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Project Summary

Energy Use Patterns and Environmental Implications of Direct-Fired Industrial Processes

Benjamin L. Blaney, Jay R. Hoover, James R. Blacksmith, and Paul W. Spaite

Field studies were initiated in 1973 to investigate the vegetative stabilization of processed oil shales and to follow moisture and soluble salt movement within the soil/shale profile. Research plots with two types of retorted shales (TOSCO II and USBM) with leaching and soil cover treatments were established at two locations: low-elevation (Anvil Points) and high-elevation (Piceance Basin) in western Colorado. Vegetation was established by intensive management including leaching, N and P fertilization, seeding, mulching, and irrigation.

After seven growing seasons, a good vegetative cover remained with few differences between treatments, with the exception of the TOSCO retorted shale, south-aspect, which consistently supported less perennial vegetative cover than other treatments. With time, a shift from perennial grasses to dominance by shrubs was observed. Rodent activity on some treatments had a significantly negative effect on vegetative cover.

After initial irrigation for establishment, the vegetation was dependent on seasonal precipitation. Spring snowmelt resulted in recharge of profiles to depths of 60 to 120 cm. By fall, plant-available moisture was depleted by evapotranspiration. Although the fine-textured TOSCO retorted shale usually produced the greatest runoff of all treatments, the surface runoff and sediment yields were generally low due to the adequate vegetative cover. Initially, some accumulation of soluble salts occurred at the surface because of ineffective leaching. With subsequent weathering salinity decreased throughout the entire profile of most treatments that were observed. Recorded surface temperatures of the black TOSCO retorted shale were sufficiently high to limit seedling establishment and increase surface evaporation.

This report follows an initial report by Harbert and Berg (1978) which detailed the construction, establishment techniques, and interpretation of measurements from 1973 to 1976.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In recent years the need to develop new energy resources within the United States has become increasingly important. In 1973, the U.S. Department of Interior estimated that the western oil shale reserves, consisting of over 64,750 square kilometers in Colorado, Wyoming, and Utah, contained over 9.5 x 10^{13} l (600 billion barrels) of recoverable crude oil. These previously undeveloped areas, used largely as range and wildlife habitats, will be subject to vast land disturbances with the development of an oil shale industry.

Various waste products will be generated by shale processing methods making it necessary to develop control technology in order to limit the environmental impact. One of the major environmental problems associated with oil shale development is the disposal of the massive amounts of waste material produced. The U.S. Department of Interior (1973) estimated that a mature oil shale industry of 1.6 x 10^{8} l of oil/day (one million barrels of oil/day) would generate approximately 20,000 ha-m per year of waste material with surface retorting methods. Part of this waste might be returned to mined areas, but a large proportion would require surface disposal. Not only the large volume, but also the chemical and physical characteristics of the waste will create challenges for the development of control technology.

A part of the solution to the management of processed shales would be the rapid establishment of a satisfactory vegetative cover on disposal piles. Vegetation would stabilize the processed shale by decreasing water and wind erosion. Transpiration by vegetation would also result in less moisture available for deep percolation. Establishment of vegetation would also aid in returning the area to a range and wildlife habitat, and provide a more aesthetic landscape.

To make reasonable predictions about the environmental impact of an oil shale industry, it is necessary to investigate both the chemical and physical properties of the waste material. Factors affecting the characteristics of the retorted shale include the natural variation in the raw shale, the degree to which the raw shale was crushed prior to retorting and the retorting process itself.

In addition to physical and chemical characteristics of the retorted shale, the location of the disposal sites in a region of complex geomorphology and varied climatic regimes will influence the success of disposal management efforts.

Thus, the following studies were initiated to evaluate intensive management techniques for the vegetative stabilization of processed oil shales. Two locations were chosen to simulate disposal sites (a low-elevation and a high-elevation). Various leaching and soil cover treatments were applied to two types of processed shales (TOSCO II and USBM). The objectives of this study were to investigate surface stability and to monitor moisture and soluble salts in the treatment profiles.

Materials and Methods

Field studies were initiated in 1973 to investigate the vegetative stabilization potential of retorted oil shales. The objectives were to examine surface stability and soluble salt movement in retorted oil shales. Two types of processed shale, USBM and TOSCO II, with various leaching and soil cover treatments were used. Study plots were established at two sites to simulate conditions existing at proposed shale waste disposal sites. The low-elevation site at Anvil Points (1,700 m) has a semi-arid climate and sparse natural vegetation of low-elevation pinyon-juniper woodlands. This site receives approximately 30 cm of annual precipitation. The vegetation types at the high-elevation Piceance Basin site (2,200 m) were high-elevation big sagebrush shrubland and low-elevation pinyon-juniper woodland. With an estimated average precipitation annually of 40 cm, this site was very similar in climate, elevation, and vegetation to the Colorado Federal Oil Shale lease sites in the Piceance Creek Basin.

Each research site contains a set of 3.3 m x 6.6 m plots with the following treatments:

1. Leached TOSCO retorted shale.
2. Leached TOSCO retorted shale with 15-cm soil cover.
3. Unleached TOSCO retorted shale with 30-cm soil cover.
4. Leached USBM retorted shale.
5. Leached USBM retorted shale with 15-cm soil cover.
6. Unleached USBM retorted shale with 30-cm soil cover at the high-elevation site or 60-cm soil cover at the low-elevation site.
7. Soil control.

Each of the seven replicated treatments had a north and a south exposure on a 4:1 (25%) slope.

The two retorted shales used in this study were products of retorting processes developed by Tosco Corporation (TOSCO II) and the U.S. Bureau of Mines (USBM). The TOSCO retorted shale was black, silt loam material retorted at the Colony Development Operation near Parachute, Colorado. The USBM retorted shale was black-gray and contained approximately 60% coarse particles (>2 mm) and 40% soil-sized particles (<2 mm).

Because these shales were retorted under experimental conditions, they may not be representative of later commercially produced material. Several years between retorting and initiation of these field studies allowed some physical and chemical changes to occur due to weathering. The USBM shale was retorted earlier and may have initially had a higher pH than when used for these studies.

The soils for the experimental control were classified as a calcareous silty clay loam at the low-elevation site, and a non-calcareous silt loam at the high-elevation site.

Construction was completed at both the high-elevation and low-elevation sites in 1973. After filling operations, the plots were outfitted with salinity sensors buried at 20 and 50 cm depths. Because of erratic readings, their use was discontinued in 1978. Neutron probe access tubes were also installed to monitor moisture patterns to a dep of 150 cm throughout the growir season by neutron probe. A surfac runoff collection system provide information on the quality and quanti of runoff from spring snowmelt c summer thunderstorms. A tipping bucket rain gauge and recorder at each study site, as well as a hygrothermograph (during the growing season) supplied climatological data.

Those treatments requiring leaching were sprinkler irrigated after construction. The low-elevation site, leached treatments, received a total of 100 cm of water. The high-elevation site, leached treatments, were irrigated by hauling water on an intermittent basis. Because of the high evaporation rate and low application rate leaching was generally ineffective and salinization of the surface occurred at the high-elevation site. Additional irrigation of 100 cm in 1975 applied continuously by sprinkler succeeded in leaching the soluble salts from the surface at this site.

After leaching, nitrogen and phosphorus fertilizers were applied to all treatments at both study sites. Phosphorus was incorporated to a depth of 10 cm at the rate of 400 kg P/ha in the form of triple superphosphate. Nitrogen was applied following germination at the rate of 66 kg N/ha as ammonium nitrate. Supplemental maintenance nitrogen was applied in following years by broadcasting 66 kg N/ha when spring regrowth began. Fertilization with nitrogen was discontinued in 1979.

The low-elevation study site was seeded in June 1973 with a mixture of native grasses and shrubs. After lightly raking, a mulch of grass hay was applied and held with cotton netting. Although the high-elevation site was initially seeded in 1974, because of the salinity problems mentioned, this site was rototilled and reseeded in June 1975. Irrigation aided the establishment of vegetation at both study sites in the first growing season. The low-elevation site received a total of 46 cm of water, while the high-elevation site received approximately 20 cm of water for stand establishment. Neither study site received any additional irrigation in following seasons, but was dependent upon naturally occurring precipitation.

Core samples were taken from 1973 through 1975. In later years, the plots were core sampled on an intermittent basis to minimize disturbance. Salinity measurements on a 1:1 by weight, soil to water ratio, were performed on 15 cm increments of the core samples. A saturated paste extract was not used because of the large sized sample required, as well as the physical characteristics of the retorted shales.

Two methods of vegetative measurements were used. The quadrat method was used to provide an estimate of germination and establishment the first two years after seeding. The line-intercept method was used in later years to provide a more quantitative measurement. In 1976, the low-elevation study site was analyzed for total above ground standing biomass.

A tipping bucket rain gauge with a continuous chart recorder was installed at both high- and low-elevation study sites. These gauges were not wind shielded, therefore, loss of precipitation in the form of snow during winter months was expected. A cylinder type precipitation gauge at this site measured approximately double the precipitation recorded by the tipping bucket gauge, January through April 1978, when snow was a major form of precipitation. Evidently, the tipping bucket gauge, even though correctly calibrated, did not adequately register annual precipitation in the form of snow.

A more detailed account and description of the construction and measurements for 1973 through 1976 was presented in an earlier report (Harbert and Berg, 1978).

Results and Discussion

Precipitation

Precipitation data for 1976-1980 are reported for both study sites in Table 1. The average annual precipitation for the low-elevation study site was estimated to be 30 cm, while that for the high-elevation was estimated to be 40 cm. Almost all of Colorado was subjected to a drought during the 1976-1977 winter season. Lack of snowfall, combined with low spring precipitation, resulted in considerable moisture stress to vegetation at both study sites. Precipitation for the summer months was also unusually low at the high-elevation site for 1978.

Low-Elevation Study Site

Vegetation

Over the 1973-1976 growing period, an adequate stand of native perennial grasses and shrubs was established (Harbert and Berg, 1978). The application of water for leaching and establishment in 1973 provided a reservoir of moisture in the soil or retorted shale profiles for plant use. Only after the 1975 growing season were the moisture recharge and extraction patterns dependent upon the natural precipitation. Because of this, 1976 vegetation data has been used in this report as a comparison for vegetation changes in later growing seasons.

In 1976, there was an adequate stand of native perennial species on all treatments except for the TOSCO retorted shale which was dominated by annuals (Table 2). Overall, north slopes supported more vegetation than drier south slopes. Below average precipitation over the 1976-1977 winter combined with a drought during the 1977 growing season resulted in significantly less vegetative cover on all treatments in 1977. With a return to nearly average precipitation in 1978 and 1979, the vegetation recovered and reached levels comparable to that before the drought.

The most noticeable change over the 1976-1980 growing period was the change in species composition from a population dominated by perennial

Table 1. *Monthly Precipitation for the Low- and High-Elevation Study Sites, 1976-1980*

	Low-Elevation Site						*High-Elevation Site*				
Month	*1976*	*1977*	*1978*	*1979*	*1980*		*1976*	*1977*	*1978*	*1979*	*1980*
						cm					
January	0.4	1.5	4.8	0.7	5.5		5.1	1.0	1.3	0.5	1.2
February	5.9	0.6	3.5	4.5	9.2		7.1	1.3	1.0	0.4	1.7
March	3.7	2.2	9.2	3.3	5.9		0.6	2.0	2.8	1.3	3.5
April	3.4	0.9	3.4	0.6	2.1		3.4	3.5	2.7	0.6	1.4
May	4.0	1.5	2.6	4.1	6.4		5.2	1.4	3.7	6.0	2.8
June	1.8	0.5	0.6	1.2	0.0		2.5	0.5	0.6	0.7	0.0
July	1.2	-	0.2	1.7	3.0		1.2	3.4	0.5	0.9	2.9
August	2.5	4.8	1.1	3.3	2.2		3.4	3.9	0.6	2.9	2.6
September	3.8	3.7	2.0	0.4	0.6		2.2	3.5	0.2	0.4	1.2
October	1.4	2.2	0.1	2.0	4.8		0.7	2.3	0.3	3.3	2.9
November	0.1	-	5.1	3.0	1.5		0.1	1.9	1.4	1.4	0.3
December	0.1	2.5	2.9	0.6	1.6		0.1	0.7	0.3	0.6	0.9
Total	28.3	20.4	35.5	25.4	42.8		31.6	25.4	15.4	19.0	21.4

- Incomplete data.

grasses to one dominated by shrubs (Table 2). The south slopes showed a greater decrease in perennial grasses and a greater increase in shrubs than did the north slopes. Most of the shrub cover increase was due to the large spreading canopy of fourwing saltbush which increased in size every growing season. Although some increase in shrub cover was measured on the north slopes, the persistence of perennial grasses, primarily western wheatgrass, was greater than on south slopes.

Overall, the TOSCO retorted shale consistently supported less perennial

Table 2. *Vegetative Cover by Species Categories for the Low-Elevation Study Treatments, 1976-1980*

Treatment	Species Categories	1976	1977	1978	1979	1980
		%				
		NORTH ASPECT				
TOSCO Spent Shale	Perennial Grasses	28	21	33	16	12
	Shrubs	13	6	23	27	24
	Annuals	52	<1	55	29	15
15 cm Soil Cover/TOSCO	Perennial Grasses	73	28	52	45	36
	Shrubs	4	5	13	15	10
	Annuals	15	<1	43	25	12
30 cm Soil Cover/TOSCO	Perennial Grasses	53	25	44	42	29
	Shrubs	17	13	9	14	23
	Annuals	14	<1	5	30	13
USBM Spent Shale	Perennial Grasses	62	52	39	40	17
	Shrubs	14	10	15	17	33
	Annuals	17	<1	28	30	15
15 cm Soil Cover/USBM	Perennial Grasses	85	39	61	63	27
	Shrubs	16	16	16	28	19
	Annuals	1	<1	4	6	7
60 cm Soil Cover/USBM	Perennial Grasses	66	28	47	48	20
	Shrubs	24	12	30	41	30
	Annuals	7	<1	11	14	15
Soil Control	Perennial Grasses	78	28	65	53	31
	Shrubs	18	22	17	23	30
	Annuals	2	<1	10	20	10
		SOUTH ASPECT				
TOSCO Spent Shale	Perennial Grasses	23	8	6	12	6
	Shrubs	21	24	17	34	55
	Annuals	22	<1	35	6	32
15 cm Soil Cover/TOSCO	Perennial Grasses	66	14	30	37	13
	Shrubs	5	9	18	27	31
	Annuals	7	<1	28	22	20
30 cm Soil Cover/TOSCO	Perennial Grasses	45	13	17	17	7
	Shrubs	37	45	57	56	36
	Annuals	5	<1	15	10	23
USBM Spent Shale	Perennial Grasses	40	13	15	11	6
	Shrubs	21	32	47	50	34
	Annuals	11	<1	6	18	21
15 cm Soil Cover/USBM	Perennial Grasses	50	6	15	18	5
	Shrubs	23	21	40	52	50
	Annuals	6	<1	14	12	16
60 cm Soil Cover/USBM	Perennial Grasses	53	18	37	37	11
	Shrubs	24	31	31	26	44
	Annuals	3	<1	14	13	17
Soil Control	Perennial Grasses	79	16	40	56	21
	Shrubs	19	7	19	11	13
	Annuals	1	<1	22	10	13

vegetative cover than the USBM retorted shale, soil cover treatments, or the soil control. This was believed, in part, to be a reflection of the reduction in perennials caused by the resalinization in 1973 of the TOSCO profile after leaching. Measured surface temperatures indicated that evaporation of moisture from the black TOSCO material could have also significantly affected the vegetation. Runoff has also been greater on the TOSCO retorted shale due to the silty texture creating slow infiltration and resulting in less moisture recharge of the profile. All of these factors have probably contributed to less perennial vegetation cover on the TOSCO retorted shale. Vegetative analysis by individual species is reported in the appendix to this report.

Moisture in Retorted Shale and Soil Treatments

Spring measurements in 1976 revealed a large reservoir of plant-available moisture in all treatments. Residual moisture from establishment irrigations was most likely responsible for the considerable amount of moisture measured (25% to 30% by volume). By fall, plant-available moisture was depleted to a depth of 90 cm to 120 cm, with moisture use greatest on the USBM retorted shale treatments. The least amount of water used was by plants growing on the TOSCO retorted shale.

Overwinter precipitation, from October of 1976 through 1977 growing season, was considerably less than average for this study site. For this reason, recharge of the moisture profiles was minimal. Consequently, plant-available water was limiting. The north-aspect of TOSCO retorted shale showed the most water lost throughout the growing season. Water losses were slight to insignificant on all other treatments.

With the return to more normal precipitation during the winter of 1977 and spring of 1978, recharge of the moisture profiles for all treatments averaged 25% moisture by volume. Water losses throughout the growing season were similar for both USBM and TOSCO treatments. The soil control showed the least amount of water lost, most probably due to the absence of fourwing saltbush on this treatment.

Patterns of recharge and depletion in the moisture profiles for 1979 measurements were very similar to 1978 values. In 1980, recharge from spring snowmelt averaged 20% to 25% moisture by volume, which, by the end of the growing season was depleted to approximately 10% moisture by volume. Once again, the soil control averaged the least amount of water lost from its profile, probably due to the lack of large shrubs on the treatment.

After seven growing seasons, the vegetative composition on these treatments is fairly stable. The large fourwing saltbush shrubs currently dominating the vegetation will most likely continue to extract substantial amounts of water from the moisture profiles of all treatments. If overwinter precipitation is average, the recharge and extraction patterns of both USBM and TOSCO retorted shale should continue to provide adequate plant-available moisture to support the present vegetative cover.

Leaching and Movement of Soluble Salts

Soluble salts in the TOSCO retorted shale extracts, before leaching, averaged about 18 mmhos/cm. Immediately after leaching in early 1973, the EC values fell to around 5 mmhos/cm, but due to a combination of factors, the profiles of the TOSCO retorted shale were resalinized by the fall of 1974 (Harbert and Berg, 1978). A large reservoir of subsurface moisture, the movement of that moisture along with dissolved salts upward, and rapid surface evaporation from the black material combined to cause the resalinization. The concentration of salts at the shale surface was particularly noticeable, with EC values of shale extracts reaching 15 to 17 mmhos/cm. Soluble salts did not accumulate at the surface of the TOSCO shale treatments which had not been leached because subsurface water in excess of field capacity was not available to transport dissolved salts upward.

Core samples taken in subsequent years indicated that additional moisture from winter and spring precipitation was effective in moving the soluble salts downward within the profile. Although when sampled in 1978, there was a small overall increase in salinity throughout the entire profile of the TOSCO shale plots, which was likely due to leaching of soluble salts from large particles of the processed shale. Further precipitation and continued weathering of the shale particles resulted in an overall decrease of salinity throughout the entire profile of the TOSCO shales by 1980. This, combined with a satisfactory vegetative cover which effectively utilized moisture from the profile, should reduce the potential for upward movement of water and dissolved salts.

The salinity hazard of the USBM shale was initially less than the TOSCO shale, and after the 1973 leaching, has continued to remain at an acceptable level. Resalinization of the USBM shales did not occur, probably because of the coarse texture of this material, which restricted upward capillary movement.

The soil control was non-saline originally and no salt accumulation was observed during the study period.

Runoff and Water Quality

Surface runoff has primarily been the result of spring snowmelt, although occasional summer thunderstorms have resulted in measureable surface runoff. Volume of runoff, sediment yields, conductivity, and chemical analyses are presented in the full report. Runoff and water quality data for the 1973-1976 period were reported in Harbert and Berg (1978).

Overwinter precipitation for 1976-1977 was severely limiting, resulting in no measurable spring snowmelt runoff except for one north-aspect, 15-cm soil cover/TOSCO plot. Runoff calculated from this plot only amounted to 0.02 cm. In September of 1977, two separate summer thunderstorms produced limited runoff on a few treatment plots. The only significant runoff was confined to the TOSCO retorted shales and was ranked as posing a low salinity hazard. Sediment yields from the TOSCO shale treatments were highest, but when compared to agricultural soils, were small. Caution must be used in interpreting these data as it has been observed that small amounts of runoff dissolved salts concentrated at the surface. Larger amounts of runoff simply diluted these salts, decreasing the salinity hazard of the runoff water.

In 1978, spring snowmelt produced runoff primarily restricted to the various TOSCO shale treatment plots. With small amounts of runoff, the salinity hazard was rated moderate to high for most treatments. Sediment yields were considered minimal.

A larger amount of spring snowmelt runoff in 1979 was rated as having a low salinity hazard with nominal sediment yields.

Spring snowmelt in 1980 produced runoff only on frozen north-aspect slopes. Because a thin layer of ice remained over the frozen ground, the water quality of the runoff posed no environmental hazard.

The well-developed vegetative cover on all treatments at this site will most likely minimize excessive runoff and erosion in future seasons. Runoff from spring snowmelt will depend primarily upon whether the ground surface is frozen or thawed, but water quality from a frozen surface should not present environmental problems. This type of runoff will, however, limit the amount of moisture that infiltrates the profile to be used by vegetation later.

Surface Temperatures

Temperatures 1 cm below the surface of TOSCO shale and soil plots, for both north and south aspects were monitored during the 1978 growing season. Previous data (Harbert and Berg, 1978) had shown temperatures sufficiently high in late June and July on the TOSCO shale, south-aspect, to limit seedling establishment. The 1978 measurements continued to support these findings. Initial establishment of vegetation without the protection of a mulch could be difficult, and the successful germination of seedlings in continuing years might depend upon the shade provided by an adequate mature vegetative cover. Evaporative losses could also be substantial, creating a difficult revegetation site.

High-Elevation Study Site

Vegetation

Because of ineffective leaching of some treatments in 1974, an unsatisfactory stand establishment resulted. All plots at this study site were releached, reseeded, and irrigated for establishment in 1975. Therefore, 1976 was the first growing season dependent upon natural precipitation, although it was likely that some moisture remained in the soil profile due to leaching.

Initially, a satisfactory vegetative cover was established in 1975, with dense stands of western wheatgrass on the TOSCO and USBM retored shales. This was probably due to the effective leaching and doubled seeding rate of western wheatgrass.

Very little overwinter precipitation and an abnormally dry growing season in 1977 combined to reduce the vegetative cover on almost all treatments. Shrubs endured the drought better than perennial grasses, the former actually increased on USBM retorted shale. Annual species dropped to less than 1% on all treatments due to lack of moisture (Table 3).

In the fall of 1977, cattle accidentally entered the study site and grazed much of the vegetation. Because of adequate moisture for plant regrowth, the overall 1978 vegetative cover was not severely reduced despite heavy grazing of fourwing saltbush. With more moisture, annual species were measured in modest amounts, particularly on the soil control.

Another season of sufficient moisture increased the vegetative cover on almost all treatments in 1979. Unfortunately, a large amount of this increase was due to the invasion of annual species such as cheatgrass and mustard (Table 3). The increase of annuals may have also been aided by the shift from a population of mainly perennial grasses to one increasingly dominated by shrubs. This transition was especially noticeable on the USBM retorted shales where rodent disturbances also allowed the invasion of annuals.

During the 1980 growing season, rodent activity increased, disturbing large areas of many treatment plots and resulting in an overall decrease of vegetative cover. Most of this decrease was attributable to the loss of perennial grasses on many treatments (Table 3). The invasion of weedy species also accompanied this disturbance.

Generally, for the years discussed, the overall vegetative cover for both TOSCO and USBM shales was comparable to the soil control. In retrospect, the doubled seeding rate of western wheatgrass on those two treatments provided an initial cover which exceeded that of the soil control. After a severe drought season in 1976-1977, vegetation on both shale treatments recovered well. However, the species composition of the shale treatments supported a much greater proportion of cover as shrubs than the soil control, a trend which is expected to continue in future growing seasons.

Moisture in Retorted Shale and Soil Treatments

Spring snowmelt generally provided a maximum moisture recharge of treatment profiles. During the growing season, vegetation extracted plant-available moisture from the treatment profiles resulting in a depletion by fall.

Moisture profiles of almost all treatments in 1976 contained residual moisture from 1975 irrigation applications. One exception seemed to be the USBM treatment on north slopes. Very little recharge from spring snowmelt occurred because of the high surface runoff for these plots (Harbert and Berg, 1978). In fact, precipitation during the 1976 growing season, combined with a less than average vegetative cover, produced an overall increase in plant-available water by the fall of 1976.

Very limited overwinter precipitation, from October 1976 through March 1977, resulted in a minimal spring recharge of moisture profiles. Because of the lack of plant-available water, vegetative growth on almost all treatments suffered, resulting in very little water loss throughout the profile.

Although precipitation for the 1977-1978 winter period was below average, spring recharge for 1978 averaged approximately 20% by volume for USBM treatments. Most of these treatments were recharged to a depth of 90 cm. The TOSCO retorted shale averaged only 10% to 15% moisture by volume to 60 cm depths. This may be a reflection of the higher surface runoff from the latter treatments. Spring recharge was greatest on the soil control, averaging 20% to 25% moisture by volume. Water loss throughout the growing season was also greater on the soil control, resulting in only about 10% moisture by volume remaining in the profile by fall of 1978. Moisture extraction patterns on all other treatments were similar.

Near average precipitation permitted a 1979 spring recharge of 20% to 25% soil moisture by volume on all treatments. Large amounts of runoff from a TOSCO retorted shale, south-aspect, plot did not seem to adversely affect spring recharge. Once again, the soil control averaged the highest spring soil moistures, and the most water lost from the profile through the growing season. Moisture measurements taken in the fall of 1979 indicated depletion to approximately 10% on most treatments, while the TOSCO retorted shale averaged 6% moisture by volume.

Seasonal moisture profiles for 1980 followed much the same patterns as in previous years. Recharge from a greater than average snowfall brought most treatments to 20% to 30% moisture by volume capacity to depths of 60 cm to 90 cm.

Table 3. Vegetative Cover by Species Categories for the High-Elevation Study Site, 1976-1980

Treatment	Species Categories	1976	1977	1978	1979	1980
		%				
		NORTH ASPECT				
TOSCO Spent Shale	Perennial Grasses	68	38	43	44	22
	Shrubs	21	12	9	33	18
	Annuals	6	<1	12	0	1
15 cm Soil Cover/TOSCO	Perennial Grasses	48	42	52	59	26
	Shrubs	13	7	21	22	11
	Annuals	7	<1	2	3	1
30 cm Soil Cover/TOSCO	Perennial Grasses	40	38	54	47	38
	Shrubs	9	<1	9	3	2
	Annuals	7	<1	5	32	11
USBM Spent Shale	Perennial Grasses	60	40	24	21	6
	Shrubs	20	30	32	51	48
	Annuals	2	<1	3	7	5
15 cm Soil Cover/USBM	Perennial Grasses	48	44	56	35	12
	Shrubs	7	10	23	38	31
	Annuals	11	<1	2	7	1
30 cm Soil cover/USBM	Perennial Grasses	29	42	42	29	9
	Shrubs	13	12	24	34	28
	Annuals	17	<1	7	29	12
Soil Control	Perennial Grasses	41	38	43	41	26
	Shrubs	16	12	9	14	9
	Annuals	14	<1	12	44	11
		SOUTH ASPECT				
TOSCO Spent Shale	Perennial Grasses	61	49	31	28	16
	Shrubs	16	23	23	30	14
	Annuals	2	<1	<1	9	17
15 cm Soil Cover/TOSCO	Perennial Grasses	45	39	45	54	19
	Shrubs	12	15	15	21	14
	Annuals	4	<1	<1	0	1
30 cm Soil Cover/TOSCO	Perennial Grasses	42	38	41	40	9
	Shrubs	23	23	10	11	29
	Annuals	7	<1	8	30	2
USBM Spent Shale	Perennial Grasses	41	21	24	16	3
	Shrubs	32	37	36	43	49
	Annuals	3	<1	<1	0	14
15 cm Soil Cover/USBM	Perennial Grasses	39	38	40	21	6
	Shrubs	16	17	27	38	40
	Annuals	16	<1	8	30	11
30 cm Soil Cover/USBM	Perennial Grasses	28	26	39	17	5
	Shrubs	24	19	17	31	39
	Annuals	18	<1	3	34	19
Soil Control	Perennial Grasses	28	25	42	24	9
	Shrubs	22	17	14	16	13
	Annuals	19	<1	12	52	19

Overall, it appeared that moisture recharge by spring snowmelt was significantly affected by the fine-textured TOSCO material, due to high runoff rates. The coarser textured USBM shale allowed faster infiltration of snowmelt which resulted in greater spring moisture levels.

Leaching and Movement of Soluble Salts

Core samples taken after leaching of the retorted shales and 15-cm soil cover/retorted shales in the fall of 1973 indicated that a reduction of salinity had not occurred. The leaching technique used was ineffective because the application of the irrigation water did not exceed the surface evaporation to the extent that soluble salts were moved a satisfactory depth in the profile. In the spring of 1974, all previously leached treatments were releached to decrease the salinity hazard of the shale. Resalinization of the TOSCO retorted shales once again occurred, primarily at the shale surface. Another application of leach water was made to all leached treatments in the spring of 1975. Core samples after leaching indicated that effective leaching had occurred throughout the profile with accompanying EC values of less than 5 mmhos/cm.

The TOSCO shale treatments covered with 30 cm of soil were never leached, and therefore, continued to maintain a higher salinity level then the leached treatments.

Core samples taken in 1978 suggested that the TOSCO shale treatments had become slightly more saline with time, although shale extracts only averaged about 5 to 7 mmhos/cm in the leached treatments, and 10 to 12 mmhos/cm in the unleached treatments. This increase was most likely due to the leaching of soluble salts from within shale particles.

Increased weathering of the shale materials, combined with seasonal precipitation resulted in an overall decrease of salinity throughout the entire profile of the TOSCO shales by 1980. Of particular interest was the downward movement of soluble salts in the 30-cm soil/unleached TOSCO shale treatments.

The USBM shale extract values were initially less saline than the TOSCO shale material, and with additional leaching have become acceptable with no indication of resalinization in succeeding years. Little or no change was observed in the salinity status of the soil control throughout the study.

Yearly precipitation and the rapid removal of subsurface water by the established vegetation cover should limit any upward resalinization.

Runoff and Water Quality

All runoff and water quality data for the 1974-1976 period of study were reported in Harbert and Berg (1978). Runoff, sediment yield, conductivity, and chemical analyses for 1977-1980 measurements are presented in the full report.

Runoff in the spring of 1977 was confined to the north aspect slopes of all treatments. This was mainly a reflection of the very limited overwinter precipitation for this year. In August of 1977, a thunderstorm produced small amounts of runoff on almost all treatment plots ranging from 0.02 to 0.12 cm. Salinity hazard was low for most treatments, but the TOSCO retorted shale runoff was rated as medium to high. One USBM retorted shale plot also produced runoff with a high salinity. Due to the small amount of runoff, surface salts were dissolved and removed by the initial runoff. Without additional runoff to dilute this concentrated salt solution, salinity hazards were high. This was clearly illustrated by the 1978 spring snowmelt runoff and analyses. Runoff from both USBM and TOSCO shale south slopes was minimal in quantity but had a very high salinity hazard, whereas runoff from the north slopes of these two treatments was approximately three times the volume, but the salinity hazard was considerably less. Sediment yields were considered negligible when compared to regional sediment yields mapped by the Soil Conservation Service.

In 1979, spring snowmelt runoff had low salinity hazard, minimal runoff, and small sediment yields.

In 1980, spring runoff was generally small in volume and rated low with respect to salinity hazard, sodium hazard, or sediment yield.

At present, runoff, erosion, and salinity hazards from the treatments are within acceptable levels. The most critical environmental factor appears to be the salinity hazard of small amounts of runoff from the retorted shale. This type of runoff is associated with limited snowmelt runoff or summer thunderstorm activity typical of this region. As far as revegetation efforts , the spring snowmelt runoff poses a problem in that moisture from snowmelt that runs off does not enter the shale or soil profile, and therefore, is not available for plant growth needs. The satisfactory vegetative cover on most treatments minimized runoff and erosion. The increased rodent activity causing surface disturbance may develop the potential for greater runoff and erosion.

Conclusions

Low-Elevation Study Site

Vegetation

1. After seven growing seasons, a good vegetative cover (52% to 68%) existed on all treatments.
2. The TOSCO retorted shale, with no soil cover, generally supported less perennial vegetation throughout the years than other treatments.
3. A shift in vegetative composition from perennial grasses to predominance by xeric shrubs occurred on all treatments.

Moisture

1. With average seasonal precipitation, most treatment profiles were recharged to levels of 20% to 25% moisture by volume in the spring to depths of 60-120 cm.
2. Good vegetative cover, especially deeper-rooted shrubs, extracted substantial moisture from all treatment profiles to approximately 10% moisture by volume by fall.
3. South-facing slopes reflected a drier soil moisture regime than north-facing slopes by a more rapid shift from grasses to xeric shrubs.

Salinity

1. Leached treatments of the fine-textured TOSCO shale initially experienced some accumulation of surface salts, and salinization of soil covers over retorted shale.
2. Seasonal precipitation in later years reduced salinity levels to 5 mmhos/cm or less throughout the entire profile of leached treatments with no indication of upward salt migration.

Runoff and Water Quality

1. The quantity and quality of spring snowmelt runoff depended on whether the ground surface was frozen or thawed.
2. A greater runoff volume resulted when the ground surface was frozen and this runoff was of higher water quality.

3. Small amounts of runoff in 1978 were rated medium to very high salinity hazard (1210 - 3200 umhos/cm).
4. The use of a mulch during vegetative establishment and the present vegetative cover contributed to low sediment yields for all treatments. Sediment yields from the TOSCO shale treatments were the highest, but even these were small when compared to agricultural soils.

High-Elevation Study Site

Vegetation

1. The initial vegetation established in 1974 was unsatisfactory because perennial grasses were seeded at a low rate, a too dense stand of big sagebrush resulted, and the inadequately leached retorted shales were resalinized.
2. After releaching, rototilling and reseeding, a good stand resulted.
3. Rodent activity, particularly pocket gophers, caused considerable surface disturbance resulting in a loss of vegetative cover.
4. A shift from perennial grasses to predominance by xeric shrubs was observed.

Moisture

1. Spring snowmelt resulted in recharge of profiles to depths of 60-120 cm.
2. Evapotranspiration resulted in depletion of plant-available moisture in the profiles by fall.

Salinity

1. Due to high evaporative demand and low irrigation rates, resalinization of the leached layer over the retorted shales resulted in 1974.
2. Resalinization did not occur after the 1975 releaching.
3. Seasonal precipitation and continued weathering reduced soluble salts to 5 mmhos/cm or less throughout the entire profile of leached treatments by 1980, with no indication of upward salt movement.

Runoff and Water Quality

1. Spring snowmelt was responsible for the majority of surface runoff on all treatments.
2. When small amounts of runoff resulted, from either limited snowmelt or summer thunderstorms, the salinity hazard was rated high to very high from the retorted shales (1120 - 7200 umhos/cm).
3. The sodium hazard and sediment yields were rated low for runoff from all treatments.

Recommendations

1. Intensive management will be required to establish a satisfactory vegetative cover within a reasonable amount of time.
2. As a specific retorting method develops, investigation of the waste as a plant growth media requires a thorough examination of the physical and chemical characteristics of the retorted shale.
3. The eventual erosion of soil cover or modified retorted shale, particularly from steep south-facing slopes, could result in continued exposure of less weathered retorted shale. This should be considered in future waste stabilization research and planning.
4. The ultimate fate of applied leach water, along with a comprehensive water balance (especially for high-elevation disposal sites) should be addressed.
5. Large herbivores were restricted from the small plots in this study by fencing, future research should evaluate both wildlife and domestic livestock use on the retorted shale disposal site.
6. The retorted shale disposal site stabilization plan must allow for localized severe rodent disturbances as observed in this study.

References

1. Harbert, H. P., III, and W. A. Berg. 1978. Vegetative stabilization of spent oil shales. EPA-600/7-78-021, U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnati, Ohio.

Benjamin L. Blaney is the EPA author and also the EPA Project Officer (see below); Jay R. Hoover and James R. Blacksmith are with Radian Corporation, Austin, TX 78766; Paul W. Spaite is a consultant, 6315 Grand Vista Avenue, Cincinnati, OH 45213.

The complete report, entitled "Energy Use Patterns and Environmental Implications of Direct-Fired Industrial Processes," (Order No. PB 81-234 221; Cost: $9.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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