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SUMMARY OF THE ENVIRONMENTAL MONITORING AT THE ROCK SPRINGS, WYOMING
SITE NO. 9, TRUE IN SITU OIL SHALE RETORTING EXPERIMENT

BY

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Table of Contents

	<u>Page</u>
ABSTRACT	1
INTRODUCTION	2
PROCESS SUMMARY	8
RESULTS AND DISCUSSION OF ENVIRONMENTAL MONITORING	12
Baseline Environmental Studies	12
Environmental Studies Concurrent with Field Operations	12
Water	12
Subsurface	12
Surface	39
Produced	40
Air	42
Process	42
Meteorology and Ambient Air	43
Land Disturbance	44
Thermal	44
Subsidence	45
Processed Shale	46
Reclamation	46
SUMMARY AND CONCLUSIONS	46
REFERENCES	48

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Tables

<u>No.</u>	<u>Page</u>
1. Advantages of In Situ Technologies	4
2. Summary of Process and Environmental Monitoring Activities for DOE/LETC Field Experiments	5
3. Summary of LETC Environmental Monitoring Program Elements with Breakdown of Water Related Activities	7
4. Well Completion Data Rock Springs Site 9	10
5. Summary of Analytical Determinations for Water Samples Obtained During the LETC Environmental Monitoring Program. .	14
6. Characteristics of Retort Water from Rock Springs Site 9 . .	41
7. Water Analyses from Individual Production Wells from Rock Springs Site 9 (April 1976).	41
8. Gas Composition Rock Springs Site 9, Volume Percent.	42

Figures

<u>No.</u>	<u>Page</u>
1. Green River Formation	3
2. Sampling Sites for Process Water Associated with In Situ Shale Projects.	6
3. Well Locations at Rock Springs Site 9	9
4. Flow Diagram - Site 9	11
5. Ionic Composition of Water in Well J, RS Site 9 on Three Dates: (A) 7/30/75 - Preop.; (B) 7/29/76 - Oper.; (C) 12/11/76 - Postop	18
6. Ionic Composition of Water in Well E, RS Site 9 on Three Dates: (A) 7/30/75 - Preop.; (B) 7/23/76 - Oper.; (C) 9/10/77 - Postop.	19
7. Ionic Composition of Water in Well F, RS Site 9 on Three Dates: (A) 7/30/75 - Preop.; (B) 7/30/76 - Oper.; (C) 10/19/77 - Postop	20
8. Temporal Changes in ROE (mg/l), Well C, RS Site 9	22
9. Ionic Composition of Water in Well C, RS Site 9 on Three Dates: (A) 7/30/75 - Preop.; (B) 7/23/76 - Oper.; (C) 10/19/77 - Postop	23
10. Temporal Changes in Dissolved Sulfate (mg/l), Well C, Site 9.	25
11. Temporal Changes in ROE (mg/l), Well G, RS Site 9	26
12. Temporal Changes in Boron Concentration (mg/l), Well G, RS Site 9	27
13. Temporal Changes in Sulfate Concentration (mg/l), Well 01, RS Site 9	29
14. Temporal Changes in ROE (mg/l) in Well 01, RS Site 9.	30
15. Ionic Composition of Water in Well 01, RS Site 9 on Three Dates: (A) 7/30/75 - Preop.; (B) 7/30/76 - Oper.; (C) 10/19/77 - Postop	31
16. Temporal Changes in Sulfate Levels (mg/l) at Wells E (a) and I (b), RS Site 9.	32
17. Temporal Changes in TOC (mg/l) with Time in Well C, RS Site 9	34
18. Temporal Changes in TOC Concentration (mg/l) at Wells 01 (a) and 8 (b), RS Site 9.	36

Summary of the Environmental Monitoring at the Rock Springs, Wyoming
Site No. 9, True In Situ Oil Shale Retorting Experiment

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ABSTRACT

The Laramie Energy Technology Center (LETC) has been studying the environmental effects and needed control technology associated with the potential in-situ retorting of oil shale in the Green River Basin (near Rock Springs, Wyoming) for over four years. This environmental monitoring program has included previous and existing in-situ oil-shale retorting field experiments and baseline data collection for potential future retorting experiments.

The most extensive environmental monitoring effort is at Rock Springs Site No. 9, a true in-situ oil-shale retorting field experiment which was ignited April 5, 1976. The purpose of this monitoring program was to identify any significant changes in the hydrology, air quality, and soils. Data have been collected during the pre-operational (baseline) and operational phases and continues to be collected during the post-operational phase.

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This report of investigation will present the results of the environmental monitoring conducted in support of the LETC Rock Springs No. 9 field experiment and the entire DOE oil shale program.

INTRODUCTION

Approximately two-thirds of the oil shale reserves found in Wyoming, Colorado, and Utah (Figure 1) are either too low grade or thin seamed to make conventional mining and processing techniques feasible. Since the early 1960's the Laramie Energy Technology Center (LETC) has been seeking an economically feasible method for processing low-grade or thin seamed shale³⁻⁶. The true in situ processing of oil shale has the potential for recovering the vast oil shale resource from these less attractive deposits in an environmentally acceptable and economically feasible manner.

The environmental concerns which are being addressed in the course of developing oil shale processing technologies include control of product and waste discharges, water resource and geohydrologic effects, ecological effects, health and safety aspects, and socioeconomic impacts⁹. Although all processing technologies have some concerns in common, the in situ recovery process offers certain environmental and economic advantages over mining and above ground retorting as indicated in Table 1. A major environmental and technological problem associated with the in situ process relates to water - both the impact on water quality and resources and the control and utilization of co-produced waters.

The LETC has been studying the environmental effects and control technology associated with the potential in situ retorting of oil shale in the Green River Basin (near Rock Springs, Wyoming) for over four years^{7,9, 15-18,34}.

Figure 1. Green River Formation

TABLE 1. - Advantages of In Situ Technologies.

	APPLICABLE TO LARGER RESOURCE BASE	LITTLE OR NO MINING REQUIRED	WASTE REDUCED
ECONOMIC ASPECTS	Under Utilized Areas Become Productive	Labor & Capital Costs Reduced	Lower For Refill Or Disposal
SURFACE ENVIRONMENT	Intensive Local Extraction Unnecessary	No Stripping; Surface Impacts Minimized	Impact Confined To Extraction Area Only
HUMAN ENVIRONMENT	Growth Dispersed; Boom Towns Less Likely	Health & Safety Hazards Reduced	Aesthetic & Recreation Conflicts Minimized

This environmental program has included previous and existing in situ oil-shale retorting field experiments and baseline data collection for potential and future Wyoming retorting experiments (Table 2). The location of these field activities is illustrated in Figure 2.

The most extensive monitoring effort is at Rock Springs Site No. 9 a true in-situ oil-shale retorting field experiment which was ignited April 5, 1976^{42,22-24}. The purpose of the environmental effort was to identify any significant changes in water quality, hydrology, air quality, and soils. Data has been collected during the pre-operational (baseline) and operational phases and continues to be collected during the post-operational phase^{9,15-17}. The monitoring program is tailored to meet the scope and size of the planned experiment and consists of the activities itemized in Table 3. This report of investigation will discuss the results through January 1, 1978 of this environmental monitoring program conducted at the LETC Rock Springs Site #9 field experiment.

TABLE 2. - Summary of Process and Environmental
Monitoring Activities for DOE/LET
Field Experiments

EXPERIMENTAL SITE DESIGNATION (REFERENCES)	PROCESS ACTIVITY	WATER QUALITY MONITORING ACTIVITY
<u>ROCK SPRINGS</u>		
Site 12 (31, 32)	Fractured in 1977. To be retorted in 1978.	Baseline monitoring. Operational monitoring Post-operational monitoring (planned).
Site 9 (43, 22-24)	Retorted in 1976.	Baseline (pre-operational) monitoring. Post-operational monitoring. Backflood study (planned).
Site 6A (30, 31)	Fractured & grouted in 1976.	Baseline monitoring.
Site 6 (38)	Ignited in 1971.	Post-operational monitoring. Backflood study.
Site 4 (5)	Retorted in 1969. Reopening planned.	Post-operational monitoring. Backflood study (planned).
<u>GREEN RIVER</u>		
Site 2 (40)	Fractured in 1971. Retorting proposed.	Post-operational monitoring.
<u>ROCK SPRINGS REGION</u>		
White Mountain - Southeast Face Green's Canyon Area (13, 20, 41)	Potential modified horizontal in situ experimental sites.	Baseline monitoring.
<u>NORTHERN GREEN RIVER BASIN</u>		
15 wells over 400 sq. mi. area (37, 36)	Resource Evaluation. Potential in situ experiments.	Baseline monitoring.

Figure 2. Sampling sites for process water associated with in situ shale projects.

TABLE 3. - Summary of LETC Environmental
Monitoring Program Elements with Breakdown of
Water Related Activities.

MONITORING AREA	MONITORING FREQUENCY		
	PRE-OPERATIONAL	OPERATIONAL	POST-OPERATIONAL
Meteorology	continuous	continuous	continuous
Air Quality	intermittent	intermittent	intermittent
Gas Process Stream	--	continuous	intermittent
Thermal Emissions	baseline	intermittent	intermittent
Land Disturbance	baseline	intermittent	intermittent
Oil Products	--	daily*	--
Ecological Baseline	as required	--	as required
Water Related Activities			
Hydrology			
Surface	quarterly*	quarterly*	quarterly*
Subsurface	quarterly	daily	quarterly
Backflood	--	--	bimonthly
Produced Water			
Production Wellhead	--	daily to monthly	intermittent*
Oil/Water Settling Tank	--	intermittent	--
Evaporation Pond	--	--	intermittent
Storage Sample	--	--	intermittent

* When flowing

PROCESS SUMMARY

The experimental site is located on the eastern side of the Green River Basin and on the extreme western slope of the Rock Springs up-lift. Topography of the area is rough and characteristic of a valley formed by differential erosion of flat lying strata. Site No. 9 sets at the foot of steeply sloped cliffs rising from a broad valley floor.

The oil shale zone is located in the Tipton member of the Green River Formation between 137 and 177 feet below the surface. The quality of the shale averages 21.3 gallons per ton of oil with a water content of 2.3 weight-percent by Fischer assay^{14,27}. Two intermittent aquifers overlying the oil shale zone and one underlying this zone have been located in the area. Pump-down tests and recharge rates of the overlying aquifers indicate that these aquifers flow very slowly. Attainment of original water levels ranged from less than one month to almost three months with one well, B, never regaining its pre-pumping level during the three month monitoring period.

The well pattern, shown in Figure 3, was a square 70 feet on a side with production wells set at each corner of the square and at the mid-points of each side. These original eight production wells were physically paired initially into four quadrants. An injection well was drilled in the center of the square and process temperature monitoring wells were located midway between the center well and the wells in the side of the square. Three wells were later drilled northeast of the basic pattern to verify suspected oil migration into that area. Eleven water observation wells were placed from 125 to 1500 feet from the perimeter of the pattern. Well completion data on the

Figure 3. Well locations at Rock Springs Site 9

above mentioned wells is listed in Table 4. Three overburden temperature sensing wells (100 feet in depth) were placed both within and outside the pattern.

Gas sampling ports were located at each quadrant and at the composite gas line which transports the production gas to the flare stack. Liquid sampling ports were located at the temporary holding, mixing, and storage tanks (Figure 4).

Retorting began on April 5, 1976 and continued through September 5, 1977. Material balance calculations indicated that 3,260 tons of oil shale was retorted, representing 21 percent of the target zone. Oil migration beyond the pattern was seen and only 2,483 gallons of shale oil was recovered. Nitrogen balances show 93 percent recovery of injected air. The caloric value of effluent gas totaled 1,515 million Btu of low Btu gas^{42,22-24}.

Table 4. Well Completion Data Rock Springs Site 9

PATTERN WELLS												
Well No.	1	2	3	4	5	6	7	8	9			
Total Depth, ft.	190	192	189	188	190	193	192	188	188			
Casing Depth, ft.	138	138	136	135	137	139	137	134	136			
OBSERVATION WELLS												
Well No.	A	B	C	E	F	G	H	I	J	11-01	D ^a	0-1
Total Depth, ft.	317	206	181	175	193	218	171	169	198	227	900	197
Casing Depth, ft.	264	153	128	122	140	165	118	116	145	156	900	197

a) Project water well

Figure 4. Flow diagram - Site 9

RESULTS AND DISCUSSION OF ENVIRONMENTAL MONITORING

The most extensive environmental monitoring effort to date in this area was conducted during the Rock Springs #9 experiment. The discussion in the following sections will concentrate on results obtained during that experiment. Other sites are discussed where there is a bearing on the site 9 experiment.

BASELINE ENVIRONMENTAL STUDIES

The extensive monitoring effort conducted at Site No. 9 gathered data that contributed to the fulfillment of the NEPA requirements for the project. Environmental Assessments (EA) were written on the LETC's in situ oil shale research program^{15,16}, and sections of these EAs describe the baseline ecology setting of Site No. 9 and the other research sites.

ENVIRONMENTAL STUDIES CONCURRENT WITH FIELD OPERATIONS

WATER

Subsurface

The most extensive portion of the LETC environmental monitoring program is the fluid migration study. Ground water data were collected during the two-year pre-operational phase¹² and during the one-year operational phase^{13,36,42}. Monitoring has continued during the post-operational phase, and will continue for an indefinite period. The frequency of sampling of the 20 production and observation wells ranged from quarterly to daily (Table 3), depending upon the phase of the experiment. Composite samples were also periodically obtained from the temporary storage tank, holding tank and evaporation pond. A 12,450 gallon sample of retort water* was also

*Water coproduced with shale oil (combined water of combustion or hydration and native ground water)⁹.

collected⁸. The samples were collected in clear and/or opaque plastic containers or polyethylene lined steel drums and shipped to one or more analytical labs for standard and/or trace element analysis.

During the review of the data available through January 1, 1977 it became apparent that some of the data was of questionable accuracy³⁶. Some of the indicators of problems were: 1) frequent cation-anion balance discrepancies, 2) total dissolved solids (TDS) calculated as the sum of constituents was lower than the sum of major cations and anions, 3) total dissolved solids obtained by evaporation of a sample - residue on evaporation (ROE) -were usually greater than the TDS (calculated) value, as expected but the ROE was frequently less than the sum of the major cations and anions, 4) samples split within a single laboratory indicate that precision is lacking in the analyses or that problems exist in obtaining a homogeneous sample, 5) plots of the available data indicate a great deal of variation from point to point, which tended to obscure trends with time. It is possible that part of this observed variation might be due to inaccuracies in laboratory analyses or differences between laboratories. Many of these problems may also be attributed to the questionable application of standard methods of water analyses to the very complex waters encountered in this work.

The data through January 1, 1977 was screened using a cation-anion balance (not including NH_3) screening technique. This technique rejected 25% of the 952 samples analyzed. In an attempt to identify overall water trends, gross parameters (ROE, TOC, COD) were examined along with parameters of particular interest listed in Table 5.

In the 1977 screening attempt, any sample showing greater than 10 percent disparity in cations or anions was discarded. A similar approach was initially used in a review of data collected through January 1, 1978 with the addi-

Table 5. Summary of Analytical Determinations for Water
Samples Obtained During the LETC Environmental Monitoring Program

ALL SAMPLES FROM EVERY SOURCE

Sodium	pH
Potassium	Boron*
Calcium	TOC
Magnesium	Conductance
Carbonate	ROE
Bicarbonate	COD
Sulfate	TKN
Fluoride	Phosphate (total and ortho)*
Nitrate*	Silica*
Chloride*	

ADDED LATER

Arsenic
Phenols*
Cadmium
Selenium
Mercury

* Pattern wells during and after retorting too colored for these analyses.

SELECTED SAMPLES FROM EVERY SOURCE

Elemental Analysis by SSMS

All periodic table elements excluding gases

tion of ammonia into the cation balance⁴². This approach reduced the rejection rate of all samples collected to 16 percent, and only 3 percent of the samples collected in 1977 were rejected. There are several possible explanations for this difference in cation-anion balance: a) There may have been fewer interferences to the chemical analyses that were present during the retorting period, or the analysis of each sample may have been more complete (some earlier analyses were for TOC only), b) the laboratories involved are by this time more experienced in some of the problems peculiar to retort water; c) ammonia was included in the ionic balance; d) samples were processed more quickly in recent months. Inherent problems with the use of the ionic balance include the rejection of samples incompletely analyzed, and the loss of all parameters for a given sample when only one may have been in error.

Because of these factors and the relatively low overall rejection rates (particularly in recent samples) it was decided to utilize the entire available data base. Additional advantages of this approach are that the results are not artificially skewed by a screening procedure, and the computer programs currently in use by the contractor can be directly applied.

Based upon the 1977 work it was thought certain parameters were more promising as indicators of water quality changes than others. After reviewing the data collected through January 1, 1978 these parameters proved to be residue on evaporation (ROE), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), boron (B), and sulfate (SO_4^{--}).

Native Ground Water

Native ground water associated with site 9 is of general low quality, characterized by high ROE values (up to 48,600 mg/l), high pH (up to 11.0), and high sodium content (up to 19,716 mg/l and usually accounting for >90% of the total cationic species). Most trace elemental concentrations in the

ground water are below detection limits, but there are some exceptions illustrated by the following (element with approximate range): boron (0-50 mg/l), arsenic (3-170 mg/l), selenium (1-10 mg/l), and mercury (<0.2-1 mg/l). The above data shows that this ground water exceeds maximum water quality criteria for irrigation purposes. When this data is compared to the proposed Wyoming Department of Environmental Quality (DEQ) ground water regulations, it meets the requirements for a Class VI (are or have the potential for being beneficially used) or a Class VII water (are or do not apparently have a potential to be beneficially used).

Ionic Composition

Trilinear plots of ionic composition were prepared for the eleven observation wells, as well as production well 8. The 1977 study³⁶ showed no statistical differences in ROE among the production wells, so for the present study, well 8 was chosen as representative of the group. Well 8 has a fairly complete data base over the time of interest.

The plotting of the trilinear diagrams had two objectives: the illustration of the ionic composition of the individual well waters, and the graphical display of changes in that composition with time. For the latter purpose three sample dates were selected for each well and plotted on the same diagram. The first date (labeled A) represents a period approximately one year before retorting, while the second date (B) was chosen to occur during the retorting operation. The last date (C) represented the most recently acquired data.

In most of the wells sodium is present in overwhelming proportions, comprising nearly 100 percent of the cations. Some exceptions occur in that the ammonium ion is an important constituent in some of the production wells. Ammonia analyses were not always conducted on the samples collected, however, so that comparisons are not always possible. The initial impression, at

least, is that ammonia may be an important water constituent during the retorting phase, and less prominent thereafter. More data are needed, and in the future ammonia analyses will be routinely run so that a cation-anion balance can be made and an accurate trilinear diagram plotted.

The most notable changes in ionic concentration are anionic in nature, since the cationic fraction is swamped with sodium. With the exception of well E, which was principally sodium chloride, all the wells appear to have initially been sodium carbonate-bicarbonate in nature. Nearly all the wells show an increase in the carbonate-bicarbonate anion fraction during the retorting period, as illustrated by Figure 5. One possible explanation of this occurrence might be that the CO_2 produced by the combustion process can react with water to produce bicarbonate:

Under alkaline conditions this product would be converted to carbonate:

Some of the wells, as exemplified by Figures 6 and 7, exhibit a decrease in carbonates and bicarbonates after the increase during the retorting period. This might be due to the equilibration of the system to conditions of lower temperature and pressure, releasing carbon dioxide to the atmosphere. The resulting reaction would be the reverse of equation (1).

In addition to the above effects, it is also possible that salts, including carbonates and bicarbonates, are simply extracted from the underground sedimentary rock simply due to the high temperatures experienced during retorting. After retorting equilibration would occur which could result in the precipitation of various carbonate salts, thus explaining an eventual reduction in carbonate-bicarbonate concentrations.

Figure 5. Ionic composition of water in well J, RS Site 9 on three dates: (A) 7/30/75 – Preop.; (B) 7/29/76 – Oper.; (C) 12/11/76 – Postop.

Figure 6. Ionic composition of water in well E, RS Site 9 on three dates: (A) 7/30/75 – Preop.; (B) 7/23/76 – Oper.; (C) 9/10/77 – Postop.

Figure 7. Ionic composition of water in well F, RS Site 9 on three dates: (A) 7/30/75 – Preop.; (B) 7/30/76 – Oper.; (C) 10/19/77 – Postop.

Well A has shown practically no change in ionic composition. This well was originally conceived as a control observation well, and apparently is outside the affected environment of the operation.

Well D is the only one completed in the Wasatch Formation which is beneath the Tipton member of the Green River Formation. All other wells are in the Tipton shale. Well D was originally drilled as a potential source of drinking water, and has been monitored regularly. When the overall quality of this water is compared to the proposed Wyoming DEQ ground water regulations, it only meets the requirements for a Class VI (are or have the potential for being beneficially used) or a Class VII water (are or do not apparently have a potential to be beneficially used). It is of some interest that a shift in ionic composition was noted in this well over time. The shift was toward a greater percentage of bicarbonate-carbonate, similar to that observed in the other wells. (Despite this ionic shift, the water quality still meets the Class VI or VII requirements.) This indicates effects may extend some distance from the center of operations during the retorting process. Well D is 900 feet deep with perforations below 450 ft compared to about 200 feet depth for most of the other wells.

Well C showed a considerable increase in ROE during the retorting period (Figure 8), but apparently (based on a single datum) returned to earlier low levels by the end of 1977. Coinciding with these changes a significant shift in anionic composition occurred (Figure 9). There is considerably more sulfate present in the later sample than in the earlier one. The pattern is similar to that observed in well E (Figure 6), although in that instance there was a considerable increase in ROE at the same time.

Figure 8. Temporal changes in ROE (mg/l), well C, RS Site 9.

Figure 9. Ionic composition of water in well C, RS Site 9 on three dates: (A) 7/30/75 – Preop.; (B) 7/23/76 – Oper.; (C) 10/19/77 – Postop.

The graph of sulfates with time for well C (Figure 10) indicates the changes observed were not only relative in nature, but that sulfate levels actually decreased markedly in the pre-retorting period, and are presently at higher levels than during initial monitoring.

A summary of the changes in ionic composition observed in these wells shows wells D, J and 01 increased the portion of carbonates and bicarbonates in the anionic fraction. The same was true of wells B, E, F, and G, except that after the retorting period the carbonate-bicarbonate fraction decreased. Not much change occurred in wells A and H.

Water Quality Trends

ROE. Nearly all the wells showed an increase in ROE with time. Some, such as wells B, E, G and I, have leveled off after an increase. Wells A and D have maintained fairly constant ROE levels. The former does show distinct, discrete peaks during the period of retorting, as well as a large peak in November 1977. It has not been determined at this point what operations this may have coincided with, but a liquid explosive was injected at Site 12 (about 1/3 mile away) on August 10, 1977. Well D shows a decided peak about June 1975, when Site 9 fracturing was taking place. Since that time no equally large ROE values have been observed. A pronounced increase in ROE was exhibited by well G (Figure 11). From relatively low ROE levels in early 1975, levels of 48,000 mg/l and above were present in 1977.

Boron. With the exception of wells A & I, which show little change, all wells increased in boron concentration with time. Even well A, however, exhibits a sharp peak in boron during April 1976, when retorting was begun. Well G has shown a particularly large trend over time to much higher boron concentrations (Figure 12). Boron is likely to exist in these waters as borate, salts of boric acid (H_3BO_3), and solubility would be increased at high

Figure 10. Temporal changes in dissolved sulfate (mg/l), well C, Site 9.

Figure 12. Temporal changes in boron concentration (mg/l), well G, RS Site 9.

pH. The samples from well G are definitely alkaline, but no great increase in pH occurred during the time boron concentrations rose. Perhaps the phenomenon is an extraction process related to the higher temperatures initiated by retorting. To date only wells B and D have shown a decrease in boron levels, and then only after an initial increase was experienced.

Sulfate. Four of the observation wells (B, H, G, O1) exhibited an increase in sulfate concentration over time. The most spectacular increase was in well O1 (Figure 13), which experienced about a 100-fold increase. This is reflected in both a shift in anionic composition, and in approximately a doubling in the ROE values (Figure 14) over the same period of time. The trilinear diagram (Figure 15) indicates that an increase in carbonate-bicarbonate, in addition to sulfate, is the principal cause of the higher ROE levels. Although well B showed an initial increase in sulfate concentration in early 1975, since that time concentrations have returned to lower levels, with an unexplained, sharp peak in July 1977. Wells A, E and I all exhibit a decrease in sulfate concentration with time.

Well C exhibits a decrease in sulfate concentrations, with an apparent upturn in 1977, although only a single sample was taken during the latter period. During this time ROE rose and fell a great deal (Figure 8), primarily due to carbonate-bicarbonate fluctuations (Figure 9). The most recent water samples at well C indicate the shift in composition from carbonate-bicarbonate to sulfate resulted in a greater proportion of sulfate than initially was the case, even though the ROE returned to the initial levels. It is the only well which showed this trend.

Wells E and I show similar behavior in respect to sulfates, as shown in Figure 16. A large peak appears in March 1976 at well E, and about two months later at well I. Well I is located somewhat further from the production zone

Figure 13. Temporal changes in sulfate concentration (mg/l), well 01, RS Site 9.

Figure 14. Temporal changes in ROE (mg/l) in well 01, RS Site 9.

Figure 15. Ionic composition of water in well 01, RS Site 9 on three dates: (A) 7/30/75 – Preop.; (B) 7/30/76 – Oper.; (C) 10/19/77 – Postop.

Figure 16. Temporal changes in sulfate levels (mg/l) at wells E (a) and I (b), RS Site 9.

than well E (Figure 3), which could explain the time lag. The increase in sulfates in well I, however, is much greater than in well E, which is difficult to understand in terms of some effect moving away from a central point.

Wells B and G, which are also in proximity to one another (Figure 3), both show an interesting, sharp peak in sulfates during early August 1977. These peaks may be related to the injections of explosives into the formation at Site 12 about 1/4 mile away, and these wells do lie on a line between Sites 9 and 12.

TOC. Levels of organic carbon would naturally be expected to increase during in situ retorting as organic material is driven from the shale. Increase in TOC levels with time are exhibited in nearly all wells. Four of the wells (01, B, C, I) decrease in respect to TOC after an increase. Well C typifies this behavior (Figure 17). The two periods of increasing TOC levels correspond to fracturing and retorting experiments. Some of the wells, particularly well G, also show a peak in TOC around March 1977. A specific cause for these peaks has not been discovered at this time. For some reason well E was relatively steady insofar as TOC levels were concerned; nearby well I showed much greater fluctuations. The effects of retorting did show up in well E in April 1976, however.

In general, TOC levels did seem to show a greater tendency to decrease after an upswing than did the other parameters studied.

TKN. The measurement of TKN includes both ammonia and organic nitrogen in the result. Definite increases in TKN (and in ammonia) are characteristically seen in the production wells during retorting. Presumably this is due to organic matter released from the shale, some of which is degraded to ammonia.

Figure 17. Temporal changes in TOC (mg/l) with time in well C, RS Site 9.

The situation with respect to the observation wells is not so obvious. The only straightforward results are in well 01, which shows a peak in 1976 which tails off toward the end of the year. This is similar to that seen in production well 8. There has been other evidence in the past that well 01 is linked to the production wells, so this merely provide supporting evidence.

A linear regression between TKN and TOC was run on well E, but did not indicate a significant correlation. It was thought a correlation might be found if the source of the nitrogen was the organic matter measured in the TOC values. In fact, the TKN values were quite variable for a given TOC level. Obviously, the relationship is more complex than might be initially thought.

COD. The COD values showed quite erratic behavior with time, such that no real interpretation can be made. The COD test was designed with the oxidation of organic matter in mind, although compounds such as aromatics and pyridines are known to be recalcitrant in this regard.

Communication Between Wells

Some observations which have been made might be related to the possibility of communication between wells. Earlier work has led LETC to believe communication does exist between the production wells and well 01. To seek further evidence of this the water quality trends in production well 8 and observation well 01 were compared.

As was noted earlier in this report, the variation of TOC in these wells are parallel to some degree, with well 01 lagging behind well 8 in time (Figure 18). The relationship in regard to ROE is not so obvious, except that both do increase with time. Nor do the fluctuations in boron or sulfate provide definite evidence of linkage between these two wells. Thus it appears it would be difficult to discern communication between wells based upon water quality analyses done. TOC would provide the best clue in this regard, at least while retorting is in progress.

Figure 18. Temporal changes in TOC concentration (mg/l) at wells 01 (a) and 8 (b), RS Site 9.

At the end of 1977, pressure tests were being made at Rock Springs Site 12, which is located slightly to the northeast of R.S. Site 9. There are some slight indications in the ROE data that certain wells may have responded to the site 12 testing, suggesting some degree of communication between the sites. Well B for example, shows a small peak in ROE in November. This well is on the northeast side of the site 9 operation. Well G, however, is somewhat closer to site 12 than well B, and exhibits no such peak. Well I also exhibits a sharp ROE peak during this time, but it is one of the wells furthest removed from site 12. Other wells which increase in ROE during this period are C and 8. Whether or not communication results between any of these wells and R.S. Site 12 cannot be said with any certainty based upon the ROE data alone.

Also, in relation to wells B and G, a sharp increase in sulfates is indicated in late 1977. This might represent a response correlated with the Site 12 operations, but cannot be sharply defined. There are also increases in TOC in some wells (01, B, C, J) which might also tie in with the activity at Site 12, but this cannot be established with any certainty.

Trace element analysis, in general, indicated levels below detection limits. Despite the best sampling efforts to obtain an adequate number of trace element analyses, insufficient data was collected during the pre-operation and operation phases of the experiment to make a firm statement about the trace element content. Future monitoring programs will address this problem^{12B}.

One of the observation wells, I, contains the highest reported values for 5 of the 9 trace elements that exceeded water quality criteria for irrigation purposes (As, Hg, Mo, Ni, V). The analyses for all of the Well I samples (baseline and operational) indicate that this water is more similar in com-

position to a trona water than any of the ground water found in all the other wells. It is believed that Well I was drilled into a trona water pocket found intermittently throughout the Green River Basin.

In general, the following trends in water quality at R.S. Site 9 were identified⁴³.

1. Most water was initially sodium carbonate-bicarbonate in nature, but underwent anionic changes during the retorting process, shifting to an even greater proportion of carbonate-bicarbonate in the anionic fraction. This shift may be related to the production of carbon dioxide in the retorting zone. Furthermore, later decreases in the carbonate-bicarbonate component in some wells could be explained by the release of carbon dioxide to the atmosphere. No relationship could be established between conductivity and ROE, because of the compositional changes which occur.

2. Boron and TOC levels both increased with time, but the TOC values seemed to return to lower levels more rapidly. Most boron levels remain high, and this will be a definite problem in regard to the potential use of such water for irrigation. (The use of native groundwater for irrigation already is unlikely).

3. When only ROE is considered, the quality of the water associated with the Wasatch Formation during the pre-operational phase meets the Class IV requirements (are or have potential for being used as irrigation waters), but becomes a Class VI (are or have the potential for being beneficially used) or Class VII (are or do not apparently have a potential to be beneficially used) when fluoride, pH, SAR, and mercury are taken into consideration. During the operational and post-operational phases this water becomes a Class V (are or have potential for being used as livestock water) when only ROE is considered, and remains a Class VI or VII when the other constituents are considered.

4. The quality of the water associated with the Tipton member only meets the Class VII requirements during all three phases of the experiment.

5. Some wells exhibited an increase in sulfates and some a decrease. No great change in pH was registered probably because of the great buffering capacity of the system.

6. TKN values were not related to TOC in any obvious manner.

7. The COD values appeared erratic and do not provide a handy means for analyzing trends in water quality.

8. Some evidence was found for the existing communication between well 01 and the production wells, but such conclusions based on chemical data alone can only be tentative. Similar observations on data from other wells should be done with caution.

Backflood Water

In order to better understand the underground mechanisms and characteristics of backflood water, a joint DOE-EPA-USGS study is being implemented not only at Site #9 but also at Site #4 which is a spent retort ignited in 1969. This extensive backflood study will include:

- 1) Determination of spent retort hydrology with modeling
- 2) Water quality analysis with standard and trace components.

The spent retort hydrologic modeling will be in conjunction with the hydrologic modeling planned for other Rock Springs sites⁴⁴.

Surface

Ambient surface water monitoring was not conducted because of the lack of perennial streams located near the site. The drainages near the site are ephemeral, flowing only in response to rainstorms or snowmelt. This region receives only approximately 10 inches of moisture each year, mostly in the form of snow.

Produced Water

The characteristics of the retort water collected at various times during the retorting experiment from the mixing tank (composite) are shown in Table 6 and Table 7²²⁻²⁴. The varying concentrations can be attributed to the changes in ground water flow and the amount of ground water pumped to the surface.

A 12,450 gal homogeneous sample of composite retort water was collected to implement numerous integrated, multi-disciplinary environmental studies⁹. This water was subjected to an intensive characterization study, and the results have been published^{10,11,21,26,28,29,39}.

A detailed evaluation of this comprehensive analytical survey has shown that standard analytical methods cannot be used to determine most water quality parameters in complex waters such as oil shale process waters. Methods specific to each type of water need to be developed and published. Instrumental methods generally produce more accurate results as these encounter few interferences than chemical methods. However, significant variation and error can result from differences in sample preparation and the fact that most of these techniques produce precision data for a subset of the total set of elements reported.

Evaluation of the applicability of "standard methods" to retort water analysis is ongoing at LETC laboratories. The recently formed ASTM Subcommittee D-19.33 on "Water Associated with Alternative Fuels Production" should augment this effort and bring national attention and solutions to specific analytical problems.

TABLE 6. - Characteristics of Retort Water From Rock Springs Site 9¹

Component	High(mg/l)	Low(mg/l)	Average(mg/l)
Sodium	5,100	2,600	3,925
Carbonates	2,000	0	662
Bicarbonates	25,000	1,000	12,040
Sulfate	4,700	1,200	2,300
Chloride	5,200	1,400	3,090
Total Organic Carbon	6,300	780	2,310
Boron	32	20	24
Fluoride	100	35	68
Chemical Oxygen Demand	22,000	5,000	11,640
Ammonium	6,700	0	3,120

¹ Average of eight samples (April - August, 1976) from mix tank. All in mg/l.

TABLE 7. - Water Analyses From Individual Production Wells
From Rock Springs Site 9 (April 1976)

	Well 3	Well 4	Well 5	Well 6	Well 8	Well 9
Total solids, gm/l.	21.2	12.6	23.0	16.0	11.6	2.4
Residue on Evaporation, gm/l.	8.6	10.8	11.9	14.2	10.8	2.2
Fixed solids, gm/l.	6.7	8.5	2.9	11.5	8.0	1.7
Carbonates, mg/l	1948	2273	3345	1786	2111	--
Bicarbonates, mg/l	2312	2642	6672	5120	3236	1651
Carbon, mg/l	749	421	1042	435	489	0
NH ₃ nitrogen, pct	.03	.005	.016	.043	.031	0
Kjeldahl nitrogen, pct	.05	.013	.029	.062	.046	.002
Chromium, mg/l	0	0	0	0	0	0
Cobalt, mg/l	0	0	0	0	0	0
Copper, mg/l	0	0	0	0	0	0
Manganese, mg/l	0	0	0	0	0	0
Magnesium, mg/l	7.2	8.8	22.6	9.5	8.7	3.0
Nickel, mg/l	0	Trace*	Trace*	0	0	0
Zinc, mg/l	.3	.3	.3	.2	.3	.6
Calcium, mg/l	9.2	9.1	9.1	2.0	1.0	14.5

*Trace: Greater than 0, but less than lowest detection limit.

AIRProcess

Gaseous effluent monitoring was accomplished during the operational phase. This monitoring took place at two different locations using several different analytical techniques. Product gas samples were collected on a routine schedule for process analysis using gas chromatography^{42,22-24}. An example of the analyses appears in Table 8²²⁻²⁴. The heating value of this off-gas ranges from 27 to 41 BTU/scf. The product was very dependent upon the

TABLE 8 - Gas Composition Rock Springs Site 9, Volume Percent

Component	Before Pump Work		After Pump Work	
	Days 60-64 96 hr avg	Days 64-68 98 hr avg	Days 80-88 195 hr avg	Days 88-91 69 hr avg
Argon	0.77	0.76	0.76	0.71
Nitrogen	69.38	68.57	69.87	64.70
Oxygen	8.74	11.65	5.97	3.70
Carbon Dioxide	9.98	7.09	12.64	14.12
Carbon Monoxide	1.70	2.85	3.38	5.08
Hydrogen	4.45	5.35	2.81	6.14
Methane	1.49	1.01	.97	1.89
Ethylene	.07	.05	.04	.05
Ethane	.24	.19	.16	.29
Propylene	.03	.01	.01	.04
Propane	.83	.76	.05	.11
Water	2.35	1.71	3.34	3.17
Percent oxygen reacted	50.7	35.6	75.7	78.7

amount of liquid (shale oil/water) in the retort. Table 8 shows that the combustion reaction increased after the pumps were repaired and liquid was removed from the formation.

Samples were also collected periodically as part of an engineering study using grab and continuous sampling techniques. The monitoring process was of

an experimental nature and an established procedure for monitoring oil-shale effluents, i.e. instrument calibration and sampling, was not developed during the retorting experiment. (Development of sampling protocols is underway at LETC).

Particulate sampling and analysis were not accomplished. Representative samples could not be obtained because of the present thermal oxidizer stack design and non-steady state operations. (Future thermal oxidizer stacks will be designed following EPA sample acquisition regulations¹⁹.)

Meteorology and Ambient Air

Site specific meteorological data (wind speed and direction, temperature, barometric pressure, relative humidity, and cloud cover) was collected during the operational phase. The data may be reduced, evaluated, and used in future atmosphere dispersion modeling studies if emissions increase enough for modeling to be significant. Existing meteorological and ambient air quality baseline data for the Rock Springs region have been identified²⁵.

Requirements associated with the preliminary dispersion analysis study for other projects has also been defined³³.

The available atmospheric dispersion models applicable to the study have been reviewed. This review indicates that sophisticated mathematical models are available which can be customized to accommodate the complex characteristics brought on by the terrain and meteorological parameters. Attempts to model and validate the chosen model will also be part of a future study.

LAND DISTURBANCE

Thermal

Subsurface and Borehole

Subsurface and borehole temperature monitoring were conducted during the retorting experiment. Subsurface temperature monitoring was conducted, in conjunction with the process monitoring, in the production wells and four temperature observation wells within the pattern^{42,22-24}. Platinum resistance temperature sensors were located in the three other temperature observation wells within and near Site #9 at depths ranging from four inches to 100 feet².

The process temperature monitor wells indicated that temperature increases were confined to the retorting zone. The attempts to monitor minor temperature changes ($\pm 1^{\circ}\text{F}$) in the overburden were unsuccessful because of equipment problems.

Aerial Infrared Imagery

Surface temperature mapping of Site #9 was conducted both during the pre-operational and operational phases of the experiment. An aerial infrared imaging system operating in the 8 to 14 μ m wavelengths was used to collect the data which were recorded on magnetic tape and computer analyzed, using ground truth temperature measurements for calibration, to produce detailed surface temperature maps. These baseline data which were collected at the maximum and minimum of the diurnal cycle were used to analyze subsequent survey data to detect surface thermal effects related to the test site operations.

Careful examination of the radiometer and thermistor data as well as comparison of computed scanner data from the December, 1975 (pre-operational) and September, 1976 (operational) studies showed no detectable changes in the surface temperatures due to the retorting process. The anomalies that were present were also present in the December study or were determined to be local effects of above surface heating from the facility¹.

A third infrared temperature map has been made during the post-operational phase (May 1978). The results of this overflight are not available at this writing.

Subsidence

Baseline elevation surveys using standard rod and transit techniques were made both before and after rubblization of the oil shale zone. Additional elevation surveys will be made periodically during the post-operational phase to determine whether any subsidence resulted from the retorting experiment. No noticeable subsidence has been observed during this experiment.

Processed Shale

Pre and post operational core samples were obtained and are being analyzed. The results of the post-operational core analyses are not available at this writing. The post-operational coring evaluations will also include a material balance for trace metals in the processed shale and stratigraphic soil mapping.

Reclamation

Revegetation of Site #9 offers a prime opportunity to research successful techniques to reclaim land impacted by in situ oil shale research. Seeding trials with different plant species could serve as valuable information to future oil shale projects. Snow fence studies for farming moisture could be combined with different soil treatment practices in seedbed preparation and for the establishment of seedlings.

In order to reclaim and revegetate Site #9, the following will be required: (1) Plowing and seedbed preparation during the early spring months. (2) Plowing done at least twice to return the topsoil to the surface, and (3)

mulch added. Plant species recommended for revegetation include: Thickspike Wheatgrass, Streambank Wheatgrass, Indian Ricegrass, and Nuttall's Saltbush³⁵.

SUMMARY AND CONCLUSIONS

In situ retorting of oil shale has the potential for recovering an oil shale resource unavailable by existent mining and above ground retorting. In situ retorting has a number of environmental advantages, but also may have some negative impacts. The DOE at LETC has been studying the environmental effects and control technology associated with this technology. The most extensive environmental monitoring effort was conducted at the LETC's Rock Springs Site No. 9 field experiment. The purpose of this effort was to identify any significant changes in the hydrology, air quality, and soils.

The conclusions of this study are listed below:

1. Statistical analysis of the Site #9 water quality data indicated temporal changes do occur with respect to at least one parameter at both the production and observation wells.
2. These temporal changes do not affect the beneficial use of the water. This water when compared to the proposed Wyoming Department of Environmental Quality ground water regulations meets the requirements for a Class VI (are or have the potential for being beneficially used) or a Class VII water (are or do not apparently have a potential to be beneficially used) throughout the three phases of the experiment.
3. Before the ultimate question of specific water quality trends can be adequately answered, the questionable application of some techniques of water analysis to the very complex waters encountered must be addressed.
4. Gaseous effluents were very dependent upon the amount of shale oil and water recovered from the retort.

5. Continuous and grab sampling techniques for gaseous and particulate effluents must be investigated further.
6. Subsurface and aerial infrared thermal studies showed that there were no thermal releases to the overburden or to the atmosphere.
7. Noticeable subsidence has not been observed.

Proposed future work should include comparison of pre-and post-operational coring evaluations and result in a material balance for trace metals.

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