A COMPUTER DECISION AID FOR RECLAIMING EASTERN ABANDONED SURFACE MINES

by

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INTRODUCTION

Since World War II the consumption of energy in the United States has doubled every 16 years. This exponential exploitation of finite natural resources is a concept of the limits to growth of world populations and industrial nations in the next hundred years (Meadows et al. 1972).

In 1970, coal comprised 46 percent of the energy source for electric power, followed by gas (24 percent), hydro-power (16 percent), oil (13 percent), and nuclear power (1 percent) (Cheney 1974). By the year 2000 the total use of energy may triple the 1970 rate, and coal represents approximately 88 percent of the United States' available energy resources for the future (Dale 1972; Cheney 1974).

Technology has increased the availability and recovery factor for both underground and surface mining of coal. Surface mining has increased in efficiency and productivity to the point where it has surpassed underground mining.

In the southern Appalachian region, characterized by steep mountainous terrain, coal recovery is accomplished by contour mining. Contour mining follows the coal seam, which is located at approximately a constant elevation in a region. The material above the seam is blasted and then removed. In the case of abandoned mines the material was pushed over the coal outcrop to form a loose outslope of mixed material. This type of mining leaves a highwall, bench area, and outslope, generally devoid of vegetation after mining. The amount of disturbed land due to the mining operation is influenced by the thickness of the coal seam, quality and price of coal to be removed, and the local topography (Fig. 1).

Surface mining, like transportation, agriculture, and urbanization, is a necessary land use which is essential to man's welfare (Paone et al. 1974). Surface mining, although environmentally more damaging than underground mining, is cheaper, more efficient, and safer than underground mining (Cheney 1974).

Copeland and Packer (1973) stated:

> "Surface mining takes many forms, but the one of greatest concern is strip mining. It creates violent disturbance of the earth's surface. Landscapes are disfigured by unsightly spoil banks and high walls that could be hazardous to man and wildlife. Vegetation is obliterated and wildlife habitat is damaged and often destroyed. Roads frequently bisect hitherto undisturbed areas; natural streams are sometimes diverted or contaminated, and erosion is often accelerated."

Surface mining has existed in many forms and to different extents since the early 1900's. Development of steam shovels and draglines facilitated removing thicker overburden and extracting lower grade ores. With further technological developments, advanced blasting, construction machinery, and the increased demand for fossil fuels, surface mining has played an increasing role in environmental disturbances (Paone et al. 1974; Grim and Hill 1974).

With increased land use by the mining industry and the desire to return the land to production, reclamation methods were put into practice. In 1918 the Indiana Coal Producers Association was founded to revegetate portions of the stripped land (Paone et al. 1974). The Wayne Coal Co. of Ohio in 1918 reseeded a mined area with sweet clover

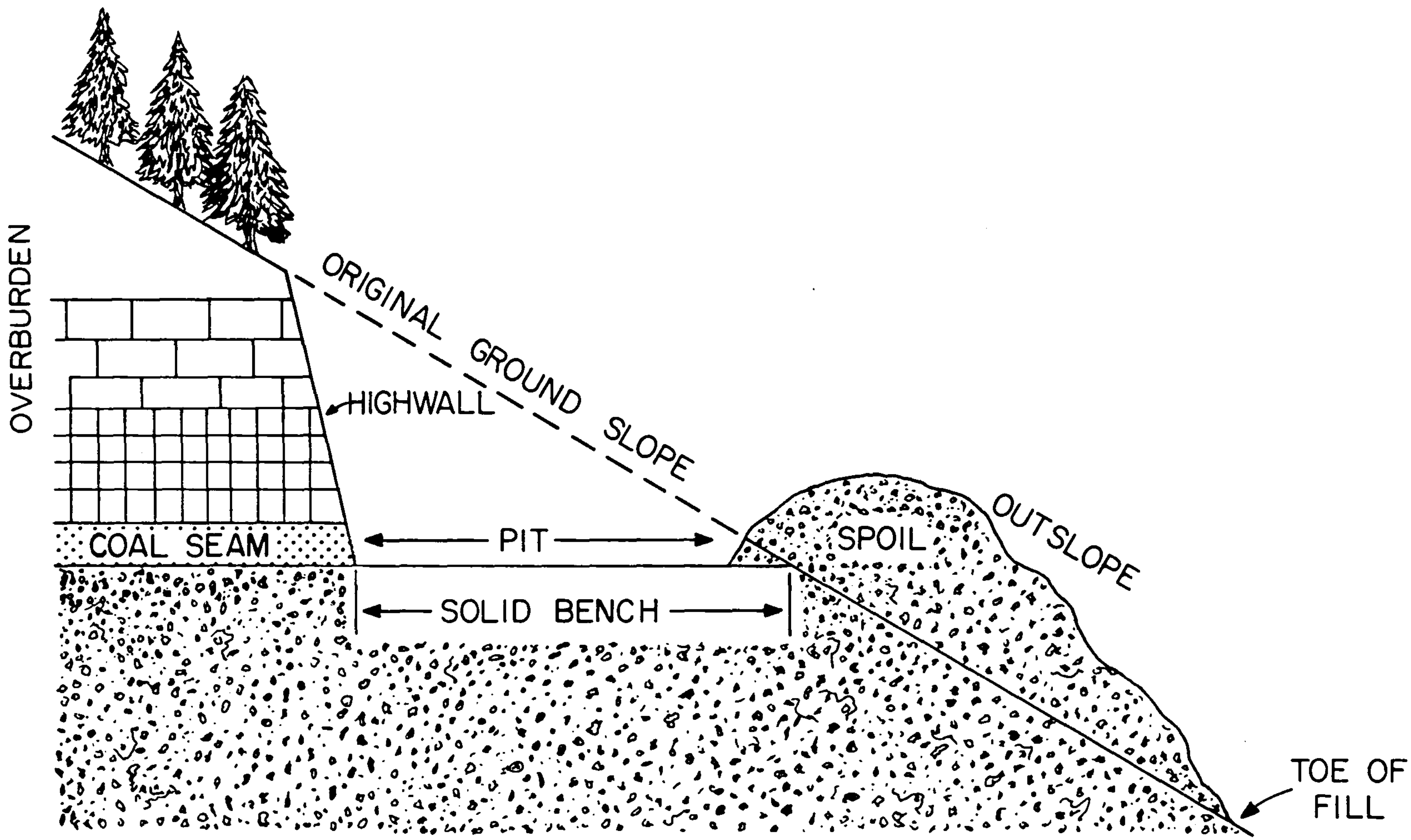


Fig. 1. Crossection description of a contour surface mine.

and subsequent tree planting 2 years later. Reforestation was done on surface mined land in southwestern Pennsylvania and Indiana in 1923 and 1926 respectively (May 1965). Czapowskyj (1973) stated that after World War II extensive tree plantings and pasture developments were established on surface mined lands.

Environmental concern and public demand for the return of these lands to a productive state resulted in the enactment of strip mine legislation (Paone et al. 1974; Grim and Hill 1974). West Virginia was the first state, in 1939, to enact this legislation. It was followed by Indiana (1941), Illinois (1943), Pennsylvania (1945), Ohio (1947), Kentucky (1954), Maryland (1955), Virginia (1966), and Tennessee (1967) (Paone et al. 1974).

Areas mined prior to the enactment of surface mine legislation have been left in the post-mining state, and are considered "orphan" or abandoned mines. Lands left in this condition are unproductive or have less than optimal productivity and should be revitalized to a more beneficial state. These are the areas with which this project is concerned.

In the period from 1930 to 1971, mining disturbed approximately 3,650,000 acres of land in the United States. Of this area, only 40 percent has been reclaimed leaving approximately 2,190,000 acres unreclaimed. More than half of this area was directly or indirectly disturbed by surface coal mining (Economic Research Service 1974; Paone et al. 1974; Rowe 1973).

Appalachia has more than 500,000 acres of abandoned surface mined lands in need of reclamation. In southwest Virginia there are approximately 19,000 acres of abandoned surface mined lands or 0.85 percent of the total land area. There are an additional 700 acres of abandoned coal haul roads which need some form of reclamation to reduce their environmental impact. Of these 19,000 or more acres, 3,000 have been sufficiently stabilized by natural processes so they do not need any reclamation. Twenty-six percent of the 19,000 abandoned acres in southwest Virginia are considered visual problems. (Holland 1973; Rowe 1973; TVA 1968).

Uncontrolled surface mining presents a situation as critical to the environment as any that have arisen before. Many mining activities have imposed large social costs on the public such as stream pollution, floods, landslides, loss of fish and wildlife habitat, unproductive land, erosion, and the impairment of natural beauty (Grim and Hill 1964).

Land disturbance due to surface mining causes great increases in erosion and sedimentation over that of undisturbed lands. Fifteen to twenty percent of the abandoned lands are causing major acid and siltation problems in watercourses (Holland 1973; Rowe 1973; TVA 1968). This, acid drainage adversely affects the watercourses as well as the ecosystem as a whole. The disturbed areas, due to their physical and topographical features are also conducive to flooding and landslides (Curtis 1971; Nephew 1972).

The stabilization of these abandoned surface mined areas is of primary concern. The initial objective of reclamation is to establish a quick ground cover to reduce the erosion of the surface.

The most difficult revegetation problems are caused by the extreme acidity of the spoil material. The oxidation of the pyritic materials overlying the coal seams leads to the formation of sulfuric acid and soluble salts, which are limiting to vegetation success (Vogel 1975).

Toxic chemicals such as Mn, Fe, Zn, and Al come into solution as the pH of the spoil decreases. As pH drops below 4.5, soluble salts and the above mentioned chemicals become increasingly toxic to plants, restricting establishment and growth. These factors all limit the potential for natural revegetation of these disturbed areas. (Barnhisel and Massey 1969; Cummins et al. 1965; Berg and Vogel 1973; Vogel and Berg 1968).

The diversity of areas and impacts from disturbance require a multi-objective approach to solve the problem of reclamation. Reclamation of these mined areas is necessary to return them to a productive state and to eliminate adverse effects. The solution to this multi-objective problem is to utilize a systems approach and simulate various reclamation strategies, thereby determining the consequences of a broad spectrum of activities.

Soil conditioning, earthmovement, erosion and sediment control, and plantings must be designed to solve the problem at the least cost and greatest benefit. For these reasons a team effort was chosen as the best method to solve this problem. The system will be analyzed from the viewpoint of, (a) a unit within a mine, (b) a mine, (c) the watershed, and the interactions among these. Two models were developed which operate interactively to solve the problem at these different levels.

The various impacts of the abandoned mine areas or of the reclamation process can interactively result in problems which would not be expected. These interactions can be modeled more effectively using computers and simulation models. By utilizing the concepts of simulation the affects of impacts or reclamation strategies over various periods of time can be measured.

The objectives of this study were to identify problem areas on a mine site and to measure the extent of natural revegetation of the area. The second objective was to identify and simulate representative reclamation strategies and their associated cost/benefit ratios. The final objective was to develop a computer system which would specify an optimum reclamation design for a specific site.

LITERATURE REVIEW

Several studies have been conducted which investigated the limiting factors affecting natural revegetation of surface mined lands. The adverse affects of abandoned surface mines on the environment have also been measured. Additionally, various reclamation strategies and their associated cost/benefit ratios have been considered. The interrelationships of these factors are problems which must be solved before any positive attempts are made to reclaim mines.

There are many factors which contribute to the lack of vegetation on abandoned surface mines such as toxic materials, unstable substrate, lack of surface organic matter, absence of soil organisms, excessive stoniness, steep slopes, and extremes of wind, temperature, light and moisture (Holland 1973). Richardson (1958) stated that there are three major factors which influence natural revegetation on surface mined areas. These are temperature, slope and aspect, and the nature of the substrate (growth medium). These variables interact with the local climate to dictate the physical and chemical properties of the overburden as a plant growth medium (Byrnes and Miller 1973).

Ecosystem development on abandoned surface mines is dependent on the age of the mine, resiliency of the system after disturbance (early successional stages are more resilient), and the above-mentioned factors. Mature systems have increased energy efficiency, a longer retention of energy in living biomass, and closed nutrient cycles. For these reasons a disturbance to mature ecosystems such as those in the Appalachian mining region, will disrupt the ecosystem dynamics (Smith et al. 1975; Riley 1975).

Natural revegetation of abandoned surface mined areas is diverse between sites as well as on an individual mine. The time span for sufficient vegetation to appear can be quite variable. Holland (1973) stated that it is usually greater than 10 years before a substantial natural vegetative cover occurs. Some toxic patches can remain devoid of vegetation for up to 45 years (Byrnes and Miller 1973).

Byrnes and Miller (1973) found that natural revegetation begins during the first year following disturbance on the most favorable spots with a preponderance of vegetation being found in the troughs. Any vegetation present on a disturbed site will provide some form of erosion control and add to the aesthetic appearance of the area.

To speed up the process of revegetation and stabilization, some form of reclamation must be initiated. The productivity of an area after treatment increases markedly. TVA (1968) found that reclaimed areas had three times the wildlife cover and twice the winter food as an unreclaimed site.

Reclamation practices are optimally designed to enhance the vegetative composition of surface mined areas. The reclamation practice should provide short term protection and increase long term production. Practices should be compatible with adjacent land use and with a time series of developments on the mine site (Thirgood 1974; Aldon 1975; Jeppson et al. 1974).

Attainment of maximum site development in the shortest period of time should be a major objective of reclamation (Haupt 1959). Aesthetics, social benefits, ecological and biological improvement of the site, and stabilization of watershed values should also be a primary concern (Monsen 1975; Haupt 1959; Jeppson et al. 1974).

Physical Properties of Spoil

Ludwig and Harper (1958) stated that soil color affects the temperature regimes and therefore available soil moisture. The potential threat of high temperature injury is more serious on black coal refuse and black shales than on lighter shales and sandstones. It is the temperature of the spoil, particularly the surface layers which first affects plant growth by the inhibition of germination (Curtis 1973; Richardson 1958).

Temperature of spoil is affected by color, texture, depth of dry layer, angle of incidence, and topography of the site. Soil moisture, porosity, content of solid particles, air moisture, and wind patterns all influence the degree of conductivity which in turn affects the surface temperature (Shulgin 1963; Deeley and Borden 1973; Vogel 1975).

Davidson and Sowa (1975) stated that spoil hinders vegetative establishment by its' physical characteristics, detrimental chemical properties, and a lack of soil organic matter. Dark soil, exposure to sun and wind, and a high rock content of the spoil cause drought conditions which are limiting to shallow-rooted plants (Curtis 1973).

Spoil weathers rapidly and breaks down into particles which erode readily. The effects of time on spoil will vary by site and be influenced by establishment of a vegetative cover (May 1965; Williams 1972; Curtis 1971).

Spoil material is a mixture of sandstone, limestone, waste coal, slate, and carbonaceous and pyritic shales, with varying levels of essential nutrients (Byrnes and Miller 1973; Cummins et al. 1965; Czapowskyj 1973; Curtis 1971; Schmidt-Bleek and Moore 1973).

Thirgood (1974) stated that spoil should be considered the "skeletal medium for future site development". New spoil banks contain little natural soil (15-45 percent) and many lack sufficient amounts of one or more essential nutrients (Berg 1968). Beyer and Hutnik (1969) stated that 20 percent soil content is sufficient for plant growth. Plass (1974) found that these coarse textured sandstones are conducive to good seedling development.

Infiltration rates were found to vary greatly due to edaphic characteristics but were found to be higher on ungraded spoil. In a Pennsylvania study, Coleman (1951) found rates of 65-297 in./hour (165.1-754.38 cm/hr.) on ungraded banks and 0.0-17 in./hour (0.0-43.18 cm/hr.) on graded areas. Merz and Finn (1951),in a study in Ohio,measured rates of 17 in./hour (43.18 cm/hr.) on graded as compared to 178 in./hour (452.12 cm/hr.) on ungraded spoil, and in Illinois, rates were found to be 0.9 in./hour (2.286 cm/hr.) on graded bare ridges and 5.2 in./hour (13.208 cm/hr.) on ungraded sites (Grandt and Land 1958). Limstrom (1960) found that infiltration rates were 7 times higher on ungraded spoil than on graded areas.

Jeppson et al. (1974) stated that low permeability indicated that the soil will not hold enough moisture to support plants during low water periods and therefore reclamation should include practices that increase soil permeability.

Slope and Aspect

Slope and aspect have been found to affect the establishment of vegetation on disturbed sites. The amount of radiation per unit area reaching the earth's surface is proportional to the cosine of the angle between the direction of the sun's ray and perpendicular to the surface (Richardson 1958). The amount of insolation per site governs related factors such as precipitation, and air and soil moisture. Also, high convex surfaces exposed to high winds are subject to erosion and weathering and are drier than adjacent sites (Spurr and Barnes 1973). Many studies in forestry have found that position on slope is a useful factor in evaluating potential growth of forest vegetation.

Toxicity and pH

Toxicity and pH of the growing medium are two interrelated factors which have a great influence on the potential productivity of an area. Acidity and phytotoxicity are major causes of mortality and poor plant survival on mined areas (Czapowskyj 1973).

Beyer and Hutnik (1969) stated that a substantial number of areas cannot be revegetated due to toxic conditions or a lack of essential nutrients rather than pH per se.

In the Appalachian coal region spoil has a pH in the range of 4.0-5.5 at post-mining. Weathering during early stages of spoil development reduces spoil pH by leaching bases (Berg and Vogel 1973; Magata and Suzuki 1968). Some plants can survive at pH levels below 5.0 but their chances of establishment are markedly decreased (Davidson and Sowa 1974; Tank 1973; Vogel and Berg 1968).

As pH drops below 4.5, toxic ions come into solution and some essential nutrients become less available. Toxic concentrations of iron, aluminum, manganese, and zinc were found in many spoils with a pH of less than 5.0. In many cases toxicity levels can be correlated to pH and for this reason pH can be used as a rough guide to toxicity in spoil samples (Massey 1971; Beyer and Hutnik 1969; Berg and Vogel 1973; Cummins et al. 1965; Vogel and Berg 1968; Barnhissel and Massey 1969; Vogel 1965).

Toxic ions, as well as high levels of soluble salts can interfere with seed germination, plant intake of water, or be limiting to plant growth. High acidity and a toxic concentration of aluminum can kill a seedling outright or weaken it to a degree where it will succumb to the stresses of the environment. Aluminum can cause a phosphorous deficiency in plants as found by Beyer and Hutnik (1969). Limited root development of some grasses grown on acid spoil indicates that there is also a toxic affect on species with fine root structure (Berg and Vogel 1973; Cummins et al. 1965; Beyer and Hutnik 1969).

Nutrient Availability

Nutrient levels can also be limiting to plant growth. Surface mine spoils in the Appalachian region are generally low to deficient in nitrogen and vary in phosphorous and potassium (Neeley and Himelick 1971; McCart 1973; Berg 1968; Zarger et al. 1969; Vogel 1975; Schramm 1966; Struther 1960; Stiver 1949). Potassium, if present in adequate quantities, is utilized in the process of growth and other plant functions by changing plant food into useable forms (Neeley and Himelick 1971). Phosphorous is essential for good root growth, tissue development and bud production.

Nitrogen

Plass and Vogel (1973) determined that nitrogen was one of the main nutrients limiting vegetation on West Virginia surface mines. Haynes and Klimstra (1975) found low nitrogen levels on surface mines in Illinois. Einsphar et al. (1955) found also in Iowa that nitrogen was limiting to vegetation establishment and growth. Aharrah (1962) found medium levels of nitrogen in Pennsylvania surface mine spoils.

Cornwell and Stone (1968) stated that nitrogen levels in anthracite spoil may be limiting but are not generally critical to plant growth.

Potassium

Potassium is generally found in adequate amounts in surface mine spoils (Czapowskyj 1973). Grandt and Lang (1958) found high potassium levels on spoil in Illinois, and in Pennsylvania Aharrah (1962) reported low levels of potassium. Cornwell and Stone (1968) stated that potassium levels varied greatly. Berg (1968) stated that naturally occurring potassium is probably adequate in most mine spoil. Haufler (1976) found potassium levels occurring in moderate amounts in Virginia as a significant factor in revegetation.

Calcium and Magnesium

Surface mine spoils appear to have low to adequate amounts of calcium (Aharrah 1962; Schramm 1966; Cornwell and Stone 1973). Spoils of low pH appear to have low calcium levels (Beyer and Hutnik 1969; Haynes and Klimstra 1975). Haufler (1976) stated that calcium levels were generally low on southwestern Virginia spoil compared with normal agronomic standards.

Studies generally indicate that magnesium is present in adequate to high levels in surface mine spoil (Haynes and Klimstra 1975; Barnhissel and Massey 1969; Czapowskyj 1973). The optimum calcium to magnesium ratio is 6.5:1 with a desirable range from 10:1 to 1:1 (Bear and Toth 1948; Haynes and Klimstra 1975). Haufler (1976) found high levels of magnesium on surface mine spoil in Virginia.

Phosphorous

Most researchers have found low levels of available phosphorous on surface mines. Einsphar (1955) found low levels in Iowa spoils.

Aharrah (1962) determined that levels were low on Pennsylvania surface mines. Plass and Vogel (1973) found limiting phosphorous levels in West Virginia surface mine spoil. Cornwell and Stone (1973) found that phosphorous limited the number of species invading Pennsylvania surface mines. Plant available phosphorous varied from extremely deficient to adequate for plant establishment (Berg 1968). Haufler (1976) stated that phosphorous was present in low amounts on most small plots sampled in Virginia.

Soluble Salts

Soluble salt levels can be found to vary on sampled spoil and with the pH of the growing medium. Berg (1965) found that soluble salt levels were inversely related to plant growth on acid spoil, interferring with the osmotic potential of spoil preventing water uptake by plants (Richards 1954). Struthers (1964) found that soluble salt levels can vary seasonally with the highest levels occurring during late summer and fall. Haufler (1976) found low soluble salt levels in summer in southwest Virginia.

Organic matter levels, a questionable indicator of fertility on surface mines, has been found in many studies to be at low levels in the spoil material (Cummins et al. 1965).

Fertilization

Because of the low available nutrient levels on surface mine spoil the application of soil amendments is beneficial to stabilizing the mine site and the production of high quality vegetation.

The application of fertilizer, if utilized in proper combinations and rates, is beneficial to the overall mine site. Different authors state that fertilizer treatments do or do not increase survival rates, but it was found to affect significantly plant growth and cover. Plant species maintained in an optimal environment are less susceptible to disease and are more productive. (Czapowskyj and Sowe 1976; Jeppson et al. 1974; Plass 1972; Thomas 1971; Neeley and Himelick 1971; TVA 1971).

Berg (1968) found that grass yields in his study, on plots with no fertilizer, ranged from low to very low, but with the addition of nitrogen and phosphorous yields increased significantly. There was no significant response to potassium when applied singly or in combination with nitrogen and phosphorous. The addition of phosphorous alone had little influence on yields, and nitrogen yields varied too greatly to determine significance.

The best responses were found to occur with the addition of nitrogen and phosphorous in combination (Plass 1972; Berg 1968; Bargston et al. 1969).

One must also consider any possible detrimental affects of fertilizer application. American beech, white oak, yellow poplar, white ash, and white pine have been found to be adversely affected by fertilizer treatments (Neeley and Himelick 1971).

Organic fertilizers may have the value of adding organic matter, increasing moisture holding capacity, reducing erosion, and providing additional soil nutrients (Brenner et al. 1975; Scanlon et al. 1973).

Erosion and Sedimentation

Erosion and sedimentation are two adverse effects resulting from abandoned surface mines. It was found that on untreated orphan mines erosion can increase 1000 times over adjacent undisturbed areas. The estimated soil loss per disturbed acre is approximately 360 tons (889.56 tons/hectare) compared to 1.8 tons (4.448 tons/hectare) per acre prior to mining (Nephew 1972; Minear and Tschantz 1974; TVA 1968). TVA (1968) stated that there is active erosion on 90 percent of the abandoned mines in the Appalachian region.

During mining and reclamation, equipment movement causes a rapid breakdown of the spoil to silt-sized particles. The rate of weathering is greater on freshly exposed material than in unmined areas. Landslides and poorly designed haul roads contribute greatly to erosion and stream sedimentation. Sediment inputs to streams adjacent to mines were found to range from 8,6000-46,400 ppm as compared to 150 ppm on adjacent forested sites (Curtis 1971; Haupt 1959). Nephew (1972) stated that acid-mine drainage caused by both deep and surface mines has altered the quality of approximately 10,500 miles (16,898.14 km) of streams in Appalachia. Acid drainage from these mines has seriously polluted some 5,700 miles (9,173.28 km) of streams reducing or eliminating aquatic vegetation.

Earthmovement

The topographic features of the landscape must be manipulated to produce the best growing conditions for planting and to meet the objectives of the reclamation strategy. Acid material or black coal waste should be buried to reduce the adverse effects on plant survival (Barnhissel et al. 1975; TVA 1968).

Many studies have found slope to be a useful factor in evaluating the growth potential of trees. Grading of the spoil material in association with other reclamation practices may be the most successful method of vegetative establishment and the reduction of impacts (May 1965; Barnhissel et al. 1975; Plass 1971).

Grading of spoil material toward the highwall will increase runoff retention on the bench area. Ponds and dams can also be designed to impound water on the bench (May 1965; Weigle 1973; Williams 1972; Plass 1971).

Highwalls can be reduced or altered to provide a more beneficial site. The aesthetic value of the land can be improved, and wildlife habitat will be altered (Plass 1971). Vegetation can be promoted which will visually screen the highwall as well as break down the spoil with its growth.

Grading operations will influence the hydrologic properties of the reclaimed site (May 1965). Loose grading provides a good growing medium for plant establishment and promotes beneficial soil-moisture relations. Differences in the moisture content of graded and ungraded spoil are attributed to rates of infiltration and percolation. Compaction of the spoil and leveling of material can result in reduced tree growth, lower infiltration rates, and changes in nutrient availability (Curtis 1973).

Surface preparation provides benefits which enhance the growing medium. Vegetation becomes established more successfully on sites that have been disked or furrowed (Curtis 1973).

Leaving spoil piles with long, high slopes of greater than 10 percent is detrimental to plant survival and encourages runoff and erosion (Aldon 1975). The flow of storm water over steep, bare ground from which the vegetative cover has been removed, as well as the low infiltration capacity of most spoil, will increase runoff and erosion if not protected by reclamation practices (Kochenderfer 1970; Jeppson et al. 1974).

Erosion terraces which reduce runoff, and enhance moisture conservation, encourage the establishment of a good vegetative cover. Curtis (1971) found a significant reduction of 42 percent in peak flow rates after terracing, as well as a colonization of the terraced area by herbaceous vegetation.

Abandoned coal haul roads must be reclaimed sufficiently to reduce their erodability and impacts on adjacent areas. Road grades must be reduced, culverts redesigned or removed and replaced by waterbars, ditching and crowning should be implemented, and the surface revegetated. Unreclaimed road surfaces provide no protection against runoff (TVA 1971; Weigle 1973; Weigle 1966; Kochenderfer 1970).

Windbreaks

Windbreak placement is an efficient method for the alleviation of moisture and wind erosion problems. Wind influences the microclimate of plants by affecting temperature, humidity, and evaporation rates. Transpiration may depend on absolute velocity at which wind changes as well as the relative changes, and the physiological affects of wind reduction can be related to the characteristics of the windbreak (Pelton 1967; Hogg 1965).

The main factors which influence wind patterns are the height, penetrability, length and general layout of the windbreak. The dimensions and structure of the windbreak, prevailing winds, weather patterns, and terrain around the windbreak also modify patterns of wind movement (Winch 1969; Hogg 1965).

Windbreaks should be designed to affect the maximum area possible and beneficially alter wind patterns. The design criteria should be influenced by the site and objectives of shelterbelt placement. Combinations of tree and shrub plantings with variable structure and height patterns, as well as thickness, should be considered. (Easton 1971; Pelton 1967; Winch 1969).

The modified wind patterns and velocities behind the windbreaks will alter moisture levels, snow accumulation, transpiration rates, and impacts from wind erosion (Pelton 1967; Hogg 1965).

Hooper (1972) stated that one could consider a shelterbelt as an ecosystem in itself, providing diversity, interspersion, and additional edge for wildlife, which enhances the total site value.

Liming

The application of lime to surface mine spoil adjusts the base saturation of exchangeable colloids, neutralizes excess acidity, and inhibits the availability of toxic elements (Czapowskyj 1973). By reducing the acidity, microorganism levels are increased as is available phosphorous (Vogel 1975). Plass (1969) found that plant growth rates can be correlated to a reduction in the concentrations of iron, copper, and zinc.

Lime application rates vary with the pH of the spoil but the recommended practice is to raise the pH to approximately 5.5 (below this manganese and aluminum are found in toxic concentrations) (Vogel 1975). Grandt and Lang (1958) found that liming rates of 40-70 tons/acre (98.84-172.97 tons/hectare) raised the spoil pH to tolerable levels. Plass (1969), in a greenhouse experiment, found that an application rate of 5.0 tons/acre on extremely acid spoil samples significantly increased pine survival. Czapowskyj and Sowa (1976) found that lime application increased the survival and ground cover of crown vetch over three growing seasons.

Mulch Application

The toxic conditions of spoil in the Appalachian region can be alleviated by the application of soil amendments. Mulching improves site conditions and reduces undesirable impacts from the mine site (Scanlon et al. 1973). Czapowskyj and Sowa (1976) found that mulching increased survival by 10 percent and doubled the ground cover of established vegetation.

Mulching modifies extremes of surface heating and cooling, and reduces surface evaporation rates (Vogel 1975; Berg and Vogel 1973). Warmer winter temperatures and cooler summer temperatures occur below 5-inch (12.7 cm) mulch layers (Donahue 1971). These conditions encourage the growth and activity of soil microorganisms and bacteria which facilitate carbon dioxide release and increase oxygen availability (Searle 1973; Donahue 1971; Jeppson et al. 1974).

The reduction of surface runoff and increased infiltration rates promote the natural leaching of salts and water soluble aluminum, therefore reducing the soil toxicity (Vogel 1975; Berg and Vogel 1973; Jeppson et al. 1974).

Application rates vary by site and by the objectives of reclamation. Schmidt-Bleek and Moore (1973) found that rates of approximately 750 pounds/acre (1853.25 kg/hectare) on a less than 5 degree slope and 1000 plus pounds/acre (2471.0 kg/hectare) on a greater than 12 degree slope were sufficient to stabilize most sites. Scanlon et al. (1973) stated that to get a stabilized organic layer in 2-3 years, application rates of between 26 and 71 tons/acre (64.25 and 175.44 tons/hectare) should be used.

Plant Selection

Variations in a disturbed area should be recognized and dealt with by planting seed mixtures best adapted to each site within an area. One must be able to predict the effect of the spoil characteristics on plant establishment and growth (Monsen 1975; Plass 1974).

Monsen (1975) stated that revegetation is dependent on artificial means since severely disturbed areas recover very slowly by natural selection. Ecosystem development is influenced by, and dependent upon overburden properties, placement of material, topography, surface compaction, and time since disturbance (Riley 1975).

Plant species should be chosen for their success in achieving the specific reclamation objectives. Various species considered for use should be evaluated for their potential to provide erosion control, as well as the production of wildlife food and cover (Brenner et al. 1975). There are two broad classes of vegetation which can be used for reclamation, those which provide quick cover (grasses, forbs, and legumes), and species which will provide long-term site protection and production (trees, shrubs, and vines) (May 1965; Plass 1975).

Plass (1975) stated that plant species should be chosen which would (1) have a potential economic value, (2) provide wildlife food and cover, (3) enrich the soil by nitrogen fixation, and (4) have aesthetic value. Native plants may be desirable to provide compatibility with surrouding areas, and combination plantings of herbaceous and woody species will provide diversity and aid soil stabilization (Monsen 1975).

Fast growing annuals such as rye, lupine, and buckwheat can be used as nursery crops for slower developing perennials, and as an "in place" mulch (May 1965). Vegetation should also be encouraged on the non-toxic sites to reduce surface evaporation on adjacent bare areas by reducing wind velocities, shading, and providing an organic litter layer (Berg and Vogel 1973).

Vegetation will affect soil moisture at various depths dependent on root structure. Deep rooted species will also provide protection against erosion and mass slide potential. Curtis (1973) reported infiltration rates of 9.3 in./hour (23.62 cm/hr.) and 0.9 in./hour (2.29 cm/hr.) on barren ungraded and graded sites as compared to 13.6 in./hour (34.54 cm/hr.) and 1.5 in./hour (3.81 cm/hr.) on vegetated ungraded and graded sites respectively.

METHODS AND PROCEDURES

Due to the complexity of the abandoned surface mine system each component has been analyzed as a separate subsystem and integrated for a total system simulation. The components need to be investigated from many levels and information integrated about them to achieve a large-scale solution.

This surface mine reclamation research project was designed as a team effort, with part of the team investigating fisheries and wildlife aspects (site characteristics included) and a systems team analyzing the problems and describing solutions utilizing computer techniques.

The systems team took two approaches, one examined the abandoned surface mine problem as related to watershed dynamics (Saunders 1977). The objective of the research discussed in this thesis was an investigation of a system of units of a mine within a watershed. The two approaches will operate interactively to produce a decision aid for reclamation.

A computer program written in Fortran IV for an IBM 370 is the results of this investigation. The program was designed to operate as a group of interacting subprograms. These subroutines were designed to be flexible enough to solve many wildland related problems outside the realm of this investigation, which greatly increases their potential utility.

Because the operation of this model is based on the interaction of the subroutines, each subroutine will be discussed as a separate program to improve understanding and to facilitate its use as an individual subprogram.

Main Drive Program

A main driving program was developed to sequence the operation of the subprograms. This and the subprograms are presented in Appendix II.

Polygon Area Estimator

This subprogram determines the area and perimeter of a unit, defined as an area of evident similar visual characteristics, determined by the objectives of the investigation. The unit is sketched on grid paper (Fig. 2) , the X and Y coordinates are recorded and are input to the program. Polygonal sections are calculated, stored, and summed. Results of the subprogram are area and perimeter calculations of each unit (Table 1) (Nordbeck and Rystedt 1972).

Potential Erosion Estimator (ERODES)

The potential erosion estimation subprogram calculates relative rates of erosion for a unit or a mine based on topographic, edaphic, vegetative and climatological information and the affects of various reclamation practices and their associated costs to achieve lower rates of erosion. The program utilizes a modified version of the Universal Soil Loss Equation (SCS 1975) to estimate sheet and rill

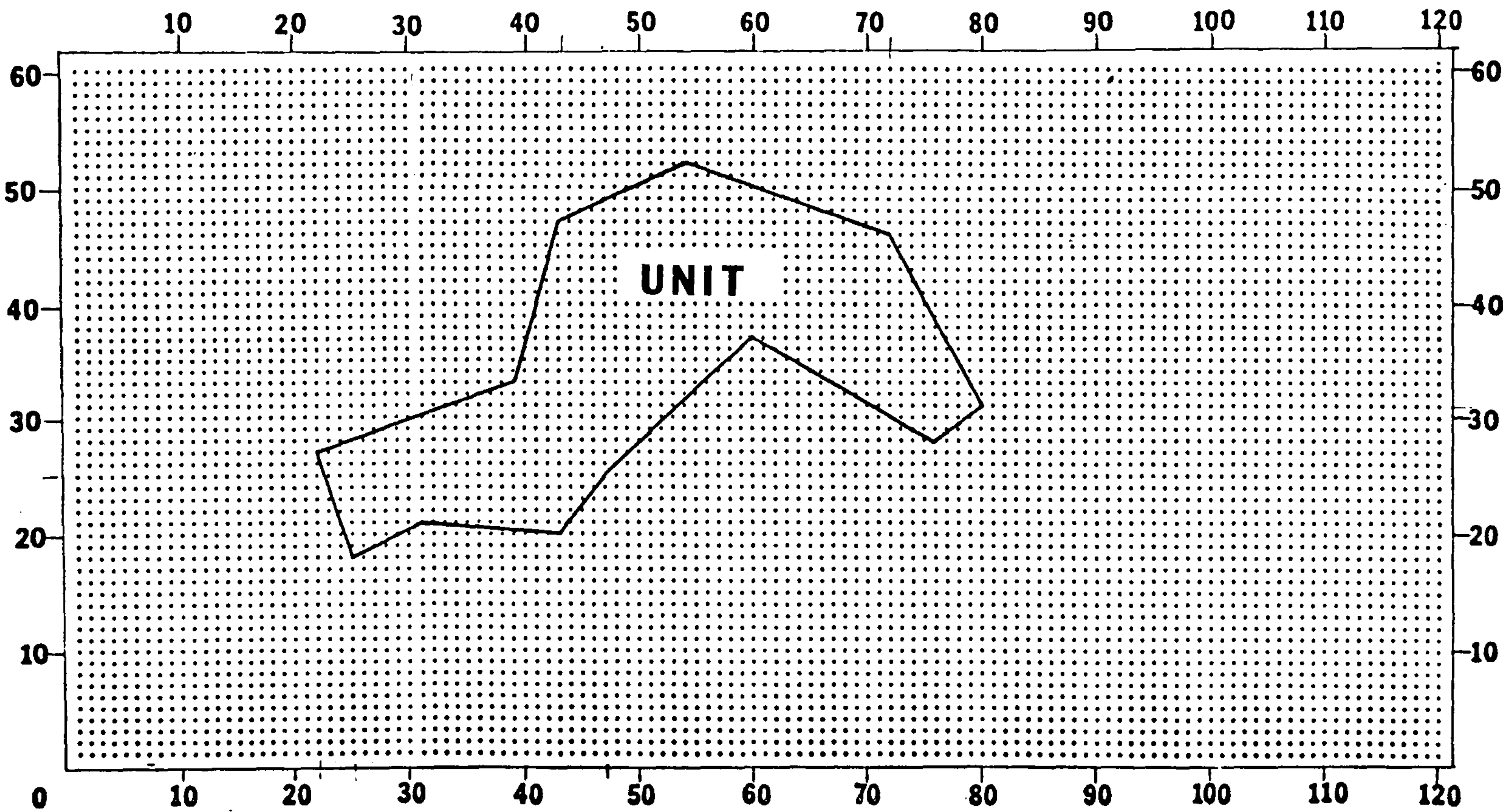


Fig. 2. Sketch of surface mine unit on grid sheet.

Table 1 . Coordinate points and area and perimeter computations from polygon area estimator for Figure A.

Point No.	Coordinates X	Y
1	22	27
2	39	33
3	43	47
4	54	52
5	72	46
6	80	31
7	76	28
8	60	37
9	47	25
10	43	20
11	31	21
12	25	18

Area = 843.00

Perimeter = 146.85

erosion (ERODE) in tons/acre/year, for each unit investigated. Metric equivalents are obtained by multiplying by 2.471 to produce tons/hectare/year. The Soil Loss Equation is:

ERODE = RFACT * SOILOS * LENSLO * CROPT * PRECL

where:

RFACT = rainfall factor. It is a measure of the erosion force of a specific rainfall. When other factors are constant, storm losses from erosion are proportional to the product of the kinetic energy of the storm multiplied by its maximum 30-minute intensity. (SCS 1975).

SOILOS = soil erodibility factor. Soil properties that influence erodibility by water are: (1) those that affect infiltration rate, permeability, and total water capacity, and (2) those that resist the dispersion, splashing, abrasion and transporting forces of rainfall and runoff. (SCS 1975).

The LEN and SLO variables are utilized in the following formula to compute the LENSLO coefficient (measure the affect of a combination slope length and percent) to be used in the soil loss formula (ERODE) (SCS 1975).

LENSLO = (SQRT(LEN)) * (0.0076 + (0.0053 * SLO) + (0.00076 * (SLO ** 2)))

where:

LEN = slope length factor. The distance from the point of origin of overland flow to: (1) the point where the slope decreases to the extent that deposition begins, or (2) the point where runoff enters a channel.

SLO = slope gradient factor. The slope of the described unit in degrees. Soil loss due to gradient is influenced by density of vegetal cover and soil particle size.

and:

CROPT = cropping management factor or percent and type cover. This factor measures the combined affects of the interrelated cover and management variables plus the growth stage (see Table 2).

PRECL = erosion control practice factor. The ratio of soil loss on an unreclaimed site to that of various reclamation practices listed in Table 3.

Table 2 presents the coefficients used as the cover factors (CROPT) in the equation. By estimating the percent ground cover on a unit and determining if it is composed of grass or forbs, and then measuring the vegetal canopy as presented in the table, the cover coefficient (CROPT) can be determined. Table 2 is read as a three dimensional matrix with PERCAN representing percent canopy cover and type with a matrix value of 1 through 10 (rows) and PERGO representing percent ground cover with a matrix value of 1 through 6 (columns). The third dimension of the matrix is the type of ground cover (grass or weed) represented by PTYPE in the subprogram and assigned a value of 1 (grass) or 2 (forb). These are used in the subprogram to identify which value, of the CROP matrix (10, 6, 2), is to be accessed.

Fig. 3 provides a method for estimating the soil erodibility factor (SOILOS) for a unit. By estimating the factors in the order given and using Figure 4 the coefficient of soil erodibility can be determined. The field investigator selects each factor in the order given and moving left to right (as shown in the example by following the dashed, arrowed line) on the figure, determines the coefficient.

Table 2. Cover values to be used as the CROPT value in the erosion control subprogram.

Vegetal Canopy: Type and height of raised canopy	Canopy cover (percent)	Type	Percent Ground Cover: 0	20	40	60	80	95-100	
Column Number:			1	2	3	4	5	6	Row No.
No appreciable canopy		Grass	.45	.20	.10	.042	.013	.003	1
		Forb	.45	.24	.15	.090	.043	.011	
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	Grass	.36	.17	.09	.038	.012	.003	2
		Forb	.36	.20	.13	.082	.041	.011	
	50	Grass	.26	.13	.07	.035	.012	.003	3
		Forb	.26	.16	.11	.075	.039	.011	
	75	Grass	.17	.10	.06	.031	.011	.003	4
		Forb	.17	.12	.09	.067	.038	.011	
Appreciable brush or bushes (2 m fall ht.)	25	Grass	.40	.18	.09	.040	.013	.003	5
		Forb	.40	.22	.14	.085	.042	.011	
	50	Grass	.34	.16	.085	.038	.012	.003	6
		Forb	.34	.19	.13	.081	.041	.001	
	75	Grass	.28	.14	.08	.036	.012	.003	7
		Forb	.28	.17	.12	.077	.041	.011	

Table 2. Continued.

Vegetal Canopy			Percent Ground Cover						
Type and height of raised canopy	Canopy cover (percent)	Type	0	20	40	60	80	95-100	
Column Number:			1	2	3	4	5	6	Row No.
Trees but no appreciable low brush (4 m fall ht.)	25	Grass	.42	.19	.10	.041	.013	.003	8
		Forb	.42	.23	.14	.087	.042	.011	
	50	Grass	.39	.18	.09	.040	.013	.011	9
		Forb	.39	.21	.14	.085	.042	.011	
	75	Grass	.36	.17	.90	.039	.012	.003	10
		Forb	.36	.20	.13	.083	.041	.011	

Table 3. Twelve erosion control practices and their associated costs and effectiveness values (to be used for PRECL variable in erosion control subprogram (ERODE).

Treatment	Comments	Pregermination erosion control & plant establishment*	Cost/acre** (dollars)
Hydromulching with 2,000-3,000 lb/acre wood fiber plus seed and fertilizer.	Produces a true mulch effect & some erosion protection. Commonly better results than 1,000 lb. fiber, or fiber plus glue.	0.35	635
Seed and fertilizer broadcast and covered with soil, and followed with hydromulch of wood fiber at 2,000-3,000 lb/acre.	Very effective, combines advantages of seed coverage and mulching.	0.45	745
Straw or hay broadcast with straw blower on the surface at 3,000 lb/acre and tacked down (asphalt emulsion, Terratack III, etc.). Seed and fertilizer broadcast with hydroseeder or by hand.	Effective as an energy absorber, mulch; straw forms small dams to hold soil. My be weedy depending on straw source. Not for slopes greater than 2:1. Cost increases for slopes over 50 feet, or on an uphill application.	0.65	650
Straw broadcast 4,000 lb/acre rolled to incorporate (punched); another 4,000 lb straw broad-cast and rolled, seeded, and fertilized. Seed and fertilizer broadcast with hydroseeder or by hand.	Common on difficult fill slopes. Very effective. Not possible on most cut slopes. Weedy. Cost increases if slopes over 50 feet from access.	0.70	975

Table 3. Continued.

Treatment	Comments	Pregermination erosion control & plant establishment*	Cost/acre (dollars)
Roll-out mats (jute, excelsior, etc.). Held in place with wire staples. Seed and fertilize by broadcasting.	Provides a good weed free mulch, adapted to small areas. Can be installed any season, cuts or fills. Unsightly, difficult to install on rocky soil.	0.60	2400
Seed and fertilizer broadcast on the surface, no soil cover or mulch.	Inexpensive and fast. Most effective on rough seedbeds with minimum slope and erod-ability where seed will cover naturally with soil. Suitable for remote or critical areas where machinery cannot be taken.	0.05	250
Hydroseeding or hydromulching (seed & fertilizer) with 500 lb. wood fiber, 1,500 gal. water/3 acres.	Similar effectiveness to broad-casting seed and fertilizer. Not enough fiber to hold seed in place or produce a mulch effect. Seed distribution would be improved by increased volume of water.	0.15	280
Seed and fertilizer broadcast and covered with soil (raking or dragging a chain, etc.)	Does not require special equipment. Generally a very effective treatment. Labor cost is high on areas not accessible by equipment.	0.10	320

** 1 dollar/acre = 2.47 dollars/hectare

Table 3. Continued.

Treatment	Comments	Pregermination erosion control & plant establishment*	Cost/acre (dollars)
Hydromulching with 1,5000 lb/acre wood fiber (plus seed & fertilizer).	A common hydromulch mix. Advantages include holding seed & fertilizer in place on steep and smooth slopes where there may not be an alternative method. Minimal mulch effect.	0 .20	475
Hydromulching with 1,500 lb/acre wood fiber plus an organic glue: Ecology Control, Terratack III, etc. plus seed and fertilizer.	The addition of an organic glue will sometimes improve fiber holding & germination. Does not increase labor or machinery costs.	0 .25	600
Polyethylene sheets (4 mil). Seed & fertilize, use clear plastic with seed, black with no seeding.	Useful for temporary control, and can be installed any season. Unsightly, wind is a problem in installation & maintenance. May be difficult to establish plants.	0 .90	2600
Seed & fertilizer broadcast, or hydromulch with fiber (500 lb/acre) followed by an erosion control chemical such as polyvinyl acetate at 6:1 dilution at 1,000 solid/acre.	Very expensive, but will hold soil and seed in difficult conditions. May restrict penetration of water into soil. Not effective on soils that crack. Will not support animal or vehicle traffic.	0.92	1220

*Effectiveness value used in the erosion control subprogram (ERODE) as the PRECL variable based on a value of 1.0 as the most effective.

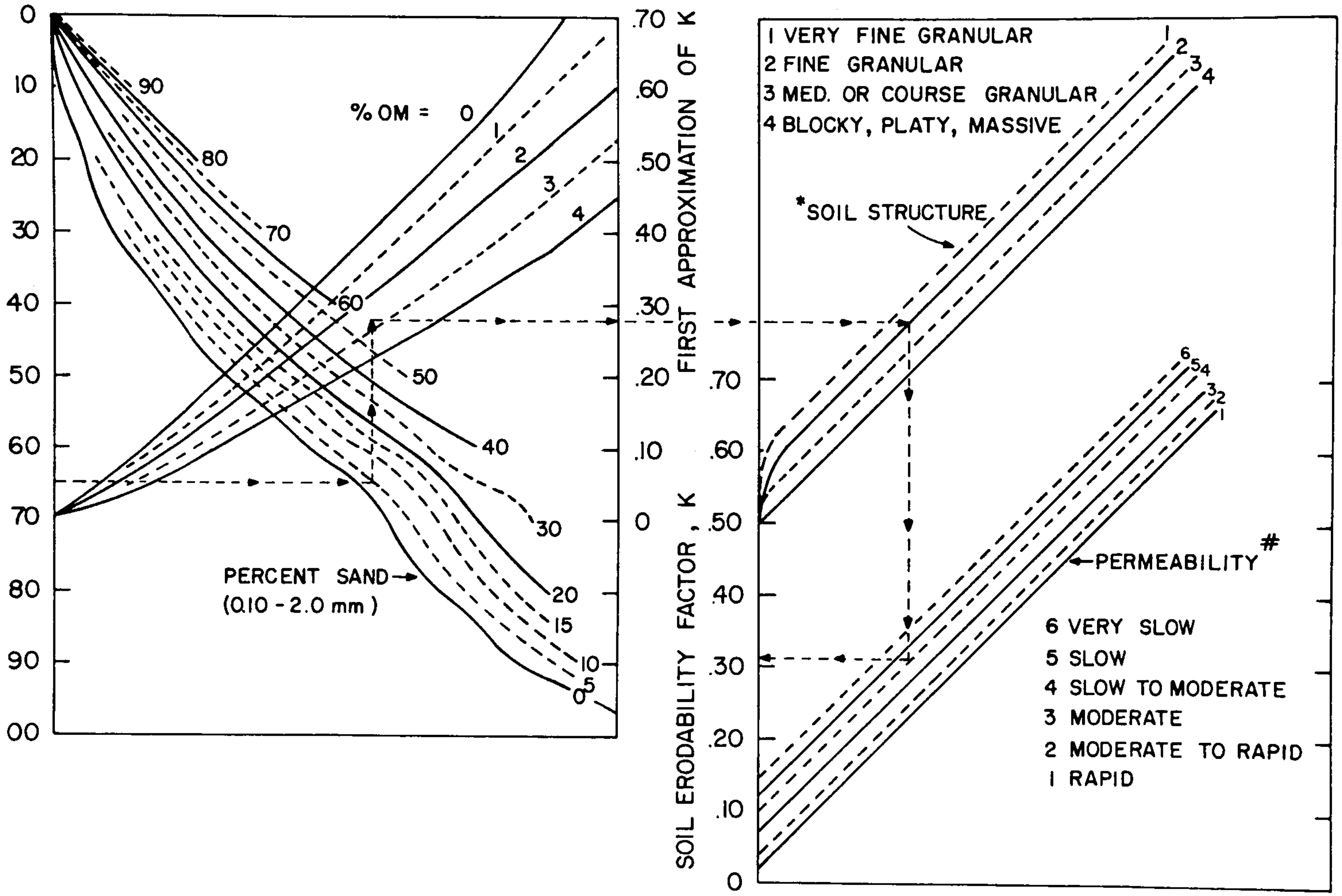


Fig. 3 . Methodology to compute the SOILOS coefficient for the ERODES subprogram.

The following are the factors to be estimated:

A. Percent silt and very fine sand
B. Percent sand (0.10-2.0 mm)
C. Percent organic matter (0-4 percent)
D. Soil structure
   1. very fine granular
   2. fine granular
   3. medium or coarse granular
   4. blocky, platy, massive
E. Permeability
   1. rapid
   2. moderate to rapid
   3. moderate
   4. slow to moderate
   5. slow
   6. very slow

Lime Application (LIME)

Given a pH value measured from a soil sample as an input, this subprogram calculates the amount of lime (tons/acre) which would be required to raise the pH of the spoil to a desired level. This liming rate is based on a table from McCart (1973) describing the rates needed to raise the pH of the spoil, calculated from the original pH and the pH which will achieve the predetermined objectives.

At present the program objectives are to raise the pH to 4.5 to 5.0 (described as optimal pH range) for stabilization and erosion control, 5.0 to 5.5 for wildlife habitat and tree production, and to 5.5 to 6.0 (or higher as would result from rate increases above the table value) for hay and pasture. Table 4 presents the rates required to achieve the three objectives, as they are computed in the subprogram.

Table 4. Lime requirements for sites with known pH (after McCart 1973).

Spoil pH	Tons lime needed per acre to increase pH to: 4.5 to 5.0 Stabilization and erosion control	5.0 to 5.5 Wildlife and tree production	5.5 to 6.0 Hay and pasture
less than 3.0	6 to 8	8 to 10	10 to 12
3.0 to 3.5	3 to 5	5 to 7	7 to 9
3.5 to 4.0	2 to 3	3 to 5	5 to 7
4.0 to 4.5	1 to 2	2 to 3	3 to 5
4.5 to 5.0	0	1 to 2	2 to 3
5.0 to 5.5	0	0	1 to 2

Fertilizer Application (FERT)

To determine the fertilizer requirements of a site, a soil sample must be collected and analyzed. The levels of nutrient availability in the sample must be measured and classified (low, medium, high) as shown in Table 5 (McCart 1973).

The levels of nutrient application are designed to fulfill the minimum requirements of a site to establish a vegetative cover. The inputs to the subprogram are the classification values of 1 (low), 2 (medium), or 3 (high) for the phosphate (PHOS) and potash (POTASH) nutrient levels , the program then computes the proper amounts of nutrient application.

Plant Selection Subprogram (PLSPEC)

Plant species must be chosen by their suitability to the site and by how well they meet the objectives of the planting strategy. The objectives will vary by site and for this reason flexibility is built into the program.

The tree, shrub, and grass selection subprograms are designed to operate with the best information presently available, and are designed to be modified as new data are collected. New objectives or objective weights, additional plant species, silvical information, and site information can be added to the programs in their present form. This can be accomplished by adding classifications, changing or adding data cards (a new species can be added by simply typing a new card with pertinent information and adding to the data deck), or

Table 5. Nutrient requirements for sites with known nutrient deficiencies (lbs./acre) (after McCart 1973).

Spoil Test	Phosphorous (P_2O_5)	Potassium (K_2O)	Nitrogen (N)
Low	120	120	60
Medium	60	60	60
High	0	0	60

changing weights on the OBJECTIVE RANK card.

These subprograms operate by an objective weighting methodology, a modified version of EFEVAL (Giles and Linn 1975), which ranks species by suitability to site characteristics and the relative weight of each objective.

Each species is assigned a classification and value for each silvical characteristic to provide a means of comparison with the site characteristic to determine suitability (Tables 6, 7, 8). The plant classification is compared to the site characteristic and then assigned a suitability value to be utilized in the ranking procedure.

The following method is employed to assign site suitability values. Because plant species survive at optimal levels in the center of their tolerance range and suboptimally on the extremes, values are assigned to depict accurately this for weighting. If a site is at the optimal range for the species (e.g. site pH = 3.5-4.0 and plant pH requirement = 3.5-4.0) a value of 2 is assigned this species in ranking matrix. If the site parameter is suboptimal, one range above or below that required by the species (e.g. site pH = 3.5-4.0, plant pH requirement 4.0-4.5) a suboptimal value of 1 (less effectiveness weight) is assigned to the ranking. If the site characteristic is outside of the suboptimal range it is assumed the species would not survive and a value of 0 is assigned to the ranking matrix. As one can see, the higher optimal value of 2 when multiplied by the objective weight will result in a higher weight for the species. As

Table 6. Classification values for tree selection subprogram.

	Class	Values
pH	1	3.5 to 4.0
	2	4.0 to 4.5
	3	4.5 to 5.0
	4	5.0 to 5.5
	5	5.5 to 6.0
	6	6.0 to 6.5
	7	6.5 to 7.0
moisture	1	dry
	2	dry to medium
	3	medium
	4	medium to wet
	5	wet
shade	1	high tolerance
	2	moderate tolerance
	3	intermediate tolerance
	4	moderate intolerance
	5	high intolerance
parent material	1	limestone
	2	shale
	3	sandstone
	4	unimportant
	5	shale and sandstone

Table 7. Classification values for grass selection subprogram.

	Class	Value
pH	1	3.5 to 4.0
	2	4.0 to 4.5
	3	4.5 to 5.0
	4	5.0 to 5.5
	5	5.5 to 6.0
	6	6.0 to 6.5
	7	6.5 to 7.0
legume	1	leguminous
	0	non-leguminous
use	1	soil preparation and erosion control
	2	wildlife
	3	aesthetics
	4	wildlife and erosion control
	5	wildlife and aesthetics
	6	erosion control and aesthetics
	7	hay and pasture
	8	erosion control and pasture
	9	wildlife and pasture
planting time	1	March to April
	2	April to June
	3	August to October
lifespan	1	annual
	2	perennial
	3	biennial

Table 8. Classification values for shrub selection subprogram.

	Class	Value
pH	1	3.5 to 4.0
	2	4.0 to 4.5
	3	4.5 to 5.0
	4	5.0 to 5.5
	5	5.5 to 6.0
	6	6.0 to 6.5
	7	6.5 to 7.0
moisture	1	dry
	2	dry to medium
	3	medium
	4	medium to wet
	5	wet
shade	1	high tolerance
	2	moderate tolerance
	3	intermediate tolerance
	4	moderate intolerance
	5	high intolerance
use	1	soil preparation and erosion control
	2	wildlife
	3	aesthetics
	4	wildlife and erosion control
	5	wildlife and aesthetics
	6	erosion control and aesthetics
	7	hay and pasture
	8	erosion control and pasture
	9	wildlife and pasture

all the values for each species and objective are summed and an overall weight assigned.

The result is an index of the likely effectiveness of a species on a site to meet specific human objectives.

Through a literature review, silvical and quality characteristics were determined for representative plant species in each group. The silvical characteristics are utilized in the site suitability comparison for each unit (Tables 9, 10, 11).

The output of the program consists of a table listing the input values with each objective assigned a number, and a normalized weight for each species. The normalized weight is computed by adding all weights and then calculating each as a proportion of the whole. An output table lists the calculated effectiveness of each species by number, name, and the normalized individual weight.

Land Manipulation Subprogram (HIWALL)

The harsh environmental effects on abandoned surface mines may be compounded by the typical highwall, bench, and outslope configurations. To develop a favorable environment for plant growth, and to produce a more aesthetically pleasing landscape, this configuration can be altered.

By inputting site characteristics such as height of highwall, outslope length and slope, original slope, and bench width, the land manipulation subprogram (HIWALL) will calculate the new landform possibilities associated with each manipulation. Associated costs of

Table 9. Silvical characteristics of selected tree species.

Species	pH range	Shade tolerance	Moisture	Growth medium*
Loblolly pine	5.5-6.0	mod. tolerance	med.-wet	--
Eastern white pine	5.5-6.0	inter. tolerance	dry-med.	--
Virginia pine	5.5-6.0	mod. tolerance	dry-med.	--
Longleaf pine	5.0-5.5	high tolerance	dry-med.	--
Shortleaf pine	5.5-6.0	mod. tolerance	dry	--
Pitch pine	5.0-5.5	high tolerance	medium	--
Red pine	5.5-6.0	mod. tolerance	dry-med.	--
Jack pine	5.5-6.0	inter. tolerance	medium	--
Eastern hemlock	5.5-6.0	high intolerance	medium	--
White spruce	6.0-6.5	mod. intolerance	med.-wet	--
Balsam fir	5.5-6.0	high intolerance	med.-wet	--
Eastern larch	6.5-7.0	mod. tolerance	medium	--
Northern red oak	5.5-6.0	inter. tolerance	dry-med.	--
Baldcypress	6.5-7.0	inter. tolerance	wet	--
Sugar maple	6.5-7.0	high tolerance	med.-wet	--
Red maple	6.5-7.0	mod. tolerance	medium	--
Black walnut	6.5-7.0	mod. tolerance	medium	limestone
Yellow poplar	6.5-7.0	mod. tolerance	medium	--
Sweet gum	6.5-7.0	mod. tolerance	med.-wet	--

Table 9. Continued.

Species	pH range	Shade tolerance	Moisture	Growth medium*
Sycamore	6.5-7.0	inter. tolerance	wet	--
Eastern cottonwood	6.5-7.0	high tolerance	wet	--
Quaking aspen	6.5-7.0	high tolerance	dry-med.	--
White ash	6.5-7.0	inter. tolerance	dry-med.	--
Green ash	6.5-7.0	inter. tolerance	medium	--
American elm	6.5-7.0	inter. tolerance	medium	--
American basswood	6.5-7.0	mod. intolerance	dry-med.	limestone
Black cherry	6.5-7.0	mod. tolerance	dry-med.	shale & sandstone
River birch	5.5-6.0	inter. tolerance	wet	--
Black birch	5.5-6.0	mod. tolerance	medium	--
American beech	5.5-6.0	high intolerance	dry-med.	--
Blackgum	5.0-5.5	inter. tolerance	medium	--
Black locust	6.5-7.0	high tolerance	dry-med.	--

*(--) signifies type of growth medium is unimportant.

Table 10. Silvical characteristics of selected shrub species.

Species	pH range	Shade tolerance	Moisture	Use
Flowering dogwood	5.5-6.0	mod. tolerance	dry	wildlife
Silky dogwood	5.0-5.5	mod. intolerance	dry	wildlife
Gray dogwood	5.0-5.5	inter. tolerance	medium	wildlife
Blackhaw	5.5-6.0	high tolerance	dry	wildlife
Amur honeysuckle	6.0-6.5	inter. tolerance	dry	wildlife
Japanese honeysuckle	6.0-6.5	mod. tolerance	dry	wildlife & erosion
Tatarian honeysuckle	4.5-5.0	mod. tolerance	medium	wildlife & erosion
Shining sumac	5.0-5.5	mod. intolerance	dry-med.	wildlife & aesthetics
Fragrant sumac	5.0-5.5	mod. intolerance	dry-med.	wildlife & aesthetics
European speckled alder	5.0-5.5	mod. intolerance	dry-med.	wildlife & erosion
Multiflora rose	5.5-6.0	mod. intolerance	medium	wildlife
Smilax spp.	5.0-5.5	inter. tolerance	medium	wildlife
Amur privet	5.0-5.5	mod. tolerance	dry	wildlife & erosion
Lowbush blueberry	3.5-4.0	mod. intolerance	dry	wildlife

Table 11. Silvical characteristics of selected grass species.

Species	pH range	Lifespan	Legume	Planting season	Use
Alfalfa	5.5-6.0	perennial	yes	March-April	hay & pasture
Red clover	5.5-6.0	perennial	yes	March-April	hay & pasture
Sweet clover	5.5-6.0	biennial	yes	March-April	hay & pasture
White clover	5.0-5.5	biennial	yes	March-April	pasture
Crownvetch	5.0-5.5	perennial	yes	March-April	erosion & pasture
Flatpea	5.5-6.0	perennial	yes	March-April	soil prep. & erosion
Sericea lespedeza	4.5-5.0	perennial	yes	March-April	wildlife & pasture
Annual lespedeza	4.5-5.0	annual	yes	March-April	wildlife & pasture
Fall fescue	5.0-5.5	perennial	no	March-April	wildlife & pasture
Weeping lovegrass	5.0-5.5	perennial	no	April-June	wildlife & erosion
Foxtail millet	5.5-6.0	annual	no	April-June	wildlife
Orchard grass	5.0-5.5	perennial	no	March-April	wildlife & pasture
Red top	4.5-5.0	perennial	no	March-April	hay & pasture
Annual ryegrass	6.0-6.5	annual	no	March-April	soil prep. & erosion
Blackwell switchgrass	6.0-6.5	perennial	no	March-April	wildlife & pasture
Grain sorghum	5.5-6.0	annual	no	April-June	wildlife & pasture
Wheat	5.5-6.0	annual	no	April-June	wildlife & pasture
Timothy	5.5-6.0	perennial	no	March-April	hay & pasture

earthmovement can also be calculated by inputting the present equipment and time costs (e.g. 0.10 dollars per cubic yard).

With incremented heights of cuts (IHC) and angles of cuts (CTANG) (based on optimal slopes for establishment of vegetation) the resultant highwall height, slope above highwall, slope on bench, cubic yards of material moved, cost of earthmovement, and total number of acres disturbed are calculated.

Figure 4 describes the variable names and a generalized diagram of the landform manipulation. This format was devised to allow a more efficient use of the equations in the HIWALL subprogram.

As the cuts are incremented, the change in program output can be used by the investigator to examine the costs and results of a group of alternatives. A slight decrease in slope percent may result in a high increase in cost or in total acres disturbed. This will be evident in the table and will provide a concrete decision base.

The HIWALL subprogram can be linked with the ERODE program to provide a more efficient decision aid. For each resultant action, relative rates of erosion can be calculated. By this method, cost/benefit ratios can be determined.

Terrace Area Subprogram (TERARE)

A terrace building subprogram (TERARE) was developed which operates similarly to the HIWALL subprogram. This subroutine calculates the amount of material removed from terraces of various

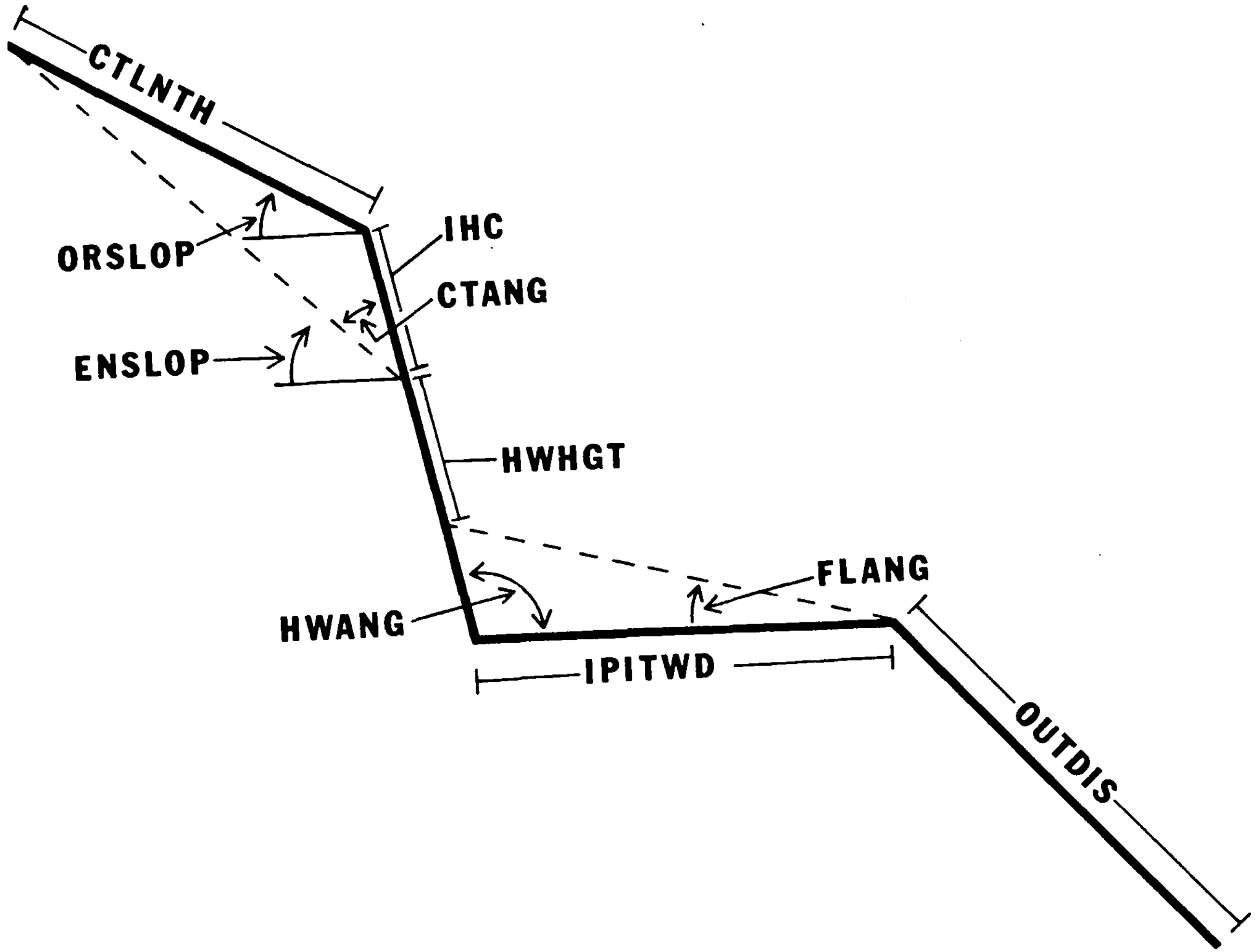


Fig. 4 . Schematic drawing of the HIWALL model with variable names included (variable names are further explained in the HIWALL subprogram)

structure, determined by the slope of the outslope, angle of terrace cut, and the horizontal depth of the cut. The area of the terrace cut is computed and the change in slope on the bench, as the material is placed there, is determined and the final topographic configurations are presented.

Inputs to the program are the outslope length, number of terraces to be built (determining the slope lengths), angle of outslope, highwall height, and width of bench. Fig 5 presents a generalized diagram and variable name identification.

Windbreak Effectiveness Subprogram (WINBRK)

The windbreak effectiveness subprogram computes the percent change in wind velocity at various distances lee and windward of barriers of varying heights and structures. Table 12presents the calculations for a windbreak of 6 feet in height and of 13 different structures. This program can be utilized to determine the effective area resulting from the placement of the windbreak structure.

Analysis of Subprograms

Sensitivity analyses were performed on the subprograms to determine the effects of varying parameters. Maximum and minimum values were used as well as a range of values if they were thought to influence the output on an increasing or decreasing scale.

The amount and the sequence of variation was analyzed to determine the sensitivity of the subprograms to internal and external

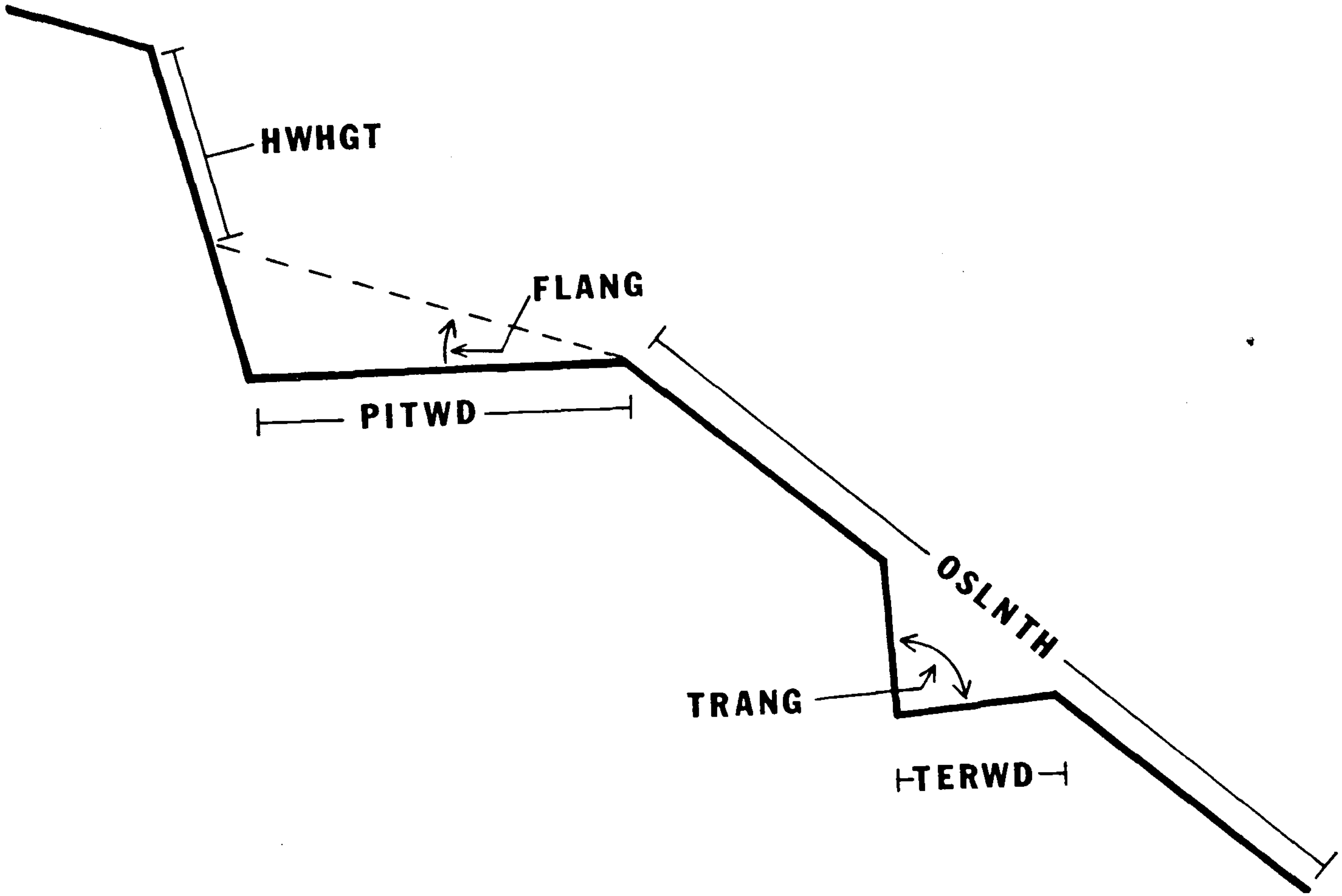


Fig. 5 . Schematic drawing of the TERARE model with variable names included(variable names are further explained in the TERARE subprogram.

Table 12. Sample table of computer generated wind velocities for incremented distances from 6 foot barriers of 13 structural types.

	Percent of Wind Velocity as Affected by Barrier															
	Distance From Barrier															
	-90.	-60.	-30.	0.	6.	12.	18.	24.	30.	60.	90.	120.	150.	180.	210.	240.
33% Wood Barrier	**	**	**	82	82	76	65	60	58	73	73	88	93	96	98	100
Thin Cottonwood	**	**	**	79	78	77	76	75	68	71	71	82	88	93	95	97
Wide Ash Grove	**	**	**	30	30	36	48	55	60	80	80	90	93	95	97	100
Cottonwood & Locust	**	**	**	40	36	28	25	32	40	63	63	75	80	85	90	95
Triple Wood Barrier	**	**	**	46	30	24	21	28	35	53	53	72	83	92	96	100
Deciduous Woods (Winter)	100	100	96	80	71	63	63	64	66	78	78	87	95	100	100	100
Loose Shelterbelt	100	100	96	65	52	40	39	40	45	72	72	85	91	97	100	100
Medium Dense Shelterbelt	100	100	96	60	45	38	35	33	35	61	61	78	90	93	98	100
Very Dense Shelterbelt	100	100	96	18	15	25	39	48	60	83	82	90	97	100	100	100
Open Bottom, Dense Top	100	96	89	55	26	18	14	11	12	40	40	60	70	80	90	92
Open Top, Dense Bottom	100	100	98	100	55	40	32	28	25	25	25	40	60	72	85	91
Dense Top and Bottom	100	96	90	0	15	23	30	35	40	57	57	70	80	86	90	97
Open Top and Bottom	100	102	110	105	85	60	57	59	60	72	72	82	90	93	95	98

** No data currently available.

changes and to provide insights to the most effective manipulations to allow use as a decision aid.

This operation is discussed in more specific detail in the appropriate areas of the results.

RESULTS

HIWALL Subprogram

Table 13 presents an example of a run of the HIWALL subprogram. By utilizing the information given and determining the possible objectives of reclamation, one can measure the success of a particular strategy, or group of strategies, in achieving the stated objectives. The degree of achievement of a specific objective can be used as a measure of the success of a particular land manipulation.

To make an optimum decision, one must have the best information available, an objective, and some hope of eventual feedback. The HIWALL subprogram provides a decision aid system to determine the costs and affects of reducing the highwall height and altering bench and above highwall slopes.

As heights of cut and cut angles are altered, the resultant topographic changes must be measured, and costs and benefits determined. If changes resulting from highwall reduction can be determined prior to reclamation, optimal solutions can be utilized.

The operation of this subprogram has provided insights to the surface manipulation problem. As the height of cut and slope percent are increased, the total cubic yards of material moved, and therefore the costs of earth-movement, are increased. To measure the cost/benefit ratio of any decision, one must consider the following factors and rank the importance of each in the decision making process; final

Table 13. Sample table of computer generated landform configurations resulting from operation of earthmovement subprogram (ERTHMOV).

Height of cut	Cut angle	Cut length	Highwall height	Final slope	Acres disturbed	Cubic yards of material	Cost (dollars)	Bench slope	Second highwall
Swell Percent			30%						
5	58.	48.	82.	27.	9.5	90502.	9050.	2.	42.
5	60.	48.	81.	25.	10.4	92635.	9263.	2.	42.
5	62.	48.	81.	23.	10.8	94684.	9468.	2.	41.
5	64.	49.	81.	21.	11.0	96646.	9665.	2.	40.
5	66.	49.	81.	19.	11.1	98521.	9852.	2.	40.
5	68.	50.	81.	17.	11.2	100306.	10031.	2.	39.
5	70.	51.	81.	15.	11.3	102000.	10200.	2.	39.
5	72.	51.	81.	13.	11.3	103603.	10360.	2.	38.
5	74.	52.	81.	11.	11.4	105112.	10511.	2.	37.
8	58.	46.	77.	27.	8.3	132984.	13298.	3.	40.
8	60.	47.	77.	25.	9.6	136044.	13604.	3.	39.
8	62.	47.	77.	23.	10.2	138968.	13897.	3.	38.
8	64.	48.	77.	21.	10.5	141754.	14175.	3.	38.
8	66.	48.	76.	19.	10.8	144400.	14440.	3.	37.
8	68.	49.	76.	17.	10.9	146902.	14690.	3.	37.
8	70.	50.	76.	15.	11.0	149260.	14926.	3.	36.

Table 13 . Continued.

Height of cut	Cut angle	Cut length	Highwall height	Final slope	Acres disturbed	Cubic yards of material	Cost (dollars)	Bench slope	Second highwall
Swell Percent			30%						
8	72.	51.	76.	13.	11.1	151470.	15147.	3.	35.
8	74.	51.	76.	11.	11.2	153531.	15353.	3.	35.
11	58.	45.	72.	27.	7.0	175467.	17547.	4.	37.
11	60.	45.	72.	25.	8.9	179453.	17945.	4.	37.
11	62.	46.	72.	23.	9.7	183252.	18325.	4.	36.

height of highwall following reduction, final slope above highwall, final slope on the bench (resulting from the placement of earth), total acres disturbed, and the cost of the earth-movement process.

Fig. 6 graphs a segment of the results of a run of the HIWALL subprogram. By utilizing a technique such as this, one can more efficiently determine the results of a particular land manipulation, or selection of land manipulations. If it is assumed that a reduced highwall, less steep slope, and a minimum number of acres disturbed, as well as minimal costs, are benefits, the optimum strategy can be examined.

The HIWALL subprogram produces two values which can be utilized in the operation of Saunders' (1977) WATEFLOW model. The total number of acres disturbed (ACREDS) and the slope calculations for the final slope above the highwall (ENSLOP) and the slope on the bench (FLANG) are averaged for a mine site and are used in the model to provide information for a watershed- based decisions.

Figs. 7 and 8 show schematic diagram of the highwall reductions. To determine the best reduction, the objectives of the reclamation decision must be determined and weighed. Each type of reduction will provide different benefits to the mine system. The terrace type highwall reduction will provide another bench type structure which is stable for plant establishment, and tends to reduce surface water flow. The angled highwall reduction greatly decreases the highwall configuration (terracing produces an additional highwall), but a disadvantage is the greater land area disturbed.

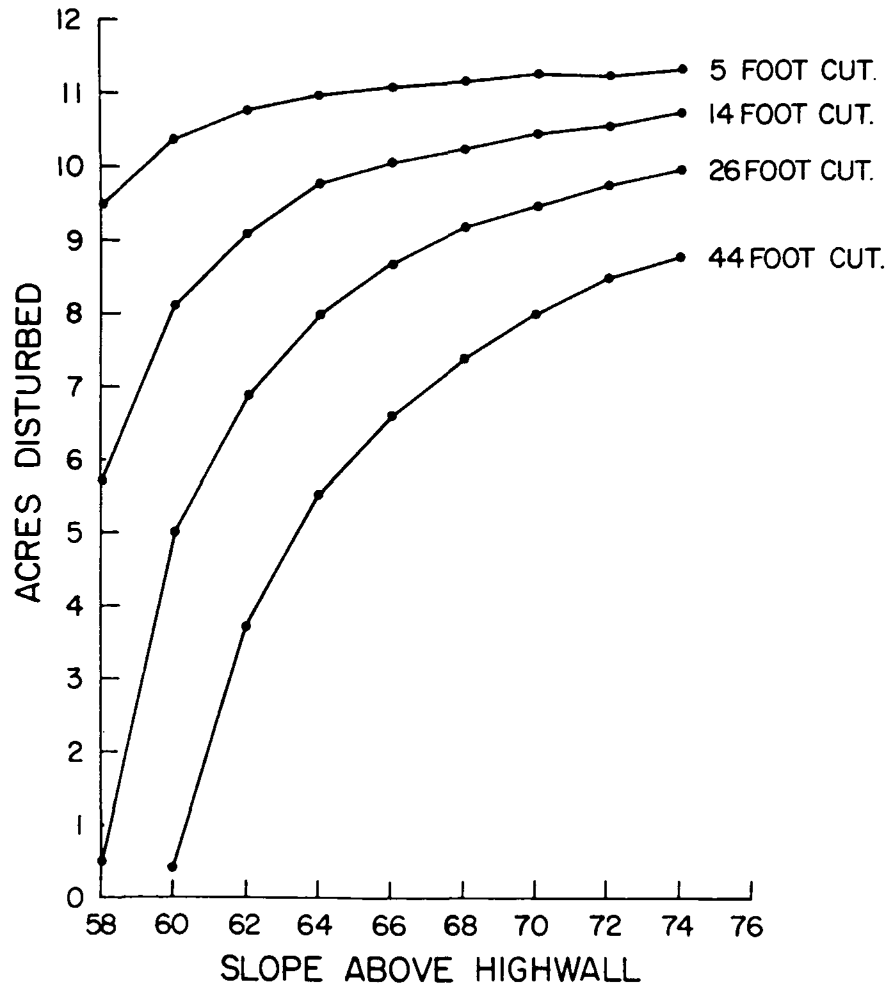


Fig. 6 . Total acreage disturbed resulting from four cuts at different slope angles.

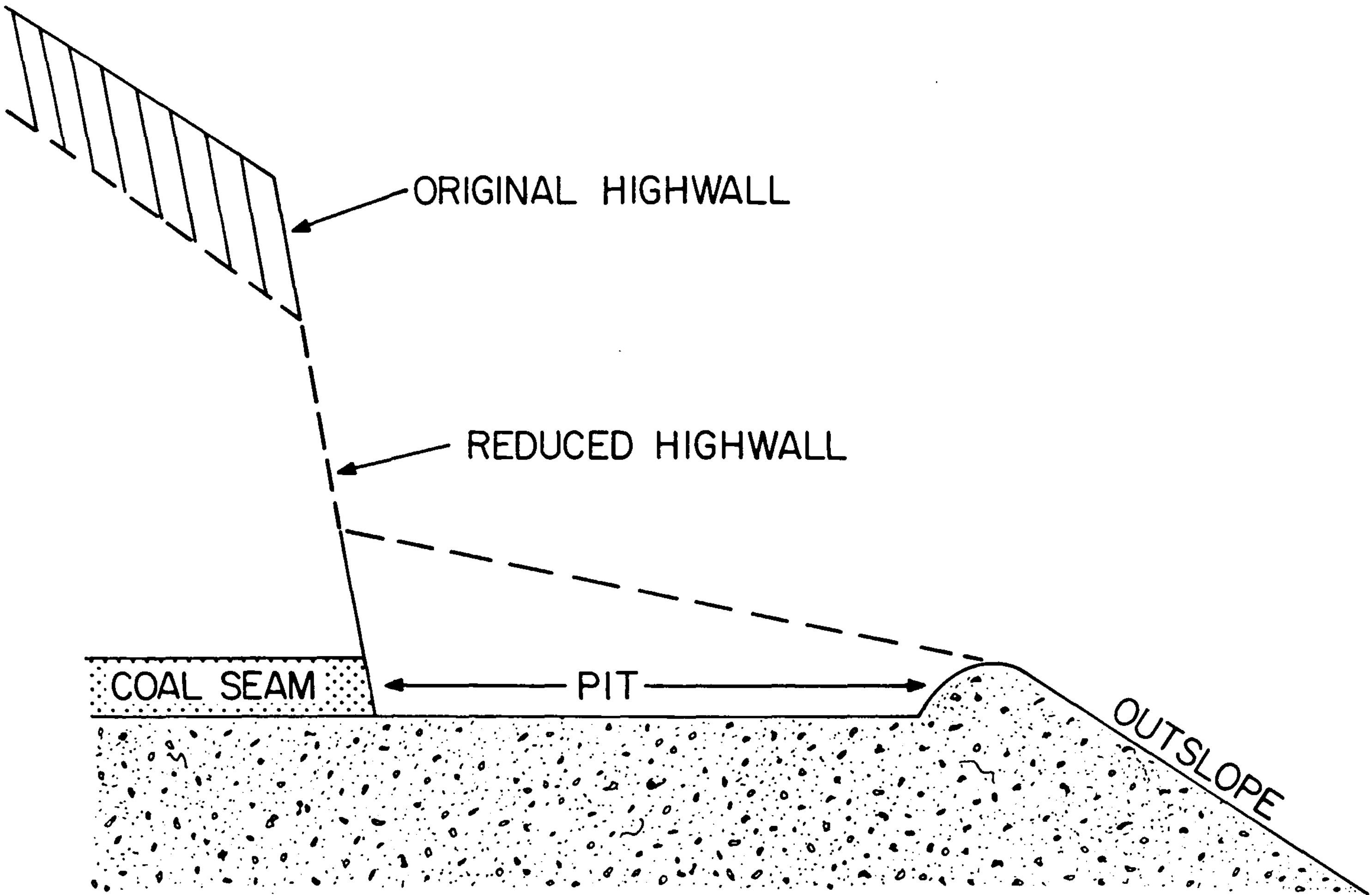


Fig. 7 . Crossectional diagram of a highwall reduction and backfilled bench area.

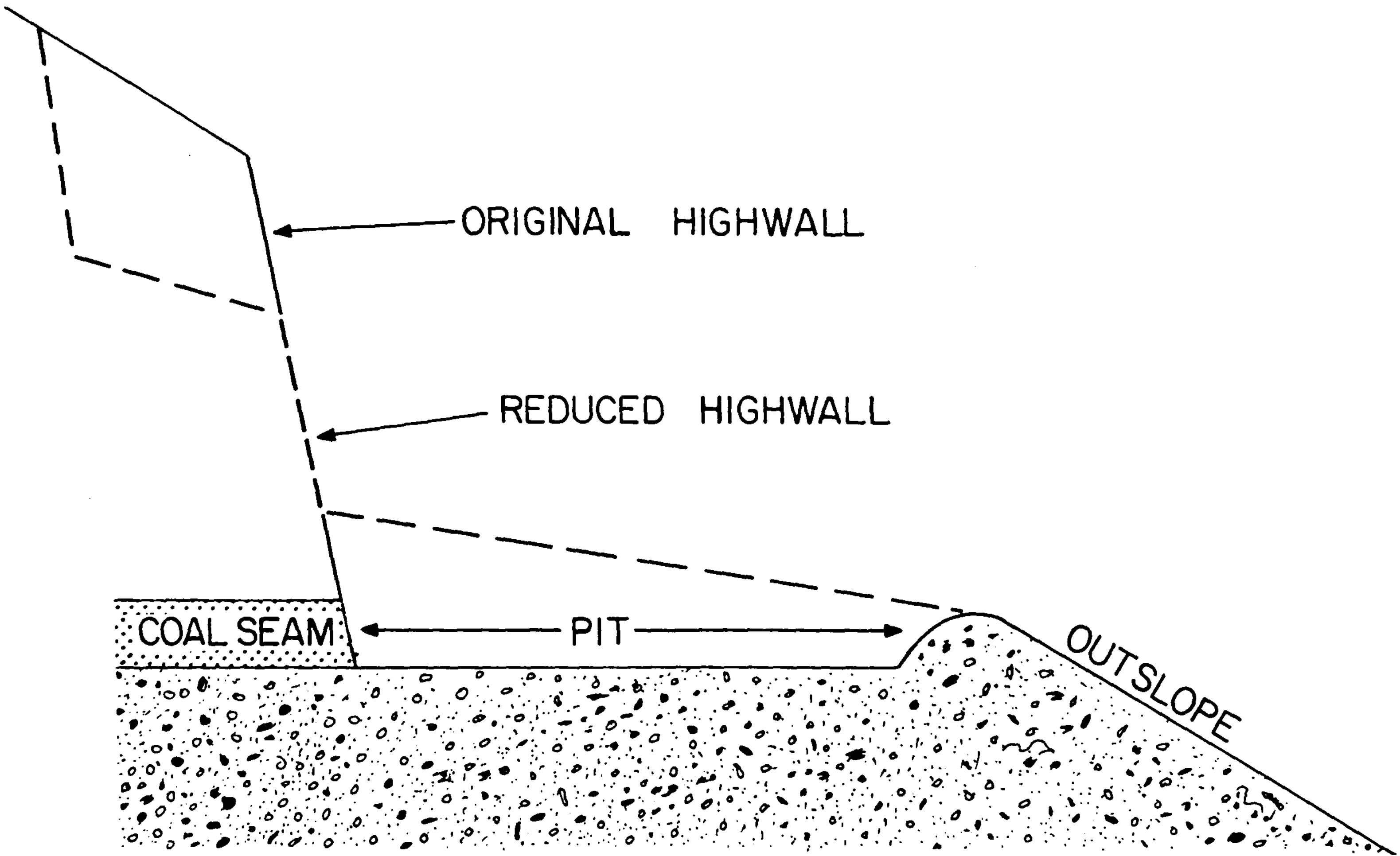


Fig. 8 . Crossectional diagram of a terrace type highwall reduction and subsequent pit fill.

There are many types of backfill practices for the bench area. The objectives of the overall reclamation practice must be stated prior to the decision stage. Figs. 9 and 10 provide two examples of highwall reductions and associated backfill practices.

Highwall reduction can vary with the objectives, size and location of the mine site, and availability of equipment (or dollars). Figs. 11 and 12 provide insights to the methodology of the highwall reduction and the complexities associated with the decision.

As an example of an objective method of decision making, a reduced highwall is more efficient for animal movements, more stable, and aesthetically more pleasing. As slopes are decreased, erosion rates will decrease, and success of plant establishment increases. The fewer acres disturbed resulting from topographical changes, the less will be site preparation and reclamation costs.

The results of combinations of the above actions can be analyzed more efficiently using the HIWALL subprogram. As the highwall is reduced the costs increase due to the increased amount of material to be moved. Additionally, with lower slopes, the total number of acres disturbed increase, but again the slopes would be increasingly more stable. This information can be utilized in the decision making process.

PLSPEC Subprogram

As discussed in the Methods and Procedures section, the plant selection subprograms rank trees, shrubs, and grasses by their suitability to the investigated site, and for meeting a complex set of

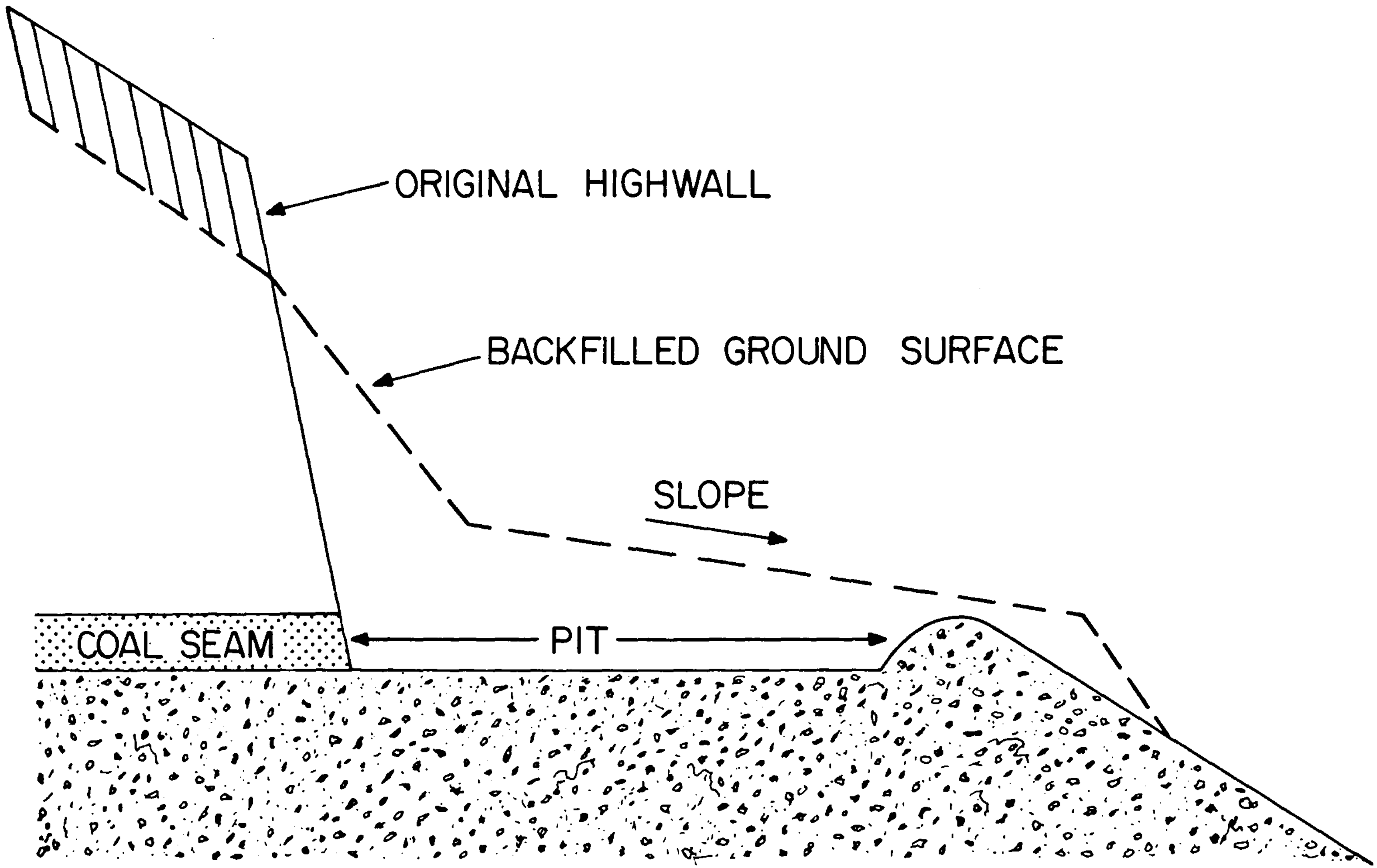


Fig. 9. Crossectional diagram of a backfilled ground surface, with a low, away from highwall slope.

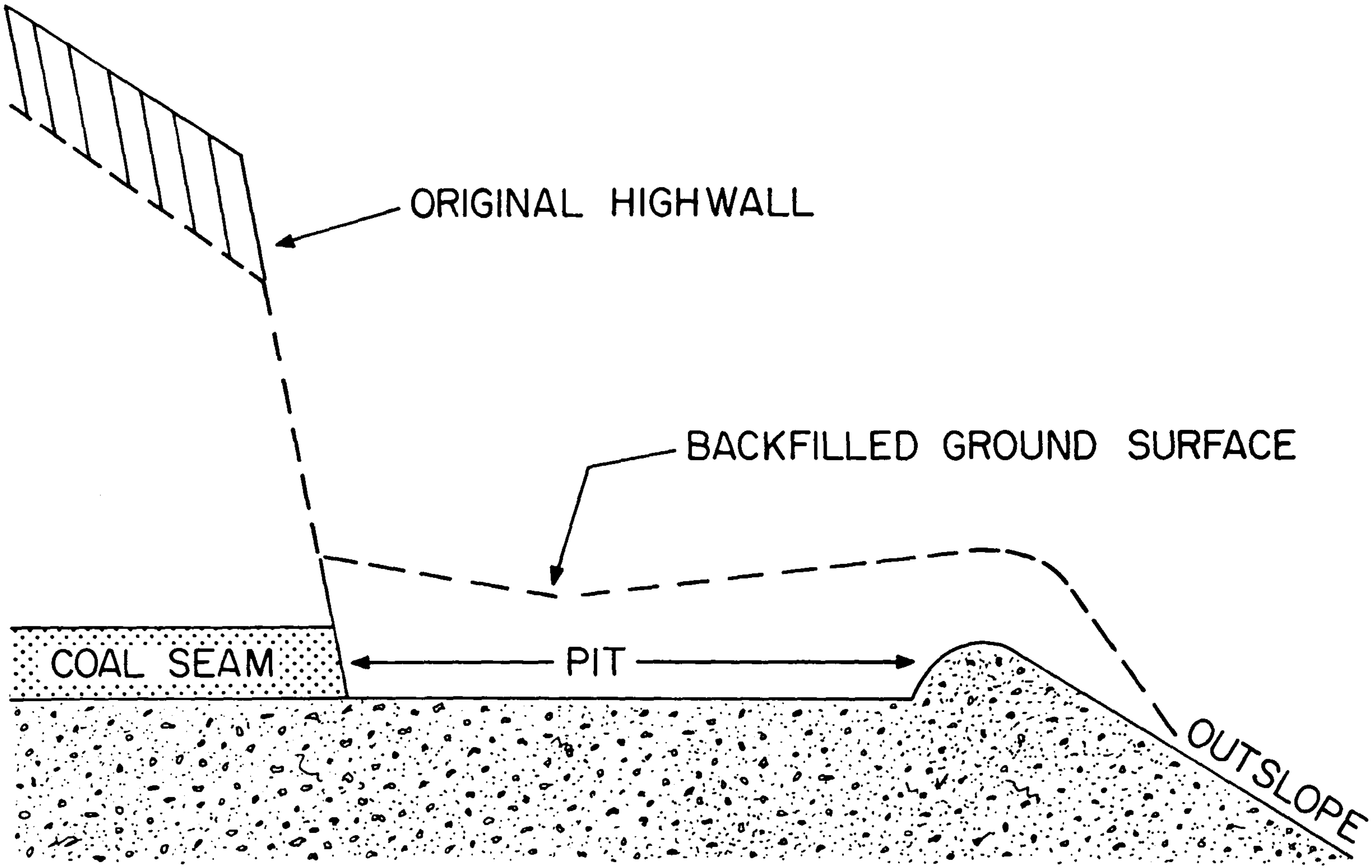


Fig. 10. Crossectional diagram of a backfilled ground surface, angled toward the highwall.

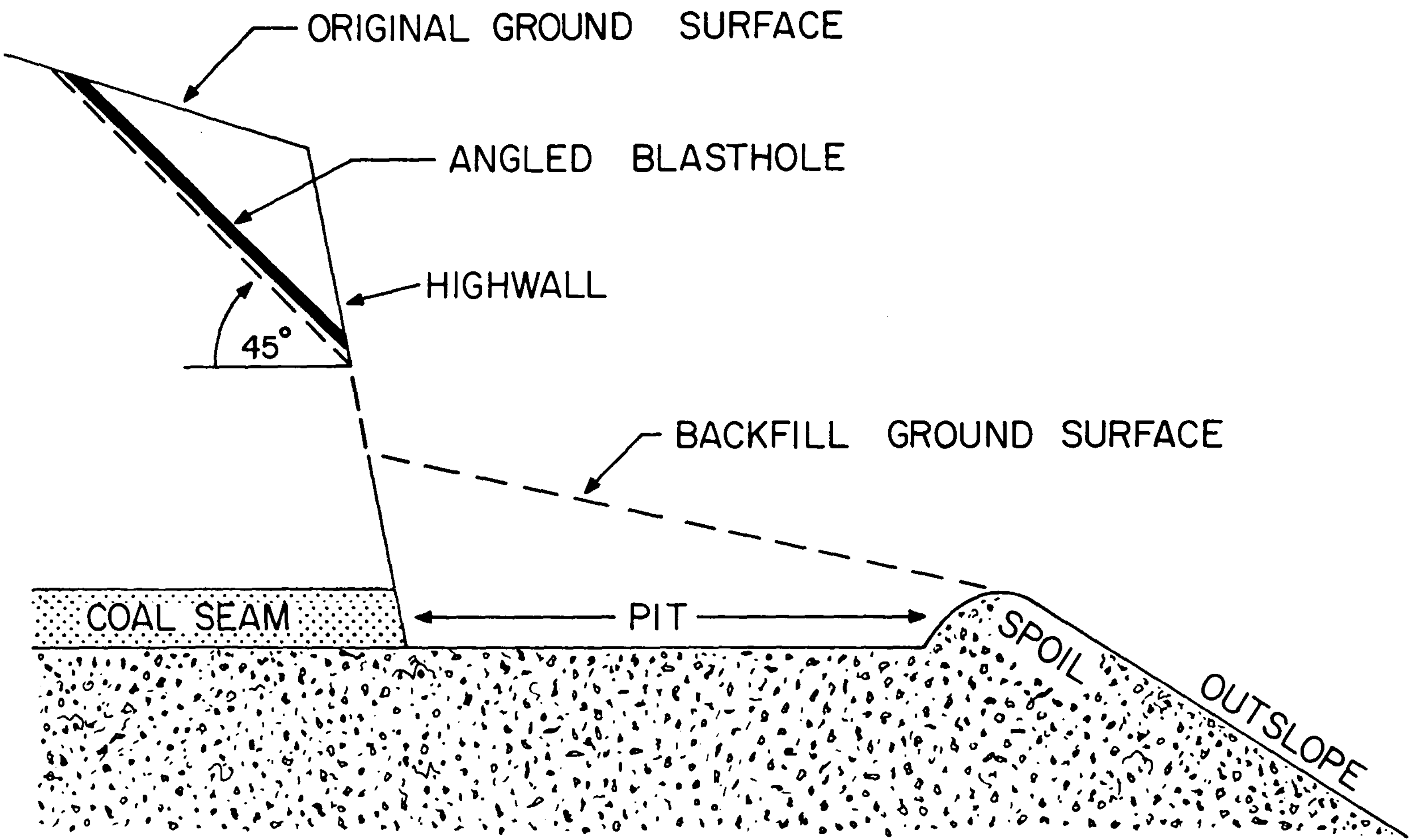


Fig. 11. Diagram of the utilization of a 45 degree, angled blasthole arrangement to reduce highwall height.

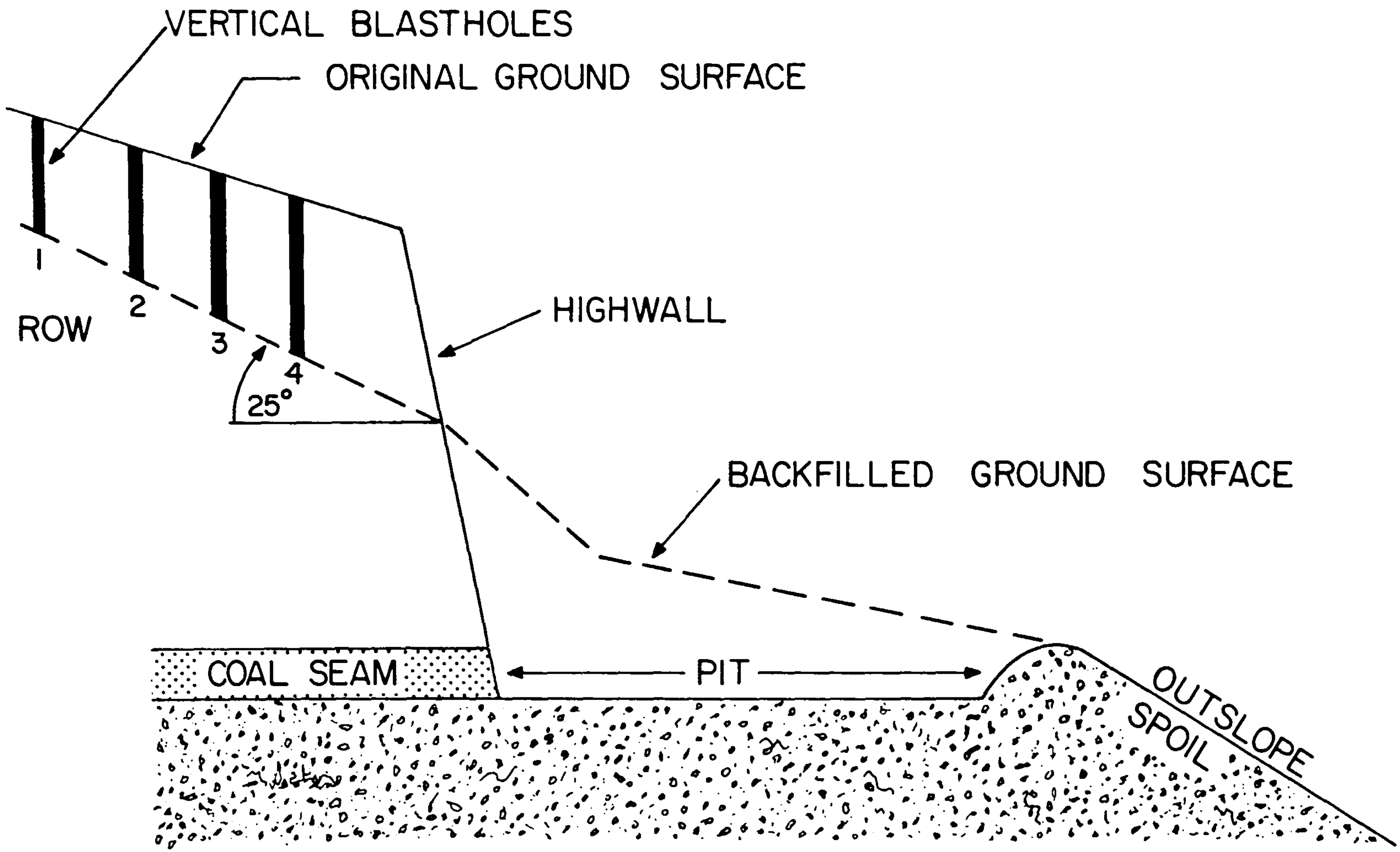


Fig. 12 . Diagram of the utilization of a series of vertical blastholes to reduce highwall height.

objectives.

By varying site characteristics the operation of the subprogram can be examined under different conditions, and the consistency of plant selection.

Tables 14 and 15 present the simulated site characteristics and the resultant suitability weight for each species under the simulated conditions. To eliminate any biasing effect on the weight due to different objective weights, each objective weight was maintained at the same level (e.g. all values were weighted at 2.0). By using this technique, each species was weighted soley for its site suitability.

Obviously as one increases or decreases the objective weights, the species' rankings will vary accordingly, nevertheless, for demonstration a brief set of results of this simulation are presented (Table 16).

Utilizing this subprogram, one can more efficiently recommend the species to be planted on a specific mine site. The investigator can determine the possible plant success due to the higher rank, and in a sense, predict the affects of the actions on site quality. Also by manipulating objective weights, species which meet specific needs are ranked accordingly. For example, if one desires good winter cover for wildlife, this objective could be weighted with a value of 10.0. In the suitability ranking, species such as white pine, Virginia pine, and spruces will receive higher weightings because they provide cover.

The higher the weight the better the species meets the stated objectives. Several species are presented in the listing because even though one plant may be ranked higher than another, nursery stock may

Table 14 . Suitability rankings of tree species for simulated sites.

Site characteristics and objectives	Site 1	Site 2	Site 3	Site 4
pH	6.0-6.5	3.5-4.0	4.0-4.5	5.5-6.0
shade	low shade	no shade	total shade	med. shade
parent material	mixed spoil	mixed spoil	mixed spoil	mixed spoil
moisture	wet	dry	dry-medium	medium-wet

Species	Site 1	Site 2	Site 3	Site 4
Northern Red Oak	.059	.063	.064	.065
Jack pine	.055	.058	.054	.060
Red pine	.061	.058	.059	.054
Pitch pine	.055	.058	.059	.054
Shortleaf pine	.061	.064	.054	.054
Longleaf pine	.055	.058	.065	.054
Virginia pine	.061	.058	.059	.054
Eastern white pine	.055	.058	.059	.060
Loblolly pine	.061	.058	.054	.060
Black cherry	.046	.043	.046	.040
Blackgum	.026	.028	.026	.032
American beech	.024	.032	.029	.024
Black birch	.026	.022	.020	.020
River birch	.026	.022	.020	.026

Table 14 . Continued.

Species	Site 1	Site 2	Site 3	Site 4
Quaking aspen	.019	.021	.031	.019
Eastern cottonwood	.018	.013	.018	.012
Sycamore	.021	.016	.014	.020
Sweetgum	.019	.014	.013	.019
Yellow poplar	.022	.017	.016	.016
Bald cypress	.023	.018	.017	.023
Eastern larch	.018	.013	.012	.012
Balsam fir	.026	.034	.026	.032
White spruce	.026	.028	.026	.032
Red maple	.022	.023	.021	.022
Eastern hemlock	.019	.027	.019	.019
Black locust	.015	.016	.026	.015
American basswood	.006	.007	.012	.006
American elm	.016	.017	.016	.022
Green ash	.015	.016	.014	.020
White ash	.014	.014	.019	.019
Black walnut	.016	.011	.010	.010
Sugar maple	.015	.016	.020	.020

Table 15. Suitability rankings of grass species for simulated sites.

Site characteristics and objectives	Site 1	Site 2	Site 3
pH	4.0-4.5	3.5-4.0	5.5-6.0
primary objective	wildlife	wildlife	soil prep. & erosion
lifespan	perennial	perennial	annual
planting season	March-April	March-April	April-June
legume	legume	legume	non-legume

Species	Site 1	Site 2	Site 3
Sericea lespedeza	.086	.086	.000
Flatpea	.086	.086	.040
Crownvetch	.086	.086	.000
Timothy	.057	.057	.040
Blackswell switchgrass	.057	.057	.040
Redtop	.057	.057	.040
Orchard grass	.057	.057	.040
Tall fescue	.057	.057	.040
Annual lespedeza	.057	.057	.040
White clover	.057	.057	.000
Sweet clover	.057	.057	.000
Red clover	.057	.057	.040
Alfalfa	.057	.089	.040

Table 15. Continued.

Species	Site 1	Site 2	Site 3
Wheat	.029	.029	.080
Soybean	.029	.029	.120
Grain sorghum	.029	.029	.120
Annual ryegrass	.029	.029	.120
Foxtail millet	.029	.029	.120
Weeping lovegrass	.029	.029	.080

Table 16. Influence of objective weights on species weightings, shown as an example of how manipulation will affect.

Site Characteristics		Objective Weights	
pH	5.5-6.0	9.0	2.0
shade	med. shade	5.0	10.0
moisture	medium-wet	3.0	3.0
parent material	mixed spoil	1.0	3.0
Wildlife Value			
Cover		2.0	1.0
Winter food		10.0	2.0
Spring food		1.0	8.0
Summer food		10.0	2.0
Fall food		1.0	2.0

Species	Rank 1	Rank 2
Northern red oak	.088	.075
Jack pine	.068	.064
Eastern white pine	.068	.064
Red pine	.062	.062
Pitch pine	.062	.062
Shortleaf pine	.062	.062
Loblolly pine	.064	.065
Virginia pine	.062	.062
Longleaf pine	.062	.062
Balsam fir	.022	.025
White spruce	.022	.025
Eastern hemlock	.014	.015
Eastern larch	.006	.012
Black cherry	.060	.039
Blackgum	.031	.029
American beech	.020	.025
Black locust	.010	.016
Black birch	.019	.020
River birch	.026	.022
Green ash	.020	.015
White ash	.017	.014
American elm	.014	.021
Quaking aspen	.018	.025
Baldcypress	.021	.020
Red maple	.020	.023
Sugar maple	.015	.016
American basswood	.003	.003
Eastern cottonwood	.006	.012
Yellow poplar	.011	.013

not be available, making a close second choice a reasonable option.

The information provided in the PLSPEC subprogram can be used in combination with the recommendations from Chapman (1977) and Flick (1977) in their songbird and small mammal investigations. Plant species may be selected from the weights which fit the needs of a species.

ERODES Subprogram

Each factor in the Universal Soil Loss Equation (therefore each site parameter) influences the resulting erosion rates for a unit. The RFACT and SOILOS parameters are climatological and edaphic factors which are not within the realm of manipulation. For this reason, in the simulation, these two factors were maintained at constant levels of 150 and 0.16 respectively. All other factors were altered independently to determine their affect on erosion rates, and to measure the intensity of this affect. This sensitivity analysis was performed to determine which factors were most critical to erosion rates, and therefore, should be the main emphasis of the reclamation decision. Each will be discussed separately.

Ground cover type; grass or forb

To analyze the affects of a grass or forb cover, all variables but these were kept constant. A slope length of 100 feet and angle of 25 percent were utilized in the equation. Canopy cover influence was eliminated by assuming no above-surface vegetation present in the simulation. A ground cover of 60 percent grass, and then forbs was used in the simulation (percent ground cover was assumed tohave only an intensity affect and this was not being investigated in this simulation).

Fig. 13 presents the results of this simulation of grass or forb cover influence on erosion rates for each of the 13 reclamation strategies discussed in the Methods and Procedures section. A forb cover significantly reduced erosion rates for the simulated unit, which indicates that a forb cover would provide greater initial protection against erosion.

Percent ground cover

All factors except percent ground cover were kept at the same level as in the previous simulation. A grass cover was arbitrarily chosen (the same patterns would result with a forb cover), and a 0 canopy cover percent was selected to eliminate the possible bias affect.

Fig. 14 presents the results of this simulation. As expected, as percent ground cover was increased, erosion rates decreased, with the affects being intensified as ground cover approached 100 percent.

Percent canopy cover; tall weeds, short brush (0.5 m fall ht.)

Percent ground cover was set at 0 for this simulation, with all other parameters set at the constant levels used in the previous simulations, and the percent canopy cover being varied from 25 to 75 percent. The results of this simulation (Fig. 15) show that as percent

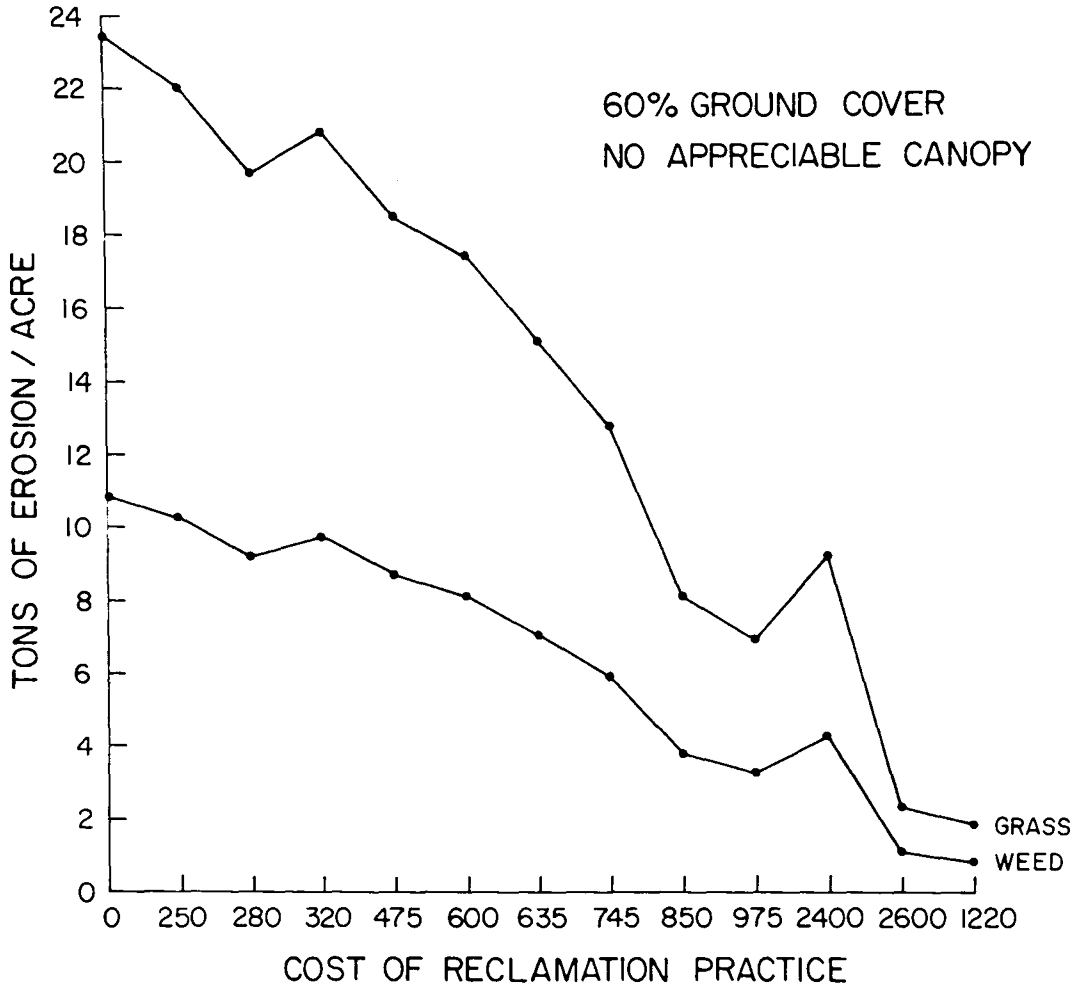


Fig. 13. Effect of a grass or forb ground cover(established at increasing costs(dollars) on erosion rates for a simulated site(cost points are based on practices in Table 3.).

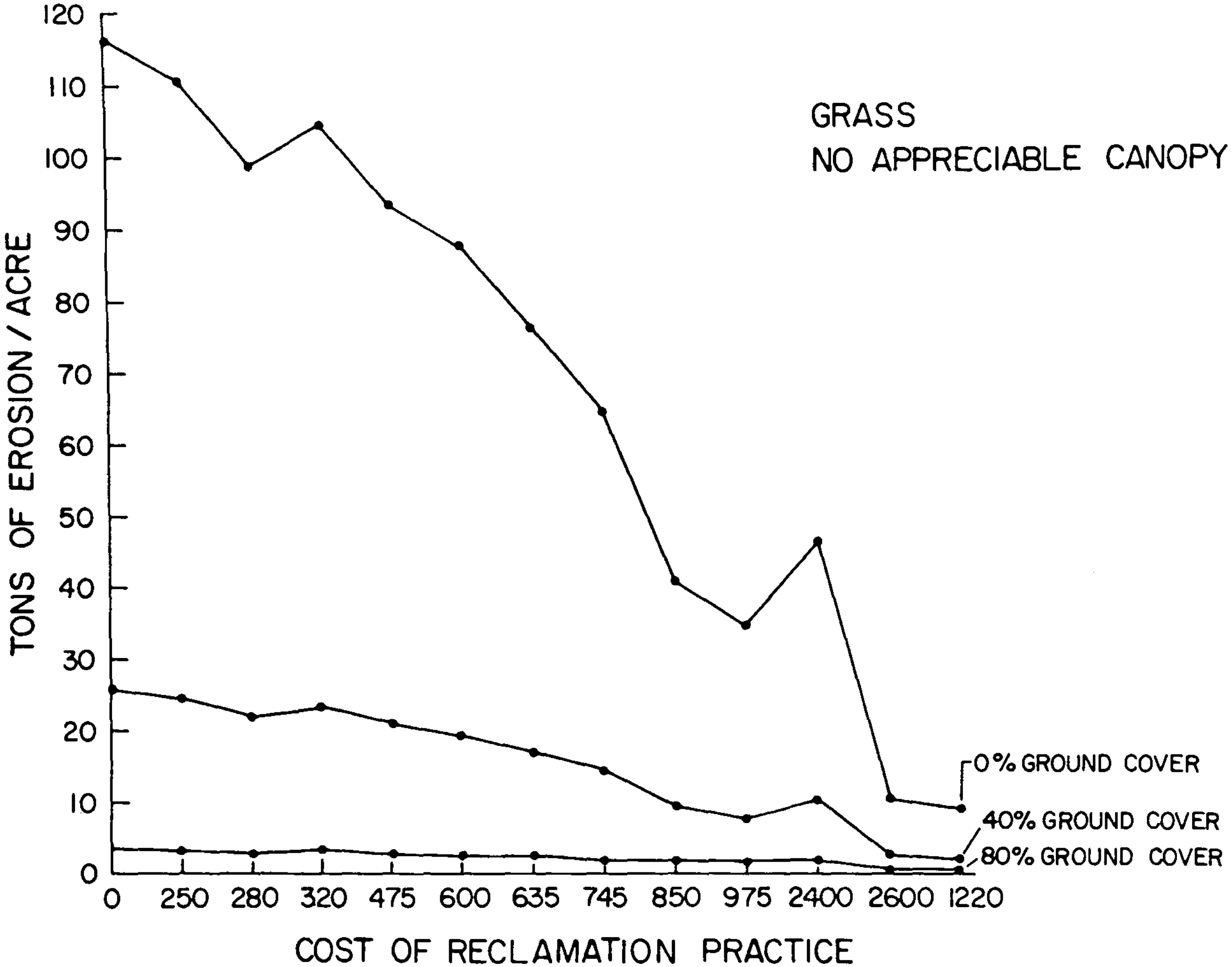


Fig. 14. Relative erosion rates (established at increasing costs (dollars)) for a simulated site with varying ground cover percentages(cost points are based on practices in Table 3.)

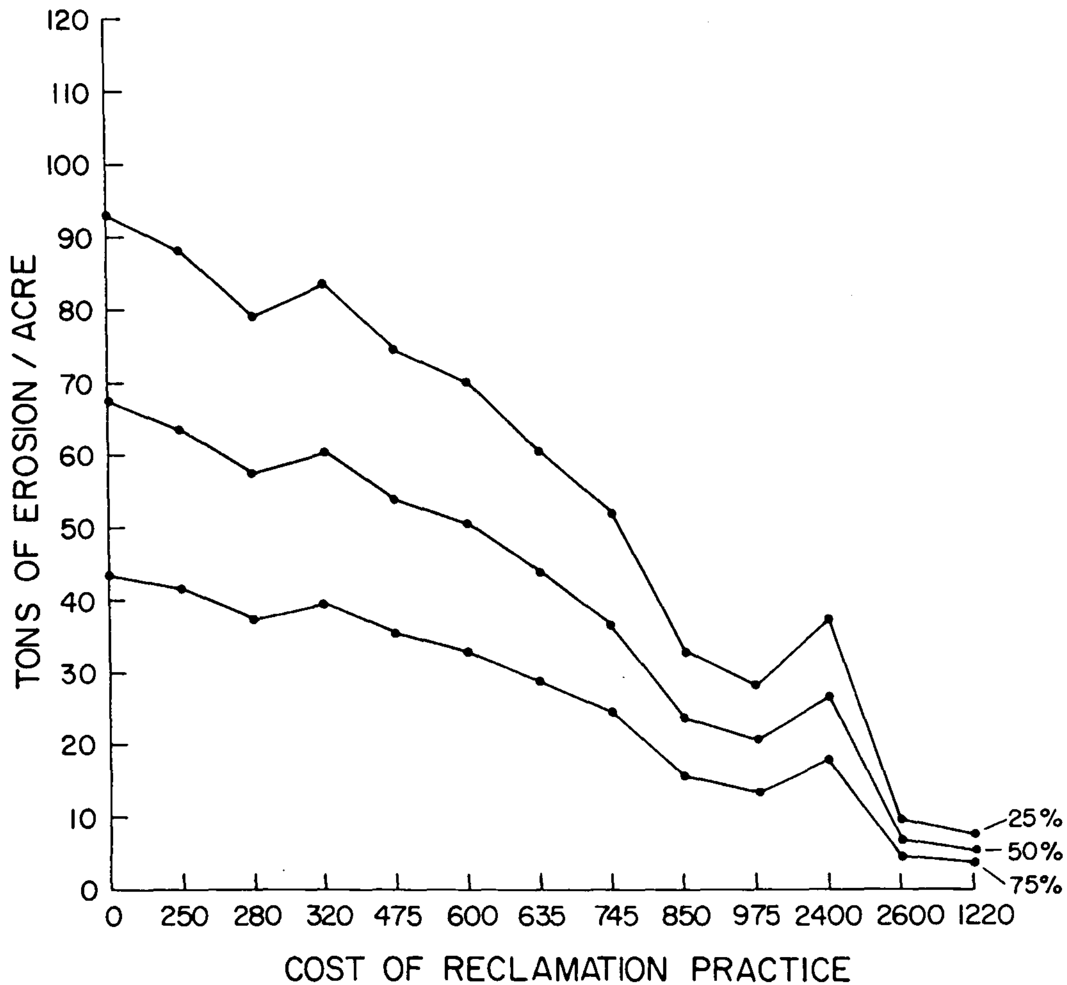


Fig. 15. Erosion rates (established at increasing costs(dollars) for a site with a canopy cover of tall weeds with 25,50, and 75 percent canopy cover (cost points are based on practices in Table 3).

canopy cover is increased the erosion rates decrease. The affect of increased canopy cover on erosion rates however, is not as intense as similar increases in percent ground cover.

Percent canopy cover; appreciable brush or bushes (2.0 m fall ht.)

Fig. 16 presents the results of this simulation. The patterns are generally the same as for tall weeds or brush but the volume of erosion was found to be higher. For example, with 0 reclamation (site as is) rates of 93 (25 percent cover), 67.5 (50 percent), and 43.5 (75 percent) tons/acre were estimated for a canopy of tall weeds as compared to rates of 103 (25 percent), 87.5 (50 percent), and 72 (75 percent) tons/acre for a cover of appreciable brush. With a tree cover with no appreciable brush the rates were still higher at 108.5 (25 percent), 100.6 (50 percent), and 93 (75 percent) tons/acre with 0 reclamation.

Percent canopy; trees, no appreciable brush (4.0 m fall ht.)

As evidenced from the previous two simulations, percent canopy cover has a strong influence on erosion rates, but the effect of a tree cover was not as pronounced as that of the two lower types. Fig. 17 shows the rates of erosion for each of the percentages.

Comparison of canopy cover types

Fig. 18 presents the results of a simulation of the three canopy cover types (tall weed, appreciable brush, a tree) with conditions of 0

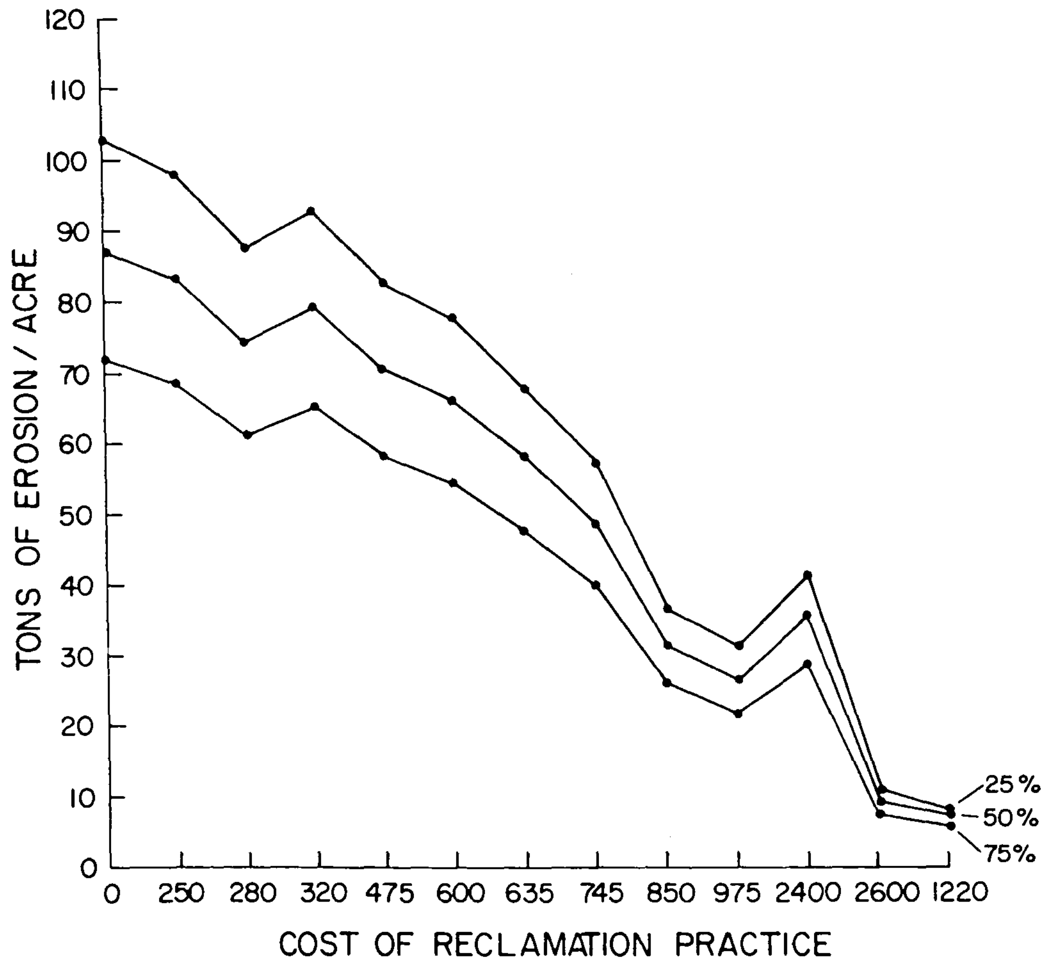


Fig. 16. Erosion rates(established at increasing costs(dollars) for a site with a canopy cover of brush or bushes with 25,50,and 75 percent canopy cover(cost points are based on practices in Table 3.)

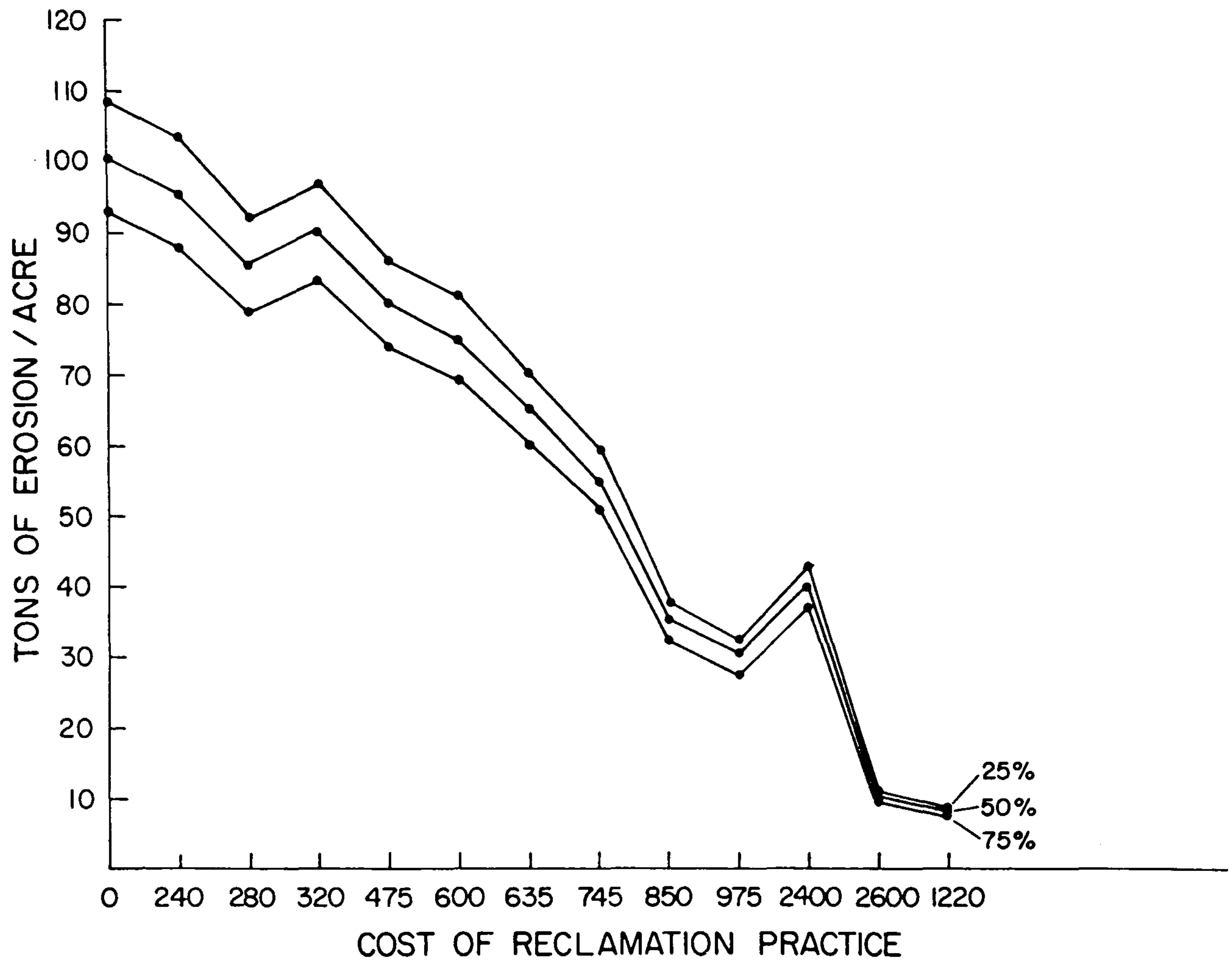


Fig. 17. Erosion rates(established at increasing costs(dollars) for a site with a canopy cover of trees with 25,50,and 75 percent canopy cover(cost points are based on practices in Table 3.

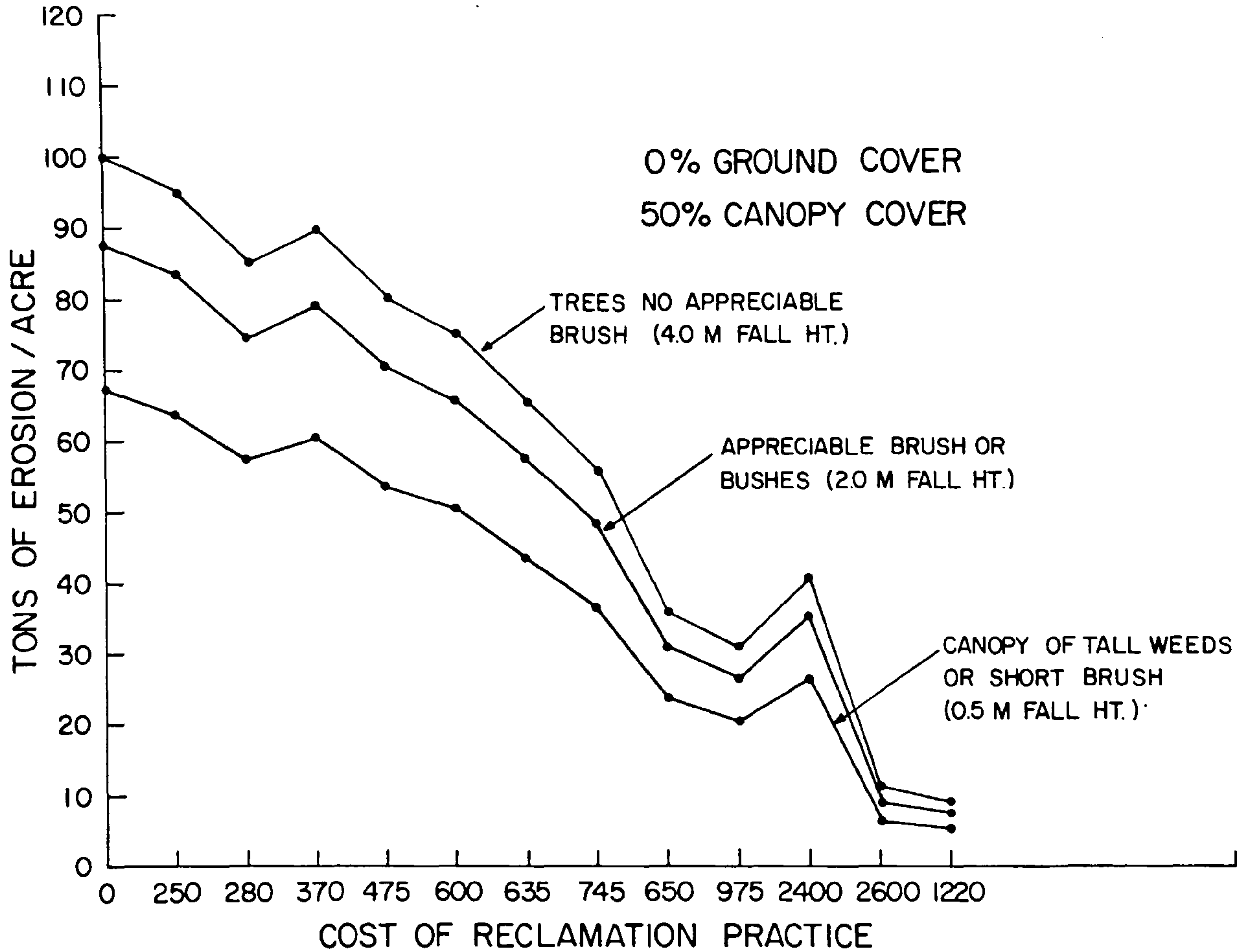


Fig. 18. Comparison of erosion rates(established at increasing costs (dollars) for a simulated site with 3 canopy cover types (cost points are based on practices in Table 3.).

ground cover and 50 percent canopy cover. The percent canopy cover as shown previously, will only affect the intensity of the erosion rates and not the actual rates due to canopy cover type.

The results of this simulation show that a canopy cover of just forbs is the most significant in reducing erosion rates, followed by appreciable brush or bushes, and finally tree cover.

Variations in erosion rates following changes in percent canopy for each type were greater for tall grass and bushes than for tree cover. This can be seen in Figs. 15, 16, and 17.

Affect of slope percent on erosion

The erosion rates increase as slope percent increase. A simulation was performed utilizing values of 0 reclamation, 40 percent ground cover, and 50 percent canopy cover. The ground and canopy cover rates, once again, only influence the intensity of the erosion rates. Slope percent is a major manipulation which can be linked to the operation of the HIWALL subprogram for a decision aid. Fig. 19 presents the results of this simulation.

Affect of slope length on erosion

Under the conditions utilized in the slope percent simulation, slope lengths were varied to determine the affect on erosion rates. As expected, as slope length increased, so increased erosion rates. This was due to the uninterrupted flow of surface water, which allows an intensity buildup, therefore a high scouring affect. Fig. 20

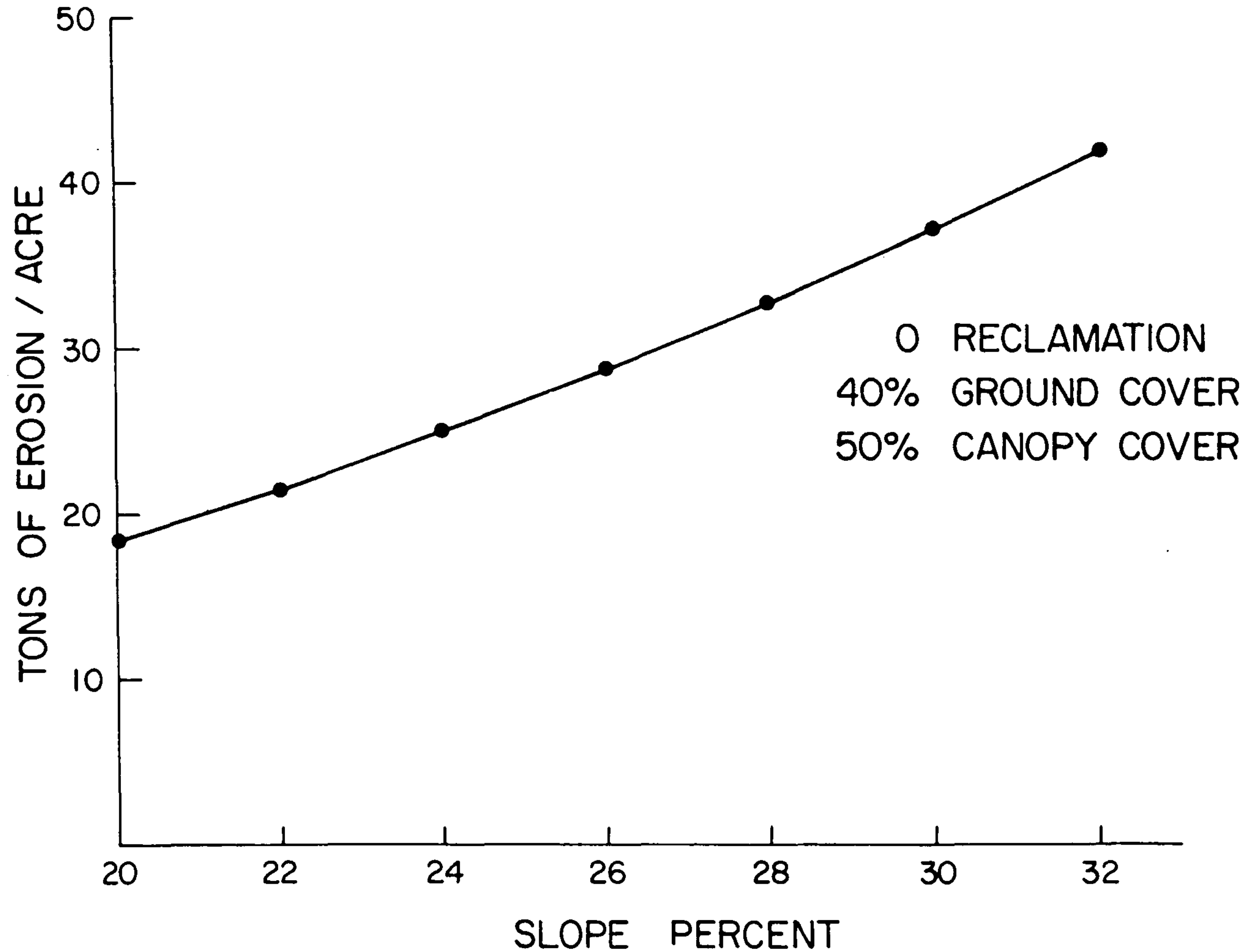


Fig. 19. Erosion rates resulting from changes in slope percent for a simulated site.

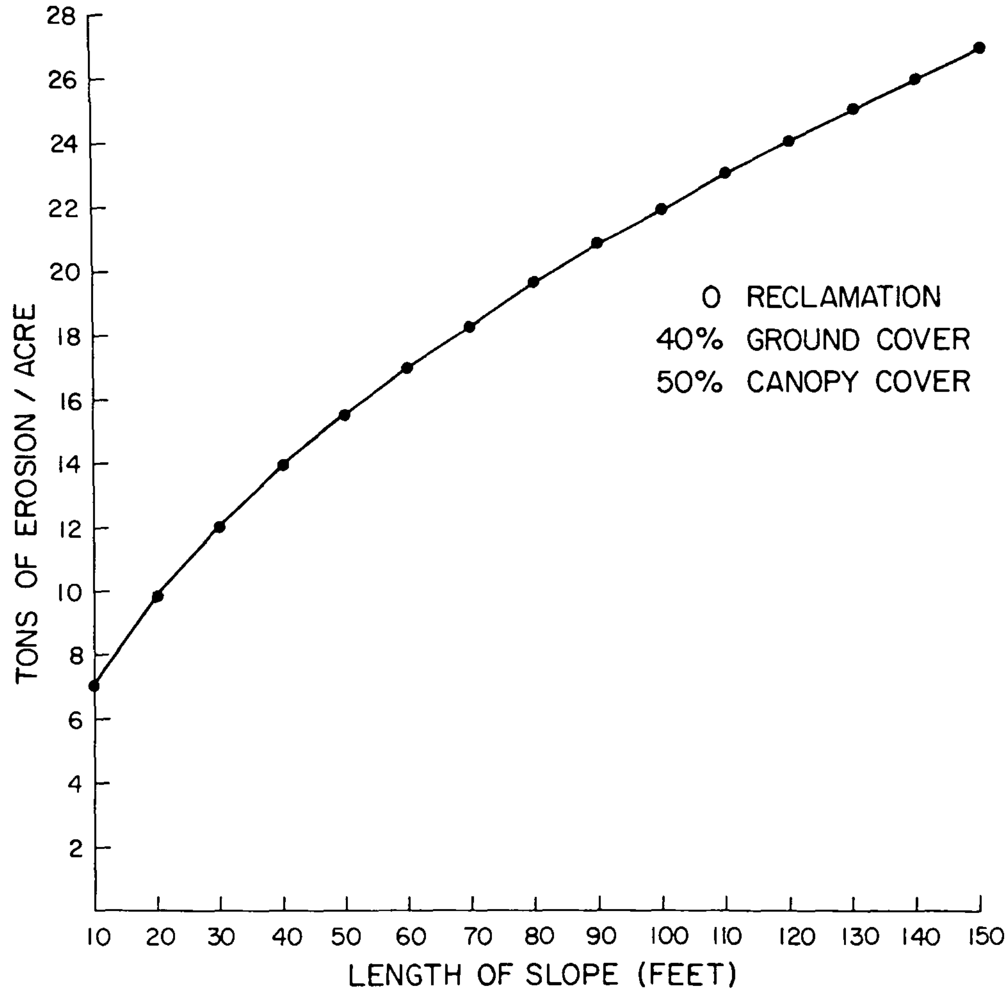


Fig. 20 . Influence of length of slope on relative erosion rates.

presents the results of this simulation.

The slope length factor can also be used in conjunction with the highwall subprogram to determine the possible consequences of each landform manipulation. The interaction of the slope length and percent factors will result in erosion patterns described in Fig. 21.

Utilization of PLSPEC Subprogram as a Decision Aid

Table 17 presents the various affects of the possible reclamation practices on erosion rates and allows for a cost/benefit ratio decision. The investigator can utilize a methodology such as this to allow for a proven and efficient objective decision system. The tons of reduced erosion/dollar/acre factor is important in evaluating the effectiveness of a particular reclamation strategy on this cost/benefit decision system.

WINBRK Subprogram

The result of this subprogram is a computer generated table of percent wind velocity values for distances in front of and behind a wind structure.

Figs. 22, 23, and 24 present expected wind velocity patterns for barriers of 6 feet in height, and 13 structural types. The physical affects of barrier placement on wind flow and climatological factors is presented in Figs. 25 and 26.

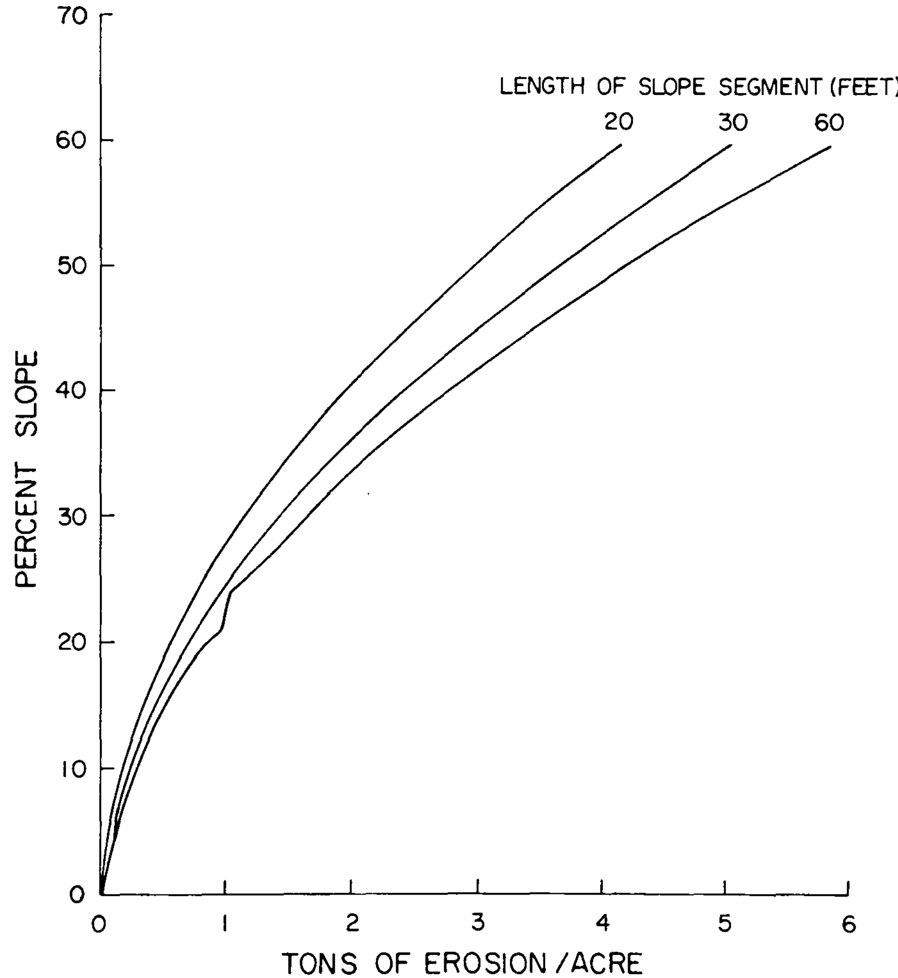


Fig. 21 . Relative erosion rates resulting from combinations of slope segment length and slope percent.

Table 17 . Effectiveness of twelve reclamation practices on a simulated site with 60 percent ground cover, no canopy, slope length=100 feet, and slope percent=25. Relative rates will apply for other sites.

Cost of reclamation (dollars)	Tons of erosion/acre	Tons of reduced erosion/dollar/acre	Percent reduction
0	23.45	0	0.0
250	22.1	0.0054	6.0
280	19.7	0.0134	16.0
350	20.9	0.0073	11.0
475	18.6	0.0102	21.0
600	17.5	0.0099	25.0
635	15.1	0.0131	36.0
745	12.8	0.0143	45.0
650	8.1	0.0236	65.0
975	7.0	0.0169	70.0
2400	9.3	0.0059	60.0
2600	2.3	0.0081	90.0
1220	1.9	0.0177	92.0

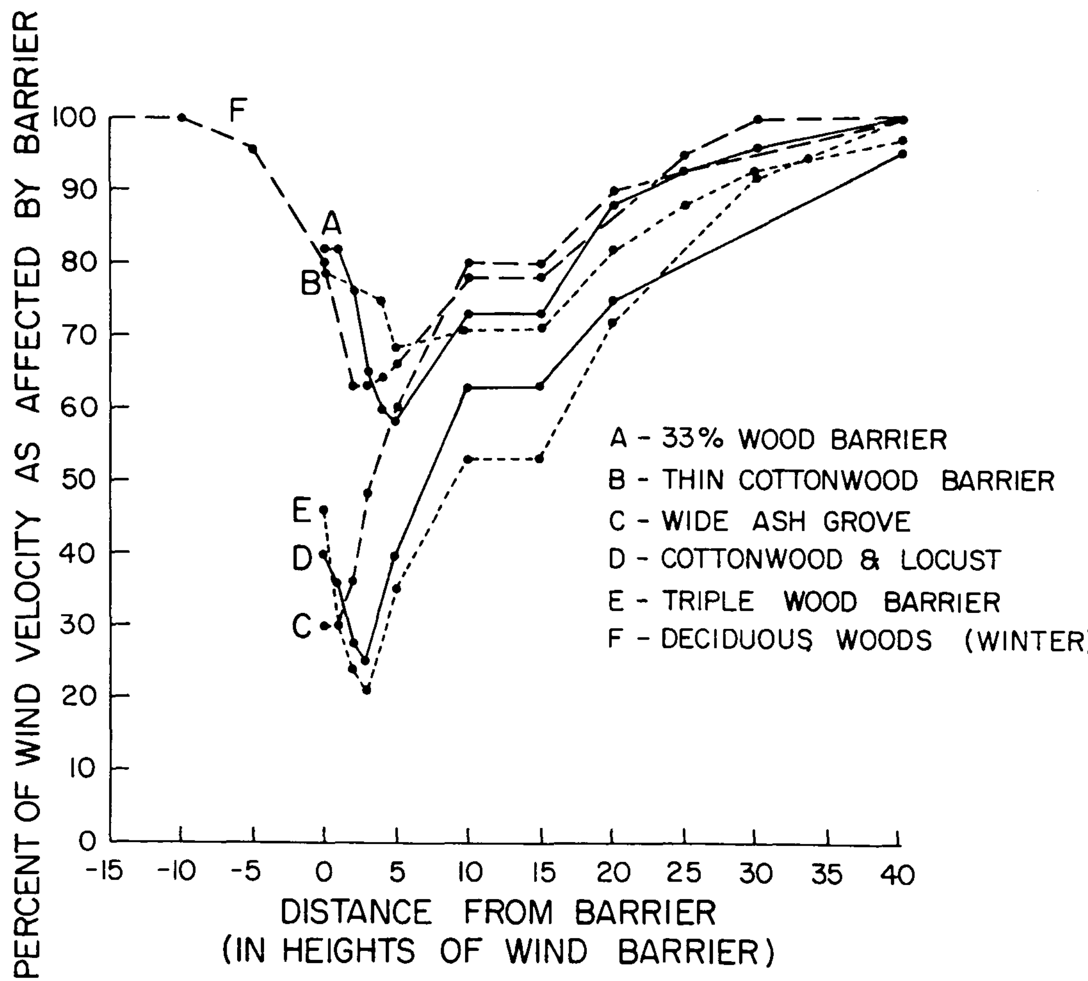


Fig. 22 . Percent wind velocities as affected by six barrier structures at various distances.

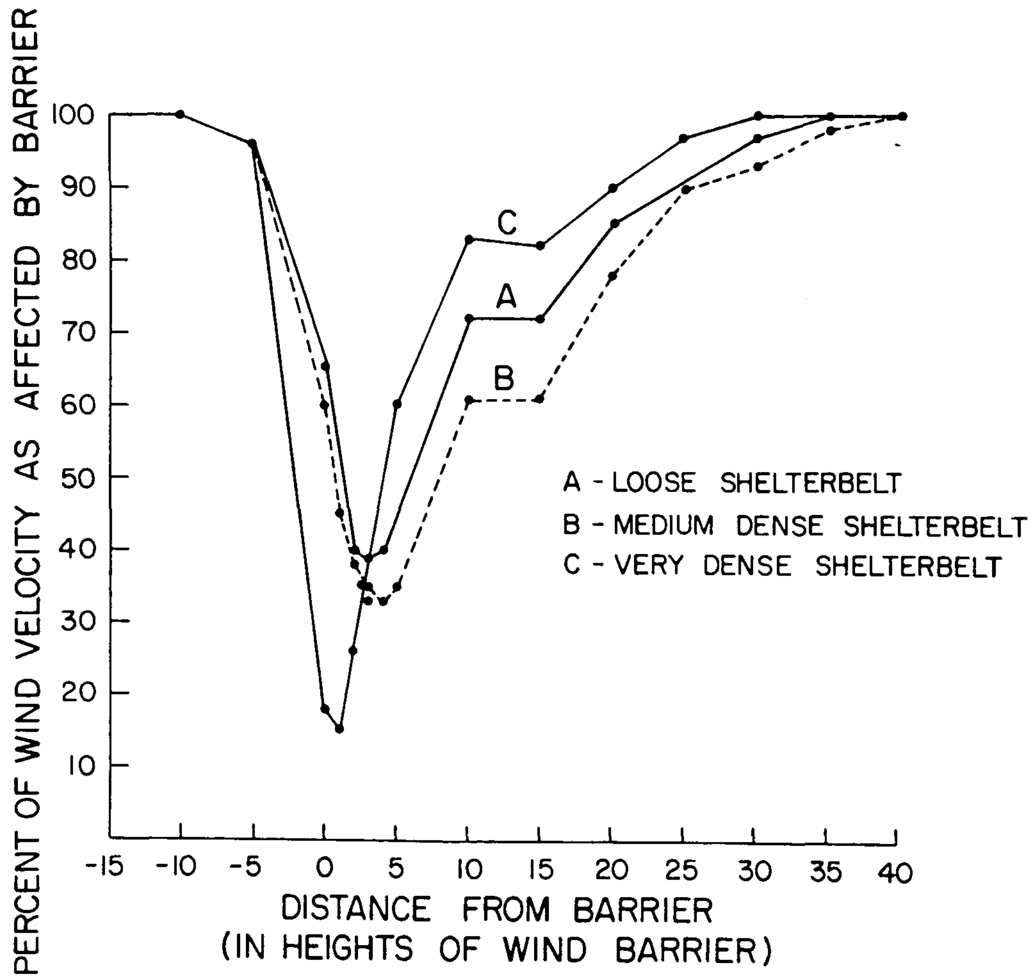


Fig. 23 . Percent wind velocities as affected by three barrier structures at various distances.

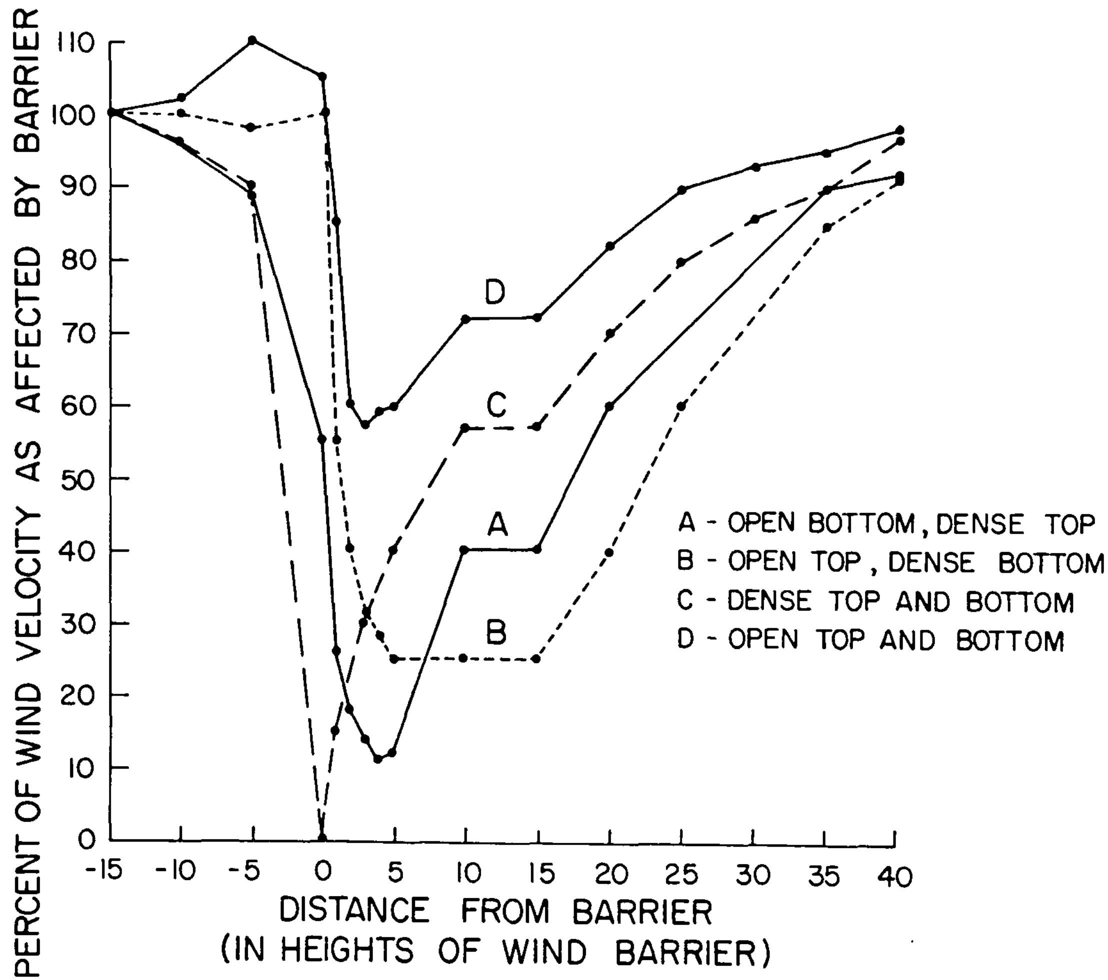
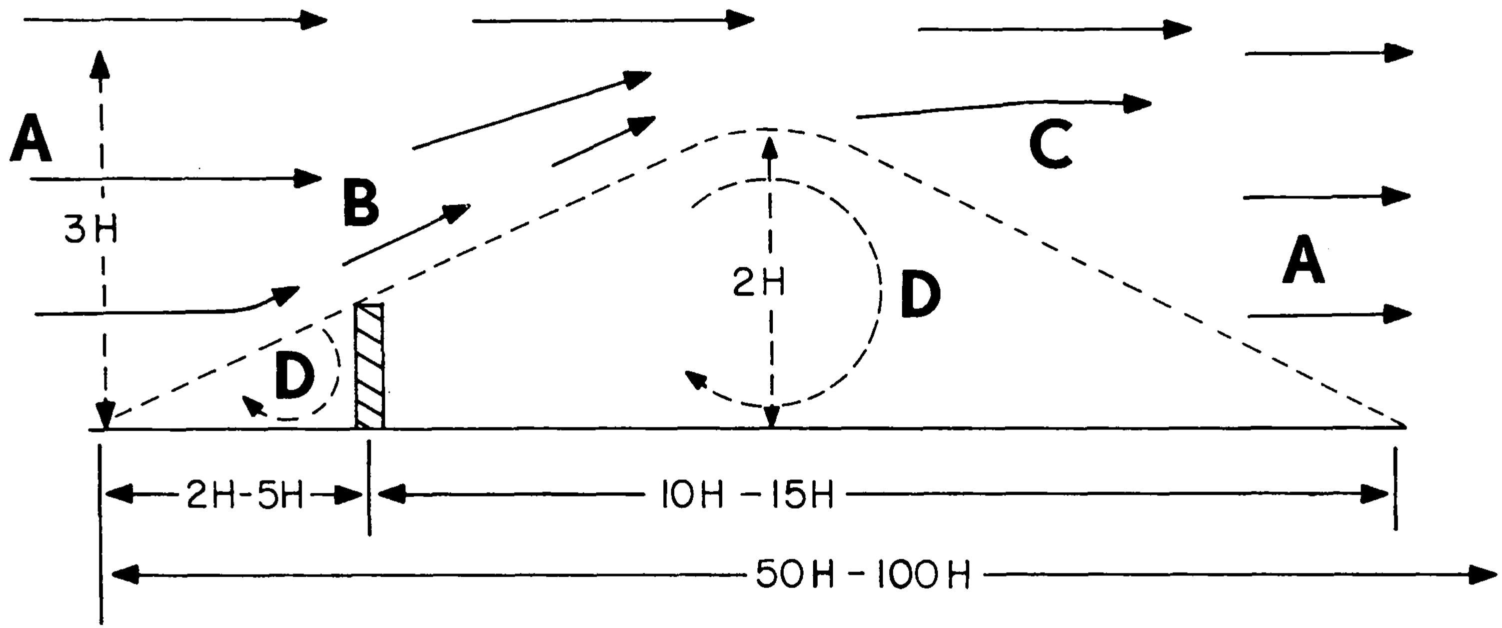


Fig. 24 . Percent wind velocities as affected by four barrier structures at various distances.



A UNDISTURBED FLOW

B SURFACE SEPARATION

C TURBULENT FLOW

D EDDYING FLOW

Fig. 25 . Wind flow patterns as influenced by wind barrier placement.

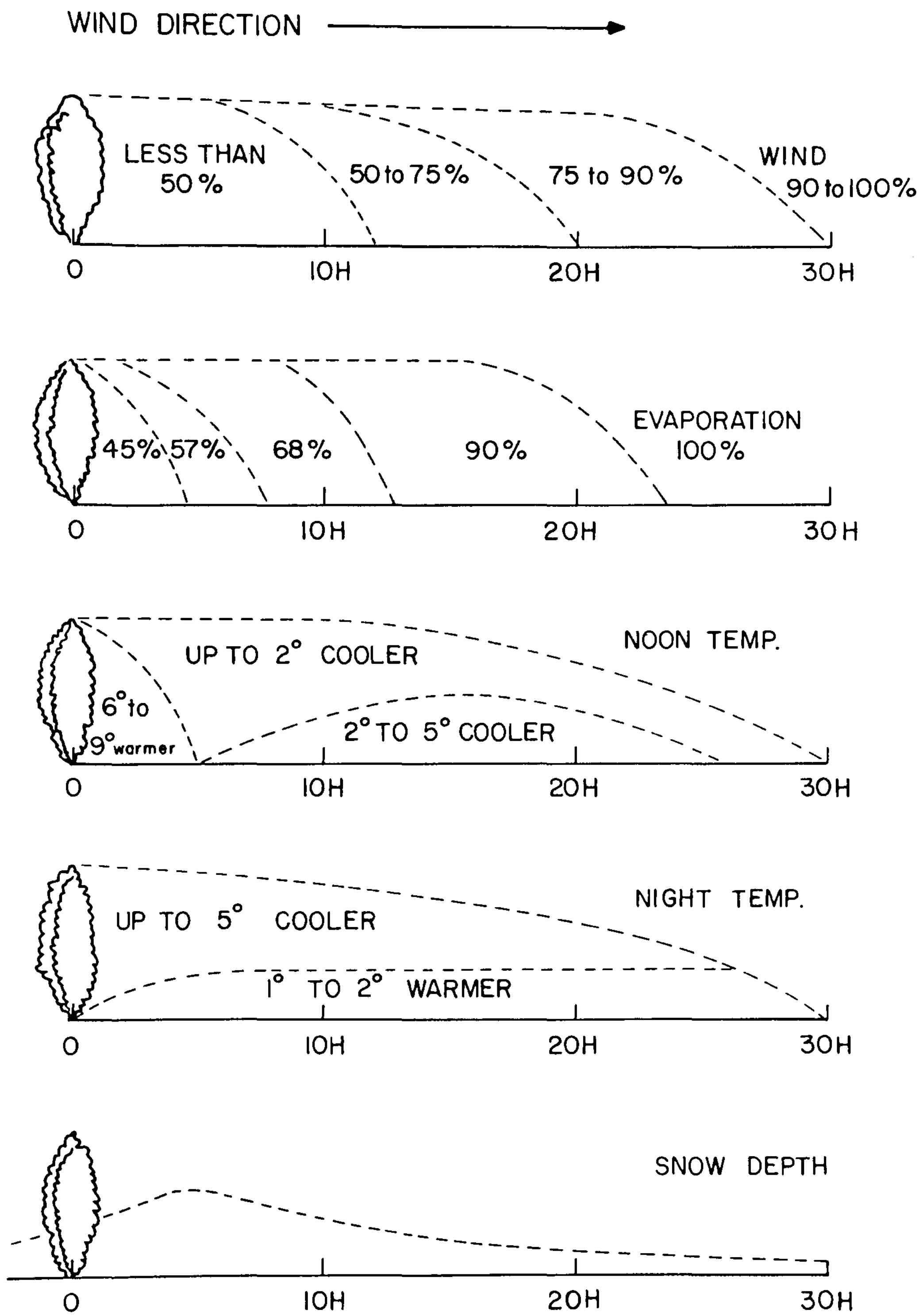


Fig. 26. Schematic drawing of the influence of a wind barrier on 6 climatological factors.

DISCUSSION

As a decision is made to redisturb an abandoned surface mine area, optimization must be a prime objective. Constraints and objectives must be determined prior to decision making, and must be adhered to in the reclamation practice.

A good vegetative cover may already exist on the abandoned surface mine area and the adverse impacts which are present after mining (e.g. erosion, acid runoff) may be lessened with ecosystem development. To decide to reclaim an area, one must determine if the practice will produce significantly greater benefits over a period than no reclamation practice. After redisturbance erosion rates will increase for a short time and the vegetative cover may be reduced. With ecosystem development after reclamation, benefits will increase with time, hopefully to a level which would be greater than the benefits accrued if the site were unreclaimed.

Fig. 27 presents a hypothetical graph of ecosystem development on an unreclaimed mine, and ecosystem development as would possibly be achieved with reclamation. The rate and degree of ecosystem development are estimates. To meet the objectives of reclamation it must be determined if benefits will be sufficient to meet the costs, in dollars, and impacts of redisturbance.

HIWALL Subprogram

By utilizing the results of this subprogram, one can make more efficient and objective decisions. Cost/benefit ratios may be determined,

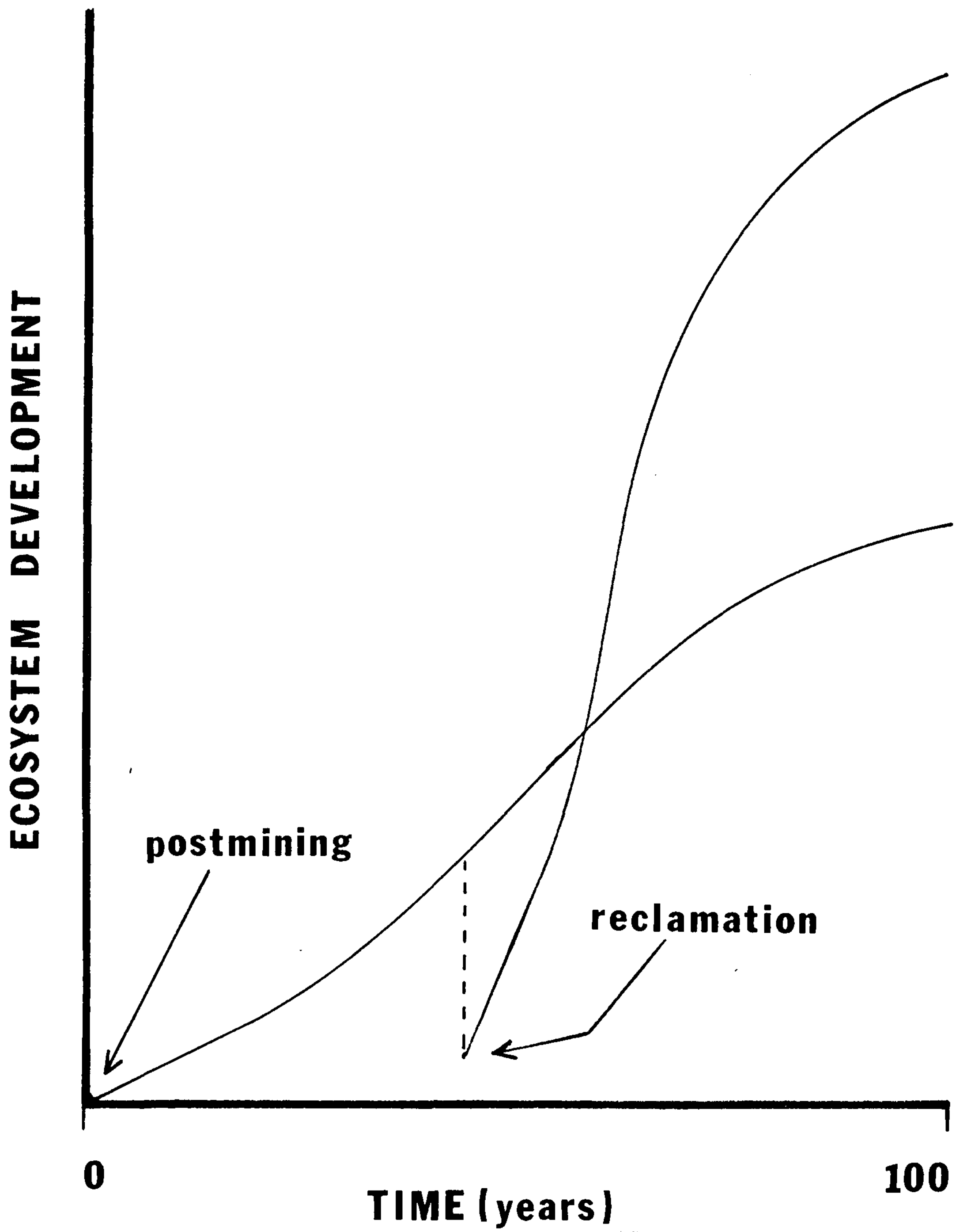


Fig. 27 . Hypothetical graph of ecosystem development on a site if reclaimed or left to develop by natural revegetation.

as well as the results of a myriad of land manipulations.

Once objectives are stated, such as to reduce highwall height, or to reduce the final slope, the costs and results of decisions can be evaluated. As the highwall height is reduced, the costs of earth-movement increase. The benefits from highwall reduction must be weighted against the costs.

By using the erosion control subprogram (ERODES) the rates of erosion for each land manipulation can be estimated. Therefore the costs of earth-movement can be weighed against the benefits of reduced erosion to provide a decision base. With reduced slope, plant establishment success is increased.

A slope of 25 percent has been found to be more beneficial to plant establishment than a slope of 33 percent. With information available at present it is not known to what degree it is more efficient, but as information becomes available, the subprogram decision base can be greatly enhanced.

PLSPEC Subprogram

As available information about the silvical requirements of plant species increases, so may increase the utility and application of this subprogram. More research is needed to determine the exact tolerance ranges of species under different site conditions and the reactions of these species to stress conditions. The productivity of species outside of their natural ranges should be investigated to determine wildlife food production and potential ecosystem development.

The plant selection subprogram is a method to determine the suitability of plant species (trees, shrubs, grasses) to a site and the success of each species to achieve the specified objectives. At present, the model operates as an example of what can be done with the information that is available and as an insight to the increased utility of the program as information becomes more accurate and more available.

The utility of this model lies in its flexibility as discussed in the Methods and Procedures section. Objectives and objective weights can be easily manipulated to fit reclamation needs. Site suitability factors can be added or improved upon as they are required.

Factors which should be included in this model but were not due to incompleteness or unavailability of information include aspect, position on slope, season of fruit production, percent ground or canopy cover at specific stages of development, and the availability of species as nursery stock. The addition of such information will greatly increase the utility of the subprogram.

ERODES Subprogram

Many factors influence erosion rates on a surface mine site. If these factors can be manipulated, erosion rates can be reduced. By simulating site conditions and performing sensitivity analyses upon parameters which were varied to extreme levels, the relative influence of individual parameters on erosion rates can be determined.

It was determined by simulation that with conditions of equal cover, a forb ground cover reduced erosion to a greater extent than a grass cover. Utilizing this information a decision could be made to design a reclamation practice which promotes a cover of forbs to reduce initial erosion rates.

Reduced erosion rates, as expected, results from increasing the percent ground cover. The results of this analysis can be applied as a model of ecosystem development on an abandoned surface mine. As time-since-disturbance increases, ground cover increases, and reduced erosion rates result. If the rate of ground cover increase could be determined, a simulation could be designed to measure efficiently the result of a practice over time.

By varying canopy types it was found that the lower, brushy type cover resulted in a more pronounced reduction of erosion than was found with an equal cover of shrubs or trees. The percent canopy cover for each type also resulted in corresponding erosion rates. Combinations of canopy and ground cover types and percents were not simulated, although the results would be expected to follow intuitively.

As slope length was reduced in the analysis, erosion rates also dropped. This information confirms the need for reclamation practices on long, uninterrupted slopes, such as terracing. By breaking up the overland flow of surface water by terraces, the resultant erosion rates are likewise reduced. The cost of building terraces can be evaluated as part of a cost/benefit ratio, with reduced erosion as a benefit. This information can be used as one part of a decision aid.

Similarly the percent slope of a site, as discussed previously, greatly affects erosion rates. By reducing slopes, as in the HIWALL subprogram, one can measure the costs and probable benefits (erosion rates).

The erosion rates are estimated by describing 12 erosion control practices as discussed in the Methods and Procedures section. Each practice has associated costs and success rates for reduced erosion. This can be utilized to determine what will result from the use of a specific strategy and provide a cost/benefit ratio as a decision aid. One may evaluate other practices by comparing the practice with the 12 listed in the table and determining what costs and erosion control value to use.

SUMMARY

A computer-based decision system was developed to provide a methodology to evaluate the possible results of reclamation decisions and to provide an objective base for decision making. By providing insights to the reclamation of surface mine units, one can estimate the costs and resultant benefits from a decision. Utilizing a cost/benefit ratio the decision maker can obtain an objective and quantitative base for his decisions.

The surface mine system is comprised of a group of interacting subsystems. The complexity of this system can best be examined and evaluated by utilizing a large data manipulation system. For this reason this model, and Saunders (1977) WATFLOW model, provide more optimal procedures to achieve the objectives of decision making.

Intensive validation of a model of this type is outside the realm of the total investigation. Simulations and sensitivity analyses were performed to observe parameter response and output changes due to land manipulations.

The model exhibits characteristics which would be expected in the surface mine system. For this reason the model can be expected to augment decision making for surface mine reclamation.

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Appendix Table I. Scientific names of plant species referenced in the text.

Common name	Scientific name
Trees	
Loblolly pine	Pinus taeda
Eastern white pine	Pinus strobus
Virginia pine	Pinus virginiana
Eastern hemlock	Tsuga canadensis
Red maple	Acer rubrum
Longleaf pine	Pinus palustris
Shortleaf pine	Pinus echinata
Pitch pine	Pinus rigida
Red pine	Pinus resinosa
Jack pine	Pinus banksiana
White spruce	Picea glauca
Balsam fir	Abies balsamea
Eastern larch	Larix laricina
Northern red oak	Quercus rubra
Baldcypress	Taxodium distichum
Sugar maple	Acer saccharum
Black walnut	Juglans nigra
Yellow poplar	Liriodendron tulipifera
Sweetgum	Liquidamber styraciflua
Sycamore	Platanus occidentalis
Eastern cottonwood	Populus deltoides
Quaking aspen	Populus tremuloides
White ash	Fraxiuus americana
Green ash	Fraxinus pennsylvania
American elm	Ulmus americana
American basswood	Tilia americana

Appendix Table I. Continued.

Common name	Scientific name
Black cherry	*Prunus serotina*
River birch	*Betula lenta*
Black birch	*Betula nigra*
American beech	*Fagus sylvatica*
Blackgum	*Nyssa sylvatica*
Black locust	*Robinia pseudoacacia*
Shrubs	
Flowering dogwood	*Cornus florida*
Blackhaw	*Viburnum prunifolium*
Shining sumac	*Rhus copallina*
European speckled alder	*Alnus rugosa*
Silky dogwood	*Cornus amomum*
Multiflora rose	*Rosa multiflora*
Smilax spp.	*Smilax* spp.
Japanese honeysuckle	*Lonicera japonica*
Tatarian honeysuckle	*Lonicera tatarica*
Amur honeysuckle	*Lonicera maacki*
Fragrant sumac	*Rhus aromatica*
Amur privet	*Ligustrum amurense*
Gray dogwood	*Cornus racemosa*
Lowbush blueberry	*Vaccinium angustifolium*
Grasses	
Alfalfa	*Medicago sativa*
Red clover	*Trifolium pratense*
White clover	*Trifolium repens*
Sweet clover	*Melilotus alba*

Appendix Table I. Continued.

Common name	Scientific name
Crownvetch	Coronilla varia
Flatpea	Lathyrus sylvestris
Sericea lespedeza	Lespedeza cuneata
Annual lespedeza	Lespedeza striata
Tall Fescue	Festuca arundinacea
Weeping lovegrass	Eragrostis curvula
Foxtail millet	Setaria italica
Orchard grass	Dactylis glomerata
Redtop	Agrostis alba
Annual ryegrass	Lolium tremulentum
Blackwell switchgrass	Panicum virgatum
Grain sorghum	Sorghum vulgare
Wheat	Triticum aestivum
Timothy	Phleum pratense

APPENDIX TABLE II. Main program and subprogram listings.

```
C*************************************************************************
C*************************************************************************
C*
C*
C*                ******* MAIN DRIVE PROGRAM *******                     *
C*
C*
C*************************************************************************
C*************************************************************************
C*        THIS IS THE MAIN DRIVING PROGRAM WHICH CALLS THE APPROPRIATE
C*        SUBROUTINES IN THE PROPER SEQUENCE.  THE RESULTS OF THIS ARE PRINTED
C*        IN TABULAR OR TEXT FORMAT.  EACH SUBPROGRAM CAN OPERATE INDEPENDENTLY
C*        OF THE MAIN PROGRAM AND CAN BE UTILIZED IN THE SOLUTION OF OTHER
C*        PROBLEMS.  EACH SUBPROGRAM HAS ITS OWN DOCUMENTATION ACCOMPANYING THE
C*        PROGRAM LISTING.  THIS MAIN DRIVE PROGRAM IS DESIGNED TO ACHIEVE
C*        ONE OBJECTIVE OF PROVIDING AN EXAMPLE OF A DECISION AID SYSTEM FOR THE
C*        RECLAMATION OF ABANDONED SURFACE MINES.
C*
C*
C*
      COMMON PH
      READ AXT
      CALL SITTXT
      CALL SITVAL
      CALL AREA
      IF(AXT.NE.HWAL) GO TO 1069
      CALL HIWALL
      CALL ERODES(ENSLOP,CTLNTH,FLANG,FLNTH)
      GO TO 1070
1069  CONTINUE
1070  CONTINUE
      CALL LIMTXT
```

```
CALL LIME
CALL FERTXT
CALL FERT
CALL WINBRK
CALL TERARE
CALL PLSPEC
CALL SHRBSP
CALL GRASSP
RETURN
END
```

```
      SUBROUTINE FERT
C*
C*
C*******************************************************************************
C*
C*
C*        THIS SUBPROGRAM COMPUTES THE POUNDS/ACRE OF PHOSPHOROUS, POTASH, AND
C*        NITROGEN REQUIRED TO RAISE THE PRODUCTIVITY OF A SITE.  DATA IS
C*        COLLECTED FROM A SOIL SAMPLE, CLASSIFYING THE RELATIVE ABUNDANCE OF
C*        EACH NUTRIENT PRESENT.
C*
C*
C*******************************************************************************
C*
C*
      READ, PHOS
      READ, POTASH
      IF(PHOS.EQ.1) PHOS=120
      IF(PHOS.EQ.2) PHOS=60
      IF(PHOS.EQ.3) PHOS=0
      IF(POTASH.EQ.1) POTASH=120
      IF(POTASH.EQ.2) POTASH=60
      IF(POTASH.EQ.3) POTASH=0
      NITRO=60
      WRITE(6,1000)
      WRITE(6,1001) PHOS,POTASH,NITRO
1000  FORMAT(/T10,'FERTILIZER RECOMMENDATIONS')
1001  FORMAT(/T10,'PHOSPHOROUS',T25,F4.0,T30,'POTASH',5X,F4.0,T50,'NITRO
     $GEN',5X,I3)
      RETURN
      END
```

```
      SUBROUTINE LIME
C*
C*
C**************************************************************************
C*
C*
C*        THIS SUBPROGRAM COMPUTES THE TONS OF LIME/ACRE REQUIRED TO RAISE THE
C*        PH OF A SITE TO A DESIRED LEVEL.  THE ORIGINAL PH OF THE SITE IS
C*        MEASURED AS AN INPUT PARAMETER.
C*
C*
C**************************************************************************
C*
C*
      READ, PH
      REAL NUMPH
      REAL TONS(6,3)/7.,6.,2.5,1.5,0.,0.,9.,6.,4.,2.5,1.5,0.,11.,8.,6.,4
     $.,2.5,1.5/
      NUMPH=(2*PH)-5
      WRITE(6,25)
      WRITE(6,30)
25    FORMAT(//T10,'TONS OF LIME NEEDED PER ACRE TO;')
30    FORMAT(/T46,'TONS/ACRE')
      WRITE(6,200)(TONS(NUMPH,I),I=1,3)
200   FORMAT(//T10,'STABILIZATION AND EROSION CONTROL',T50,F7.2,/T10,'TR
     $EES AND WILDLIFE PRODUCTION',T50,F7.2,/T10,'FORAGE PRODUCTION',T50
     $,F7.2)
      RETURN
      END
```

```
      SUBROUTINE HIWALL
C*
C*
C**************************************************************************
C*
C*
C*        THIS SUBPROGRAM COMPUTES THE VARIOUS LAND MANIPULATIONS WHICH CAN
C*        RESULT FROM HIGHWALL REDUCTIONS.  A SERIES OF REDUCTIONS ARE SIMULATED
C*        AND THE RESULTANT LAND CONFIGURATIONS ARE COMPUTED MATHEMATICALLY.
C*        A SERIES OF SLOPES ARE ACHIEVED WITH THE ASSOCIATED COSTS REQUIRED TO
C*        PRODUCE EACH.
C*
C*
C*
C**************************************************************************
C
C
C**************************************************************************
C
C         COST: COST OF EARTH MOVEMENT/CUBIC YARD
C         LENGTH: ALONG SLOPE LENGTH OF UNIT
C          SLUFF: AREA OF SLOUGH MATERIAL
C         HWANG: ANGLE OF HIGHWALL FROM BENCH
C         ORSLOP; ORIGINAL SLOPE
C         HTCUT: HEIGHT OF HIGHWALL
C         IPITWD: PIT WIDTH FROM HIGHWALL
C         ISWELL: SWELL PERCENT OF MOVED MATERIAL
C         IPTSLO: SLOPE OF PIT FILL
C         IHC: HEIGHT OF CUT FROM TOP OF HIGHWALL
C         FILHT: HEIGHT OF FILL MATERIAL AT HIGHWALL
C         FLAREA: AREA OF FILL MATERIAL
C         SLOP: ANGLE BETWEEN HIGHWALL AND ORIGINAL SLOPE
```

```
C         CTLNTH: LENGTH OF CUT FROM EDGE OF HIGHWALL
C         SLOPLN: LENGTH OF SLOPE AFTER CUT
C         CTANG: ANGLE OF CUT INTO HIGHWALL
C         HWHGT: FINAL HEIGHT OF HIGHWALL
C         ENSLOP: FINAL SLOPE ABOVE HIGHWALL
C         ABSLAR: SURFACE AREA OF DISTURBED LAND ABOVE HIGHWALL
C         FILNTH: LENGTH OF PIT SLOPE FROM EDGE OF BENCH TO HIGHWALL
C          AREBEN:SURFACE AREA OF FILL IN SQ. FEET
C         CULTAR: TOTAL SURFACE AREA OF DISTURBED LAND
C         CUBARE: AREA OF MATERIAL MOVED IN CU. YARDS
C          ACREDS:ACRES OF DISTURBED LAND
C         OUTDIS: LENGTH OF OUTSLOPE
C         MOVCOS: COST OF MOVING MATERIAL
C
C*************************************************************************
C
      COMMON IHC,CTANG,SLOP,CTLNT,HITWD,PI
      READ, COSTE
      READ, LENGTH
      READ, SLUFF
      READ, HWANG
      READ, HTCUT
      READ, ORSLOP
      READ, IPITWD
C
C
      ORSLOP=RAD(ORSLOP)
      P=HTCUT/20+.5
      Q=HTCUT/2.
      I=INT(P)
      J=INT(Q)
      PI= 4. * ATAN(1.)
```

```
C
C
      WRITE(6,22)
22    FORMAT('1')
      WRITE(6,20)
20    FORMAT(1H1,T6,'HEIGHT',T17,'CUT',T25,'CUT',T33,'HIGHWALL',T44,'FIN
     $AL',T55,'ACRES',T64,'CUBIC YARDS',T78,'COST',T85,'BENCH',T94,'SECO
     $ND',/T6,'OF CUT',T16,'ANGLE',T24,'LENGTH',T34,'HEIGHT',T44,'SLOPE'
     $,T53,'DISTURBED',T64,'OF MATERIAL',T85,'SLOPE',T93,'HIGHWALL'/)
      WRITE(6,82)
      WRITE(6,82)
82    FORMAT(' ',116('*'))
      ISWELL=30
      WRITE(6,250) ISWELL
250   FORMAT(//T10,'SWELL PERCENT',T30,I4,T35,'%',//)
C
C
      DIFF=HWANG-90
      HWANG=RAD(HWANG)
      ION=63-DIFF
      KON=30-DIFF
C
      DO 300 IHC=I,J,3
C
C
      DO 600 ICTANG=ION,KON,2
C
      CTANG=ICTANG
      SLOP=ORSLOP+HWANG
      CTANG=RAD(CTANG)
      ALFA=PI-(SLOP+CTANG)
      OVSLOP=SLOP+CTANG
```

```
      CTLNTH=IHC*(SIN(CTANG))/SIN(ALFA)
      SLOPLN=IHC*(SIN(SLOP))/SIN(ALFA)
C
C*
C*
C*       IF ANGLE OF CUT IS LESS THAN THE ORIGINAL SLOPE(AND THEREFORE THE TWO
C*       WILL NOT INTERSECT) THE SUBROUTINE HITERR IS CALLED TO COMPUTE A STEP-
C*       TYPE HIGHWALL STRUCTURE
C*
C*
      IF(PI-OVSLOP)125,125,33
C
33    CONTINUE
      FLAREA=.5*(IHC*CTLNTH*SIN(SLOP))
      GO TO 35
C
C
125   CONTINUE
C
      CALL HITERR (FLAREA)
C
35    CONTINUE
      FLAREA=FLAREA*(1.+(ISWELL/100.))
      FLAREA=FLAREA+SLUFF
      FILHT=(2*FLAREA)/(SIN(HWANG)*IPITWD)
      FILNTH=SQRT(FILHT**2+IPITWD**2-(2*FILHT*IPITWD*COS(HWANG)))
C*
C*       FLANG IS THE ANGLE WHICH RESULTS FROM THE PLACEMENT OF MATERIAL ON THE
C*       BENCH AREA.
C*
      FLANG=ARSIN((FILHT*SIN(HWANG))/FILNTH)
      HWHGT=HTCUT-(FILHT+IHC)
```

```
      ENSLOP=PI-(HWANG+CTANG)
      CTANG=DEGREE(CTANG)
      ENSLOP=DEGREE(ENSLOP)
      ABSLAR=SLOPLN*LENGTH
      AREBEN=LENGTH*FILNTH
C
C*
C*         OUTDIS COMPUTES THE LENGTH OF THE OUTSLOPE BY USING THE HIGHWALL HEIGHT
C*         AND ORIGINAL SLOPE.
C*
      OUTDIS=(3.9145*HTCUT)+(1.7342*ORSLOP)-29.0095
      OUTARE=OUTDIS*LENGTH
      CULTAR=ABSLAR+AREBEN+OUTARE
      ACREDS=CULTAR/43560
      CUBARE=LENGTH*(FLAREA*(1.+(ISWELL/100.)))/3
      TMVCOS=CUBARE*COSTE
C
C*
C*         DEGREE(FLANG) CHANGES VALUE FROM RADIANS TO DEGREES
      FLANG=DEGREE(FLANG)
C*
C*         RAD(FLANG) CHANGES VALUE FROM DEGREES TO RADIANS FOR COMPUTATIONS
      IF(FLANG.GT.33)GO TO 300
      IF(HWHGT.LE.I) GO TO 300
      IF(CTLNTH.LE.0) GO TO 2002
C
      WRITE(6,2) IHC,CTANG,CTLNTH,HWHGT,ENSLOP,ACREDS,CUBARE,TMVCOS,RECO
     $ST,TOCOST,FLANG
      GO TO 2003
 2002 CONTINUE
      WRITE(6,2) IHC,CTANG,CTLNT,HWHGT,ENSLOP,ACREDS,CUBARE,TMVCOS,FLANG
     $,HITWO
```

```
2003  CONTINUE
2     FORMAT('0',T7,I2,T17,F4.0,T25,F5.0,T35,F4.0,T45,F3.0,T55,F4.1,T66,
     $F8.0,T77,F7.0,T86,F3.0,T95,F4.0)
C
600   CONTINUE
300   CONTINUE
C
      WRITE(6,65)
65    FORMAT(' ')
C
C
      WRITE(6,700) OUTDIS
700   FORMAT(//T10,'OUTSLOPE LENGTH',T35,F7.1,3X,'FT.')
C
      WRITE(6,825)
825   FORMAT(1H1)
      STOP
      END
      SUBROUTINE HITERR(FLAREA)
      COMMON IHC,CTANG,SLOP,CTLNT,HITWO,PI
      REAL NHWANG
      TERCUT=50
      NHWANG=92
      NHWANG=RAD(NHWANG)
      ANGLE=SQRT((IHC**2)+(TERCUT**2)-((2*IHC*TERCUT)*COS(CTANG)))
      GAMMA1=ARSIN((IHC/ANGLE)*SIN(CTANG))
      ALFA1=ARSIN((TERCUT/ANGLE)*SIN(CTANG))
      GAMMA2=NHWANG-GAMMA1
      ALFA2=SLOP-ALFA1
      SIGMA=(2*PI)-CTANG-SLOP-NHWANG
      CTLNT=(ANGLE*SIN(GAMMA2))/SIN(SIGMA)
      HITWO=(ANGLE*SIN(ALFA2))/SIN(SIGMA)
```

```
FLAREA=.5*((IHC*TERCUT*SIN(CTANG))+(CTLNT*CTANG*SIN(SIGMA)))
RETURN
END
REAL FUNCTION RAD(X)
PI=4.*ATAN(1.)
RAD=X*(PI/180)
RETURN
END
REAL FUNCTION DEGREE(Y)
PI=4.*ATAN(1.)
DEGREE=Y*(180/PI)
RETURN
END
```

```
      SUBROUTINE WINBRK
C*
C*
C******************************************************************************
C*
C*
C*         THIS SUBPROGRAM PRODUCES A TABLE OF PERCENT WIND VELOCITIES AS AFFECTED
C*         BY WIND BARRIERS OF VARYING HEIGHT AND CONSTRUCTION.  THE WIND
C*         VELOCITIES ARE COMPUTED FOR DISTANCES IN FRONT AND BEHIND THE BARRIERS.
C*
C*         WHERE:
C*
C*
C*         BARR= DISTANCE FROM THE BARRIER IN BARRIER HEIGHT
C*         SHELT= PERCENT WIND REDUCTION IN AT INCREMANTED DISTANCES
C*
C*
C******************************************************************************
C*
C*
      INTEGER BARR,SHELT
      DIMENSION BARR(16),DIST(16),SHELT(13,16),TITLE(8,13)
      READ, HEIGT
      DATA BARR/-15,-10,-5,0,1,2,3,4,5,10,15,20,25,30,35,40/
      DO 125 I=1,16
125   DIST(I)=HEIGT*BARR(I)
      READ(5,100) TITLE
100   FORMAT(8A4)
      READ(5,200) SHELT
200   FORMAT(13(3X,I3))
      WRITE(6,195)
195   FORMAT('1',T58,'PERCENT OF WIND VELOCITY AS AFFECTED BY BARRIER'//
```

```
     $T68,'DISTANCE FROM BARRIER',//1X,120('*'),/T37,84('*')//)
      WRITE(6,190) DIST
190   FORMAT(' ',T40,16(F4.0,1X))
      DO 400 J=1,13
      WRITE(6,300) (TITLE(IN,J),IN=1,8),(SHELT(J,I),I=1,16)
300   FORMAT(5X,8A4,T40,16(I3,2X)//)
400   CONTINUE
      STOP
      END
```

```
      SUBROUTINE TERARE
C*
C*
C*****************************************************************************
C*
C*
C*       THIS TERRACE AREA SUBPROGRAM COMPUTES THE AMOUNT OF MATERIAL TO BE
C*       REMOVED FROM AN OUTSLOPE TERRACE AND PLACED ON THE BENCH.  THE
C*       RESULTING SLOPE CHANGE ON THE BENCH IS COMPUTED.
C*
C*
C*       OSLNTH=LENGTH OF OUTSLOPE
C*       ITERWD=WIDTH OF TERRACE CUT
C*       TERNUM=NUMBER OF TERRACES TO BE CONSTRUCTED
C*       HWHGT=HEIGHT OF HIGHWALL
C*       HWANG=ANGLE OF HIGHWALL
C*       OSLANG=ANGLE OF OUTSLOPE
C*       PITWD=WIDTH OF BENCH
C*       ITRANG=ANGLE OF VERTICAL TERRACE CUT
C*
C*
C*****************************************************************************
C*
C*
      READ, OSLNTH
      READ, TERNUM
      READ, HWHGT
      READ, OSLANG
      READ, PITWD
      HWANG=RAD(HWANG)
      OSLANG=RAD(OSLANG)
      PITWD=120.
```

```
C*
C*
C*        THIS ITERATION COMPUTES THE RESULTS OF PRODUCING VARIOUS CUT ANGLES AND
C*        LENGTHS TO PROVIDE TERRACES.
C*
C*
      DO 300 ITRANG=95,105,5
      DO 200 ITERWD=15,35,5
      TERWD=ITERWD*1.
      TRANG=ITRANG*1.
      TRANG=RAD(TRANG)
      TERLT=(SIN(TRANG)*TERWD)/SIN(TRANG+OSLANG)
      TERARE=(SIN(OSLANG)*TERLT*TERWD)/2
      FLAREA=TERARE*TERNUM
      FILHT=(2*FLAREA)/(SIN(HWANG)*PITWD)
      FILNTH=SQRT(FILHT**2+PITWD**2-(2*COS(HWANG)))
      FLANG=ARSIN((FILHT*SIN(HWANG))/FILNTH)
C*        DEGREE(TRANG) CHANGES TRANG FROM RADIANS TO DEGREES
C*        RAD(TRANG) CHANGES TRANG FROM DEGREES TO RADIANS
      FLANG=DEGREE(FLANG)
      WRITE(6,100)
100   FORMAT('1',T10,'TERRACE',T30,'FILL',T50,'FILL',/T12,'AREA',T29,'LE
     $NGTH',T50,'ANGLE'//)
      WRITE(6,105)
105   FORMAT(' ',65('*'))
      WRITE(6,110)TERARE,FILNTH,FLANG
110   FORMAT(' ',//T9,F6.1,T28,F6.1,T48,F6.1)
200   CONTINUE
300   CONTINUE
      STOP
      END
      REAL FUNCTION RAD (X)
```

```
PI=4.*ATAN(1.)
RAD=X*(PI/180)
RETURN
END
REAL FUNCTION DEGREE (Y)
PI=4.*ATAN(1.)
DEGREE=Y*(180/PI)
RETURN
END
```

```
      SUBROUTINE AREA
C*
C*
C***********************************************************************
C*
C*
C*        THE AREA SUBROUTINE CALAUATES THE PERIMETER AND AREA OF A FIGURE BY ITS
C*        X AND Y COORDINATES. THESE VALUES ARE INPUT TO THE PROGRAM IN REAL
C*        NUMBERS ON DATA CARDS.  THE COORIDNATES ARF PRINTED IN PAIRS(X IN
C*        COLUMNS 0-3,AND Y IN 4-6) IN CLOCKWISE ORDER.
C*
C*
C***********************************************************************
C*
C*
      REAL X(50),Y(50)
   10 READ(5,*,END=20)  (X(I),Y(I),I=1,50)
   20 I=I-1
      PRIM=0.
      AREA=0.
      DO 50 J=1,I
      K1=J+1
      IF (J.EQ.I) GO TO 30
      PRIM=PRIM+SQRT((X(J)-X(K1))**2+(Y(J)-Y(K1))**2)
      GO TO 40
   30 K1=1
   40 AREA=AREA+X(K1)*Y(J)-X(J)*Y(K1)
   50 CONTINUE
      AREA=AREA*.5
      WRITE(6,206)
206   FORMAT(////////)
      WRITE(6,60) AREA,PRIM,(J,X(J),Y(J),J=1,I)
```

```
   60 FORMAT('1',10X,'AREA = ',F8.2/11X,'PERIMETER = ',F8.2/'0',T10,'POI
     1NT #',T20,'X',T25,'Y'/(' ',T10,I5,3X,F3.0,2X,F3.0))
      WRITE (6,6666)
 6666 FORMAT (1H1)
      RETURN
      END
```

```
C     SUBROUTINE ERODE
C*
C*
C*****************************************************************************************
C*
C*
C*        THIS SUBPROGRAM COMPUTES THE RELATIVE EROSION RATES FOR A SITE
C*        DETERMINED BY THE SITE CHARACTERISTICS AND RECLAMATION PRACTICES.  THE
C*        RATES ARE COMPUTED IN TONS/ACRE AND ASSOCIATED COSTS ARE CALCULATED.
C*        EACH UNIT IS DESCRIBED BY SITE CHARACTERISTICS WHERE:
C*
C*
C*        RFACT=IS RAINFALL INTENSITY FACTOR
C*        SOILOS=SOIL ERODIBILITY FACTOR
C*        LEN=LENGTH OF SLOPE SEGMENT
C*        SLO=SLOPE PERCENT
C*        PERCAN=PERCENT CANOPY COVER AND TYPE
C*        PERGO=PERCENT GROUND COVER
C*        PTYPE=TYPE OF GROUND COVER(GRASS OR WEED)
C*
C*
C*****************************************************************************************
C*
C*
      REAL LEN,LENSLO
      INTEGER PERCAN,PERGO,PTYPE
      REAL PRECL(13)/1.,.95,.85,.9,.8,.75,.65,.55,.35,.3,.4,.1,.08/
      REAL COST(13)/0.,250.,280.,320.,475.,600.,635.,745.,650.,975.,2400
     $.,2600.,1220./
      REAL CROP(10,6,2)/.45,.36,.26,.17,.4,.34,.28,.42,.39,.36,.2,.17,.1
     $3,.1,.18,.16,.14,.19,.18,.17,.1,.09,.07,.06,.09,.085,.08,.1,.09,.0
     $9,.042,.038,.035,.031,.040,.038,.036,.041,.04,.039,.013,.012,.012,
```

```
     $.011,.013,.012,.012,.013,.013,.012,.003,.003,.003,.003,.003,.003,.
     $003,.003,.003,.003,.45,.36,.26,.17,.4,.34,.28,.42,.39,.36,.24,.2,.
     $16,.12,.22,.19,.17,.23,.21,.2,.15,.13,.11,.09,.14,.13,.12,.14,.14,
     $.13,.09,.082,.075,.067,.085,.081,.077,.087,.085,.083,.043,.041,.03
     $9,.038,.042,.041,.041,.042,.042,.041,.011,.011,.011,.011,.011,.011
     $,.011,.011,.011,.011/
      READ, RFACT
      READ, SOILOS
      READ, LEN
      READ, SLO
      READ, PERGO
      READ, PTYPE
      WRITE(6,300)
300   FORMAT('1',T88,'EROSION/ACRE',T102,'COST OF RECLAMATION',/T106,'PR
     $ACTICE',//)
      DO 50 PERCAN=5,10
      LENSLO=(SQRT(LEN))*(.0076+(.0053*SLO)+(.00076*(SLO**2)))
      CROPT=CROP(PERCAN,PERGO,PTYPE)
      DO 200 I=1,13
      ERODE=RFACT*SOILOS*LENSLO*CROPT*PRECL(I)
      WRITE(6,400) ERODE,COST(I),LEN,SLO,CROPT
400   FORMAT(' ',T10,F8.2,T25,F8.2,T40,F5.0,T50,F3.0,T60,F6.4)
200   CONTINUE
50    CONTINUE
      STOP
      END
```

```
      SUBROUTINE PLSPEC
C*
C*
C***************************************************************************
C*
C*
C*         THIS SUBPROGRAM RANKS PLANT SPECIES (TREES,SHRUBS, OR GRASSES) BY
C*         THEIR SITE SUITABILITY OR RELATIVE EFFECTIVENESS TO MEET SPECIFIC
C*         THE SILVICAL CHARACTERISTICS OF EACH SPECIES ARE COMPARED TO THE SITE
C*         CHARACTERISTICS, AND ARE RANKED BY THE RELATIVE WEIGHT OF EACH
C*         OBJECTIVE.
C*
C*
C***************************************************************************
C*
C*
      DIMENSION NAMER(20),NAMEOB(20),MR(49,100),METH(3,100),ADR(100),    EFE   83
     1   OR(41),RANK(3,100)                                              EFE   84
      INTEGER        ORC(4),MRA(49),AST, AVE,NO(41),DONE                 EFE   85
      INTEGER PLANPH,PLSHAD,PLANPM,PLMOIS,PH,SHADE,PARMAT,RMOIST
      DATA AST/'*    '/,AVE/'*AVE'/,DONE/'DONE'/                         EFE   86
      WRITE(6,254)                                                       EFE   87
254   FORMAT('1',T50,'PLANT SELECTION',/T56,'BY',/T47,'MAURICE N. LEFRAN
     $C JR.',/T45,'VIRGINIA POLYTECHNIC INSTITUTE',/T47,'BLACKSBURG, VIR
     $GINIA 24061'///)
   90 WRITE(6,200)                                                       EFE   96
      JOBEND=0                                                           EFE   97
      NM=1                                                               EFE   98
      SW=0.0                                                             EFE   99
C*          INPUT OF SITE CHARACTERISTICS(CLASSES)
      READ(5,1092) PH,SHADE,PARMAT,RMOIST
1092  FORMAT(T23,4(I4))
```

```
      READ(5,97) NC
      IF(NC.LT.1.OR.NC.GT.3) STOP
      IF(NC.EQ.1) N=11
      IF(NC.EQ.2) N=26
      IF(NC.EQ.3) N=41
   98 READ(5,100) NAMER
      WRITE(6,201)NAMER
      IF(NAMER(1).NE.AVE)GO TO 99
      IF(NAMER(2).EQ.AST) SW=1
      IF(SW.NE.1) GO TO 99
      GO TO 98
   99 READ(5,100) NAMEOB
      WRITE(6,201)NAMEOB
      READ(5,101)ORC,WEIGHT,(OR(I),I=1,11)
      IF(N.GT.11) READ(5,106)(OR(I),I=12,N)
      SUMOR=0.0
      DO 150 I=1,N
      NO(I)=I
      SUMOR=SUMOR+OR(I)
  150 IF(OR(I).NE.0) NN=I
      DO 151 I=1,NN
  151 OR(I)=OR(I)/SUMOR
      IF(SW.EQ.1) WRITE(6,303) NM
      WRITE(6,204) (NO(I),I=1,NN )
      NNN=NN+2
      WRITE(6,205)  ORC,(OR(I),I=1,NN)
      SUMR=0.0
  104 DO 2 J=1,100
      IF(SW.EQ.2) GO TO 103
      READ(5,102) MR (1,J),(METH(M,J),M=1,3),(MR(I,J),I=2,13 )
C*       SILVICAL CHARACTERISTICS OF SPECIFIC PLANTS(CLASSES)
      READ(5,1096) PLANPH,PLSHAD,PLANPM,PLMOIS,PLCOV,PLFOOD
```

```
C*         SITE COMPARISON EVALUATION
      PLVAL=0
      IF(PLANPH.EQ.PH) PLVAL=2
      IF(PLANPH.EQ.PH+1.OR.PLANPH.EQ.PH-1) PLVAL=1
      SHAVAL=0
      IF(PLSHAD.EQ.SHADE) SHAVAL=2
      IF(PLSHAD.EQ.SHADE+1.OR.PLSHAD.EQ.SHADE-1) SHAVAL=1
      PMVAL=0
      IF(PLANPM.EQ.PARMAT) PMVAL=2
      IF(PLANPM.EQ.PARMAT+1.OR.PLANPM.EQ.PARMAT-1) PMVAL=1
      RMOVAL=0
      IF(PLMOIS.EQ.RMOIST) RMOVAL=2
      IF(PLMOIS.EQ.RMOIST+1.OR.PLMOIS.EQ.RMOIST-1) RMOVAL=1
      FODVAL=PLFOOD*1
      COVVAL=PLCOV*1
      GO TO 1095
1094  PLVAL=0
      SHAVAL=0
      PMVAL=0
      RMOVAL=0
      COVVAL=0
      FODVAL=0
1095  CONTINUE
      MR(2,J)=MR(2,J)*PLVAL
      MR(3,J)=MR(3,J)*SHAVAL
      MR(4,J)=MR(4,J)*PMVAL
      MR(5,J)=MR(5,J)*RMOVAL
      IF(WEIGHT.NE.1.0.OR.MR(2,J).EQ.0) GO TO 123
      DO 122 K=3,NNN
  122 MR(K,J)=MR(K,J)*MR(2,J)
  123 RANK(1,J)=0.0
      RANK(2,J)=0.0
```

```
      RANK(3,J)=0.0
      MR(49,J)=0
C     STOP READ IF MR(1,J) EQUAL ZERO
      IF(MR(1,J).EQ.0) GO TO 3
      IF(NNN.GT.13) READ(5,105) (MR(I,J),I=14,NNN)
  105 FORMAT(15I5,5X)
      JJ=J
  103 DO 1 K=1,NN
      IF(SW.EQ.1 ) GO TO 22
    1 RANK(1,J)=RANK(1,J)+MR(K+2,J)*OR(K)
      SUMR=SUMR+RANK(1,J)
      MR(46,J)=RANK(1,J)
   22 WRITE(6,900) MR(1,J),(METH(M,J),M=1,3),(MR (I,J),I=3,NNN)
      IF(SW.EQ.2.AND.J.EQ.JJ) GO TO 3
    2 CONTINUE
    3 JJJ=JJ-1
      DO 33 J=1,JJ
   33 RANK(1,J)=RANK(1,J)/SUMR
      DO 4 J=1,JJ
      DO 4 K=1,JJ
      IF(J.EQ.K)GO TO 4
      SUM=RANK(1,J)+RANK(1,K)
      IF(SUM.GT.RANK(2,J) ) MR(44,J)=MR(1,J)
      IF(SUM.GT.RANK(2,J) ) MR(45,J)=MR(1,K)
      IF(SUM.GT.RANK(2,J) ) RANK(2,J)=SUM
    4 CONTINUE
      DO 5 J=1,JJ
      DO 5 K=1,JJ
      IF (J.EQ.K)  GO TO 5
      PROD=MR(46,J)*MR(46,K)
      IF(PROD.GT.RANK(3,J) ) MR(47,J)=MR(1,J)
      IF(PROD.GT.RANK(3,J) ) MR(48,J)=MR(1,K)
```

```
      IF(PROD.GT.RANK(3,J) ) RANK(3,J)= PROD
    5 CONTINUE
      SUMR=0.0
      DO 55 J=1,JJ
   55 SUMR=SUMR+RANK(3,J)
      DO 56 J=1,JJ
   56 RANK(3,J)=RANK(3,J)/SUMR
C     ASSOCIATE ARRAY ADDRESS WITH RANK(INTEGER)
      DO 6 J=1,JJ
    6 ADR(J)= J *.01+ MR(46,J)
C     SORT RANK AND ITS ASSOCIATED ADDRESS(THE DIGITS AFTER THE DECIMAL
C        POINT IS THE SORTED ADDRESS OF THE DATA WHICH IS NOW PUT INTO
C*       THE SEQUENCE INTO WHICH THE DATA IS TO BE PRINTED
    7 SW=0
      DO 9 I=1,JJJ
      IF(ADR(I).GT.ADR(I+1))GO TO 8
1096  FORMAT(T23,4(I4),2(F3.1,1X))
      SW=1
      TEMP=ADR(I)
      ADR(I)=ADR(I+1)
      ADR(I+1)=TEMP
    8 IF(SW.EQ.0.AND.I.EQ.JJJ) GO TO 10
    9 CONTINUE
      GO TO 7
   10 DO 11 I= 1,JJ
      IAD =ADR(I)
   11 ADR(I)=(ADR(I)-IAD)* 100.0+.555
      WRITE(6,202)
      DO 12 J =1,JJ
      I = ADR(J)
      IF(J.EQ.1) WRITE(6,203)MR(1,I),(METH(M,I),M=1,3),RANK(1,I)
      IF(J.NE.1) WRITE(6,203)MR(1,I),(METH(M,I),M=1,3),RANK(1,I)
```

```
   12 CONTINUE
      READ(5,107) JOBEND
      IF(JOBEND.NE.DONE) GO TO 90
      STOP
      GO TO 104
C
   97 FORMAT(I1)
  100 FORMAT(20A4)
  101 FORMAT(3A4,A3,    12F5.0,5X)
  102 FORMAT(I4,2A4,A3,12I5,5X)
  106 FORMAT(15F5.0,5X)
  107 FORMAT(A4)
200   FORMAT(1H1,'COMBINED RATING OF PLANT SPECIES'//)
201   FORMAT(1X,T10,20A4/)
202   FORMAT('0',1X,'SPECIES      SPECIES     NORMALIZED',/1X,' NUMBER        NAM
     $E              RANK'/)
203   FORMAT(1X,I6,5X,2A4,A3,5X,F5.3,5X,2I8,F11.3,7X,2I8,F11.3)
204   FORMAT('0','OBJECTIVE NO.',T21,17I5/20X,22I5)
205   FORMAT(1X,3A4,A3,4X,17F5.2/20X,22F5.200)
  303 FORMAT(/// ' INDIVIDUAL MANAGERS RATINGS OF OBJECTIVES', 10X,
     1   'DATA GROUP NO.  ',I3)
900   FORMAT(1X,I5,2A4,A3,3X,17I5,/20X,20I5//)
      WRITE(6,999)
999   FORMAT(1H1)
      STOP
      END
```

```
      SUBROUTINE SITEVAL
C**********************************************************************
C**********************************************************************
C*
C*
C*        THIS SUBROUTINE SITEVAL EVALUATES A SITE BY HOW WELL IT MEETS THE
C*        CRITERIA FOR AN ESTABLISHED SITE. -WENTY FACTORS AR MEASURED AND
C*        USED AS INPUT TO THE PROGRAM.  -HESE FACTORS ARE EVALUATED AND A
C*        'SCORE' IS ASSIGNED TO THE SITE.  THE HIGHEST TOTAL SCORE IS 187.  EACH
C*        SITE SCORE CAN BE COMPARED TO THE HIGHEST POSSIBLE SCORE TO DETERMINE
C*        ITS RANK RELATIVE TO A GOOD SITE.  THIS SUBPROGRAM CAN BE USED AS A
C*        DECISION AID TO DETERMINE THE RELATIVE IMPORTANCE OF RECLAIMING
C*        ABANDONED SURFACE MINE SITES
C*
C*
C**********************************************************************
C*
C*
C**********************************************************************
C**********************************************************************
C*
C*
C*        PCANCO:PERCENT CANOPY COVER(ESTIMATED)
C*        PGROCO:PERCENT GROUND COVER
C*        OLTREE:OLDEST TREE ON SITE 2,8,12,20 YEARS
C*        SPOCOL:SPOIL COLOR1=BLACK,2=GRAY3=LIGHT BROWN,4=MEDIUM BROWN
C*        VISBLVISIBILITY OF MINE SITE 1=NOT VISBLE,2=SLIGHTLY VISIBLE
C*        3=VISIBLE FROM ROADS,4=VISIBLE FROM TOWN OR MAJOR HIGHWAY
C*        WILFOD:WILDLIFE FOOD 1=NONE,2=LOW,3=MEDIUM,4=HIGH
C*        WILCOV:WILDLIFE COVER 1=NONE,2=LITTLE,3=SEASONAL,4=YEAR ROUND
C*        SPOIPH:SPOIL PH 1= LESS THAN 3.5,2=4.0-5.0,3=5.0-5.5,4=GREATER THAN 5.5
C*        NITRO:NITROGEN AT SITE 1=LOW,2=MEDIUM,3=HIGH
```

```
C*        PHOSP:PHOSPHOROUS AT SITE 1=LOW,2=MEDIUM,3=HIGH
C*        POTASS:POTASSIUM AT SITE 1=LOW,2=MEDIUM,3=HIGH
C*        TOXIC:TOXICITY TO PLANTS 1=HIGH,2=MEDIUM,3=NON-TOXIC
C*        EROD: EROSION IMPACT FROM SITE 1=HIGH EROSION AT PRESENT,2=LOW EROSION
C*        AT PRESENT,3=INTERMITTENT,4NO EROSION
C*        ACDH2O: ACID RUNOFF 1=HIGH,2=MEDIUM,3=NO ACID RUNOFF
C*        STREM: STREAM BELOW MINE SITE 1=ABOVE LARGE WATERWAY,2=ABOVE STREAM,
C*        3=ABOVE SMALL STREAM,4=NO STREAM
C*        ADJAC:ADJACENCY TO PEOPLE 1=NOT NEAR,2=NEAR,3=VERY CLOSE
C*        ACCSS:ACCESSIBILITY OF SITE 1=NO ACCESS,2=POOR ROAD,3=PASSABLE ROAD
C*        4=EASY ACCESS
C*        POND:POND PRESENT ON SITE 1=NO POND,2=SEASONAL,3=SMALL POND,4=GOOD POND
C*        REMINE:POTENTIAL FOR REMINING OF SITE 1=GOOD,2=MEDIUM,3=NO CHANCE
C*        UTILIZ:UTILIZATION OF SITE BY WILDLIFE 1=NONE,2=LITTLE,3=MODERATE
C*        4=HIGH USAGE
C*        ENDANG:ENDANGERED SPECIES ON SITE 1=NONE,2=MARGINAL,3=PRESENT
C*
C*
C*
C*        ALL INPUT VALUES ARE TWO DIGIT INTEGERNUMBERS
C*
       INTEGER PCANCO,PGROCO,OLTREE,SPOCOL,VISBL,WILFOD,WILCOV,SPOIPH,NIT
      $RO,PHOSP,POTASS,TOXIC,ADJAC,ACCSS,EROD,ACDH2O,STREM,POND,REMINE,UT
      $ILIZ,ENDANG,SITVAL
       INTEGER PCANVL,PGRVL,OLVL,SPOVL,VISVL,WILVL,WCVL,SPOIVL,NITVL,PHOV
      $L,POTVL,TOXVL,ERDVL,ACDVL,STRVL,ADJVL,ACCVL,PONVL,REMVL,UTIVL,ENOV
      $L
       READ(5,100) PCANCO,PGROCO,OLTREE,SPOCOL,VISBL,WILFOD,WILCOV,SPOIPH
      $,NITRO,PHOSP,POTASS,TOXIC,ADJAC,ACCSS,EROD,ACDH2O,STREM,POND,REMIN
      $E,UTILIZ,ENDANG
100    FORMAT(21(I2))
       IF(PCANCO.EQ.20) PCANVL=2
```

```
IF(PCANCO.EQ.40) PCANVL=4
IF(PCANCO.EQ.60) PCANVL=6
IF(PCANCO.EQ.80) PCANVL=10
IF(PGROCO.EQ.20) PGRVL=2
IF(PGROCO.EQ.40) PGRVL=4
IF(PGROCO.EQ.60) PGRVL=6
IF(PGROCO.EQ.80) PGRVL=10
IF(OLTREE.EQ.2)OLVL=2
IF(OLTREE.EQ.8)OLVL=4
IF(OLTREE.EQ.12)OLVL=6
IF(OLTREE.EQ.20)OLVL=8
IF(SPOCOL.EQ.1)SPOVL=2
IF(SPOCOL.EQ.2)SPOVL=4
IF(SPOCOL.EQ.3)SPOVL=6
IF(SPOCOL.EQ.4)SPOVL=8
IF(VISBL.EQ.1)VISVL=10
IF(VISBL.EQ.2)VISVL=6
IF(VISBL.EQ.3)VISVL=4
IF(VISBL.EQ.4)VISVL=2
IF(WILFOD.EQ.1)WILVL=2
IF(WILFOD.EQ.2)WILVL=4
IF(WILFOD.EQ.3)WILVL=6
IF(WILFOD.EQ.4)WILVL=10
IF(WILCOV.EQ.1)WCVL=2
IF(WILCOV.EQ.2)WCVL=4
IF(WILCOV.EQ.3)WCVL=6
IF(WILCOV.EQ.4)WCVL=10
IF(SPOIPH.EQ.1)SPOIVL=1
IF(SPOIPH.EQ.2)SPOIVL=3
IF(SPOIPH.EQ.3)SPOIVL=5
IF(SPOIPH.EQ.4)SPOIVL=10
IF(NITRO.EQ.1)NITVL=2
```

```
IF(NITRO.EQ.2)NITVL=4
IF(NITRO.EQ.3)NITVL=8
IF(PHOSP.EQ.1)PHOVL=2
IF(PHOSP.EQ.2)PHOVL=4
IF(PHOSP.EQ.3)PHOVL=8
IF(POTASS.EQ.1)POTVL=2
IF(POTASS.EQ.2)POTVL=4
IF(POTASS.EQ.3)POTVL=8
IF(TOXIC.EQ.1)TOXVL=2
IF(TOXIC.EQ.2)TOXVL=4
IF(TOXIC.EQ.3)TOXVL=8
IF(EROD.EQ.1)ERDVL=2
IF(EROD.EQ.2)ERDVL=4
IF(EROD.EQ.3)ERDVL=6
IF(EROD.EQ.4)ERDVL=10
IF(ACDH2O.EQ.1)ACDVL=3
IF(ACDH2O.EQ.2)ACDVL=6
IF(ACDH2O.EQ.3)ACDVL=9
IF(STREM.EQ.1)STRVL=2
IF(STREM.EQ.2)STRVL=4
IF(STREM.EQ.3)STRVL=6
IF(STREM.EQ.4)STRVL=8
IF(ADJAC.EQ.1)ADJVL=10
IF(ADJAC.EQ.2)ADJVL=6
IF(ADJAC.EQ.3)ADJVL=2
IF(ACCSS.EQ.1)ACCVL=8
IF(ACCSS.EQ.2)ACCVL=6
IF(ACCSS.EQ.3)ACCVL=4
IF(ACCSS.EQ.4)ACCVL=2
IF(POND.EQ.1)PONVL=2
IF(POND.EQ.2)PONVL=4
IF(POND.EQ.3)PONVL=6
```

```
      IF(POND.EQ.4)PONVL=8
      IF(REMINE.EQ.1)REMVL=8
      IF(REMINE.EQ.2)REMVL=4
      IF(REMINE.EQ.3)REMVL=2
      IF(UTILIZ.EQ.1)UTIVL=2
      IF(UTILIZ.EQ.2)UTIVL=4
      IF(UTILIZ.EQ.3)UTIVL=6
      IF(UTILIZ.EQ.4)UTIVL=10
      IF(ENDANG.EQ.1)ENDVL=8
      IF(ENDANG.EQ.2)ENDVL=6
      IF(ENDANG.EQ.3)ENDVL=2
      SITVAL=PCANVL+PGRVL+OLVL+SPCVL+VISVL+WILVL+WCVL+SPOIVL+NITVL+PHOVL
     $+POTVL+TOXVL+EROVL+ACOVL+STRVL+ADJVL+ACCVL+PONVL+REMVL+UTIVL+ENDVL
      WRITE(6,101) SITVAL
101   FORMAT(1H1,'THE PRESENT VALUE BASED ON THE ABOVE EVALUATICN, PROVI
     $DES A DECISION BASE FOR RECLAMATION OF AN ABANDONED SURFACE MINED
     $AREA',/'THIS SITE HAS RECEIVED A VALUE OF',2X,I4,2X,'OUT OF A POSS
     $IBLE 187 POINTS')
      WRITE(6,1001)
1001  FORMAT(1H1)
      STOP
      END
```

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A COMPUTER DECISION AID FOR RECLAIMING

EASTERN ABANDONED SURFACE MINES

by

Maurice Noel LeFranc, Jr.

ABSTRACT

A computer model was developed to provide a decision aid for the reclamation of eastern abandoned surface mined lands. Edaphic, topographic, climatological, and economic factors provide the inputs to the model. By utilizing the present costs and benefits from representative reclamation practices, objective and efficient decisions can be made.

The model is comprised of interacting subprograms, which operate as a system of independent decision aids. The subprograms presently in the system are HIWALL(land manipulation), PLSPEC (plant species suitability evaluator), ERODES(erosion predictor, and cost/benefit analyzer), TERARE(computes results of terrace building), LIME(rates of lime application required to enhance site quality), FERT(nutrient requirements for a site), and WINBRK(a windbreak effectiveness subprogram).

Evaluation of the model was accomplished by using simulation and sensitivity analyses. The operation of the HIWALL and ERODES subprogram, and the sensitivity analyses performed on each,

provided insights to the factors which influence the effectiveness of decisions, and land configurations.

The cost/benefit ratio can be utilized in the decision making process. Present costs can be manipulated to meet future needs, or to predict future rates of development.

Explanatory Note:

The figure captions used in the text are exceptions to the rules of the graduate manual. The captions should be consistent with the lettering used in the figure. This exception applies only to this thesis.