

ASARCO'S REVEGETATION OF MILL TAILINGS AND OVERBURDEN WASTES
FROM OPEN-PIT COPPER MINING OPERATIONS IN ARIZONA¹

Stuart A. Bengson²

Abstract.--Revegetation of mining wastes, especially in an arid environment is a difficult task. This paper describes the problems encountered and techniques developed by Asarco to solve those problems. By using the proper revegetation techniques, Asarco has successfully revegetated over 160 acres of mill tailings and overburden wastes slopes in southern Arizona.

INTRODUCTION

Arizona has been a major copper producing region for well over half a century. In addition, proven copper ore reserves in Arizona amount to well over 12 billion tons, with an additional 30%-40% highly probable (AZ Dept. of Mineral Resources 1981). For nearly a quarter of a century Asarco has been a proud participant of the copper industry in Arizona.

Today's average copper ore grades approach 0.6% or less and stripping ratios may run 3:1 or higher. With milling capacities of 70,000 tons per day (TPD) to over 100,000 TPD it is easy to appreciate the large volumes of solid inorganic mine wastes that are generated. These wastes include the overburden rock and alluvium that must be excavated to expose the ore body and the mill tailings which consists of finely ground rock that has been processed to separate the copper. These wastes are deposited on the land surface to form large flat-topped mounds. Although the impact of these waste deposits on the surface environment is immediate and dramatic, to date less than 0.26% of Arizona (193,000 acres) has been impacted by mining (AZ Mining Assoc. 1979). For the U.S. as a whole, mining has disturbed less than 0.16% of the land area (Bengson, Stuart A. 1980). No matter how small an area is impacted however, these waste deposits do present a starkly visible, polluted impression to the public, especially when located in close proximity to populated areas. Although these wastes present little, if any, real hazardous pollution; wind and water erosion intensifies the aesthetic degradation and off-site impacts which are becoming unacceptable to the public. The

public then demands a more acceptable aesthetic vista, return of the lands natural productivity, and stabilization of these mining wastes. Therefore vegetative stabilization of mine wastes is becoming an integral part of mining operations in Arizona.

Presently Asarco is actively working on the vegetative stabilization of three (3) open-pit copper mining properties in southern Arizona: the Mission/San Xavier/Eisenhower complex near Green Valley, the Silver Bell Unit northeast of Tucson, and the Sacaton Unit near Casa Grande. Asarco's revegetation work was initiated in the early 1960's with test plantings and development of primary revegetation techniques. Slowly this work evolved until in 1973 an intensive and comprehensive revegetation program was initiated to solve the problems and develop sound techniques for the practical and successful revegetation of copper mining wastes. To date Asarco has successfully revegetated some 160 acres of tailing and overburden waste dump slopes. As most of these mines are still active (despite temporary closures due to present economics) the revegetation work continues.

REVEGETATION PROBLEMS

There are numerous, complex and unique problems facing mine revegetation today. Although some of the earliest mine reclamation work dates back to 1918 it wasn't until the early and mid-1970's that any real research was conducted (Bengson, Stuart A. 1980). With this recent research, and a dramatic increase in the revegetation work being done, came the realization that, as mineral deposits and mining/milling techniques vary, each mine site will have its own specifically unique set of revegetation problems (COSMAR Report 1979). In southern Arizona this site specific variability is further complicated by the dominate aridity of the environment. Here rainfall can vary from as little as 3 inches or less to over 20 inches

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²Stuart A. Bengson is Agronomist for ASARCO Incorporated - Mission Unit, P.O. Box 111, Sahuarita, Arizona 85629.

or more from year to year, and evaporation potentials can exceed 17 or 18 inches (see Graph 1) (UA Coop. Ext. Serv. 1969 & WSU Ag. Ext. Sta. 1972). This basic aridity creates a very complex natural ecosystem. The Soil Conservation Service - USDA describes at least five (5) distinctly different desert ecosystems for southern Arizona (UA Coop. Ext. Serv. 1969). This can create some very significant problems in trying to re-establish a truly "native" ecosystem on mine wastes.

Average annual rainfall at Asarco's three mines in southern Arizona ranges from 10-12 inches at Mission and Silver Bell to 6-8 inches at Sacaton (see Graph 2). Ecosystems vary from a typical desert grassland at Mission to a typical desert shrub ecosystem at Sacaton, with Silver Bell lying on the ecotone of the two extremes. Added to the aridity problems are the complex and unique physical problems of the mine wastes encountered at each specific site. These problems involve the variable pH of the waste materials (see Table 1); complex textural parameters; severe deficiencies or total lack of vital nutrients, organics and essential mycorrhizae; complex salinity/alkalinity, pyritic or sulfide crusting problems; and excessive concentrations of phytotoxic heavy metals and salts (see Table 1) (Bengson, Stuart A. 1977). In addition vegetation trying to become established has to contend with elevated surface temperatures (in excess of 160°F) and extreme albedos from light colored wastes; excessive surface drought and other moisture regime problems; extremely steep slopes (1:1.5 angle of repose); and the highly erosive nature of the mine wastes that can bury, abrade, or wash away the emerging seedlings (Bengson, Stuart A. 1977). These factors all interact to make it very difficult for vegetation to become established on these mining wastes naturally. Without the help of man it may take nature hundreds of years to revegetate some of these wastes.

REVEGETATION TECHNIQUES

The successful revegetation of any mine waste must first start with the proper preparation of the site for planting or seeding. This site preparation maximizes seedling emergence and plant survival. These preparation techniques vary from very complex topsoiling and regrading to simple soil scarification or surface treatments to enhance vegetative establishment. At Asarco, as with all large open-pit mines, regrading the steep slopes of the mine wastes is impossible due to the tremendous volumes of waste to be disposed of and the constraints of land ownership patterns and geographic features that reduce the availability of suitable disposal sites. Also, because the pit is stationary and active for long periods of time (50-75 years in many cases) the wastes cannot be disposed of in the pit as coal spoils often are (COSMAR rept. 1979).

At Asarco the first step in mine waste revegetation is to plate or cap the waste materials with alluvial soil material. In the arid southwest there is no true "topsoil" in the classical sense.

Any "A" horizon, or true "topsoil" will only be a fraction of an inch at best with most desert soil profiles. However, most of these soils are deep alluviums with texture and physical characteristics quite satisfactory for revegetation. At Asarco this alluvial soil material is usually salvaged from areas prior to any waste disposal on the surface, or stockpiled from pit excavation. The capping of the wastes with soil material serves two immediate functions. First it ameliorates the surface environment for vegetative establishment by adding some organics, native seed, some nutrients, mycorrhizae, and improves the surface texture. Secondly it has a camouflaging effect to reduce the visual impact of the harsh light colored wastes. With most mill tailings it only requires a thin cap of soil, perhaps less than an inch, or just mixing a small amount of soil in with the tailings. This "topsoiling" however, is only practical at sites where adequate soil materials are readily available. Some topsoiling costs have exceeded \$65,000 per acre (Bengson, Stuart A. 1980). At Asarco the topsoiling costs average \$2,500 per acre. It is totally impractical to "import" soil material, and would only leave another scar where the soil was excavated. At Asarco's Silver Bell unit soils are extremely shallow and rocky. What little soil that is available is used very judiciously. To alleviate the shortage of suitable soil for capping, new techniques of incorporating organics into the mill tailings is being developed at Silver Bell. This technique involves adding organics such as sewage sludge and livestock manures to the tailings. Annual crops are then grown to cultivate back into the tailings to build up a soil medium. The organics help to moderate pH, improves the moisture regime, and enhances the nutrients and mycorrhizal levels. With this technique very good stands of grasses and shrubs have been established on the tailing surface. Ecologically speaking this technique can be quite advantageous. A harsh mine waste is not simply "buried" under topsoil to possibly later erode, become exposed and left denuded of vegetation. This technique of using organics does have its drawbacks however. It is quite difficult, if not altogether impossible, to utilize this technique on some of the steep slopes encountered. Also this technique can involve several years of intensive cultivation to build up the tailings sufficiently to support vegetation on its own. There is also the problem of availability of organic materials and the costs. Thus far Asarco's work with organics has been limited to experimentation and costs are difficult to determine at this time. It is conceivable that costs could exceed \$5,000 per acre. Many factors need to be considered in selecting the proper preparation techniques to be used at each site.

Table 1.--Asarco Tailings

	pH range	ppm TDS levels	ppm Cu levels	ppm Na levels
Sacaton	2.7-9.5	3549-65870	.7-8800	to 2000
Mission	5.9-7.5	to 2858	.1	to 25
Silver Bell	3.3-7.9	to 135834	to 7460	to 130

The next step in Asarco's professional mine revegetation program is selection of the plant species composition to be used. This process can be quite complex and involved but generally relates to species adaptability to the site and ultimate future land use. At Asarco the basic premise of mine revegetation is one of aesthetics and waste stabilization. Secondary considerations involve returning the land to a viable and productive ecosystem equal to or greater than it was before. In Asarco's revegetation program species are selected based on the physical environment of each site, the species value for livestock and wildlife forage, aesthetics, and blending into the natural surrounding ecosystem. At the Mission Unit the rainfall and physical environment is conducive to a desert grassland ecosystem. Here the primary species for revegetation are grasses. Principally three species of grass are used: Lehman's lovegrass (Eragrostis lehmaniana), blue panicgrass (Panicum antidotale), and buffleggrass (Pennisetum ciliare). Associated with the grasses are several shrub and tree species to diversify the plant community, give it more of a natural appearance, and enhance the wildlife cover and browse values. The principal shrub and tree species include: eucalyptus (Eucalyptus sp.), saltbush (Atriplex sp.), mesquite (Prosopis sp.), paloverde (Cercidium sp and Parkinsonia aculeata), hopseed (Dodonea viscosa), ruby sheep bush (Enchileana tomentosa) and fairy duster (Calliandra eriophylla). At Silver Bell a similar species composition is used. Variations would include acacias (Accacia sp.), sagebrush (Artemisia sp.), jojoba (Simmondsia chinensis), and saltcedar (Tamarix pentandra). At the Sacaton Unit a totally different ecosystem exists. Here the rainfall dictates a desert shrub plant community. Very few, if any, grasses would survive even if established. However, many desert shrub species can be quite productive and aesthetically pleasing. These species would include mesquite (Prosopis sp), paloverde (Cercidium sp. and Parkinsonia aculeata), creosote (Larrea tridentata), buckwheat (Eriogonum sp.), several different species of saltbush (Atriplex sp.), Australian acacias (Accacia redelense and nobilis), and ruby sheep bush (Enchileana tomentosa). Not all of these species are indigeous to the site and adjacent natural area. Many "exotic" species are selected because they are better adapted to the particular site environment and have a higher value for forage (Bengson, Stuart A. 1977). Also many of the "native" species are not available in sufficient quantity from plant material sources for large scale revegetation. Another problem with many "natives" is that the plant physiology of these species is not well known and proper cultivation and planting techniques have not been developed. Asarco's revegetation plan takes the natural ecosystem into account in its species composition selection. Species are selected that will blend in with and compliment the natural plant community providing a stable ecosystem and a more productive environment. Of course one of the problems encountered with this forage improvement is that it acts as an attractant for livestock and wildlife which can

result in damage to the young and tender plants before they are fully capable of sustaining grazing. To control this problem Asarco has had to fence its properties and provide habitat to attract predator species to control rabbits and ground squirrels, etc.

Once the desired species composition has been selected the proper technique to establish the vegetation on the mine wastes must be chosen. Basically there are two techniques for establishing vegetation: direct seeding and hand planting seedlings. Of course there are many intricate and complex details of each technique, and as many variations or combinations of both (Bengson, Stuart A. 1977). Direct seeding is probably the most practical and preferred method. Here the main concern is amount of seed required (PLS) pure live seed seeding rates (seed purity x percent germination = PLS), good seed/soil contact, and the various aspects and requirements of the species for germination (Bengson, Stuart A. 1977). Often the seed of various species will require different treatments and may preclude their use in a seed mix. The critical aspect of direct seeding is initiating germination and then maintaining minimal conditions until the seedling is well enough established to survive. Numerous factors can intercede to destroy emerging seedlings: heat, cold, drought, erosive forces, excessive sunlight, and insect and disease predation.

There are two basic methods of direct seeding: broadcasting and drilling. Drilling seed is the preferred method as this technique actually places the seed in the soil at the correct depth for that particular species, spaces the seed correctly for proper plant density, and then covers the seed for good soil contact. The next best technique is to broadcast, or simply scatter the seed over the soil surface. Here scarification of the soil surface is most essential to assure that the seed gets down into the soil. Of course, depth of seed in the soil and adequate soil coverage are quite variable and uncontrolled. Hence for broadcast seeding the PLS rates of seed application (pounds per acre) recommended for a given species should be doubled or tripled.

Because of the intricate problems of seeding and the uncertainties of ultimate vegetative establishment, hand planting seedlings can offer several advantages. Of course the initial costs can be quite abit higher than seeding because of the cost for each individual plant and more intensive labor required. However, the seedling has already survived the rigors of germination and emergence and has developed a root system and plant vigor that may enhance its chances of survival. Also, due to lack of sufficient seed sources, specific and technical germination requirements, or other technical problems of direct seeding, hand planting seedlings of a specific species may be the only alternative available. Again there are many variations to hand planting techniques (Bengson, Stuart A. 1977);

but basically the main principal is to get the tender seedling into the ground with minimal disturbance. Of prime importance in both hand planting and direct seeding is that the plant/seed source of any given specie be selected from local sources. Even though a specie may be the same in Utah, Nevada or southern Arizona, small intricate genetic variances due to specific site characteristics will dictate superior vegetative response of the local variety.

Both direct seeding and hand planting techniques are employed in all of Asarco's mine revegetation programs in southern Arizona. This combination of techniques seems to best answer the specific revegetation needs of each unit. Because of the steep slopes encountered most of the direct seeding is done with a Bowie Model 1500 Hydromulcher. This machine mixes seed, any fertilizer requirements, and a hydromulch material into a thick slurry to spray onto the slopes. It is an exceptionally practical method to evenly disperse and hold seed onto a steep slope. In addition it may be the only effective method for mixing a species composition complicated by seeds of disproportionate size variation, or trashy seeds, that would inhibit flow through conventional seeding equipment. At Asarco hydro-seeding averages \$425-\$650 per acre. Although this technique has proven very practical and effective for Asarco's revegetation program it is not without its drawbacks. There are problems such as seed damage by the pump impellers, seed germination negatively affected by prolonged soaking, and the seed being suspended away from the soil surface by heavy applications of hydromulch material (Bengson, Stuart A. 1977). Also the price of commercial hydromulches has dramatically increased in recent years (from \$215 to over \$400 per acre). Another problem is that these hydromulches do not provide the optimum mulch protection for the seed, in fact some products can impede seedling emergence.

To alleviate these problems Asarco has been working with new and modified hydromulching techniques. To reduce damage to the seed by the pump and prolonged soaking, the seed is added to the mix last, just before spraying onto the slope. To alleviate suspension of the seed in a heavy mulch a two-step technique is employed. This involves hydromulching the seed with a minimal amount of hydromulch, just enough to hold the seed onto the slope; and applying a heavy application of mulch over the top of the seed in a second operation. Also there are several inexpensive and effective hydromulch substitutes Asarco has found that will make a suitable slurry to hold the seed to the slope. These include seed chaff, sawdust, and excelsior wastes. For a more effective mulch preliminary tests indicate that one to two tons of prairie hay per acre, with a tackifier to hold it to the slope, will provide superior mulching benefits and improve vegetative establishment.

Asarco's hand planting techniques involve

nursery grown containerized plants. Past experience has proven that bare-root transplants of native trees, or trying to transplant native trees and shrubs from the undisturbed natural areas is unsuccessful. Most desert plant species have extensive root systems that cannot withstand the shock of transplanting. Transplant success of natives dwindles to less than 15%. Similarly small seedlings have such immature root systems that they have great difficulty surviving the rigors of the harsh mine environment. Survival percentages for many of these small seedlings average less than 45%. Asarco has found the gallon-sized plant to be a practical compromise even though they may cost more. Also by adopting a tubling container, approximately 2½ inches by 10 inches, superior plants are produced. The tube shape of these containers trains the tap roots of these desert species to grow downward. Also these containers are easier to handle on the steep slopes and can reduce planting costs by 2 to 3 times. Planting gallon-sized plants averages \$2.50-\$3.00 per plant--tubling plants average \$1.50-\$2.00 each. Total hand planting costs at Asarco average \$760 per acre.

One of the major problems with handplanting nursery grown stock is an adequate supply of the desired species. This may also be said of seed supplies as well. To alleviate this problem Asarco has collected seed of certain species at specific locations on its own. This seed is then given to commercial nurseries to produce plant material under contract. Asarco has also found it beneficial to encourage the growth and development of competitive nursery operations to enhance the supply of plant materials. Also Asarco works very closely with local Plant Material Centers of the Soil Conservation Service - USDA to develop new species, superior varieties, and increase the supply of plant materials adapted to the various site conditions.

Once the mine waste slopes have been seeded or planted a supplemental irrigation program should be implemented. In the semi-arid environment of southern Arizona irrigation is often essential to assure seed germination and plant establishment. Although there is a great deal of controversy over the use of irrigation (Bengson, Stuart A. 1977), and there are some instances of successful revegetation without it, Asarco utilizes irrigation techniques to assure revegetation success. Because rainfall events are totally unpredictable, adequate moisture for seed germination and plant establishment during critical periods is often lacking. Also the steep slopes and textures of the wastes can effectively reduce the moisture available for plant establishment by 50% or more. This results in failure of the revegetation attempt and requires costly re-seeding or re-planting. Asarco's irrigation techniques are designed to supplement the natural rainfall through the first growing season to establish viable stands of grasses and shrubs and are then removed entirely.

Basically there are two different irrigation techniques employed by Asarco, sprinkler

and drip irrigation. Asarco uses sprinkler irrigation to establish grasses and shrubs on the tailing slopes at Mission and Silver Bell (Bengson, Stuart A. 1977). Here sprinkler systems are designed and operated to simulate $\frac{1}{4}$ to $\frac{1}{2}$ inch rainfall events over 2-3 hour periods once a day through the critical periods of seed germination and plant establishment. By utilizing irrigation techniques the slopes may be seeded or planted during periods of optimal temperatures rather than waiting for the anticipated "rainy season" when temperatures may not be optimal. Of course sprinkler irrigation is not without its problems. The biggest problems are erosion and water supply (Bengson, Stuart A. 1977). Water systems to provide this type of irrigation may be uneconomical, or be completely beyond the capabilities of the water supply available. At Asarco a typical sprinkler irrigation system can cost \$2500 per acre exclusive of a water delivery system.

To alleviate the problems with sprinkler irrigation Asarco has opted for the drip irrigation technique at the Sacaton Unit. Here the water supply is quite limited and the revegetation limited to shrubs and trees. The main advantage of a drip irrigation system is that it requires less than 1/10 the water of sprinkler irrigation systems (see Graph 3) (Bengson, Stuart A. 1977). Here drip irrigation systems provide one gallon of water per hour to each plant over 8 hour periods 2-3 times per week for the first few months of establishment. This has successfully established a tree/shrub ecosystem on the waste and tailings slopes that is equal to or greater than the plant density of the natural desert biome. Here also though, there are problems with drip irrigation systems. The biggest problems are plant density limitations, linear appearance, and high maintenance requirements (Bengson, Stuart A. 1977). Asarco's costs for a drip irrigation system has averaged \$2,000 per acre exclusive of water delivery systems.

Revegetation of mining wastes can be successful, even under the adversities encountered in southern Arizona. All that is required is time, money, and ingenuity to develop the proper techniques. Asarco has developed many new irrigation techniques involving smaller nozzles, micro-sprinklers, specified irrigation schedules, and hydroseeding shrub species on drip irrigation systems utilizing new emitters. Other innovations Asarco is working on involve new crop species of adapted plants for agricultural use of the mining wastes after the mine is closed. With the costs of revegetation rising to \$8,000 per acre or more revegetation strictly for wildlife and aesthetics is not practical. The use of species with potential crop values becomes a viable alternative. Although this would involve perpetual care and management, in some instances the crop values would justify the investment required. Crops such as jojoba, grape, olives, eucalyptus fuel wood, and Christmas trees have been successfully planted on raw mill tailings at Silver Bell. The potential of these and other crops on other sites

is limited only by the lack of imagination or innovative capacity.

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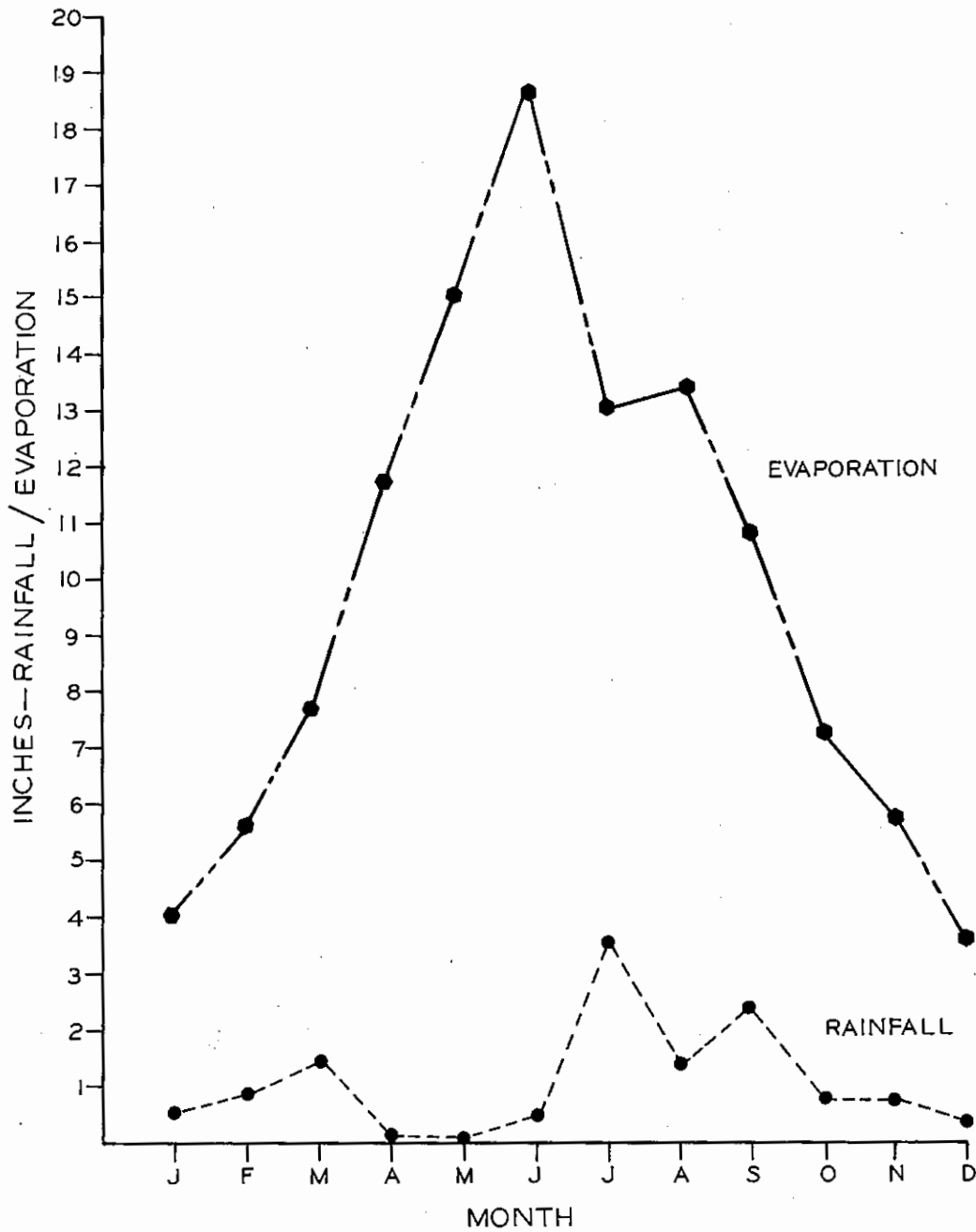
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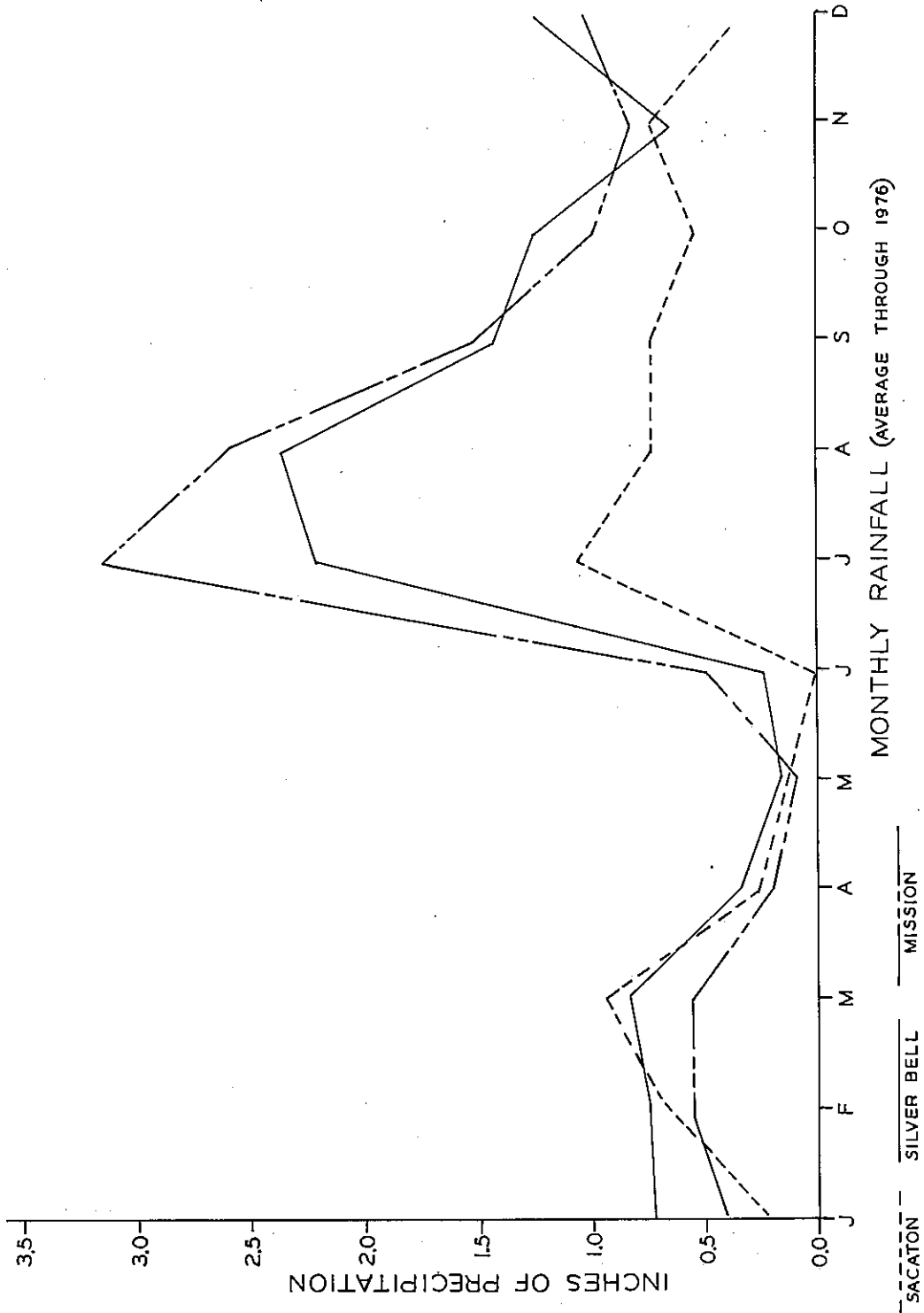
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GRAPH 1
AVERAGE RAINFALL / EVAPORATION
IN SOUTHERN ARIZONA

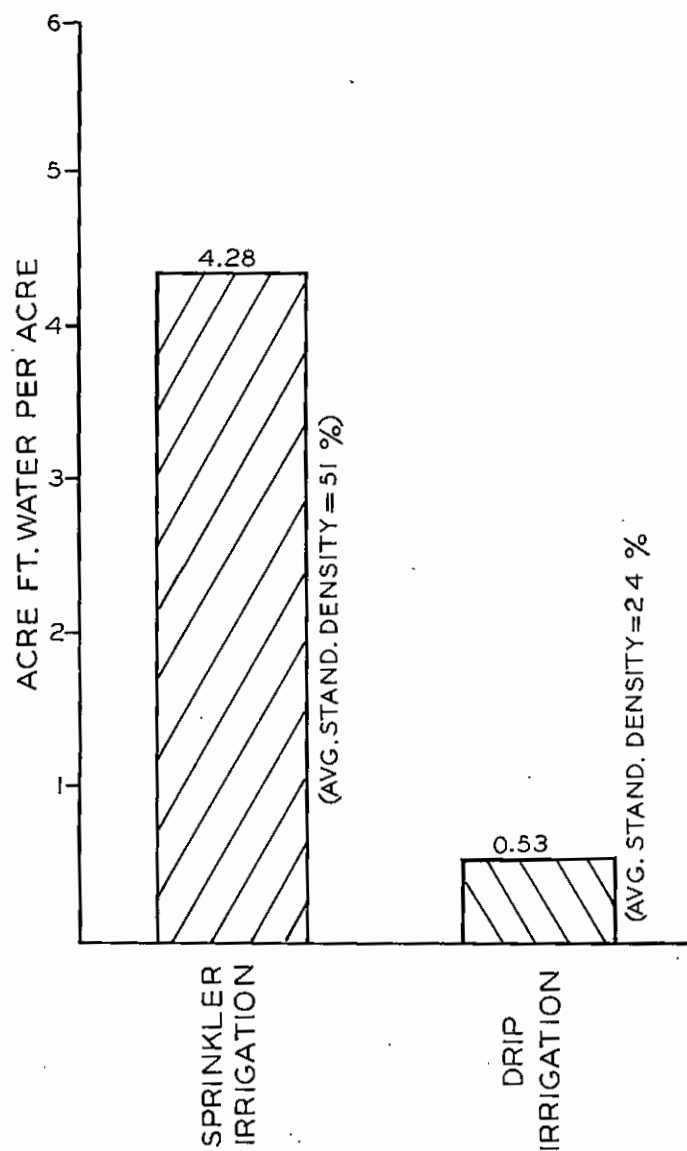


GRAPH 2



AVERAGE ANNUAL IRRIGATION WATER CONSUMPTION

GRAPH 3



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