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# **COMPREHENSIVE PLANNING FOR STRIP MINING RECLAMATION IN DRY REGIONS WITH EMPHASIS ON WATER HARVESTING**

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## STRIP MINE RECLAMATION IN DRY REGIONS

### FOREWORD

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# STRIP MINE RECLAMATION IN DRY REGIONS

## COMPREHENSIVE PLANNING FOR STRIP MINE RECLAMATION IN DRY REGIONS WITH EMPHASIS ON WATER HARVESTING

### INTRODUCTION

Peabody Coal Company has been mining coal within a 65,000 acre area on the Black Mesa, Arizona's leased from the Navajo nation. Although Indian lands do not fall under the federal reclamation law, and there is no surface mine reclamation law for the state of Arizona, the Navajos have an environmental council that works closely with the Office of Surface Mining. Thus, the requirements of the Federal law are virtually the same for the Black Mesa, namely:

to restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood, so long as such use or uses do not present any actual or probable hazard to public health or safety or pose any actual or probable threat of water diminution or pollution, and the permit applicants' declared proposed land use following reclamation is not deemed to be impractical or unreasonable, inconsistent with applicable land use policies or plans, involves unreasonable delay in implementation, or is violative of Federal, State, or local law (United States Congress, 1977).

Presently, the aim of Peabody's reclamation efforts is to return the mined land to productive range land. Methods involve reregrading spoil to slopes no greater than 15 percent, topsoiling to a depth of at least 6 inches, mulching at rates of about 1.5 tons/acre, contour disking, planting a seed mixture of native and non-indigenous species, and fencing reclaimed areas against livestock.

In arid lands such as the Black Mesa water is the limiting factor for plant growth. Soil nutrients and sunlight are plentiful, but precipitation is sparse and erratic. The annual precipitation on the Black Mesa is about 10 or 11 inches and supports a sparse native vegetation dominated by juniper and pinyon pine. The primary use of the lease area prior to mining was grazing and occasional wood harvesting for domestic use. The area was heavily overgrazed.

## STRIP MINE RECLAMATION IN DRY REGIONS

The reclamation efforts being made by Peabody are perhaps the best approach to establishing range on the mined areas of the Black Mesa. There are several problems including (1) high costs which range from \$12,000 to \$20,000 an acre, (2) low economic returns (similar, non-Indian lands lease for about \$.05 per acre per year), (3) the uncertainty of success due to the vagaries of precipitation which could delay vegetation establishment (even with reseeded) up to 8 or 10 years, (4) the lack of assurances that once the land is released back to the Navajo the excessive grazing presently practiced by local inhabitants will not be continued, (5) the difficulty of excluding livestock from reclaimed areas during vegetation establishment, and (6) the present reclamation offers no alternative use of the land. With increasing population on the reservation and subsequent pressure on family use areas this might be a short-sighted view; a view supported by the letter of the surface mining regulations.

Unfortunately, even with a completely successful conversion of mine lands to good range lands little will have been done to improve the income, nutrition and employment opportunities of the local people.

Water harvesting (i.e. concentrating water from precipitation falling on a larger catchment area for growing high value crops on a smaller agricultural area) has several advantages over conventional reclamation including (1) lower costs of reclamation by not requiring topsoil, (2) the certainty of early establishment and sustained crop production in areas of uncertain precipitation, (3) higher economic returns from higher value land use, (4) greater opportunities for improving local nutrition, (5) greater density and intensity of land use, (6) increased employment opportunities.

Water harvesting is viewed as an alternative or supplement to conventional reclamation. It requires more work and a knowledge different from that needed for managing livestock. It would perhaps not be appropriate to convert an entire operation the size of the Black Mesa Mines entirely to water harvesting, but rather to have a mixture of land uses.

Water harvesting is at variance with the surface mining regulations in not regrading to original contour and in not completely revegetating the entire area with native species. However, these disadvantages appear considerably outweighed by the potential advantages.

The Bureau of Mines agreed to fund a project that would investigate the potential of water harvesting on the Black Mesa. Funding began in April 1978 and ended April 1982. However, because of the success demonstrated on the project, arrangements are presently being made with Brigham Young University to assume and continue the operation.

This report briefly reviews the 1978-1981 progress and covers in more detail the progress made during 1981.

## STRIP MINE RECLAMATION IN DRY REGIONS

### OBJECTIVE

The primary objective of the project was to demonstrate and evaluate water harvesting as a method of developing water from sparse precipitation to increase the economic and social benefits of reclamation.

### SCOPE

The aim of the project was to develop a prototype of a self sufficient, family farm. Although there is a body of world-wide experience (see Appendix) on water harvesting systems in dry regions, this is the first attempt ever made to undertake such an extensive project on mined land. Thus, the project was viewed as one of research as well as demonstration where different techniques could be tested and experience gained in operating and managing such systems.

Originally it was planned to operate the project for 5 years. However, because of funding problems the project was only supported for 4 years. Nevertheless, it was possible to achieve the primary objective in 4 years. Sufficient information and experience was gained to design and operate water harvesting systems, whether or not on mine spoils, in dry regions of the west.

### PROGRESS

#### Summary of 1978 season (April 1978 - March 1979)

A water harvesting system was originally designed to be installed on ungraded spoil and to make use of the final cut at the high wall for water storage. However, the Surface Mining law, promulgated after the initial design had been made, required the reduction of high walls and prohibited the use of post regulation spoil areas for water harvesting. It was therefore necessary to choose a site among the available pre-regulation areas and to design a system which would minimize reshaping the topography of the already regraded spoil. Activities during the first year are summarized in Table 1.

In May, the final design was completed and the selected site was fenced. This was followed by leveling and terracing the farm area and excavating the ponds. Catchment areas were graded, drainage ways installed, and the areas were salt treated. The contributions of Peabody Coal Company in developing the site were substantial (Table 2).

An attempt was made to reduce costs by crushing and screening the rock chips needed for the catchment area treatment on site. Due to the breakdown of Peabody's main rock crusher, the smaller crusher being used by the project was appropriated. Crushing and screening on site had to be abandoned and it was necessary to purchase the materials needed.

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Table 1. Project activities prior to April 1, 1979.

Site selection	Mar. 1978
Plan development	Apr. 1978
Computer simulation to test plan	Apr. 1978
Final plan	May 1978
Area fenced	May 1978
Farm area leveled and terraced	June 1978
Ponds excavated	June 1978
Catchment area graded and drainage ways installed	July 1978
Spillways and control structures constructed	Aug.-Sept. 1978
Catchment area salt-treated	Oct. 1978
Screening plant for rock chips modified and installed	Nov. 1978
Orchard shaped	Nov. 1978
Materials ordered and plans made during inclement weather	Dec.-Jan. 1979
Holes for fruit trees drilled and filled with topsoil	Jan. 1979
Chip screening plant modifications	Jan.-Mar. 1979
Fruit trees "heeled in" in trench at Tuba City	Feb. 1979
Garden layout finalized, seeds ordered	Feb. 1979
East catchment area compacted	Mar. 1979
Chip screening system dismantled	Mar. 1979

Table 2. Partial listing of contributions from Peabody Coal Co. for 1978.

<u>Heavy Equipment</u>	<u>Hours</u>
Dozer w/operator	136
Grader w/operator	69
Scraper w/operator	12
Dump trucks w/operators	6
Large front end loader w/operator	6
Cherry picker w/operator	8
Backhoe w/operator	6
Backhoe w/operator	4
<u>Support</u>	
Welders	10
Electricians	6
Crusher operator	40
Reclamation personnel	120
<u>Facilities</u>	
Trailer	
Office space and supplies	
Fencing, 5,000 feet @ \$7.00/foot	

## STRIP MINE RECLAMATION IN DRY REGIONS

A major problem in site development was the distance of the project from supplies of equipment and materials. For example, sawdust had to be trucked from 170 miles, salt from 300 miles, and rock chips hauled from over 100 miles. Flagstaff (150 miles) was the nearest source of rental equipment. Often the cost of transportation was greater than that of the materials. In November, the orchard area was shaped into a "road" system of water harvesting. The area was later coated with asphalt-fiberglass and trees were planted.

Subsidence immediately after site preparation caused some problems, particularly with settlement and crack development in the ponds. Some damage also occurred to the spillways, and there was some subsidence on the agriculture terraces. This experience has led to the conclusion that it would be best in future projects of this kind to roughly shape the area, and then wait two or three years for earth settlement before final installation.

### 1979 Season (April 1979 - March 1980)

Activities during the second year are summarized in Table 3. By the spring of 1979 the shaping and grading of the site was completed and sufficient water was available to begin agricultural testing while completing the treatments of the catchments.

In early April, 72 fruit trees and 20 berry vines were planted. Because of a high electrical conductivity of the spoil material in the orchard area, it was decided not to risk planting the fruit trees directly in the spoil. Instead, during January a truck-mounted 24"-diameter auger was used to drill 5 foot deep holes which were then filled with a mixture consisting of 60% by volume topsoil and 40% decayed sawdust. One and one-fourth pounds of 16-20-0 fertilizer was sprinkled into the hole during filling. Subsidence along the bottom of the catchment "V's", where runoff is concentrated and infiltration greatest, was a problem at some of the planting spots. Additional fill was added to these planting spots in November to prevent ponding of water during the winter.

The agricultural terraces were leveled, seed beds prepared, and several trial crops were planted by late May. The agricultural harvest began in mid August with table beets, squash, and tomatoes. Little rain fell that summer (0.83 inch total for June, July, August and September), and water for irrigation was short. On September 6, a premature final harvest was made of the beets, cabbage, chard, bush beans, pole beans, peas, carrots, lettuce, New Zealand spinach, spinach, and turnips. Irrigation was discontinued for the pinto beans, potatoes, and onions, but was continued for the tomatoes, squashes, and melons. On October 10, a final harvest was made on everything that remained.

Some of the most promising crops and production data are presented in Table 4. Chard, beets, and turnips were clearly capable of doing well in the heavy, salty spoils. Other types, like carrots and potatoes, were

STRIP MINE RECLAMATION IN DRY REGIONS

Table 3. Project activities during the period April 1, 1979 through January 31, 1980.

Planting of fruit trees and berry vines	early Apr. 1979
Repair of subsidence damage to pond sluices	Apr. 1979
Leveling of agricultural terraces with land plane	mid Apr. 1979
Plowing of agricultural terraces	late Apr. 1979
Removal of rocks from agricultural terraces	Apr.-Sept. 1979
Repair of subsidence and piping damage along main ditch	Apr.-Sept. 1979
Disking of garden area	early May 1979
Garden area furrowed; leaf and root crops planted and irrigated with harvested water	early May 1979
Initial rough layout of west catchment	mid May 1979
Repair of stuccoed ditch sections damaged by frost heaving	May 1979
Peas, beans and tomato sets planted	late May 1979
Delivery of rock chips for covering asphalt membrane	late May-early June 1979
Hand smoothing in preparation for placement of membrane	early June 1979
Application of salt in orchard and on repaired ditch areas	early June 1979
Planting of multi-colored corn in upper-terrace garden and transplanting of corn seedlings on lower terrace	early June 1979
Compaction of orchard and of repaired ditch areas	early June 1979
Placement of about 9 acres of chip-covered, fiberglass-reinforced asphalt membrane	early-mid June 1979
Planting of hybrid sweet corn on lower terrace	late June 1979
Placement of fill dirt in selected spots around pond edges to repair damage due to slumping and subsidence	June-July 1979
First harvest (radishes)	mid July 1979
Final surveying and cutting of ditches on west catchment	early Aug. 1979
Delivery of water by Peabody	early Aug.-early Sept. 1979
Harvest of 121 pounds of beets	mid Aug. 1979
Beginning of squash and tomato harvesting	mid Aug. 1979
Site visit by Navajo Tribal Vice-chairman Frank E. Paul and State Representative Daniel Peaches	late Aug. 1979
Meeting in Flagstaff to formulate general plans for agricultural activities during 1980	early Sept. 1979
Rock raking on west catchment	early-mid Sept. 1979
Hand raking and rock removal on west catchment	mid Sept.-mid Oct. 1979
Harvest of hybrid sweet corn	late Sept. 1979
Harvest of multi-colored corn	early Oct. 1979
Final harvest in garden	mid Oct. 1979
Construction of pipeline/gravity siphon between upper and middle pond	mid Oct. 1979
Last irrigation of fruit trees	late Oct. 1979
Spreading of salt on west catchment	late Oct. 1979
Placement of prototype couple fiberglass-covered evaporation control panels on middle pond	early Dec. 1979
Pumping of water from lower to middle pond	early Dec. 1979
Logistics and planning in preparation for 1980 field season	Jan. 1980

Table 4. Production data for selected crops, 1979.

	Area planted (acres)	Production (pounds)	Equivalent Yield per Acre (pounds/acre)	Average Yield <sup>(1)</sup> per Acre for U.S. (pounds/acre)	Black Mesa Yield as Percentage of Average Yield for U.S.
Beets, with greens attached	0.031	322.00	10,387	11,900 <sup>(2)</sup>	87% <sup>(6)</sup>
Cabbage	0.025	105.00	4,200	22,500 <sup>(3)</sup>	19% <sup>(6)</sup>
Corn, multi-colored harvested dry	0.085	33.00	388	no data	-
Onions	0.012	83.50	6,958	31,400 <sup>(4)</sup>	22%
Potatoes, Norgold Russet	0.025	59.25	2,370	25,900 <sup>(5)</sup>	9%
Tomatoes	0.049	235.00	4,796	16,500 <sup>(5)</sup>	29% <sup>(7)</sup>
Turnips	0.025	201.50 <sup>(6)</sup>	8,060	no data	-

(1) Data in this column from Agricultural Statistics 1978, USDA, U.S. Govt. Printing Office, 1978.

(2) Beets grown for fresh market, average for 1966 through 1968.

(3) Cabbage grown for fresh market, average for 1975 through 1977.

(4) Onions grown mostly for fresh market use, average for 1975 through 1977.

(5) Average for 1955 through 1957.

(6) Many were harvested prematurely due to lack of stored water for further irrigation.

(7) Rows were planted on 64" spacing. Closer spacing would have caused no problems and would have increased the yield.

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unable to push the heavy substrate aside to provide added space for normal growth. Local crusting tended to inhibit the emergence of some types (e.g. carrots), but had no apparent negative effect on others (e.g. squash).

In the spring of 1979, the final smoothing of the east catchment was completed and materials were assembled in preparation for laying the fiberglass-asphalt-chipcoat membrane. On June 6 a crew of seven began placing the membrane on the orchard area (excluding 6-foot strips along which the trees had been planted), the main ditch, and the east catchment. A roller was attached beneath an asphalt boot truck several feet ahead of

the spray bar to feed the 10 mil, 78-inch wide fiberglass gauze as the truck pulled forward. The emulsified CRS-2 asphalt was simultaneously sprayed onto the gauze, penetrating it, and tacking it to the compacted surface. The dump truck, equipped with a chip spreader, backed along the sprayed strip, covering it with chips.

During early August, the design of the west catchment, and the surveying and staking of the ditch alignments was completed. Rough grading of the ditches took place immediately. Final grading of the ditches and smoothing of the higher rock area in the southwest corner of the site took place in early September and rock-raking with a tractor-pulled windrower was completed by mid September. The catchment surface was groomed by hand. Larger rocks were concentrated into piles, and removed from the site. Salt was applied at rates slightly in excess of 25 tons to approximately 7 acres of catchment in late October. A front loader and a tractor-drawn fertilizer spreader was used in the application. The salt-treated catchment was compacted with a vibrator-compactator in March.

Measurements were made of changes in the soil chemistry of spoil and topsoil material due to irrigation. The effects of irrigation appear similar for both types of material. The pH was raised slightly, but remained in a range quite acceptable for growing vegetables. The level of soluble salts, at least in the furrows, was decreased. Sampling for changes in soluble salts and pH in the topsoil and spoil was not intensive. Analysis of samples taken March 21, 1978 indicates the topsoil contained 777 ppm of soluble salts and had a pH of 7.0. Analysis of spoil at this same date showed a soluble salt content of 2996 ppm and a pH of 6.8. Subsequent sampling on March 21, 1980 revealed a pH of 7.9 and a soluble salt content of 385 ppm for the topsoil and a pH of 7.2 and a soluble salt content of 2513 ppm for the spoil.

A partial list of the contributions to the project made by Peabody during the 1979 season are summarized in Table 5.

### 1980 season (April 1980 - March 1981)

Operation of the system for the production of crops was emphasized this season. In addition to measuring the production of various crops, the relative

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Table 5. Partial list of contributions from Peabody Coal Co. for 1979.

---

<u>Equipment</u>	<u>Hours</u>
Dozer w/operator	3
Grader w/operator	36
Scraper w/operator	10
Dump truck w/operator	5
Loader w/operator	3
Farm tractors w/operators	45
Farm tractors w/operators	300
Water trucks	12
<u>Support</u>	
Welding	10
Machining	4
Reclamation personnel	80
<u>Facilities</u>	
Trailer w/water and electricity	
Office space, telephone and supplies	
Metal fence posts	
Fertilizer	

---

productivity of spoil and topsoil was tested to determine the cost-effectiveness of re-topsoiling the irrigated area. One garden in the spoil and one in the topsoil were planted to the same crops during the period May 28th through June 2nd. These gardens were on the upper terrace. It was decided not to irrigate the lower terraced to insure enough water for an adequate test. The reservoirs were at one-half capacity at the beginning of the season. The total amount of water applied was about one million gallons, or two feet over the cropped area of 1.74 acres. 460 lbs/acre of 16-48-0 fertilizer was applied to the entire upper terrace, with the topsoil end receiving an additional 380 lbs/acre of urea (46-0-0).

The seasons total labor hours of 2,400 can be divided into 200 hours of catchment completion, 200 hours of non-agricultural weeding (most tumbleweed removal from the catchments), 1,800 hours of farming (planting, irrigating, weeding, harvesting, distributing produce, tractor driving and maintenance, etc.), and 200 hours of miscellaneous (mainly picking up supplies and office work). The 70 horse-power tractor and the 3 horse-power irrigation pump each logged 100 hours.

Agricultural production was affected this first season by problems with irrigation and pests. Certain areas of the fields subsided as much as one

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foot, making flood irrigation difficult. The infiltration rate on the spoil was slow, often requiring three days to absorb irrigation water. Mice dug out many seeds. Corn was damaged by ear worms (Heliothis zea), cabbage by flea beetles (Subfamily Aticinae) and aphids (Family Aphididae), and beets by fungus.

Despite these problems the overall performance of the crops was good (Table 6), with the production of table beets and sugar beets exceeding the national average, and the production of carrots, corn, and summer squash also being high. Beets and carrots did better in the spoil than in the topsoil, indicating that topsoiling is not necessary for these crops. The young fruit and nut trees developed more than a foot of new growth.

The water catchment and storage system worked well. Runoff from both salt-treated and fibreglassed-asphalt-chipcoat catchments was observed after only 1.10 inch of rain. No more seepage from the upper pond was observed. Very little new subsidence occurred in the orchard, indicating that subsidence was slowing with time.

One hundred evaporation-control floats were installed on the middle pond in May. They were made of fibreglassed, four foot by eight foot, 3/4 inch polyurethane sheets tied together with nylon cords. A row of pole beans was planted on the windward side of the pond to reduce wind removal of these covers.

A tracking solar photovoltaic collector was installed in August. Ordinary mirrors concentrate 5x-suns of power on single-sun photovoltaic panels. The collector is large enough to provide all the necessary power for pumping.

It was concluded that to increase agricultural production, the key improvements would be: the use of sprinklers for better irrigation in subsidence areas, better control of pests, and relatively larger plantings of successful crops like carrots, summer squash, and beets.

### WORK ACCOMPLISHED DURING THE 1981 SEASON APRIL 1981 - MARCH 1982

The work this season attempted to answer several questions:

1. What is the best irrigation method for the site?
2. How well do various floating materials work for evaporation control?
3. What are the hydrological characteristics of the catchment-pond system?
4. How well does the solar generator function in the context of a remote farm?
5. What are some of the economics of the water harvesting system?

Table 6. Production Data.

Crop 6.	Spoils or Topsoil	Area (acres)	Yield (lbs)	Production 1980 (lbs/acre) "Prod"	Production 1979 (lbs/acre)	Spoils Prod Topsoil Prod	National Avg <sup>t</sup> (lbs/acre)	Prod/Nat Avg	Value* (\$/lb)	Estimated Income Irrigated Area (\$/acre year)	Est Income Including Catchments (\$/acre year)
Beans, Pinto	S	.073	46	630				.49	.16 <sup>a</sup>	101	14
	T	.055	46	829		.76	1,279 <sup>a</sup>	.65		133	19
Beets, Early Wonder	S	.073	1,613	22,089	10,387			1.65	.08 <sup>c</sup>	1,767	252
	T	.055	926	16,685		1.32	13,400 <sup>b</sup>	1.25		1,335	191
Cabbage, Surehead	S	.073	46	630	4,200			.03	.08 <sup>d</sup>	50	7
	T	.055	325	5,847		.11	23,800 <sup>d</sup>	.25		468	67
Carrots, Goldinhardt	S	.047	812	16,666				.65	.10 <sup>d</sup>	1,667	238
	T	.037	607	13,709		1.22	25,800 <sup>d</sup>	.53		1,371	196
Corn, Ornamental	S	.183	1,050	5,750	388			.81	.03 <sup>e</sup>	173	25
	T	.139	1,545	10,439		.55	7,084 <sup>e</sup>	1.47		313	45
Potatoes, Kennebec	S	.040	265	6,545	2,370			.25	.04 <sup>d</sup>	262	37
	T	.019	139	7,490		.87	6,300 <sup>d</sup>	.28		300	43
Sugar Beets, SSE1	S	.024	1,474	60,544				1.47	.01 <sup>f</sup>	605	86
	T	.019	1,275	68,956		.88	1,200 <sup>f</sup>	1.67		690	99
Summer Squash, Early Golden	S	.073	1,424	19,507					N.A.		
	T	.055	1,705	30,721		.63	N.A.		N.A.		
Sweet Corn, Early Sunflow	S	.183	416	2,278				.30	.09 <sup>d</sup>	205	29
	T	.139	621	4,196		.54	4,700 <sup>d</sup>	.54		378	54
Winter Squash, Bush Table Queen	S	.073	505	6,918					N.A.		
	T	.055	399	7,189		.96	N.A.		N.A.		

\* National Average from U.S.D.A. 1979  
<sup>a</sup> 1978, cleaned    <sup>b</sup> 1968, fresh    <sup>c</sup> estimated    <sup>d</sup> U.S.D.A. 1979 1978, tresh    <sup>e</sup> 1978, husked    <sup>f</sup> 1977

## STRIP MINE RECLAMATION IN DRY REGIONS

### Site description

The site is located at an elevation of 6,600 feet in northeastern Arizona in the pinyon-juniper vegetation zone. The climate is cool and arid; the average annual precipitation is about ten inches (Figure 1) falling primarily as late summer convective storms. An example of one of these storms is shown in Figure 2. Rainfall during the growing seasons 1979-1981 are given in Table 7.

Table 7. Rainfall during growing seasons.

	June	July	August	September	Total
	----- inches -----				
1978	Trace	1.18	.27	.33	1.78
1979	.22	0	.61	0	.83
1980	.29	.77	.79	2.30	4.15
1981	.06	2.89	1.85	1.90	6.70

Rainfall this season was high compared with the last two years. The frost-free growing season was 145 days, from May 21 to October 13. The season last year was 142 days.

The total area covered by the Black Mesa Water Harvesting Agrisystem is 30 acres consisting of: 8 acres of fiberglass-asphalt-chipcoat (FAC) catchment, 7 acres of salt-treated catchment, 5 acres of natural catchment (primarily roadways and field borders), 1 acre of ponds, an upper 2-1/2 acres agricultural terrace, a lower 2-1/2 acre agricultural terrace, one acre of FAC catchment orchard, and 3 acres of unused lower area (Figure 3).

The lower terrace was topsoiled during the winter by the Peabody reclamation crew. This provided another opportunity to compare growth between topsoiled and spoil areas.

The topsoil is classified as Fruitland series, coarse-loamy mixed (calcareous), mesic Typic Torriorthent (Day 1979). The spoil, which remains exposed on the western 2/3 of the upper terrace, consists of fragmented and mixed overburden materials; derived from Cretaceous sandstones, siltstones, and mudstones of the Wepo Formation. Soil analyses (Table 8) indicate that the topsoil is low in phosphorus and nitrogen, and the spoil is low in phosphorus and high in salts. These conditions can be remedied with soil amendments to improve fertility and and by scheduling irrigation to better leach the spoil.

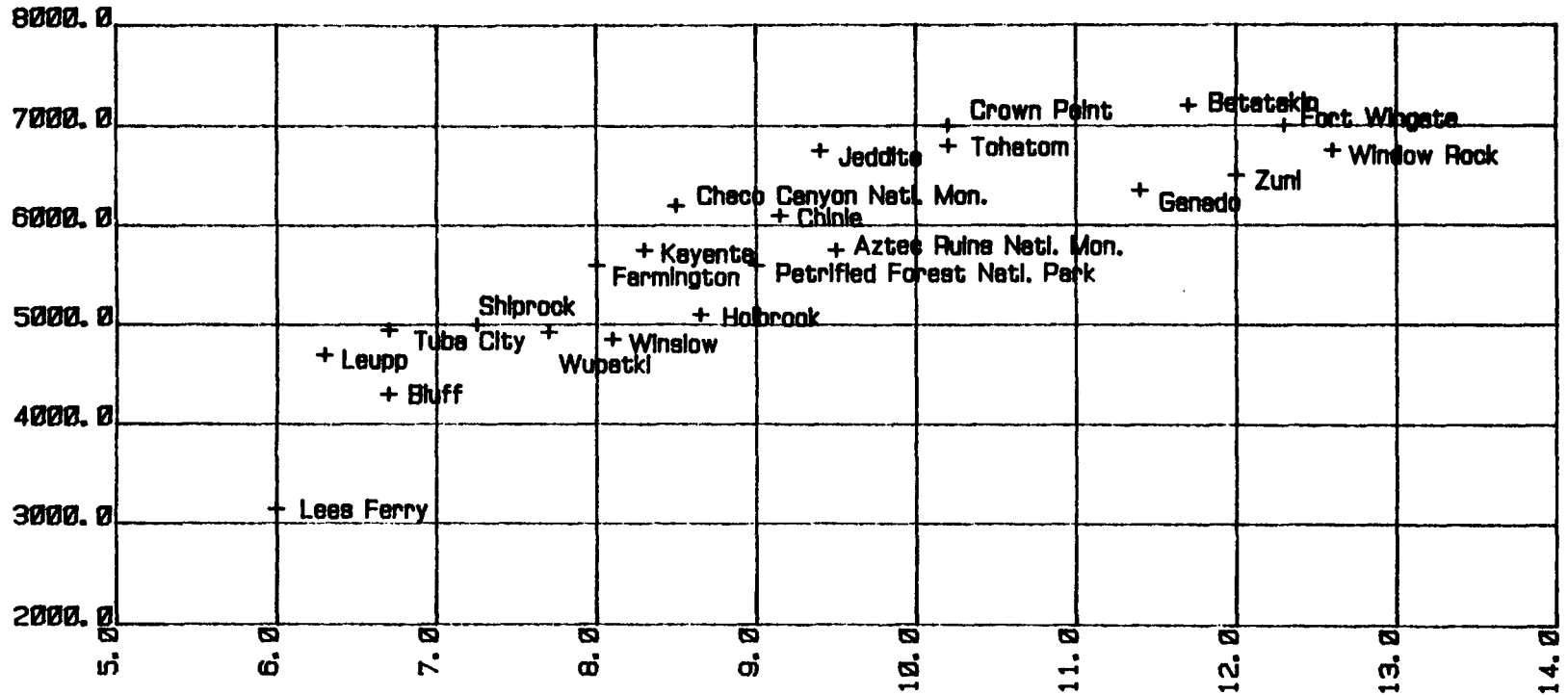


Figure 1. Scatter diagram of altitude and mean annual precipitation in the Navajo and Hopi Reservations and adjoining regions. (Adapted from Cooley et al.)

# STRIP MINE RECLAMATION IN DRY REGIONS

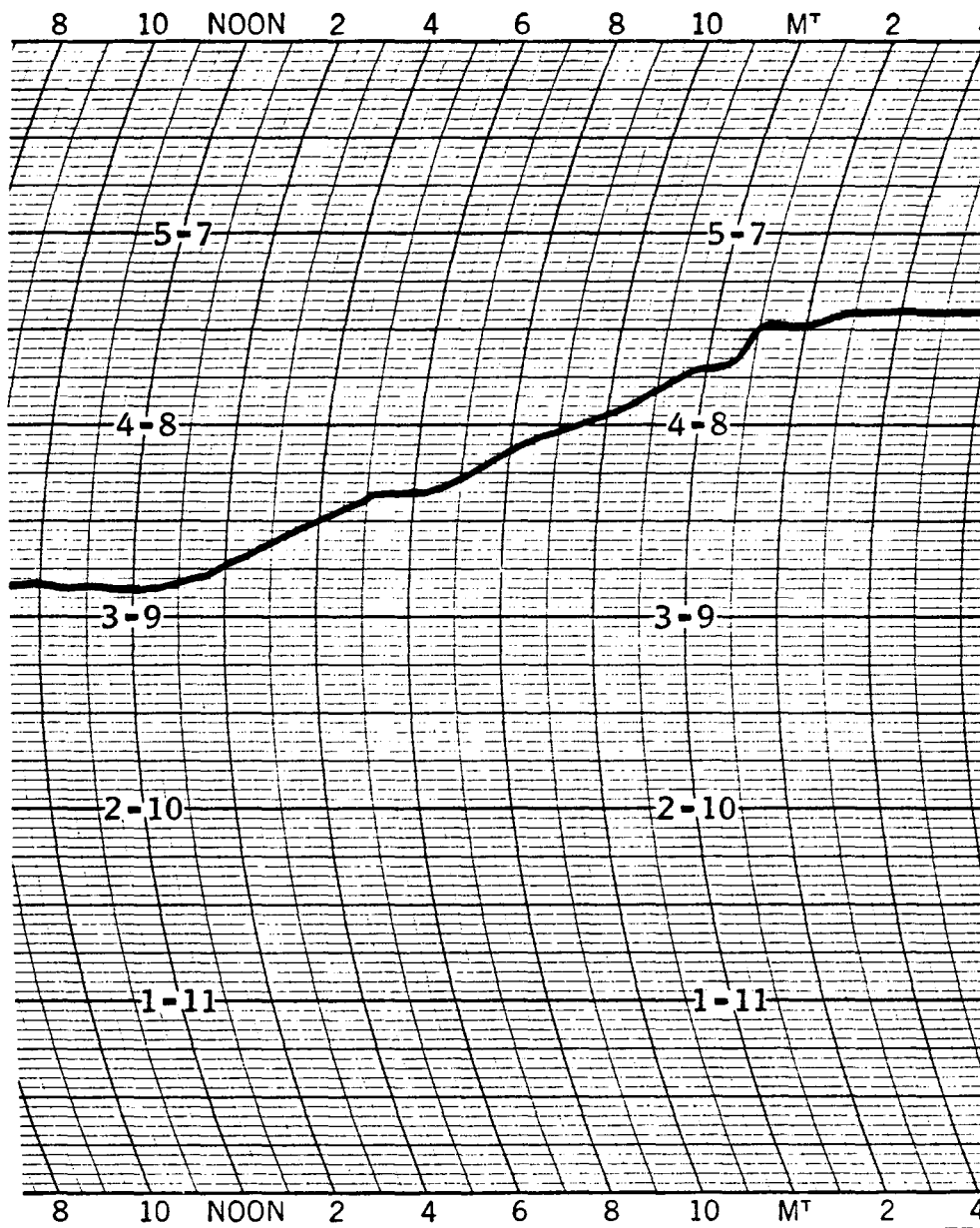


Figure 2. Strip chart record of a large convective storm.

# STRIP MINE RECLAMATION IN DRY REGIONS

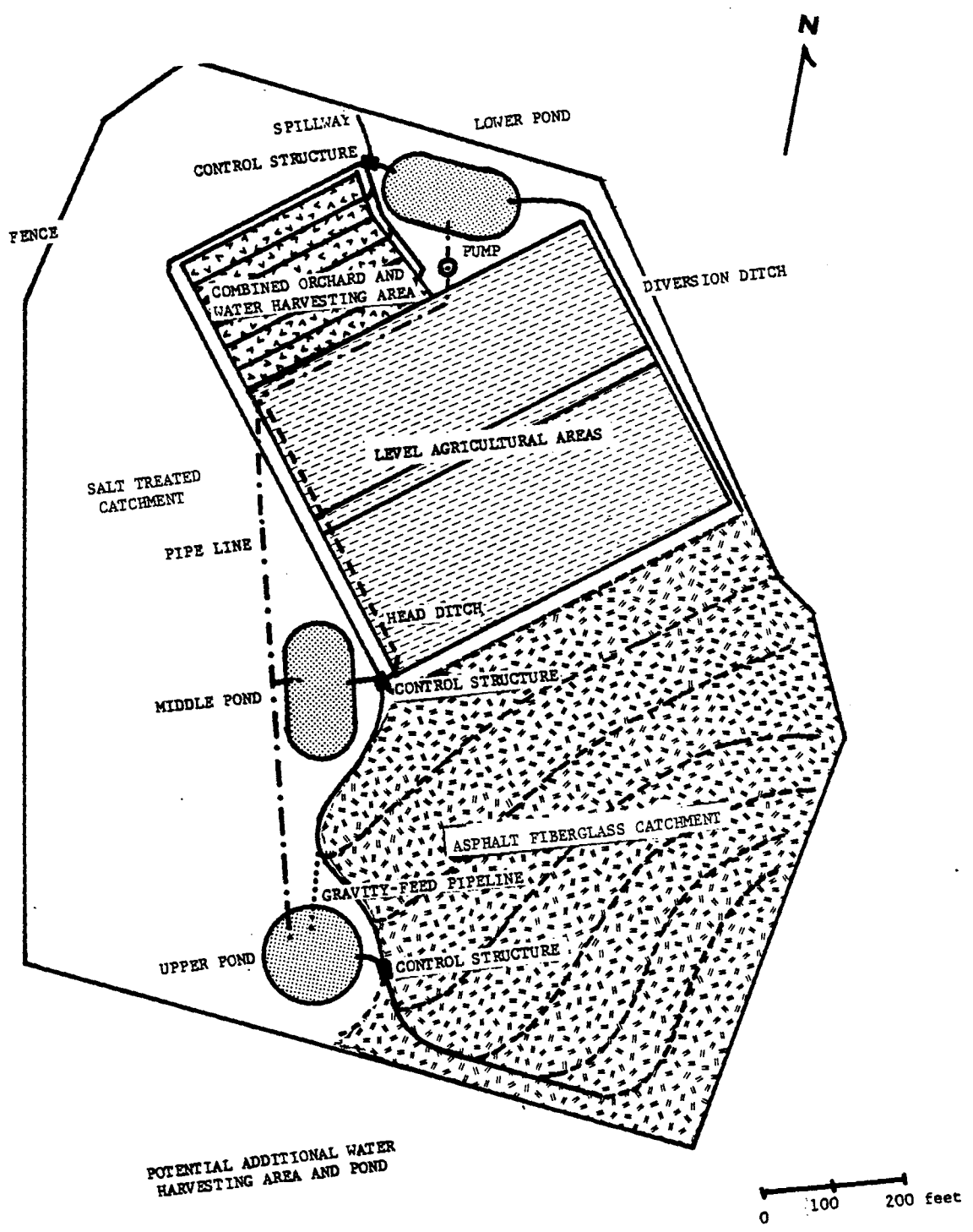


Figure 3. Site Layout -- Black Mesa Water Harvesting Agrisystem.

Table 8. Soil Analysis

Area	Sample depth inches	Soil type	pH*	ECe <sub>3</sub> x10 <sup>3</sup>	-----Saturation Extract-----									
					Soluble salts ppm	Na meq/L	ESP <sup>t</sup>	N <sup>o</sup> ppm	P <sup>@</sup> ppm	K <sup>m</sup> meq/L	Fe# ppm	Mn# ppm	Cu# ppm	Zu# ppm
Topsoil	0-6	sandy loam	7.9	.56	392	.86	-.43	.25	.88	.12	0	0	0	0
Spoil	0-6	loam	7.2	3.60	2,520	5.06	.64	32.00	.75	.26	10.64	14.12	.37	1.14

Analyzed at the University of Arizona Soils, Water and Plant Tissue Testing Lab.

\* Paste with distilled H<sub>2</sub>O

<sup>t</sup> Estimated exchangeable sodium percentage (ESP)

<sup>o</sup> From CO<sub>2</sub> extraction. Technicon reduction of nitrate reported as N.

To convert N to NO<sub>3</sub> multiply N x 4.4.

<sup>@</sup> CO<sub>2</sub> extraction and orthophosphate determination (Technicon).

To convert P to PO<sub>4</sub> multiply P by 3.1.

<sup>m</sup> Saturation extract. Water soluble K values are not to be used as a basis for fertilizer recommendation.

# Soluble fraction, DTPA method.

## STRIP MINE RECLAMATION IN DRY REGIONS

The high level of nitrogen in the spoil may be due to nitrogen accumulation in the now exposed shales (Strathouse 1980) and possibly the use of ammonium nitrate for blasting of the overburden prior to mining.

The site was completely operable in 1981. The planting season began with about 1.2 million gallons of water in storage.

### Planting - Perennials (1981 season)

The orchard was pruned in May and, given 3 supplemental irrigations during the growing season. Additional perennials were planted in the orchard area and at other locations on the site. Five empty sites in the orchard were planted with 3 "Moonglow" pears (standard root), one "Lodi" apple, (semidwarf root), and one "New Summer Scarlet" apple (semidwarf root). These apple varieties are a summer type that fruit early in the season, and may be well suited to the short growing season of the Black Mesa.

Van Buren and Lakemont varieties of grapes were planted at three locations outside the orchard. They were planted (1) in an area near the lower pond which receives water as runoff from the north bank of the lower terrace and from pond seepage (2) in one-foot diameter holes cut into the lining of the lower tributary ditch on the asphalt catchment, and (3) on the salt treated catchment in a sandy area at the bottom of a tributary ditch. About 15 vines of each variety were planted at each location. Two vines were planted in each planting spot.

An assortment of perennial cultivars, recommended by the Plant Science Department of the University, were also planted at the foot of the bank between the upper and lower terrace at the topsoil (east) side. This site was chosen to make maximum use of space and available runoff water, and to provide a windbreak for the lower terrace. Three Oriental-American chestnuts, 3 Thomas Black walnuts, 3 Latham raspberries, and one Early McIntosh apple were planted.

### Planting - Annuals (1981 season)

The upper terrace and the western third of the lower terrace were prepared for crops this spring. The total cropped area was 2.40 acres. Five hundred pounds per acre of fertilizer (16-48-0) were applied to the fields which had been mulched with alfalfa hay and plowed in October, 1980. The winter was dry. Thus, much of the crop residue and straw did not decompose, and was plowed in spring.

Furrows were plowed on five-foot centers. This wide spacing was used to permit easy access and improve water control. Sprinkler irrigation was used this year to reduce labor time, achieve a more even distribution of water, and conserve water. Peabody loaned the project Rainbird sprinkler pipes and a diesel pump, and donated fuel for the irrigation system. Before the system was

## STRIP MINE RECLAMATION IN DRY REGIONS

installed, an initial pre-seeding irrigation was applied by the furrow-flood method. The fixed sprinkler lines irrigated the entire cropped area except some of the borders which were furrow irrigated. This combination avoided the waste of water that occurs from sprinkler edge-loss. The fields were irrigated, depending on the soil moisture content, on the average of about every five days.

The major crops for this year's plantings were the best performers of previous season: beets, carrots, sweet corn and summer squash. Green beans were selected this year over the pinto beans planted last year because of their higher economic value. Pumpkins did not do well the previous season, but because of the excellent performance of summer squash (closely related to pumpkin) another trial was made. Watermelon was planted because of high local demand. A list of the varieties and their production is given in Table 9. Tomatoes were also planted between the trees in the orchard to make use of the water and sunlight not currently used by the young trees.

Table 9. Crop varieties ordered from Burrell Seed Company, Rocky Ford, Colorado.

---

Beans, Topcrop Bush Green
Beets, Ruby Queen Table
Carrots, Nantes Improved Coreless
Corn, Early Sunglow Sweet
Pumpkin, Small Sugar
Squash, Early Prolific Summer
Watermelon, Sugar Baby

---

Crop residues were not plowed under this fall to determine if soil moisture could be increased over the winter. It was thought that the standing corn stalks and other residues would catch snow and increase the infiltration to sublimation ratio.

### Maintenance

Farm maintenance labor was low this year. One full-time person worked from May 18 to October 18, another full-time person was added for the month of June, and other help added an additional 20 person-days. The total labor cost was about 140 person-days. The John Deere 70 horsepower tractor logged 70 hours this season, and the irrigation pump consumed about 100 gallons of diesel.

The catchments and ponds required very little care. Three person-days were spent weeding the asphalt catchment. Very little weeding was done on the

## STRIP MINE RECLAMATION IN DRY REGIONS

salt-treated catchment; this was partly to save labor expense, and partly to reduce wind erosion. The weeds (mostly Salsola Kali) may reduce the runoff yield and are seed sources for weeds in the agricultural fields.

### Irrigation water

The water in the storage ponds was analyzed to examine suitability for irrigation (Table 10). The analyses indicate that the quality of the water is fair. However, there is a relatively high amount of sodium. The procedure developed by the Food and Agriculture Organization (Ayerst 1976) for adjusting the sodium absorption ratio for arid and salt affected soils indicates an adjusted sodium absorption ration of 6.08 [The adjusted SAR for typical Colorado River water is 4.7.]. Irrigation water with this S.A.R. applied on montmorillonitic soil could result in a permeability problem. There could also be some sodium and bicarbonate toxicity to sensitive crops especially if using sprinkler irrigation when evaporation rates are high. Another consideration is that in order to maintain a soil EC (electrical conductivity of soil water extract) of two mmhos/cm or less when using this water of ECw of about one mmhos/cm, there needs to be a 10 percent leaching fraction. The spoil has a low infiltration rate, and providing a 10 percent leaching fraction may be difficult without drowning crop roots. However, infiltration will probably increase on the terraces as soil structure improves. It is possible that deep leaching could aggravate the subsidence problem.

### Hydrological design (1981 season)

One major change in the hydrological design was made this year. Runoff from the upper portion of the salt-treated catchment was routed into the middle pond which formerly received no runoff from the salt treated catchment. This was done to help save the cost of pumping from the lower pond to the middle pond. The original plan was to concentrate sediment from the salt-treated catchment to facilitate sealing of the lower pond which was built in the more permeable, unmined earth. The bottom of the lower pond has sealed, but the side still leak, particularly when the water level is high. The benefits of concentrating sediment in the lower pond no longer outweigh the cost of pumping.

Another design modification was the construction of low-slope overflow from the upper pond to the concrete ditch leading to the middle pond. An overflow channel was needed to prevent erosion when the pond is overfull. The channel served its purpose several times this season.

Small H-flumes were installed on portions of the salt and FAC catchments in May to measure runoff efficiencies of the catchments. The runoff data used to derive the models for each catchment was collected from June 16, 1981 through October 31, 1981. The empirical models were derived from rainfall-runoff relationships on the salt-treated catchment and the FAC catchment. The

Table 10. Water Analysis

EC x 10 <sup>3</sup>	Solu Salts ppm	pH	Milligrams per liter*											
			Ca	Mg	Na	Cl	SO <sub>4</sub>	HCO <sub>3</sub>	CO <sub>3</sub>	F	N <sup>+</sup>	Pb	SAR <sup>™</sup>	STU <sup>-2</sup> <sub>3</sub>
0.9	527	7.7	41	6.1	122	189	30	140	0	0.6	0.1	0	4.7	3.2

Analyzed at the University of Arizona Soils, Water and Plant Tissue Testing Lab.

\* mg/l is approximately equal to ppm

+ Analyzed as nitrate

™ Sodium Absorption Ratio

## STRIP MINE RECLAMATION IN DRY REGIONS

Statistical Package for the Social Sciences (SPSS) was used to run correlation analyses on the collected data. Runoff data from the salt-treated and FAC catchments were compared with regard to average intensity, maximum 30 minute intensity, and amount of storm precipitation. Bivariate and multiple correlation analyses indicated the best linear relation had similar  $r^2$  values to that of the multiple correlation.

Table 10a shows poor correlations between runoff and average intensity and between runoff and maximum 30 minute intensity. The correlations for both catchments for runoff versus the amount of storm precipitation were reasonably high. Table 10b shows the multiple correlation analyses of runoff from both catchments versus maximum 30 minute intensity and total storm precipitation.

Although  $r^2$  values were slightly higher for the multiple correlation analysis of both catchments, the simpler linear models gave essentially the same values. The choice of the linear model was further justified if one considers that additional error would be introduced from reading maximum 30 minute intensities from strip charts. The linear runoff models for the salt-treated and FAC catchments are illustrated in Figures 3a and 3b, respectively.

The runoff model for the salt-treated catchment is:

$$QSALT = 0.62500 (PPT) + 0.00895$$

PPT = amount of storm precipitation (in.)

QSALT = runoff from salt-treated catchment (in.)

and the runoff model for the FAC catchment:

$$QFAC = 0.55401 (PPT) - 0.01210$$

PPT = amount of storm precipitation (in.)

QFAC = runoff from FAC catchment (in.)

Analysis of variance was performed to determine whether a significant difference existed between runoff from the two catchments. The F ratio was equal to 0.2718 and the critical value of F at the 0.10 alpha level was 2.86, therefore differences among the samples were not significant. Restated, the runoff from the salt-treated catchment is not significantly different from runoff from the FAC catchment at a 0.10 alpha level. This implies one runoff model could be derived to predict runoff for both catchments, however, using two separate models did not pose any difficulties in the computer program and predicted runoff accurately.

STRIP MINE RECLAMATION IN DRY REGIONS

Table 10a. Results of SPSS bivariate analyses for runoff.

Correlations are shown for runoff from the salt-treated catchment, SR0, and from the fiberglass-asphalt-chipcoat catchment, FACRO, versus average intensity, AVGI, 30-minute intensity, I30, and storm precipitation, PPT.

---

Correlation	$r^2$
SR0 vs. AVGI	0.02458
FACRO vs. AVGI	0.04576
SR0 vs. I30	0.07793
FACRO vs. I30	0.08038
SR0 vs. PPT	0.92321
FACRO vs. PPT	0.96969

---

Table 10b. Results of SPSS multiple correlation analysis for SR0 and FACRU versus I30 and PPT.

Correlation	$r^2$
SR0 vs. I30 & PPT	0.92380
FACRO vs. I30 & PPT	0.97018

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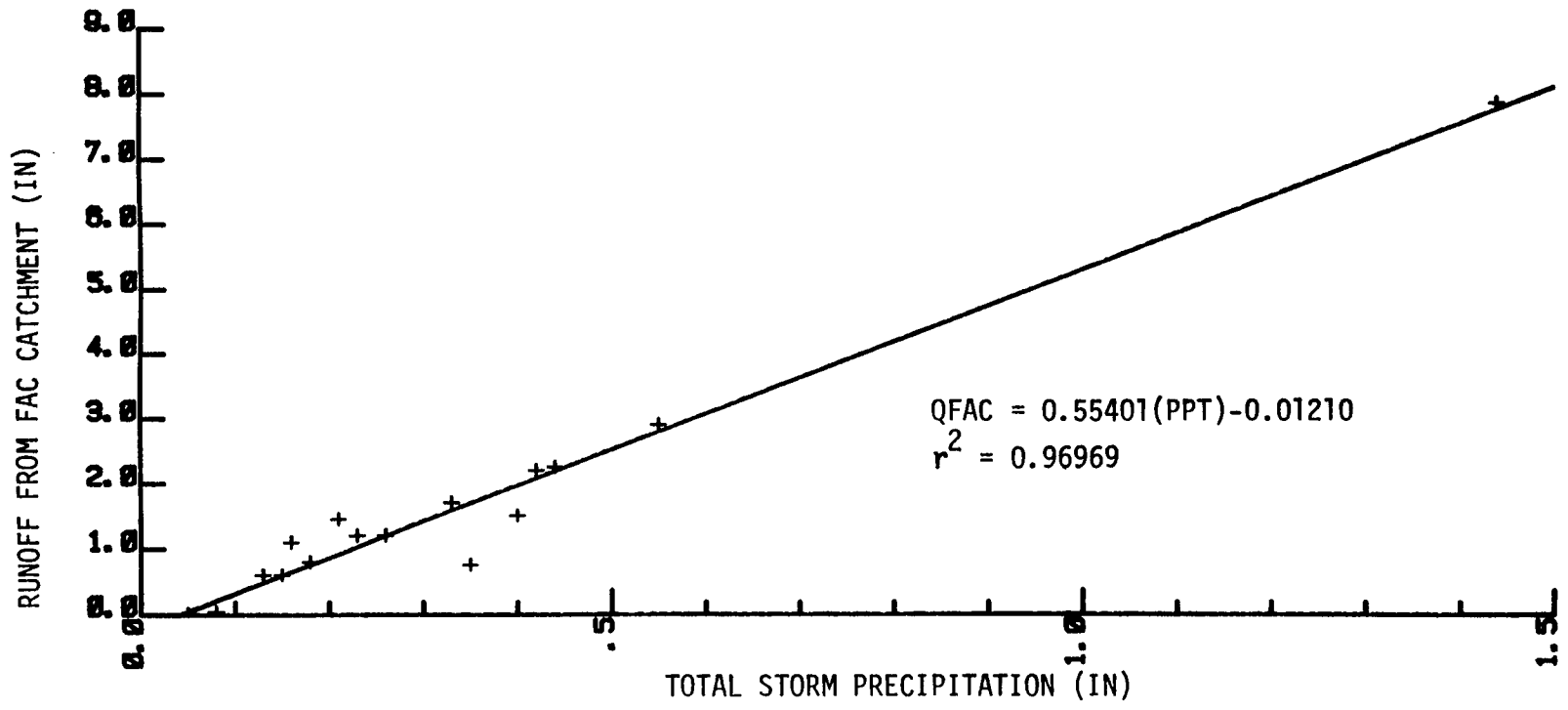


Figure 3a. Runoff model for the salt-treated catchment.

STRIP MINE RECLAMATION IN DRY REGIONS

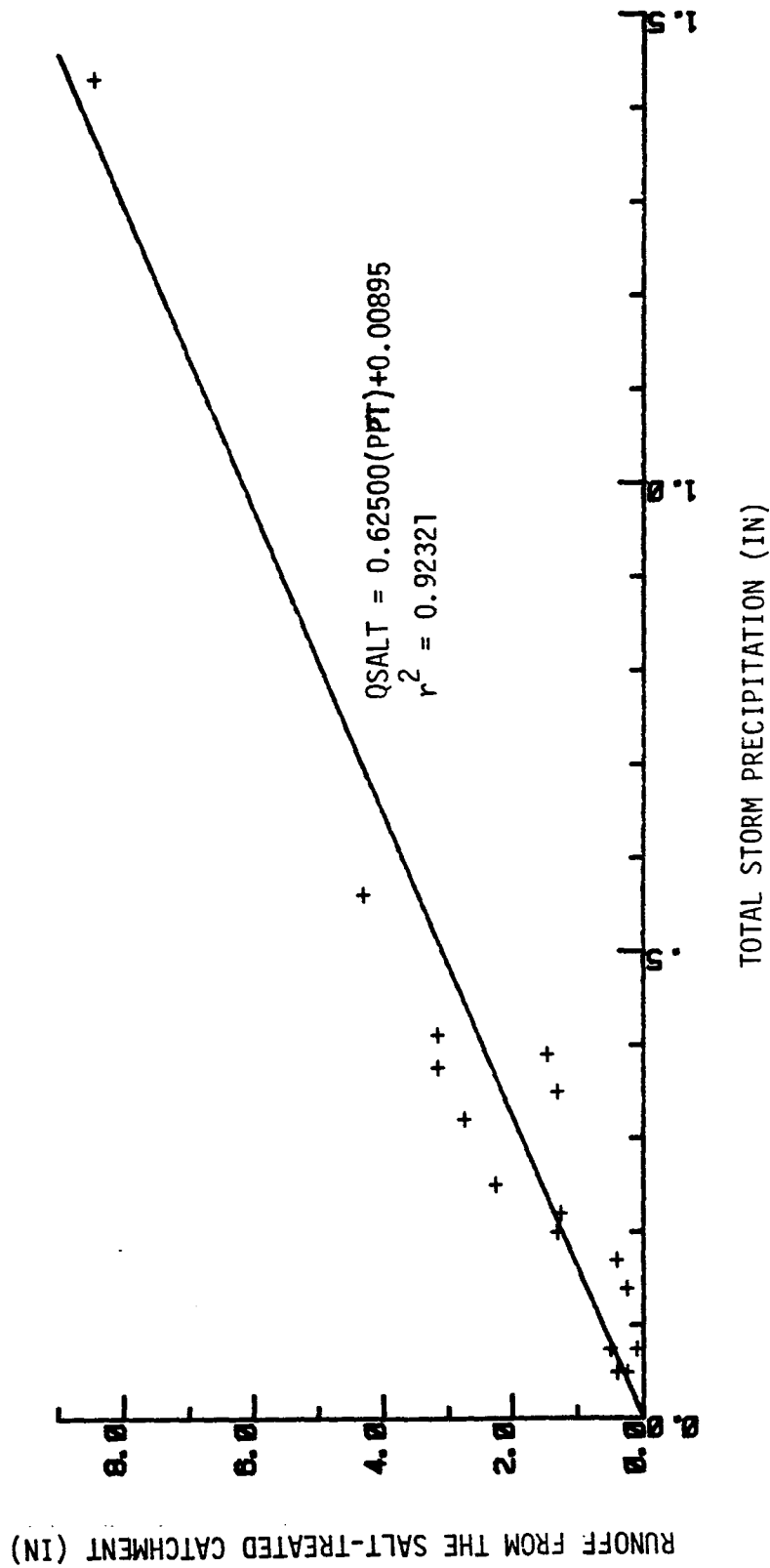


Figure 3b. Runoff model for the FAC catchment.

STRIP MINE RECLAMATION IN DRY REGIONS

Cluff and Frobel (1978) found runoff efficiencies for salt-treated catchments to range from 50-70 percent and in the range of 90-100 percent for FAC catchments. The average observed salt-treated runoff efficiency was 60.3 percent and in agreement with Cluff's estimate. However, the average observed FAC runoff efficiency was 49 percent, well below the estimated range. The difference may be explained, in part, by the thin gravel layer on the surface of the FAC catchment. Cooley et al, (1975) states that such a gravel layer reduces runoff efficiency by retaining part of the water which is then lost to evaporation.

Evaporation control (1981 season)

A number of evaporation-control floats were tested: wax-coated polystyrene, fiberglass-coated expanded polyurethane, and silicone-painted expanded polystyrene (SPEP). Ten thousand square feet of the silicon-styrene foam were made and installed in spring. The construction method we used was to pour a measured minimum amount (about 200 ml) of white silicon paint on a four foot by eight foot by 3/4 inch expanded polystyrene sheet, and spread the paint with a flat edge on a handle. The sheets were cut into two foot by two foot squares to make handling easier when they become water-logged, and then the floats were launched painted-side up. The construction costs were low (Table 11).

Table 11. Cost of silicon-styrene foam, evaporation-reduction floats.

	<u>\$/ft<sup>2</sup></u>
3/4" x 4' x 8' expanded polystyrene sheets	.10
one coat of Dow Corning Silicon 3-500 construction coating, white, on one side of the sheets	.04
labor cost for painting, cutting, and loading @ \$5.00/hr	<u>.02</u>
Subtotal	.16
estimate of overhead (building maintenance, etc.)	<u>.16</u>
Estimated Total (excluding transportation and installation)	.32

## STRIP MINE RECLAMATION IN DRY REGIONS

### RESULTS AND DISCUSSION -- 1981 SEASON

#### Site development

Subsidence decreased this season, but continue to cause some problems. Two major cracks occurred in the upper terrace during the initial flood irrigation. They were dammed off and filled with about 4 cubic yards of soil material.

The middle and upper ponds lost water at a rate of about .02 foot per day in May. This loss is close to the evaporation rate for the area. The lower pond had a shallower depth of water, but losses were at a rate of about .05 foot per day. This indicates that the upper and middle pond were sealed but the lower pond was still losing some water by seepage. The lower pond is located in an unmined area on natural soil material. It is likely that the sodium-dispersed clay particles washed from the salt treated catchment have effectively sealed the bottom but not the sides of the pond.

After construction of the low-slope spillway on the upper pond and the routing of water from the upper salt treated catchment into the middle pond, the waer collection and transfer system performed without problem.

The evaporation-control floats (SPEP) had the same problem with wind removal as had all predecessors. Winds gusting above fifty miles per hour occur occasionally on Black Mesa. The floats, especially before they become heavy with water, which takes about six weeks, are blown off, sometimes break, and require retrieval. Several times whirlwinds carried floats up and away. An attempt was made to hold the floats together with bird netting. The netting quickly became tangled with the floats, and the procedure was abandoned. In October, a majority of the floats installed in the spring were still on the ponds, although many were blown-off returns. SPEP is low cost and has the potential to prevent evaporation from water surfaces, but methods for keeping it in place need to be developed.

An improvement in the solar generator system was made this year: a deeper and better sealed supporting-pond was installed. A number of electrical and mechanical problems kept the generator from operating well until September 28. This left too little to make an adequate evaluation of performance.

#### Production - Perennials

The perennials (fruits, nuts, berries and grapes) growing on the site as of September 1981 are listed in Table 12. All plants appeared to be thriving and most of them put on a foot or more of new growth during the season. The plants are still too young to produce fruit in quantity. However, some of the apple and peach trees matured fruit this third year after planting. The fruit was of good quality and free of defects, and pest damage. The fruit was of excellent taste. The apples were Newton Pippin and Winesap, and the peaches

STRIP MINE RECLAMATION IN DRY REGIONS

Table 12. Inventory of Perennials

---

Almonds	
Davey	2
Non-Pareil	2
Apples	
Early McIntosh	1
Golden Delicious	6
Lodi	1
McIntosh	5
New Summer Scarlet	1
Newton Pippin	4
Red Delicious	25
Winesap	5
Chestnuts	
Oriental-American	1
Grapes	
Lakemont	40
Van Buren	40
Nectarines	
Fantasia	3
Peaches	
Elberta	2
J.H. Hale	3
Pears	
Bartlett	1
Moonglow	3
Seckel	3
Raspberries	
Latham	1

---

## STRIP MINE RECLAMATION IN DRY REGIONS

were J.H. Hale. The almond trees put on the best vegetative growth, but their potential for fruit production is not known because of the sensitivity of the blossoms to frost.

The grapes, planted at locations outside the orchard, performed surprisingly well in spite of adverse planting conditions (e.g. delayed planting, minimum irrigation, minimum soil preparation). Protection with chicken wire was necessary to exclude rabbits.

Short season grapes were selected because of the high altitude of the site. If the grapes continue to thrive and become productive, they could become one of the most profitable products of water harvesting. Since grapes require a large amount of heat during the growing season to produce sugar, planting within the asphalt catchment (which heats up from solar absorption) appears promising.

Results thus far indicate that orchard crops have a high economic potential. Fresh fruit is scarce in the area and the demand is high. Orchards require little maintenance, and, in the Black Mesa area, pest problems seem to be minimal.

Subsidence, which was a major problem in the orchard early in the project, seems to have stopped. Drainage has been largely taken care of by ditching.

### Production - Annuals

All of the crops grew well despite some problems caused by pests and by some of the cultural techniques. Production of each crop is summarized in Figure 4 and Table 13.

Carrots did not perform as well as expected in terms of production per acre. The reasons for this lie mainly in the way the furrows were constructed. They were made deep and five-feet wide to allow walking on dry ridges and for better water distribution. However, the unplanted walkways covered about 1/3 of the area of the field; thus, the pounds-per-acre values underestimate the real productiveness and water-use efficiency. This is also true for the green beans and beets. Nevertheless, carrots yielded the highest return in dollars, even greater than those crops that exceeded the national production averages.

Green bean production was next highest in value and exceeded the national average by \$295 per acre. This result is interesting since green beans are one of the more salt sensitive crops. Thus, they were not expected to perform as well as they did with the salt conditions of the soil materials. No differences in performance of beans were observed between topsoil and spoil areas.

Table beets also exceeded the national average (by \$515 per acre in 1980 and by \$65 per acre in 1981). There appeared to be no differences in

STRIP MINE RECLAMATION IN DRY REGIONS

Figure 4. Production Summary

	Estimated Gross Income, \$/acre <sup>a</sup>	
<b>BEANS, GREEN @ \$.275/lb</b>		
U.S. average	935	_____
1981	1230	_____
<b>BEETS, TABLE @ \$.08/lb</b>		
U.S. average	1072	_____
1980	1587	_____
1981	1141	_____
<b>CARRUTS @ \$.10/lb</b>		
U.S. average	2680	_____
1980	1570	_____
1981	1727	_____
<b>CORN, SWEET @ \$.10/lb</b>		
U.S. average	790	_____
1980	322	_____
1981	355	_____

<sup>a</sup> The production for the Black Mesa Water Harvesting Agrisystem is in \$/irrigated acre. To convert to \$/acre for the whole system, divide by five.

productivity between the two soil materials. Beets are an uncommon food in the area, but requests of the local inhabitants this year greatly exceeded the supply.

The value of corn was the lowest of all crops. Production was less than half the national average. This was not unexpected, but corn is an important traditional food in the area, and was planted primarily for social reasons.

The Handbook of Agricultural Statistics gave no data on the national production of squash and pumpkin. However, both are in demand and both exceeded each of the other crops in pounds per acre produced.

Watermelon was planted because of local requests. Production was only fair as was expected from previous trials.

STRIP MINE RECLAMATION IN DRY REGIONS

Table 13. Varieties and production, 1981

	lbs.	sq.ft.	\$ actual	lbs/acre	\$/lb	\$/acre
BEANS, GREEN, Topcrop Bush	945	9,200	260	4,474	0.275	1,230
BEETS, TABLE, Ruby Queen	1,820	5,560	146	14,259	0.08	1,141
CARROTS, Nantes Improved Coreless						
mine spoil, early crop	2,350	5,080	235	20,151	0.10	2,015
mine spoil, late crop	4,698	14,500	470	14,113	0.10	1,411
topsoil, early crop	2,382	4,530	238	22,905	0.10	2,291
topsoil, late crop	3,501	8,500	350	17,942	0.10	1,794
CORN, SWEET, Early Sunglow						
mine spoil	1,491	11,980	150	5,443	0.10	544
topsoil	774	15,855	77	2,126	0.10	213
PUMPKINS, Small Sugar	5,625	7,460		32,845		
SQUASH, SUMMER, Early Prolific Yellow Straightneck	11,180	20,220		24,085		
WATERMELON, Sugar Baby	220	1,480		6,475		

Problems in Production

Several problems were encountered during the growing season with pests and garden layout. An awareness of these problems is necessary to manage the project efficiently in the future, and to understand some of the limitations that may have affected production.

The major problems with corn was corn-ear worm (*Heliothis zea*), corn smut and ravens. The corn-ear worm was as common this year as last. An attempt was made to control it by hand dusting the silks with 5 percent Sevin insecticide. The worms were frequently still living in the ear after dusting, or new ones arrived. Considerable time was spent in dusting every three days and changing clothes after each dusting. Furthermore, the poison could also have interfered with the wasps and small birds that were abundant and were killing some of the worms. Dusting was abandoned.

Ravens (*Corvus corax*) destroyed hundreds of corn ears. This occurred mainly when the ears were within a foot of the ground. A simple control measure for next year could be to use taller varieties.

## STRIP MINE RECLAMATION IN DRY REGIONS

Corn smut (order Ustilaginales) appeared again this season. Curiously, the first outbreak occurred in the freshly applied topsoil on the lower terrace and not in the soil of the upper terrace where it was prevalent last year. For the first week or two of the outbreak the smutted plants were cut and buried. It is not known if this procedure helped, but the fungus did not affect as much of the crop as it did last year.

If corn is to be a major crop, an integrated method of pest control should be found. There were no pest problems with the green beans between planting and harvest. There were also no pest problems with the carrots, squash, beets, and pumpkins after they became established.

Mice (Peromyscus sp.) were a problem in establishing most of the crops except the green beans. They dug the seeds from hundreds of feet of planted rows. The squash and beets were most affected. Snap traps were set and poison put out, but after considerable damage had already been done. Rodent control should be an important part of future operations. Biological control should be considered.

There is a high demand in the area for tomatoes and peppers. Previous trials (1980) were not very successful because of frost in late spring. An additional trial was made this season with 100 tomatoes and 50 pepper plants that were set out in the orchard area. Frost was not a problem this year, but cutworms (family Noctuidae) were numerous in the northern part of the state (communication from Larry White, Agriculture Extension Agent). The mulch around the orchard trees could have provided especially good shelter for them over the winter. Only 5 tomato plants survived. These were sprayed with malathion and given protective collars made from one-gallon plastic milk jugs. No further damage was done, and the survivors produced well. Despite the lack of success, additional experimentation would be worthwhile since tomatoes and peppers have a high value. Transplanting late, perhaps the middle of June, might be considered (cutworm populations decrease with increasing temperatures). Mulching near planting locations should be avoided.

In addition to the walkways, there were two other problems arising from the garden layout: (1) sediment washed from steep furrow slopes that interfered with seed germination in the valleys, and (2) since the fertilizer was buried under the ridges, it was too far from seedling roots where it was needed. The latter problem was particularly important with the tap-rooted crops like carrots and beets.

### Chemical analysis of plant materials

In the reclamation of surface mines, there is always concern over the possible uptake of toxic elements by plants. Accordingly, a tissue analysis was made of a sugar beet root grown in spoil. Results of the analysis (Table 14) indicated that the chromium level was suspiciously high, but that all other

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Table 14. Tissue analysis of sugar beet root grown in spoil.

Fe	Mn	Cu	Zn	K	Pb	Cr	Hg	Total Cd	Total Se	Total As
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
181.75	22.5	10.0	40.0	11935	1.93	7.75	0.78	0.75	0	0

elements were well below toxic levels. After a literature review and a discussion with Charles Weber of the Animal Science Department, University of Arizona, the level of total chromium was determined not to be dangerously high. In fact, the occurrence of chromium in crops may be a plus, since chromium is an essential element (National Academy of Science 1974). Apparently trivalent chromium presents little danger, but the hexavalent compound, such as found in cigarettes, is dangerous. Since the analyses were made on only a single sample and only for total chromium, further sampling and more analyses are indicated.

### CONCLUSIONS

1. The potential high quality of spoil from the Black Mesa Mines as agricultural soil is indicated by its loam texture, neutral pH, and high nitrogen level. The nitrate content of the top two feet of an acre of Black Mesa spoil is about 1133 pounds, which is a significant agricultural bonus. After three years of irrigation, the spoil is developing a friable, granular structure. It seems that all it needs to become very productive is phosphorus and water. Thus far, the system has provided more than enough water to meet crop needs.
2. In comparing the productivity of the spoil versus topsoil, the data shows that carrots performed better in topsoil, and corn performed better in spoil. This results reinforces the conclusion of last year's extensive comparison of the two soils: that in a level, irrigated field, mine spoil is as good a media for plant growth as the local entisol topsoil.
3. The water harvesting site also provides a good environment for local agricultural education. Irrigation and cultivation techniques have been demonstrated, and crop varieties tested for this highland area of the Southwest.
4. Crop production has been high, particularly with carrots, beets, green beans, squash and pumpkins. Corn production per acre was low in comparison with the production from the corn growing states of the midwest but it has been

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higher than that of local dry-land areas.

5. The orchard has exceeded original expectations, and its produce holds promise of becoming a major benefit from water harvesting. Grapes, though only tested for one season, also promise high returns for the future.

6. The design of the system appears capable of supplying adequate water to the farm and orchard. At present there is in excess of 1.6 million gallons of water in storage; sufficient to supply water for both terraces and the orchard with little or no summer rainfall.

7. An economic analysis (based on 1981 results) indicated that the net returns of the system would be greater than \$1,000 per acre as opposed to a return of slightly over \$2 per acre for conventional reclamation. The analysis did not include returns that would accrue in the future from the orchard or from horticultural crops planted outside the cultivated areas.

8. Many of the local people have shown interest in the system and the new crops produced. If managed properly, water harvesting systems could make available nutritious food and additional income for the local people.

### RECOMMENDATIONS FOR FUTURE OPERATION

1. The most important improvement that should be made next year is in field preparation. It is recommended that the field should first be disced to incorporate the dead plant material from the preceding crop, and to kill the early weeds. Then furrows should be plowed open in such a way that last year's ridges become this year's furrows. Fertilizer should then be spread. Finally the field should be harrowed to knock down the ridge tops, cover the fertilizer, and to make the furrow slopes more gentle.

2. Various methods should be tested to control tumbleweeds on the salt-treated catchment. Crushing young tumbleweeds with a roller and selective herbicide use are two possibilities.

3. Strategies for pest control should be planned and preparations made before pests become a major problem.

4. Some of the slopes on the salt-treated catchment are as steep as 13.8% and are developing rills, some of which are one to four inches deep. Erosion transports clay and the absorbed sodium to the ponds. In addition to this problem, steep slopes make compaction difficult. These problems should be closely monitored. Additional salt should not be added to the catchment slopes until erosion has been greatly reduced. Future designs of water harvesting systems should limit salt treatment catchment slopes to 5 percent or less depending upon slope length.

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5. Experimentation with varieties of crops that are easy to market or in high demand should continue. Local preferences may override apparent economic value.
6. Methods of harvesting root crops need to be improved.
7. The non-catchment, unirrigated areas of the farm (for example, field borders) should be planted to drought-resistant, non-weedy plants; and preferably ones that retard erosion, exclude weeds, or support beneficial organisms. Three examples are: wildflowers that provide nectar for predaceous wasps, legumes that maintain nitrogen-fixing bacteria, and trees that shelter owls and other useful birds.

### QUESTIONS FOR FUTURE RESEARCH

Research at the Black Mesa Water Harvesting Agrisystem has demonstrated the feasibility and profitability of this system of coal mine reclamation in dry climates. Some questions for further research are:

1. What is the expected rate of subsidence on the spoil?
2. How will time affect catchment treatments?
3. To what extent will the mine spoil continue to improve as agricultural soil?
4. What is the potential value of this kind of farm to the community?
5. What is the nitrogen budget of the mine spoil? (i.e. what is the source of nitrogen? Do nitrates leach into the ground water?)

### ECONOMIC ANALYSIS

#### Framework

An economic analysis of a water-harvesting system such as the Black Mesa/Kayenta should include not only the private investment tradeoffs of reclamation costs for the firm and net agricultural production versus grazing for the final system user but also considerations of economic/social welfare impacts as well. A general expository model of the net benefits generated by reclamation can be shown as:

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$$\text{Net Benefits} = (\text{PVB} - \sum_t^T \text{O \& M}) - \text{RI} + \Delta\text{SW}$$

where:

PVB = the discounted present value of the future stream of benefits from reclaimed land-grazing or water-harvesting

$\sum_t^T \text{O \& M}$  = the sum over time operating and maintenance costs to sustain the use of the land for grazing or water-harvesting

RI = the reclamation investment made by the mining firm

SW = the change in social welfare

The evaluation of this model is necessarily site specific recognizing there is direct dependence on the environment, ecological community, and human social considerations.

The analysis of the Black Mesa project used variables concerning the private investment decisions, the issue of social welfare was not within the scope of this study.

The potential for direct return on a water-harvesting system revenues can be generated in two ways:

1) The reclamation procedures include recontouring spoils, topsoil placement and revegetation. These procedures are enacted to guard against degradation in soil, water quality, and wildlife habitat and to develop lands for grazing. The expense involved in reclamation is high. Thus, if there is an alternative reclaimed land use system such as water-harvesting, which can be constructed at less expense, then it behooves the firm to implement it, since the firm's motives are simple and straightforward - to minimize costs.

2) The construction and implementation of the water-harvesting system allows for agricultural cultivation of the spoils area. If the estimated net value of agriculture is greater than that of grazing, then there would be a potential gain in profits by changing land use systems. It is important to note that this gain cannot accrue to the mining firm because of the nature of the federal land tenure system in this area. The gainers would be the residents of the reservation lands.

### Investment potential for the firm

The basic economic reason for any action of a firm is to maximize profits. The derivation of the profits is total revenues minus costs. In this case, the price and amount demanded of coal is set by government and private industry arbitration. The only recourse for the firm to increase profits is to minimize

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the costs of coal extraction and/or costs of reclamation.

An economic model of the costs of reclamation at the firm's decision level is presented by Yokell and Sanders (1981) where they represent the private and social costs of reclamation. The results of their theoretical modelling effort offers a standard of optimum resource allocation to the mining firm for the reclamation process. The most important result for purposes of this analysis is where the marginal benefits of reclamation are less than the marginal costs incurred by reclamation. That is, the last cost increment added to the sum of the reclamation costs is greater than the added value of the sum of the potential future benefits to be derived from mining. It is in the best interest of the firm, whose production level is predetermined, to minimize costs by choosing, whenever possible, the least-cost land reclamation option in order to maintain normal profits. The normal profit is defined as that profit necessary to maintain the firm in that occupation. Further, the reclamation costs are forwarded on the price of coal (even under regulated pricing) generating net social loss. This implies that the company can, by decreasing its reclamation costs, improve its fiscal position. There is also a potential for a net increase in social welfare.

### Investment potential for the future water system consumers

In Black Mesa/Kayenta, as in all surface mines, the disturbance of the land without reclamation decreases the productive and aesthetic quality of the land. These problems are especially critical in the Black Mesa/Kayenta area because it is in an arid, harsh region and it serves a population with a low income.

Unreclaimed mine spoils are not suitable for grazing which was the main use of the land before mining.

The estimated before-mining grazing capacity of the mine area is from one animal unit (Au) per 250 acres per year for range and scrub vegetation to one Au per 1000 acres per year for pinyon-juniper vegetation (Hilgedick, 1981).

### Economic feasibility analysis

To compare the alternative reclamation systems, the present value of direct net benefits (income minus production and reclamation costs) were calculated for grazing (conventional reclamation) or cropping (water-harvesting system reclamation). For a more detailed account of the analyses see: Nieves, 1981. The net present values are presented in 1979 dollar (vis a vis the Consumer Price Index) and a real discount rate of 4 percent is assumed.

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### CONVENTIONAL RECLAMATION

#### Reclamation costs

Mr. Hilgedick of Peabody Coal estimates the weighted average cost of moving one cubic yard of overburden is \$0.82. It follows that the estimated cost of leveling each acre is \$7,840. Peabody Coal cost estimates as high as \$9,000 to \$12,000 have been given by Dawson (1980). The range of cost estimates for topsoiling in the Black Mesa area is from \$2,000 to \$5,000 per acre (Dawson, 1980). In this study, Dawson's study estimate of \$3,000 per acre is used. The revegetation process costs range from \$375 per acre to \$440 per acre; \$420 per acre cost was used in this study. Combining all costs of grading/leveling (\$7,840/acre), topsoiling (\$3,000/acre), and revegetation costs (\$420/acre) produces an estimated average present value of reclamation costs at the Kayenta mine of \$11,260 per acre.

#### Grazing costs

The grazing of sheep and cattle is the major use of the Black Mesa/Kayenta lands. Estimates of premining grazing capacity range between one animal unit per 250 acres to 1,000 acres. It is possible that the reclaimed land will have a higher grazing capacity since, instead of the previous predominance of inedible species, the post-mining vegetation is expected to consist primarily of forage species. The Bureau of Indian Affairs (USDI/BIA 1964) estimated an eight-fold increase in stocking rate (from about 412 acres per Au to 57 acres per Au) for the Black Mesa area with "proper utilization and management." Dr. C. Robertson, Professor of Farm Management at the University of Arizona, has estimated the total annual cost of grazing cattle in this area as \$140 per cow in herd (this includes cash costs, depreciation, replacement costs, grazing fees, and wages for the hired labor). Using an estimate of 550 acres required for each animal unit, the grazing cost per acre is (\$140 divided by 550 acres) \$0.26 per acre, and the present value for grazing costs for 10 years is \$2.11 per acres (Nieves, 1981).

#### Grazing income

The grazing income estimate was calculated from the expected annual yield per cow. Nieves (1981) used the following production and price assumptions: 65% for calving percentage; calves selling weights of 356 lb. and 317 lb. for steers and heifers, respectively; selling price of \$57.72/cwt (three year adjusted state average). The estimated average calves selling weight is 337 lb. Applying this to the average calving percentage (65%) the expected yield of one cow would be 220 lb. This produces an income from grazing of about \$130/cow. Dividing income per cow by 550 acres produces an income estimate of \$0.23 per acre. The present net value of this income stream over 10 years is \$1.87/acre, however, it is assumed that grazing is breakeven activity (see Table 15).

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### Net present value of grazing

If the grazing cost and income estimates calculated above are accurate, grazing is not a breakeven operation on the Black Mesa. Costs exceed income, though the losses incurred are only \$0.03/acre annually and \$0.24/acre on a present value basis. Since there is considerable uncertainty embodied in the cost and income estimates and in the estimate of required acreage per cow, it is usually assumed that grazing is a breakeven operation (see Nieves, 1981).

## WATER-HARVESTING SYSTEM

### Reclamation costs

The costs of moving overburden to construct the water-harvesting system are estimated to be at least as much as in the conventional system, or \$7,840. Topsoiling is not necessary in this system. Thus, the total reclamation cost is \$7,840 per acre.

### Water-harvesting system costs

There are many alternative slope treatments (i.e. FAC, salt, etc.) and a wide range of initial construction costs. Further, there are annual operating and maintenance costs to be considered; retreatment costs are assumed to occur at the end of ten years. These recurring costs are discounted at 4% to calculate the present value of all slope treatment costs. Actual construction costs of the entire project were about \$8,000/acre (Constant and Thames, 1979). This included both the FAC and salt treatments. Using 4% per annum applied to the \$8,000 costs, the approximate 10 year O & M costs are \$1,000 or \$100 per year.

### Crop incomes

Using crop production data from the 1981 season (Table 13) and agricultural prices from Agricultural Statistics (USDA, 1980), the calculation of the the total value of production in consensurable 1979 dollars equals approximately \$1,100/acre. The prices used are bulk wholesale prices, but since the production is to be for subsistence, the prices are not necessarily representative of values to the consumer. Assuming that the costs of buying the goods produced at retail prices in the Black Mesa/Kayenta area would be at least twice the wholesale price (considering transportation and handling), the total value of production for the 1981 crop season is \$2,200 per acre (for a reference on commodity prices used in development projects, see Squire and Van der Tak, 1975).

Cropping costs are estimated to be \$100 per cultivated acre for seed, fertilizer, and agricultural chemicals; \$110 fuel expenses for irrigation

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pumpage; and \$400 per acre for land preparation (tractor time, 20 hrs. at \$20 per hour). The labor requirements were estimated to be 500 to 1000 person hours, however, since this is a subsistence crop system the value of labor is not explicitly included.

### Comparison of the systems

The comparison of conventional reclamation to the water-harvesting system demonstrated in this project shows both saving for the firm engaging in reclamation and the individuals receiving the future stream of benefits from the reclaimed lands. A major reason for the savings is that the firm and the Black Mesa inhabitants receive separable benefits from the water-harvesting system implementation. The firm minimizes costs and does not internalize the long-term revenues from the reclaimed land; the Black Mesa inhabitants do not realize the initial construction costs only the operating and maintenance costs.

Table 15 summarizes the economic analyses of grazing and water-harvesting. The grazing activity is a breakeven production per acre. The water-harvesting project yielded about \$1,700 net revenues (i.e. revenue is zero) (profit) per cultivated acre in 1981. Agricultural yields are expected to increase when the orchard begins to bear and with further experimentation with annual crops, but the grazing potential is not expected to change.

Table 15. Comparison of system costs and net revenue, 1981.

	Conventional system (Grazing)	Water-Harvesting System
	-----dollars per acre-----	
Construction	\$11,260	\$7,840
System Operating Costs (PNV 10 yrs @ 4%)	\$2.11	\$400 <sup>1/</sup>
Cropping Costs	0	\$610
Income	\$2.11	\$2,200
NET REVENUE	\$0.00	\$1,190 <sup>2/</sup>

<sup>1/</sup> Estimated 4 to 1, catchment to crop ratio.

<sup>2/</sup> Includes only crop acreage.

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### SUMMARY

#### Site development

Originally, a water harvesting system was to be designed for an ungraded site and to use the final cut at the high wall for water storage. However, the Surface Mining Law, promulgated after the initial design had been made, required the reduction of high walls and prohibited the use of post regulation spoil areas for water harvesting. It was therefore necessary to choose a site among the available pre-regulation areas and to design a system which would minimize reshaping the topography of the already regraded soil.

The final design of the water harvesting system consisting of (1) three water storage ponds with a total capacity of 800,000 gallons, (2) two leveled agricultural terraces of two and one-half acres each, (3) an orchard 'road' catchment system of one acre which drained into the lower pond, (4) a fiberglass-asphalt-chip treated catchment of 8 acres, and (5) a salt treated catchment of 7 acres.

A system was installed to transfer water between ponds. In order to reduce evaporation water was concentrated as much as possible in the central pond which was partially covered by was-impregnated styrofoam flats. Because of the high clay content of the spoil it was not necessary to seal the bottoms and sides of the ponds.

Contour drainages were constructed on the catchments to direct runoff water into the ponds. The drainages on steep slopes were paved with concrete to prevent erosion. It was originally thought necessary to use the expensive fiberglass-asphalt-chip treatment to help insure success, but it was found later that the simple and expensive salt treatment made an equally efficient catchment surface.

The agricultural terraces were irrigated from the ponds as often as necessary. Initially, flood irrigation was used, but because of problems with subsidence and the difficulty of maintaining dead level surfaces a sprinkler system was later employed. The orchard received runoff water directly from the 'roads' but was also irrigated as needed. In shaping the agricultural terraces it was found that about one-third of their areas toward the northeast had been covered with only a thin layer of spoil. The native soil material was then exposed during leveling. However, this provided an interesting comparison between spoil and native soil material. The system was operative one year after initiation. Crops have been grown for the past three seasons.

#### Production

With the exception of Indian corn there was not information available on vegetable crops that might be suitable to the area. Accordingly, the first two seasons were devoted to species trials and to improving the operation of the

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system.

Crops tested included beets, onions, turnips, potatoes, chard, lettuce, cabbage, tomatoes, squash, beans, pumpkins, melons, mangles and corn. With the exception of tomatoes, all crops did surprisingly well, some producing at levels above the national average.

There appeared to be no differences in production between the native soil material exposed on the northeast ends of the terraced and the mine spoil. Chemical analysis indicated that salt content was high (about 1000 ppm) but levels (Fe, Mn, Cu, Zn, K, Pb, Cr, Hg, Cd, Se and As) minerals were well below toxic levels. Interestingly the mine spoil was developing a friable structure by the end of the third growing season.

During the last two seasons (1980 and 1981) some of the higher producing crops were planted. Carrots did not perform as well as expected in terms of production per acre. The reasons for this lie mainly in the way the furrows were constructed. They were made deep and five-feet wide to allow walking on dry ridges and for better water distribution. However, the unplanted walkways covered about 1/3 of the area of the field; thus, the pounds-per-acre values underestimate the real productiveness and water-use efficiency. This is also true for the green beans and beets. Nevertheless, carrots yielded the highest return in dollars, even greater than those crops that exceeded the national production averages.

Green bean production was next highest in value and exceeded the national average by \$295 per acre. This result is interesting since green beans are one of the more salt sensitive crops. Thus, they were not expected to perform as well as they did with the salt conditions of the soil materials. No differences in performance of beans were observed between topsoil and spoil areas.

Table beets also exceeded the national average (by \$515 per acre in 1980 and by \$65 per acre in 1981). There appeared to be no differences in productivity between the two soil materials. Beets are an uncommon food in the area, but requests by the local inhabitants greatly exceeded the supply.

The value of corn was the lowest of all crops. Production was less than half the national average. This was not expected, but corn is an important traditional food in the area, and was planted primarily for social reasons.

There are no data on the national production of squash and pumpkin. However, both are in demand and both exceeded each of the other crops in pounds per acre. Watermelon was planted because of local requests. Production was only fair as was expected from previous trials.

Fruit trees had never been grown in the area before. Thus, several species believed to be suitable were planted that included two varieties of almonds, eight varieties of apples, two varieties of peaches, three varieties

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of pears and one variety each of chestnut and nectarine for a total of 68 plants. All trees were growing well after the third growing season. A few apple and peach trees produced large fruits of excellent taste, but it is too soon after only 3 growing seasons to determine the potential of the varieties planted.

### Economic analysis

A comparison of conventional reclamation to the water-harvesting system shows both savings for the mining company and the individuals receiving the future stream of benefits from the reclaimed lands. A major reason for the savings is that the mining company and the Black Mesa inhabitants receive separable benefits. The company minimizes costs (primarily in not having to topsoil) and does not internalize the long-term revenues from the reclaimed land; the Black Mesa inhabitants do not realize the initial construction costs only the operating and maintenance costs.

The water-harvesting project yielded about \$1,700 net revenues per cultivated acre in 1981. Agricultural yields are expected to increase when the orchard begins to bear and with further experimentation with annual crops, but the grazing potential is not expected to change.

## STRIP MINE RECLAMATION IN DRY REGIONS

### REFERENCES FOR ECONOMIC ANALYSIS SECTION

- Constant, C.L. and J. Thames. 1979. "Battelle Mound and Valley Water Harvesting System." Progress Report, School of Renewable Natural Resources, University of Arizona, Tucson, Arizona.
- Dawson, D. 1980. "Compliance - The Coal Industry Experience." Peabody Coal Co., Flagstaff, Arizona.
- Hilgedick, W. 1981. Personnel communication.
- Nieves, L.A. 1981. "Reclamation Versus Land Use Transformation a Cost Comparison." (In the Proceedings: Conference on the Economics of Mined Land Reclamation, Land Reclamation Program, Argonne National Laboratory and U.S. Dept. of Energy) Sept 1-2. Chicago.
- Squire, L. and H. Van der Tak. 1975. Economic Analysis of Projects. The John Hopkins University Press, Baltimore.
- USDA. 1980. Agricultural Statistics. GPO, Washington.
- USDI/BIA. 1964. Summary Report Soil and Range Inventory of the 1882 Executive Order Area (Exclusive of District Six) Arizona. Branch of Land Operations.
- Yokell, M.D. and G. Sanders. 1981. "The Economics of Reclamation." (In the Proceeding: Conference on the Economics of Mined-Land Reclamation, Land Reclamation Program, Argonne Laboratory and U.S. Dept. of Energy) Sept. 1-2. Chicago.

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### APPENDIX

#### LITERATURE REVIEW

Coal in the western United States will continue to be a major energy source in the near future. Twenty-seven billion tons of coal could be produced from 1.5 million acres of the West using current surface-mining methods (National Academy of Science 1974). This amount of coal is a huge energy resource equivalent to the entire U.S. energy consumption in 1975 ( $76 \times 10^{15}$  kilojoules) multiplied by 9.4, and probably it will be quickly mined to maintain our standard of living. The area involved, 2296 square miles in all, is large enough to warrant careful planning to minimize environmental damage during the after mining.

Congress recognized the importance of formulating a policy to guide the restoration of our common heritage of land and its resources; and it passed the "Surface Mining Control and Reclamation Act of 1977." The central theme of this act requires the mine operator to, "restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, ... or better uses." (United States Congress 1977). This is certainly a necessary goal. However, there needs to be regional flexibility in the land-use strategy used to attain this goal. "The potential for rehabilitating any surface mined area in the West is critically site-specific... Rehabilitation objectives may range from no treatment at all through the gamut of reshaping and revegetating to complete redesign of the landscape." (National Academy of Science 1974). The Federal policy of restoring the mined area to the original landscape contours and topsoiling the surface may be, in the West, an unnecessary and overly expensive process.

In the East, "failure to stabilize the mined area by backfilling the pit and establishing vegetation often resulted in erosion, acid water runoff, and landslide damages extending beyond the boundaries of the actual mine site." (Nephew 1974). The acid water runoff and acidic pH of the mined area is due to large amounts of pyrite ( $\text{FeS}_2$ ) which, on exposure to air, oxidizes to sulfate and sulfuric acid. The resulting acid condition kills stream life and renders revegetation difficult or impossible (Ehrlich 1977). Topsoiling seems to be the best way of re-establishing plant growth on the eastern, acidic mine spoils. ("Spoil" refers to the shale and sandstone "overburden" that is removed during open pit mining to get at the coal layer.)

The West's main revegetation problem is not acidity, but lack of water.

We believe that those areas receiving ten inches (250 mm) or more of annual rainfall can usually be rehabilitated, provided that evapotranspiration is not excessive, landscapes are properly shaped and techniques demonstrated to be successful in rehabilitating disturbed rangeland are applied... Revegetation of the drier areas can probably be

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accomplished only with major, sustained inputs of water, fertilizer, and management... Rehabilitation of the drier sites may occur naturally on a time scale that is unacceptable to society, because it may take decades, or even centuries, for natural succession to reach stable conditions... In the foothill shrub natural ecosystem, even the best methods may fail during drought years. (National Academy of Science 1974)

The reclamation policy adopted for the West should reflect this major change in environmental conditions.

In the following comparison between Eastern and Western conditions, I will use the Black Mesa, Arizona, mines that are operated by Peabody Coal Company as a representative example of Western conditions. Black Mesa is in the "foothill shrub natural ecosystem" referred to above, and so the potential for successful reclamation using conventional, forage-establishment methods is low due to lack of precipitation.

In spite of this poor prospect, society is paying a high price to return the land to a grazing economy. LaFevers (1978) estimated that the reclamation cost for Black Mesa is about \$5000/acre; Wiener (1981) puts the cost at \$12,000-\$18,000/acre. The larger estimate is close to what I have heard the coal mine operators state as the cost, and so I favor the \$12,000-\$18,000/acre estimate. This great expense might be justified if a good income could be made from the reclaimed land. But sparse rainfall limits the production of forage, so that this form of livelihood can barely break even. The pre-mining grazing capacity of the land was one sheep for 130 acres (United States Bureau of Indian Affairs 1964). The poor returns expected from the current reclamation goal emphasize the need to look for alternatives that would cost less to accomplish and/or give a higher return in the future. Other authors have referred to this research need:

Disturbed land is not merely something to be screened from view, but rather a resource that has some potential value (Ripley 1978).

The ultimate goal of this work is the development of an efficient and cost-effective way to return to productive use lands that have been disturbed by mining (Argonne National Laboratory 1981).

Pragmatically, reclamation success should be based on utility, not on whether identical ecosystem composition has been achieved (Imes 1978).

One of the major factors that must be considered in forming reclamation policy for a specific site is the nature of the spoil material and its arrangement. Corn yield reduction on mine spoil in the Pennsylvania-Illinois region varied from 4% to 90% depending on reclamation procedure and spoil qualities (Nielsen Miller 1980). Apparently, this is one important factor in improving spoil for plant growth in southwestern Pennsylvania -- eight-year old spoil gave corn yields that were 89% of unmined land, while 23-year-old spoil gave yields that were 100% of unmined land (Nielsen, Cunningham 1980). Black

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Mesa spoil contains enough calcium to neutralize the acid-forming sulfur. This reaction produces a more-or-less neutral soil with a high salt content. The spoil has a loam texture and is high in nitrogen. Aldag (1980) reports high nitrogen levels (up to 0.7% = 7000 ppm) in coal mine spoil. According to Power (1978), "many shales contain 10-50 ppm exchangeable ammonium (NH<sub>4</sub>). This substance is readily nitrified to nitrate within a few months after exposure to the atmosphere." However, only 37% of the nitrate remains after four years in the surface 30 cm, presumably due to denitrification. An analysis of Black Mesa spoil also shows a high nitrogen content of 32 ppm, high enough to eliminate the cost of nitrogen fertilizer for most crops (Powelson 1980).

In a test for toxic elements in the Black Mesa spoil, a tissue analysis of sugar beet root showed no toxicity. The chromium level of 7.75 ppm was high, but not dangerously so. In fact, the level of chromium found may be beneficial since it is an essential nutrient (National Academy of Science 1974).

The high cation exchange capacity of mine spoil is accounted for by the high absorptive capacity of the carbonaceous matter (coal blossom) in the spoil (Pedersen 1978). Oxidized, low-grade coal is rich in humate which may improve soil. Gosz (1978) found that the addition of humate at 800 lbs/acre resulted in the greatest number of both bacteria and fungi associated with plant roots. Ponder (1979) reports that "apparently there is no problem in getting endomycorrhizal infection on coal mine spoil." However, Aldon (1978) found that fourwing saltbush (Atriplex canescens) plants infected by Glomus mossae endomycorrhizal fungus had 256% of the size of non-infected plants after growing two years in mine spoil. Vimerstedt (1969) found that the available phosphorus of spoilbanks was increased 165% in six months by earthworms that were increasing the rate of leaf decay.

In the Bowen Basin coalfield of Australia, plant growth "is better on the overburden than on the original leached topsoil" (Bradshaw 1980). With the addition of water to leach excess salts out of the root zone of Black Mesa spoil, and the addition of phosphorus to complete the nutrient supply, the spoil forms a good agricultural soil (Powelson 1980). Thames (1975) concludes that on Black Mesa, "it seems reasonable that the mine spoil, because of its adequate nutrient supply, great depth and water holding capacity, has a high potential for the production of good range forage."

The Black Mesa topsoil that is being applied over the spoil at a cost of about \$3000 per acre (Dawson 1980) is not what a person used to good farmland would call "topsoil". Most of the good soil has washed away in the last hundred years or so. What remains is classified as a Torriorthent (Day 1979), and is low in nitrogen, humus, and phosphorus, and is high in salts. In the West there are "wide variations in overburden material and lack of adequate topsoil... In some cases the saving and spreading of topsoil can do more harm than good, for instance, where the calcium carbonate layer underlying much arid land soil is mixed with the nitrogen-rich organic layer, and the biologic carbon-nitrogen balance is destroyed" (Doyle 1976). Also, "topsoil from an area in fair or poor condition would contain undesirable, aggressive, and

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perhaps noxious weed seed." (Hodder 1978). Since the Black Mesa spoil has relatively good soil potential, and the local topsoil is of low quality, reclamation policy for this area should contain alternatives to the expensive topsoiling procedure now used.

The final productiveness of the land can be greatly influenced by the system on overburden placement. In Estonia, U.S.S.R., limestone overburden is placed in the bottom of the worked-out pit; the backfilled limestone is then covered with quarternary deposits (sands, peat, etc.) (Luik 1980). Similarly, burying spoil high in pyrite in the American East, and burying high-salt spoil in the West greatly improves conditions for reclamation. As Hodder (1978) puts it, "Selective placement of toxic spoils materials well above the potentially saturated zone, yet substantially below the plant root zone, may become a common approach." In Great Britain, the National Coal Board "has imposed codes of practice that require the colliery management to compact the shale in thin layers, building a tip that contains the minimum air." (Ayerst 1978). Power (1978) points out that "typical bulk density values of overburden are 1.4-1.7 g/cm<sup>3</sup>... Differential subsidence will probably continue for many years unless mining methods are changed to permit more uniform packing of spoil materials. Such subsidence will continually alter surface drainage." Anderson (1979) emphasizes the use of terraces for row crops to prevent excessive erosion on reclaimed spoil. In Australia, the spoil heaps were shaped with a bulldozer to give a flat top 10-20 meter wide (Coaldrake 1978). Stiller (1980) points out that "successful revegetation will not control erosion on a large scale in the semi-arid western states if the post-mining topography is not also designed and constructed to limit erosion." For example, the final layout "should have at least the pre-mining drainage density." This concept is supported by Smith's (1978) conclusion that doubling the slope length results in three times the sediment discharge.

The effect of coal mining and reclamation on water supply is both external to the mine and internal. Two external water problems that have occurred from Eastern coal mining are acid drainage and stream siltation. However, "at Western mines, acid drainage and the associated toxic metals common in the East should be minimal because of the small amounts of acid-forming substances (i.e. pyrite) and the generally alkaline nature of overburden and soils... The effect of the Big Horn Coal Mine (Wyoming) on concentrations of dissolved conservative constituents is the Tongue River is small, and is within the range of analytical precision and short-term variations in ambient concentrations." (Detman 1978). Silt transport from the mine seems to be well controlled at the Black Mesa mine by the use of dams, culverts, regrading, and revegetation.

One external water problem that was not major in the East, but may have great impact on the West is water consumption of coal-fired electricity generation and synfuel production. Sheridan (1981) has calculated that the water needs of "pending" coal-fed energy developments in the upper Colorado Basin would total 570,000 acre-feet per year. Does the Colorado River have the supply to meet this new major demand? The expensive desalinization plant that the United States is building in Yuma, Arizona, to assure that Mexico receives

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Colorado River water of quality required by treaty indicates that the supply is already over-used.

Within the mine site a number of techniques can be used to improve water conditions for reclamation. The methods of reducing erosion mentioned above, like construction of a high drainage density and terracing, will also improve water supply. Schuman (1980) found that growing a grass, and cutting it to leave a standing stubble improved revegetation success compared to the use of crimped straw mulch. The soil protected by stubble had a higher water infiltration rate, more moisture, and cooler temperature. The stubble technique resulted in a more desirable population of grasses with less weeds, and it was cheaper to use. Saulman (1973) measured an increase in snowmelt runoff from a water harvesting catchment of 0.3 to 4.7 inches by using snow fencing. Kruspe (1978) found that mulching individual trees with plastic offered a method of increasing the survival and growth of tree seedlings on surface mine spoil. Engstrom (1979) took the approach of using supplemental irrigation to establish grass to meet a cold, dry reclamation challenge in Wyoming.

Since native plant species have proven their adaptation to the local climate, they are top choices to stabilize the land surface and to provide an environment for animal wildlife. Several coal mines, including the one on Black Mesa, are located in the Great Basin desert shrub region which is dominated by big sagebrush (Artemisia tridentata). The slopes and ridges are co-dominated by Colorado pinyon pine (Pinus edulis) and one seed juniper (Juniperus monosperma). Other common shrubs are: fourwing saltbush (Atriplex canescens), Green rabbitbush (Chrysothamnus Greenei), pale wolfberry (Lycium pallidum), snakeweed (Gutierrezia sarothrae), and winterfat (Eurotia lamata). Greasewood (Sarcobatus vermiculatus) and rabbitbush (Chrysothamnus nauseosus) occur in the lowest sites. Important grasses are western wheatgrass (Agropyron smithii), galeta (Hilaria jamesii), Indian ricegrass (Oryzopsis hymenoides), and blue grama (Bouteloua gracilis). Two common herbaceous perennials are: white aster (Leuceline ericoides) and red globe mallow (Sphaeralcea ciccubea) (Wagner 1978). In saline reclamation situations, the use of salt desert shrubs which have a far greater salinity tolerance than that of agronomic species will improve revegetation success (McKell 1978).

There may be some non-native species which have better forage or other qualities. Monsen (1978) found that "Russian wildrye (Elymus junceus) is particularly adapted to the infertile substrata that are being exposed by coal mining in many Western states," and he points out that "planting short-lived nurse crops can prevent the invasion of weeds." Weber (1981) recommends Pinus eldarica as a fast growing, heat, drought, and cold resistant tree. Bjugstad (1978) emphasizes the importance of establishing trees in northern high plains reclamation efforts since "the existing woody draws (650,000 acres) could produce a tangible annual income of at least \$3 million based on potential wood and game production alone. Other benefits, such as livestock protection,, aesthetic values, water, and wind management, are extras."

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The research described in the preceding paragraphs was primarily focused on ways to restore mined land to a condition similar to the pre-mining conditions. However, in some arid situations, it may be beneficial to create a different landscape to use water-harvesting techniques to grow high value crops. The water-harvesting strategy is based on the principle that since water is the limiting factor for plant growth in arid zones, better agricultural yields can be obtained by providing fewer plants with ample water than many plants with little water. In other words, by farming in areas where runoff naturally concentrates, or by artificially concentrating runoff, a desert farmer can increase production. This water-limited condition prevails in the western coal areas.

People in arid lands have used water concentration techniques for centuries. The most well studied example is the people who lived in the Negev Desert beginning around 1000 B.C. (Evenari 1961). In this desert, the loess soil has 2-5% total soluble salts which forms a surface crust that sheds much of the rainfall. By using a system of ditches and terraces, the people were able to grow grain and fruit with a rainfall of only 80 mm/year (3.15 inches/year). A good summary of ancient and modern water-harvesting systems can be found in Boers (1979). The authors point out that in spite of the deficiency of rainfall in arid lands, enormous amounts of water are lost during floods, and that water-harvesting systems are flexible enough to catch and use much of it. Karschon (1981) developed a method of using small watersheds to irrigate tree clusters for recreation and fuelwood. The ratio of irrigated area to untreated catchment area in his study was between 1:20 and 1:30. Water-harvesting for livestock is described in Frasier (1980). He found that gravel-covered polyethylene is more cost effective than asphalt for runoff enhancement. Aldon (1975) used small (0.37 m<sup>2</sup>) plastic water catchments to more than triple the growth rate of fourwing saltbush on mine spoil in New Mexico. In the arid Columbia Basin of Washington, minimal regrading of mine spoil ridges into a 1:3 cropped to catchment ratio, and covering the catchment with plastic produced better than five times the wheat yield expected for that area (Anonymous 1978). The Black Mesa Water-Harvesting Agrisystem was conceived to test the reclamation suitability of water-harvesting on mine spoil to provide irrigation to high value crops. Schwennesen (1980) described the hydrologic system of this project, and the vegetable-growing success of the first production year.

Because of the tremendous variations in mine spoil characteristics, climates, local land-use plans, and reclamation technologies, reclamation policy should move away from rigid legislation of methods to a more flexible policy custom-formulated from negotiations between the mining company, representatives of the local population, scientists, and, to represent broader interests, the federal government. The federal government should also be responsible to see that the environment external to the mine is not excessively damaged, and to see that the mining company is economically rewarded for using the most cost-effective reclamation technology.

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The policy of protecting the environment by specifying the technological means as found in the Federal Water Pollution Control Amendments of 1972 and the Surface Mining Control and Reclamation Act of 1977 has been shown to be inappropriate and expensive. A better model for mine reclamation is the Clean Air Amendments of 1970 where the end product, air quality, is measured and controlled, but the means of achieving it is not (Freeman 1978). Using this method of regulation to make reclamation policy might take the form of establishing air and water quality standards during the after mining, and setting the long-term economic potential of the reclaimed land.

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### REFERENCES

- Aldag, R.W. and Z. Strzyszcz (1980), "Inorganic and organic nitrogen compounds in carbonaceous phyllosilicates on spoils with regard to forest reclamation," Reclamation Review 3: 69-78.
- Aldon, Earl F. (1978), "Endomycorrhizae enhance shrub growth and survival on mine spoils," The Reclamation of Disturbed Arid Lands, Robert A. Wright, (ed.), University of New Mexico Press, Albuquerque, N.M. p. 174-180.
- Aldon, Earl F. and H.W. Springfield (1975), "Problems and techniques in revegetating coal mine spoils in New Mexico," Practices and Problems of Land Reclamation in Western North America, Mohan K. Wali (ed.), University of North Dakota Press, p. 122-132.
- Anderson, C.E. and J.M. Briggs (1979), "Planning erosion control for coal mining and reclamation," J. Soil and Water Conservation, 34 (5): 234.
- Anonymous (1978), "Alternative reclamation methods hold promise for the West," Mining Engineering 30(12): 1644-1645.
- Argonne National Laboratory (1981), Proceedings, Conference on the Economics of Mined Land Reclamation, National Technical Service, Springfield, Virginia.
- Ayerst, John M. (1978), "The effect of compaction of coal shale on the revegetation of spoil heaps," Reclamation Review 1: 27-30.
- Bjugstad, Ardell J. (1978), "Reestablishment of woody plants on mine spoils and management of mine water impoundments: An overview of forest service research on the northern high plains," The Reclamation of Disturbed Arid Lands, Robert A. Wright, (ed.), University of New Mexico Press, Albuquerque, N.M., p. 3-12.
- Boers, T.M. and J. Ben-Asher (1980), "Harvesting water in the desert", International Institute for Land Reclamation and Improvement, Annual Report 1979, p. 6-23.
- Bradshaw, A.D. and M.J. Chadwick (1980), The Restoration of Land, Blackwell Scientific Publications, Oxford, England.
- Cluff, C.B. and R.K. Frobel (1978), Water Harvesting Catchment and Reservoir Construction Methods. Water Resources Contribution No. 2, Water Resources Research Center, University of Arizona, Tucson. 48 p.
- Coaldrake, J.E. and M.J. Russel (1978), "Rehabilitation with pasture after open-cut coal mining at three sites in the Bowen Coal Basin of Queensland," Reclamation Review 1: 1-8.

## STRIP MINE RECLAMATION IN DRY REGIONS

- Cooley, Keith R., Allen R. Dedrick, and Gary W. Frasier (1975), Water Harvesting: State of the Art, p. 1-21. In Proceedings Symposium on Watershed Management by Irrigation Division of ASCE, August 11-13, Logan, Utah.
- Day, A.D., T.C. Tucker, and J.L. Thames (1979), "Russian thistle for soil mulch in coal mine reclamation," Reclamation Review 1(2): 39-42.
- Dettmann, Edward H. and Richard D. Olsen (1978), "Assessment of water quality impacts of a Western coal mine," The Reclamation of Disturbed Arid Land, Robert A. Wright (ed.), University of New Mexico Press, Albuquerque, p. 53-68.
- Doyle, William S. (1976), Strip Mining of Coal, Noyes Data Corporation.
- Ehrlich, Paul R., Anne H. Ehrlich, and John P. Holdren (1977), Ecoscience: Population Resources, Environment, W.H. Freeman and Co., San Francisco, California, p. 416-422.
- Engstrom, Louis A. and Evert Bainter (1979), "A cold, dry reclamation challenge," Soil Conservation, June, 1979, p. 10.
- Evenari, M., L. Shanan, N. Tadmor, and Y. Aharoni (1961), "Ancient agriculture in the Negev," Science 133: 979-995.
- Food and Agriculture Organization of the United Nations (1979), Water Quality for Agriculture.
- Frasier, Gary W. (1980), "Harvesting water for agricultural, wildlife, and domestic uses," J. Soil and Water Conservation, 35 (3): 125.
- Freeman III, A. Myrick (1978), "Air and water pollution policy," Current Issues in U.S. Environmental Policy, Paul R. Portney (ed.), Johns Hopkins University Press, Baltimore, Maryland, p. 12-67.
- Gosz, James R., et. al. (1978), "An evaluation of New Mexico humate deposits for restoration of mine spoils," The Reclamation of Disturbed Arid Lands, Robert A. Wright (ed.), University of New Mexico Press, Albuquerque, N.M., p. 180-188.
- Hodder, Richard L. (1978), "Potentials and predictions concerning reclamation of semiarid mined lands," The Reclamation of Disturbed Arid Lands, Robert A. Wright (ed.), University of New Mexico Press, Albuquerque, N.M., p. 149-154.
- Imes, Andrew C. and Mohan K. Wali (1978), "Governmental regulation of reclamation in the western United States: an ecological perspective," Reclamation Review 1: 75-88.

## STRIP MINE RECLAMATION IN DRY REGIONS

- Karschon, R. and J. Kaplan (1981), "Tree ponds for recreation and fuelwood," Arid Lands Newsletter 13, March 1981, p. 16-21.
- Kruspe, R.R. (1978), "Individual tree mulching as an aid to the establishment of trees on surface mine spoil," Reclamation Review 1: 139-142.
- La Fevers, James R. (1978), "Economics of mined land reclamation and land-use planning in the Western States," Reclamation of Disturbed Arid Lands, Robert A. Wright (ed.), University of New Mexico Press, Albuquerque, N.M., p. 68-71.
- Luik, H. (1980), "Recultivation work in the oil shale basin of Estonia, U.S.S.R.," Reclamation Review 3: 161-168.
- McKell, Cyrus M. (1978), "Establishment of native plants for the rehabilitation of paraho processed oil shale in an arid environment," The Reclamation of Disturbed Arid Lands, Robert A. Wright (ed.), University of New Mexico Press, Albuquerque, N.M., p. 13-32.
- McRae, Stuart G. (1979), "The agricultural restoration of sand and gravel quarries in Great Britain," Reclamation Review 2(3): 133-141.
- Monsen, Stephen and A. Perry Plumer (1978), "Plants and treatment for revegetation of disturbed sites in the intermountain area," The Reclamation of Disturbed Arid Lands, Robert A. Wright (ed.), University of New Mexico Press, Albuquerque, N.M., p. 155-173.
- National Academy of Sciences (1974), Rehabilitation Potential of Western Coal Lands, Ballinger Publishing Co., Cambridge, Massachusetts.
- Nephew, E.A. and R.L. Spore (1974), "Coal mining and the environment," Energy Conservation and the Environment, Oak Ridge National Laboratory, Tennessee, p. 36-54, ORNL-NSF-EP-77.
- Nielsen, Gerald A. and Eilif V. Miller (1980), "Crop yields on native soils and strip mine soils: a comparison," J. of Soil and Water Conservation 35(1): 44-46.
- Parr, Patricia Dryer and Fred G. Taylor (1980), "Incorporation of chromium in vegetation through root uptake and foliar absorption pathways," Environmental Experimental Botany, 20(2): 157-160.
- Pedersen, T.A. (1978), "Comparison of morphological and chemical characteristics of some soils and mine soils," Reclamation Review 1: 143-156.
- Ponder, Felix J. (1979), "Presence of endomycorrhizal fungi in recently graded coal mine spoil," J. Soil and Water Conservation 34(4): 186.

## STRIP MINE RECLAMATION IN DRY REGIONS

- Power, J.F., et. al. (1978), "Restoration of productivity to disturbed land in the northern Great Plains," The Reclamation of Disturbed Arid Lands, Robert A. Wright (ed.), University of New Mexico Press, Albuquerque, N.M., p. 33-50.
- Ripley, Earle A., Robert E. Redmann, and James Maxwell (1978), Environmental Impact of Mining in Canada, Queen's University Press, Kingston.
- Saulman, R.W. (1973), "Snowdrift management can increase water-harvesting yields," J. Soil and Water Conservation 28(3).
- Schuman, G.E., et. al. (1980), "Standing stubble versus crimped straw mulch for establishing grass on mined lands," J. Soil and Water Conservation 35(1): 25.
- Schwennesen, Eric and Oliver Whitehair (1980), "On Black Mesa spoil heaps, harvested water becomes the key to a harvest of vegetables," Progressive Agriculture in Arizona 31: 1-3.
- Sheridan, David (1981), Desertification of the United States, U.S. Government Printing Office, Washington, D.C. 334-983/8306.
- Smith, Roger E. and David A. Woolhiser (1978), "Some applications of hydrologic simulation models for design of surface mine topography," The Reclamation of Disturbed Arid Lands, Robert A. Wright (ed.), University of New Mexico Press, Albuquerque, N.M., p. 189-196.
- Soane, B.D. and D.H. Saunder (1959), "Nickel and Chromium toxicity of serpentine soils in southern Rhodesia," Soil Science 88: 322-330.
- Stiller, D.M., G.L. Zimpfer, and Mike Bishop (1980), "Application of geomorphic principles to surface mine reclamation in the semiarid West," J. of Soil and Water Conservation 35: 274-276.
- Sweeney, Larry R. (1979), "Surface mining reclamation in Appalachia: Impact of the 1977 Surface Mining Control and Reclamation Act," J. Soil and Water Conservation 34(5): 199.
- Thames, John L. and Tika R. Verma (1975), "Coal mine reclamation on the Black Mesa and the Four Corners areas of northeastern Arizona," Practices and Problems of Land Reclamation in Western North America, Mohan K. Wali (ed.), University of North Dakota Press, Grand Forks, N.D., p. 48-64.
- Vimmerstedt, J.P. (1969), "Earthworms speed leaf decay on spoilbanks," Ohio Report 54(1): 3-5, Ohio Research and Development Center, Wooster, Ohio.
- Wagner, Warren L., William C. Martin, and Earl F. Aldon (1978), "Natural succession on strip-mined lands in northwestern New Mexico," Reclamation Review 1: 67-73.

## STRIP MINE RECLAMATION IN DRY REGIONS

Weber, Edmund J. (1981), "Pinus eldarica: A valuable resource for arid zones," Arid Lands Newsletter 13, March 1981, p. 40-44.

Wiener, Daniel P. (1981), "Economics of surface mine reclamation," Proceedings: Conference on the Economics of Mined-Land Reclamation, Argonne National Laboratory, U.S. Department of Energy, p. 45-54.

Yokell, Michael D. and Geoff Sanders (1981), "The Economics of Reclamation," Proceedings: Conference on the Economics of Mined-Land Reclamation, Argonne National Laboratory, U.S. Department of Energy, p. 3-36.