MILL TAILING RECLAMATION AT CYPRUS MIAMI MINING CORPORATION[1]

by

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Abstract. In 1989, Cyprus Miami Mining Corporation initiated a mill tailing reclamation project on inactive tailing dams located between Globe and Miami, Arizona. In addition to utilizing the more traditional reclamation methods of soil replacement, fertilization, and seeding to reestablish vegetation, Cyprus Miami is piloting the use of selected principles of Holistic Resource Management (HRM) to generate new soil from barren tailing material. One HRM technique employs carefully monitored animal impact (i.e. the effects of dunging, urinating, hoof action, and grazing as tools) to promote soil generation and to stimulate plant succession in an attempt to accelerate nature's own processes.

Additional Key Words: soil redistribution, hydromulching, revegetation, cattle grazing.

Preface

In 1989, tailing dam reclamation at Cyprus Miami Mining Corporation's (CMMC) operations began in earnest under the title of Tailing Dam Dust Control. One phase has been completed, a second phase is nearing completion, and a request for an appropriation for the third phase of the project has been submitted as of this writing. Those who have worked on the project are encouraged by the results demonstrated thus far and challenged by the work remaining to be accomplished.

Whenever possible, this discussion will attempt to record the progression of the project in chronological sequence from its inception. However, since some activities were conducted concurrently, priority has been given to the consolidation of topical information within sections.

The author acknowledges the lack of scientific documentation in some important areas. The project has progressed so quickly that, at times, more effort has been spent in expediting the progress than in documenting it. As an example, transects of the revegetated areas, necessary to establish baseline data for future comparison, are only now being performed.

Introduction

CMMC Operations and Locality

Cyprus Miami Mining Corporation's copper mining operations are located in the vicinity of the communities of Globe and Miami, Arizona, approximately 80 mi East of Phoenix. Owned and operated by Inspiration Consolidated Copper Company prior to July 1988, Cyprus Miami's operations include open pit mining, dump leaching, solvent extraction, electrowinning and refining, toll smelting, and copper rod fabricating.

Climate and Elevation

The climate of the Globe-Miami district is mild and dry. Maximum temperatures, occurring in June and July, generally range from 104° F to 108° F and rarely exceed 110° F. December and January are normally the coldest months when minimum temperatures may fall within the range of 11° F to 22° F during the early morning hours.

TABLE 1
CLIMATE AVERAGES

Month	Daily Max. (°F)	Daily Min. (°F)	Average Total Precipitation (in)
January	55.0	32.7	2.06
February	60.4	35.4	1.25
March	65.1	39.5	1.78
April	74.7	47.3	0.66
May	84.5	55.7	0.25
June	93.7	64.2	0.26
July	97.0	70.3	2.34
August	93.9	67.9	3.33
September	89.7	62.9	1.53
October	78.8	52.0	1.07
November	65.4	40.5	1.12
December	56.6	34.2	2.40
Year	76.2	50.2	18.05

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Average temperatures and precipitation for the Globe-Miami area, obtained from the Chamber of Commerce Community Profile, are presented in Table 1.

The mean elevation above sea level of the top of tailing dams No. 3, No. 4, and No. 6 is 3525 ft. The top of No. 5 is somewhat lower at 3465 ft.

Tailing Dam Dimensions

From 1915 until January 1985, Inspiration Copper had processed sulfide ores by crushing, milling, and concentrating. During that period, five contiguous tailing dams were completed and a sixth was nearing its gravity-flow capacity.

Seventy years of tailing deposition has yielded a vast expanse of sandy and slimy waste materials covering a total of 1,038 ac or 1.62 sq mi. The relatively flat tailing dam tops consist of 871 acres or 84% of the total covered area; the remaining 167 acres or 16% may be characterized as dam faces, consisting of slopes standing at approximately 1.34:1 (horiz. to vert.), separated by 25 ft wide benches generally on 30 to 35 ft vertical intervals. The faces, having an overall slope of approximately 2:1, extend nearly 25,000 ft in length and rise to a maximum height of 220 ft.

Tailing Material Analysis

A sample taken on the top of No. 6 Dam, and considered representative of the surfaces of all dams, provided the following constituent analysis: Silica (SiO_2) 67.8%, Alumina (Al_2O_3) 16.4%, Iron (Fe) 2.3%, Lime (CaO) 1.2%, Sulphur (S) 0.3%, Copper (Cu) 0.1%, and Manganese (Mn) 0.01%. The remaining 11.89% was not determined; nevertheless, past experience implies that this portion is composed primarily of organics containing complex nitrates.

Stabilized Areas

In July 1988, when Cyprus purchased the property, nearly one third of the dams' top acreage had been stabilized by overlays of various types. (Refer to Figure 1 for orientation of tailing dams).

No. 1 and No. 2 Dams. The Miami smelter's active slag dump covered 35% of No. 1 dam, ponding a lake of plant make-up water that inundated another 29%. The surface of No. 2 dam was 80% covered by water. Historically, neither No. 1 nor No. 2 dams had produced an appreciable amount of fugitive dust. Consequently, neither was considered a significant reclamation priority.

No. 3 Dam. The Town of Miami maintains 4 sewage treatment lagoons covering 33% of the acreage atop the No. 3 dam. An additional 21% of No. 3 dam (Area 3-2) was partially carpeted with spotty patches of Bermuda grasses from a previous revegetation trial.

No. 4 and No. 6 Dams. Approximately 40% of the combined acreage of No. 4 and No. 6 dams was inundated by evaporation ponds constructed to accommodate the dewatering of Webster Lake, an artificial containment impounding diluted leaching plant solutions from Inspiration Copper's discontinued vat leaching process.

No. 5 Dam and Summary. No. 5 dam, the last to receive tailing material, lay uncapped by any stabilizing cover. In summary, 336 ac, or 32.3%, of the total tailing dam acreage had been at least temporarily stabilized, leaving 702 ac untreated and subject to natural erosional effects.

Unsuccessful Erosion Control

During the deposition of tailing material, unsuccessful efforts were made to control erosion of the dam faces. Extensive damage to the slopes and intermediate benches continued, resulting in complete deterioration in some sections. Vain attempts at remedial action, including the formation of berms on the bench crests, met with disappointing results when ponded rainfall overran or piped beneath the berms unleashing pools of water to further erode slopes and benches below. Airborne tailing sands, lifted by seasonal winds, scoured the unprotected tailing surfaces depositing dunes on the leeward crests and slopes and dispersing plumes of fugitive dust over the surrounding terrain.

Remedial Action Necessary

It became apparent that a remedial action program was needed. Recently proposed amendments by the EPA to the Clean Water Act, requiring a permit to discharge water having come into contact with mine products and byproducts, were looming on the horizon. In addition, the Arizona Department of Environmental Quality was proposing conditional stipulations linking approval of a new mine operating permit to submittal of a plan for revegetation of inactive tailing dams.

Project Planning

Field Assessment

To assess the magnitude of the problem, periodic site examinations were conducted, particularly during windy weather, to define the most troublesome areas. As expected, certain areas, due to their location, exposure, and lack of stabilizing cover, were found to be the prime contributors to the fugitive dust problem. (Refer to Figure 1 for orientation of tailing dams).

Prevailing spring winds blew primarily from southwest to northeast, scouring the westernmost tailing

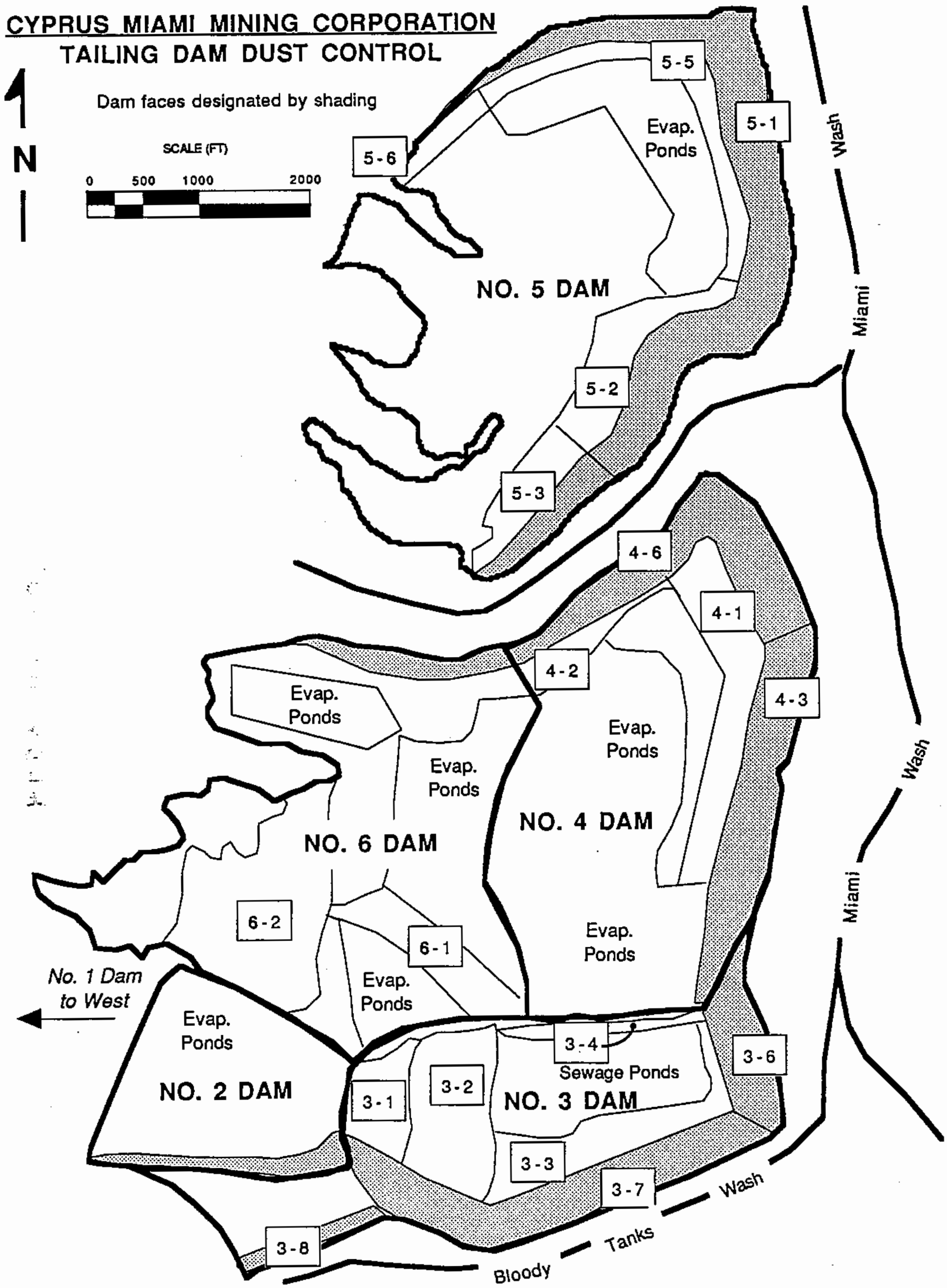

Figure 1.
Tailing Dam Reclamation Areas

dam surfaces, principally those of the No. 6 dam. Over time, the prevailing spring winds had deposited dunes on the outer crest and upper benches at the northeast corner of No. 4 dam. Any semblance of a terraced face had been obscured by cascading sand.

When winds approached from the southeast, dust and sand from the dunes on No. 4 dam were transported north across a canyon to No. 5 dam, settling on the top and southern face.

When summer storms altered the wind flow toward the south, the effect was reversed and dust migrated back to No. 4 dam while dust from the southernmost tailing dams spread out across the community of Claypool to the south.

Selection of Stabilization Methods

Tops of Tailing Dams. From the onset of the project in 1989, it was recognized that the flat surface area on top of the tailing dams would be best suited to application of a soil cap generated from native soil ridges adjacent to the dams. Although a 2 to 3 in cap would probably suffice for small plant and grass growth, a 6 in thickness was deemed more practical to apply uniformly with spreading equipment such as dozers and graders. Furthermore, a 6 in soil blanket would be expected to provide a better bed for establishment of larger plants and shrubs such as mesquites, scrub oaks, and junipers which are indigenous to the area.

Faces of Tailing Dams. Consideration was given to several methods of slope stabilization including facing with a layer of crushed slag and capping with mine-run waste material. Slag, although abundantly available in proximity to the tailing dams, seemed an aesthetically poor choice that would also preempt future revegetation efforts. The use of mine-run waste material, albeit a more aesthetically attractive plating, was precluded due to the expensive 12 to 14 mi haul cycle and the lack of properly sized equipment on hand for use in this service.

Contractor Input. Several contractors, many with previous reclamation experience, were contacted and asked to propose suitable solutions and economical methods for overlaying sections of the tailing dams with soil. All were given a tour of the tailing dams, shown the areas of most concern, and asked to prepare bids on a "per acre" unit basis. All contractors recognized the importance of smoothing the eroded slopes to decrease the surface roughness prior to soil distribution. Several bidders mentioned using an extended dozer or shovel track drawn along the slopes between dozers pulling from adjacent benches. Various types of haulage equipment were envisioned including ten-wheel end dumps, semi-tractor drawn bottom- and end-dump trailers, 35 tn haul trucks, and scrapers.

Introduction of Holistic Resource Management

While the contractors' bids and methods were being analyzed, Cyprus was approached by a local businessman promoting the virtues of Holistic Resource Management (HRM) and its possible beneficial use in our reclamation efforts.

Arizona Ranch Management proposed that HRM techniques were capable of converting poor or barren soil to a productive state suitable for sustaining vegetative growth. Animal impact could be used as a tool to promote succession in the revegetated areas and possibly to generate new soil on barren tailing material.

A comprehensive discourse on the principles of HRM is beyond the scope of this discussion and will not be attempted. Holistic Resource Management, Allan Savory's 1988 text on the theme is recommended for those desiring a more thorough understanding of the subject. However, a brief summary may be appropriate for those unfamiliar with the concept.

HRM employs a "thought model" approach in establishing clearly defined and achievable goals. Key elements, described as Ecosystem Foundation Blocks, incorporate nature's water and mineral cycles, energy flow, and succession. Tools which may be applied to these foundations include animal impact, grazing, rest, living organisms, fire, and technology, as well as human creativity, money, and labor. Rather than visualizing nature as if it were composed of numerous, unrelated variables (i.e. water, soil, air, minerals) that function mechanistically, HRM philosophy maintains that nature's environmental systems are composed of complex, interrelated variables that interact synergistically to produce a whole.

According to Mr. Savory, HRM requires an iterative cycle of planning, monitoring, controlling, and replanning. "Once a *plan* is made it is then *monitored.* If there is any deviation from the planned route then *control* is instituted and the deviation is brought back to plan. Occasionally events go beyond our control . . . and there is a need to *replan.*"

Arizona Ranch Management advocated the use of animal impact as an effective tool in breaking up consolidated soils, preparing a viable seed bed, fertilizing, and spreading seed in a continuous cycle upon redistributed soil and tailing material.

The project team felt that the HRM concept had merit but required further study for application on the tailing dams; accordingly, a 3 year pilot study was initiated leaving the bulk of the budget allocated for soil redistribution to, and revegetation of, the most offensive dust-producing areas.

Tailing Dam Dust Control
Phase I

Phase I soil distribution was accomplished during the months from April 1989 through early January 1990. Revegetation of the areas covered with soil during Phase I began in June 1989 and was completed in July 1990.

Phase I of the HRM study also began in April 1989 with the introduction of cattle onto the tailing dams and continued through October 1989 when the cattle were removed.

The decision to confine Phase I work to the top of the tailing dams provided an opportunity to accumulate valuable experience prior to attacking the more difficult faces and to develop cost data for future phases.

Mechanical Stabilization

Equipment Mobilized. A local contracting company was chosen as successful bidder by virtue of previous experience, submittal of the lowest bid, and ability to begin immediately. Equipment mobilized for the project consisted of (1) multiple Caterpillar and Komatsu track dozers for developing a borrow pit and spreading soil, (2) a 420 Komatsu 6 yd loader for loading trucks, (3) a fleet of five ten-wheel dump trucks for hauling soil, (4) a Cat 14E motor grader for spreading soil, maintaining roads, and scarifying the soil cap prior to seeding, and (5) a water truck for dust control.

Augmenting the Contractor. Previous arrangements had been made to augment the contractor's work force with equipment and manpower from the mine. Three Wabco 85 tn haulage trucks from a retired fleet were mobilized to be used with a Cat 992 loader supplied by the contractor.

Borrow Pit. In mid-April 1989, the contractor began preparation of a soil borrow pit in a Gila conglomerate ridge adjacent to No. 6 dam. Drilling and blasting, necessary to free consolidated soil for loading with the large 992 loader, was performed by Cyprus Miami personnel.

Haul Roads. Concurrently, the contractor began building a 2,100 ft long, 50 ft wide haul road south from the borrow pit, across No. 6 dam, to the first plot to be covered at the west end of No. 3 dam (Area 3-1, 11.4 ac). To support the 170 tn loaded weight of the Wabco trucks, the road was constructed to a minimum 1.5 ft thickness, though sections crossing pockets of slimy material sometimes required a 3 to 5 ft thickness.

A second road was prepared from the borrow pit East, across No. 6 and No. 4 dams, to transport soil to a 26.9 ac plot on the eastern crest of No. 4 dam (Area 4-1) and a 5.9 ac plot with a moderate slope on the northern crest of No. 4 dam (Area 4-2). Both haul roads were constructed using the ten-wheel trucks prior to introduction of the Wabco units.

Soil Distribution. Soil covering continued through mid-June 1989. Areas accessible from the haul roads were covered utilizing the Wabco trucks for haulage. In soft areas, where the 6 in soil cap would not bear the weight of the large trucks, the ten-wheel dump trucks were used to transport material.

The contractor returned in late December 1989 to cover a 40 ac plot which had been producing substantial amounts of fugitive dust on the No. 6 dam. Because of the unstable bearing surface of slimy sand and dampness from a nearby decant pond, the contractor was unable to access fringe areas of the plot and work was curtailed after approximately 32.1 ac had been covered (Area 6-2).

Phase I Soil Distribution Costs

Phase I was considered a success in providing a noticeable relief from fugitive dust in the newly stabilized areas.

In total, 101.5 ac (including 6 ac covered beneath a mile of 1.5 ft thick haul roads) had been covered with 91,550 cu yd of earth at a cost of approximately $1,660 per ac or a unit cost of $1.85 per cu yd for drilling, blasting, loading, hauling, and spreading the material. Stated in terms of other units, nearly 198,000 tn were moved and placed for $0.85 per tn.

These costs are somewhat inflated due to the necessity of hauling more material to build thicker roads and transporting soil to a stockpile for later use. Had the extra material been spread at the normal 6 in thickness, an additional 12 acres could have been capped lowering the cost to about $1,485 per ac.

Phase I Revegetation

Seeding of the soil capped areas began in June 1989 in anticipation of moisture expected during the annual monsoon season of July and August. Soil compaction, induced by wheel traffic during distribution, necessitated scarifying the soil cover with the rippers of a motor grader.

A 12-volt cyclone seeder was purchased and installed on the tailgate of a pickup truck. Several species of drought tolerant seed were broadcast including the following: Sand Dropseed (Sporobolus cryptandrus), Alkali Sacaton (Sporobolus airoides), Vaughan Sideoats Grama (Bouteloua curtipendula), Bufflegrass (Cenchrus ciliaris), Lehmann Lovegrass (Eragrostis lehmanniana), Weeping Lovegrass (Eragrostis curvula), and Four-Wing

Saltbush (Atriplex canescens). Various mixtures of these seeds were broadcast at a rate of 20 to 22 lb/ac. Ammonium nitrate prill, used as a blasting agent ingredient in the mine, was applied for fertilization at a rate of 200 lb/ac.

Seeding of an additional 32.1 acres (Area 6-2) was completed during the months of May through July 1990 utilizing a Bowie 800 gal capacity hydro-mulcher borrowed from Cyprus' Thompson Creek property near Challis, Idaho. Application rates per acre of seed species broadcast are as follows: 2 lb Giant Bermudagrass (Cynodon dactylon aridus), 3 lb Bufflegrass (Anchrus ciliaris), 2 lb Vaughan Sideoats Grama (Bouteloua curtipendula), 1 lb Indian Ricegrass (Oryzopsis hymenoides), 1 lb Lehmann Lovegrass (Eragrostis lehmanniana), and 1 lb Cochise Lovegrass (Eragrostis trichophora).

Conwed wood fibre mulch was added at the rate of approximately 1800 lb/ac. Ammonium nitrate prill, applied for fertilization, was sprayed separately at rates varying from 200 lb/ac to 1000 lb/ac.

HRM in Practice

The Holistic Resource Management pilot study began on April 13, 1989. Arizona Ranch Management of Globe, Arizona was contracted to provide management, labor, and consulting services. As envisioned, the HRM study required that all desired ecological change must be self-sustainable and not reliant upon the continual and expensive use of inputs such as man-made fertilizers, irrigation, and mechanical earth moving.

Treatment Areas Defined. Prior to introduction of cattle to the tailing dams, electric fences were constructed to enclose three distinct types of areas on No. 3 dam (refer to Figure 1).

Area 3-1, located at the extreme west end of the No. 3 dam, was composed of 6.5 ac which had been capped with a 6 in soil blanket. The north half of the area had been vegetated and set aside to determine if lack of grazing would be detrimental to sustaining the vegetation over time.

Area 3-2, located immediately east of and contiguous with Area 3-1, consisted of 21.7 ac of patchy Bermuda grass growth from a 1984 revegetation attempt employing irrigation on barren tailing material.

Area 3-3, located south of the Town of Miami sewage lagoons, was comprised of 13.9 ac of barren tailing material. Each area was subdivided with fences into 1 to 2 ac paddocks to establish optimum animal density.

Herd Introduced to Area 3-2. Seventy-six head of locally obtained cattle were introduced to Area 3-2 on July 8, 1989. Area 3-2 was chosen as a starting point for two reasons. It contained remnants of Bermuda grasses needing revitalization and densification, which hopefully could be accomplished by grazing. Also, it was expected that the Bermuda seed would subsequently be redistributed, via the cattle manure, into the barren tailing paddocks of Area 3-3 when the herd was moved. The grasses in this area began to show signs of revitalization soon after the herd was withdrawn.

Rotation Through Area 3-3. After grazing the paddocks of Area 3-2 for 9 days, the herd (numbering 77 with the addition of a newborn calf) was relocated to the barren paddocks of Area 3-3. Lacking vegetation upon which to graze, the cattle were fed a variety of oat hay, mesquite bean pods, and corn.

The herd was rotated through 3 paddocks on 7 to 10 day intervals, providing what appeared to be an appropriate amount of time to produce an effectively dense ground cover of manure and hay litter. Within 7 to 10 days after treatment, the previously barren paddocks began to sprout oat and corn seedlings in or near piles of manure and beneath the litter from the hay. Mesquite seedlings were found and flagged to be protected during future grazing cycles.

Ambient air temperatures in the range of 90° F to 100° F and the advent of the summer monsoon season undoubtedly helped promote the rapid growth.

Rotation Through Area 3-1. Finally, the cattle herd was moved to the soil capped, unvegetated paddocks on the south half of Area 3-1, where feeding continued. The soil cap, which had become exceedingly consolidated and crusty, responded favorably to the tilling action of the cattle hooves. Fertilized with manure and urine, emerging seedlings exhibited appreciable growth within a matter of days. By April 1990, the ground cover had become sufficiently dense to permit grazing during the Phase II campaign. Continual rotation of the herd prevented disrupting the growth stage of the newly established foliage.

Cattle Removed. The cattle were returned to their owners on October 29, 1989 after having spent 114 days on the tailing dams. Weight gains were not documented since the herd consisted primarily of mature cattle. Vegetation established during Phase I was allowed to rest through the dormant winter months.

Tailing Dam Dust Control
Phase II

Phase II slope reparation of the No. 5 tailing dam began in October 1990. Soil distribution began shortly thereafter and continued through mid-April 1991.

Revegetation of this area commenced in February 1991 and is nearing completion as of this writing in mid-April 1991.

Phase II of the HRM study began in mid-April 1990 and will continue through October 1991.

HRM on the Tops of the Dams

It was decided to use cattle supplied by the Cyprus-owned Byner Cattle Co. at Wickiup, Arizona for the continuation of the HRM study. In this manner, Cyprus would reap the benefit of the weight gain upon sale of the herd.

Arrival of the First Byner Herd. On April 11, 1990, 92 head of weaned calves were delivered to the project site at Cyprus Miami. Upon arrival, the 56 steers received weighed an average of 276 lb each. The heifers averaged 260 lb. Another 18 head of locally obtained longhorn cattle were added to the herd, increasing the total head count to 110. No attempt was made to weigh the longhorn cattle.

Precipitation. The tailing dams were very dry and dusty when the cattle arrived and continued to be so through the end of June. Only 3.63 in of precipitation had been recorded for January through March 1990. The second quarter of the year proved to be even drier when only 0.62 in of rain fell during April through June for a year-to-date total of 4.25 in. The third quarter, which included the annual monsoon season, was kinder, blessing the project with 10.15 in of rain and the fourth quarter added another 5.60 in. for a 1990 annual total of 20.00 in, slightly more than the 19 in average (compiled at the mine since 1933). The previous year, 1989, had produced only 12.86 in of precipitation.

Areas 3-1 and 3-2. The herd was initially used to graze the south half of Area 3-1 and to resume fertilizing and densifying the sparse Bermuda grasses of the adjacent area (Area 3-2) for approximately 1 month.

Area 3-3. For the next 6 weeks, the herd was used to impact the barren area (Area 3-3) located south of the Miami sewage ponds. Area 3-3 had been treated during Phase I, but the applied animal density and/or impact duration had been insufficient to establish the desired vegetation density. To rectify this shortcoming, the area was subdivided into smaller (0.5 ac) paddocks and the cattle were rotated on less frequent 10 to 15 day intervals.

Evidence mounted that animal density was a key factor in the response of plant growth. Newly established vegetation was found to be more diverse as well as more densely established and vigorous in the areas of highest animal concentration.

Unfortunately, much of Area 3-3 was flooded when a sewage pond dike was breached in January 1991. After repairing the dike, intentions were to pump the effluent back into the sewage pond. However, unusually wet weather and insufficient pond capacity precluded pumping until mid-April 1991 and much of Area 3-3 remains inundated.

HRM on the Faces of the Dams

Encouraged by the results observed on the previously barren Area 3-3, the decision was made to attempt new soil generation on a 6 ac section of side slopes located at the south end of Area 4-3.

Preparation Required. Due to the abundant gullies and wash-outs present in the area chosen for treatment, mechanical preparation became necessary. Benches were lowered approximately 1 ft in depth, spoiling the loosened tailing material down the slope to fill the majority of the gullies. Vehicular access was provided to benches to facilitate distribution of feed and water and an electric fence was installed encircling the treatment area.

Before introduction of the Byner herd, the sloped area was further subdivided into approximately 0.5 ac paddocks measuring 100 ft in width and extending 250 ft in length down the slope. The narrower subdivision encompassed the upper crest of the dam, as well as 3 benches and 3 intermediate slopes.

A Slight Delay. The community's 4th of July fireworks spectacular, originating from the southeast corner of the No. 3 dam, forced the relocation of the herd to a more placid location. The following day, the longhorn cattle were separated from the Byner herd and moved to a soil covered, revegetated area (Area 6-1) to graze on the abundant seed-bearing grasses. The Byner herd was relocated to a similar area north of the Miami sewage ponds (Area 3-4). The strategy was to allow the Byner herd to graze upon the mature grasses, ingesting seeds to be transported to the slopes and redistributed thereon.

Hooves on the Slopes. As the cattle were driven onto the slopes, various varieties of hay were cast upon the slopes, forcing the herd to ascend or descend to the feed source. In effect, the tailing material was tilled by hoof action, mixing seed-bearing hay litter, dung, and urine as deep as 1 ft below the surface. The litter provided a conduit for aeration of the tailing material as well as acting as a binding agent to temporarily delay wind erosion. Cupped hoof prints acted as small water traps and helped prevent water erosion. Over 10 in of rain fell during the summer monsoon season yet water erosion on the treated area was minor.

Four perennial grass species, 2 annual grass species, 3 annual weed species, and a few mesquite seedlings were identified following the summer rains.

Departure of the First Byner Herd. On September 30, 1990, the first herd supplied by the Byner cattle company was shipped to sale after having spent 170 days on the Cyprus Miami tailing dams. Discounting the death of 1 steer, caused by ingestion of plastic sheeting and survey ribbon, the herd had remained healthy during their entire stay. Occasionally, during periods of windy weather, wind-blown sands produced some eye irritation and tearing, but this malady was temporary and minor.

Weight Gain. Weight gain for the herd was excellent. The steers gained an average of 252 lb (1.48 lb/head/day) and the heifers gained an average of 148 lb (0.87 lb/head/day). Weight gain alone produced a return of $17,335 for the Byner Cattle Co.

Cost of Phase I Slope Stabilization Utilizing Cattle Impact. The first Byner herd spent 88 days impacting 6 ac on the face of No. 4 dam (the south end of Area 4-3). Documentation by Arizona Ranch Management indicated a cost of $2,585 per ac to treat the subject area. Crediting the return from weight gain produced a net cost of $1,083 per acre. These costs do not include mechanical preparation of the area or the cost of fencing.

Although the Phase I slope treatment appears to have been effective in stabilizing the effects of wind and water erosion, established vegetation has been spotty. Patches of dense grasses may be found but they are widely disseminated. It is presumed that the herd was rotated too infrequently, allowing seeds to be buried deeper than desired by hoof action. In comparison, Phase II cattle impact on the slopes, which limited the duration within paddocks to 3 to 5 days, has produced a much more homogeneous cover of grass.

Arrival of the Second Byner Herd

The second Byner cattle herd loaned to Cyprus Miami arrived at the project site on November 10, 1990. Wild as the range from which they had come, they immediately stampeded through multiple electric fences and eventually gathered in the one vegetated area that had been set aside to demonstrate the effects of non-grazing. Common sense overcoming valor, the herders allowed them to regain their composure before coaxing them into the proper paddock.

When the dust had settled, the count proceeded. The shipment included 52 steers and 39 heifers totalling 91 head for a combined weight of 37,000 lb, or an average of 406.6 lb/head. No weight differentiation was made by gender.

Another small shipment of 4 steers and 7 heifers followed on December 6, 1990 raising the head count to 56 steers and 46 heifers for a total Byner herd of 102. Unfortunately, no one thought to weigh the new arrivals, a fact that will produce much head-scratching and extrapolation when weight gains are calculated at the conclusion of Phase II.

The second Byner herd was allowed to graze and fertilize revegetated areas and to become accustomed to their new environment atop the tailing dams for approximately 2 months before being moved to the slopes. During this time the north end of Area 4-3 was prepared. As before, benches were restored for access and the largest erosional patterns on the slopes were filled with excess tailing material. The perimeter fence used for the first herd was extended to enclose a total area of 27.1 ac.

On January 11, 1991 the second Byner cattle herd began impacting the face on the north end of Area 4-3. A temporary electric fence, constructed of nylon tape interlaced with metallic filaments, was used to further subdivide areas within the perimeter fence and to contain the cattle within 0.5 ac paddocks. The material used for the temporary containment facilitated relocation of the fence as the herd was moved.

The cattle have been fed bales of oat and alfalfa hay as well as baled, seed-bearing Bermuda and Sudan grasses. The hay and grasses have been complemented with molasses-based Purina Sup-R-Block and pelletized Purina Cattle Grower feed supplements providing protein and vitamins to enhance weight gain. Salt blocks have also been provided.

Seeds species including Blue Panicgrass (Panicum antidotale) and a pasture Bermuda mix known as Tierra Verde, have been mixed in the feed in hopes of dispersing the seed in the cattle dung. Tierra Verde is comprised of 38.75% Bermudagrass (Cynodon dactylon), 38.75% Giant Bermudagrass (Cynodon dactylon aridus), and 19.50% Guymon Bermudagrass (Cynodon dactylon guymon).

As of mid-April 1991, the herd has completed impacting approximately 6 ac at the north end of Area 4-3. The herd has worked from north to south and areas first impacted at the north end have shown exceptional growth of annual oat grasses from seeds contained in the hay. The green slopes are quite noticeable from the community's highways and have produced many favorable comments from area residents. Blue Panicgrass and various Bermuda grass seedlings are beginning to appear but cold nighttime temperatures continue to inhibit growth.

The second Byner herd will continue working to the south impacting the remaining acreage of Area 4-3 until October 1991 when the heifers will be culled for replacements and the remaining heifers and steers will be sold for slaughter.

The longhorn cattle, now numbering 38 head (including 7 births), have remained on the tops of the dams since their introduction to the project in April 1990. They have been primarily employed in further impacting and fertilizing the soil covered, revegetated areas and presently reside in Area 4-1.

Analysis of Feed Source Vegetation

During early April 1991, live grass samples taken from three revegetated areas were analyzed to confirm the suitability of the vegetation for continued animal consumption. Results of the analyses are presented in Table 2 below.

Sample 1 contained oat grasses established on the north end of Area 4-3 in the spring of 1991. Sample 1 contained 76.34% water.

Sample 2 contained grasses (primarily Bufflegrass and various Lovegrasses) from Area 3-4 which had been revegetated during Phase I in the first half of 1990. Sample 2 contained 59.57% water.

Sample 3 contained Bermudagrass gathered from Area 3-2, which had been the location of the previous revegetation attempt abandoned in 1984. Grasses within this area had been revitalized by grazing during Phases I and II. Sample 3 contained 55.22 % water.

Although analyses were made on wet and dried samples, only the wet values are presented here. All values are presented in parts per million (PPM). "Trace" represents a value of less than 0.0001 PPM.

TABLE 2
VEGETATION ANALYSIS

Constituent	Sample 1 (PPM)	Sample 2 (PPM)	Sample 3 (PPM)
Arsenic (As)	Trace	Trace	Trace
Selenium (Se)	Trace	Trace	Trace
Cadmium (Cd)	0.003	0.004	0.015
Lead (Pb)	0.011	0.011	0.022
Copper (Cu)	1.88	3.64	5.84
Zinc (Zn)	0.511	0.299	0.314
Iron (Fe)	5.07	9.67	15.16
Manganese (Mn)	0.876	2.06	0.116
Magnesium (Mg)	65.4	35.4	21.5
Calcium (Ca)	50.2	96.1	79.7
Aluminum (Al)	18.66	24.56	36.17

No. 5 Dam Slope Reclamation

In early October 1990, reclamation work began on the face of No. 5 dam (Area 5-1, 57.2 ac). The northernmost dam, No. 5 had been the last to receive tailing material and had consequently suffered less erosion than the older southern dams (see Figure 1).

Configuration of No. 5 Dam. The west side of No. 5 dam abuts natural hillsides. The north, east, and south sides are composed of faces which had 25 ft wide benches and intermediate slopes which stood at approximately 1.34:1 (horiz. to vert.) when work began. The vertical distance between benches varies between 21 and 45 ft. The total horizontal length of the faces is 8600 ft or 1.63 mi. The dam has 8 benches and a maximum height of 210 ft on the East side.

Preparation. Prior to beginning restoration of the benches, spigots were removed from the tailing disposal header line to prevent them from protruding through the soil cap. The 18 in diameter header line, constructed of asbestos concrete pipe, was left in place and subsequently buried with soil.

Numerous soil borrow pits were strategically established around the perimeter of the dam to minimize haulage distance.

Slope and Bench Reparation. In most areas, bench restoration and slope preparation was a one-step operation. Wind and water erosion had sloped redistributed tailing material across the benches denying access. To reestablish the benches, the top 3 to 5 ft of material was dozed, spoiling the material down the slope to fill gullies, thereby smoothing the surface and lessening the amount of soil needed for cover.

In one particular area, however, severe erosion prevented a quick fix. The northeast corner of the dam had suffered extensive damage from water erosion initiated by ramps that had been built to access an emergency pond. In effect, the entire corner had to be recontoured. Beginning on top of the dam, a large dozer reshaped the entire corner, bench by bench, using excess material to fill the extensive wash-outs.

Soil covering. As benches were prepared for access and slopes readied for the introduction of the cap, soil was hauled from hillsides in the vicinity of the dam, and redistributed on benches and slopes. Benches were graded at a -2% from crest to toe and 1.5 ft high berms of soil were constructed at the crest to help prevent water erosion of the slopes. In the future, water bars, or berms oriented perpendicularly to the crest berms, will be added to form containment cells. Recently, some water erosion of the soil cap has occurred, resulting from ponded water having escaped from low sections of the benches. In these areas, some form of extra slope protection is being considered.

Regrading the Slopes. As soil covering progressed, it became apparent that more soil was having to be hauled than had been anticipated. The contractor complained that he was losing money on the soil coverage portion of the contract.

The slopes between benches stood at approximately 1.34:1 (horiz. to vert.) while the applied soil layer stood at a flatter slope of 1.5:1. Load upon load of soil dumped from the bench crest above accumulated at the toe of the bench beneath before beginning to stack up and cover the slope to the desired 6 in thickness.

This problem was solved by changing the angle of the slopes to more closely match the natural angle of repose of the dumped soil. A 100 ft length of ship anchor chain was attached to a pair of dozers pulling from adjacent benches and drug across the sloped face. After much practice, the method was perfected to redistribute tailing material from the crest of the upper bench to the toe of the lower bench, thereby flattening and optimizing the angle of the slope for soil coverage. As an ancillary benefit, the links of the chain gouged shallow horizontal channels into the tailing material providing an underlying anchorage for the soil cap. The anchor chain treatment lowered soil distribution costs by nearly 80% while expediting the progress of the job.

Unfortunately, resloping also had the effect of narrowing the width of the benches from 25 ft to 12 ft. However, this width has proved to be sufficient for hydro-mulching and maintenance access.

Soil Covering the Top of No. 5 Dam

Extremely windy weather during the spring of 1991 produced extensive fugitive dust originating from the top surface of No. 5 dam. Winds blowing from the southwest began lifting dry tailing material from the top surface of the dam and depositing it upon the face which had recently been covered with soil. The project budget was insufficient to sustain the cost of covering the entire top of the dam with soil; furthermore, property-wide dewatering efforts necessitated preserving the heart of the dam for construction of evaporation ponds.

A strip around the crest of the dam, varying in width from 100 ft to 400 ft and containing approximately 40 ac, was covered with 6 in of soil, to help prevent the redistribution of tailing material upon the reclaimed face. The strip is designated as Areas 5-2, 5-3, 5-5, and 5-6 on Figure 1.

Repair of No. 4 Dam Face

While work was progressing on the No. 5 dam, dozers began restoring the northern faces of the No. 4 dam (Area 4-6). Dunes produced by years of accumulated fugitive dust had settled on the face in this area obscuring benches and preventing access much the same as had been encountered on the face of No. 5 dam. Countless dozer shifts reestablished benches producing excess tailing material to cover the extensive rills and gullies on the slopes.

Work progressed until tailing material began to encroach upon an active powerline located on a lower bench of the dam. Relocation of the powerline is currently nearing completion.

The recontouring of Area 4-6 has produced the lamentable result of releasing extensive fugitive dust during the windy spring season. Unfortunately, this freshly uncovered material tends to migrate to the soil covered face of the No. 5 dam. A provision to finish this area has been included in the AFE for Phase III.

Vegetating the Face of No.5 Dam

On February 1, 1991, work began to vegetate the soil covered slopes of No. 5 dam (Area 5-1).

Hydro-mulching. A Bowie Victor 1100 trailer-mounted hydro-mulcher, having a capacity of 1125 gal, had been purchased in September 1990. A 15 tn Mack 4-wheel-drive truck, previously fitted with a large generator for geophysical work, was refurbished and retrofitted with a 1200 gal steel tank and pump. The ability to carry an additional load of water reduced resupply trips by 50%.

Seed Species. Seed species sprayed on the soil covered slopes of No. 5 dam and application rates per ac are as follows: Lehmann Lovegrass (Eragrostis lehmanniana) 2 lb, Weeping Lovegrass (Eragrostis curvula) 2 lb, Bufflegrass (Cenchrus ciliare) 8 lb, Yellow Blossom Sweet Clover (Metilotus officinalis) 3.5 lb, Vaughan Sideoats Grama (Bouteloua curtipendula) 5 lb, Giant Bermudagrass (Cynodon dactylon aridus) 5 lb, and Plantago/Indian Wheat (Plantago insularis) 3 lb. Seed cost per ac totaled approximately $95. Seedlings have just recently begun to appear on the face of No. 5 dam as of this date in mid-April 1991.

Mulch, Tackifier, and Fertilizers. Silva-Fibre Plus mulch, composed of whole wood fibers and containing a powdered tackifier to help bind soil, mulch, seed, and fertilizer in place, was applied at a rate of 1800 lb/ac. Two types of fertilizer were tested. Biosol, a 6-1-3 fertilizer, i.e. 6% Nitrogen (N), 1% Phosphoric Acid (P_2O_5), and 3% Potash (K_2O), and Grow Power, a 5-3-1 fertilizer were mixed with the seed, mulch, and tackifier and applied at a rate of 800 to 1000 lb/ac.

Tailing Dam Dust Control
Future Phase III

Phase III, expected to commence in mid-1991, will concentrate on reclaiming the faces of No. 3 and No.4 tailing dams.

Faces of No. 3 Dam

The faces of No. 3 dam are highly visible to area residents, as well as tourists, due to the proximity of U.S. Highway 60 and State Route 88. U. S. 60 generally divides the Cyprus Miami property, and particularly the tailing dam area, from private property to the south.

Recent development of commercial properties south of U.S. 60 has heightened the awareness of the general public to the highly eroded face of No. 3 dam. Although years of exposure to the elements have crusted the surface of the tailing material, minimizing the transmission of fugitive dust, the face remains aesthetically unattractive. With respect to the faces of all the dams, No. 3 has suffered the highest degree of water erosion, which has produced severe surface deterioration.

Treatment methods developed during the reclamation of the face of No. 5 dam will be utilized and adapted as necessary. Areas 3-6, 3-7, and 3-8 (see Figure 1), comprising an area of approximately 62 ac, will be reclaimed through face reparation, soil redistribution, and revegetation. Prior to working the face, a phone line skirting the base of the dam will be relocated to facilitate access to the lower slope.

Completion of Area 4-6

Additionally, area 4-6 reclamation, begun during Phase II, will be completed, eliminating one of the more troublesome dust producing sources. Again, the intent is to establish a soil cover sufficiently deep to allow revegetation of this area.

Continuation of HRM Study

The reclamation study involving cattle will be continued through October 1991. After that date, the Cyprus-owned Byner Cattle Co. will be unable to furnish cattle for continuation of the project. Alternative sources, including the use of cattle from a neighboring ranch, are being considered as substitutes.

Conclusion

The project began with little scientific expertise. As engineers, we are not charged with creating science, but with applying the tools which science has provided. Despite our lack of scientific credentials, we are well on our way to providing relief from the fugitive dust problem that has plagued the Globe-Miami area for years.

Questions remain to be answered. Will vegetation established on soil covered areas be sustainable in our dry climate without the need for irrigation? Will animal impact provide the necessary nutritional building blocks to generate new soil capable of sustaining vegetation? Only time will provide the answers.

The era of environmental neglect has come to a close. Mining concerns are faced with an enormous challenge in reclaiming areas defaced by the deposition of waste materials. Cyprus Miami Mining Corporation, an integral part of the environmentally-conscious family of companies that constitute Cyprus Minerals Company, is justifiably encouraged by the results of the continuing effort to return the Miami tailing dams to an environmentally productive state, capable of supporting vegetation and wildlife.

Those who have worked on the project realize a plural satisfaction. As employees, we are pleased by the success of our labor. As inhabitants of the community, and in a larger sense, of the Earth, we are cheerful that in the near future, we will again be blessed with bountiful vistas, unobstructed by plumes of fugitive dust.