

Another legal entity which would appear to be an appropriate vehicle for the development, financing and operating of a geothermal heat system would be a Water Users' District, previously known as Water Conservancy Districts, organized under SDCL 46-16. Such Districts are authorized for the construction, storage, distribution and utilization of water. SDCL 46-16-1. The procedures for organizing such a Water Users' District, the requirements of locating lands within the District, the governing of such a District, the powers of such Districts (including that of eminent domain), their contracting authority, their authority to raise revenues, and other specific controls are all contained in SDCL 46-16 as amended. Such Water User Districts do not have taxing authority, however, they do have the authority to obtain grants or loans from the federal government or private sources. This would make such Water User Districts eligible for loan guarantee programs under the Geothermal Energy Research, Development, and Demonstration Act of 1974. 30 U.S.C. 1101.

IV.

CONCLUSION:

It is our recommendation that interested parties should study the various types of legislation governing the development of geothermal resources which have been passed in some of the other western states, and develop proposed legislation for South Dakota which will allow for proper development, utilization and conservation of the geothermal resources within

the state. Special treatment may be necessary for the geothermal resources that is in the form of hot water rather than steam. A unique feature that should be addressed in any proposed legislation, would be the legal implications of utilizing the heat from the geothermal resources then restoring the water to its natural state or otherwise returning it for other uses. In the development of any such new legislation, particular attention should be paid to existing laws regarding underground water, artesian wells, and to a lesser extent, minerals oil and gas, to prevent conflicting statutes or ambiguities.

Dated this 15 day of September, 1977.

LYNN, JACKSON, SHULTZ, IRELAND & LEBRUN, P.C.

BY:

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ANNEX 4-1

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APPENDIX A

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APPENDIX

Analytical Techniques

Parameter	Title of Method	Source
pH	pH Value	Standard Methods, 13th Ed., p p. 276-281
Sp. Cond.	Specific Conductance	Standard Methods, 13th Ed., pp. 323-327
TDS	Residue	Standard Methods 13th Ed., pp.286-293
T. Hardness	EDTA Titrimetric	Standard Methods 13th Ed., pp. 179-184
Ca	EDTA Titrimetric	Standard Methods 13th Ed., pp.84-86
Mg	(Calculated from T. Hardness and Ca)	
Na	Flame Photometric	Standard Methods 13th Ed., pp. 317-320
K	Flame Photometric	Standard Methods 13th Ed., pp.283-284
T. Alk.	Alkalinity	Standard Methods 13th Ed., pp. 52-56
Chloride	Mercuric Nitrate	Standard Methods 13th Ed., pp.97-99
Fluoride	(Also by Selective Ion Electrode)	
Sulfate	Selective Ion Electrode	EPA Manual, pp. 65-67
As	Turbimetric	EPA Manual, pp. 277-278
Be	AA - Gaseous Hydride	AA Newsletter, Vol. 12, No. 4, pp. 93-97
Cd	Carbon Rod Atomizer	Water Analysis by AA- Varian, pp. 21-22
Cr	Carbon Rod Atomizer	Water Analysis by AA- Varian, pp. 21-22
Cu	Carbon Rod Atomizer	Water Analysis by AA- Varian, pp. 21-22
Fe	Ferrozine	Hach, Water and Waste- water Analysis Procedures, 2nd Ed., pp. 2-58 to 2-59
Hg	Cold Vapor Technique	EPA Manual, pp. 118-126
Mn	Carbon Rod Atomizer	Water Analysis by AA- Varian, pp. 21-22
Pb	Carbon Rod Atomizer	Water Analysis by AA- Varian, pp. 21-22
Se	AA-Gaseous Hydride	AA Newsletter, Vol. 12, No. 4, pp. 93-97
Zn	Atomic Absorption	Water Analysis by AA- Varian, pp. 72-73

APPENDIX B

ALBERTA

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POROSITY EVALUATION
of the
MADISON GROUP CARBONATES
in
WESTERN SOUTH DAKOTA

Prepared for
SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY
Rapid City, South Dakota

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TABLE OF CONTENTS

<u>Topic</u>	<u>Page</u>
Objective and Scope	1
Porosity-Permeability Relationship	3
General Comments	4
Techniques and Parameters used to Derive Porosity Values from Well Logs	5-7
List of Symbols	8
Appendix	9
List of Figures:	
Figure 1. Map of Western South Dakota showing locations of wells used in Madison porosity study	2
Figure 2. Porosity - Lithology Cross Plot	6

SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY

POROSITY EVALUATION
OF THE MADISON GROUP
IN SELECTED WELLS
IN THE

WILLISTON BASIN, SOUTH DAKOTA

This report has been prepared to evaluate the Madison group porosity in the South Dakota portion of the Williston Basin. The objective of this study is to provide basic data for evaluating the potential of geothermal applications in the Madison aquifer in western South Dakota.

Insofar as possible, the Madison was divided into Charles, Mission Canyon and Lodgepole formations. In wells where correlation was doubtful, the formation groupings were omitted.

The porosity values were calculated from electrical well logs. The logs and associated data were obtained from the South Dakota School of Mines and Technology Geology Department well files and from the Rocky Mountain Well Log Library, Denver, Colorado. The techniques and parameters employed to derive porosity values are described in a later section.

Figure 1. is a map showing the locations of the wells analyzed for this report. The results are contained in the Appendix. Depth intervals, porosities and porosity-feet products are tabulated for each of the wells examined.

Figure 1.

Map of Western South Dakota
showing location of wells used in
SDSMT Madison Porosity Study

POROSITY - PERMEABILITY RELATIONSHIP

A study of permeability and porosity versus permeability relationships of the Madison porous intervals was not attempted due to scarcity of data in the wells used in this report. To formulate porosity-permeability relationships the following data is required:

1. Porosity figures (from logs or cores);
2. Net porous feet (from log or cores);
3. Flow test data (from formation tests);
4. Pressure build-up data (from formation tests).

Due to the heterogenous nature of the Madison carbonates, the above data from several wells will be required to develop porosity versus permeability relationships for a given Madison zone in a localized area.

GENERAL COMMENTS

An isopach of ϕ_h for the gross Madison or for each of the three major formations within the Madison was not attempted due to the erratic areal porosity development noted.

In general, it was noted that the ϕ_h development tended to be lower on the southeast and eastern edges of the Williston Basin. Of the three formations evaluated the Mission Canyon appeared to have the most consistent ϕ_h spread through western South Dakota. In the Mission Canyon low ϕ_h s (ϕ_h = to 10 or less) were noted in northern Butte County and southern Harding County. Higher ϕ_h s (ϕ_h = to or greater than 10) were noted in southwest Corson County, central Ziebach County and southwest Dewey County.

The Lodgepole formation appeared to have the most erratic porosity development of the three formations evaluated. Good porosities were noted in southwest Dewey County and spotty areas of high ϕ_h s were noted in north-central Harding County.

Considering the Madison group as one unit, high ϕ_h s (ϕ_h = to or greater than 20) were noted in the following areas: northwest Corson County, Dewey County, Ziebach County, western Haakon County, central Meade County, Harding County and eastern Butte County. Low porosity in thicknesses (ϕ_h = to or less than 15) were noted in Jones County, Stanley County, Potter County, southern Jackson County and northern Butte County.

TECHNIQUES AND PARAMETERS
USED TO
DERIVE POROSITY VALUES FROM WELL LOGS
MADISON GROUP FORMATIONS
WILLISTON BASIN, SOUTH DAKOTA

Where multiple porosity logs or lithologic information were not available, the rock type was assumed to be limestone with intercrystalline matrix porosity.

Zones having a porosity less than 7% were not considered for this study.

The following interpretative techniques were used to derive porosity values from well logs:

<u>Type of Well Log</u>	<u>Methods Used to Derive Porosity Values</u>
Acoustic Log	<p>Basic equation: $\phi = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$</p> <p>Parameters used: $\Delta t_{ma} = 47.6 \frac{\mu sec}{ft}$</p> <p>$\Delta t_f = 189 \frac{\mu sec}{ft}$</p>
Neutron-Density Combination Log	<p>Graphical cross-plotting technique using laboratory-derived log response curves for different lithologies. An example graph is shown on Figure 2.</p>
Density Log	<p>Basic equation: $\phi = \frac{\rho_{ma} - \rho_{log}}{\rho_{ma} - \rho_f}$</p> <p>Parameters used: $\rho_{ma} = 2.71 \frac{gm}{cc}$</p> <p>$\rho_f = 1.0 \frac{gm}{cc}$ (fresh mud)</p> <p>$\rho_f = 1.1 \frac{gm}{cc}$ (salt mud)</p>
Neutron Logs	
1. SNP, CNL type (Newer-type Neutron Logs)	<p>Porosity values are computed automatically during logging operations and printed on the log as porosity values.</p>

POROSITY AND LITHOLOGY DETERMINATION FROM FORMATION DENSITY LOG AND COMPENSATED NEUTRON LOG (CNL)

FRESH WATER, LIQUID-FILLED HOLES

Figure 2.

2. GNT type
(Older-type
Neutron Logs)

Basic equation used: $ND = C_1 + C_2 \log \phi$
Where ND = neutron log curve deflection
in chart divisions

$C_1, C_2 = \text{constants}$

Using marker bed porosity values, a log response versus porosity graph can be constructed on semi-log paper with $\log \phi$ as the ordinate and neutron curve deflection as the abscissa. Log response in known anhydrite zones ($\phi = 1-1.5\%$) and shale zones ($\phi = 17-20\%$) in the Paleozoic rocks can be used to define two control points, thus defining the straight line. The graph can then be used to derive porosity values, using log response data.

Electrical Survey Logs

In those wells where only a resistivity log was available, the following technique was used to derive porosities:

Basic equation: $S_w^{-2} = 1.0 = \frac{R_{16}}{(\phi^{-2} R_{mf})}$ ("Archie Equation")

or by rearranging terms: $\phi = \left(\frac{R_{mf}}{R_{16}} \right)^{\frac{1}{2}}$

The Madison porous zones were assumed to be 100% water-bearing, $S_w = 1.0$. R_{16} is the resistivity value of the shallow-investigating 16" normal curve. It was assumed that the porous rock was completely invaded by drilling mud filtrate to the depth of investigation of the 16" normal device. The resistivity of the drilling mud filtrate (R_{mf}) is measured by the logging company at the time the log was run.

In wells having a microlog, the resistivity of the 2" normal device was used to calculate porosity.

LIST OF SYMBOLS

<u>Symbols</u>	<u>Definition</u>
S_w	connate water saturation
R_{16}	resistivity of 16" normal device $\frac{\Omega m}{m^2}$
R_{mf}	resistivity of mud filtrate, $\frac{\Omega m}{m^2}$
ND	Neutron log deflection, in chart divisions
ϕ	porosity, fraction or percentage of pore volume of rock
Δt_{log}	reading of the acoustic log, $\frac{\mu sec}{ft}$
Δt_{ma}	transit time of the matrix material, $\frac{\mu sec}{ft}$
Δt_f	transit time of the fluid contained in the rock pores, $\frac{\mu sec}{ft}$
ρ_{log}	bulk density recorded on the log, $\frac{gm}{cc}$
ρ_{ma}	density of the matrix, $\frac{gm}{cc}$
ρ_f	density of the fluid contained in the rock pores, $\frac{gm}{cc}$

APPENDIX

MADISON FORMATION RESERVOIR STUDY

O. N. Beer Inc. - Stirling-Govt #1
C Lot 1, NE NE Section 2-T8N-R8E
Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
3462-3466	4	13.0	0.52	No Lodgepole top can be found from correlation.
3503-3508	5	10.0	0.5	
3532-3540	8	7.0	0.56	
3562-3568	6	21.0	1.26	
3616-3622	6	15.5	0.93	
3703-3708	5	16.5	0.825	
3795-3806	<u>11</u>	28.5	<u>3.135</u>	
	45		7.73	
<u>Mission Canyon</u>				
3876-3883	7	22.0	1.54	
3888-3897	9	16.0	1.44	
3897-3902	5	16.5	0.825	
3902-3907	5	16.0	0.8	
3907-3914	7	11.5	0.805	
3914-3920	6	14.5	0.87	
3922-3932	10	16.0	1.6	
3932-3940	8	16.5	1.32	
3960-3965	5	22.0	1.1	
3986-3990	4	23.0	0.92	
3990-3995	5	22.0	1.1	
3995-4000	5	20.4	1.02	
4002-4006	4	15.0	0.6	
4006-4012	6	18.0	1.08	
4012-4014	2	17.5	0.35	
4014-4020	6	12.0	0.72	
4022-4026	4	18.5	0.74	
4020-4026	6	22.0	1.32	
4027-4030	3	18.0	0.54	
4040-4045	5	15.0	0.75	
4045-4050	5	12.0	0.6	
4085-4090	5	9.0	0.45	
4090-4096	6	8.0	0.48	
4096-4102	<u>6</u>	10.0	<u>0.6</u>	
	134		21.57	

ϕ Average: .16368
 ϕh , Total: 29.300
h,ft Total: 179

MADISON FORMATION RESERVOIR STUDY

Wm. Seyler Company, Inc. - Carl A. Anderson #1
 SW NW SE Section 12-T8N-R5E
 Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4220-4228	8	12.5	1.0	Well TD 80' in Madison
4228-4238	18	9.5	1.71	
4238-4248	10	9.0	0.9	
4248-4253	5	8.8	0.44	
4253-4261	8	7.0	0.56	
4271-4283	<u>12</u>	9.2	<u>1.104</u>	
	61		5.714	

ϕ Average: .09367
 ϕh , Total: 5.714
 h, ft Total: 61

MADISON FORMATION RESEVOIR STUDY

Energy Reserves Group - #1 State
NE SE Section 36-T9N-R6E
Butte County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
3880-3885	5	16.0	0.8	
3895-3900	5	18.0	0.9	
3976-3980	4	20.0	0.8	
3986-3990	4	20.0	0.8	
4026-4034	8	7.0	0.56	
4034-4039	5	20.0	1.0	
4050-4052	2	14.0	0.28	
4102-4108	6	9.5	0.57	
4154-4162	8	7.0	0.56	
4176-4180	<u>4</u>	18.0	<u>0.72</u>	
	51		6.99	
<u>Mission Canyon</u>				
4242-4250	8	12.0	0.96	
4254-4260	6	11.0	0.66	
4264-4660	2	22.0	0.44	
4268-4273	5	20.0	1.0	
4302-4305	3	10.0	0.3	
4306-4310	6	10.0	0.6	
4310-4315	5	10.0	0.5	
4325-4328	3	8.0	0.24	
4418-4424	6	7.0	0.42	
4424-4430	6	10.0	0.6	
4456-4458	2	8.0	0.16	
4460-4464	4	8.0	0.32	
4466-4474	8	10.0	0.8	
4546-4552	6	8.0	0.48	
4610-4614	4	8.0	0.32	
4706-4716	10	12.0	1.2	
4740-4743	7	7.0	0.49	
4744-4748	4	8.0	0.32	
4778-4785	<u>7</u>	10.0	<u>0.7</u>	
	102		10.51	

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Lodgepole</u>				
4804-4807	3	8.0	0.24	
4807-4811	4	8.0	0.32	
4814-4818	4	10.0	0.4	
4820-4825	5	11.0	0.55	
4830-4840	10	10.0	1.0	
4849-4844	4	12.0	0.48	
4844-4848	4	10.0	0.4	
4850-4860	10	12.0	1.2	
4910-4916	6	9.5	0.57	
5024-5028	4	7.0	0.28	
5050-5054	4	8.0	0.32	
5054-5060	6	14.0	0.84	
5062-5068	6	8.0	0.48	
5080-5088	<u>8</u>	14.0	<u>1.12</u>	
	78		8.20	

ϕ Average: .11125
 ϕh Total: 25.7
h, ft Total: 231

MADISON FORMATION RESERVOIR STUDY

Mobil Oil Company - George Sipilin F-11-14-P
 NW NW Section 14-T9N-R8E
 Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4910-4920	10	19.0	1.9	DST 4687-4841 Charles
4950-4960	10	15.5	1.55	Op 1 hr, ISI 40 min, FSI 1 hr
5000-5030	30	9.0	2.7	rec 210' MCW, 4481' fw, ISIP
5030-5040	10	15.5	1.55	2007 psi, FSIP 2007 psi, FFP
5070-5085	15	12.0	1.8	2007 psi, IHP 2429 psi, FH
5085-5100	15	15.5	2.325	2363 psi, max temp 152°F
5260-5270	10	13.0	1.3	Mission Canyon and Lodgepole are not identifiable. Depths could be off 3'± due to a very small reduced log and poor print.
5270-5280	10	13.0	1.3	
5280-5298	18	8.5	1.53	
5300-5310	10	8.5	0.85	
5370-5380	10	12.0	1.2	
5450-5500	50	9.0	4.5	
5520-5540	20	12.0	2.4	
5700-5745	45	10.0	4.5	
	263		29.405	

ϕ Average: .11180
 ϕh , Total: 29.405
 h,ft Total: 263

MADISON FORMATION RESERVOIR STUDY

Mobil Oil Company - A. B. Mickelson #F41-7-P
C NE NE Section 7-T9N-R9E
Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
5204-5220	16	9.4	1.504	Scout card identifies top of Madison and top of Red River, however, the Mission Canyon and Lodgepole are not identifiable.
5222-5234	12	9.5	1.14	
5264-5277	13	11.0	1.43	
5313-5324	11	8.6	0.946	
5364-5373	9	7.5	0.675	
5538-5546	8	13.0	1.04	
5546-5556	10	14.0	1.4	
5766-5578	12	13.0	1.56	
5578-5590	12	7.8	0.936	
5836-5846	<u>10</u>	9.6	<u>0.96</u>	
	113		11.591	

ϕ Average: .10257
 ϕh , Total: 11.591
h,ft Total: 113

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - W. Johnson #23-23
C NE SW Section 23- T10N-R1E
Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
3275-3286	11	9.5	1.045	
3298-3303	5	9.0	0.45	
3336-3343	7	9.4	0.658	
3364-3370	6	8.6	0.516	
3370-3375	5	9.8	0.49	
3428-3434	6	9.3	0.558	
	40		3.717	
<u>Mission Canyon</u>				
3460-3466	6	10.8	0.648	
3466-3473	7	9.6	0.672	
3477-3482	5	9.0	0.45	
3482-3488	6	10.5	0.63	
3491-3504	13	9.4	1.222	
3504-3509	5	9.8	0.49	
3516-3522	6	9.0	0.54	
3540-3545	5	9.4	0.47	
3560-3566	6	9.5	0.57	
3594-3600	6	10.4	0.624	
3604-3612	8	10.0	0.8	
	73		7.116	
<u>Lodgepole</u>				
3620-3626	6	10.2	0.612	
3626-3630	4	10.4	0.416	
3635-3638	3	10.6	0.318	
3638-3643	5	12.5	0.625	
3643-3646	3	12.0	0.36	
3648-3652	4	11.5	0.46	
3652-3654	2	10.7	0.214	
3655-3657	2	12.0	0.24	
3680-3690	10	9.0	0.90	
3695-3704	9	13.2	1.188	
3708-3714	6	14.2	0.852	
3742-3747	5	9.8	0.49	
	59		6.675	
				ϕ Average: .10179
				ϕh , Total: 17.508
				h, ft Total: 172

MADISON FORMATION RESERVOIR STUDY

Valwood Exploration Company - Widdoss-Kimble #1
SW SW Section 15-T12N-R2E
Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5014-5017	3	13.0	0.39	
5026-5031	5	12.0	0.6	
5040-5043	3	9.0	0.27	
5082-5085	3	14.0	0.42	
5096-5100	4	14.0	0.56	
5102-5105	3	12.0	0.36	
5116-5125	<u>9</u>	12.0	<u>1.08</u>	
	30		3.68	
<u>Mission Canyon</u>				
5190-5195	5	9.0	0.45	
5258-5265	7	9.0	0.63	
5265-5270	5	12.0	0.6	
5376-5383	7	9.0	0.63	
5373-5390	17	9.0	1.53	
5390-5394	4	7.0	0.28	
5414-5422	8	12.0	0.96	
5432-5439	7	12.0	0.84	
5482-5488	<u>6</u>	9.0	<u>0.54</u>	
	66		6.46	
<u>Lodgepole</u>				
5562-5565	3	9.0	0.27	

ϕ Average: .10515
 ϕh , Total: 10.41
h, ft Total: 99

MADISON FORMATION RESERVOIR STUDY

Superior Oil Company - Indian Creek #1-33
SE SW Section 33-T13N-R2E
Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5180-5185	5	9.3	0.465	
5185-5193	8	11.0	0.88	
5193-5197	<u>4</u>	9.3	<u>0.372</u>	
	17		1.717	
<u>Mission Canyon</u>				
5472-5488	16	13.0	2.08	
5590-5610	<u>20</u>	8.6	<u>1.72</u>	
	36		3.8	
<u>Lodgepole</u>				
5732-5755	23	7.3	1.679	
5880-5905	<u>25</u>	9.4	<u>2.35</u>	
	48		4.029	

ϕ Average: .09451
 ϕh , Total: 9.546
h,ft Total: 101

MADISON FORMATION RESERVOIR STUDY

Amerada Petroleum Corporation - State #1
 NW NW Section 4-T14N-R4E
 Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5703-5709	6	8.0	0.48	DST 5827-5848
5932-5939	7	9.0	0.63	Op 4 hrs strong blow, 150 mins
5966-5974	8	17.0	1.36	Rec 2730' fresh wtr, top 180'
5990-5998	8	12.0	0.96	SMC, bottom 270' black w/sl
6034-6042	8	8.0	0.64	odor, FP 100-1200 psi, SIP
6116-6122	6	9.0	0.54	(15 min) 2710 psi, HP 8420-3290
6133-6140	7	8.3	0.581	psi
6168-6174	6	9.0	0.54	
	<u>56</u>		<u>5.731</u>	Mission Canyon is not identifiable.
<u>Mission Canyon</u>				
6238-6244	6	9.5	0.57	
6255-6260	5	9.5	0.475	
6360-6366	6	10.0	0.6	
	<u>17</u>		<u>1.645</u>	

ϕ Average: .10104
 ϕh , Total: 7.376
 h, ft Total: 73

MADISON FORMATION RESERVOIR STUDY

The Pure Oil Company - U. S. Govt #1
 2140' FNL, 660' FWL, Section 27-T14N-R2E
 Butte County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5410-5416	6	10.0	0.6	
5447-5450	<u>3</u>	10.0	<u>0.3</u>	
	9		0.9	
<u>Mission Canyon</u>				
5590-5595	5	9.0	0.45	
5607-5612	5	9.0	0.45	
5614-5622	8	9.0	0.72	
5645-5650	5	7.5	0.375	
5650-5659	9	7.5	0.675	
5684-6590	6	12.0	0.72	
5698-5710	12	12.0	1.44	
5730-5740	10	9.0	0.90	
5758-5766	8	9.0	0.72	
5766-5770	4	12.0	0.48	
5834-5840	<u>6</u>	12.0	<u>0.72</u>	
	78		7.65	
<u>Lodgepole</u>				
5934-5940	6	9.0	0.54	
6052-6060	8	9.0	0.72	
6098-6104	6	12.0	0.72	
6132-6136	4	12.0	0.48	
6136-6140	4	9.0	0.36	
6206-6210	4	9.0	0.36	
6216-6220	4	9.0	0.36	
6232-6236	4	10.0	0.4	
6240-6245	<u>5</u>	12.0	<u>0.6</u>	
	45		4.54	

ϕ Average: .09916
 ϕh , Total: 13.09
 h, ft Total: 132

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - Evridge #22-12
C SE NW Section 12-T18N-R19E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>	-	-	-	
<u>Mission Canyon</u>				
4708-4712	4	14.8	0.592	
4732-4740	8	13.2	1.056	
4766-4780	14	12.6	1.764	
4862-4996	134	15.3	20.502	
5028-5048	20	16.5	3.3	
5052-5084	<u>32</u>	16.4	<u>5.248</u>	
	212		32.462	
<u>Lodgepole</u>				
5378-5504	126	15.4	19.404	

Ø Average: .15344
Øh Total: 51.866
h,ft Total: 338

MADISON FORMATION RESERVOIR STUDY

W. S. Kilroy - School #1
C NE NW Section 26-T18N-R21E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
4460-4470	10	8.0	0.8	Madison group correlation not positive.
4522-4535	13	9.0	1.17	
4750-4776	26	8.0	2.08	
4812-4845	33	8.9	2.937	
5018-5100	82	9.7	7.954	
5120-5135	<u>35</u>	11.0	<u>3.85</u>	
	199		18.791	
				ϕ Average: .09442
				ϕh , Total: 18.791
				h,ft Total: 199

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - Government #11-23
C NW NW Section 23-T19N-R18E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>	-	-	-	
<u>Mission Canyon</u>				
5095-5108	13	8.5	1.105	
5126-5208	82	10.5	8.61	
5238-5249	11	9.5	1.045	
5254-5258	4	9.0	0.36	
5287-5300	13	11.5	1.495	
5329-5334	5	10.3	0.515	
5350-5353	3	9.0	0.27	
5380-5391	11	11.3	1.243	
5391-5394	3	9.1	0.273	
5460-5470	10	8.5	0.85	
5474-5492	18	9.6	1.728	
5496-5499	3	8.6	0.258	
	<u>176</u>		<u>17.752</u>	
<u>Lodgepole</u>				
5545-5555	10	7.8	0.78	
5555-5564	9	8.9	0.801	
	<u>19</u>		<u>1.581</u>	

ϕ Average: .09914
 ϕh , Total: 19.333
h, ft Total: 195

MADISON FORMATION RESERVOIR STUDY

Youngblood and Youngblood - Macheel #1
C SW SW Section 8-T21N-R19E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5130-5148	18	10.2	1.836	DST 5410-5430 Mission Canyon
5202-5220	18	9.5	1.71	½" THC, 5/8" BHC, op 1 hr
5255-5284	29	12.1	3.509	SI 30 min, steady blow thruout,
5284-5350	66	18.8	12.408	rec 140' sl SWCM w/sl scum &
	131		19.463	brown oil specks, 80' sl sulf
				H ₂ O cut mud w/pinpoints oil,
				FP 30-96 psi, SIP 2404 psi,
<u>Mission Canyon</u>	-	-	-	HP 2988 psi
				Sp Gr. 60/60°F 1.0083
<u>Lodgepole</u>				Alkalinity 678
				Hardness 3330
5710-5720	10	9.3	0.93	pH 6.65
				Ca 1100
				Mg 138
				Sodium CALC Na+ 3450
				HCO ₃ 827
				SO ₄ 7000
				Cl 2033
				R _w = .740 @77°F

ϕ Average: .14463
 ϕh , Total: 20.393
h,ft Total: 141

MADISON FORMATION RESERVOIR STUDY

Murphy Oil Corporation - State "A" #1
SW SW Section 8-T21N-R24E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
4104-4112	8	11.5	0.92	Correlation for Madison group tops not conclusive.
4115-4122	7	12.0	0.84	
4138-4148	10	11.0	1.1	
4180-4198	18	9.0	1.62	
4208-4228	20	9.8	1.96	
4234-4272	36	10.2	3.672	
4280-4290	10	10.0	1.0	
4320-4344	24	11.0	2.64	
4354-4410	56	15.2	8.512	
4410-4450	<u>50</u>	<u>12.4</u>	<u>4.96</u>	
	229		27.224	

ϕ Average: .11888
 ϕh , Total: 27.224
h,ft Total: 229

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - J. K. Winter #1
C NW SW Section 11-T22N-R19E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>φ, %</u>	<u>φh</u>	<u>Remarks</u>
<u>Charles</u>				
5288-5296	8	10.5	0.84	DST 5413-5472 Charles
5368-5374	6	6.2	0.372	Fluid 30' from top
5418-5435	17	15.3	2.601	Sp. Gr 60/60°F 1.0264
5454-5504	50	22.5	11.25	Alkalinity 310
5542-5550	8	8.3	0.664	Hardness 5070
	89		15.727	pH 6.38
				Cal 1780
				Mg 153
				Calc-Na 9360
				HCO ₃ 380
5606-5659	53	10.7	5.671	SO ₄ 3200
5758-5816	58	11.2	6.496	Cl 15420
	111		12.167	Resistivity 0.23 @77° F
				DST 5606-5659 Madison
				Fluid 4145' from top
				Sp. Gr 1.0059
				Alkalinity 560
				Hardness 2400
				pH 6.6
				Ca 696
				Mg 322
				Calc-Na 1280
				HCO ₃ 690
				SO ₄ 2000
				Cl 2250
				H ₂ S 130 Mg/L
				R _w = 1.04 @77°F
				DST 5758-5820 Madison
				Fluid 840' from top
				Sp. Gr 1.0094
				Alkalinity 320
				Hardness 3900
				pH 7.1
				Ca 1235
				Mg 198
				Calc-Na 3380
				HCO ₃ 390
				SO ₄ 2300
				Cl 6050
				R _w = 0.49 @77°F
		φ Average:	.13148	
		φh, Total:	36.946	
		h,ft Total:	281	

MADISON FORMATION RESERVOIR STUDY

I. J. Wilhite - State #1
SE SW Section 36-T22N-R21E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4558-4586	28	10.5	2.94	
4608-4624	14	12.2	1.708	
4653-4663	10	4.5	0.45	
4706-4730	24	4.4	1.056	
4734-4744	10	4.0	0.4	
4744-4760	16	6.0	0.96	
4770-4780	<u>10</u>	5.3	<u>0.53</u>	
	112		8.044	
<u>Mission Canyon</u>				
4866-4884	10	11.5	1.15	
4980-4996	18	12.0	2.16	
5134-5150	16	9.3	1.488	
5173-5211	<u>38</u>	8.3	<u>3.154</u>	
	82		7.952	

ϕ Average: .08245
 ϕh , Total: 15.996
h,ft Total: 194

MADISON FORMATION RESERVOIR STUDY

Youngblood and Youngblood - Dan Winter #1
C SW SW Section 23-T22N-R19E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5230-5250	20	9.2	1.84	DST 5295-5329 Charles zone Op 1 hr, rec 35' mud, 55' muddy SW, FP 35-75 psi, SIP 2100 psi/1 hr, HP 2925-2900 psi
5290-5320	30	11.2	3.36	
5350-5390	<u>40</u>	13.2	<u>5.28</u>	
	90		10.48	
<u>Mission Canyon</u>				
5453-5479	26	8.8	2.288	DST 5454-5479 Mission Canyon Op 1 hr, rec 33' H ₂ O cut mud, brown & black oil specks w/ odor, 90' sl OC muddy H ₂ O, 450' black sul H ₂ O, FP 75-220 psi, SIP 2330 psi/30 min, HP 2905 psi. Sp Gr. 1.0099 Alkalinity 630 Hardness 2840 Ca 875 Mg 159 Sodium CALC Nat 2520 HCO ₃ 769 SO ₄ 5200 Cl 1610 R _w = .805 @77°F
				ϕ Average: .11006
				ϕh , Total: 12.768
				h,ft Total: 116

MADISON FORMATION RESERVOIR STUDY

Cockrell Corporation - A. P. Lillegaard #1
SE NE Section 13-T22N-R18E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5516-5530	15	14.0	2.1	Dresser Atlas nomograph for ϕ determination was found to read high by some 3-5% other methods and nomographs were used.
5540-5550	12	5.0	0.6	
5620-5635	<u>16</u>	15.3	<u>2.448</u>	
	43		5.148	
<u>Mission Canyon</u>				
5900-5970	70	12.5	8.75	
<u>Lodgepole</u>				
6136-6148	12	11.1	1.332	
6216-6236	<u>20</u>	10.0	<u>2.0</u>	
	32		3.332	

ϕ Average: .11882
 ϕh , Total: 17.23
h,ft Total: 145

MADISON FORMATION RESERVOIR STUDY

A. M. Bartlett - Guyer #1
SW SW Section 20-T23N-R23E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
4670-4687	17	11.0	1.87	Unable to identify Madison group.
4702-4712	10	11.2	1.12	
4754-4768	14	8.2	1.148	
4776-4802	26	11.4	2.964	
4812-4826	14	8.0	1.12	
4840-4854	42	14.8	6.216	
4854-4882	28	8.0	2.24	
4886-4898	12	25.0	3.0	
4921-4942	21	5.0	1.05	
4948-4964	16	11.2	1.792	
5130-5180	50	8.1	4.05	
5190-5258	62	10.8	6.696	
5508-5610	<u>102</u>	12.0	<u>12.24</u>	
	414		45.506	
				ϕ Average: .10991
				ϕh , Total: 45.506
				h, ft Total: 414

MADISON FORMATION RESERVOIR STUDY

Youngblood and Youngblood - John Drascovich
C SE SE Section 20-T23N-R22E
Corson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4842-4862	20	10.0	2.0	DST 5118-5145 op 1 hr, SI 15 min, weak blow thruout, rec 95' slGCW w/black oil specks, 180' slMCSW, 90' black sulf wtr. IFP 90-235 psi, FFP 235 psi, SIP 1915 psi, IHP 2775-2730 psi, FH 2730 psi.
4940-4980	40	12.0	4.8	
5000-5050	<u>50</u>	13.5	<u>6.75</u>	
	110		13.55	
<u>Mission Canyon</u>				
5118-5145	27	8.2	2.214	
5120-5260	<u>40</u>	15.1	<u>6.04</u>	
	67		21.804	
				ϕ Average: .12318
				ϕh , Total: 21.804
				h,ft Total: 177

MADISON FORMATION RESERVOIR STUDY

Bueno Drilling Company - Holloway-State #1
NW NW Section 4-T12N-R22E
Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
4068-4073	3	14.9	0.448	
4079-4104	<u>25</u>	18.3	<u>4.576</u>	
	28		5.024	
<u>Mission Canyon</u>				
4120-4130	10	19.0	1.9	
4130-4156	26	15.0	3.893	
4156-4162	6	12.7	0.765	
4170-4180	10	12.7	1.275	
4188-4194	6	9.6	0.578	
4194-4200	6	12.7	0.765	
4204-4208	4	12.4	0.5	
4212-4220	8	11.4	0.912	
4230-4235	5	11.4	0.57	
4235-4240	5	9.6	0.578	
4294-4302	8	13.6	1.09	
4376-4378	<u>2</u>	9.0	<u>0.18</u>	
	96		13.006	
<u>Lodgepole</u>				
4385-4388	3	10.2	0.307	
4392-4402	10	12.5	1.255	
4420-4426	6	11.2	0.673	
4441-4450	9	10.7	0.963	
4450-4468	18	14.5	2.608	
4612-4618	6	9.5	0.569	
4618-4628	10	11.8	1.183	
4628-4640	12	15.9	1.905	
4640-4668	28	17.7	4.67	
4662-4666	4	10.2	0.41	
4690-4702	12	8.9	1.065	
4702-4710	<u>8</u>	12.5	<u>1.004</u>	
	127		16.612	

Ø Average: .13801
Øh Total: 34.642
h,ft Total: 251

MADISON FORMATION RESERVOIR STUDY

Investors Drilling Ventures, Inc. - Holloway #7
NW SW Section 4-T12N-R22E
Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4070-4076	6	18.4	1.102	
4083-4108	<u>25</u>	23.7	<u>5.929</u>	
	31		7.031	

Mission Canyon

4126-4136	10	25.7	2.569	
4138-4142	4	20.3	0.812	
4148-4160	12	19.1	2.298	
4164-4166	2	14.8	0.297	
4168-4170	2	14.8	0.297	
4174-4180	6	14.8	0.89	
4196-4202	6	16.2	0.975	
4206-4209	3	14.6	0.438	
4212-4218	6	12.8	0.771	
4230-4235	5	11.5	0.574	
4235-4241	6	8.8	0.529	
4248-4252	4	10.5	0.42	
4252-4260	8	12.1	0.969	
4260-4266	6	11.0	0.657	
4269-4274	5	11.5	0.574	
4291-4293	2	11.5	0.23	
4295-4302	7	12.1	0.848	
4307-4310	<u>3</u>	12.8	<u>0.385</u>	
	103		14.533	

ϕ Average: .16092
 ϕh , Total: 21.564
h, ft Total: 134

MADISON FORMATION RESERVOIR STUDY

Investors Drilling Ventures, Inc. - Williams & State #1
NE SW Section 11-T12N-R22E
Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
4092-4096	4	18.1	0.725	
4112-4122	10	24.6	2.456	
4122-4135	<u>13</u>	22.2	<u>2.889</u>	
	27		6.07	

Mission Canyon

4152-4155	3	15.2	0.456	
4155-4164	9	24.0	2.158	
4168-4182	14	18.1	2.538	
4189-4197	8	11.1	0.889	
4204-4242	38	14.0	5.333	
4242-4256	14	12.3	1.719	
4256-4262	6	8.2	0.491	
4262-4280	18	12.3	2.211	
4280-4292	12	13.5	1.614	
4292-4300	8	18.7	1.497	
4300-4306	6	10.5	0.632	
4306-4323	17	12.3	2.088	
4323-4328	5	15.2	0.76	
4328-4334	6	18.1	1.088	
4399-4404	<u>5</u>	8.2	<u>0.409</u>	
	169		23.883	

Lodgepole

4429-4439	10	12.9	1.287	
4478-4481	3	9.4	0.281	
4488-4492	4	10.5	0.421	
4492-4497	5	12.9	0.643	
4568-4588	20	8.8	1.754	
4588-4596	8	9.9	0.795	
4596-4602	6	11.7	0.702	
4638-4650	12	15.2	1.825	
4650-4663	13	24.0	3.117	
4663-4675	12	12.3	1.474	
4675-4682	7	25.7	1.801	
4682-4690	8	21.1	1.684	
4696-4698	<u>2</u>	9.9	<u>0.199</u>	
	110		15.983	

Ø Average: .15011
Øh Total: 45.936
h,ft Total: 306

MADISON FORMATION RESERVOIR STUDY

Town of Eagle Butte - Water Well #1
 NW SW Section 17-T12N-R24E
 Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
3980-3988	8	11.0	0.88	DST Mission Canyon blowing 15 min & died. Fluid within 320' of surface. BHP 1700 psi. Flowed 30 GPM after first perf. Perf bullets 4/ft 4034-4156'
3992-3994	<u>2</u>	10.0	<u>0.2</u>	
	10		1.08	
<u>Mission Canyon</u>				
4010-4016	6	11.0	0.66	
4018-4024	6	12.0	0.72	
4034-4158	124	12.8	15.872	
4190-4200	<u>10</u>	12.2	<u>1.22</u>	
	146		18.472	
<u>Lodgepole</u>				
4210-4216	6	12.6	0.756	

ϕ Average: .12535
 ϕh Total: 20.308
 h, ft Total: 162

MADISON FORMATION RESERVOIR STUDY

Investors Drilling Ventures, Inc. - Jacob Little Skunk Estate Brooks #1
NW NW Section 29-T13N-R22E
Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
4058-4066	8	12.3	0.986	
4086-4096	10	11.4	1.145	
4098-4116	<u>18</u>	13.5	<u>2.421</u>	
	36		4.552	

Mission Canyon

4140-4155	15	13.3	1.991	
4160-4168	8	12.7	1.015	
4168-4174	6	10.4	0.606	
4174-4182	8	7.3	0.582	
4192-4200	8	8.2	0.656	
4210-4220	10	10.8	1.075	
4220-4226	6	10.0	0.6	
4226-4236	10	9.6	0.962	
4248-4258	10	9.4	0.939	
4270-4282	12	10.6	1.271	
4290-4298	8	9.7	0.725	
4312-4320	<u>8</u>	8.9	<u>0.71</u>	
	109		11.132	

Lodgepole

4460-4473	13	7.7	1.007	
4478-4490	12	8.7	1.039	
4641-4645	4	8.9	0.358	
4645-4655	10	10.1	1.014	
4655-4670	15	11.1	1.671	
4670-4678	8	9.9	0.789	
4678-4694	16	12.0	1.92	
4729-4736	<u>7</u>	9.3	<u>0.648</u>	
	85		8.446	

Ø Average: .10491
Øh Total: 24.13
h,ft Total: 230

MADISON FORMATION RESERVOIR STUDY

Kerr-McGee Oil Ind., Inc. - Wallace Cook #1
SW NW SW Section 32-T13N-R22E
Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>	-	-	-	
<u>Mission Canyon</u>				
4194-4238	44	9.0	3.96	DST 4310-75 Mission Canyon 35 min flow, fresh H ₂ O in 15 min @61 BPH. FP 1070-1935 psiw. SIP 20 min 1990 psiw. HP 2320 psiw.
4240-4287	47	10.5	4.935	
4306-4314	8	12.5	1.0	
4320-4322	2	14.0	0.28	
4324-4326	2	14.0	0.28	
4326-4332	6	14.5	0.87	
4343-4348	5	14.7	0.735	
4350-4352	2	13.0	0.26	
4355-4368	23	14.0	3.22	
4374-4377	3	13.0	0.39	
4382-4388	6	14.0	0.84	
	148		16.77	
<u>Lodgepole</u>				
4486-4490	4	13.0	0.52	
4491-4495	4	12.0	0.48	
4499-4502	3	12.0	0.36	
4509-4512	3	13.0	0.39	
4515-4517	2	14.1	0.282	
4518-4520	12	13.0	1.56	
4522-4526	4	14.0	0.56	
4532-4534	2	13.5	0.27	
4556-4564	8	13.0	1.04	
4567-4572	5	13.5	0.675	
4574-4586	12	13.5	1.62	
4595-4599	4	14.0	0.56	
4600-4610	10	13.5	1.35	
4618-4624	6	13.0	0.78	
4626-4632	6	13.0	0.78	
4680-4686	6	12.5	0.75	
4703-4723	20	13.5	2.7	
	111		14.677	
				ϕ Average: .12141
				ϕh Total: 31.447
				h, ft Total: 259

MADISON FORMATION RESERVOIR STUDY

Herndon Drilling Company - State #1
SW NW Section 34-T13N-R24E
Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
3784-3802	18	16.5	2.973	
3834-3843	9	16.5	1.486	
3849-3856	<u>7</u>	18.3	<u>1.278</u>	
	34		5.737	
<u>Mission Canyon</u>				
3865-3872	7	12.2	0.857	
3944-3970	26	8.7	2.252	
3970-3976	6	11.8	0.709	
3976-3990	14	9.6	1.345	
3990-4024	34	10.4	3.551	
4024-4044	20	8.2	1.633	
4044-4060	16	10.9	1.753	
4086-4092	6	8.7	0.522	
4130-4140	<u>10</u>	8.9	<u>0.894</u>	
	139		13.516	
<u>Lodgepole</u>				
4166-4179	13	7.7	1.007	
4193-4218	25	10.9	2.725	
4246-4262	16	8.4	1.344	
4290-4316	26	8.4	2.184	
4316-4340	24	8.9	2.136	
4340-4384	44	9.6	4.224	
4384-4419	35	19.4	6.778	
4450-4470	<u>29</u>	8.9	<u>1.78</u>	
	203		22.178	
				Ø Average: .11018
				Øh Total: 41.431
				h,ft Total: 376

MADISON FORMATION RESERVOIR STUDY

Youngblood and Youngblood - Galvin #1
SE SE Section 25-T16N-R22E
Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4134-4147	13	12.25	1.592	
4197-4205	<u>8</u>	22.3	<u>1.789</u>	
	21		3.381	
<u>Mission Canyon</u>				
4283-4400	117	8.94	10.465	
4400-4418	18	16.2	2.907	
4418-4437	<u>19</u>	8.66	<u>1.645</u>	
	154		15.017	
<u>Lodgepole</u>				
4510-4553	43	10.95	4.71	
4588-4602	14	8.94	1.252	
4602-4616	14	15.19	2.127	
4216-4230	14	7.9	1.113	
4720-4830	<u>110</u>	10.95	<u>12.045</u>	
	195		21.247	

ϕ Average: .10714
 ϕh , Total: 39.645
h, ft Total: 370

MADISON FORMATION RESERVOIR STUDY

Herndon Drilling Company - Louis Merkle #1
SE SE Section 27-T17N-R27E
Dewey County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
3250-3264	14	11.5	1.617	
3285-3291	6	12.6	0.759	
3295-3300	5	13.3	0.667	
3300-3320	20	23.1	4.619	
3320-3328	<u>8</u>	20.0	<u>1.6</u>	
	53		9.262	
<u>Mission Canyon</u>				
3345-3356	11	11.1	1.22	
3410-3450	40	9.2	3.671	
3450-3490	40	9.7	3.88	
3490-3500	10	14.5	1.451	
3554-3560	<u>6</u>	9.7	<u>0.582</u>	
	107		10.804	
<u>Lodgepole</u>				
3595-3631	36	9.7	3.492	
3667-3678	11	10.3	1.136	
3678-3688	<u>10</u>	12.6	<u>1.265</u>	
	57		5.893	

Ø Average: .11962
Øh Total: 25.959
h,ft Total 217

MADISON FORMATION RESERVOIR STUDY

North Central Oil Corporation - State-Gary #1
C NE SE Section 16-T9S-R7E
Fall River County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4266-4272	6	8.0	0.48	Top Madison 4200'
4276-4280	4	7.0	0.28	Well TD 120' in Madison
4282-4286	4	8.0	0.32	
4302-4305	3	8.0	0.24	
4305-4308	<u>6</u>	7.2	<u>0.432</u>	
	23		1.752	
				ϕ Average: .07617
				ϕh , Total: 1.752
				h,ft Total: 23

MADISON FORMATION RESERVOIR STUDY

Kerr-McGee Oil Ind., Inc. - Chute #1
C SW SW Section 33-T3N-R19E
Haakon County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4308-4316	8	7.0	0.56	DST 4394-4404 op 1 hr rec 120' MH ₂ O, 4164' fw, FP 1700 psi, SIP 15 min 1700 psi, HP 2400 psi.
4328-4338	10	7.0	0.7	
4374-4388	<u>14</u>	7.0	<u>0.98</u>	
	32		2.24	
<u>Mission Canyon</u>				
4396-4492	96	10.0	9.6	
4494-4498	4	8.0	0.32	
4500-4508	8	8.3	0.664	
4512-4522	10	7.0	0.7	
4524-4528	4	8.0	0.32	
4532-4534	2	6.5	0.13	
4546-4550	<u>4</u>	7.0	<u>0.28</u>	
	128		12.014	
<u>Lodgepole</u>				
4563-4584	21	7.0	0.84	
4586-4588	2	6.7	0.134	
4590-4594	4	8.8	0.352	
4596-4606	10	7.0	0.7	
4612-4620	8	9.0	0.72	
4620-4626	6	5.0	0.3	
4626-4660	34	9.7	3.298	
4666-4670	4	8.1	0.324	
4672-4676	4	7.0	0.28	
4680-4743	63	6.9	4.347	
4744-4750	<u>6</u>	7.3	<u>0.438</u>	
	162		11.733	

ϕ Average: .08070
 ϕh , Total: 25.987
h,ft Total: 322

MADISON FORMATION RESERVOIR STUDY

Carter Oil Company - James W. Danielson #1
C SE NW Section 5-T3N-R22E
Haakon County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon</u>				
4010-4022	12	18.5	2.22	DST 3986-4037 Mission Canyon
4022-4036	14	17.0	2.38	Op 1½ hr, SI 15 min, IFP
4036-4048	12	14.2	1.704	1800 psi, FFP 1800 psi, SIP
4055-4070	15	18.5	2.775	1800 psi, HP 1975, wtr to
4120-4130	10	18.0	1.8	sfc in 25 min
4150-4160	10	13.5	1.35	
4240-4250	<u>10</u>	<u>20.0</u>	<u>2.0</u>	
	83		14.229	
ϕ Average: .17143 ϕh , Total: 14.229 h, ft Total: 83				

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Company - C. E. Harry #1
 SW SW Section 4-T3N-R23E
 Haakon County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon</u>				
3626-3632	6	15.2	0.912	
3632-3638	6	10.5	0.63	
3638-3642	4	12.3	0.492	
4136-4142	6	16.0	0.96	
4143-4145	2	16.5	0.33	
4150-4160	10	17.2	1.72	
4160-4170	10	18.6	1.86	
4170-4173	3	16.5	0.495	
4173-4176	<u>3</u>	13.0	<u>0.39</u>	
	50		7.789	

ϕ Average: .15578
 ϕh , Total: 7.789
 h,ft Total: 50

MADISON FORMATION RESERVOIR STUDY

John Gilmartin - May #1
SE NE SE Section 21-T4N-R18E
Haakon County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>	-	-	-	
<u>Mission Canyon</u>				
4428-4434	6	17.0	1.02	
4446-4450	4	17.1	0.684	
4450-4454	4	15.2	0.608	
4454-4462	8	17.3	1.384	
4462-4476	14	16.5	2.31	
4476-4490	14	16.9	2.366	
4490-4504	14	16.0	2.24	
4504-4518	14	17.8	2.492	
4518-4526	8	16.3	1.304	
4526-4550	24	17.7	4.248	
4550-4554	4	18.0	0.72	
4560-4576	16	15.6	2.496	
4582-4586	4	15.7	0.628	
4593-4596	3	18.0	0.54	
4604-4612	8	14.0	1.12	
4616-4624	8	14.4	1.152	
	153		25.312	
<u>Lodgepole</u>				
4668-4683	15	17.3	2.595	
4704-4754	50	17.3	8.65	
4754-4758	4	17.9	0.716	
4758-4768	10	15.6	1.56	
4768-4780	12	18.1	2.172	
4780-4796	16	18.5	2.96	
4796-4806	10	18.2	1.82	
4806-4884	78	15.2	11.856	
	195		32.329	

Ø Average: .16563
Øh Total: 57.641
h,ft Total: 348

MADISON FORMATION RESERVOIR STUDY

Exeter Drilling and Exploration Company - Morris Grain #6-13
 SW SW Section 6-T4N-R21E
 Haakon County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
3947-3960	13	15	1.95	
4048-4060	12	20	2.4	
4076-4094	18	20	3.6	
4210-4222	12	16	1.92	
4252-4272	20	14	2.8	
4300-4306	6	14	0.84	
4358-4366	<u>8</u>	<u>10</u>	<u>0.8</u>	
	89		14.31	

ϕ Average: .16078
 ϕh , Total: 14.31
 h,ft Total: 89

MADISON FORMATION RESERVOIR STUDY

Texaco, Inc. - State #1-B
NW SE Section 36-T6N-R21E
Haakon County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
3662-3670	8	10.0	0.8	Group identification not positive.
3672-3680	8	22.0	1.76	
3686-3696	10	13.0	1.3	
3694-3100	6	19.0	1.14	
3710-3724	14	10.2	1.428	
3724-3734	10	19.5	1.95	
3744-3754	10	19.8	1.98	
3754-3774	20	9.5	1.9	
3774-3782	8	19.0	1.52	
3796-3830	34	6.4	2.176	
3834-3866	32	10.1	3.232	
3880-3894	14	9.3	1.302	
3900-3914	14	10.0	1.4	
3934-3966	32	8.7	2.784	
3966-3990	24	12.5	3.0	
3998-4054	56	9.5	5.32	
4054-4120	<u>66</u>	13.4	<u>8.844</u>	
	366		41.836	

ϕ Average: .11430
 ϕh , Total: 41.836
h, ft Total: 366

MADISON FORMATION RESERVOIR STUDY

Sam G. Harrison - Truman #1
1980' FWL, 550' FNL, Section 21-T15N-R3E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5522-5527	5	6.0	0.3	
5528-5530	2	9.0	0.18	
5624-5626	<u>2</u>	9.0	<u>0.18</u>	
	9		0.66	
<u>Mission Canyon</u>				
5706-5713	7	9.0	0.63	
5729-5734	5	13.5	0.675	
5770-5784	14	9.0	1.26	
5794-5798	4	12.0	0.48	
5828-5832	4	9.0	0.36	
5900-5904	4	12.0	0.48	
5904-5908	4	9.0	0.36	
5924-5928	4	7.5	0.3	
5928-5933	5	13.5	0.675	
5946-5950	4	10.5	0.42	
5955-5959	4	10.5	0.42	
5961-5965	4	10.5	0.42	
5970-5975	5	7.0	0.35	
6000-6006	<u>6</u>	7.0	<u>0.42</u>	
	74		7.25	
<u>Lodgepole</u>				
6033-6038	5	7.0	0.35	
6170-6175	5	12.0	0.6	
6347-6355	<u>8</u>	15.0	<u>1.2</u>	
	18		2.15	

ϕ Average: .09960
 ϕh , Total: 10.06
h, ft Total: 101

MADISON FORMATION RESERVOIR STUDY

Texaco, Inc. - Govt-A Sallerdal (NCT-1) #1
SW NW Section 12-T15N-R6E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon</u>				
5868-5875	7	11.5	0.805	DST 5980-6020
5875-5879	4	9.0	0.36	Op 2 hrs, Rec 390' WCM, 360'
5880-5885	5	11.5	0.575	MCW, 1080' brackish wtr, 790'
5986-5990	4	7.0	0.28	sl sulfurous wtr, FP 1532-2599 psi,
5990-5992	2	9.0	0.18	SIP (90 min) 2771 psi, HP 3369 psi
5992-5994	2	11.0	0.22	
6003-6006	3	10.0	0.30	
6008-6010	2	7.0	0.14	
6015-6019	4	7.0	0.28	
6019-6024	5	11.0	0.55	
6025-6030	5	12.0	0.6	
6054-6058	4	10.0	0.4	
6079-6088	9	9.0	0.81	
6098-6102	4	10.0	0.4	
6106-6109	3	10.0	0.3	
6109-6113	4	9.0	0.36	
6132-6135	3	10.0	0.3	
6135-6139	5	7.0	0.35	
6144-6150	6	7.5	0.45	
6150-6154	4	7.0	0.28	
6156-6160	<u>4</u>	12.0	<u>0.48</u>	
	89		8.42	
<u>Lodgepole</u>				
6190-6194	4	13.0	0.52	
6194-6196	2	12.0	0.27	
6196-6200	4	17.0	0.68	
6220-6224	4	13.0	0.52	
6224-6226	2	12.0	0.24	
6375-6380	5	7.0	0.35	
6590-6594	4	7.0	0.28	
6600-6604	<u>4</u>	9.0	<u>0.36</u>	
	29		3.22	

ϕ Average: .09864
 ϕh , Total: 11.64
h, ft Total: 118

MADISON FORMATION RESERVOIR STUDY

Sinclair Oil and Gas Company - Wallace White #1
SW NE Section 34-T15N-R7E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5876-5880	4	8.0	0.32	Mission Canyon and Lodgepole tops are not clear.
6010-6016	6	12.0	0.72	
6028-6032	4	7.0	0.28	
6045-6050	5	12.0	0.6	
6080-6084	4	7.0	0.28	
6084-6088	4	16.0	0.64	
6090-6096	6	9.5	0.57	
6114-6120	6	12.0	0.72	
6204-6208	4	9.5	0.38	
6224-6229	5	9.5	0.475	
6264-6268	4	9.5	0.38	
6271-6275	4	8.5	0.34	
6282-6288	6	9.5	0.57	
6294-6298	4	8.0	0.32	
6300-6303	3	11.5	0.345	
6312-6317	5	9.5	0.475	
6318-6324	6	11.5	0.69	
6346-6352	6	8.5	0.51	
6355-6360	5	9.5	0.475	
6362-6366	4	8.5	0.34	
6370-6374	4	8.5	0.34	
6376-6380	4	8.5	0.34	
6437-6340	3	13.5	0.405	
6482-6486	4	13.5	0.54	
6502-6506	4	8.5	0.34	
6574-6580	6	8.5	0.51	
6611-6615	4	11.5	0.46	
6616-6621	5	9.5	0.475	
6666-6676	10	11.5	1.15	
6694-6699	5	7.0	0.35	
6747-6753	6	7.0	0.42	
6783-6788	5	9.5	0.475	
6796-6802	6	18.0	1.08	
6804-6807	3	11.5	0.345	
6808-6813	5	12.0	0.6	
6814-6820	6	9.5	0.57	
6820-6824	4	12.0	0.48	
6832-6848	16	10.0	1.6	
6910-6914	4	12.0	0.48	
6913-6920	7	12.0	0.84	
6923-6928	5	12.0	0.6	
6929-6934	5	7.0	0.35	
	216		22.18	ϕ Average: .10268 ϕh , Total: 22.18 h,ft Total: 216

MADISON FORMATION RESERVOIR STUDY

Ladd Petroleum Corporation - Lofin #1
NE NE Section 11-T17-R7E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon</u>				
6706-6712	6	10.5	0.63	
6806-6812	6	10.5	0.63	
6832-6837	5	11.0	0.55	
6840-6845	5	11.0	0.55	
6860-6866	6	10.0	0.60	
6866-6870	4	9.0	0.36	
6870-6875	5	9.0	0.45	
6880-6888	8	9.0	0.72	
6894-6898	4	10.0	0.40	
6899-6904	5	14.0	0.7	
6910-6922	12	11.0	1.32	
6947-6951	4	13.0	0.52	
6951-6955	4	11.5	0.46	
6960-6965	5	12.0	0.6	
6967-6973	6	11.5	0.69	
7009-7013	4	8.0	0.32	
7015-7019	4	8.0	0.32	
7034-7037	3	10.0	0.30	
7202-7206	4	11.5	0.46	
7259-7262	3	8.5	0.255	
7424-7429	5	8.5	0.425	
	108		11.26	

ϕ Average: .10425
 ϕh , Total: 11.26
h,ft Total: 108

MADISON FORMATION RESERVOIR STUDY

Amerada Petroleum - USA-Ellis #1
Tr 1-C SE SE Section 24-T17N-R1E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6372-6330	8	8.0	0.64	
6334-6340	6	8.0	0.48	
6366-6371	5	8.4	0.42	
6436-6446	10	12.5	1.25	
6458-6464	6	10.0	0.6	
6472-6479	7	11.0	0.77	
6482-6490	8	12.5	1.0	
6500-6504	4	14.0	0.56	
6504-6512	8	16.0	1.28	
6512-6518	6	20.0	1.2	
6518-6521	3	20.0	0.6	
6525-6530	5	10.4	0.52	
6554-6564	10	9.5	0.95	
6606-6614	8	10.0	0.8	
6656-6664	8	12.0	0.96	
	102		12.03	
<u>Mission Canyon</u>				
6680-6686	6	13.0	0.78	
6700-6705	5	12.5	0.625	
6720-6728	8	10.0	0.8	
6740-6745	5	10.0	0.5	
6754-6762	8	11.5	0.92	
6766-6772	6	10.0	0.6	
6772-6777	5	10.0	0.5	
6778-6785	7	9.5	0.665	
6785-6790	5	9.0	0.45	
6790-6796	6	8.8	0.528	
6796-6800	4	8.0	0.32	
6806-6812	6	10.0	0.6	
6834-6840	6	14.0	0.84	
6846-6853	7	18.5	1.295	
6892-6896	4	9.5	0.38	
6900-6906	6	12.0	0.72	
6920-6925	5	9.0	0.45	
6986-6992	6	10.2	0.612	
7292-7300	8	9.0	0.72	
7310-7328	18	9.8	1.764	
7328-7336	8	9.6	0.768	
7344-7352	8	9.8	0.784	
	147		15.621	
				ϕ Average: .11104
				ϕh , Total: 27.651
				h,ft Total: 249

MADISON FORMATION RESERVOIR STUDY

Richfield Oil - State #1
SW SE NW Section 16-T17N-R4E
Harding County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6125-6135	10	12.5	1.25	
6138-6148	10	14.5	1.45	
6150-6165	15	9.5	1.425	
6165-6172	7	12.0	0.84	
6172-6175	3	15.0	0.45	
6180-6190	10	10.5	1.05	
6258-6262	4	7.0	0.28	
6280-6286	6	9.0	0.54	
6296-6300	4	10.1	0.404	
	69		7.689	
<u>Mission Canyon</u>				
6382-6390	8	10.2	0.816	
6391-6397	6	10.5	0.63	
6400-6404	4	17.5	0.7	
6440-6454	14	9.0	1.26	
6475-6482	7	9.2	0.644	
6497-6502	5	9.2	0.46	
6504-6508	4	9.5	0.38	
6528-6530	2	9.4	0.188	
6528-6534	6	17.5	1.05	
6570-6578	8	10.5	0.84	
6582-6589	7	15.0	1.05	
6640-6648	8	9.0	0.72	
6649-6656	7	10.2	0.714	
6656-6670	14	14.5	2.03	
6674-6676	2	10.2	0.204	
6676-6680	4	8.5	0.34	
6690-6698	8	9.5	0.76	
6708-6714	6	15.0	0.9	
	120		13.686	

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Lodgepole</u>				
6714-6718	4	10.5	0.42	
6718-6720	2	9.2	0.184	
6720-6728	8	8.8	0.704	
6728-6730	2	10.8	0.216	
6732-6740	8	17.0	1.36	
6988-6998	10	10.0	1.0	
6998-7004	6	9.0	0.54	
7006-7010	4	9.2	0.368	
7016-7018	2	9.4	1.88	
7120-7126	<u>6</u>	9.5	<u>0.57</u>	
	52		7.242	

ϕ Average: .11874
 ϕh , Total: 28.617
h,ft Total: 241

MADISON FORMATION RESERVOIR STUDY

Hunt Oil - School Lands #1-C
C NE NW Section 23-T18N-R1E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5704-5732	28	7.5	2.1	Depths can be off 2'± due to the only well log was recorded on 2" = 100' only.
5740-5758	18	13.0	2.34	
5770-5810	40	7.0	2.8	
5900-5930	30	11.5	3.45	
5980-6015	35	7.0	2.45	
6055-6070	15	9.0	1.35	
6111-6150	39	11.5	4.485	
6200-6210	<u>10</u>	10.5	<u>1.05</u>	
	215		20.025	
<u>Mission Canyon</u>				
6220-6230	10	9.5	0.95	
6230-6250	20	8.8	1.76	
6250-6290	40	7.0	2.8	
6370-6390	20	11.5	2.3	
6390-6410	<u>20</u>	7.5	<u>1.5</u>	
	110		9.31	
<u>Lodgepole</u>				
6465-6532	67	8.0	5.36	
6560-6594	30	8.5	2.55	
6655-6685	30	7.3	2.19	
6730-6750	20	11.5	2.3	
6750-6770	20	8.4	1.68	
6804-6840	<u>36</u>	8.0	<u>2.88</u>	
	203		16.96	
				ϕ Average: .08767
				ϕh , Total: 46.295
				h ft Total: 528

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - State 41-23 Carson Area #8
C NE NE Section 23-T18N-R8E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6390-6402	12	9.5	1.14	Lodgpole in Madison group is not identifiable.
6418-6422	4	12.3	0.492	
6426-6434	8	13.2	1.056	
6444-6454	<u>10</u>	14.5	<u>1.45</u>	
	34		4.138	
<u>Mission Canyon</u>				
6550-6560	10	13.0	1.3	
6560-6573	13	8.5	1.105	
6650-6655	5	9.3	0.465	
6655-6659	4	10.4	0.416	
6659-6665	6	9.0	0.54	
6665-6671	<u>6</u>	11.6	<u>0.696</u>	
	44		4.522	
<u>Lodgpole</u>				
7026-7050	24	8.5	2.04	
7050-7072	22	9.4	2.068	
7080-7088	8	9.8	0.784	
7104-7110	6	10.4	0.624	
7144-7154	10	9.5	0.95	
7227-7236	9	10.6	0.954	
7360-7366	6	11.4	0.684	
7370-7376	6	10.8	0.648	
7380-7385	5	9.5	0.475	
7396-7404	8	9.5	0.76	
7526-7532	<u>6</u>	10.4	<u>0.624</u>	
	110		10.611	
				ϕ Average: .10250
				ϕh , Total: 19.271
				h,ft Total: 188

MADISON FORMATION RESERVOIR STUDY

Webb Resources, Inc. - Lyons-Cenex #11-11
C NE SW Section 11-T19N-R5E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6470-6476	6	7.0	0.42	
6476-6478	2	9.0	0.18	
6513-6520	7	10.0	0.7	
6574-6578	4	7.0	0.28	
6582-6584	2	10.0	0.2	
6586-6590	<u>4</u>	7.0	<u>0.28</u>	
	25		2.06	
<u>Mission Canyon</u>				
6612-6616	4	14.0	0.56	
6694-6700	6	10.0	0.6	
6704-6712	8	9.5	0.76	
6718-6724	6	10.0	0.6	
6750-6756	6	11.0	0.66	
6758-6764	6	11.0	0.66	
6770-6775	5	8.0	0.4	
6782-6786	4	10.0	0.4	
6788-6792	4	16.0	0.64	
6808-6816	8	12.0	0.96	
6838-6845	8	10.0	0.8	
6852-6858	5	8.0	0.4	
6864-6866	2	12.5	0.25	
6908-6914	<u>6</u>	8.0	<u>0.48</u>	
	78		8.17	
<u>Lodgepole</u>				
7308-7312	4	9.0	0.36	
7468-6472	<u>4</u>	7.8	<u>0.312</u>	
	8		0.672	

ϕ Average: .09821
 ϕh , Total: 10.902
h, ft Total: 111

MADISON FORMATION RESERVOIR STUDY

Webb Resources, Inc. - Cenex-State #22-6
SE NW Section 22-T19N-R7E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6540-6560	20	8.0	1.6	
6590-6600	5	4.0	0.2	
6606-6612	6	18.0	1.08	
6612-6614	2	8.0	0.16	
6614-6616	2	7.0	0.14	
6626-6632	6	7.0	0.42	
6632-6640	8	6.0	0.48	
6640-6646	6	7.0	0.42	
6720-6726	6	3.0	0.18	
6726-6730	4	3.0	0.12	
6730-6740	10	8.0	0.8	
6740-6746	<u>6</u>	2.0	<u>0.12</u>	
	81		5.72	
<u>Mission Canyon</u>				
6752-6758	6	4.0	0.24	
6762-6790	28	7.0	1.96	
6790-6800	10	6.0	0.6	
6800-6804	4	5.0	0.2	
6832-6838	6	6.0	0.36	
6881-6893	12	12.0	1.44	
6902-6906	4	12.0	0.48	
6916-6922	6	12.0	0.72	
6930-6935	5	10.0	0.5	
6935-6940	5	10.0	0.5	
6950-6955	5	16.0	0.8	
6962-6968	6	8.0	0.48	
6980-6986	6	18.0	1.08	
7000-7006	6	7.0	0.42	
7006-7010	4	6.5	0.26	
7012-7026	14	7.5	1.05	
7080-7086	6	16.0	0.96	
7086-7094	8	7.0	0.56	
7162-7170	8	15.0	1.2	
7397-7406	9	14.0	1.26	
7460-7466	6	12.0	0.72	
7466-7470	4	8.0	0.32	
7470-7474	4	10.0	0.4	
7474-7477	3	8.0	0.24	
7477-7484	<u>7</u>	12.0	<u>0.84</u>	
	182		17.59	
				ϕ Average: .08863
				ϕh , Total: 23.31
				hft, Total: 263

MADISON FORMATION RESERVOIR STUDY

Webb Resources, Inc. - State Jasper Unit #11-13
C SW SW Section 11-T19N-R7E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6166-6170	4	12.0	0.48	
6182-6186	4	10.0	0.4	
6186-6192	6	10.0	0.6	
6402-6407	5	12.0	0.6	
6407-6410	3	4.0	0.12	
6410-6415	5	20.0	1.0	
6415-6418	3	6.0	0.18	
6418-6423	5	7.0	0.35	
6460-6470	<u>10</u>	7.0	<u>0.7</u>	
	45		4.43	
<u>Mission Canyon</u>				
6480-6486	6	13.0	0.78	
6486-6492	6	11.0	0.66	
6530-6537	7	10.0	0.7	
6640-6645	5	12.0	0.6	
6645-6649	4	10.0	0.4	
6658-6664	6	9.5	0.57	
6738-6748	10	14.0	1.4	
6754-6762	8	8.0	0.64	
6768-6775	7	7.0	0.49	
6800-6804	4	8.0	0.32	
6804-6808	4	8.5	0.34	
6884-6890	<u>6</u>	16.0	<u>0.96</u>	
	73		7.86	
<u>Lodgepole</u>				
7276-7284	8	8.0	0.64	
7320-7326	6	7.0	0.42	
7412-7418	<u>6</u>	12.0	<u>0.72</u>	
	20		1.78	

ϕ Average: .10195
 ϕh , Total: 14.07
h, ft Total: 138

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Company - Johnson-State #1-16
 1980' FWL, 100' FSL, Section 16-T20N-R5E
 Harding County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6542-6552	10	10.0	1.0	
6558-6566	8	7.0	0.56	
6603-6620	17	10.0	1.7	
6622-6628	6	8.0	0.48	
6630-6633	3	12.0	0.36	
6633-6637	4	10.0	0.4	
6637-6640	3	7.2	0.216	
6660-6672	12	8.0	0.96	
6688-6692	4	15.0	0.6	
6692-6696	4	13.0	0.52	
6696-6698	2	10.0	0.2	
6713-6620	7	12.0	0.84	
	80		7.836	
<u>Mission Canyon</u>				
6724-6726	2	16.0	0.32	
6726-6729	3	10.0	0.3	
6730-6734	4	11.0	0.44	
6738-6750	12	8.0	0.96	
6752-6758	6	10.0	0.6	
6762-6768	6	8.0	0.48	
6768-6776	8	8.0	0.64	
6804-6815	11	8.0	0.88	
6815-6820	5	9.0	0.45	
6900-6906	6	10.0	0.6	
6906-6912	6	12.0	0.72	
6913-6917	5	16.0	0.8	
6917-6924	7	10.0	0.7	
6924-6928	4	16.3	0.652	
6928-6940	12	8.0	0.96	
6940-6947	7	12.8	0.896	
6947-6949	2	10.0	0.2	
6949-6952	3	13.8	0.414	
6962-6970	8	7.2	0.576	
6970-6977	7	12.3	0.861	
6977-6980	3	16.0	0.48	
6990-6997	7	11.9	0.833	
6997-7005	8	13.8	1.104	
7028-7032	4	15.0	0.6	
7032-7035	3	14.0	0.42	
7035-7039	4	13.0	0.52	
7100-7104	4	14.0	0.56	
7104-7108	4	12.0	0.48	

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon (continued)</u>				
7108-7112	4	8.0	0.32	
7112-7116	4	12.0	0.48	
7116-7122	6	14.0	0.84	
7142-7148	6	12.0	0.72	
7148-7154	6	7.0	0.42	
7160-7164	4	8.0	0.32	
7164-7168	4	10.0	0.4	
7168-7174	6	12.0	0.72	
7206-7210	4	10.0	0.4	
7210-7214	4	10.0	0.4	
7214-7220	6	10.5	0.63	
7220-7224	4	8.0	0.32	
7224-7228	4	8.0	0.32	
7228-7232	4	8.0	0.32	
7234-7242	8	8.0	0.64	
7250-7258	8	9.0	0.72	
7266-7270	4	8.0	0.32	
7282-7300	<u>18</u>	14.0	<u>2.52</u>	
	265		28.256	

Lodgepole

7300-7304	4	10.0	0.4
7306-7314	8	8.0	0.64
7314-7320	6	15.0	0.9
7320-7330	10	8.0	0.8
7356-7362	6	7.0	0.42
7362-7367	5	9.0	0.45
7400-7407	7	9.0	0.63
7512-7517	5	16.0	0.8
7520-7524	4	10.0	0.4
7532-7540	8	12.0	0.96
7552-7564	12	8.0	0.96
7564-7570	6	9.0	0.52
7570-7600	30	7.0	2.1
7600-7606	6	9.0	0.54
7632-7640	8	14.0	1.12
7640-7646	6	9.0	0.54
7646-7650	4	13.0	0.52
7650-7656	6	8.0	0.48
7656-7662	6	14.0	0.84
7662-7666	4	12.0	0.48
7666-7670	4	12.3	0.492
7670-7676	6	10.0	0.6
7676-7680	4	8.0	0.32
7680-7686	<u>6</u>	13.0	<u>0.78</u>

171

16.692

ϕ Average: .10229
 ϕh , Total: 52.784
h,ft Total: 516

MADISON FORMATION RESERVOIR STUDY

Koch Exploration Company - State #32-3
SW NE Section 3-T20N-R4E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6288-6292	4	8.0	0.32	
6304-6308	4	8.0	0.32	
6314-6318	4	7.0	0.28	
6382-6388	6	7.0	0.42	
6340-6345	5	7.0	0.35	
6440-6443	3	16.0	0.48	
6453-6457	4	16.0	0.64	
6475-6481	<u>6</u>	<u>15.0</u>	<u>0.9</u>	
	36		3.71	

Mission Canyon

6532-6536	4	7.0	0.28	
6536-6540	4	10.0	0.4	
6660-6666	6	7.4	0.444	
6668-6672	4	7.0	0.28	
6706-6710	4	14.0	0.56	
6736-6740	4	10.0	0.4	
6749-6753	4	10.0	0.4	
6756-6773	17	8.0	1.36	
6844-6850	6	10.0	0.6	
6890-6894	4	15.0	0.6	
6904-6909	5	15.5	0.775	
6911-6918	7	10.0	0.7	
6918-6923	5	12.0	0.6	
6934-6939	5	9.2	0.46	
6947-6951	4	13.0	0.52	
6961-6968	7	9.0	0.63	
7015-7020	5	10.0	0.5	
7080-7086	6	7.0	0.42	
7091-7097	6	13.0	0.78	
7120-7128	8	8.0	0.64	
7128-7132	4	15.5	0.62	
7736-7746	10	10.0	1.0	
7764-7776	12	9.0	1.08	
7884-7892	<u>8</u>	<u>9.5</u>	<u>0.76</u>	
	149		14.809	

ϕ Average: .10010
 ϕh , Total: 18.519
h, ft Total: 185

MADISON FORMATION RESERVOIR STUDY

Koch Exploration Company - State #12-3
SW NW Section 3-T20N-R4E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6822-6828	6	10.0	0.6	
6828-6834	6	8.0	0.48	
6868-6875	7	12.0	0.84	
6895-6900	<u>5</u>	13.4	<u>0.67</u>	
	24		2.59	

Mission Canyon

6920-6926	6	8.0	0.48	
6926-6929	3	14.0	0.42	
6940-6946	6	8.0	0.48	
6950-6955	5	7.5	0.375	
6958-6965	7	7.5	0.525	
7116-7122	6	16.0	0.96	
7138-7145	7	8.0	0.56	
7166-7177	11	8.0	0.88	
7182-7186	4	7.8	0.312	
7190-7196	6	8.0	0.48	
7216-7224	8	7.0	0.56	
7294-7298	4	10.0	0.4	
7299-7304	5	12.0	0.6	
7306-7310	4	10.0	0.4	
7312-7318	6	14.0	0.84	
7406-7416	10	11.0	1.1	
7416-7420	4	12.0	0.48	
7420-7426	6	7.4	0.444	
7465-7473	8	8.0	0.64	
7532-7536	4	7.3	0.292	
7538-7542	4	9.5	0.38	
7714-7724	10	7.0	0.7	
7740-7752	12	7.5	0.9	
7878-7888	<u>10</u>	8.0	<u>0.8</u>	
	156		14.008	

ϕ Average: .09221
 ϕh , Total: 16.598
h,ft Total: 180

MADISON FORMATION RESERVOIR STUDY

Pennzoil Company - Tilus #14-11A
 SW SW Section 11-T20N-R4E
 Harding County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6673-6686	13	11.0	1.43	
6706-6709	3	11.5	0.345	
6709-6713	4	7.0	0.28	
6718-6721	3	7.5	0.225	
6743-6748	5	13.5	0.675	
6754-6757	3	8.9	0.267	
6753-6758	5	16.0	0.8	
6762-6765	3	10.0	0.3	
6765-6768	<u>3</u>	10.5	<u>0.315</u>	
	42		4.637	
<u>Mission Canyon</u>				
6798-6802	4	14.0	0.56	
6802-6804	2	12.0	0.24	
6806-6814	8	7.5	0.6	
6815-6818	3	13.0	0.39	
6818-6826	8	9.0	0.72	
6826-6828	2	14.0	0.28	
6830-6837	7	7.0	0.49	
6837-6841	4	9.5	0.38	
6860-6864	4	15.5	0.62	
6944-6948	4	15.0	0.6	
6966-6974	8	9.0	0.72	
6974-6986	12	11.0	1.32	
6986-6994	8	7.0	0.56	
7002-7010	8	11.0	0.88	
7012-7018	6	10.0	0.6	
7030-7036	6	8.5	0.51	
7038-7042	4	7.0	0.28	
7044-7048	4	11.5	0.46	
7064-7068	4	9.0	0.36	
7068-7076	8	10.0	0.8	
7094-7102	8	11.5	0.92	
7102-7016	4	8.8	0.352	
7106-7112	6	11.5	0.69	
7167-7173	6	9.0	0.54	
7196-7202	6	7.0	0.42	
7204-7208	4	7.0	0.28	
7210-7214	4	9.3	0.372	
7230-7246	<u>16</u>	5.7	<u>0.912</u>	
	168		15.856	

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Lodgepole</u>				
7281-7286	5	9.5	0.475	
7354-7358	4	9.0	0.36	
7582-7590	8	10.0	0.8	
7607-7612	5	12.0	0.6	
7626-7632	6	9.0	0.54	
7634-7640	6	11.0	0.66	
7657-7660	3	8.0	0.24	
7660-7664	4	15.5	0.62	
7682-7686	4	18.5	0.74	
7722-7727	5	17.0	0.85	
7730-7733	3	17.0	0.51	
7813-7817	4	9.0	0.36	
7838-7841	<u>3</u>	9.0	<u>0.27</u>	
	60		7.025	

ϕ Average: .10191
 ϕh , Total: 27.518
h,ft Total: 270

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Company - State Cave Hills #1
SW NE Section 16-T20N-R5E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6646-6648	2	8.4	0.168	
6648-6652	4	7.0	0.28	
6700-6708	8	10.0	0.8	
6738-6742	4	18.0	0.72	
6744-6748	4	16.0	0.64	
6766-6772	6	10.0	0.6	
6775-6778	<u>3</u>	<u>7.0</u>	<u>0.21</u>	
	31		3.418	

Mission Canyon

6876-6882	6	8.2	0.492
6885-6890	5	13.5	0.675
6892-6896	4	10.0	0.4
6916-6920	4	9.0	0.36
6926-6930	4	8.3	0.332
6946-6952	6	12.0	0.72
6966-6972	6	9.5	0.57
6978-6984	6	11.8	0.708
6984-6989	5	14.0	0.7
6997-7004	7	9.8	0.686
7004-7010	6	12.0	0.72
7035-7043	8	14.0	1.12
7044-7050	6	10.0	0.6
7107-7110	3	13.0	0.39
7148-7168	20	8.0	1.6
7177-7181	4	12.0	0.48
7212-7215	3	8.0	0.24
7218-7222	4	8.2	0.328
7236-7239	3	8.0	0.24
7242-7246	4	7.5	0.3
7303-7307	4	12.0	0.48
7312-7316	4	8.0	0.32
7316-7320	4	8.0	0.32
7322-7324	2	8.0	0.16
7328-7332	4	8.0	0.32
7361-7368	7	11.0	0.77
7505-7510	5	7.0	0.35
7522-7528	6	12.0	0.72
7546-7553	7	9.0	0.63
7670-7674	4	10.0	0.4
7684-7689	<u>5</u>	<u>7.8</u>	<u>0.39</u>

166

16.521

ϕ Average: .10121
 ϕh , Total: 19.939
h,ft Total: 197

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Company - Fred E. Denzin #1
C SE SE Section 10-T20N-R7E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6344-6348	4	7.0	0.28	Geological top in the Madison group are not clear, however, top of Madison and top of Devonian are clear which are top and bottom markers for Madison.
6350-6356	6	13.0	0.78	
6420-6424	4	8.0	0.32	
6720-6723	3	12.0	0.36	
6786-6790	4	10.0	0.4	
6890-6894	4	10.0	0.4	
6937-6942	5	8.0	0.4	
6960-6965	5	10.0	0.5	
7045-7050	5	12.0	0.6	
7050-7055	5	13.7	0.685	
7112-7115	3	14.0	0.42	
7516-7522	6	8.0	0.48	
	54		5.625	

ϕ Average: .10416
 ϕh , Total: 5.625
h,ft Total: 54

MADISON FORMATION RESERVOIR STUDY

Signal Drilling and Exploration, Inc. - Olson #1
C NW NE Section 23-T20N-R7E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6434-6440	6	15.0	0.9	
6496-6502	6	7.5	0.45	
6550-6556	<u>6</u>	10.0	<u>0.6</u>	
	18		1.95	
<u>Mission Canyon</u>				
6618-6624	6	12.0	0.72	
6625-6632	7	12.0	0.84	
6716-6724	8	8.5	0.68	
6731-6738	7	15.0	1.05	
6768-6773	5	16.5	0.825	
6776-6781	5	12.0	0.6	
6781-6786	5	7.0	0.35	
6792-6800	8	9.5	0.76	
6813-6820	7	9.5	0.665	
6828-6837	9	9.5	0.855	
6850-6856	6	9.5	0.57	
6876-6889	13	12.0	1.56	
6893-6897	4	8.5	0.34	
6902-6905	3	8.5	0.255	
6944-6949	5	15.0	0.75	
7041-7045	<u>4</u>	8.5	<u>0.34</u>	
	103		11.16	
<u>Lodgepole</u>				
7106-7110	6	9.5	0.57	
7348-7353	5	12.0	0.6	
7434-7439	5	12.0	0.6	
7521-7525	<u>4</u>	14.0	<u>0.57</u>	
	20		2.33	

ϕ Average: .10950
 ϕh , Total: 15.44
h,ft Total: 141

MADISON FORMATION RESERVOIR STUDY

Champlin Petroleum Company - Clarkson Estate #1
C NW SE Section 22-T21N-R3E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>φ, %</u>	<u>φh</u>	<u>Remarks</u>
<u>Charles</u>				
6688-6692	4	10.0	0.4	DST 6842-6910
6788-6790	2	8.0	0.16	SI 1 hr, op 2 hrs, SI 2 hrs,
6794-6798	4	19.0	0.76	rec 300' WCM, 470' sl md wtr,
6804-6810	6	10.0	0.6	FP 93-375 psi, SIP 3080-2886
6866-6870	4	15.0	0.6	psi, HP 3661-3649 psi
6904-6910	6	14.0	0.84	
6912-6918	6	16.0	0.96	DST 7110-7158
6920-6930	10	10.0	1.0	SI 1 hr, op 2 hrs, SI 1½ hrs,
6930-6936	6	14.0	0.84	rec 900' WCM, 1620' Md wtr,
6942-6950	8	14.0	1.12	4394' sulf wtr, FSIP 3179 psi,
6960-6968	8	22.0	1.76	FHP 347 psi
6968-6972	4	14.0	0.56	
7016-7020	4	10.0	0.4	DST 7330-7475
	72		10.0	SI 1 hr, op 1 hr, SI 30 mins
				fl MCW in 30 mins, rec 630'
				MCW, 6845' sulf wtr,
				FP 1410-3233 psi, SIP 3295-
				3232 psi, HP 3788-3763 psi
<u>Mission Canyon</u>				
7114-7118	4	14.0	0.56	
7150-7156	6	10.5	0.63	
7158-7166	8	12.0	0.96	
7196-7200	4	7.0	0.28	
7202-7210	8	8.3	0.664	
7210-7216	6	8.9	0.534	
7226-7234	8	8.0	0.64	
7234-7240	6	10.0	0.6	
7258-7266	8	10.0	0.8	
	58		5.668	
<u>Lodgepole</u>				
7546-7550	4	7.5	0.3	
7556-7560	4	8.5	0.34	
7564-7568	4	10.0	0.4	
7596-7602	6	10.2	0.612	
7634-7640	6	10.2	0.612	
7642-7646	4	10.0	0.4	
7794-7802	8	9.0	0.72	
7808-7818	10	7.5	0.74	
7848-7880	32	14.0	4.48	φ Average: .11674
	78		8.614	φh, Total: 24.282
				h,ft Total: 208

MADISON FORMATION RESERVOIR STUDY

Ken Luff & Hanover - Brown #1-23
 1850' FNL, 560' FEL, Section 23-T21N-R5E
 Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6542-6558	16	12.0	1.92	
6562-6580	18	6.5	1.17	
6596-6626	30	5.5	1.65	
6810-6818	8	6.8	0.544	
6826-6831	<u>5</u>	9.2	<u>0.46</u>	
	77		5.744	
<u>Mission Canyon</u>				
7090-7108	18	11.5	2.07	
7228-7243	<u>15</u>	6.2	<u>0.93</u>	
	33		3.0	
<u>Lodgepole</u>				
7709-7716	7	12.5	0.875	
7716-7730	14	5.0	0.7	
7742-7754	<u>12</u>	7.5	<u>0.9</u>	
	33		2.475	

ϕ Average: .07845
 ϕh , Total: 11.219
 h, ft Total: 143

MADISON FORMATION RESERVOIR STUDY

Anadarko Production Company - Kloyda-A #1
 SW SE Section 23-T21N-R7E
 Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, ft</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
6443-6454	11	7.5	0.825	Bottom of Madison looks like ϕ is best. Madison group is not conclusive.
6476-6488	12	5.5	0.66	
6624-6634	10	9.5	0.95	
6708-6726	18	6.3	1.134	
6836-6850	14	6.5	0.91	
6966-6992	26	9.3	2.418	
7010-7014	4	7.3	0.292	
7028-7034	6	9.0	0.54	
7042-7054	12	12.3	1.476	
7062-7072	10	9.0	0.9	
7074-7078	4	7.5	0.3	
7090-7106	16	14.5	2.32	
7228-7232	4	7.0	0.28	
7574-7582	8	10.0	0.8	
7700-7706	6	9.0	0.54	
	161		14.345	

ϕ Average: .08909
 ϕ h, Total: 14.345
 h,ft Total: 161

MADISON FORMATION RESERVOIR STUDY

Hanover Planning Company, Inc. - Kalisiak #1-7
C NW, 412' FNL, 1300' FWL, Section 7-T22N-R6E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6992-7000	8	8.2	0.656	
7060-7070	<u>10</u>	8.1	<u>0.81</u>	
	18		1.466	
<u>Mission Canyon</u>				
7212-7220	8	12.2	0.976	
7234-7248	25	9.3	2.325	
7248-7258	10	16.0	1.6	
7266-7274	8	13.0	1.04	
7242-7300	38	16.2	6.156	
7300-7308	8	16.0	1.28	
7328-7330	2	11.2	0.224	
7330-7340	10	13.0	1.3	
7410-7418	8	18.0	1.44	
7420-7430	10	16.0	1.6	
7462-7476	14	11.0	1.54	
8406-8430	24	13.0	3.12	
8442-8450	8	16.2	1.296	
8456-8466	10	13.0	1.3	
8486-8494	8	7.0	0.56	
8510-8540	<u>30</u>	9.5	<u>2.85</u>	
	221		28.607	

ϕ Average: .12582
 ϕh , Total: 30.073
h, ft Total: 239

MADISON FORMATION RESERVOIR STUDY

Depco, Inc. - Federal #42-27
SE NE Section 27-T22N-R5E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
7156-7165	9	9.0	0.81	DST 7087-7155 Charles SI 1 hr, op 2 hrs, SI 2 hrs, rec 93' O&WCM, 465' MCSW, 918' SW, FP 139-696 psi, SIP 3227-3021 psi, HP 3892-3896 psi
7165-7174	9	5.0	0.45	
7194-7204	10	8.0	0.8	
7210-7220	<u>10</u>	8.9	<u>0.89</u>	
	38		2.95	
<u>Mission Canyon</u>				
7490-7510	20	7.5	1.5	
7554-7560	6	4.5	0.27	
7583-7590	7	5.3	0.371	
7600-7640	<u>40</u>	6.0	<u>2.4</u>	
	73		4.541	
<u>Lodgepole</u>				
7996-8040	44	7.2	3.168	
				ϕ Average: .06876
				ϕh , Total: 10.659
				h,ft Total: 155

MADISON FORMATION RESERVOIR STUDY

Consolidated Oil and Gas, Inc. - Federal #1-21
SW NW Section 21-T22N-R3E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6996-7008	16	9.0	1.44	DST 7020-7100 Charles SI 10 min, op 90 min, SI 30 min, rec 6071' SMCSW, 180' mud, FP 1020-2917 psi, SIP 2997-3078 psi, HP 3844-3804 psi
7070-7090	<u>20</u>	9.8	<u>1.96</u>	
	36		3.4	
<u>Mission Canyon</u>	-	-	-	
<u>Lodgepole</u>				
8106-8116	10	6.5	0.65	
8118-8128	<u>10</u>	12.0	<u>1.2</u>	
	20		1.85	

ϕ Average: .09375
 ϕh , Total: 5.25
h,ft Total: 56

MADISON FORMATION RESERVOIR STUDY

Phillips Petroleum Company - Thune "A" #1
 NE SW NE Section 31-T22N-R4E
 Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6935-6950	25	14.0	3.5	
<u>Mission Canyon</u>				
7270-7290	20	9.5	1.9	
7340-7420	<u>80</u>	8.8	<u>7.04</u>	
	100		8.94	

ϕ Average: .09952
 ϕh , Total: 12.44
 h,ft Total: 125

MADISON FORMATION RESERVOIR STUDY

Consolidated Oil and Gas, Inc. - Federal #8-22-3-2
660' FNL, 1983' FEL Section 8-T22N-R3E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6950-6962	12	8.5	1.02	DST 7170-7326 Mission Canyon SI 2½ hrs, Op 30 min, SI 1 hr, rec 4370' sulf wtr, 1302' MC sulf wtr, FP 279-536 psi, SIP 3219-3173 psi, HP 3750- 3736 psi
6962-6972	10	13.5	1.35	
6978-6986	8	9.0	0.72	
6986-6994	8	12.0	0.96	
6998-7008	10	26.2	2.62	
7046-7074	<u>28</u>	9.0	<u>2.52</u>	
	76		9.19	
<u>Mission Canyon</u>				
7176-7184	8	7.4	0.592	
7190-7196	6	10.0	0.6	
7226-7234	8	12.0	0.96	
7236-7244	8	5.1	0.408	
7246-7258	12	9.5	1.14	
7220-7240	20	7.5	1.5	
7240-7310	70	6.5	4.55	
7312-7330	18	5.5	0.99	
7448-7464	18	6.3	1.134	
7480-7500	20	9.2	1.84	
7868-7876	8	11.5	0.92	
7900-7920	20	8.2	1.64	
7932-7940	8	13.0	1.04	
7990-8010	20	13.5	2.7	
8050-8058	8	5.5	0.44	
8060-8070	<u>10</u>	6.5	<u>0.65</u>	
	262		21.104	

ϕ Average: .08962
 ϕh , Total: 30.294
h,ft Total: 338

MADISON FORMATION RESEROIR STUDY

Kenneth D. Luff and Hanover - Nygaard #1-7
SE SE Section 7-T22N-R7E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
7030-7035	5	10	0.5	Lodgepole top is not conclusive, however, there is a definite Dev. top which is base of Madison group.
7036-7044	8	8	0.64	
7176-7180	4	14	0.56	
7184-7186	2	8	0.16	
7280-7284	4	10	0.4	
	23		2.26	
<u>Mission Canyon</u>				
7394-7400	6	10	0.6	
7400-7404	4	20	0.8	
7404-7410	6	14	0.84	
7418-7420	2	8	0.16	
7422-7426	4	25	1.0	
7440-7448	8	22	1.76	
7460-7466	6	14	0.84	
7466-7474	8	8	0.64	
7474-7482	8	10	0.8	
7488-7492	4	16	0.64	
7495-7500	5	20	1.0	
7500-7510	10	7	0.7	
7524-7540	16	16	2.56	
7550-7555	5	8	0.4	
7578-7586	8	8	0.64	
7588-7594	6	10	0.6	
7602-7608	6	8	0.48	
7614-7624	10	9	0.9	
7630-7636	10	10	1.0	
7640-7653	13	8	1.04	
7658-7663	5	8	0.4	
7704-7710	6	12	0.72	
7764-7768	4	12	0.48	
8020-8026	6	10	0.6	
8084-8094	10	13	1.3	
	176		20.9	

ϕ Average: .11638
 ϕh , Total: 23.16
h,ft Total: 199

MADISON FORMATION RESERVOIR STUDY

Phillips Petroleum Company - NJOS #1
SW NW Section 34-T23N-R3E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6992-7002	10	6.4	0.64	
7140-7152	12	7.0	0.84	
7158-7168	<u>10</u>	7.5	<u>0.75</u>	
	32		2.23	
<u>Mission Canyon</u>				
7216-7222	6	12.0	0.72	
7366-7386	20	6.8	1.36	
7438-7448	10	7.3	0.73	
7606-7620	<u>14</u>	7.6	<u>1.064</u>	
	50		3.874	

ϕ Average: .07443
 ϕh , Total: 6.104
h, ft Total: 82

MADISON FORMATION RESERVOIR STUDY

Consolidated Oil and Gas, Inc. - NJOS #33-23-3-13
SW SW Section 33-T23N-R3E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6916-6920	4	7.2	0.288	DST 7064-7162 Charles SI 30 min, Op 1 hr, SI 1 hr, rec 120' WCM, 180' MCW, FP 165-613 psi, SIP 3134-3092 psi, HP 3675-3510 psi
6936-6940	4	8.3	0.332	
6942-6948	6	10.0	0.6	
7003-7016	13	8.0	1.04	
7030-7038	8	14.0	1.12	
7044-7050	6	16.0	0.96	
7050-7096	46	9.3	4.278	
7104-7112	8	10.4	0.832	
7130-7160	<u>30</u>	10.6	<u>3.18</u>	
	125		12.63	
<u>Mission Canyon</u>				
7550-7584	34	9.5	3.23	
7584-7600	<u>16</u>	12.0	<u>1.92</u>	
	50		5.15	
<u>Lodgepole</u>				
7970-8036	6	8.6	0.516	
				ϕ Average: .10108
				ϕh , Total: 18.296
				h, ft Total: 181

MADISON FORMATION RESERVOIR STUDY

Helmerich and Payne - Miller-Federal #1-31
C NE NE Section 31-T23N-R3E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon</u>				
7813-7826	13	6.0	0.78	
7836-7850	14	8.0	1.12	
7858-7866	8	8.0	0.64	
7870-7880	10	7.5	0.75	
7882-7896	14	5.0	0.7	
7906-7914	8	10.0	0.8	
7940-7952	12	7.5	0.9	
7963-7980	17	8.3	1.411	
8008-8020	12	10.3	1.236	
8020-8030	<u>10</u>	7.2	<u>0.72</u>	
	118		9.057	

Lodgepole

8242-8252	10	7.5	0.75
8280-8292	12	13.5	1.62
8360-8374	14	9.0	1.26
8464-8474	<u>10</u>	9.3	<u>0.93</u>
	46		4.56

ϕ Average: .08303
 ϕh , Total: 13.617
h, ft Total: 164

MADISON FORMATION RESERVOIR STUDY

Depco, Inc. and Hanover - Ferkingstad #33-20
 NW SE Section 20-T23N-R5E
 Harding County, South Dakota

<u>Interval</u>	<u>h, ft.</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6980-6994	14	4.5	0.63	
7070-7084	14	8.0	1.12	
7124-7148	<u>24</u>	9.5	<u>2.28</u>	
	52		4.03	
<u>Mission Canyon</u>				
7368-7382	14	20.0	2.8	
7388-7400	12	16.0	1.92	
7412-7430	18	8.5	1.53	
7442-7450	8	20.0	1.6	
7460-7498	38	8.9	3.382	
7550-7620	70	10.0	7.0	
7658-7666	<u>8</u>	7.3	<u>0.584</u>	
	168		18.816	

ϕ Average: .10384
 ϕh , Total: 22.846
 h, ft Total: 220

MADISON FORMATION RESERVOIR STUDY

Depco, Inc. and Hanover - Otterness #41-22
 Lot 1, 660' FEL, 660' FNL, Section 22-T23N-R5E
 Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6954-6968	14	6.5	0.91	
7042-7060	18	6.8	1.224	
7110-7116	6	11.0	0.66	
7160-7180	<u>20</u>	9.3	<u>1.86</u>	
	58		4.654	
<u>Lodgepole</u>				
8044-8058	14	15.0	2.1	

ϕ Average: .09380
 ϕh , Total: 6.754
 h, ft Total: 72

MADISON FORMATION RESERVOIR STUDY

K. D. Luff, Inc. - Dworshak #1-19
SE NW Section 19-T23N-R6E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
7114-7130	16	9.0	1.44	
<u>Mission Canyon</u>				
7270-7273	3	9.4	0.282	
7310-7320	10	10.0	1.0	
7340-7350	10	8.5	0.85	
7392-7412	20	8.0	1.6	
7450-7466	16	10.0	1.6	
7474-7482	8	14.0	1.12	
7528-7538	10	14.5	1.45	
8008-8023	<u>15</u>	10.0	<u>1.5</u>	
	92		9.402	

ϕ Average: .10038
 ϕh , Total: 10.842
h,ft Total: 108

MADISON FORMATION RESERVOIR STUDY

Natol Petroleum Corporation - Arithson #1
 NW SW Section 21-T23N-R4E
 Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
7012-7036	24	5.2	1.248	
7038-7046	8	5.4	0.432	
7060-7080	20	5.3	1.06	
7084-7098	14	5.2	0.728	
7110-7114	4	14.0	0.56	
7134-7148	14	10.0	1.4	
7204-7214	10	10.0	1.0	
7242-7248	6	11.0	0.66	
7256-7288	32	10.0	3.2	
7290-7304	14	15.2	2.128	
7348-7360	12	9.8	1.176	
	<u>158</u>		<u>13.592</u>	
<u>Mission Canyon</u>				
8182-8196	14	13.0	1.82	

ϕ Average: .08960
 ϕh , Total: 15.412
 h,ft Total: 172

MADISON FORMATION RESERVOIR STUDY

K. D. Luff and Hanover - Miller #1-27
SE SW NE Section 27-T23N-R6E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6860-6866	6	16.0	0.96	
6922-6930	8	8.5	0.68	
6986-7006	<u>20</u>	9.2	<u>1.84</u>	
	34		3.48	
<u>Mission Canyon</u>				
7256-7270	14	10.2	1.428	
7332-7344	12	20.0	2.4	
7358-7376	18	7.5	1.35	
7414-7434	20	12.0	2.4	
7586-7598	<u>12</u>	12.3	<u>1.476</u>	
	76		9.054	

ϕ Average: .11394
 ϕh , Total: 12.534
h,ft Total: 110

MADISON FORMATION RESERVOIR STUDY

Petroleum, Inc. - State of South Dakota #1
C NE SE Section 24-T23N-R3E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
7426-7438	12	11.0	1.32	DST 7344-7374 Top Mission Canyon
7448-7454	6	9.0	0.54	Op 10 min, SI 30 min, op 120 min,
7460-7470	10	10.0	1.0	SI 60 min, rec 279' mud, 465' MC
7480-7490	10	10.0	1.0	SW, 409' SW, FP 320-545 psi,
7510-7520	10	11.0	1.1	SIP 3288-3269 psi, HP 4095 psi.
7520-7530	10	12.0	1.2	
7606-7614	8	5.0	0.4	Well log very difficult to corre-
7620-7630	10	9.0	0.9	late & positively identify
7640-7650	10	14.2	1.42	Madison group zones.
7664-7670	6	13.5	0.81	
7680-7696	16	12.6	2.016	
8062-8074	12	11.0	1.32	
	120		13.026	
				ϕ Average: .10855
				ϕ h, Total: 13.026
				h,ft Total: 120

MADISON FORMATION RESERVOIR STUDY

Smokey Oil Company, Inc. - Gruber #24-19
SE SW Section 19-T23N-R8E
Harding County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
7196-7200	4	10.0	0.4	
7204-7207	3	8.0	0.24	
7218-7222	<u>4</u>	15.0	<u>0.6</u>	
	11		1.24	

Mission Canyon

7350-7355	5	8.0	0.4	
7371-7376	5	16.0	0.8	
7376-7379	3	19.0	0.57	
7379-7383	4	15.0	0.6	
7390-7395	5	16.0	0.8	
7406-7413	7	14.0	0.98	
7423-7430	7	14.0	0.98	
7436-7440	4	8.0	0.32	
7452-7460	8	9.0	0.72	
7966-7972	<u>6</u>	10.0	<u>0.6</u>	
	54		6.77	

ϕ Average: .12323
 ϕh , Total: 8.01
h,ft Total: 65

MADISON FORMATION RESERVOIR STUDY

Harragan Petroleum - #1 Jackson Federal
Section 28-T1S-R18E
Jackson County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Madison</u>				
4376-4380	4	18.0	0.72	Madison top is very clear from correlation, however, the group (Mission Canyon and Lodgepole) are not positive.
4380-4384	4	21.0	0.84	
4444-4450	6	12.0	0.72	
4454-4457	3	12.0	0.36	
4466-4472	6	9.0	0.54	
4478-4483	5	12.0	0.6	
4488-4496	8	18.0	1.44	
4500-4514	14	7.0	0.98	
4514-4520	6	17.0	1.02	
4520-4526	6	15.0	0.9	
4526-4532	6	18.0	1.08	
4532-4538	6	21.0	1.26	
4538-4542	4	18.0	0.72	
4542-4545	3	22.0	0.66	
4550-4556	4	18.0	0.72	
4556-4560	4	12.0	0.48	
4560-4563	3	21.0	0.63	
4568-4572	4	24.0	0.96	
4572-4576	4	18.0	0.72	
4576-4580	4	15.0	0.6	
4586-4590	4	9.0	0.36	
4596-4605	9	27.0	2.43	
4605-4610	5	15.0	0.75	
4610-4615	5	15.0	0.75	
4615-4620	5	24.0	1.2	
4624-4628	4	24.0	0.96	
4630-4634	4	18.0	0.72	
4634-4640	6	24.0	1.44	
4642-4644	2	18.0	0.36	
4644-4648	4	18.0	0.72	
4654-4658	4	30.0	1.2	
4658-4664	6	21.0	1.26	
4664-4668	4	18.0	0.72	
4668-4672	4	18.0	0.72	
4672-4675	3	25.0	0.75	
4680-4686	6	30.0	1.8	
4686-4690	4	30.0	1.2	

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
4692-4696	4	27.0	1.08	
4696-4700	4	24.0	0.96	
4700-4708	8	21.0	1.68	
4708-4713	<u>5</u>	28.0	<u>1.4</u>	
	204		38.41	

Ø Average: .18828
Øh Total: 38.41
h,ft Total: 204

MADISON FORMATION RESERVOIR STUDY

Kerr-McGee Corporation - #1 Renning
660'FSL 660'FEL Section 35-T1S-R22E
Jackson County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Madison</u>				
4009-4018	9	28.0	2.52	
4022-4028	6	28.0	1.68	
4028-4032	4	26.0	1.04	
4058-4064	6	28.0	1.68	
4066-4069	3	15.0	0.45	
4072-4078	6	20.0	1.2	
4086-4089	3	13.0	0.39	
4079-4082	3	22.0	0.66	
4082-4085	3	17.0	0.51	
4085-4088	3	19.0	0.57	
4100-4102	2	21.0	0.42	
4104-4106	2	20.0	0.4	
4108-4114	6	18.0	1.08	
4118-4122	4	20.0	0.8	
4124-4130	6	28.0	1.68	
4130-4134	4	27.0	1.08	
4138-4142	4	20.0	0.8	
4146-4150	4	17.0	0.68	
4150-4155	5	28.5	1.425	
4155-4158	3	27.0	0.81	
4158-4161	3	27.0	0.81	
4162-4164	2	22.0	0.44	
4164-4167	3	12.0	0.66	
4167-4170	3	16.0	0.48	
4170-4174	4	23.0	0.92	
4174-4178	4	16.0	0.64	
4180-4184	4	28.5	1.14	
4186-4189	3	27.0	0.81	
4190-4192	2	25.0	0.5	
4192-4195	3	16.0	0.48	
4195-4197	2	20.0	0.4	
4197-4199	2	16.0	0.32	
4199-4203	4	20.0	0.8	
4203-4206	3	24.0	0.72	

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Madison (continued)</u>				
4211-4214	3	12.0	0.36	
4214-4216	2	19.0	0.38	
4216-4218	2	19.0	0.38	
4218-4222	4	12.0	0.48	
4222-4227	5	23.0	1.15	
4227-4230	3	20.0	0.6	
4230-4234	4	25.0	1.0	
4234-4237	3	25.0	0.75	
4250-4256	6	12.0	0.72	
	160		34.815	

Ø Average: .21759
Øh Total: 34.815
h,ft Total: 160

MADISON FORMATION RESERVOIR STUDY

Cities Service Oil Company - Phipps #A-1
NW SW Section 4-T2S-R23E
Jackson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon</u>				
3936-3941	5	12.0	0.6	
3963-3968	5	12.0	0.6	
3970-3976	6	12.0	0.72	
3980-3988	8	12.0	0.96	
3988-3996	8	9.0	0.72	
4000-4005	5	9.0	0.45	
4010-4016	6	10.0	0.6	
4017-4024	7	11.5	0.805	
4036-4040	4	12.0	0.48	
4054-4066	12	9.0	1.08	
4072-4078	<u>6</u>	9.0	<u>0.54</u>	
	72		7.555	

ϕ Average: .10493
 ϕh , Total: 7.555
h,ft Total: 72

MADISON FORMATION RESERVOIR STUDY

Cities Service Oil Company - Vilhauer #A-1
 Section 17-T2S-R25E
 Jackson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
3698-3704	6	12.0	0.72	Positive identification impossible.
3726-3728	2	9.0	0.18	
3730-3734	4	12.0	0.48	
3748-3753	5	14.0	0.7	
3770-3774	4	14.0	0.56	
3780-3792	12	12.0	1.44	
3795-3798	3	12.0	0.36	
3801-3805	4	12.0	0.48	
3808-3812	4	12.0	0.48	
3814-3819	5	10.0	0.5	
3819-3823	4	12.0	0.48	
3828-3832	4	12.0	0.48	
3834-3837	3	12.0	0.36	
3840-3850	10	12.0	1.2	
3852-3858	6	16.0	0.96	
3862-3866	4	25.0	1.0	
3890-3896	6	16.0	0.96	
	86		11.34	

ϕ Average: .13186
 ϕh , Total: 11.34
 h,ft Total: 86

MADISON FORMATION RESERVOIR STUDY

Kerr McGee Corporation - Buckles Martin #1
 NW NE SW Section 3-T3S-R19E
 Jackson County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
3480-3486	6	19.0	1.14	Top of Madison and top of Devonian defined very well, however, Mission Canyon and Lodgepole appear to be missing.
3564-3572	8	16.0	1.28	
3683-3689	6	15.0	0.9	
	20		3.32	
				ϕ Average: .16600
				ϕ h, Total: 3.32
				h,ft Total: 20

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Corporation - Sandy #1
 Section 21-T2S-R27E
 Jones County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
3364-3366	2	27.0	0.54	Charles zone only.
3366-3368	2	12.0	0.24	Mission Canyon and Lodgepole
3368-3371	3	23.0	0.69	missing.
3372-3378	6	13.5	0.81	
3378-3380	<u>2</u>	24.0	<u>0.48</u>	
	15		2.76	
				ϕ Average: .18400
				ϕh , Total: 2.76
				h, ft Total: 15

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Company - Dahlke #1
NW NW Section 4-T3S-R30E
Jones County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
2734-2738	4	11.0	0.44	Charles zone only.
2803-2809	6	10.0	0.6	Mission Canyon and Lodgepole
2809-2812	3	19.0	0.57	missing.
2846-2852	6	11.0	0.66	
2854-2860	6	13.5	0.81	
2868-2872	<u>4</u>	11.0	<u>0.44</u>	
	29		3.52	
				ϕ Average: .12137
				ϕh , Total: 3.52
				h,ft Total: 29

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Corporation - Hight #1
SE SE Section 15-T3S-R29E
Jones County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
2952-2958	6	16.0	0.96	Positive identification not possible.
2958-2962	4	12.0	0.48	
2964-2970	6	9.0	0.54	
2970-2972	2	16.0	0.32	
2994-2998	4	9.0	0.36	
3002-3008	6	9.0	0.54	
3028-3033	5	9.5	0.475	
3038-3048	10	9.5	0.95	
3058-3063	5	9.5	0.475	
3090-3106	16	19.0	3.04	
3106-3110	4	22.0	0.88	
3146-3154	8	19.0	1.52	
3162-3164	<u>2</u>	19.0	<u>0.38</u>	
	78		10.92	

ϕ Average: .14000
 ϕh , Total: 10.92
h,ft Total: 78

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Corporation - Gulf-State #1
SE NW Section 2-T4S-R28E
Jones County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
2840-2852	12	16.0	1.92	Positive correlation is not available.
2862-2874	25	11.5	2.875	
2876-2880	4	7.2	0.288	
2900-2914	14	22.0	3.08	
2914-2922	8	16.0	1.28	
2922-2930	8	21.0	1.68	
2930-2934	4	19.0	0.76	
2934-2940	6	17.0	1.02	
2940-2946	6	18.0	1.08	
2946-2954	8	22.0	1.76	
3020-3026	6	16.0	0.96	
3035-3040	5	7.0	0.35	
	106		17.053	

ϕ Average: .16087
 ϕh , Total: 17.053
h,ft Total: 106

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - Wilber Olson et al #1
C NW SE Section 8-T2N-R26E
Jones County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
3046-3058	12	10.2	1.224	Top and bottom of Madison group well marked, however, Mission Canyon and Lodgepole no markers.
3076-3080	4	10.5	0.42	
3080-3086	6	9.5	0.57	
3086-3096	10	10.5	1.05	
3110-3120	10	9.5	0.9	
3190-3200	10	11.0	1.1	
3202-3212	10	9.5	0.95	
3212-3222	10	10.0	1.0	
3225-3234	9	8.5	0.765	
3254-3264	10	13.0	1.3	
3270-3276	6	11.0	0.66	
3290-3300	<u>10</u>	<u>14.5</u>	<u>1.45</u>	
	107		11.389	

ϕ Average: .10643
 ϕh , Total: 11.389
h, ft Total: 107

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - A. E. Herman #2
NW NE Section 3-T1N-R29E
Jones County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
2876-2884	12	8.5	1.02	DST 2868-2969 Charles
2932-2939	7	16.5	1.155	Op 2 hrs, ff wtr, 1 hr rate
2942-2945	3	13.0	0.39	75 BPD, IFP 410 psi, FFP 1290
2947-2952	5	17.0	0.85	psi, SI 45 min, SIP 1380 psi,
2962-2964	2	10.5	0.21	IHP 1600 psi, FHP 1580 psi
2967-2970	3	10.5	0.315	
2976-2980	4	9.5	0.38	Short Madison group top and
2986-2992	6	10.5	0.63	bottom good markers, however,
2992-2996	4	8.5	0.34	Mission Canyon and Lodgepole
2996-3000	<u>4</u>	<u>10.0</u>	<u>0.4</u>	not identified.
	50		5.69	
				ϕ Average: .11380
				ϕh , Total: 5.69
				h,ft Total: 50

MADISON FORMATION RESERVOIR STUDY

Weller-Bush Corporation - Weisman #1
 NW SW SE Section 30-T7N-R4E
 Lawrence County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
2042-2048	6	10.0	0.6	Lodgepole top is not clearly defined.
2050-2057	7	9.5	0.665	
2070-2085	15	11.5	1.725	Mission Canyon ϕ all below 7%.
2134-2146	12	14.5	1.74	
2152-2160	8	14.0	1.12	
	48		5.85	
				ϕ Average: .12187
				ϕh , Total: 5.85
				h,ft Total: 48

MADISON FORMATION RESERVOIR STUDY

Amerada Petroleum Corporation - Meade Corwin #1
NE NE Section 18-T6N-R13E
Meade County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
4592-4600	8	16.0	1.28	Top Madison can be identified - rest of the group very uncertain.
4640-4650	10	12.0	1.2	
4805-4825	20	13.0	2.6	
4876-4898	22	11.5	2.53	
5070-5084	14	9.5	1.33	Depths can be off 3'± due to 2'=100' log print was all that was available.
5090-5100	10	20.5	2.05	
5130-4140	<u>10</u>	11.5	<u>1.15</u>	
	94		12.14	

ϕ Average: .12914
 ϕh , Total: 12.14
h,ft Total: 94

MADISON FORMATION RESERVOIR STUDY

Phillips Petroleum Company - Ferguson #1-A
NE SE Section 34-T7N-R13E
Meade County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4828-4830	2	9.5	0.19	
4834-4838	4	8.4	0.336	
4844-4848	4	7.4	0.296	
4888-4892	4	9.5	0.38	
4902-4906	4	11.5	0.46	
4934-4937	3	9.5	0.285	
4937-4930	3	11.5	0.345	
4950-4954	4	10.5	0.42	
4954-4958	4	12.0	0.48	
4984-4990	6	15.0	0.9	
4991-4996	<u>5</u>	15.0	<u>0.75</u>	
	43		4.842	
<u>Mission Canyon</u>				
5004-5008	4	8.5	0.34	
5026-5032	6	9.5	0.57	
5043-5048	5	7.4	0.37	
5056-5064	8	8.5	0.68	
5076-5078	2	9.5	0.19	
5078-5086	8	11.0	0.88	
5086-5090	4	10.5	0.42	
5090-5094	4	9.5	0.38	
5110-5116	6	11.0	0.66	
5120-5124	4	8.6	0.344	
5134-5138	4	9.8	0.392	
5152-5158	6	14.0	0.84	
5186-5192	6	7.5	0.45	
5212-5220	8	7.5	0.6	
5247-5262	5	8.5	0.425	
5273-5280	7	9.5	0.665	
5250-5280	<u>30</u>	9.5	<u>2.85</u>	
	117		11.056	

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Lodgepole</u>				
5314-5318	4	9.5	0.38	
5318-5325	7	15.0	1.05	
5333-5338	5	14.0	0.7	
5338-5340	2	7.0	0.14	
5356-5373	17	7.4	1.258	
5373-5378	5	9.0	0.45	
5370-5385	15	8.4	1.26	
5400-5406	6	7.5	0.45	
5412-5418	6	8.5	0.51	
5422-5428	6	9.5	0.57	
5453-5463	10	8.5	0.85	
5484-5490	<u>6</u>	8.6	<u>0.516</u>	
	89		8.134	
				ϕ Average: .09651
				ϕh , Total: 24.032
				h,ft Total: 249

MADISON FORMATION RESERVOIR STUDY

Herndon Drilling - #1 C. D. Price
C SE SE Section 15-T9N-R13E
Meade County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
5082-5100	18	16.0	2.88	
5100-5114	14	12.0	1.68	
5138-5152	14	11.5	1.61	
5208-5220	12	11.0	1.32	
5250-5270	20	12.0	2.4	
5285-5300	15	11.8	1.77	
5330-5340	10	12.5	1.25	
5350-5365	15	12.0	1.8	
5370-5380	<u>10</u>	14.0	<u>1.4</u>	
	128		16.11	

Lodgepole

5392-5400	8	9.0	0.72	
5432-5442	10	8.8	0.88	
5454-5464	10	11.5	1.15	
5492-5503	11	12.7	1.397	
5514-5524	10	10.2	1.02	
5548-5560	12	14.5	1.74	
5560-5570	10	10.0	1.0	
5570-5580	10	9.5	0.95	
5580-5590	10	9.0	0.9	
5602-5610	8	10.2	0.816	
5620-5630	10	9.8	0.98	
5644-5653	9	10.2	0.918	
5660-5666	6	10.8	0.648	
5680-5690	10	9.0	0.9	
5702-5712	10	10.5	1.05	
5712-5724	12	10.0	1.2	
5724-5730	6	11.0	0.66	
5734-5740	6	11.2	0.672	
5740-5750	10	15.0	1.5	
5750-5760	<u>10</u>	16.5	<u>1.65</u>	
	188		20.751	

Ø Average: .11664
Øh Total: 36.861
h, ft Total: 316

MADISON FORMATION RESERVOIR STUDY

Herndon Drilling Company - A. G. Oakland #1
C NE SE Section 20-T10N-R17E
Meade County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4075-4090	15	16.5	2.475	
4590-4600	<u>10</u>	17.5	<u>1.75</u>	
	25		4.225	
<u>Mission Canyon</u>				
4890-4908	18	8.5	1.53	
<u>Lodgepole</u>				
5045-5058	13	10.5	1.365	
5135-5145	<u>10</u>	8.7	<u>.87</u>	
	23		2.235	

ϕ Average: .12106
 ϕh , Total: 7.99
h, ft Total: 66

MADISON FORMATION RESERVOIR STUDY

True, Fulton & Reserve Drilling - Govt-Knox #1
C NW NW Section 29-T5N-R17E
Pennington County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4295-4305	10	12.5	1.25	Lodgepole does not have positive top.
4332-4340	8	14.5	1.16	
4345-4352	7	15.8	1.106	
4378-4385	7	16.8	1.176	
4385-4393	8	15.0	1.2	
4393-4402	9	17.0	1.53	
4444-4454	<u>10</u>	14.5	<u>1.45</u>	
	59		8.872	
<u>Mission Canyon</u>				
4482-4496	14	18.8	2.632	
4633-4648	15	7.0	1.05	
4656-4666	10	17.2	1.72	
4676-4678	2	10.2	0.204	
4682-4688	6	9.5	0.57	
4688-4700	12	9.0	1.08	
4732-4740	8	10.0	0.8	
4746-4756	10	12.8	1.28	
4756-4766	10	11.0	1.1	
4766-4797	<u>31</u>	13.8	<u>4.278</u>	
	118		14.714	
				ϕ Average: .13325
				ϕh , Total: 23.586
				h,ft Total: 177

MADISON FORMATION RESERVOIR STUDY

Mule Creek Oil Company, Inc. - State #41-33
C NE NE Section 33-T13N-R10E
Perkins County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5370-5376	6	16.0	0.96	
5380-5383	3	19.0	0.57	
5388-5394	6	8.0	0.48	
5400-5404	4	14.5	0.58	
5425-5430	5	12.0	0.6	
5430-5436	6	10.0	0.6	
5470-5480	10	16.0	1.6	
5482-5488	6	12.0	0.72	
5516-5522	6	16.0	0.72	
5528-5535	7	27.0	1.89	
5543-5550	7	9.0	0.63	
5568-5572	<u>4</u>	9.0	<u>0.36</u>	
	70		9.71	
<u>Mission Canyon</u>				
5674-5680	6	9.0	0.54	
5710-5720	10	10.0	1.0	
5730-5740	10	9.5	0.95	
5740-5750	10	12.0	1.2	
5766-5774	8	12.0	0.96	
5798-5810	12	10.0	1.2	
5818-5822	4	12.0	0.48	
5824-5828	4	12.0	0.48	
5886-5890	<u>4</u>	12.0	<u>0.48</u>	
	68		7.29	
<u>Lodgepole</u>				
6280-6290	10	12.0	1.2	

ϕ Average: .12297
 ϕh , Total: 18.2
h,ft Total: 148

MADISON FORMATION RESERVOIR STUDY

J. P. Evans - J. R. Querbes Trust Howard Capp #1
C NW NW Section 9-T13N-R16E
Perkins County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5020-5040	20	18.0	3.6	
5110-5128	18	10.0	1.8	
5128-5140	12	10.5	1.26	
5140-5156	<u>16</u>	9.0	<u>1.44</u>	
	66		8.1	
<u>Mission Canyon</u>				
5310-5330	20	9.5	1.9	
5450-5456	<u>6</u>	10.5	<u>0.63</u>	
	26		2.53	
<u>Lodgepole</u>				
5780-5804	24	9.8	2.352	
5882-5886	4	15.0	0.6	
5886-5890	4	15.5	0.62	
5910-5920	<u>10</u>	10.5	<u>1.05</u>	
	42		4.622	

ϕ Average: .11382
 ϕh , Total: 15.252
h,ft Total: 134

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - M. C. Bastian #22-7
C SE NW Section 7-T15N-R16E
Perkins County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5104-5108	4	11.5	0.46	
5113-5118	5	11.0	0.55	
5130-5135	5	14.0	0.7	
5135-5140	5	13.0	0.65	
5147-5152	5	7.0	0.35	
5152-5160	8	9.5	0.76	
5162-5168	6	14.0	0.84	
5170-5176	6	12.4	0.744	
5178-5183	5	14.0	0.7	
5183-5190	7	16.0	1.12	
5200-5204	4	10.5	0.42	
5210-5216	<u>6</u>	10.5	<u>0.63</u>	
	66		7.924	
<u>Mission Canyon</u>				
5258-5266	8	7.0	0.56	
5290-5296	6	10.5	0.63	
5296-5304	8	10.0	0.8	
5315-5323	8	8.5	0.68	
5338-5344	6	8.5	0.51	
5350-5360	10	7.8	0.78	
5364-5370	6	7.8	0.468	
5372-5380	8	8.5	0.68	
5380-5388	8	7.0	0.56	
5388-5394	6	7.5	0.45	
5394-5408	14	7.8	1.092	
5413-5420	<u>7</u>	7.8	<u>0.546</u>	
	95		7.756	
<u>Lodgepole</u>				
5484-5490	6	7.6	0.456	
5602-5608	6	8.5	0.51	
5616-5620	4	7.8	0.312	
5654-5660	6	8.6	0.516	
5687-5695	8	7.5	0.6	
5745-5752	7	7.0	0.49	

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
Lodgepole (continued)				
5770-5778	8	7.5	0.6	
5830-5838	8	8.5	0.68	
5838-5847	9	7.8	0.702	
5847-5850	3	8.5	0.255	
5854-5860	6	8.5	0.51	
5868-5874	6	7.8	0.468	
5880-5900	<u>20</u>	8.8	<u>1.76</u>	
	97		7.859	

ϕ Average: .09123
 ϕh , Total: 23.539
h, ft Total: 258

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - H. D. Veal #1
C SE SE Section 7-T17N-R15E
Perkins County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5738-5444	6	7.0	0.42	
5747-5754	7	10.5	0.735	
5770-5780	10	7.8	0.78	
5784-5790	6	12.5	0.75	
5812-5816	4	8.5	0.34	
5828-5834	6	8.6	0.516	
5834-5840	6	7.0	0.42	
5840-5850	10	8.8	0.88	
5856-5868	12	7.0	0.84	
5868-5886	18	7.0	1.26	
5886-5896	10	7.5	0.75	
5906-5914	8	10.5	0.84	
5940-5950	10	13.5	1.35	
5955-5965	10	15.0	1.5	
5980-5990	10	7.0	0.7	
	133		12.081	
<u>Mission Canyon</u>				
6098-6104	6	10.5	0.63	
6106-6110	4	10.5	0.42	
6137-6146	9	7.0	0.63	
6190-6198	8	7.8	0.624	
	27		2.304	
<u>Lodgepole</u>				
6346-6354	8	7.0	0.56	
6364-6372	8	12.5	1.0	
6415-6422	7	10.5	0.735	
6438-6444	6	7.7	0.462	
	29		2.757	

ϕ Average: .09069
 ϕh , Total: 17.142
h,ft Total: 189

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - J. T. Homme #1
C NW SE Section 13-T20N-R12E
Perkins County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6270-6277	7	12.5	0.875	Unable to identify top of
6280-6288	8	10.5	0.84	Lodgepole even from correlation
6304-6310	6	15.0	0.9	
6310-6314	4	10.5	0.42	DST 6140-6230 Charles
6314-6320	6	10.5	0.63	Sp. Gr 60/60°F 1.0052
6320-6324	4	17.5	0.7	Alkalinity 260
6326-6332	6	15.0	0.9	Hardness 2620
6363-6368	5	28.0	1.4	pH 6.95
6370-6375	5	8.5	0.425	Ca 924
6382-6386	4	7.0	0.28	Mg 76
	55		7.37	Calc-Na 1090
				HCO ₃ 320
				SO ₄ 3400
				Cl 850
				Total 6660
				Res. 1.26 ohm @77°F
<u>Mission Canyon</u>				
6405-6410	5	28.0	1.4	
6415-6417	2	10.5	0.21	
6430-6440	10	10.5	1.05	DST 6460-6483 Mission Canyon
6443-6448	5	10.0	0.5	Sp. Gr 60/60°F 1.0051
6455-6460	5	18.0	0.9	Alkalinity 240
6467-6473	6	12.5	0.75	Hardness 2510
6486-6492	6	10.5	0.63	pH 7.45
6495-6500	5	10.5	0.525	Ca 890
6524-6532	8	12.5	1.0	Mg 72
6542-6548	6	12.0	0.72	CaCl-Na 1120
6556-6566	10	12.5	1.25	HCO ₃ 290
6574-6580	6	9.5	0.57	SO ₄ 3200
6582-6586	4	7.5	0.3	Cl 970
6598-6604	6	8.5	0.51	Total 6542
6606-6613	7	10.5	0.735	Res. 1.27 ohm @77°F
6616-6622	6	15.0	0.9	
6656-6660	4	7.0	0.28	
6684-6688	4	10.5	0.42	
6824-6830	6	8.5	0.51	
6838-6844	6	12.5	0.75	
6846-6850	4	8.5	0.34	
6850-6856	6	8.5	0.51	
7078-7086	8	9.5	0.76	
	135		15.52	ϕ Average: .12047
				ϕh , Total: 22.89
				h, ft Total: 190

MADISON FORMATION RESERVOIR STUDY

Youngblood and Youngblood - Tron-Anderson #1
NE NE Section 26-T21N-R14E
Perkins County, South Dakota

Page 1

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5020-5029	9	7.5	0.675	
5048-5053	5	11.5	0.575	
5058-5062	4	7.0	0.28	
5078-5082	4	17.5	0.7	
5085-5088	3	15.5	0.465	
5092-5095	3	12.0	0.36	
6102-6104	2	9.0	0.18	
6113-6118	5	11.0	0.55	
6118-6120	2	11.5	0.23	
6136-6138	2	13.0	0.26	
6138-6140	2	15.0	0.3	
6140-6143	3	16.0	0.48	
6145-6148	3	9.0	0.27	
6148-6151	3	7.8	0.234	
6153-6155	2	8.8	0.176	
6233-6237	4	9.5	0.38	
	56		6.115	

Mission Canyon

6255-6258	3	7.0	0.21	
6260-6263	3	7.7	0.231	
6264-6267	3	8.8	0.264	
6267-6269	2	10.0	0.2	
6269-6272	3	11.5	0.345	
6276-6279	3	9.0	0.27	
6279-6282	3	7.0	0.21	
6282-6285	3	7.2	0.216	
6285-6287	2	7.0	0.14	
6292-6295	3	8.4	0.252	
6321-6325	4	7.4	0.296	
6325-6327	2	7.5	0.15	
6327-6330	3	7.0	0.21	
6340-6344	4	8.5	0.34	
6362-6365	3	7.5	0.225	
6384-6386	2	10.0	0.2	
6425-6428	3	7.0	0.21	
6495-6498	3	7.5	0.225	
	52		4.194	

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Lodgepole</u>				
6529-6533	4	7.8	0.312	
6773-6776	3	7.5	0.225	
6896-6900	4	8.4	0.336	
6913-6917	4	8.5	0.34	
6917-6920	3	9.0	0.27	
6920-6925	5	8.4	0.42	
6923-6927	4	8.8	0.352	
6961-6965	4	7.2	0.288	
	31		2.543	

ϕ Average: .09246
 ϕh , Total: 12.852
h,ft Total: 139

MADISON FORMATION RESERVOIR STUDY

W. H. Hunt and Z. Brooks - Federal #1
C NW SE Section 8-T22N-R11E
Perkins County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
6558-6560	2	9.0	0.18	
6572-6576	4	8.5	0.34	
6722-6725	3	13.5	0.405	
6742-6750	8	14.2	1.136	
6778-6784	<u>6</u>	13.5	<u>0.81</u>	
	23		2.871	
<u>Mission Canyon</u>				
6884-6892	8	14.5	1.16	
6914-6920	6	13.5	0.81	
6945-6958	13	14.6	1.898	
6973-6984	11	13.8	1.518	
6992-6995	3	9.5	0.285	
6998-7002	4	13.5	0.54	
7020-7030	10	13.8	1.38	
7030-7038	8	14.0	1.12	
7090-7100	10	13.0	1.3	
7102-7108	6	13.0	0.78	
7134-7145	11	13.2	1.452	
7220-7226	<u>6</u>	10.0	<u>0.6</u>	
	96		12.843	
<u>Lodgepole</u>				
7340-7343	3	15.5	0.465	
7358-7360	2	8.5	0.17	
7361-7365	4	9.5	0.38	
7590-7594	4	17.5	0.7	
7662-7666	<u>4</u>	17.0	<u>0.68</u>	
	17		2.395	

ϕ Average: .13315
 ϕh , Total: 18.109
h, ft Total: 136

MADISON FORMATION RESERVOIR STUDY

The Carter Oil Company - South Dakota Exploration #1
 NE Section 34-T118N-R78W
 Potter County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
2460-2480	20	9.3	1.86	Entire group identification not positive.
2495-2520	25	8.2	2.05	
2560-2610	50	8.8	4.4	
2765-2860	<u>95</u>	10.3	<u>9.785</u>	
	190		18.095	

ϕ Average: .09523
 ϕh , Total: 18.095
 h, ft Total: 190

MADISON FORMATION RESERVOIR STUDY

The Carter Oil Company - S. Dakota Exploration #1
NE Section 34-T118N-R78W
Potter County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
5064-5078	24	8	1.92	
5112-5128	16	5	0.8	
5128-5138	10	5	0.5	
5144-5168	24	5	1.2	
5192-5206	14	11	1.54	
5214-5232	18	15	2.7	
5248-5304	<u>56</u>	18	<u>10.08</u>	
	162		18.74	
<u>Mission Canyon</u>				
5490-5504	14	9	1.26	
5558-5704	<u>146</u>	9	<u>13.14</u>	
	160		14.4	
<u>Lodgepole</u>				
5710-5792	82	9	7.38	
5846-5918	72	9	6.48	
5918-5924	6	11	0.66	
5950-6000	<u>50</u>	11	<u>5.55</u>	
	210		20.02	

ϕ Average: .09992
 ϕh , Total: 53.16
h, ft Total: 532

MADISON FORMATION RESERVOIR STUDY

Dakota-Texas Oil - Williams Thompson #1
C NW SE Section 27-T119W-R78W
Potter County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon</u>				
2680-2700	2	10.8	0.216	
2920-2970	50	9.3	4.65	
3020-3050	<u>30</u>	14.0	<u>4.2</u>	
	82		9.066	

ϕ Average: .11056
 ϕh , Total: 9.066
h,ft Total: 82

MADISON FORMATION RESERVOIR STUDY

Independent Drilling Company - Hinckley #1
C NW NW Section 7-T120N-R75W
Potter County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
2535-2575	40	10.2	4.08	DST #1 2630-60
2625-2655	<u>30</u>	12.3	<u>3.69</u>	Mission Canyon Op 70 mins, SI 15 mins. flFW in 1 hr, FP 0-150 psi, SIP 1280 psi, HP 1400 psi
	70		7.77	DST #2 2758-2860 Op 1 hr, SI 15 min, fl FW in 22 min, FP 20-55 psi, SIP 1332 psi, HP 1630 psi
<u>Lodgepole</u>				
2722-2760	38	15.6	5.928	DST #3 2722-2760 Used straddle packer. 100' tail pipe, rec 1250' H ₂ O cut drlg mud, FP 30-545 psi, SIP 1275 psi, HP 1575 psi.
				ϕ Average: .12683
				ϕh , Total: 13.698
				h,ft Total: 108

MADISON FORMATION RESERVOIR STUDY

Shell Oil Company - McCrone #1
C NW NW Section 23-T3N-R25E
Stanley County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
3256-3280	24	8.3	1.992	Madison group unable to identify.
3298-3316	18	7.1	1.278	
3416-3428	12	9.0	1.08	
3460-3478	18	10.0	1.8	
3490-3512	<u>22</u>	10.9	<u>2.398</u>	
	94		8.548	

ϕ Average: .09093
 ϕh , Total: 8.548
h,ft Total: 94

MADISON FORMATION RESERVOIR STUDY

Tenneco Oil Company - Rankin Trust #1
NW NW Section 10-T4N-R28E
Stanley County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
2188-2196	8	13	1.04	DST Lodgepole 2695-2733 412' MCW. BHT 83°
2200-2202	2	9	0.18	
2204-2210	6	10	0.6	
2212-2220	8	12	0.96	
2236-2242	6	12	0.72	
2244-2250	6	14	0.84	
2256-2268	12	17	2.04	
2272-2276	4	18	0.72	
2278-2284	6	17	1.02	
2290-2292	2	13	0.26	
2294-2298	4	14	0.56	
2304-2309	5	20	1.0	
2322-2328	6	17	1.02	
2332-2346	14	20	2.8	
2351-2357	<u>6</u>	17	<u>1.02</u>	
	95		14.78	
<u>Mission Canyon</u>				
2419-2422	3	16	0.48	
2424-2428	4	14	0.56	
2500-2508	8	8	0.64	
2510-2514	4	6	0.24	
2518-2525	7	21	1.47	
2528-2534	6	8	0.48	
2540-2550	10	13	1.3	
2554-2560	6	6	0.36	
2566-2572	<u>6</u>	16	<u>0.96</u>	
	54		6.49	
<u>Lodgepole</u>				
2692-2700	8	26	2.08	
2702-2708	6	19	1.14	
2708-2712	4	23	0.92	
2713-2733	<u>10</u>	-	<u>-</u>	
	28		4.14	
				ϕ Average: .14355
				ϕh , Total: 25.41
				h,ft Total: 177

MADISON FORMATION RESERVOIR STUDY

Cities Service Oil Company - Wagner #1
 NW NW Section 13-T5N-R29E
 Stanley County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
2646-2656	10	18	1.8	Group identification not positive
2664-2676	12	5	0.6	
2684-2696	12	5	0.6	
2706-2714	8	36	2.88	
2740-2760	20	11	2.2	
2760-2772	12	15	1.8	
2772-2792	20	8	1.6	
2848-2858	<u>10</u>	30	<u>3.0</u>	
	104		14.48	

ϕ Average: .13923
 ϕh , Total: 14.48
 h,ft Total: 104

MADISON FORMATION RESERVOIR STUDY

Phillips Petroleum Company - Stanley #1
C NW NW SE Section 36-T5N-R27E
Stanley County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Mission Canyon</u>				
2614-2622	8	12.1	0.968	DST 2565-2767 fl FW
2628-2674	<u>62</u>	19.5	<u>12.09</u>	
	70		13.058	
				ϕ Average: .18654
				ϕh , Total: 13.058
				h,ft Total: 70

MADISON FORMATION RESERVOIR STUDY

Paul G. Benedum - Wily-Shaffner #1
C NW NW Section 26-T6N-R27E
Stanley County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>φ, %</u>	<u>φh</u>	<u>Remarks</u>
<u>Madison</u>				
3160-3170	10	12.0	1.2	DST 3178-3208 Mission Canyon
3300-3340	40	15.8	6.32	Op 30 mins, rec 2850' clear wtr,
3440-3490	50	10.1	5.05	no gas to sfc - flowing, ISI
				285 psi, FSI 1345 psi, SI 15 mins,
	100		12.57	1490 psi, hydrostatic 1600 psi

	<u>PPM</u>	<u>MEQ</u>	<u>MEQ%</u>
Sodium	57	2.47	3.82
Calcium	418	20.86	32.22
Magnesium	110	9.04	13.96
Sulfate	1236	25.71	39.71
Chloride	108	3.05	4.71
Carbonate	-	-	-
Chloride as NaCl	178 PPM		
pH	7.4		
Resistivity @68°F	4.60 ohms		
DST packer was set in best φ			

Madison group correlation not
identifiable.

MADISON FORMATION RESERVOIR STUDY

Cities Service-Barrick Tripple U Ranch #1-A
 Section 18-T7N-R28E
 Stanley County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Lodgepole</u>				
3350-3370	20	6.0	1.2	DST 3350-3461 Lodgepole
3370-3384	14	16.0	2.24	Bottom 20' of DST in Dev.
3384-3388	4	30.0	1.2	Wtr to sfc in 20 min, fw.
3388-3394	<u>6</u>	12.0	<u>0.72</u>	Est flow 42 BPH, HP 1806-1819,
	44		5.36	SIP 1631-1658, FP 1308-1595
ϕ Average: .12181 ϕh , Total: 5.36 h,ft Total: 44				

MADISON FORMATION RESERVOIR STUDY

Shamrock Oil and Gas - Barrich #3
C SW SW Section 23-T7N-R26E
Stanley County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
3080-3130	50	9.0	4.5	Madison group unable to identify
3230-3245	15	8.8	1.32	
3420-3470	50	9.6	4.8	
3500-3540	<u>40</u>	9.8	<u>3.92</u>	
	155		14.54	
				ϕ Average: .09380
				ϕh , Total: 14.54
				h,ft Total: 155

MADISON FORMATION RESERVOIR STUDY

Gulf Oil Corporation - Stanley-Federal #1
SE NW Section 22-T8N-R26E
Stanley County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
2814-2844	30	10.3	3.09	Entire group not identifiable.
2860-2868	8	9.6	0.768	
2932-2956	24	11.0	2.64	
3236-3292	<u>56</u>	13.4	<u>7.504</u>	
	118		14.002	
				ϕ Average: .11866
				ϕh , Total: 14.002
				h,ft Total: 118

MADISON FORMATION RESERVOIR STUDY

Max Pray - Kranzler #1
NW NW Section 14-T121N-R77W
Walworth County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Madison</u>				
2515-2558	43	13.6	5.848	Positive correlation not clear.
2560-2590	30	8.2	2.46	
2590-2620	30	7.6	2.28	
2984-3024	<u>40</u>	7.9	<u>3.16</u>	
	143		13.748	

ϕ Average: .09613
 ϕh , Total: 13.748
h,ft Total: 143

MADISON FORMATION RESERVOIR STUDY

Peppers Refining Company - S. Dakota State #1
C NE SE Section 36-T123N-R76W
Walworth County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>	-	-	-	Oil staining in Madison @2814 (samples)
<u>Mission Canyon</u>				
2688-2702	14	15.4	2.156	
2712-2714	52	13.4	6.968	
2790-2802	12	15.6	1.872	
2803-2809	6	13.2	0.792	
2812-2818	<u>6</u>	15.6	<u>0.936</u>	
	90		12.724	
<u>Lodgepole</u>				
2921-2928	7	17.4	1.218	
2934-2952	18	15.6	2.808	
2954-2963	9	15.3	1.377	
2964-2969	5	13.6	0.68	
2971-2973	2	17.2	0.344	
2974-3006	32	16.2	5.184	
3008-3055	47	15.5	7.285	
3081-3100	19	16.5	3.135	
3115-3140	25	15.7	3.925	
3154-3184	<u>30</u>	15.2	<u>4.56</u>	
	194		30.516	

ϕ Average: .15225
 ϕh , Total: 43.24
h, ft, Total: 284

MADISON FORMATION RESERVOIR STUDY

Investors Drilling Ventures, Inc. - Eulberg #1
NW SE Section 14-T13N-R21E
Ziebach County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4104-4112	8	15.5	1.24	Lodgepole top is not conclusive.
4112-4122	10	19.5	1.95	
4122-4128	6	15.5	0.93	
4160-4164	4	17.0	0.68	
4164-4168	4	19.0	0.76	
4170-4174	4	16.0	0.64	
4174-4186	12	19.0	2.28	
4220-4225	<u>5</u>	19.0	<u>0.95</u>	
	53		9.43	

Mission Canyon

4254-4259	5	16.0	0.8
4264-4270	6	16.0	0.96
4270-4274	4	9.0	0.36
4274-4278	4	12.0	0.48
4280-4286	6	12.0	0.72
5320-4325	5	12.0	0.6
4328-4340	12	12.0	1.44
4340-4350	10	9.0	0.9
4350-4360	10	12.0	1.2
4360-4373	13	9.0	1.17
4373-4378	5	12.0	0.6
4378-4383	5	7.0	0.35
4460-4464	4	12.0	0.48
4474-4498	24	9.0	2.16
4510-4517	7	9.0	0.63
4528-4534	6	65.0	3.9
4574-4590	16	9.0	1.44
4600-4605	5	12.0	0.6
4740-4752	12	23.0	2.16
4754-4770	<u>16</u>	26.5	<u>4.24</u>
	175		25.19

ϕ Average: .15184
 ϕh , Total: 34.62
h, ft Total: 228

MADISON FORMATION RESERVOIR STUDY

Norris Oil Company - Cheyenne #1
 Section 25-T15N-R21E
 Ziebach County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>ϕ, %</u>	<u>ϕh</u>	<u>Remarks</u>
<u>Charles</u>				
4212-4217	5	15.5	0.775	
4217-4222	5	19.5	0.975	
4226-4230	4	11.0	0.44	
4230-4244	14	21.5	3.01	
4250-4255	5	19.0	0.95	
4280-4290	<u>10</u>	20.0	<u>2.0</u>	
	43		8.15	
<u>Mission Canyon</u>				
4308-4312	4	11.0	0.44	
4330-4335	5	11.0	0.55	
4335-4340	5	11.0	0.55	
4340-4350	10	10.0	1.0	
4350-4360	10	13.0	1.3	
4360-4370	10	11.0	1.1	
4370-4374	6	15.5	0.93	
4388-4396	8	11.5	0.92	
4400-4410	10	9.0	0.9	
4410-4420	10	11.0	1.1	
4420-4426	6	11.0	0.66	
4428-4433	5	9.0	0.45	
4467-4472	5	15.5	0.775	
4472-4475	3	10.0	0.3	
4475-4478	3	15.5	0.465	
4539-4545	6	9.0	0.54	
4550-4560	10	9.0	0.9	
4600-4616	16	9.0	1.44	
4635-4644	<u>9</u>	9.0	<u>0.81</u>	
	141		15.13	
<u>Lodgepole</u>				
4674-4678	4	11.0	0.44	
4760-4782	22	9.0	1.98	
4782-4816	34	9.0	3.06	
4824-4830	6	9.0	0.54	
4846-4852	6	9.0	0.54	
4854-4858	4	9.0	0.36	
4862-4870	<u>8</u>	11.0	<u>0.88</u>	
	84		7.8	

ϕ Average: .11597
 ϕh , Total: 31.08
 h, ft Total: 268

MADISON FORMATION RESERVOIR STUDY

Amerada Petroleum Corporation - Roy Trent Tr. 1 #1
SW NE Section 26-T16N-R18E
Ziebach County, South Dakota

<u>Interval</u>	<u>h, ft</u>	<u>Ø, %</u>	<u>Øh</u>	<u>Remarks</u>
<u>Charles</u>				
4690-4700	10	11.5	1.15	
4700-4704	4	13.0	0.52	
4710-4716	6	27.0	1.62	
4720-4723	3	24.0	0.72	
4740-4745	5	9.0	0.45	
4780-4784	4	11.0	0.44	
4814-4818	4	13.0	0.52	
4818-4820	2	11.0	0.22	
4835-4842	7	19.5	1.365	
4843-4848	5	19.5	0.975	
4854-4860	6	19.5	1.17	
4870-4878	8	20.0	1.6	
	64		10.75	

Mission Canyon

4980-4986	6	9.0	0.54	
4990-4995	5	9.0	0.45	
5002-5008	6	10.0	0.60	
5010-5020	10	11.0	1.1	
5020-5050	30	9.0	2.7	
5052-5056	4	10.0	0.40	
5056-5062	6	9.0	0.54	
5062-5066	4	11.0	0.44	
5066-5090	24	9.0	2.16	
5090-5098	8	11.0	0.88	
5098-5104	6	9.0	0.54	
5146-5156	10	11.0	1.1	
5278-5283	5	9.5	0.475	
	124		11.925	

Lodgepole

5453-5528	75	9.0	6.75	
5544-5550	6	9.0	0.54	
5560-5565	5	9.0	0.45	
5568-5573	5	9.2	0.46	
	91		8.2	

Ø Average: .11066
Øh Total: 30.875
h,ft Total: 279

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