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TOPOGRAPHIC AND SOIL VARIABLES SIGNIFICANT IN THE RECLAMATION OF GRASSLAND SITES

By

Ronald J. Middleton

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

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Date April 21/86

ABSTRACT

The productivity of the reclaimed landscape compared to that of the pre-disturbance landscape is considered to be an index of reclamation success in Alberta and many other jurisdictions. Although several methods have been developed for determining the productive capability of the undisturbed landscape, few tools exist for predicting the productive capability of a reclaimed site. The scientific literature gives an indication of the general manner in which topographic and soil variables affect productivity but does not provide a comprehensive picture of the major determinants of vegetation productivity in the prairie environment.

Studies were carried out in two grassland sites in southern Alberta. Samples of native vegetation were taken, field plots were established, topographic variables were measured, soils were analyzed and greenhouse trials using soils from the sites were carried out. Analysis of the results found high correlation between initial vegetation cover and re-growth in the field plots, but low correlation between field and greenhouse results. Topographic variables, notably slope shape, and soil organic matter content were found to be the most significant determinants of productivity. Relationships between aspect and slope and productivity were not detected. Methods of incorporating the results of this study into reclamation planning are examined. The productivity index that is generated is found to be a potentially useful way of comparing the pre-disturbance landscape to the reclaimed landscape and in examining reclamation options.

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PREFACE

This study is an outgrowth from practical work in which the author has been involved, attempting to reclaim disturbed mixed prairie sites in southern Alberta. The objective of the reclamation planner in this province, as defined by the legislation (Government of the Province of Alberta, 1973; Land Conservation and Reclamation Council, 1977), is to return land to a state of equal capability with that of the pre-disturbance landscape.

The legislation permits land use change between the pre-disturbance and post-disturbance landscape, assuming, for example, that land reclaimed for wildlife habitat may have ecological value equal to the same land reclaimed for agriculture, regardless of what the land was used for previously. This allows the reclamation planner and the regulating agency a great deal of flexibility in approach to reclamation strategies.

The Alberta legislation is much less rigid than that used in many other jurisdictions, although the concept of post-reclamation productive capability is a common theme. Moore, et al. (1977), and Harthill and McKell (1979) review much of the reclamation legislation used throughout the United States. In many instances the legislation is concerned with establishing a permanent, stable vegetation cover equivalent to the pre-disturbance landscape. For example, Moore, et al. (1977) quote United States Federal Legislation (Title 30, CFS 211.40, Operating and Reclamation Standards):

> "(a)(13)(i) The operator shall . . . establish on regraded area and all other affected lands a diverse vegetative cover, native to the area and capable of regeneration and plant succession, at least equal in density and permanence to the natural vegetation."

While the basic principles of this and any similar legislation are clear and laudable, they ignore many practical considerations. The emphasis on native vegetation cover may preclude a legitimate change in land use. It also makes certain assumptions about native vegetation that may or may not be valid.

It assumes that native vegetation is the more productive and better adapted to the site than introduced species. Smreciu and Currah (1981) adhere to this view pointing to the obvious adaptation of the natives to the site conditions and the longer term climatic variations in the area.

The adaptation of native species to the site, however, does not preclude the adaptability of non-natives to the same conditions. Several trials have found that exotic agronomic species have outperformed their native counterparts in virtually any measure of reclamation success (Ries, et al., 1978; Konrad, 1984).

Moore, et al. (1977), and Harthill and McKell (1979) also argue against defining reclamation success in terms of stable, diverse vegetative cover. They maintain that this view violates basic ecological principles of succession, and argue that a disturbed site should be reclaimed to an early successional stage and that successional processes then be allowed to occur.

This view may be countered by the work of Jonescu (1979) and Sindelar (1979). Both of these studies examined natural revegetation and successional development on surface-mined lands. Both studies demonstrated that even in landscapes that had been abandoned for 40 or

50 years, many sites were still dominated by pioneer weed species and that succession was occurring extremely slowly, if at all.

The work of Coupland (1961) gives dramatic evidence of the inherent variability of supposedly stable climax mixed prairie communities over time. A change in productivity from year to year of over 100 percent due to weather is not uncommon, and even a change in species composition over a large area can occur in response to longer term climatic fluctuations.

If reclamation success is defined in terms of vegetation establishment, proving the success of a reclamation effort in face of such inherent variability and difficult theoretical arguments, can be an onerous task. Requiring the proponent to demonstrate ecological stability and production equal to the pre-disturbance situation would bind him to the site for decades after the operation had moved on. Regardless of the philosophical questions involved, it is not administratively practical to require such commitment from a proponent. Beyond the establishment of sufficient cover to stabilize the soil to prevent wind and water erosion, and to exclude an unacceptable level of invasion by weed species, it is impractical to define reclamation success in terms of the vegetation cover without reference to the pre-disturbance landscape.

The Guidelines for the Reclamation of Land in Alberta (Land Conservation and Reclamation Council, 1977) define the success of reclamation in several ways, based in part on land use and in part on practical considerations. Specifically, they state:

> "(1) Where the prescribed post-disturbance land use is agricultural production, the operator shall remain responsible for the maintenance of the reclaimed land during the period of time that is required to demonstrate that the agricultural productivity of any soil placed by the operator on the reclaimed lands is comparable
>
> (a) to the agricultural productivity that existed prior to the surface disturbance, or
>
> (b) where the pre-disturbance use of the land was not agricultural production, to such other productivity standard as the Approving Authority may prescribe.
>
> (2) Where the prescribed post-disturbance land use is a use other than agricultural production, the operator shall remain responsible for the maintenance of the reclaimed lands until
>
> (a) the soil surface has been stabilized and the composition, density, growth and vigor of vegetation established by the operator is comparable to the composition, density, growth and vigor of revegetation that existed before the surface disturbance, or
>
> (b) the condition of the land is comparable to the condition of other similar lands that have been reclaimed in a manner satisfactory to the Approving Authority
>
> (c) 320 established seedling trees per acre are growing on the site without assistance when the prescribed post-disturbance land use is commercial timber production."

It is obvious that the Approving Authority has left itself a great deal of flexibility in determining when a site has been adequately reclaimed. This is likely a reflection of a lack of sufficient knowledge of many of the important factors that determine the productivity of the post-reclamation landscape. Thus, although the guidelines appear to put great onus on a project proponent to demonstrate successful reclamation, they also provide the means for terminating the project when he has done all that can reasonably be expected as far as the Approving Authority is concerned.

A lack of knowledge regarding the determinants of productivity is also evident in the guidelines where contouring and soil reconstruction are addressed. In the discussion of contouring, for all uses, the proponent is advised to return the land to contours as near as possible to those of the pre-disturbance landscape. The underlying assumption appears to be that "what is, is best."

The guidelines regarding soil reconstruction are more vague advising simply that:

> "(1) Where the prescribed post-disturbance land use is agricultural production, the operator shall place root zone soil, having a depth that is sufficient to support agricultural plant growth, in proper sequence, on the surface of the reclaimed lands.
> (2) Where the prescribed post-disturbance land use is a use other than agricultural production, the operator shall place soil or other plant-supporting materials on the surface of the reclaimed lands so that a restructured soil, having a depth, and chemical and physical characteristics suitable and sufficient for supporting plant life, is available to achieve the prescribed post-disturbance land use."

Needless to say, the terms "suitable" and "sufficient" are left undefined and form the basis for debate between project developers and the regulating agency.

Until it can be demonstrated that other approaches can result in an equally productive landscape, the natural tendency, on the part of regulating agencies responsible for land reclamation, will tend to be that things should be put back the way they were. In order to demonstrate that other approaches may be successful, a better understanding of the factors that control productivity in the landscape is needed.

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INTRODUCTION

This study is an examination of some of the site factors that are important in determining the productivity of the reclaimed landscape in the mixed prairie region of southern Alberta. The kind of surface disturbances that are being dealt with are of a relatively minor nature such as would be experienced in shallow clay or gravel borrow areas, or in regrading resulting from road or similar construction. The study does not address problems related to groundwater or to phytotoxic materials that occur as a result of deeper disturbances such as coal mining.

This project is aimed at the development of useful tools for the reclamation planner to assist in the formulation of reclamation plans and the evaluation of alternatives to arrive at practices that are ecologically and economically sound. Thus, it is felt that an evaluation of the practical applications of the findings of this study are as important as an assessment of their scientific validity. Consequently, the first part of this study deals with an assessment of some of the factors controlling productivity, and the concluding sections are an examination of how such findings might be incorporated into the reclamation planning process.

In a site that is disturbed in the course of developing a gravel pit, constructing a road, or any similar construction activity, the main elements of the natural landscape are dismembered. Vegetation is destroyed, soil is removed, and topography reshaped. It falls to the reclamation planner to determine what the arrangement of these landscape elements will be, once the project is complete. He may provide directions for the reshaping of the land, standards for topsoil replacement and amendment, and specifications for replanting. Often he has little more than his own experience and intuition to rely on in formulating his recommendations. Ziemkiewicz (1985) reveals that the focus of most reclamation research in Alberta is on specific reclamation problems, in areas where there has been little reclamation success to date. These include problems such as the revegetation of tar sand mine tailings and thermal power plant ash. In the plains region of the province, reclamation research has largely centered on coal mining.

The focus of this study is directed toward reclamation of relatively minor surface disturbances such as gravel or clay borrow pits, or roadway construction. Rather than attempting to address a particular reclamation problem, it was intended to begin to develop guidelines for determining an acceptable approach to reclaiming a disturbance with particular emphasis on landform. The area of investigation was the prairie grassland of southern Alberta.

The specific objectives of this study were:

1. To determine which topographic and soil variables were the most significant determinants of productivity in the native prairie grasslands of southern Alberta.
2. To determine if these same variables were significant in controlling the productivity of reclamation vegetation in the region.
3. To examine how knowledge of these relationships could be effectively incorporated into the reclamation planning process.

REVIEW OF LITERATURE

TOPOGRAPHY-VEGETATION RELATIONSHIPS

The relationships between topography and vegetation in the mixed prairie have been mentioned by many researchers, but have been the subject of relatively few studies.

Most studies of vegetation in the mixed prairie region have been aimed at improving methods of range management. The work has generally focused on the classification of sites according to floristic characteristics and relating these to grazing pressure and herbage production. Some of the earliest descriptions of the mixed prairie of Alberta and southern Saskatchewan were in the reports of range investigations (Clark, 1930; Clark and Tisdale, 1936; Clark, et al., 1942, 1943). Further general descriptions can be found in the works of Moss (1944, 1955).

Coupland (1950, 1961) conducted extensive field studies of prairie sites in Alberta and Saskatchewan and developed a classification of vegetation that has been followed in various range management publications, including Smoliak, et al., 1976b; Wroe, et al., 1979; Wroe, et al., 1981. Looman (1963, 1980, 1981) has also done extensive studies of the vegetation of the Prairie Provinces. He has generally adhered to the Zurich-Montpellier system to develop a classification for the mixed prairie of Alberta and Saskatchewan. Currah, et al. (1982) utilized a form of cluster analysis to assess similarities among prairie sites in southern Alberta based on species composition of forbs in study plots but did not derive a formal classification. Singh, et al. (1983) utilized indices of floristic similarity and diversity as well as standing crop data to examine some structural and functional attributes of the vegetation of the northern mixed prairie.

Several of these studies acknowledge the importance of topography to vegetative composition of a site. Coupland (1950, 1961) observed that slope position can result in the formation of vegetation communities that are "azonal."

> "Within the area as a whole, variations in water content of soil caused by differences in climate are revealed in the nature of the vegetation. Each climax grassland type is associated with certain conditions of soil moisture as affected by soil and topography. The influence of soil texture and topography on the moisture supply within any one locality is reflected in the composition of the vegetation."

He found that plant communities on lower slope positions tended to resemble those from moister climatic zones and conversely that the crests of hills tended to have plant communities resembling those of drier areas.

He did not do more than comment on these variations, however. In fact, his studies avoided the variability that topography introduced in species composition and productivity.

> "Where the topography was rough enough to cause appreciable differences in drainage throughout the site, only the well-drained habitats of intermediate slope were sampled."

Looman (1980) observed that

> "within the zones, habitat-types . . . support deviating vegetation types. For example, in the Stipion sparteae zone, slopes with southern exposure on which run-off reduces the effective precipitation to less than 450 mm, a Stipion curtisetae variant can occur. If the effective precipitation is reduced to less than 370 mm, the variant can be of the Boutelouion gracilis type. On the other hand, low areas and northeasterly exposed slopes in the Boutelouion gracilis zone can have moisture conditions equivalent to those of 450 mm or more precipitation. In these

> areas, associates or variants of the Stipion curtisetae . . . may occur. However, in most instances edaphic or topographic compensation for climatic factors is only partial, and usually only the more tolerant species occur in "azonal" vegetation."

Looman does not, however, assess or quantify the slope and aspect characteristics that resulted in the different levels of "effective precipitation."

Currah, et al. (1982) classified vegetation according to site preference related to moisture conditions. Although several topographic factors were measured in their studies, in the end no quantitative relationships were established between slope, aspect, and vegetation.

Singh, et al. (1983) observed that the topographic situation affects the balance between cool season (C_3) and warm season (C_4) species in mixed prairie with the lowland moist habitats favouring C_3 species and upland dry habitats promoting C_4 species.

One of the few studies that attempted to assess the effect of topographic variables on vegetation in a systematic fashion was that of Ayyad and Dix (1964). In this study, the floristic composition of stands near Saskatoon, Saskatchewan with different slope aspects and positions were compared and the site "preference" of several species was determined. While some of the species were ubiquitous, others tended to be largely restricted to certain aspects and/or slope positions. The authors maintained that, in agreement with Gieger (1957), the maximum aspect contrast could be found between southwest facing and northeast facing slopes. No assessment was made, in the Ayyad and Dix (1964) study, of total cover, or productivity, related to aspect and position.

In a study of natural revegetation of strip-mined land, Jones (1979) found north facing aspects to have significantly more cover than south facing aspects, and even more marked differences between east and west aspects, with east slopes having much higher cover.

SOIL-VEGETATION RELATIONSHIPS

Regarding the relationships between soil characteristics and vegetation, Coupland (1950, 1961) relates his faciations both to broad soil zones, and to soils of varying texture and physical characteristics within the zones, stating that the moisture supply within the soils is the significant determinant. For example, in that part of the prairie where he identifies the Stipa-Bouteloua faciation as the characteristic climax type on medium textured soils, soils of coarser texture tend to favour an increased relative abundance of Bouteloua gracilis, while on finer textured soils the Stipa-Agropyron faciation tends to dominate. He also identifies specific communities that are associated with eroded sites, clay soils and solonetzic soils.

Looman (1980) goes somewhat further, relating vegetation within his Boutelouion gracilis alliance to the specific soil characteristics namely, soil texture, pH, available moisture, and nutrient status. He does not claim to have complete data but provides examples of how specific vegetation types can be related to these characteristics through a series of equations. One of the examples is as follows:

On soils of loam texture:

f (pH 6.5-7.5; $C < 1$; M_1) = Astragaletum pectinati

f (pH > 7.5; $C > 1$; M_2) = Ast. pect. Distichlis var.

f (pH 6.5-8.0; $C < 1$; M_0) = Ast. pect. eriogonetosum where,

C = total nutrient content expressed as conductivity in mmhos/cm;

M_0 = 10-15% available moisture during brief periods only;

M_1 = 10-15% available moisture during prolonged periods;

M_2 = 15-20% available moisture during prolonged periods.

Sauer and Wilson (1977) attempted to identify plant species that could be utilized as indicators of soil and groundwater conditions for use in terrain evaluation in a prairie environment. Their work, was carried out in the aspen parkland, however, and only their driest sites contain grassland vegetation. They did find that there was a direct correlation between species diversity and soil moisture conditions with larger numbers of species being found in communities on moister sites.

The reclamation literature regarding the relationships between soil and vegetation in the prairies tends to deal with the importance of topsoil in reclamation and the response of various species to extreme chemical characteristics of soils.

Several studies have examined the effects of the presence or absence of topsoil and topsoil thickness on reclamation success in the grasslands (Redente, et al., 1982; Ries, et al., 1977, 1978; Schuman and Power, 1981). These were intended to establish optimum topsoil thickness for reclamation and to provide guidelines that could be used in developing materials handling plans for reclamation. The results of these studies were broadly similar indicating the importance of topsoil in successful reclamation. Redente, et al. (1982) examined the effects of soil thickness over retorted shale on reclamation vegetation composition and production. The shale was found to be an unsuitable plant growth medium and both cover and production tended to increase with increased soil depth to the maximum 90 cm studied. It was also found that production was significantly increased by application of nitrogen and phosphorus fertilizer, but that the grasses tended to increase at the expense of the forbs.

Ries, et al. (1978) found that plots with as little as 5 cm of topsoil spread over sodic mine spoil had significantly greater density and dry matter production of grasses than plots with no topsoil. An increase in topsoil depth up to 30 cm did not result in an increase in cover but did increase production. Fertilizer application was found to increase productivity but did not affect stand density.

Schuman and Power (1981) found that yield increased as total soil thickness (topsoil and subsoil) over sodic spoil increased to between 75 and 100 cm with little difference found between treatments with 20 cm and 60 cm of topsoil.

Looman (1980) maintained that soil fertility has little influence on productivity, but could have a noticeable effect on botanical composition. Looman's view that fertility has little influence on grassland productivity is not fully supported by range fertilization trials. Stoddart, et al 1975), Taylor (1967), and Mitchell (1977) in their reviews of range fertilization studies reported great variation in results but found many instances in which the addition of nutrients has resulted in increased yield.

Other studies have attempted to assess the effects of certain soil characteristics, such as pH and salinity, on the success of revegetation (Sieg, et al., 1983; Kent, 1980, 1981). In examining old mine sites, they were able to identify many instances where reclamation failures or the lack of natural colonization by native plant species could be attributed to adverse soil chemistry. Others have attempted to determine the tolerance of various prairie species to such soil characteristics to determine their suitability for use in specific reclamation situations (Plummer, 1975; Safaya, 1979; Nicholas and McGuinnies, 1982). These studies identify some of the adverse soil characteristics on reclaimed sites and assess the tolerance of reclamation species to these characteristics.

Schuman and Power (1981) maintain that quality of topsoil, referring to its physical and chemical characteristics, can influence reclamation success. The Alberta Soils Advisory Committee (1981) has developed a table indicating acceptable ranges of several soil characteristics for reclamation purposes (Table 1).

Parkinson (1979) discussed the importance of soil biological processes in the ecosystem and how they become disrupted in surface disturbance and reclamation. He suggested that the re-establishment of soil microflora and fauna are important components in successful reclamation.

TOPOGRAPHY-SOIL RELATIONSHIPS

Due to the paucity of literature relating grassland productivity to topography, literature regarding soil-topography relationships was examined in the hope that the same variables might be controlling both. The catena or toposequence is a common concept in soil sciences (Buol, et al., 1980). It refers to a group of soils whose properties vary in accordance with their position on a slope. Buol, et al., acknowledge that such relationships between soil properties and topographic positions do occur but state that "the reasons for these relationships,

TABLE 1

CRITERIA FOR EVALUATING THE SUITABILITY OF TOPSOIL FOR REVEGETATION USE

RATING/PROPERTY	GOOD (G)	FAIR (F)	POOR (P)	UNSUITABLE (U)
Reaction (pH)	6.5 - 7.5	5.5 - 6.4, 7.6 - 8.4	4.5 - 5.4, 8.5 - 9.0	< 4.5, > 9.0
Salinity (mmhos/cm)	< 2	2 - 4	4 - 8	> 8
Sodicity (SAR)	< 4	4 - 8	8 - 12	> 12
Saturation %	30 - 60	20 - 30 60 - 80	15 - 20 80 - 120	< 15, > 120
Stoniness Class	S0, S1	S2	S3, S4	S5
Texture	fSL, vfSL, L, SiL, SL	CL, SCL, SiCL	LS, S, SiC*, C*, HC*	
Consistency of moist sample	very friable, friable	loose	firm, very firm	extremely firm
Modulus of Rupture (bars)**	< 1.0	1.0 - 2.5	2.5 - 5.0	< 5
Organic Carbon %	> 2	1 - 2	< 1	
Calcium Carbonate Equivalent %	< 2	2 - 20	20 - 70	> 70

* Finer textured soils may be upgraded to fair or good in some arid areas.

** Tentative limits only pending further research.

SOURCE: Alberta Soils Advisory Committee (1981).

however, may not easily be seen. They may be because of micro-climatic relationships, water table relationships, vegetative relationships, erosion-deposition, or a combination of these."

Ruhe and Walker in their two papers (Ruhe and Walker, 1968; Walker and Ruhe, 1968) examined hill slopes in both closed and open geomorphic systems (i.e. systems in which the drainage flowed to a central basin in the first instance and systems in which the drainage is comprised of gullies that open onto a larger drainage system thus allowing sediment transport away from the slope in the second). They were able to generate equations to predict certain soil properties (coarse/fine silt ratio, depth to maximum clay, soil thickness, depth to base saturation, depth to > 1% $CaCO_3$, depth to > 1% organic carbon) from slope gradient and distance from hill crest for the slopes examined.

Acton (1965) examined soils on three different glacial landforms and determined that "there appeared to be a relationship between the gradient of the slope segments and the soils occurring thereon, as well as a relationship between the proportion of the different slope segments and the type of landform." He found that different soil types, as indicated by horizon development, corresponded to different slope classes (1-3%, 3-5%, 5-8%, 6-8%, > 8%).

King, et al. (1983) carried out a study similar to Acton's (1965) work and found that the relationship between topography and soils could be explained by the concavity or convexity of the slopes. It was found that slopes could readily be subdivided into convex units, concave units, usually with short rectilinear units connecting them, and depressional units; and that these generally coincided with observable soil divisions, shallow soils on convex segments, deep soils on concave ones, and gleyed soils in depressional areas.

Hanna, et al. (1983) carried out a study on the effect of slope position and aspect on soil water recharge and found significant differences in soil water and soil water recharge related to both aspect and position. Soils on the north facing slope studied were found to be less efficient in recharge of available water than were soils on the south and east slopes examined. Soils on footslopes (the lowest position) were found to be more efficient than those in other positions.

All of these slope studies are quite location-specific and although relationships were determined for the slopes under study, no attempts were made to generalize the results.

OTHER FACTORS AFFECTING PRODUCTIVITY

There is little doubt that the most significant factor influencing general range productivity in any given year is weather, and more particularly the quantity and timing of precipitation (Smoliak, et al., 1986). This can result in changes in production of several hundred percent from year to year. There is no indication that response to weather is likely to severely alter the pattern of productivity within an area, that is the most productive parts of a site are likely to remain the most productive even if total production varies.

Grazing is likely the second most significant factor affecting grassland productivity (Ellison, 1960; Naeth, 1985), both on native and reclaimed sites. The degree to which grazing alters the pattern of productivity within a site is not clear. Grazers are selective in their diet and exert unequal influence on plant species and communities within a site. Similarly increased grazing and trampling tends to occur near water supplies and salt licks, while on the other hand comparatively inaccessible areas, such as steep slopes may be left relatively untouched.

SOIL-TOPOGRAPHY ANALYSIS FOR RECLAMATION PLANNING

Hills (1961) and McHarg (1969) provide methods that can be used to incorporate soil and topographic variables into an assessment of the capability of the undisturbed landscape. Ecological Land Classification, as these methods have come to be called, has been used in many large (Canada Land Inventory, 1965) and smaller scale (Kamar, 1976) studies to identify the relative capability, for a stated use, of different land units.

The McHarg (1969) approach involves either graphically, or mathematically overlaying maps of the environmental variables that are significant in determining the capability of a land unit for the intended use. If the determining variables and their relationship to the intended use are known, it provides a practical method of data handling that is suited to computerized analysis (MacDougall, 1983).

Kent (1980, 1981) developed a method of classifying site units for the assessment of plant growth problems for colliery spoil reclamation. Some 162 site units were identified on 34 abandoned coal spoil sites on the basis of topography, vegetation, and substrate. Ordination and cluster analysis were then used to categorize the site units on the basis of soil and vegetation variables. His intent was to assess plant growth problems associated with colliery spoils across a region.

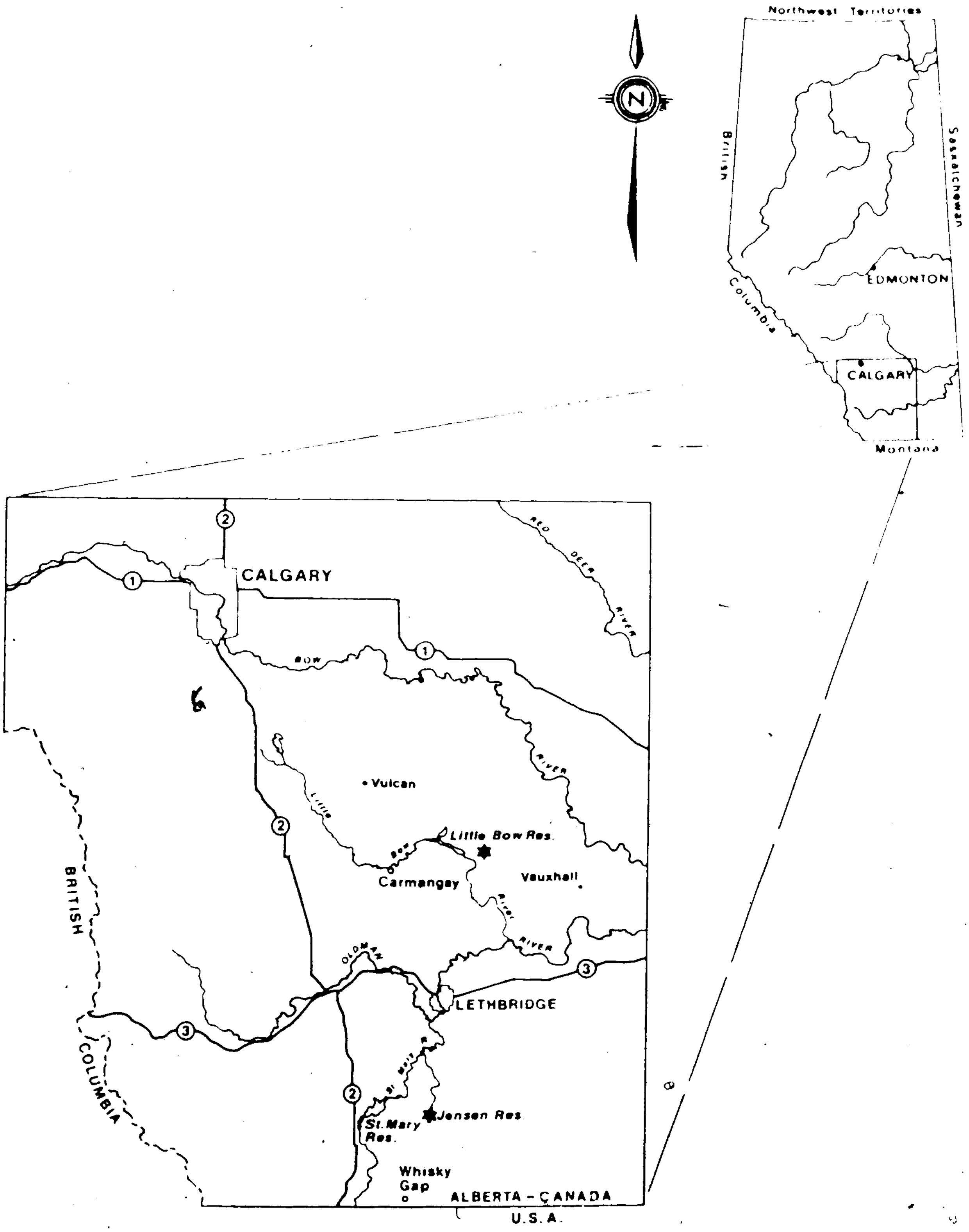
THE STUDY SITES

Two areas of land adjacent to reservoirs in southern Alberta, Jensen Reservoir and Little Bow Reservoir, (Figure 1) were selected for study. They were chosen for several reasons:

1. Both contained areas of relatively undisturbed prairie grassland.
2. Both offered a variety of slopes, aspects and positions that could be studied.
3. They were secure from cattle access, but were still quite accessible for study.
4. Although broadly similar in vegetation, the sites offered sufficient contrast in several characteristics to permit the testing of the generality of all relationships that were observed.

Although both sites are located in the Mixed Prairie Region, as defined by Coupland (1950), Strong and Legatt (1981) subdivide this region into several ecoregions, placing Jensen Reservoir in the Fescue Grass ecoregion near its border with the Mixed Grass ecoregion. Little Bow Reservoir, on the other hand, is located within the Short Grass ecoregion near the boundary with the Mixed Grass ecoregion.

Jensen Reservoir is located on the edge of a landform known as the Milk River Ridge. The ridge is marked by a steep escarpment that rises abruptly from the surrounding plain. The rise generally is approximately 150 to 200 metres over a distance of 3 to 6 kilometres. Jensen Reservoir, at 1,000 m above sea level is well below the summit of



LOCATION PLAN

FIGURE 1

the ridge which is approximately 1,400 m above sea level, and 100 m higher than the nearby town of Magrath.

The Jensen Reservoir area is underlain by sandstones and shales of the St. Mary River and Bearpaw formations (Geological Survey of Canada, 1951) that outcrop in the valley. These are covered by a thick layer of morainal material containing a large number of stones. There has been localized water erosion in the area but no significant post-glacial sorting of material.

The zonal soil is a Black Chernozem (Wyatt, et al., 1939; Canada Soil Survey Committee, 1978) with a well developed Ah horizon and a B horizon with blocky structure.

In the area there is wide variation in the profile development throughout the site due to topographic variation. The soils in the study area generally have a clay loam texture.

The study area has a hilly topography, with the landform conforming to the Open System Hillslope model described by Ruhe and Walker (1968). It is comprised of an upland area dissected by a series of coulees that open onto what was formerly the Pothole Creek Valley, now the Jensen Reservoir. These coulees tend to be aligned in a more or less southwesterly direction. This phenomenon of aligned coulees is common throughout southern Alberta (Beaty, 1975) and may be related to prevailing winds.

Little Bow Reservoir is located in the Eastern Alberta Plain physiographic region at an elevation of approximately 850 masl. The bedrock of this area is made up of sandstones and shales of the Bearpaw formation (Geological Survey of Canada, 1951). This has been overlain by glacial deposits. In the Little Bow Reservoir area, these consist of a blanket of lacustrine and aeolian sands over morainal deposits. The thickness of the sands in the study area varies from approximately 20 cm to in excess of 1.5 m.

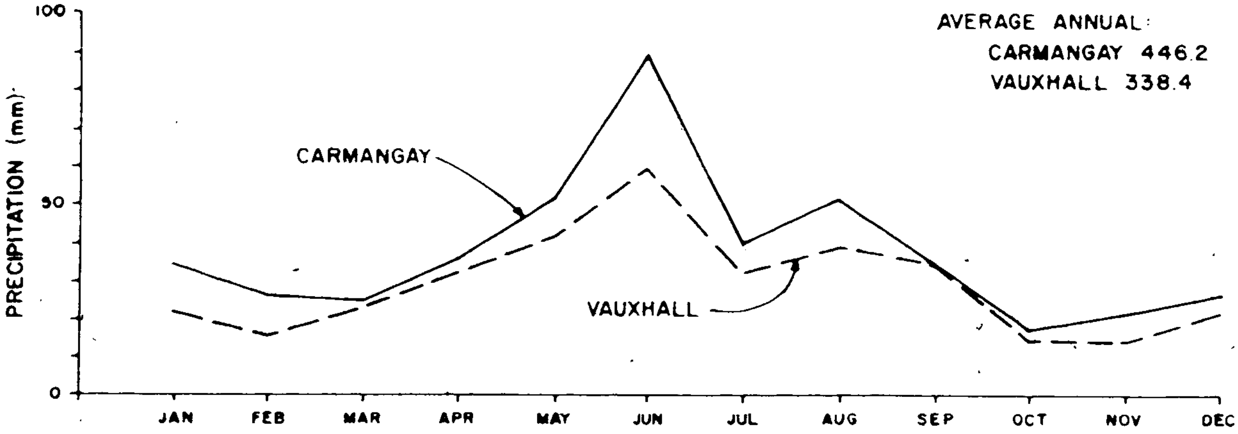
The zonal soil is a Brown Chernozem (Wyatt and Newton, 1925; Canada Soil Survey Committee, 1978) with a fine sand texture. The topography is rolling and horizon development varies to some extent throughout the site.

The hillslopes at Little Bow Reservoir tend to follow the closed model described by Walker and Ruhe (1968) as discussed earlier. The drainage tends to run to local depressions, thus eroded material from the uplands tends to accumulate rather than being transported out of the system.

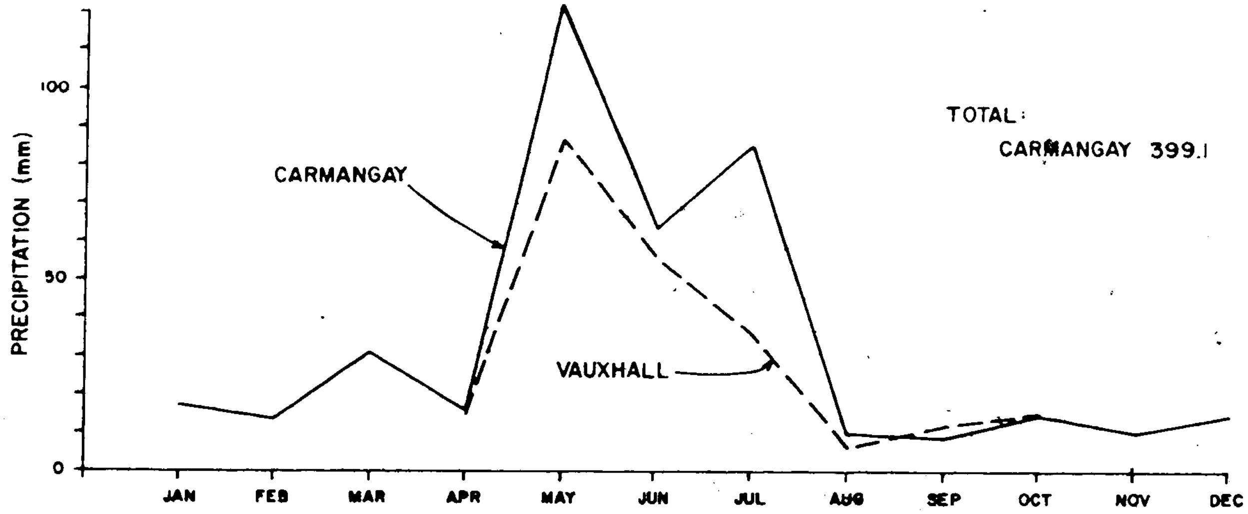
Climate data for the two sites reflects the differences expected from the classification of Strong and Leggatt (1981). Jensen Reservoir is approximately half way between the Lethbridge Airport and Whiskey Gap weather stations. Long-term average, 1981, and 1982 precipitation and temperatures have been graphed for these stations (Figures 2 and 3). The same data have been graphed for the Vauxhall and Vulcan weather stations (Figures 4 and 5), the two closest to the Little Bow Reservoir.

The long-term averages indicate that the Little Bow Reservoir site is somewhat drier and hotter than the Jensen Reservoir site. In 1981, the year before the field studies, both sites experienced higher than average May-June rainfalls. This is the most critical period of rainfall for grass production in the mixed prairie (Smoliak, et al., 1976a; Smoliak, 1986) and should have resulted in higher than average yields when the clipping took place in the spring of 1982. There was no cattle grazing at either site during 1981 or 1982, although there may

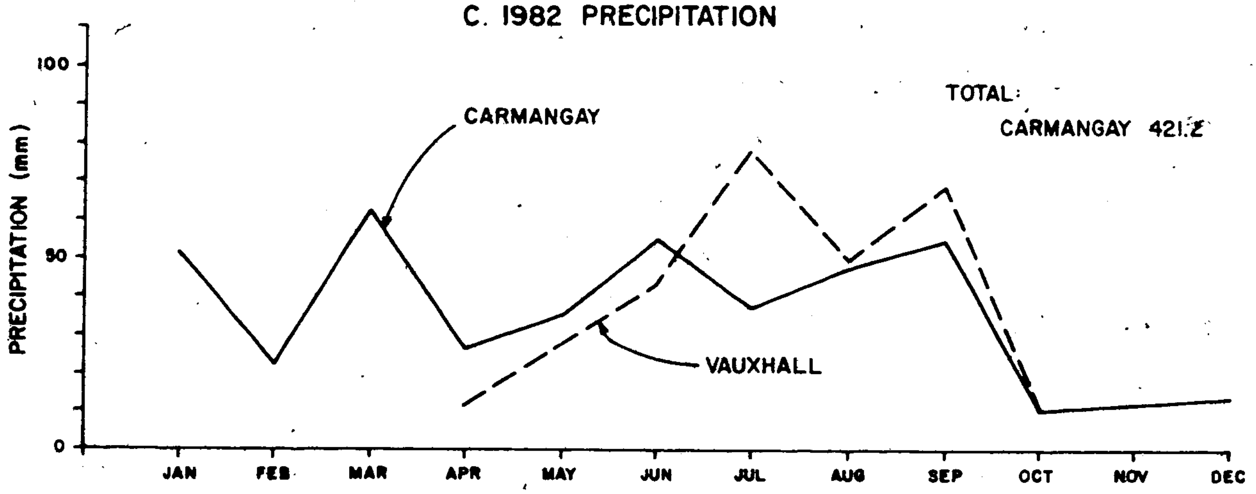
A. LONG TERM AVERAGE PRECIPITATION



B. 1981 PRECIPITATION



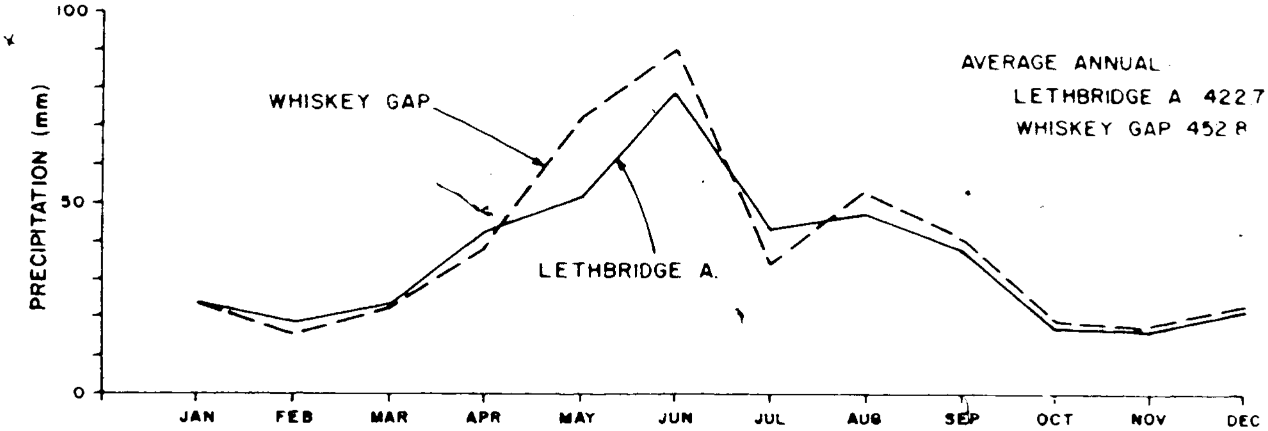
C. 1982 PRECIPITATION



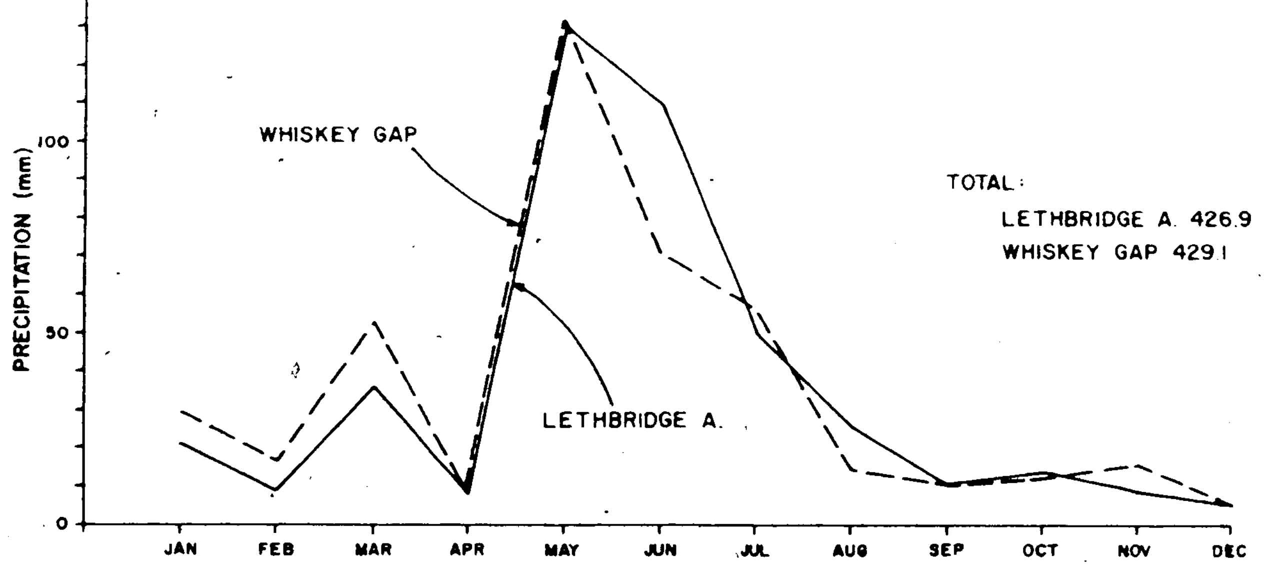
PRECIPITATION-
LITTLE BOW RESERVOIR

FIGURE 2

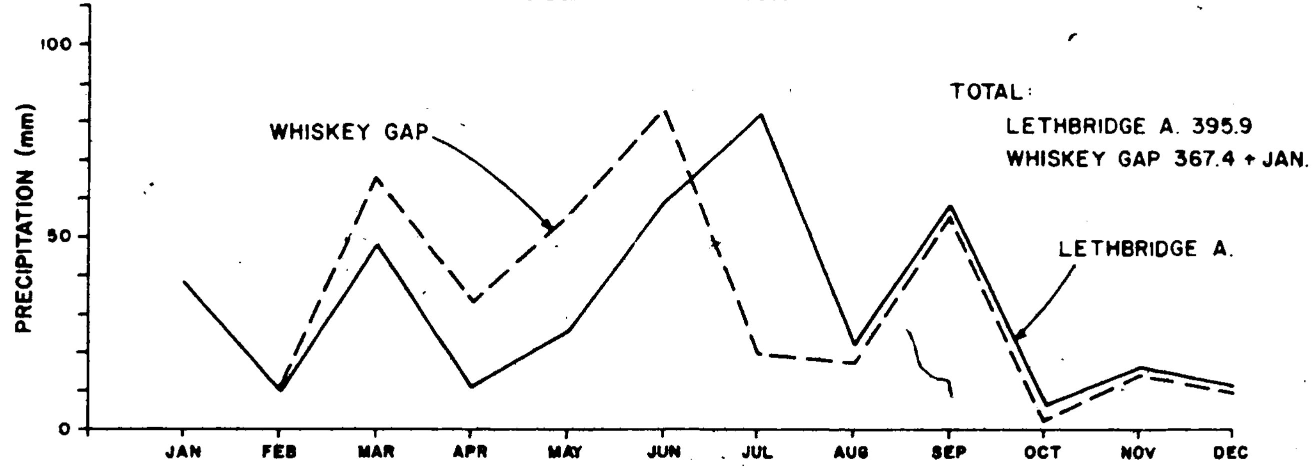
A. LONG TERM AVERAGE PRECIPITATION



B. 1981 PRECIPITATION



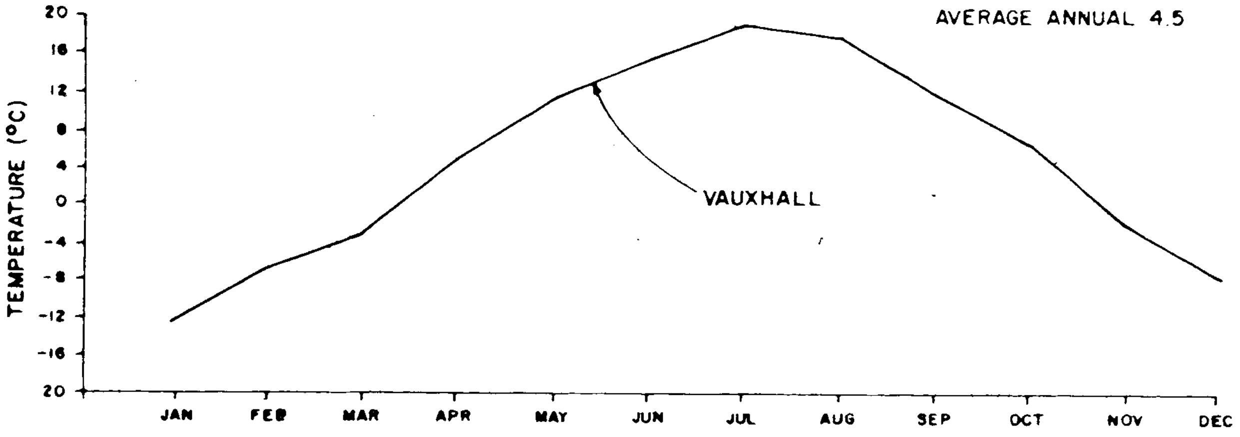
C. 1982 PRECIPITATION



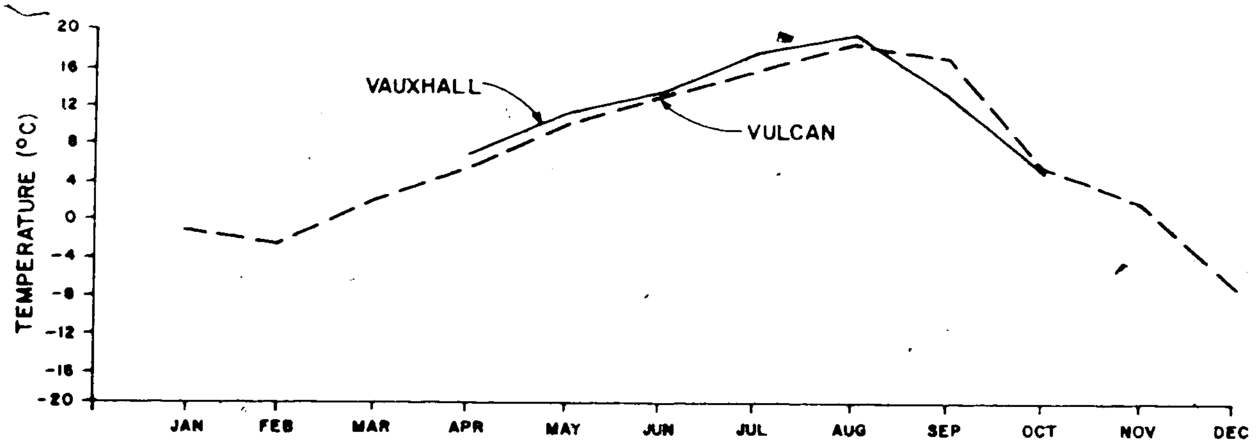
PRECIPITATION-
JENSEN RESERVOIR

FIGURE 3

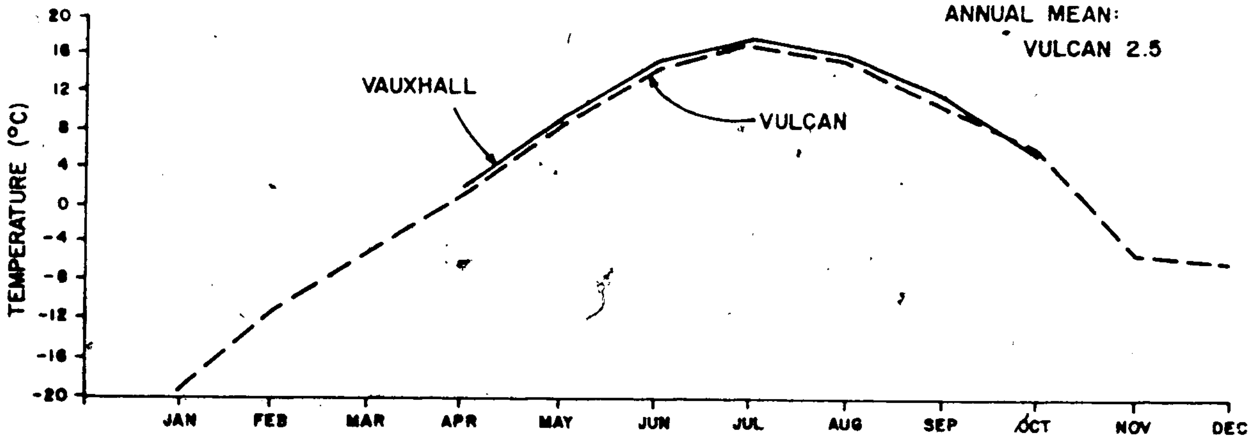
A. 1951-1980 AVERAGE TEMPERATURE



B. 1981 MEAN MONTHLY TEMPERATURE



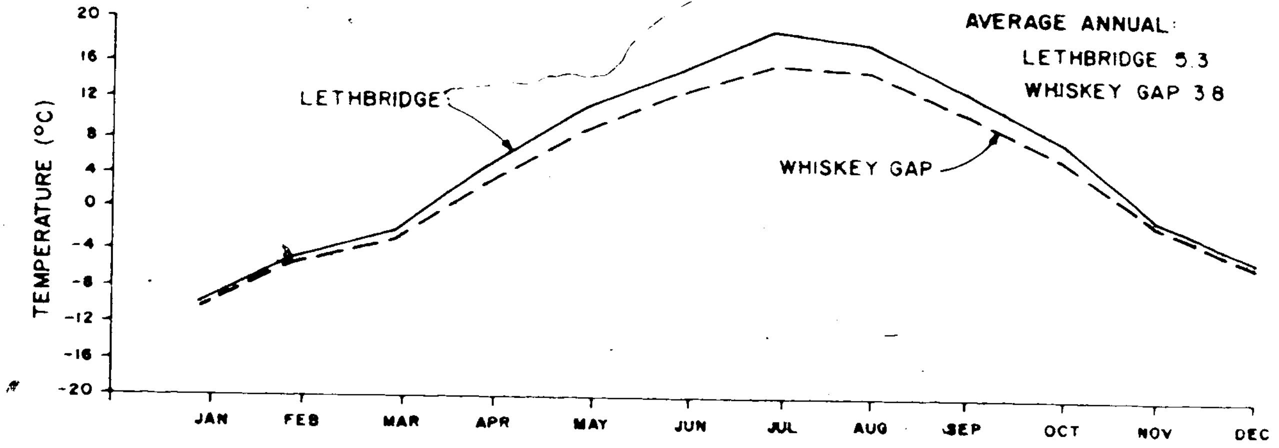
C. 1982 MEAN MONTHLY TEMPERATURE



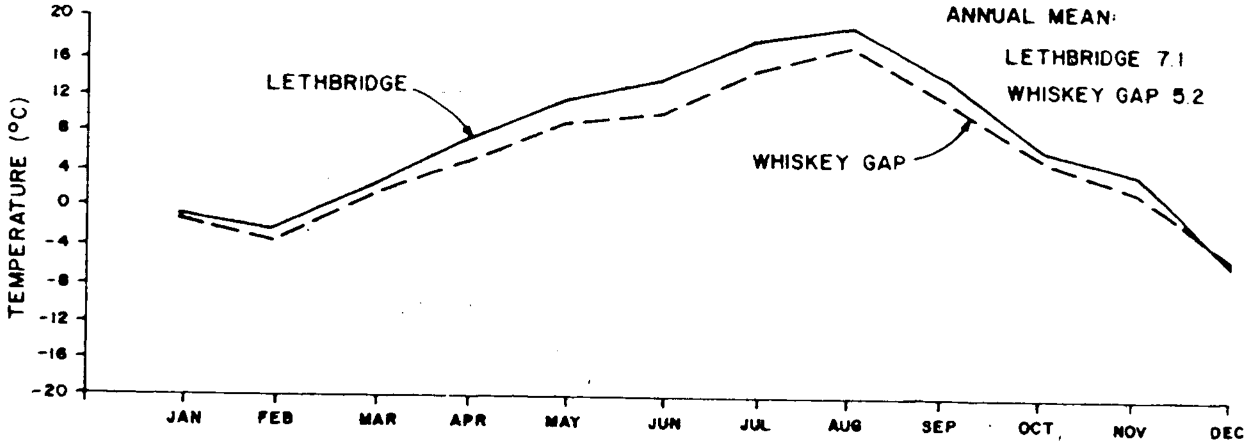
MEAN MONTHLY TEMPERATURE-
LITTLE BOW RESERVOIR

FIGURE 4

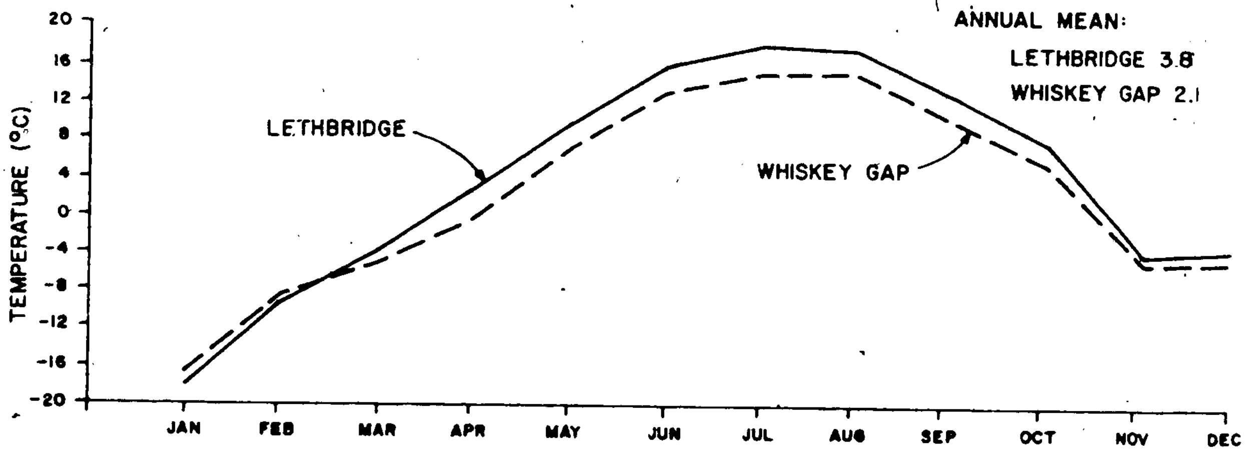
A. 1951-1980 AVERAGE TEMPERATURE



B. 1981 MEAN MONTHLY TEMPERATURE



C. 1982 MEAN MONTHLY TEMPERATURE



MEAN MONTHLY TEMPERATURE-
JENSEN RESERVOIR

FIGURE 5

have been some grazing by wildlife during that period. Rainfall at both sites was below long-term average in 1982 and may have resulted in the relatively low germination rate experienced in the field plots, particularly at the Little Bow Reservoir Site. Summer temperatures at both sites were close to average that year and it is likely these had no undue effect on plot establishment or growth.

The vegetation of both sites has been described by Smreciu and Currah (1981) and Currah, et al. (1982). Species lists for the sites developed from these studies have been supplemented by the author's observations and comprise Tables 2 and 3.

As can be seen, the Jensen Reservoir site has much greater species richness than the Little Bow Reservoir site. This is attributable to the greater topographic variation at the Jensen Reservoir site resulting in the creation of a much larger range of edaphic conditions, the slightly less harsh climatic conditions of the site, possibly more favourable soil conditions, and to differing grazing histories. Although fenced off during the course of this study, the Little Bow Reservoir site had been heavily grazed in the past. Prior to 1981, it was part of a large grazing reserve.

The Jensen Reservoir site, on the other hand, is only a fragment of grassland, largely surrounded by cropland. At most, it receives only sporadic use by stray cattle and wildlife.

TABLE 2

SPECIES PRESENT, LITTLE BOW RESERVOIR

Agropyron cristatum
Allium textile
Androsace septentrionalis
Artemisia campestris
Artemisia frigida
Artemisia ludoviciana
Astragalus pectinatus
Bouteloua gracilis
Bromus inermis
Carex filifolia
Chrysopsis villosa
Cirsium canadensis
Cirsium vulgare
Comandra pallida
Descurania sophia
Draba species
Erigeron caespitosus
Erysimum inconspicuum
Eurotia lanata
Gaura coccinea
Grindelia squarrosa
Gutierrezia sarothrae
Haplopappus spinulosus
Hordeum jubatum
Koeleria cristata
Lepidium densiflorum
Lesquerella arenosa
Liatris punctata
Linum rigidum
Lithospermum incisum
Lithospermum ruderale
Mamillaria vivipara
Musineon divaricatum
Parmelia chlorochroa
Penstemon albidus
Phleum pratense
Phlox hoodii
Poa species
Ratibida columnifera
Rosa arkansana
Selaginella densa
Solidago species
Sphaeralcea coccinea
Stipa comata
Taraxacum officinale
Thermopsis rhombifolia

NOTE: Nomenclature according to Moss (1983).

TABLE 3

SPECIES PRESENT, JENSEN RESERVOIR

Achillea millefolium
Agoseris glauca
Allium cernuum
Allium textile
Anemone multifida
Anemone patens. var. wolfganginana
Antennaria species
Arenaria congesta var. lithophila
Artemisia absinthium
Artemisia campestris
Artemisia frigida
Artemisia ludoviciana
Aster laevis var. geyeri
Aster pansus
Aster species
Astragalus drummondii
Astragalus flexuosus
Astragalus striatus
Astragalus triphyllus
Besseya cinerea
Bouteloua gracilis
Bromus inermis
Carex filifolia
Cerastium arvense
Chrysopsis villosa
Cirsium vulgare
Comandra pallida
Cryptantha macounii
Delphinium bicolor
Dodecatheon conjugens
Draba nemorosa
Erigeron caespitosus
Eriogonum flavum
Festuca scabrella
Fritillaria pudica
Gaillardia aristata
Galium boreale
Gaura coccinea
Geranium viscosissimum
Geum triflorum
Glycyrrhiza lepidota
Guttierezia sarothrae
Happlopapus spinulosus
Hymenoxys acaulis
Hymenoxys richardsonii
Liatris punctata
Linum lewisii
Lithospermum ruderale
Lithospermum incisum
Lomatium simplex
Lupinus argenteus
Mamillaria vivipara
Medicago sativa
Melilotus alba
Melilotus officinalis
Musineon divaricatum
Oxytropis sericea var. spicata
Parmelia chlorochroa
Paronychia sessiliflora
Penstemon confertus
Penstemon nitidus ?
Petalostemon purpureum
Phleum pratense
Phlox hoodii
Poa species
Potentilla concinna
Potentilla effusa
Rabitida columnifera
Rosa arkansana
Rosa woodsii
Senecio canus
Silene noctiflora
Sisyrinchium montanum
Solidago mollis
Solidago rigida
Stipa comata
Symphoricarpos occidentalis
Taraxacum officianle
Thermopsis rhombifolia
Townsendia sericea
Tragopogon dubius
Trifolium hybridum
Vicia sparsifolia
Viola adunca
Viola vallicola
Zygadenus gramineus

NOTE: Nomenclature according to Moss (1983).

MATERIALS AND METHODS

THE STUDY DESIGN

As reclamation planning involves separate handling of vegetation, soil and topography, a study design was developed that attempted to isolate the effects of each in determining productivity. Field plots were established where topography and soil characteristics were measured and native grassland productivity measured in order to examine the relationships. To eliminate the effect of species composition on productivity and to simulate a reclaimed landscape, field plots were established at the native vegetation sampling locations. These were planted to a single species (Agropyron cristatum). It was hypothesized that the monoculture would demonstrate a greater response to environmental variables than the native grassland. This is due to the fact that in a monoculture, the species selected would be forced to adapt to a wide range of environmental conditions, many of which would be less than optional for its productivity; whereas in a native grassland, natural selection would be expected to result in a species composition that was changed and adapted to varying conditions throughout the site.

The field plots were split in half and 15 cm of topsoil removed from one of the subplots prior to seeding. Stripping the subplots permitted the examination of the effects of topography on productivity, without the effect of topsoil. This is acknowledged to be an imperfect test as soil characteristics in the areas where the field studies were carried out do not vary abruptly with depth; that is, B horizon material shares many characteristics with A horizon material. It was felt, however, that if topsoil did play an important role in determining productivity that an effect, due to its removal, would be detected.

Finally, the topsoil that was removed from the field plots was used in greenhouse trials. The same species that had been planted in the field was planted in pots in the greenhouse. This was done in an attempt to assess the productivity of the soils in the absence of the effects of topography and species composition. By comparing this with the field data, it was hoped that some assessment could be made of the relative contribution of soil and topography to productivity.

VARIABLES ASSESSED

The literature review suggested directly or indirectly several topographic variables that might be significant in the determination of grassland productivity. A number of these were selected for assessment in this study.

A) Slope Angle or Steepness

Most other studies examined utilized slope classes based on a range in percent slope (vertical distance/horizontal distance x 100) herein referred to as Slope. McHarg (1969) used classes of 0-5%, 5-15%, 15-25%, > 25%. Acton (1965) found 1-3%, 3-5%, 5-8%, > 8% to be useful classes for soil classification. Kent (1980, 1981) used < 4%, 4-8%, 8-15%, 15-30%, > 30%. As no common basis for categorization could be found, slope in this study was simply measured and recorded to the nearest percent with an Abney level over a 10 m slope segment.

Productivity was expected to decrease with increased slope.

B) Slope Position

Two measurements of slope-position were taken in this study. The first was simply distance of the plot from top of slope as used by Ruhe and Walker (1968) and Hanna, et al. (1973). While this measurement had been shown to be meaningful in studies of characteristics relating to individual slopes, the author felt that an index that adjusted for the length of a slope might be more generally meaningful. Consequently, proportional distance downslope (distance of plot from top of slope/total slope length) was also measured. Distances were measured in metres with a 50 m tape measure. Based on the literature review, it appeared likely that the minimum productivity would be at the shoulder of the slope (the slope break) with productivity generally increasing downslope.

C) Aspect

Aspect, or the direction a slope is facing, was also measured in two ways. The first was with a due south slope given a value of 0° and a due north slope 180°. Aspect was measured as degrees of deviation from true south. Thus, the east and west slopes both had a value of 90°. This is the method used by Duffie and Beckman (1974) for the calculation of solar energy striking a plane. This was to be a measure of solar exposure. Since Ayyad and Dix (1964) found the maximum contrast in vegetation to be between southwest and northeast slopes, for the purpose of comparison, a second aspect, in which the scale was rotated such that southwest was 0° and northeast 180°, was calculated for each sampling station. It was expected that maximum productivity would be found on northeast facing slopes.

Field measurements were taken with a hand compass correcting for magnetic declination and recorded to the nearest degree.

D) Slope-Aspect Composites

Slope and aspect interact in their effect on microclimate. In an attempt to deal with this interaction, three different indices combining slope and aspect were calculated. These were:

1) A composite variable based on the following equation from Duffie and Beckman (1974), intended to give the angle of incidence of beam radiation from the sun striking a plane.

$$\begin{aligned}\cos i = {} & \sin d \cos l \cos s - \sin d \cos l \sin s \cos a \\ & + \cos d \cos l \cos s \cos w + \cos d \sin l \sin s \cos a \\ & \cos w + \cos d \sin s \sin a \sin w\end{aligned}$$

where, l = latitude

d = declination

s = slope

a = the surface azimuth angle, that is, the deviation of the normal to the surface from the local meridian (the aspect), the zero point being due south, east positive and west negative.

w = hour angle, solar noon being zero, and each house equalling 15° of longitude with mornings positive and afternoons negative.

i = the angle of incidence of beam radiation, the angle being measured between the beam and the normal to the plane.

By restricting the comparison to solar noon, the equation becomes somewhat simplified:

$$\cos i = \sin d \cos l \cos s - \sin d \cos l \sin s \cos a + \cos d \cos l \cos s + \cos d \sin l \sin s \cos a$$

By selecting a date when declination is equal to zero, the equinox, the equation is further simplified:

$$\cos i = \cos l \cos s + \sin l \sin s \cos a$$

While the selection of this date is arbitrary and not necessarily the most appropriate, if the principle is sound, the relationship should be apparent.

2) Equivalent latitude based on an equation from MacDougall (1983)

$$E = \arcsin [(\sin s \cos a \cos l) + (\cos s \sin l)]$$

where, E = equivalent latitude

s = slope

a = aspect

l = latitude

3) An intuitively generated slope-aspect composite based on the fact that it appears that slope steepness amplifies the microclimatic characteristics related to aspect. That is, they serve to make south or southwest slopes hotter and drier than would otherwise be the case and make north and northwest slopes cooler and moister. Using this principle, the following equation was developed.

$$c = s/100\,[a - 90]$$

where, c is the slope aspect composite

s is the slope in percent

a is the aspect measure in degrees from south.

These indices were calculated for both the south normal and southwest rotated aspect data resulting in a total of six values for each sampling station.

E) Topographic Shape

The topographic shape variables utilized were based on Ruhe and Walker (1968) who distinguish between vertical and horizontal shape identifying nine basic slope geometries: "(1) linear, convex, or concave slope width with linear slope length; (2) the same slope widths with convex slope length and (3) the same slope widths with concave slope length."

Slope length refers to the line described by a cross-section through a slope taken at right angles to the contour. Vertical shape refers to the concavity or convexity of that cross section. While Ruhe and Walker only identify three shapes - linear, convex and concave, a five-point scale was used in this study with 1 being highly convex, 2 somewhat convex, 3 linear, 4 somewhat concave, and 5 highly concave. Subjective estimates were made to the nearest 0.5.

Slope width is defined by the contour line running through the point in question and horizontal shape refers to the concavity or convexity of that contour line. As with vertical shape, in this study a five-point scale was used to describe horizontal shape rather than the three categories used by Ruhe and Walker.

In addition to the two individual measurements of topographic shape, two composite indices were calculated. These were:

i) An additive composite slope shape index defined by the equation:

$c = h + v$

where, c = the composite index

h = the horizontal shape

v = the vertical shape

ii) A multiplicative composite slope shape index (C_2) defined by

$C_2 = hv$

It was expected that productivity would increase with increasing concavity in both vertical and horizontal shape as well as in the composites.

Ten soil variables were utilized in this study. These included the same variables used by Currah, et al. (1982) in their study of Little Bow, Jensen and eight other southern Alberta sites. An additional variable, sulphur, was added to those used by Currah, et al., for Little Bow Reservoir. This was at the advice of an Alberta Agriculture soil scientist who had found that some soils in the area have a sulphur deficiency. All soil analysis was performed by the Alberta Agriculture Soil and Feed testing laboratory in Edmonton.

The variables tested for included:

A) Soil Texture

Looman (1980) and Coupland (1950) both observed that soil characteristics relating to water retention and availability significantly affected species composition in the mixed prairie. Thus, soil texture and soil organic matter content would be expected to influence productivity within a site. Optimum soil texture would be associated with soils of fine loam texture (silt loam, or very fine sandy loam) which would store the greatest amount of available water between rainfall events (Longwell, et al., 1963). Coarser textured soils would not retain as much water and finer textured soils would lose most to runoff. Thus, productivity would be expected to increase as texture becomes finer until ideal texture is reached then drop off.

Texture was determined subjectively by laboratory personnel on a five-point scale ranging from very coarse to very fine.

B) Organic Matter Content

Organic matter tends to improve soil structure increasing infiltration and moisture retention, and is also the major reservoir of available nitrogen and phosphorus in the soil (Black, 1968). The expected relationship would be an increase in productivity towards a maximum as soil organic matter content increased, followed by a levelling off.

C) pH

Looman (1980) identified pH as a determinant of species composition but not necessarily productivity. He was dealing, however, with a relatively narrow range of pH. More extreme pH values are known to interfere with nutrient uptake with extremely low values leading to aluminum toxicity (Black, 1968). It is to be expected, then, that productivity-pH relationships would be detected only where the values were significantly outside the mid-range (6.5-7.5).

D) Electrical Conductivity

Electrical conductivity is generally taken as a measure of soil salinity with any value in excess of 2 mmhos/cm indicating a salt content sufficient to interfere to some degree with osmosis (Alberta Soil Advisory Committee, 1981). Looman (1980) used electrical conductivity, at low levels, as an indication of nutrient status. If his assessment is accurate, productivity would be expected to increase as electrical conductivity increased to somewhere between 2 and 3 mmhos/cm and then decrease as salinity effects on osmotic phenomena became significant.

E) Free Lime

High levels of free lime have been shown to interfere with phosphorus availability (Tisdale and Nelson, 1975); thus, productivity would be expected to decline with increasing levels. The laboratory results report levels according to an arbitrary scale ranging from nil to high levels of free lime in a soil sample.

F) Nitrogen, Phosphorus and Potassium

The three main plant nutrients - nitrogen, phosphorus and potassium - were tested for. As these nutrients cannot substitute for one another, a low value in any of the three would be expected to limit productivity. Soil test results expressed elemental concentration of nutrients in the soil samples. An interpretation sheet provided within the soil test results indicated when concentrations of nutrients in the soil would be considered low, medium and high. For nitrogen and phosphorus concentrations in excess of 25 ppm would be considered high and for potassium a high concentration would be over 150 ppm.

G) Sulphur

Analysis for sulphate-sulphur was made on soil samples from Little Bow Reservoir at the recommendation of an Alberta Agriculture soil scientist as some soils in the area were known to have a sulphur deficiency. Results were expressed as ppm of elemental sulphur with values of greater than 12.5 ppm being considered high.

H) Sodium

Sodium is an essential micro-nutrient for at least some grassland plant species (Brownell and Wood, 1957), but at higher concentrations has an adverse effect on soil structure (Black, 1968). The laboratory classified sodium content on a subjective scale from nil to high. On native grassland, productivity was expected to increase as sodium increased from nil to low and decrease with increasing sodium concentrations.

FIELD STUDIES

Field studies involved sampling soil, vegetation and topographic variables at 54 stations divided between the two sites. The stations were comprised of sets of three selected from upper, mid, and lower slope positions on a given slope. A minimum of two sets of stations from slopes having aspects roughly representing N, S, E, and W were established at each site, thus requiring a minimum sample size of 48 stations (3 positions x 4 aspects x 2 sets x 2 sites). Areas with woody vegetation were avoided. At Little Bow Reservoir, stations were established on every slope within the area available for study. Due to the topography, two sets of stations were set up on one slope as it was the only slope with an easterly aspect available. There were, however, two additional slopes with southerly aspects available and stations were established on both of these. As a result, 30 stations were established at Little Bow Reservoir.

At Jensen Reservoir, slopes on which stations were to be established were selected by starting at the access road and walking north along the area available for study and establishing stations on each available slope until the minimum sample size had been attained. Thus, 24 stations were established at Jensen Reservoir, resulting in a total of 54 stations between the two sites.

Due to the topography, it was not possible to select true N, S, E, and W aspects, for all slopes at either site, but it was possible to locate slopes roughly corresponding to each of these compass points (± 20°).

Once a slope was selected for sampling, the sampling stations were established. For upper slope positions, this was done by walking to the approximate shoulder of the slope and, with eyes closed, tossing a spike with a long survey flagging tail. The land point of the spike became the centre of the downhill boundary of a 1.0 x 2.0 m plot with the long axis running perpendicular to the slope. The plot was staked out with 25 x 50 mm wooden stakes and labelled. The procedure was repeated in the mid and lower slope positions with the plots being roughly in line downslope from each other. Each plot was assigned a unique identifier comprised of a letter code for the site (L for Little Bow, J for Jensen), another for the aspect (N, S, E, or W), a third for slope position (U for upper, M for mid-slope, and L for lower slope), and a digit to differentiate the replications. This same four character identifier was retained throughout the field studies, greenhouse studies, and soil analysis.

Measures of slope gradient, slope aspect, distance from the top of the slope, horizontal slope shape, and vertical slope shape were taken at each station. In addition, the total slope length to the bottom of the depression, or, where relevant, to the reservoir water level was measured and recorded.

VEGETATION SAMPLING

All above-ground vegetation (including standing litter and living vegetation) from each of the 54 stations was clipped at a height of 15 mm using hand shears, bagged, and labelled. Sampling was carried out on May 15 and 16, 1982 at Little Bow Reservoir and May 17 and 18, 1982 at Jensen Reservoir. As sites with woody vegetation were avoided, the samples consisted almost exclusively of grasses and forbs. These samples were air-dried for a period of four weeks and weighed.

SOIL SAMPLING

The 1 x 2 metre field plots were subdivided into two 1 x 1 metre sub-plots. One of each pair of sub-plots was selected by coin toss for soil sampling. The top 15 cm of soil was removed from each selected sub-plot. This is the depth of soil normally removed in stripping operations associated with surface disturbances. This is also the standard depth of sampling utilized by the laboratory that carried out the soil analysis. It was generally comprised of A horizon material, but in some cases included B horizon as well. Twenty litres of the soil from each of these plots was placed in plastic buckets and subsequently utilized in the greenhouse trials. Sub-samples (500 ml) were taken from each bucket, dried and sent to the Alberta Agriculture Soil and Feed Testing Laboratory for analysis. Tests for available nitrogen, phosphorus and potassium, pH, electrical conductivity, sodium, free lime, texture, and organic matter were carried out on all samples. In addition, on the advice of an Alberta Agriculture soil scientist, the samples from Little Bow Reservoir were analyzed for sulphate sulphur, as some soils in the area were known to have a sulphur deficiency.

FIELD PLOTS

Both the subplots from which the topsoil had been stripped and those in which it was retained were roto-tilled to depth of approximately 15 cm. Thus, they were intended to represent disturbed sites on which no topsoil replacement has been carried out and disturbed sites on which 15 cm of topsoil has been replaced, respectively.

Five grams of crested wheatgrass (Agropyron cristatum, cv. Fairway) were scattered on each 1 x 1 m sub-plot (a rate equivalent to 50 kg/ha), and raked in. The species was chosen because of its extensive use for reclamation throughout the region and documented tolerance for a wide range of soil and moisture conditions (Watson, et al., 1980). The seeding rate was two and one-half times the 20 kg/ha that is recommended by Schiechtl (1980) for reclamation purposes but was utilized in an attempt to achieve quick establishment of grass and limit weed competition.

The Jensen Reservoir plots were seeded on May 29, 1982; the Little Bow Reservoir plots were seeded on May 30, 1982. Ninety-two days after seeding, all above-ground vegetation (including volunteer growth) on the

Jensen Reservoir subplots was hand clipped, bagged, and labelled. The Little Bow Reservoir plots were clipped 97 days after seeding. The samples were oven-dried at 42°C for 24 hours and the contents of the bags weighed.

GREENHOUSE TRIALS

The soil collected from each station was used to fill 54 sets of eight standard 15 cm diameter plastic greenhouse pots to a depth of 12.5 cm. Large stones, lumps, and pieces of organic matter were excluded from the pots but no attempt was made to sift or screen the soil as texture was one of the variables being examined. An additional 8 pots were filled with the standard potting mixture used in the University of Alberta greenhouses. This made a total of 440 pots.

Four greenhouse benches were used in the trials. Eleven double rows, 5 pots long, were set up on each bench (see Appendix A), creating 55 possible pot locations on each bench. A site identifier was randomly assigned to each of the locations. Fifty-four cards with the site identifiers written on them and one blank were shuffled and one placed on each location. Two pots of the soil from each station thus identified were placed at each location.

Forty seeds of <u>Agropyron cristatum</u>, cv. Fairway, were planted in each pot (this is a rate approximately equivalent to that used in the field plots).* These were stirred in slightly with a stick and the soil surface lightly compacted by hand.

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* Calculation.
$(15\text{ cm}/2)^2 \times 5\text{ gm}/1\text{ m}^2 \times 1\text{ m}^2/10{,}000\text{ cm}^2 \times 400\text{ seeds/gm} = 35.3$
15 cm = pot diameter
Number of seeds per gm from Schiechtl (1980).

All pots were watered daily for one week following seeding, at which time all showed good germination. Following this, half of each double row was watered daily (wet treatment), the other half every second day (dry treatment).

The number of pots precluded the precise metering of quantity of water applied, but was approximately 150 ml/pot/watering. Spot-checks were done to assure that the soil on the bottom of the pots was becoming moist without undue flowthrough of water. Under the greenhouse conditions, the soil in the pots watered daily generally did not dry out and was more or less constantly moist. On the other hand, the soil in the pots watered every second day was generally dry when it came time to water again ~~and~~ the plants were often beginning to wilt.

The first watering was done on June 7, 1982. Any broad-leaved plants were removed as soon as they emerged. No grasses other than the planted species were found to be growing in any of the pots. After 92 days, the grass in each pot was clipped at 15 mm, cut into approximately 5 cm lengths, bagged, and labelled. All the samples were dried at 42°C for 24 hours and weighed.

DATA ANALYSIS

All statistical analysis was done on the University of Alberta computer utilizing the SPSSX software (SPSS INC. 1983). The data were written on coding sheets and entered into two computer files. One consisted of greenhouse data and indicated the following for each pot:

1) Replicate.

2) Row on bench.

3) Treatment (wet or dry).

4) Plot identifier of station from which soil was taken.

5) Number of stems at harvest (culms and tillers).

6) Dry weight of harvested material.

The other data file included the following for each sampling station:

1) Plot identifier (comprising site, aspect, slope position, and replicate number).

2) Slope (in percent).

3) Compass bearing (in degrees).

4) Distance from top of slope.

5) Length of slope.

6) Horizontal slope shape.

7) Vertical slope shape.

8) Dry weight of material harvested at the beginning of the study (representing 2 m²).

9) Dry weight of material harvested from topsoiled 1 x 1 m sub-plot in the fall.

10) Dry weight of material harvested from non-topsoiled 1 x 1 m sub-plot in the fall.

11) Dry weight of the material harvest in the greenhouse trials (dry treatment) for the four replicates using soil from the station.

12) The number of stems at the time of the harvest in the greenhouse trials (dry treatment) for the four replicates using soils from the station.

13) The same values as described in 11 and 12 for the wet treatment.

14) Soil test data for the soil collected at the station, including (nitrogen, phosphorus, potassium, sulphur, pH, electrical conductivity, sodium, free lime, texture, and organic matter content.

The data analyses were intended to examine the effects of the soil and topographic variables on productivity both as single independent variables and in combination. In handling the data, results from the Little Bow and Jensen sites were examined separately. Although splitting the results reduced the number of degrees of freedom for statistical analysis, it was not valid to lump them. Data from the two sites are not homogeneous. Splitting the results did, however, permit independent confirmation of results. There was greater confidence in relationships detected at both sites than in those observations restricted to one location.

The Pearson Product-Moment Correlation was used to examine relationships between pairs of variables. Significance levels were computed for each correlation coefficient. For all cases where the significance of the correlation coefficient was less than 0.05, scattergrams of the relationships were plotted and the least squares regression line calculated. The scattergrams were intended to aid in the detection of non-linear relationships and possible outliers, to facilitate possible data transformation and thus refinement of the computed relationships.

Topographic and soil variables whose correlation coefficient with initial harvest, non-topsoiled harvest, or topsoiled harvest was calculated to have a probability of significance of less than 0.05, were selected for use in multiple regression analysis. Multiple stepwise regression used initial harvest, topsoiled plot harvest and stripped-plot harvest as dependent variables. Topographic and soil factors were used as independent variables in the analysis, both separately and in combination. A maximum probability for F of 0.05 was used at each step of the regression analysis for inclusion of variables into the equation. Multiple R and R square values were calculated for each step of the analysis.

Due to obvious interrelationships among many of the variables, it was decided to carry out Principal Components Analysis (described by Harris, 1975) utilizing those variables selected as independent variables in the multiple regression analysis. Topographic and soil factors were analyzed, both independently and in combination, utilizing the procedures of principle component analysis with a varimax rotation method. Principal components were extracted and factor loadings computed for each of the variables in the analysis. Factor scores were computed for each case in the data file. The extracted principal components were then used as independent variables in regression analysis with initial harvest, and topsoiled and non-topsoiled harvest as dependent variables.

Similar regression analyses were carried out with soil texture and organic matter content as dependent variables and topographic factors as independent variables.

Analysis was also carried out with the greenhouse data using wet and dry treatment productivity, separately as the dependent variable and soil characteristics as the independent variables.

MODEL DEVELOPMENT AND APPLICATION ASSESSMENT

From the multiple regression analyses, an equation was developed that would predict productivity on the basis of soil and topographic variables. The selection of the variables was based in part on their predictive value as released by the data analysis and in part on the ease with which they could be incorporated into the reclamation planning process.

A case study involving the preparation of a reclamation plan for a borrow area in southern Alberta was conducted utilizing the equation that had been developed as a working model. The case study was not designed to test the validity of the model, but to examine how such a model might be incorporated into the reclamation planning process and the value it might have in that process.

RESULTS AND DISCUSSION

PRODUCTIVITY

Table 4 presents the mean productivity data for the field and greenhouse studies. A more detailed summary of productivity data is presented in Appendix B (Table B-1). As expected by the differences in climate, the initial harvest revealed the Jensen Reservoir site to be more productive than the Little Bow Reservoir site. There is a wide range in productivity among the stations at both sites (700% at Jensen, 1,000% at Little Bow). If this within-site variation is attributable to local topography and soils, it gives an indication of the potential for increasing or reducing the productivity of a site through site disturbance and reclamation.

One problem did occur with the field plantings. No weed control was carried out and the harvested vegetation on several plots included a large number of weeds. This was most pronounced at Little Bow Reservoir where the grass germination was very poor and some of the plots were dominated by large, highly productive weeds such as Russian thistle (*Salsola kali*) and wild tomato (*Solanum triflorum*). The effect of this can be seen in the wide ranging data and high mean productivity recorded at the Little Bow Reservoir plots (Table B-1). It should be noted that despite the large difference in mean productivity in the field plantings between the two sites, this difference was not found to be statistically significant.

Although the stripped plots were depressed and consequently had a somewhat more favourable micro-climate than the adjacent topsoiled plots, they consistently yielded lower quantities of biomass than the

TABLE 4

MEAN PRODUCTIVITY OF FIELD PLOTS AND GREENHOUSE TRIALS

SAMPLING	YIELD JENSEN RESERVOIR	 LITTLE BOW RESERVOIR
FIELD (g/m^2)		
Initial Harvest of Standing Crop and Litter**	405.6	138.4
Topsoiled Plot Harvest	72.7	174.7
Stripped-Plot Harvest	50.2	31.4
GREENHOUSE (g/pot)		
Wet Treatment**	2.49	2.12
Dry Treatment	1.71	1.73

** Denotes a highly significant difference ($p < 0.01$) between sites.

topsoiled plots. This supports the findings of Redente, et al. (1982), Reis, et al. (1977, 1978) and Schuman and Power (1981) regarding the importance of topsoil in reclamation.

In the greenhouse trials, it was found that there was a significant difference in the productivity of soils from the two sites in the wet treatment but not in the dry treatment (Table 4). It is reasonable to conclude, therefore, that differences in soil fertility between the two sites are only apparent under certain growing conditions. Where environmental factors, in this case water supply, restrict growth the differences in soil fertility between the two sites do not affect productivity to any measurable degree. This suggests that differences in productivity observed in the field studies between the two sites may be dependent not on soil fertility but on climatic and topographic variations.

There was, however, a large variation in the productivity of soils from different locations within each site in both wet and dry treatments (Table 5).

There was a strong correlation, at the Jensen Reservoir site (Table 6), between initial May harvest and harvest from both topsoiled and stripped-plot regrowth treatments in the field trials. This was not found to be the case with the Little Bow Reservoir data (Table 7). The fact that this relationship was not found at Little Bow Reservoir is believed to be a result of the weed growth masking the results, as discussed above. The strong correlations between initial growth and regrowth at Jensen Reservoir suggest that the factors controlling the productivity of native vegetation are, by and large, the same as those controlling the establishment and growth of reclamation plant material.

TABLE 5

BREAKDOWN OF GREENHOUSE PRODUCTIVITY DATA BY WATERING TREATMENT AND SOIL SOURCE

TREATMENT	SOIL SOURCE	NO. OF SOILS	PRODUCTIVITY (g/pot) MINIMUM	MEAN	MAXIMUM
Wet	Little Bow	30	1.18	2.12	3.91
	Jensen	24	1.44	2.49	3.51
Dry	Little Bow	30	1.10	1.73	2.59
	Jensen	24	1.06	1.71	2.57

TABLE 6

MATRIX OF PEARSON'S CORRELATION COEFFICIENTS BETWEEN PRODUCTIVITY VALUES FOR GREENHOUSE TREATMENTS AND FIELD TRIALS JENSEN RESERVOIR DATA

	GREENHOUSE DRY TREATMENT	GREENHOUSE WET TREATMENT	STRIPPED-PLOT HARVEST	TOPSOILED HARVEST
Initial Harvest	-0.27	-0.16	0.81**	0.79**
Topsoiled Plot Harvest	-0.13	-0.11	0.85**	
Stripped Plot Harvest	-0.04	-0.01		
Greenhouse Wet Treatment	0.89**			

** $p < 0.01$

TABLE 7

MATRIX OF PEARSON'S CORRELATION COEFFICIENTS BETWEEN PRODUCTIVITY VALUES FOR GREENHOUSE TREATMENT AND FIELD TRIALS LITTLE BOW RESERVOIR DATA

	GREENHOUSE DRY TREATMENT	GREENHOUSE WET TREATMENT	STRIPPED-PLOT HARVEST	TOPSOILED HARVEST
Initial Harvest	0.04	0.12	0.03	0.02
Topsoiled Plot Harvest	0.20	0.11	0.36*	
Stripped Plot Harvest	0.45**	0.51**		
Greenhouse Wet Treatment	0.79**			

* $p < 0.05$
** $p < 0.01$

Consequently, observations of the response of native vegetation to topographic and soil variation should provide an indication of the response of reclamation planting to those same variables. Indeed, due to problems such as weed growth and local seeding failure, native vegetation likely provides a better indication of long-term productivity than short-term field trials do.

As discussed above, the greenhouse trials were intended to provide an assessment of the effects of soil characteristics on productivity isolated from the effects of topography. It was also hoped that these trials would provide an indication of soil fertility effects that might not be revealed by the soils laboratory analysis results.

It was anticipated that there would be a positive relationship between field and greenhouse results although this was expected to be modified by the topographic variables. With one exception, there was essentially no correlation between greenhouse and field results. The exception is the relationship between the two greenhouse trials and stripped-plot harvest at Little Bow Reservoir (see Table 7). No adequate explanation for this result was found.

One interpretation for the inconsistent relationship shown between greenhouse and field trials might be that, under field conditions, variation in soil characteristics within a site has little influence on productivity. This does not, however, appear to be the case. Analysis of data from the field studies indicated that some soil characteristics were significant in controlling productivity. The conclusion that one can draw is that plants in the greenhouse trials responded to different sets of variables than plants in the field trails. This will be discussed in greater detail below.

TOPOGRAPHIC EFFECTS

Due to the morphological differences between the two sites, it was possible to assess the effects of a relatively wide range of topographic variations on vegetation. The Jensen Reservoir site provided a series of short steep slopes in contrast to the longer flatter slopes at the Little Bow Reservoir site. Slope changes are more abrupt at Jensen Reservoir and this is reflected in the slope shapes assessed. A summary of the topographic data from the two sites is provided in Appendix 5.

Table 8 provides a summary of the significant correlations between topographic variables and productivity.

1. Slope:

It was predicted that there should be an inverse relationship between slope and productivity and that due to the presence of steeper slopes that this should be more pronounced at Jensen Reservoir.

This anticipated result did not materialize. Slope was not found to be a significant determinant of productivity at either site and, if anything, less so at Jensen Reservoir than Little Bow Reservoir. The one statistically significant correlation that was found indicated that in the topsoiled regrowth trials at Jensen Reservoir, productivity tended to increase rather than decrease with increased steepness of slope.

There are several possible explanations for this lack of apparent relationship. One is that perhaps even the moderately steep slopes that are found at Jensen Reservoir (up to 37 percent) are not sufficient to present a limitation to productivity. Another possible explanation is that slope interacts with other

TABLE 8

SIGNIFICANT PEARSON'S CORRELATION COEFFICIENTS BETWEEN FIELD PRODUCTIVITY AND TOPOGRAPHIC CHARACTERISTICS

TOPOGRAPHIC VARIABLES	INITIAL HARVEST		TOPSOILED REGROWTH		STRIPPED-PLOT REGROWTH	
	JENSEN	LITTLE BOW	JENSEN	LITTLE BOW	JENSEN	LITTLE BOW
Slope	--	--	.40 *	--	--	--
Distance from top	--	.39 *	--	--	--	.33 *
Horizontal Shape	.54 **	.55 **	.54 **	--	.59 **	--
Vertical Shape	.51 **	.42 **	.55 **	.30 *	.57 **	--
Downslope Proportion	.43 *	.42 **	.40 *	--	.35 *	--
Aspect (SW=0)	.49 **	--	.52 **	--	.52 **	.39 *

* $p < 0.05$

** $p < 0.01$

variables, such as aspect, so that its effects are masked in this analysis. For example, on a north-facing slope at Jensen Reservoir, a steeper gradient would be shadier and therefore cooler than a shallower gradient, whereas on a south-facing slope, a steeper gradient would tend to be hotter and drier than a shallower one. This possible interaction is discussed below.

2. Slope Position:

Two direct measures of slope position were analyzed, distance from top of slope and the proportional distance downslope. It was expected that productivity would increase relative to the distance downslope.

Simple distance from top of slope was not a good predictor of productivity. It was correlated only with initial harvest and stripped-plot regrowth at Little Bow Reservoir. This is not surprising given that this measure is so strongly related to the individual slopes being assessed. Although Puhe and Walker (1968) were able to develop equations predicting soil characteristics in relation to distance from top of slope, these equations were for specific locations and could not be applied to other situations because of the fact that each slope has a different length.

Proportional distance, on the other hand, is adjusted for slope length and was a good predictor of productivity in most cases (see Table 8).

3. Vertical Shape:

Productivity was expected to increase as concavity of vertical shape increased. This is because vertical shape is related to position on slope. Convex slopes are generally found in upslope positions where erosional forces control shape, whereas concave slopes are indicative of lower slope positions where soil is accumulating and soil moisture levels are generally higher. The results in virtually all cases are consistent with the predictions, and support the findings of King, et al. (1983) that concavity and convexity are valuable [illegible]dicators of soil conditions.

4. Aspect:

It was predicted that productivity would increase with increased deviation from a southwest slope aspect. This was the case for all measures of productivity at Jensen Reservoir but for only one of the productivity variables (stripped-plot harvest) at Little Bow Reservoir. The steeper slopes at Jensen Reservoir may explain why aspect effects would be greater there than at Little Bow Reservoir since the temperature and moisture changes related to aspect would be more exaggerated on steeper slopes. If this is the case, it begins to suggest ranges within which aspect may be a significant determinant of production.

Ayyad and Dix (1964) confined their work to slopes of between 23 and 32 percent and found marked differences in floristic composition related to aspect. Unfortunately; they do not provide productivity figures with which to make comparison. Regardless, the slopes they used were steeper than any at Little Bow Reservoir and than most at Jensen Reservoir.

5. Horizontal Shape:

This is an indication of how watergathering or watershedding a slope may be. It was found to be a very good predictor of production in most cases.

As described earlier, some six composite variables were calculated combining slope and aspect, and correlation coefficients were calculated between all six indices and all measures of field productivity (Table 9). None of the indices were significantly better than aspect alone in predicting productivity. In fact, at Little Bow Reservoir, some of the indices have correlations opposite to those anticipated.

The failure to confirm the significance of two such widely used variables as slope and aspect in terrain analysis is among the more perplexing results of this study. While the author is not prepared to state that slope and aspect are not important variables in the determination of productivity in the mixed prairie, it is not possible to show a relationship with the data gained in this study. A study with more observations including a broader range of gradients may yield more definitive results.

The attempts to combine the two slope shape indices into a single variable proved somewhat more fruitful. A composite slope shape index was felt to be more useful for analytical purposes than two separate measures. It is consistent with the general description of slope concavity or convexity as described by Ruhe and Walker (1968). The value of this index is discussed further in the section "Implications and Applications".

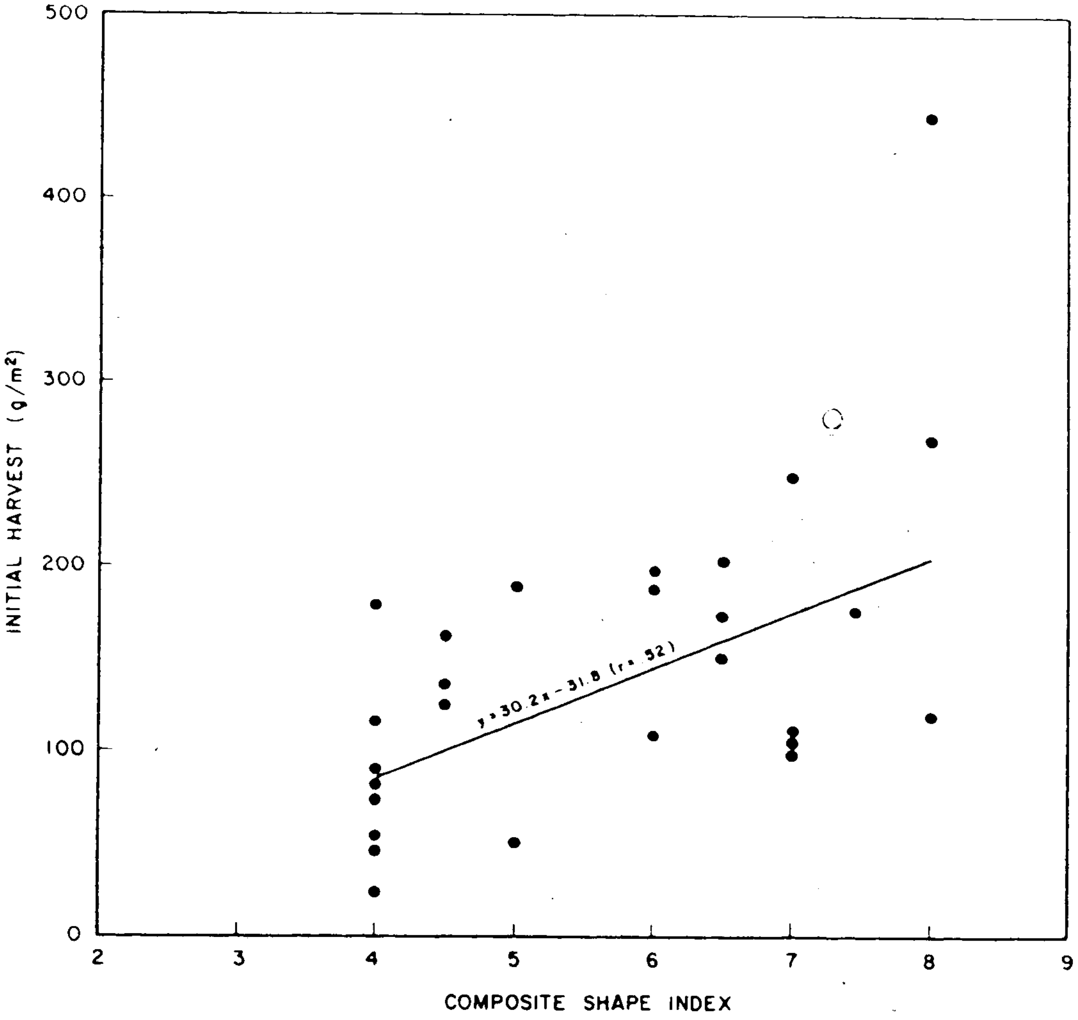
As described earlier, both additive and multiplicative indices were calculated. The correlation coefficients for both indices and field productivity were calculated (Table 9). The relationship between initial harvest and the additive slope shape index was also examined graphically (Figures 6 and 7).

TABLE 9

PEARSON'S CORRELATION COEFFICIENTS BETWEEN FIELD PRODUCTIVITY AND COMPOSITE TOPOGRAPHIC VARIABLES

COMPOSITE TOPOGRAPHIC VARIABLES	INITIAL HARVEST		TOPSOILED PLOT HARVEST		STRIPPED PLOT HARVEST	
	JENSEN	LITTLE BOW	JENSEN	LITTLE BOW	JENSEN	LITTLE BOW
Angle of Incidence	.43*	-.32*	.29	.20	.43*	.57**
Equivalent Latitude	-.45*	.32*	-.31	-.19	-.44*	-.57**
Slope-Aspect Composite	.43*	-.33*	.30	.20	.44*	.58***
SW Rotated Angle of Incidence	.43*	-.14	.58**	.18	.49**	.44**
SW Rotated Equivalent Latitude	-.43*	.14	-.59**	-.18	-.49**	-.44**
SW Rotated Slope-Aspect Composite	.42*	-.14	.54**	.19	.47**	.44**
Shape Composite (Additive)	.61**	.52**	.64**	.22	.69**	.11
Shape Composite (Multiplicative)	.62**	.53**	.66**	.12	.69**	.10

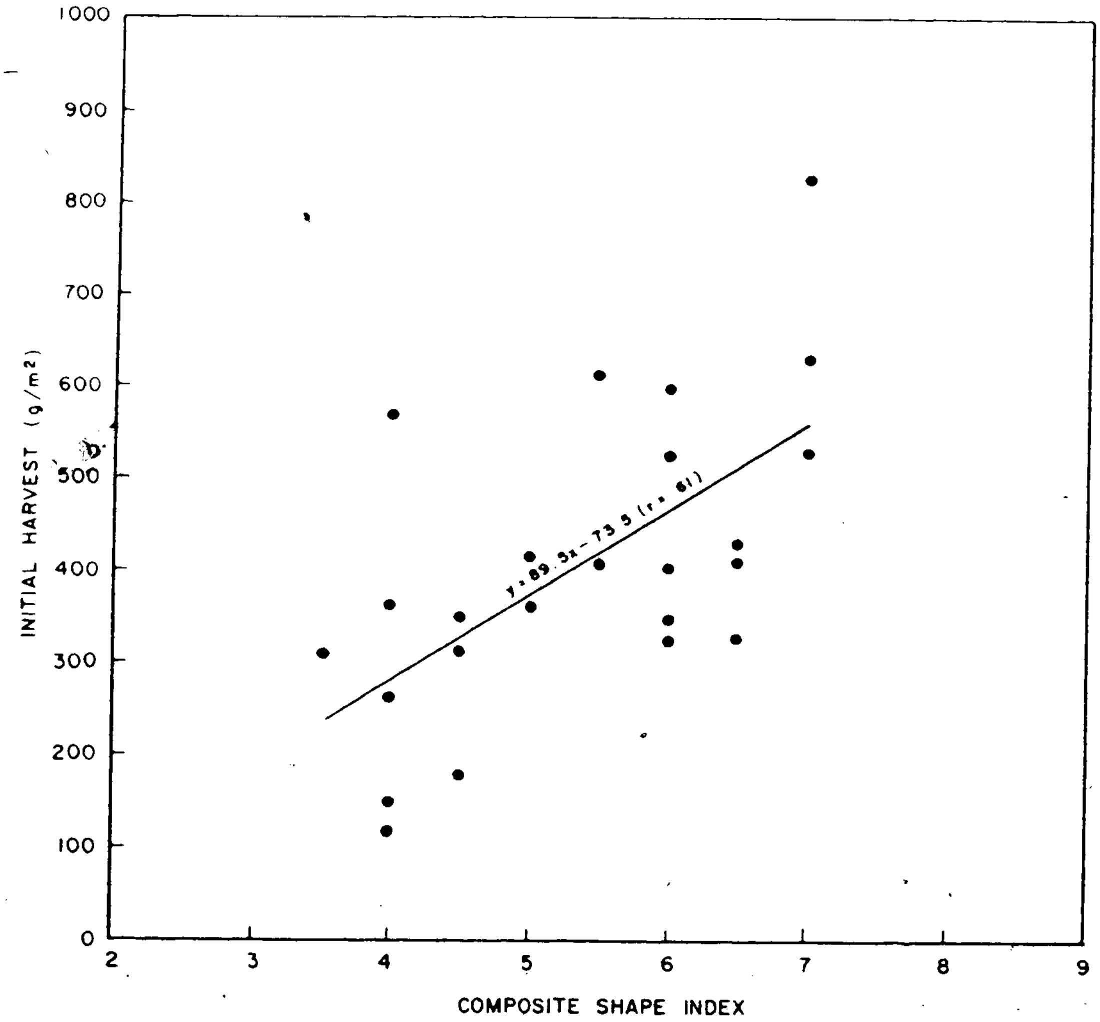
* $p < 0.05$
** $p < 0.01$



NOTE Topographic Composite Shape Index = v+h, where
v = vertical shape – range from 1 (highly convex) to 5 (highly concave)
h = horizontal shape – range from 1 (highly convex) to 5 (highly concave)

INITIAL HARVEST – COMPOSITE SHAPE INDEX
RELATIONSHIP – LITTLE BOW RESERVOIR

FIGURE 6



NOTE: Topographic Composite Shape Index = v+h, where:
v = vertical shape - range from 1 (highly convex) to 5 (highly concave)
h = horizontal shape - range from 1 (highly convex) to 5 (highly concave)

INITIAL HARVEST - COMPOSITE SHAPE INDEX
RELATIONSHIP - JENSEN RESERVOIR

FIGURE 7

Both composite indices yielded somewhat higher correlation coefficients for the Jensen Reservoir data than either individual slope shape variable. For the Little Bow Reservoir data, the composite shape indices yielded correlation coefficients comparable to those calculated for the individual shape variables. There appeared to be little or no difference between the two indices in their correlation with productivity at this site.

PRODUCTIVITY-SOIL RELATIONSHIPS

The results of the soil analysis are summarized in Appendix B. Some of the soil samples from Jensen Reservoir were quite wet when taken and could not be dried immediately. Some of the soil samples from this site show abnormally high nitrogen values. This is probably attributable to the delay in drying as microbial activity in moist soils can result in a greater release of nitrogen from soil organic matter. In order to maintain consistency in sampling dates and procedures, it was not considered desirable to take additional samples from the Jensen stations.

The soils from Jensen Reservoir had a finer texture and a higher organic matter content than those collected from Little Bow Reservoir. Neither had any chemical characteristics that would be expected to pose a serious limitation to productivity. On average, both were adequately supplied with the chemical nutrients needed to support vigorous grass cover. Of the soil characteristics tested, only soil organic matter and texture were found to be relatively consistent influences on productivity in the field trials (Table 10). This tends to support the view that, in the grasslands, the most significant soil variables

TABLE 10

SIGNIFICANT PEARSON'S CORRELATION COEFFICIENTS BETWEEN BIOMASS AND SOIL VARIABLES

SOIL VARIABLE	FIELD TRIAL						GREENHOUSE TRIAL			
	INITIAL HARVEST		TOPSOILED PLOT HARVEST		STRIPPED PLOT HARVEST		GREENHOUSE WET TREATMENT		GREENHOUSE DRY TREATMENT	
	JENSEN	LITTLE BOW	JENSEN	LITTLE BOW	JENSEN	LITTLE BOW	JENSEN	LITTLE BOW	JENSEN	LITTLE BOW
P		0.33*					0.51**		0.53**	
K						0.31*		0.68**		0.59**
pH	-0.38*		-0.47**		-0.45**			-0.51**		-0.47**
Elec. Cond.							0.50**		0.47**	
Lime							-0.35*		-0.39*	
Texture	0.55**		0.45**	0.44**	0.58**			0.44**		0.45**
Organic Matter Content	0.58**		0.55**	0.50**	0.60**	0.36*		0.57**		0.52**

* $p < 0.05$
** $p < 0.01$

controlling productivity tend to be those related to moisture retention. As mentioned earlier, there appeared to be little relationship between field results and greenhouse results. It was thought that the greenhouse "dry treatment" might more closely approximate field conditions than the wet treatment. This was not the case. Although the wet treatment was substantially more productive, it appeared to be responding to the same variables as the dry treatment.

Although the results of the analysis of the relationships between productivity and soil characteristics are far from consistent and conclusive, they do provide some basis for evaluation of some of the predictions discussed earlier.

1. Texture:

Soil texture can be important both to the moisture holding characteristics of soils and to nutrient availability. Generally, one might have expected the results from Little Bow Reservoir to show greater sensitivity to soil texture than those from Jensen Reservoir, due to the coarser nature of the soils, and since most of the samples from Jensen Reservoir had close to what is considered to be ideal texture (fine loam).

Productivity was higher on soils of finer texture in the field trials at Jensen Reservoir but not with the same soils in the greenhouse trials.

In the case of Little Bow Reservoir, productivity on one of the regrowth trials was correlated with texture and in the greenhouse trials, productivity was higher on the finer textured soils.

The moisture retention characteristics of the soils from Jensen Reservoir are probably important in the field but not necessarily in the greenhouse, where adequate water was available. Even the finer textured soils at Little Bow Reservoir may not differ sufficiently in moisture holding capacity to significantly affect productivity under natural grassland cover, though this characteristic may be significant for the establishment of reclamation plant material.

It should be noted that the soil texture data used in this study was determined subjectively by the laboratory, and has only five categories. It is also highly correlated with organic matter content and to a degree reflects soil structure as well. A more quantitative approach to defining texture, such as particle size distribution, might give more definitive results.

2. Organic Matter:

As noted above, percent organic matter is highly correlated with soil texture (Little Bow Reservoir $r = 0.71$, $p < 0.01$; Jensen Reservoir $r = 0.75$, $p < 0.01$) and is seen to have virtually the same effect on productivity. At Jensen Reservoir, productivity increased as percent organic matter increased in the field trials but not in the greenhouse. At Little Bow Reservoir, productivity increased with increasing organic matter content in all cases except the initial harvest.

The correlation between organic matter and fall harvest for both sites probably reflects the value of organic matter in retaining moisture and creating a suitable soil structure for the establishment of reclamation vegetation. The value of soil organic matter in maintaining soil structure and enhancing moisture and nutrient availability is well documented.

Unfortunately, it was not possible to separate the effects of soil texture and soil organic matter content on productivity, due to their high intercorrelation. In practise, however, there is little reason to do so. Within limits, the effects of increasing organic matter, and an increase in proportion of fine particles in the soil have similar effects on productivity. In the author's opinion, the most significant effect in both cases is the increase in the moisture holding capacity of the soil. A second possibly important effect is an increase in nutrient availability due to increased cation exchange capacity.

3. pH:

At both sites, pH values were within the range where little or no effect would be anticipated. Samples from Jensen Reservoir were almost all within the range that is considered neutral (6.5 - 7.5). Those from Little Bow Reservoir were slightly more alkaline but the maximum was only 7.8. Consequently, the strong negative correlations between pH and field productivity at Jensen Reservoir and greenhouse productivity for the Little Bow Reservoir sites were somewhat surprising. In both cases, productivity declined sharply as pH increased.

The relationships, however, are probably not pH effects, as such, but are related to the fact that the pH at both sites is highly correlated with other soil factors. At Little Bow Reservoir, pH is negatively correlated with phosphorus (r = -0.41, p = 0.01), potassium (r = -0.65, p < 0.01), texture (r = -0.54,

$p < 0.01$), and organic matter content ($r = -0.54$, $p < 0.01$). At Jensen Reservoir, pH is negatively correlated with nitrogen ($r = -0.40$, $p = 0.02$), phosphorus ($r = -0.56$, $p < 0.01$), conductivity ($r = -0.46$, $p = 0.01$), texture ($r = -0.70$, $p < 0.01$), and organic matter content ($r = -0.85$, $p < 0.01$), and positively with free lime ($r = 0.47$, $p = 0.01$).

Although not anticipated, this high correlation between pH and other soil characteristics is readily explained. The parent material of most prairie soils in Alberta is slightly alkaline (Wyatt, et al., 1939). As the material weathers under soil forming processes, calcium carbonate is leached out of the topsoil, and soil organic matter and consequently organic acids increase resulting in a lowering of pH. Thus, within an area that has the same parent material, pH is an indicator of the stage in soil formation.

4. Conductivity:

None of the samples tested had soluble salt concentrations high enough to be expected to adversely affect production. The conductivity values for Jensen Reservoir were higher and covered a broader range than those for Little Bow Reservoir. Thus, on these two sites, productivity would be expected to increase with an increase in electrical conductivity, and the effects should be more apparent at Jensen Reservoir than Little Bow Reservoir. These results were partially confirmed as there were significant positive correlations between electrical conductivity and productivity for one of the field trials from Little Bow Reservoir, and for the greenhouse trials with the Jensen Reservoir soils. This lends some credence to the use of electrical conductivity as a general indicator of nutrient status as used by Looman (1980). The value of conductivity measurement could be further enhanced by simultaneously examining soil pH.

There may be significant value in the use of pH as an indicator of organic matter content. The relationship between organic matter content and pH is shown in Figure 8. At this site, the calculated regression equation could be used to predict, relatively accurately, the organic matter content from the pH.

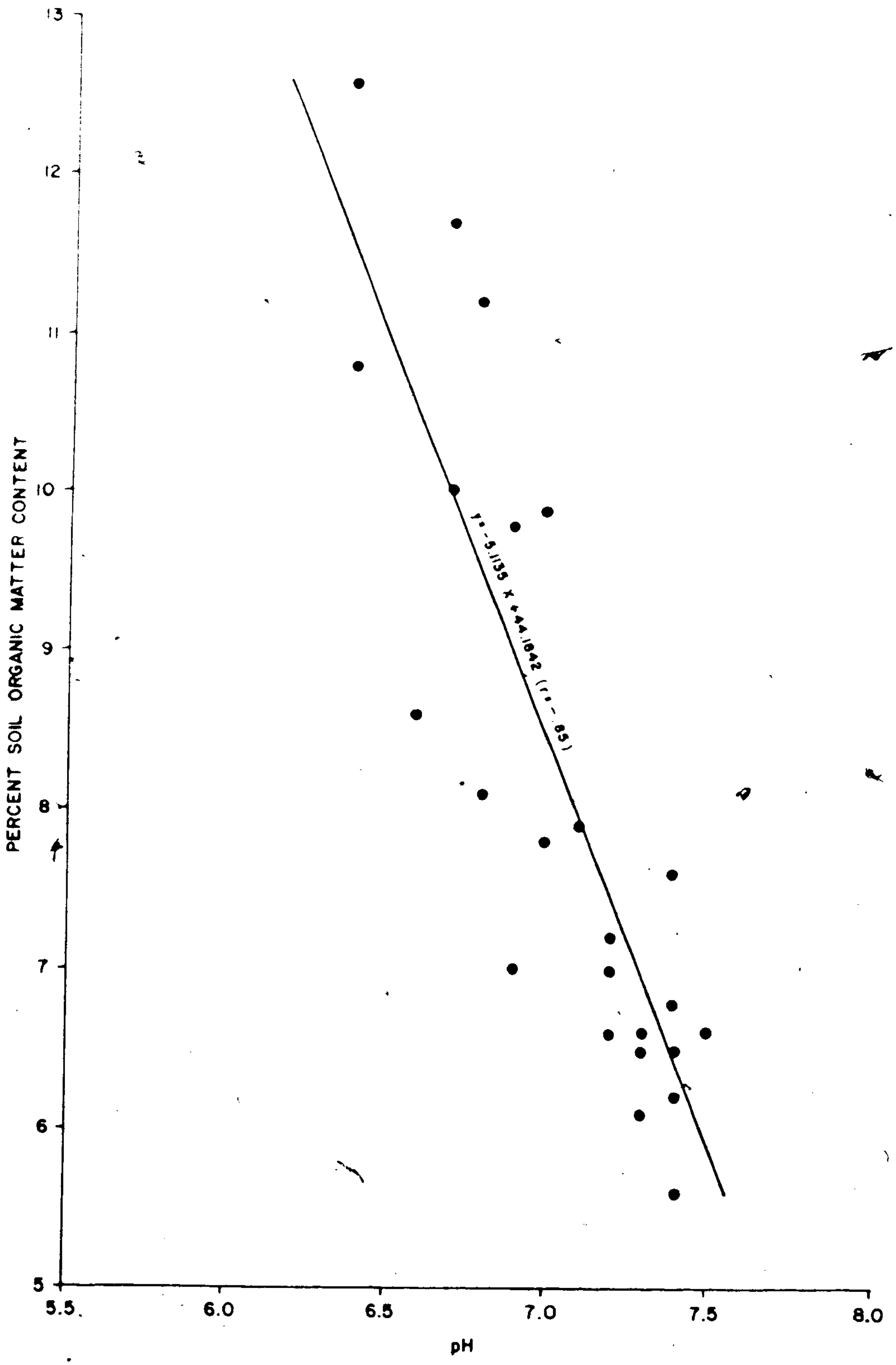
The relative ease with which both these tests can be made holds some promise for the use of them in the field for characterizing soils over a large area quickly and economically.

5. Free lime:

Free lime values were generally low at both sites but were high enough in some of the Jensen Reservoir samples that some effects were anticipated. These effects were not revealed in the field studies but did appear in the greenhouse trials where some reduction in productivity was found with increased levels of free lime. The discrepancy between field and greenhouse results in this case is probably due to moisture not nutrients being limiting in the field.

6. Nitrogen:

The nitrogen values for both sites were quite high, with most values being high enough that little response to differing levels within the sites was anticipated. The results of both greenhouse and field trials are consistent with this expectation. No correlation between productivity and soil test nitrogen was found.



pH-SOIL ORGANIC MATTER CONTENT
RELATIONSHIP-JENSEN RESERVOIR

FIGURE 8

7. Phosphorus:

According to the interpretive notes supplied with the soil test results, phosphorus was the only nutrient tested that had values low enough to be expected to adversely affect productivity. It could be considered the limiting nutrient. There was a large enough range in values within the sites that a productivity response to varying phosphorus levels was anticipated. In the case of Little Bow Reservoir, this relationship did show up in the initial harvest results but not in any of the other field treatments nor the greenhouse trials.

In the case of Jensen Reservoir, phosphorus concentration did appear to have an effect in the greenhouse treatments but not in the field (Table 10).

The difference in observed productivity response between the two sites cannot be explained by the levels of the nutrient since they are not significantly different. A more likely explanation is that other nutrients and soil characteristics (such as organic matter content) are limiting in the Little Bow Reservoir soils under greenhouse conditions. In the field under established grassland vegetation, phosphorus may be limiting at times at Little Bow Reservoir since the sandy soil, low in organic matter, may not be able to make phosphorus available quickly enough in the relatively short periods of growth. Most phosphorus in the soil is bound in the organic matter (Black, 1968) and is made available through decomposition processes.

At Jensen Reservoir, the moister conditions and more favourable texture and organic matter characteristics of the soil would likely permit a more continuous supply of phosphorus as it becomes available through decomposition of organic matter. In the more benign growing conditions of the greenhouse, however, the vegetation growth was rapid enough to outstrip the ability of the soils to supply phosphorus.

8. Potassium:

Although much higher in the Jensen samples than in the Little Bow samples, potassium levels were quite high in the soils from both sites and were not expected to have a significant effect on productivity. This was the case for Jensen Reservoir in both the field and greenhouse trials.

At Little Bow Reservoir, however, potassium appeared to be significant in the stripped-plot field trial and limiting in the greenhouse trials as productivity increased with increasing potassium levels. It is impossible to determine to what degree potassium concentration is, in fact, influencing productivity as it is also highly correlated with organic matter content ($r = 0.81$, $p < 0.01$), texture ($r = 0.59$, $p < 0.01$) and pH ($r = -0.65$, $p < 0.01$) in the Little Bow Reservoir soils. The potassium response may simply be a spurious correlation. It may be, however, that potassium uptake is being limited by the coarseness of the soils despite the relatively high soil test levels of the nutrient.

9. Sulphur:

A few values for sulphur were low enough that they might be expected to have an influence on productivity, but most were in the range where little or no effect would be expected. No significant increases in productivity attributable to sulphur were detected in either the greenhouse or field trials.

10. Sodium:

Sodium levels were low at both sites and had very little variation. No effects due to sodium were expected and none were detected.

The most striking feature about the soil analysis is the lack of relationship between the greenhouse results and the field results. Even though there were differences in the soils, that under greenhouse conditions gave a great range in productivity, there was no correlation between the growth in the greenhouse and that in the field. This casts great doubt on the value of such greenhouse trials as a kind of bioassay as suggested by Kent (1980) except when one is dealing with toxic levels of certain elements. The study revealed that the plants in the greenhouse responded to a different set of soil factors than those in the field.

Variations in vegetation composition could explain part of the difference between greenhouse and field results. Species adaptation would tend to moderate differences in productivity related to soil and topographic characteristics. The re-growth field plot treatments were intended to eliminate species effects on productivity and would thus be expected to demonstrate a closer relationship to the greenhouse trials than the initial plot harvests. This was not the case.

Although the soil test data did provide some indication of which soil variables might influence productivity in the greenhouse, they did not supply adequate data to make a reasonable prediction of productivity. The nutrient testing was particularly unrewarding.

There are several possible explanations for the lack of correlation between the soil test results and productivity. The problem of interactions among the nutrient variables and non-linear relationships between soil characteristics and productivity present methodological barriers to the detection of true relationships. Because plant nutrients cannot to any significant degree substitute for one another, it is the nutrient that is in the lowest concentration relative to plant needs that tends to control productivity. Supply of a nutrient beyond a certain level will not significantly increase productivity. In an attempt to deal with this problem, data transformations were carried out on several variables. A value corresponding to what the soil test interpretation information indicated to be an optimum level for each variable was selected (30 ppm for N, 25 ppm for P, 300 ppm for K, and 12.5 ppm for S). The difference between the observed value and the optimum was calculated. Any value above the optimum was set at zero. Thus, only differences from optimum levels were used in further analysis. Correlation coefficients were then calculated between all measures of greenhouse and field production and the new variables. These did not yield any stronger correlations than the untransformed data.

A possible explanation for the lack of relationship between chemical soil test results and field productivity is that perhaps the analysis was inappropriate. Only topsoil samples were taken and, as has been noted, the Little Bow Reservoir site has a complex and variable soil profile due to the sand veneer over the till. Some method of incorporating subsoil testing may have yielded more definitive results. As mentioned, a more precise test of soil texture might have given more information as might a direct measure of moisture holding capacity. Similarly, other soil characteristics, such as cation exchange capacity might have been advantageous.

It is entirely possible that no measure of soil characteristics could yield better results. The general conclusion must be that topographic variation is more important than variation in soil characteristics over the range in variables analyzed in determining patterns of productivity within a mixed prairie site and that the most significant soil characteristics tend to be those relating to soil moisture retention.

SOIL-TOPOGRAPHY RELATIONSHIPS

In general, the relationships that were detected between soil characteristics and topography appear to complement the findings regarding the relationships between topography and productivity (Tables 11 and 12). As with productivity, slope did not appear to be a significant determinant of any of the soil characteristics examined.

The relationships are consistent with the findings of several authors (Ruhe and Walker, 1968; Walker and Ruhe, 1968; King, et al., 1983). Ruhe and Walker's work would predict soils of finer texture with higher organic matter on lower slope positions accompanied by a decrease in free lime and pH. All of these relationships were found on at least one of the sites.

The work of King, et al., (1983) found several soil characteristics, including texture, pH and potassium content to be highly correlated with slope shape. This was found ~~to~~ be the case at

TABLE 11

SIGNIFICANT PEARSON CORRELATION COEFFICIENTS BETWEEN SOIL AND TOPOGRAPHIC VARIABLES LITTLE BOW RESERVOIR

	TOPOGRAPHIC VARIABLES					
SOIL VARIABLES	SLOPE	ASPECT (SW=0)	DISTANCE FROM SUMMIT	PROPORTIONAL DISTANCE DOWNSLOPE	HORIZONTAL SHAPE	VERTICAL SHAPE
Nitrogen					.39*	
Phosphorus		-.40*				
Potassium			.50**	.43**	.39*	.43**
pH	.36*	.37*	-.75**	-.44**	-.31*	-.59**
Electrical Conductivity					.47*	
Texture			.36**			.34*
Soil Organic Matter			.46**	.49**	.33*	.51**

* $p < 0.05$
** $p < 0.01$

TABLE 12

SIGNIFICANT PEARSON CORRELATION COEFFICIENTS
BETWEEN SOIL AND TOPOGRAPHIC VARIABLES
JENSEN RESERVOIR

	TOPOGRAPHIC VARIABLES			
SOIL VARIABLES	SLOPE	ASPECT (SW=0)	HORIZONTAL SHAPE	VERTICAL SHAPE
Phosphorus		-.53**		
Potassium			.35*	.44*
pH	-.49**	-.71**	-.44*	
Free lime				-.41*
Texture		.67**	.65**	
Soil Organic Matter		.72**	.57**	

* $p < 0.05$
** $p < 0.01$

both sites with several of the soil characteristics examined being highly correlated with vertical and/or horizontal shape.

Soil organic matter content and texture appeared generally to be sensitive to the same topographic characteristics that were found to be correlated with productivity. Organic matter content and soil texture at Little Bow Reservoir were correlated with horizontal and vertical slope shape. Horizontal shape appeared to be the most significant factor in determining productivity at that site.

At Jensen Reservoir, in addition to being strongly related to horizontal slope shape, soil organic matter content was highly correlated with aspect, much more so than was productivity. The lack of correlation between productivity and the organic matter content of the soil is related in part to the differing responses of plants and soil micro-organisms to environmental factors.

Soil organic matter accumulation is determined by the relationship between the rate of production and the rate of decomposition (Richards, 1974). Plants are the primary source of organic matter in the soils of the mixed prairie and consequently areas of high productivity would tend to be high in soil organic matter content. This is complicated by the fact that an increase in soil organic matter content tends to enhance productivity through the improvement of soil fertility and structure resulting in the further increase in productivity.

On the other hand, although a physical environment hospitable to plant growth is also hospitable to the growth of soil micro-organisms, the decomposers, these micro-organisms are somewhat less sensitive than plants to drought and other environmental stresses. They respond quickly to environmental changes, consequently patterns of decomposition do not exactly match those of production. The differences between organic matter accumulation and plant productivity may reflect these differences in adaptation to environmental stress.

PRINCIPAL COMPONENTS ANALYSIS

In nature, physical and biological characteristics tend to vary in concert as a series of repeating patterns. Thus, one cannot without a certain risk conclude a causal relationship between two variables simply because they are correlated. Principal Components Analysis (described by Harris, 1975) was carried out in order to assess the underlying "structure" of the data before attempting regression analysis.

Only variables that had been found to have a significant correlation with field productivity were used in the analysis.

Two sets of analyses were carried out for each site - one utilizing only topographic variables, and one utilizing both topographic and soil variables. The results are summarized in Tables 13 and 14. The titles applied to each component extracted indicate the variables that, in the author's opinion, best account for that component.

In the case of the Little Bow Reservoir site, the analysis reveals strong interrelationships between the two measures of slope shape as well as proportional distance downslope. As well, at this site, there appears to be a strong relationship between slope length and aspect. The two soil variables utilized (organic matter and texture) were strongly related to each other but not to any of the topographic variables utilized.

The results for Jensen Reservoir indicate that vertical shape, proportional distance downslope, and to a lesser extent, distance from

TABLE 13

FACTOR LOADINGS ON PRINCIPAL COMPONENTS - LITTLE BOW RESERVOIR

A. FACTOR MATRIX - TOPOGRAPHIC VARIABLES ONLY

	PC1 (Shape-Position)	PC2 (Length-Aspect)
Slope	-0.1733	-0.5253
Distance from Top	0.6394 ++	0.6703 ++
Slope Length	0.0667	0.8584 +
Horizontal Shape	0.8766 +	-0.0176
Vertical Shape	0.8964 +	0.2849
Proportion Downslope	0.9189 +	0.1373
Aspect	-0.0215	-0.7463 +

B. FACTOR MATRIX - TOPOGRAPHIC AND SELECT SOIL VARIABLES

	PC1 (Shape-Position)	PC2 (Length-Aspect)	PC3 (Soil)
Slope	-0.1739	-0.5194	-0.0532
Slope Length	-0.0551	0.8738 +	0.2817
Distance from Top	0.5405	0.7027 +	0.2828
Horizontal Shape	0.8932 +	0.0113	0.0639
Vertical Shape	0.8356 +	0.3226	0.2586
Texture	0.1301	0.1069	0.9003 +
Organic Matter	0.3450	0.1691	0.8111 +
Proportion Downslope	0.9063 +	0.1694	0.1574
Aspect	-0.1481	-0.7302 +	0.5310

---

† Primary variable comprising the component.

†† Secondary variable comprising the component.

TABLE 14

FACTOR LOADINGS IN PRINCIPAL COMPONENTS - JENSEN RESERVOIR

A. FACTOR MATRIX - TOPOGRAPHIC VARIABLES ONLY

	PC1 (Horizontal Shape-Length)	PC2 (Position)	PC3 (Slope-Aspect)
Slope	-0.1828	0.1968	0.9062
Distance from Top	-0.6496 ++	0.7055 +	0.1616
Slope Length	-0.9041 +	-0.0817	0.1207
Horizontal Shape	0.8927 +	0.1391	0.2460
Vertical Shape	0.3794	0.8719 +	0.0488
Proportion Downslope	-0.0197	0.9795 ++	0.0413
Aspect	0.5513	-0.1317	0.7902

B. FACTOR MATRIX - TOPOGRAPHIC AND SELECT SOIL VARIABLES

	PC1 (Soil-Aspect)	PC2 (Position)	PC3 (Length)
Slope	0.5828	0.2832	0.5132
Slope Length	-0.2350	-0.0911	0.8729 +
Distance from Top	-0.1160	0.6839 ++	0.6773 ++
Horizontal Shape	0.6388 ++	0.1552	-0.6763 ++
Vertical Shape	0.2457	0.8727	-0.2667
Texture	0.8157 +	0.1921	-0.1815
Organic Matter	0.8509 +	0.0650	-0.1432
Proportion Downslope	0.0376	0.9744 +	0.1123
Aspect	0.9285 +	-0.0941	-0.1663

† Primary variable comprising the component.

†† Secondary variable comprising the component.

top of slope are interrelated. Unlike the data from the Little Bow Reservoir site, at Jensen Reservoir there does not appear to be a strong relationship between these variables and horizontal shape. Horizontal shape does appear to be somewhat related to slope length and soil organic matter content and texture at this site. As well, as with the Little Bow Reservoir data, soil texture and organic matter content are highly interrelated, but at Jensen Reservoir they are also strongly related to aspect.

The results of this analysis are generally reassuring. The fact that several topographic variables are related is not surprising. Indeed, several of them are largely different ways of measuring the same thing (e.g. vertical shape and proportional distance downslope). A judicious analyst need not be confused by these relationships. Indeed one can sometimes capitalize on them by utilizing one variable to infer another.

The correlation between different soil variables has been commented on earlier and, as with the topographic variables, this correlation, if dealt with properly, does not seriously impede further analysis.

The relationship between aspect and the soil variables at the Jensen Reservoir site is of somewhat greater concern, however. One cannot be certain, in analysis utilizing these data, to what degree one is measuring a direct effect of one of the variables and to what degree an indirect effect of the other.

REGRESSION ANALYSIS

Multiple stepwise regression analysis was used to attempt to build a working model to predict productivity from soil and topography variables.

All field productivity variables were utilized as dependent variables and various combinations of topographic and soil variables were used as independent variables. Some of the components generated in the principal components analysis were also used as independent variables in some of the regression calculations.

Results of this analysis are summarized in Appendix C. Data from both sites yielded similar results, but the Jensen Reservoir data yielded consistently stronger relationships than did the Little Bow Reservoir data.

There were some interpretation difficulties with some of the results. For example, the following two equations generated from the Jensen Reservoir site data were found to have almost equal predictive value:

$$B = 99M + 709P - 301 \qquad (r^2 = 0.54)$$

(Range - M 5.6% - 12.%, P 0.11 - 0.75)

$$\text{Log}_{10}B = 0.26H + 0.0094D + 11.95 \qquad (r^2 = 0.58)$$

(Range - H 2 - 4, D 5 - 53 M)

where, B is biomass (based on initial harvest)

M is % soil organic matter content

P is proportional distance downslope

H is horizontal slope shape

D is distance from top of slope.

Thus, two different sets of variables were found to explain over half the variation in the dependent variable.

The principal components analysis sheds some light on the apparent discrepancy. Organic matter content and horizontal slope shape were found to be somewhat correlated at the site as were proportional distance downslope and distance from top of slope. The most consistent results were achieved from the Jensen Reservoir data utilizing Principal Components as variables.

$$B = 183.71\ PC_1 + 161.59\ PC_2 + 817.59 \quad (r^2 = 0.54)$$

$$\text{Log}_{10}B = 0.104\ PC_1 + 0.101\ PC_2 + 2.8721 \quad (r^2 = 0.51)$$

$$B_1 = 27.46\ PC_1 + 23.18\ PC_2 + 73.52 \quad (r^2 = 0.50)$$

$$B_2 = 26.16\ PC_1 + 17.26\ PC_2 + 49.77 \quad (r^2 = 0.53)$$

where, B is biomass based on initial harvest

B_1 is biomass of topsoiled plots

B_2 is biomass of stripped plots

PC_1 is the principal component from Table 14B which was labelled soil-aspect

PC_2 is the principal component from Table 14B which was labelled position

The Little Bow Reservoir data demonstrated similar results, but in a less convincing fashion.

Although, by no means conclusive, the analysis quite consistently demonstrated that slope shape and/or position are the most significant topographic determinants of productivity of native vegetation in the sample and the establishment and growth of reclamation vegetation. The precise manner in which slope position is measured does not appear to be very important. Principal components analysis demonstrated that vertical slope shape, proportional distance downslope, and in some cases distance from top of slope are highly intercorrelated. Any of these measurements is likely to yield similar results (although distance from top of slope is probably the least useful).

Similarly, the earlier analysis of slope shape composites demonstrated that vertical and horizontal shape indices can be successfully combined.

Determination of which of these variables to select in futu[illegible] studies should probably be based to a large degree on ease of co[illegible]tion and analysis. This is discussed further below.

Soil characteristics, and specifically soil organic matter content, were found to be significant in many of the equations generated. The fact that organic matter accumulation appears to be related to aspect makes it difficult to propose it as a determinant of productivity, without some measure of qualification. It is, however, important. The precise degree of its importance, due to the inability to isolate it totally from other variables, is all that remains in doubt.

Although the regression analysis utilizing principal components was valuable in helping to understand the main determinants of productivity, it did not produce useful equations for further analysis and experimentation. Principal components are not useful variables in their own right because of their make-up.

The following equation was generated from the Jensen Reservoir data and is proposed as a working equation for further investigation:

$$B = 63C + 32M - 192 \quad (r^2 = 0.52)$$

$$(\text{Range} - C\ 3.5 - 7,\ M\ 5.6\% - 12.6\%)$$

where, B is above-ground biomass in gm/m²
C is additive slope shape composite
M is % soil organic matter content

While this was not the "best fit" equation, it is thought to be relatively robust since composite shape seems strongly related to most significant topographic variables, and organic matter content to several important soil characteristics, and is used in the investigation of possible applications of the study results in the following section.

SUMMARY OF CONCLUSIONS

The following points summarize the major conclusions resulting from analysis of study data:

1. Slope position, vertical slope shape, and horizontal slope shape are reliable topographic predictors of productivity in prairie grasslands.
2. Soil organic matter content and soil texture are also significant determinants of productivity on mixed prairie sites.

3. Slope aspect may have some significance in the determination of productivity and successful reclamation, but is a less significant topographic influence than slope position and shape at least over the range of conditions assessed in this study.
4. Slope, within the range analyzed in this study, is not a primary determinant of productivity.
5. The same characteristics that determine productivity of native grassland vegetation of the mixed prairie are significant in the establishment of reclamation vegetation. The establishment of reclamation vegetation may be more influenced by topsoil characteristics, notably those associated with moisture retention, and micro-climate than is the productivity of native grassland vegetation.
6. The use of topsoil significantly increases the level of success in the establishment of reclamation vegetation.
7. Greenhouse trials in which reclamation species are grown in topsoil samples cannot be used as reliable indicators of productivity in the field.
8. Standard soil tests as used in this study did not provide a reliable basis for the prediction of soil productivity, either in the greenhouse or the field.
9. Soil pH and electrical conductivity may be useful indicators of soil organic matter content and the general nutrient status of soils, that could readily and economically be incorporated into field studies.

IMPLICATIONS AND APPLICATIONS

This study has confirmed that the way topsoil is handled and land reshaped may significantly influence productivity of reclaimed mixed prairie grassland sites and a working model of the relationship has been developed; but how can the results of this and similar studies be used to improve the manner in which land surface disturbances are reclaimed? If the results of this work cannot be incorporated into the planning and design process, they are of little more than academic interest.

Essentially, this study was an attempt to determine if it was possible to predict productivity on both disturbed and undisturbed grassland on the basis of topographic and soil characteristics. While the results are far from definitive, it has been demonstrated that, to a large extent, this can be done.

As discussed earlier, productivity is the main indicator of reclamation success. Being able to predict productivity on the basis of indirect measurement rather than the measurement of actual production would be helpful. It would allow the comparison of the productivity of both disturbed and undisturbed sites that are under different levels of management or different land uses. It would allow the comparison of different options in the selection of borrow sites, the manner of excavation, land reshaping, and topsoil handling. The option with the lowest net loss or conceivably greatest net increase in productivity would be given preference. If it were found that grading and topsoil redistribution could, in fact, increase productivity it might then be possible to use these methods to replace habitat that is lost due to project development.

Through analysis of topography and soils of the landscape to be reclaimed, it may become possible to identify locations within sites that may present difficulties for reclamation, areas where it would be difficult to establish vegetation. There are significant theoretical benefits to the determination of the relationships between topography, soils, and productivity, but can this knowledge be easily and economically integrated into the planning and design process?

SELECTION OF VARIABLES

This study examined several topographic variables, some of which were measured quantitatively, and some of which were determined subjectively. For a variable to be truly useful for scientific investigation and as a design tool, it must be possible to measure it accurately and consistently in the field and on the drawing board. Some of the variables analyzed adapt themselves better to these purposes than others. To determine the value of topographic variables, it is useful to examine the manner in which topography is dealt with in the design process.

The term topography refers to the three-dimensional shape of the ground surface. This shape can be represented two-dimensionally using a variety of pictorial, descriptive, and quantitative methods, but the most common representation used by cartographers and designers is through the use of contour lines. This provides a very flexible representation of a three-dimensional surface. It allows the experienced reader to visualize the land's surface and make useful calculations, such as cut and fill estimates for grading. The accuracy of the method can be adjusted to the requirements of the task by changing the contour interval.

For relatively small areas, contour maps are generally produced by examining a series of spot elevations on a grid. Contour lines are then interpolated as lines connecting points of equal elevation within the grid. With the increased use of computers in design and cartography, digital data, such as the point elevations within the grid, are often fed directly into computers where they can be used to generate traditional contour maps as well as other land surface representation such as perspective views and cross-sections. These data, through the use of appropriate software can also be used to analyze topographic characteristics, such as slope and aspect (MacDougall, 1983). While the computer does not perform any task that cannot be done manually, the speed and accuracy with which it performs such tasks allows such things to be used in design and planning to an extent not formerly possible.

It is desirable that one should be able to read any topographic variable to be used in reclamation planning from contour plans and also from their computerized counterparts, digital terrain models.

Slope is very easy to determine from a contour plan. Since adjoining contours are at a constant vertical interval, one merely divides the contour interval by the distance between two adjacent contour lines and multiplies by 100 to determine percent slope ([change in elevation/distance] x 100).

The mathematics for determining slope from a digital terrain model is somewhat more complex but is a common feature of programs designed to determine runoff and is by no means a difficult computing task. Examples are found in MacDougall (1983).

Similarly, aspect is readily determined from contour maps as the compass bearing of lines perpendicular to contour lines, and again is readily determined in digital terrain models (MacDougall, 1983).

One of the features that makes the determination of slope and aspect simple is that it can be determined for virtually each point on a contour plan and each pixel in a digital terrain model by referring, at most, to adjacent contours or pixels. Some of the other topographic variables are not as easy to deal with. Length of slope, distance from top of slope, and proportional distance downslope are all dependent on being able to determine the top and bottom of slope relevant to each point or pixel on a map. This is a complex and time consuming task and requires substantial interpretation both in the field and on the drawing board. Where topography is simple, it may be possible to accurately determine the top and bottom of a slope; but even in this study, several subjective decisions had to be made to determine where to begin and end measurements. For example, when working across the coulees at Jensen Reservoir, the thalweg of the coulees was taken as the bottom of the side slopes. The ground that was taken as the bottom was not flat because the coulee slopes into the valley and is thus not comparable to the bottom of a slope in a closed drainage. At Little Bow Reservoir, one of the slopes is complex in that there is a short length that levels off and, in fact, rises slightly in part of a much longer slope. A subjective decision had to be made as to whether to break the slope into two or to consider the level area a small aberration in a general landform.

These problems may be further complicated by the fact that in a plan, one may have a representation of only a portion of the landscape in question that may not even include the top and bottom of slopes. King, et al., (1983) discuss some of these problems. In their studies, slope position was defined with respect to differences in slope between slope segments. While less sensitive to some of the problems mentioned above, this approach was useful only in classifying slope into units rather than providing a continuous variable representing position and required several subjective decisions in dealing with intersecting landforms. Consequently, although slope length, distance from top and proportional distance downslope were found to be significantly correlated with productivity in several instances in this study, they were not considered to be particularly useful variables in reclamation planning.

Vertical slope shape, as has been pointed out previously, is also a measure of slope position and within a given site, tends to be correlated with distance from top of slope and proportional distance downslope. It has been demonstrated to be a relatively good predictor of productivity in this study and complements the findings of King, et al. (1983). Horizontal shape has also been shown in this study to be a significant determinant of productivity and would be valuable as a variable if it could be incorporated readily into the design process.

The subjective determination of slope shape as was done in this study is of little value in the reclamation planning process. It would be time consuming in carrying out a grading problem and subject to error in individual judgement, but it is a simple matter to develop an index of curvature for both vertical and horizontal slope shape that could be objectively measured on a topographic plan.

Horizontal shape could, for example, be expressed as degree of curvature, over some defined distance. Curvature could be expressed as a negative value when the curve is toward the uphill side and as a positive value when towards the downhill side (see Figure 9).

Vertical shape can easily be indexed through measurement of contour lines on a map. A point on a contour line can be compared with points on contour lines directly up and downslope from it. If the point in question is equidistant between the two other points, the slope, as measured at that point, is flat. If the point is closer to the downhill point, the slope is convex; if closer to the uphill point, the slope is concave. The ratio of the distances between the points at which slope is being measured and points on the adjoining contours provide an index of slope shape. These relationships are shown in Figure 9.

Computation of similar indices would also be a simple matter when utilizing a digital terrain model. Let us assume that the following represents five points indicating elevation on a digital terrain model:

$$\begin{array}{ccc} & a & \\ b & x & c \\ & d & \end{array}$$

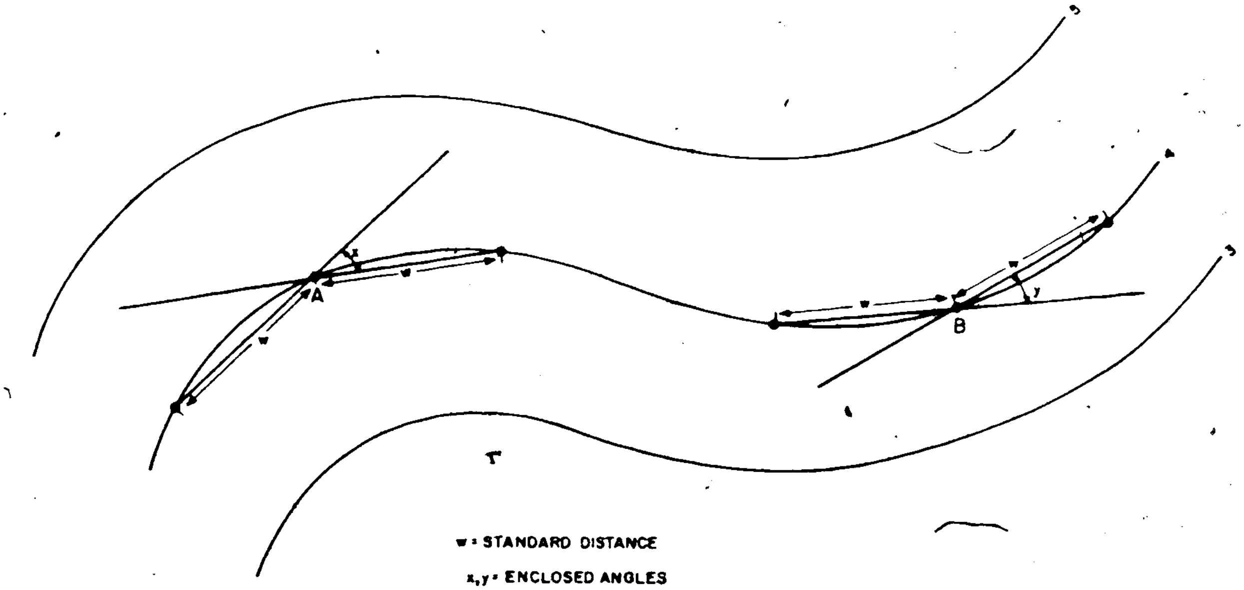
where x is the point at which we wish to determine horizontal (H) and vertical (V) slope shape. If the slope aspect is parallel to line a d then an index of vertical shape could be described by:

$$V = \frac{a + d}{2} - x.$$

and one for horizontal shape by:

$$H = \frac{b + c}{2} - x.$$

DETERMINATION OF HORIZONTAL SHAPE FROM A CONTOUR PLAN



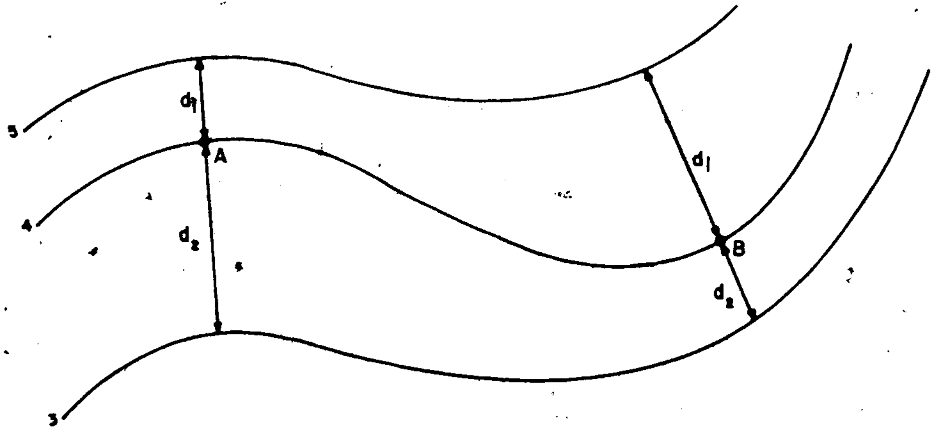
w = STANDARD DISTANCE

x, y = ENCLOSED ANGLES

HORIZONTAL SHAPE AT POINT A = x

HORIZONTAL SHAPE AT POINT B = −y

DETERMINATION OF VERTICAL SHAPE FROM A CONTOUR PLAN



VERTICAL SHAPE AT POINTS A & B = $\frac{d_1}{d_2}$

IF $d_1 < d_2$ SHAPE IS CONCAVE

IF $d_1 > d_2$ SHAPE IS CONVEX

DETERMINATION OF SLOPE
SHAPE FROM A CONTOUR PLAN

FIGURE 9

A composite index of shape (S) could be defined equally by:

$$S = \frac{a + b + c + d}{4} - x \quad , \quad \text{or} \qquad S = \frac{H + V}{2}$$

In all cases, a value of 0 would represent a flat slope, a positive value a concave slope, and a negative value a convex slope. This is illustrated in Figure 10. Many other composite shape indices, such as the multiplicative one discussed earlier, are possible but this one will serve for illustrative purposes.

Of course, in most cases, aspect will not be parallel to the grid of the terrain model and a correction for aspect would have to be calculated. MacDougall (1983) provides us an equation for determining aspect (A) measured at point x on the digital terrain model below.

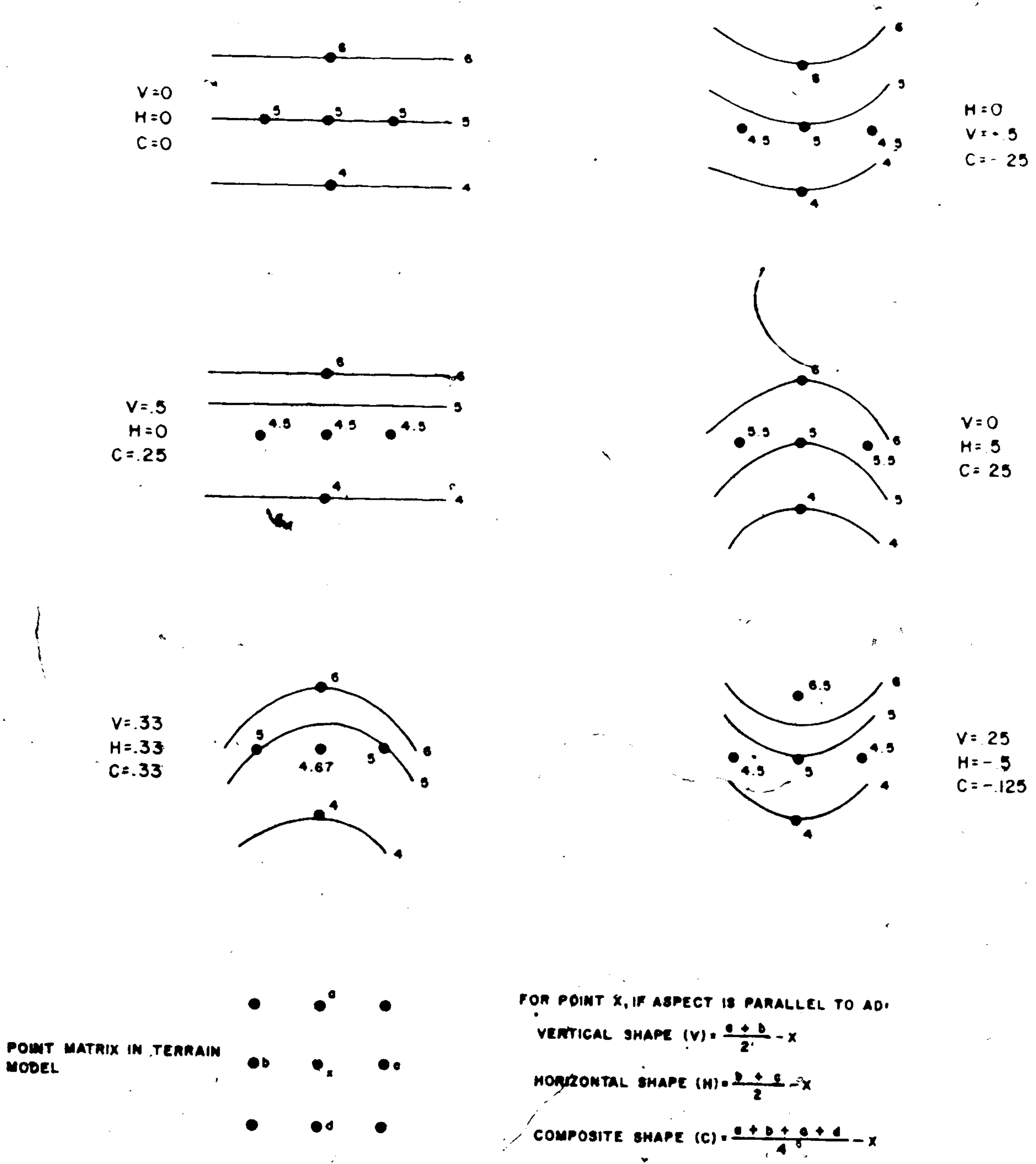
$$\begin{array}{ccc} & a & \\ b & x & c \\ & d & \end{array}$$

$$A = \text{Arctan}\ (E2/E1)$$

$$\text{where, } E1 = d - a$$

$$E2 = b - c.$$

This yields an aspect that has a value between 0 and 90° with due north or due south slopes having an aspect of 0° and calculated aspect values expressing deviation from these compass points. Aspects in the northwest and southeast quadrants would be negative and those in the northeast and southwest would be positive.



FOR POINT X, IF ASPECT IS PARALLEL TO AD:

VERTICAL SHAPE $(V) = \frac{a+b}{2} - X$

HORIZONTAL SHAPE $(H) = \frac{b+c}{2} - X$

COMPOSITE SHAPE $(C) = \frac{a+b+c+d}{4} - X$

HORIZONTAL, VERTICAL AND COMPOSITE SLOPE SHAPE INDICES FROM DIGITAL TERRAIN MODELS

FIGURE 10

Once this is computed, adjusted values may be computed by:

$$\text{If } A < 0 \quad a_1 = R(b - a) + a$$

$$b_1 = R(d - b) + b$$

$$c_1 = R(a - c) + c$$

$$d_1 = R(d - c) + d$$

$$\text{If } A > 0 \quad a_1 = R(a - c) + a$$

$$b_1 = R(b - a) + b$$

$$c_1 = R(d - c) + c$$

$$d_1 = R(b - d) + d$$

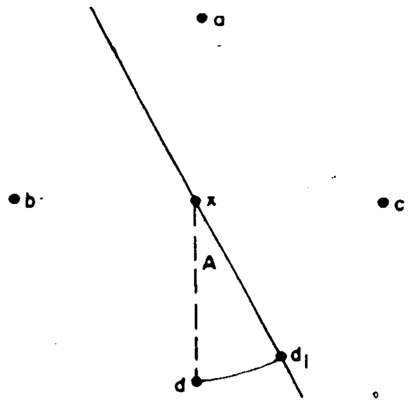
$$\text{where, } R = \left|\frac{A}{90}\right|$$

Figure 11 demonstrates this adjustment. From the adjusted values, one may calculate the horizontal and vertical slope shape indices. This calculation only gives an approximate adjustment. A more accurate value would be calculated by utilizing four points, as shown in Figure 11, but requires a more complex calculation. The derivation of this equation is shown in Appendix D.

If the simple additive composite slope shape index is found to be adequate to predict productivity, adjusting the values for aspect is unnecessary, as the equation $C = \frac{a + b + c + d}{4} - x$ will yield the same result with adjusted or unadjusted values.

To show how these and other variables could be incorporated into the reclamation planning and design process, the somewhat simplified contour plan of a borrow area employed in the reconstruction of a syphon for the St. Mary River Irrigation District in southern Alberta (Figure 12) is used as an example. The site is called Forty Mile Coulee and is located in the Mixed Prairie Region. The general topography of

APPROXIMATE CORRECTION

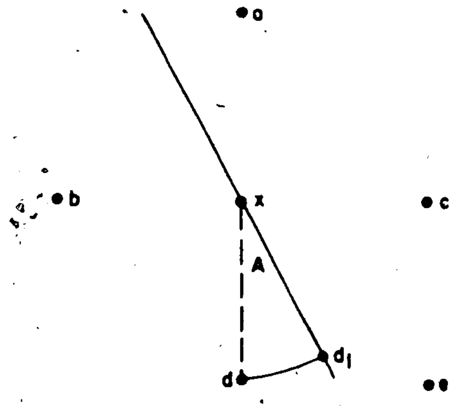


A = aspect

d_1 = adjusted elevation of d

$$d_1 = \frac{A}{90}(c-d)+d$$

MORE PRECISE CORRECTION

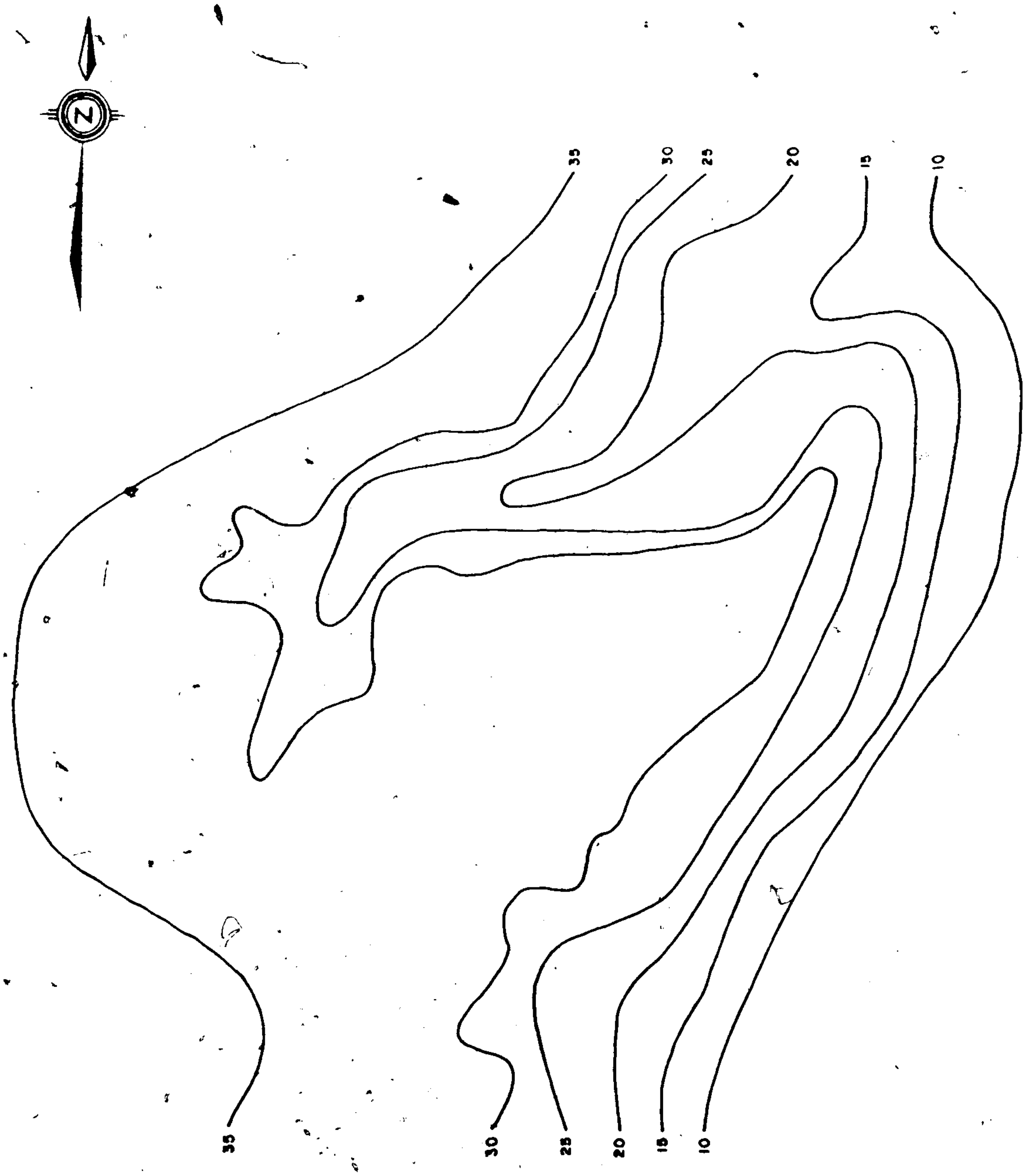


$$d = x + \cos A(d-x) + \sin A(c-x) + \sin A \cos A(e+x-c-d)$$

NOTE SEE APPENDIX C FOR PROOF

CORRECTIONS FOR ASPECT FOR SLOPE ANALYSIS

FIGURE 11



NOT TO SCALE

CONTOUR ELEVATION IN METRES

CONTOUR PLAN-
UNDISTURBED SITE

FIGURE 12

the area is similar to that of the Jensen Reservoir site, but the climate is somewhat hotter and drier.

The site was in native grass cover prior to disturbance. As can be seen in the contour plan, the site comprises a point of land projecting into the valley that is dissected by a deep, sharp coulee. The shape of the parcel and the steep slopes had limited the usefulness of the parcel to the owner, but the diversity of vegetation in the coulee created good wildlife habitat.

A grid was laid over the contour plan and spot elevations interpolated for each point to produce a digital terrain model for the site (Figure 13). The numbers represent the elevation of the points at the centres of the squares. Utilizing the equation for the composite slope shape index, slope shape was calculated for each point in the model. These values were then adjusted so that the total range in shape values was comparable to the range of composite slope shape values derived for Jensen Reservoir. These have been plotted as an overlay (Figure 14).

Soil testing for the site determined that there were no significant nutrient deficiencies, nor any adverse chemical or physical soil properties that would be expected to limit production. The soil organic matter content was found to have a maximum of approximately 10 percent on the site.

The following equation was derived from the Jensen Reservoir data.

$$M = 0.00282A + 0.444$$

where, M = soil organic matter index

$$\left(\frac{\text{\% soil organic matter content}}{\text{local maximum \% soil organic matter content}}\right)$$

A = aspect measured as degrees from SW

36	36	36	35	33	27	19	17	15	14	12
36	36	35	33	31	24	19	20	22	22	13
34	33	31	29	25	22	20	22	25	25	13
30	30	23	21	20	22	23	24	31	24	13
28	26	28	30	31	31	31	31	30	20	13
31	26	31	32	32	32	32	31	27	20	13
31	30	31	32	33	32	31	29	23	17	12
30	31	32	33	32	31	28	25	14	9	
32	32	32	32	31	30	27	20	12	7	
34	33	32	31	29	27	23	15	8	5	

**VALUES ARE ELEVATIONS OF
CENTRE POINTS OF CELLS IN METRES**

NOT TO SCALE
CONTOUR ELEVATION IN METRES

DIGITAL TERRAIN MODEL-
UNDISTURBED SITE

FIGURE 13

5.00	5.00	5.50	6.25	6.75	7.75	6.00	4.50	2.50
5.75	5.00	4.50	6.50	6.75	7.50	6.25	6.00	2.00
4.00	10.50	8.00	10.75	8.00	7.25	8.75	.75	4.25
8.00	5.50	4.00	3.25	4.00	4.25	4.00	3.25	7.75
9.50	4.25	5.25	6.00	5.75	5.25	4.75	5.00	5.25
5.75	6.25	6.25	5.00	5.75	5.25	4.50	4.75	9.00
6.00	5.75	5.00	6.00	5.50	6.50	3.75	9.25	
6.00	6.00	5.75	5.75	5.00	4.25	5.75	6.25	

MEAN 5.74
STANDARD DEVIATION 1.81

[illegible]
[illegible]

COMPOSITE SLOPE SHAPE INDEX-
UNDISTURBED SITE

FIGURE 14

It must be noted that this relationship is untested for sites other than Jensen Reservoir and is used simply as a convenient method of generating the data required for this investigation of reclamation planning techniques.

The aspect at each point on the digital terrain model was taken as the aspect of a tangent to a point on the nearest contour line on the plan. A contour on a south-facing slope that ran exactly east-west had a value of zero. Deviations from this were measured both east and west to a maximum of 180° for a contour on a north-facing slope that ran exactly east-west. It was easier to measure from the contour lines than calculate from the digital terrain model for this example. These aspects have also been mapped as an overlay (Figure 15). Utilizing the equation listed above with a local organic matter content maximum of 10 percent, values were calculated and mapped for each point (Figure 16). This method of determining soil organic matter distribution is not being proposed, as the correlation is not strong. It is used here largely to generate the values needed for demonstration purposes. The following equation was also derived from the Jensen Reservoir data:

$$P = 0.0761S + 0.0381M - 0.23$$

where, P = productivity index (1 = local maximum)

S = shape composite (horizontal shape + vertical shape)

M = soil organic matter content.

As with the equation for organnaic matter index presented above, it must be noted that this equation has not been tested for sites other than Jensen Reservoir and, apart from the general topographic similarity between the Jensen Reservoir and Forty Mile Coulee site, there is no

45	45	45	45	45	70	91	20	130	170
25	28	30	50	67	70	40	140	178	37
20	20	17	1	50	50	40	42	120	90
15	60	10	175	175	178	179	157	45	80
40	70	54	140	162	178	170	155	70	80
60	180	75	90	180	90	45	60	70	74
70	140	120	120	45	45	45	33	60	72
160	130	130	45	45	45	55	66	50	60
60	100	45	45	45	90	55	60	60	60
60	45	45	45	90	19	55	70	61	60

ASPECT ANALYSIS-
UNDISTURBED SITE

FIGURE 15

5.23	5.29	5.85	6.33	6.41	5.57	8.39	9.46	5.48
5.00	4.92	4.47	5.85	5.85	5.57	5.62	7.82	6.98
6.13	4.72	9.37	9.37	9.46	9.49	8.87	5.71	6.70
6.41	5.96	8.39	9.01	9.46	9.23	8.81	6.41	6.70
9.52	6.55	6.98	9.52	6.98	5.71	6.13	6.41	6.53
8.39	7.82	7.82	5.71	5.71	5.71	5.37	6.13	6.47
8.11	8.11	5.71	5.71	5.71	5.99	6.30	5.85	
7.26	5.71	5.71	5.71	6.98	5.99	6.13	6.13	

NUMBERS ARE AVERAGE
% SOIL ORGANIC MATTER CONTENT FOR CELL
NOT TO SCALE
CONTOUR ELEVATION IN METRES

SOIL ORGANIC MATTER CONTENT ANALYSIS-
UNDISTURBED SITE

FIGURE 16

basis for assuming that this particular model would produce valid results for the Forty Mile Coulee site. It is, however, assumed that a valid model could be generated for this site. The equation derived from the Jensen Reserovir data is only used as a convenient example for the investigation of how such models can be used in the reclamation planning process.

The equation was used to calculate a productivity index for each point on the digital terrain model. Descriptive statistics were then calculated for the new variable (Figure 17).

According to standard construction practice, the topsoil was stripped from the entire site, stockpiled until excavation was complete, then spread uniformly over the site. Sufficient mixing occurred in this procedure that replaced material was assumed to be relatively homogeneous in physical and chemical properties. Thus, the soil organic matter content for each point in the reclaimed landscape is expected to be close to the mean value for that of the undisturbed site. The mean soil organic matter content for the undisturbed site was 6.784 percent. This value was used for each pixel in the reclaimed site.

Since the landowner wished to use the reclaimed area for seeded pasture or tame hay, it was agreed that the side slopes of the reclaimed site would be gradual and that the land would be smoothed both horizontally and vertically to facilitate harvesting and seeding. Figure 18 is an approximate contour plan of the reclaimed site. This, too, was gridded and spot elevations interpolated (Figure 19). Composite slope shape was calculated in the same manner as for the undisturbed site (Figure 20). Utilizing these values and the mean soil organic matter content, the productivity index was calculated for each

.35	.35	.41	.49	.53	.57	.55	.47	.17
.40	.34	.28	.49	.51	.55	.46	.52	.19
.31	.75	.74	.95	.74	.68	.77	.04	.35
.62	.42	.39	.36	.43	.45	.41	.26	.61
.86	.34	.44	.59	.47	.39	.37	.39	.42
.53	.54	54	.37	.43	.39	.32	.37	.70
.54	.52	.37	.44	.40	.49	.30	.70	
.50	.44	.43	.43	.42	.32	.44	.48	

MEAN 0.465

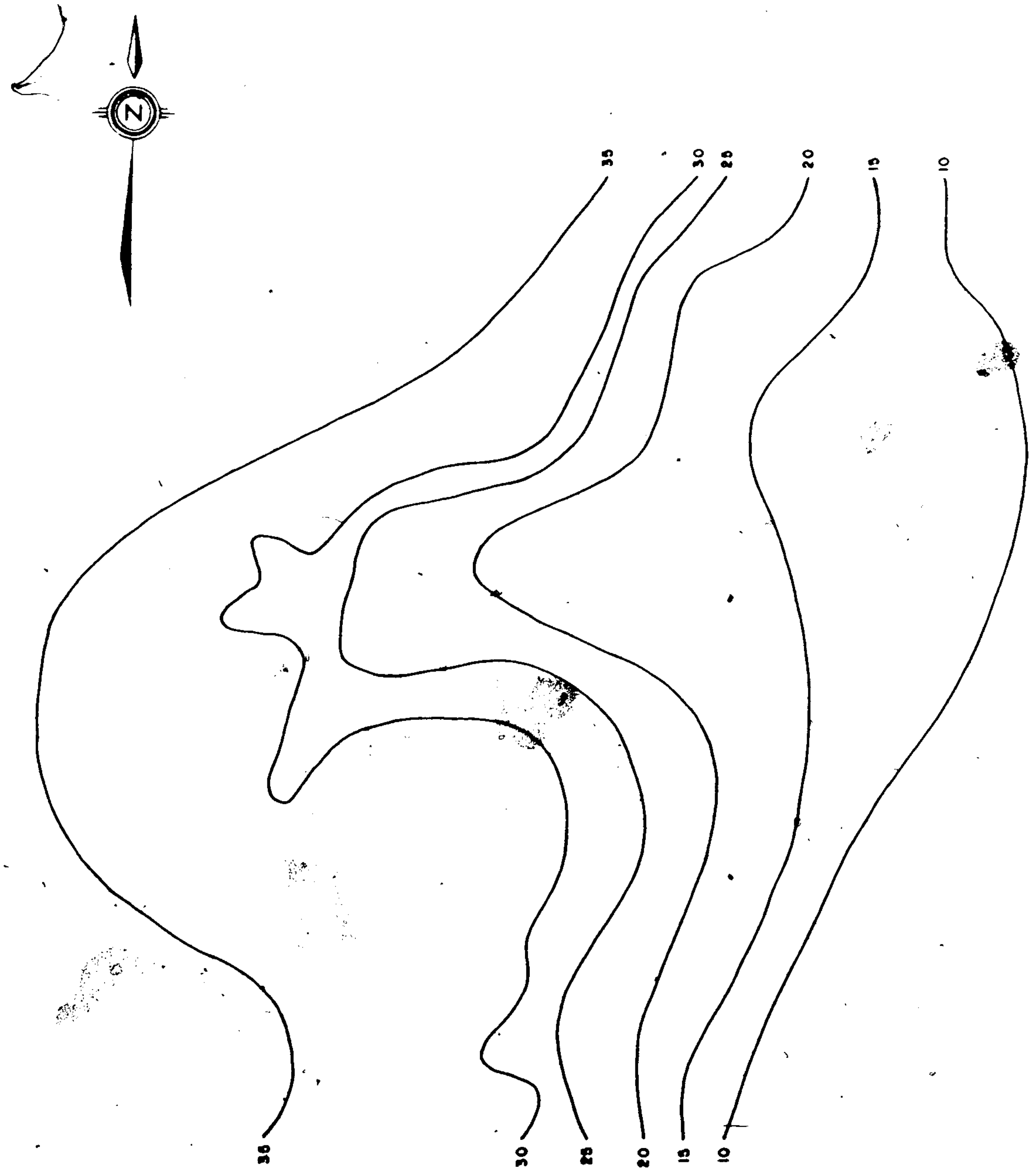
STANDARD DEVIATION 0.156

NOT TO SCALE

CONTOUR ELEVATIONS IN METERS

PRODUCTIVITY INDEX-
UNDISTURBED SITE

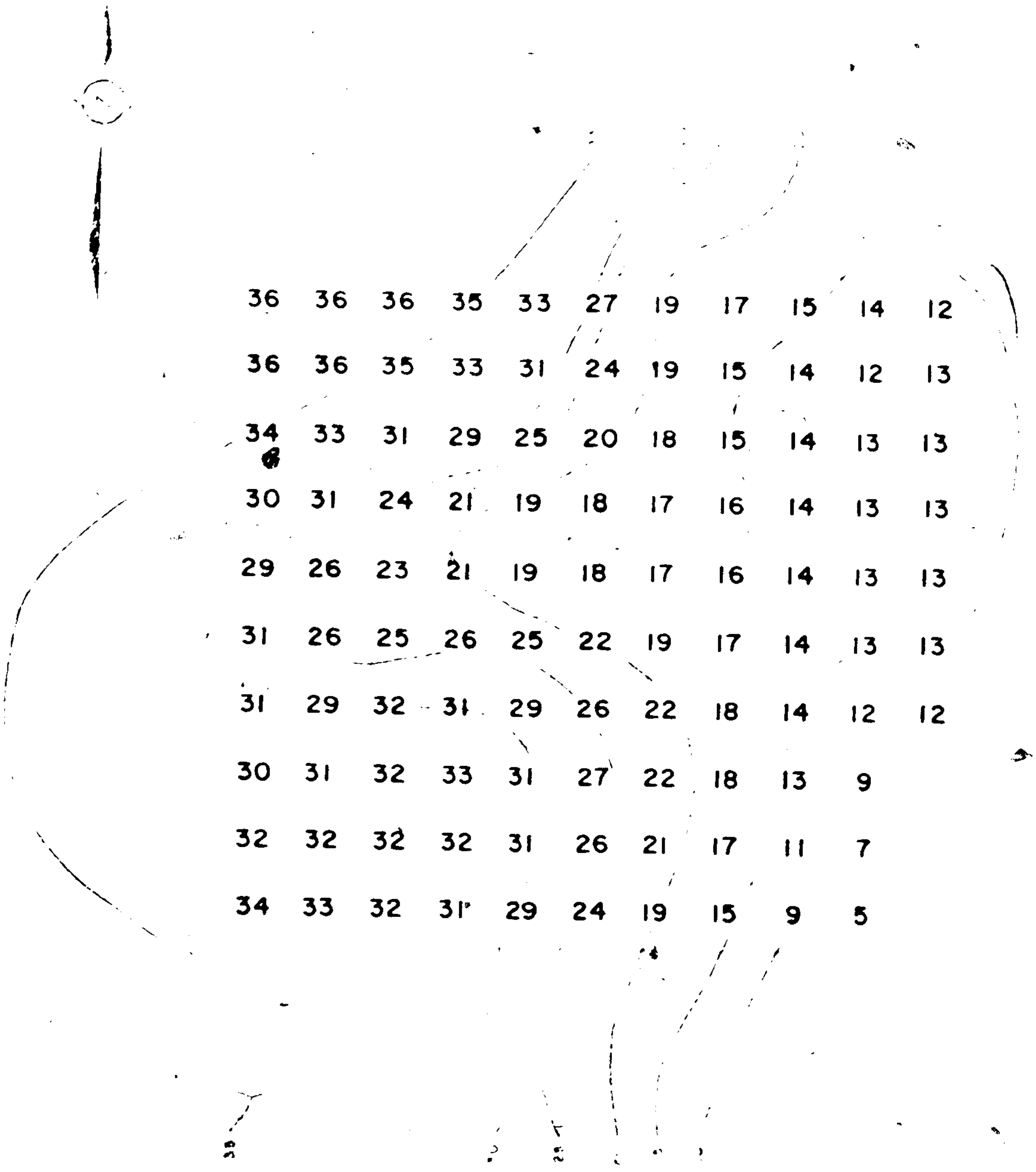
FIGURE 17



NOT TO SCALE
CONTOUR ELEVATION IN METRES

CONTOUR PLAN-
RECLAIMED SITE

FIGURE 18



36	36	36	35	33	27	19	17	15	14	12
36	36	35	33	31	24	19	15	14	12	13
34	33	31	29	25	20	18	15	14	13	13
30	31	24	21	19	18	17	16	14	13	13
29	26	23	21	19	18	17	16	14	13	13
31	26	25	26	25	22	19	17	14	13	13
31	29	32	31	29	26	22	18	14	12	12
30	31	32	33	31	27	22	18	13	9	
32	32	32	32	31	26	21	17	11	7	
34	33	32	31	29	24	19	15	9	5	

VALUES ARE ELEVATIONS
OF CENTRE POINTS OF
CELLS IN METRES

NOT TO SCALE

CONTOUR ELEVATION IN METRES

DIGITAL TERRAIN MODEL-
RECLAIMED SITE

FIGURE 19

5.00	5.00	5.50	3.75	6.25	6.00	7.25	6.00	7.50
6.00	5.25	4.50	5.75	7.25	6.00	6.75	6.00	6.00
3.25	8.50	8.25	7.75	6.50	6.25	5.50	6.25	6.25
7.25	7.00	7.25	7.75	7.00	6.50	6.00	6.25	6.25
7.75	7.75	5.50	5.00	6.00	6.50	5.75	6.50	6.00
7.00	3.25	5.00	5.25	5.00	5.25	5.75	6.25	6.00
5.75	6.00	4.50	5.00	5.25	6.00	5.50	6.00	
6.00	6.00	5.75	4.50	5.75	6.00	5.25	6.50	

MEAN 6.01
STANDARD DEVIATION 1.04
NOT TO SCALE
CONTOUR ELEVATION IN METRES

COMPOSITE SLOPE SHAPE INDEX-
RECLAIMED SITE

FIGURE 20

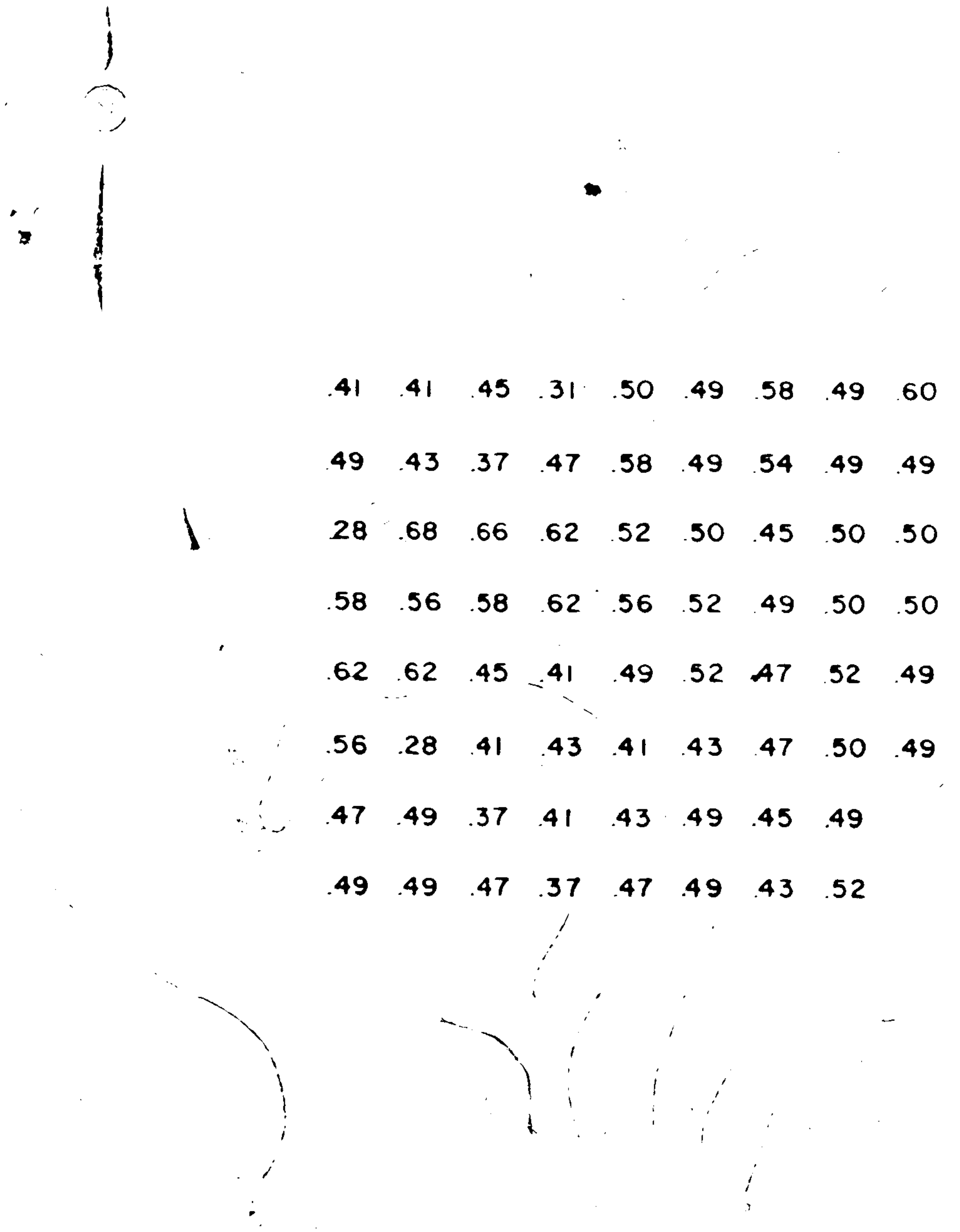
point on the digital terrain model and descriptive statistics computed (Figure 21).

Comparing the productivity index totals, it can be seen that the model predicts an increase in productivity in the reclaimed site of approximately 4.5 percent over that of the undisturbed site.

The Productivity Index overlay can be inspected for points with low values that indicate areas that might be difficult to reclaim. In this case, there are few low values and perhaps those that do exist could be modified with moderate regrading.

Inspection of the descriptive statistics for the pre-disturbance and reclaimed sites also reveals some interesting facts. The range of productivity values and their standard deviation is significantly reduced in the reclaimed landscape. This is to be expected by the general smoothing of the landscape that occurred; however, as noted above, the pre-disturbance landscape has a high wildlife value, while the reclaimed landscape was intended for pasture or hay. The large range and standard deviation for the undisturbed site provide an indication of the site diversity, which created the wildlife value. The greater homogeneity of the reclaimed site is, of course, preferable for cropping.

The productivity index has the advantage of being independent of the level of management and land use of both the pre-disturbance and post-disturbance landscape and thus potentially provides a common currency for comparing the value of land reclaimed for wildlife habitat, grazing, or cropland. It appears that through the use of descriptive statistics, it may also be possible to evaluate the suitability of a



.41	.41	.45	.31	.50	.49	.58	.49	.60
.49	.43	.37	.47	.58	.49	.54	.49	.49
.28	.68	.66	.62	.52	.50	.45	.50	.50
.58	.56	.58	.62	.56	.52	.49	.50	.50
.62	.62	.45	.41	.49	.52	.47	.52	.49
.56	.28	.41	.43	.41	.43	.47	.50	.49
.47	.49	.37	.41	.43	.49	.45	.49	
.49	.49	.47	.37	.47	.49	.43	.52	

MEAN .488

STANDARD DEVIATION 0.079

NOT TO SCALE

CONTOUR ELEVATION IN METRES

PRODUCTIVITY INDEX-
RECLAIMED SITE

FIGURE 21

given reclamation strategy for the intended use (e.g. a large standard deviation required for wildlife habitat).

Of course, no index frees the planner from the need for the use of common sense, and it should also be noted that although the topographic and soil relationships dealt with here appear to hold constant for native and reclaimed grassland, they may not hold true for cropland.

Despite the necessarily tentative nature of these conclusions, the productivity index based on soil and topographic variables does appear to be a potentially useful tool in reclamation planning.

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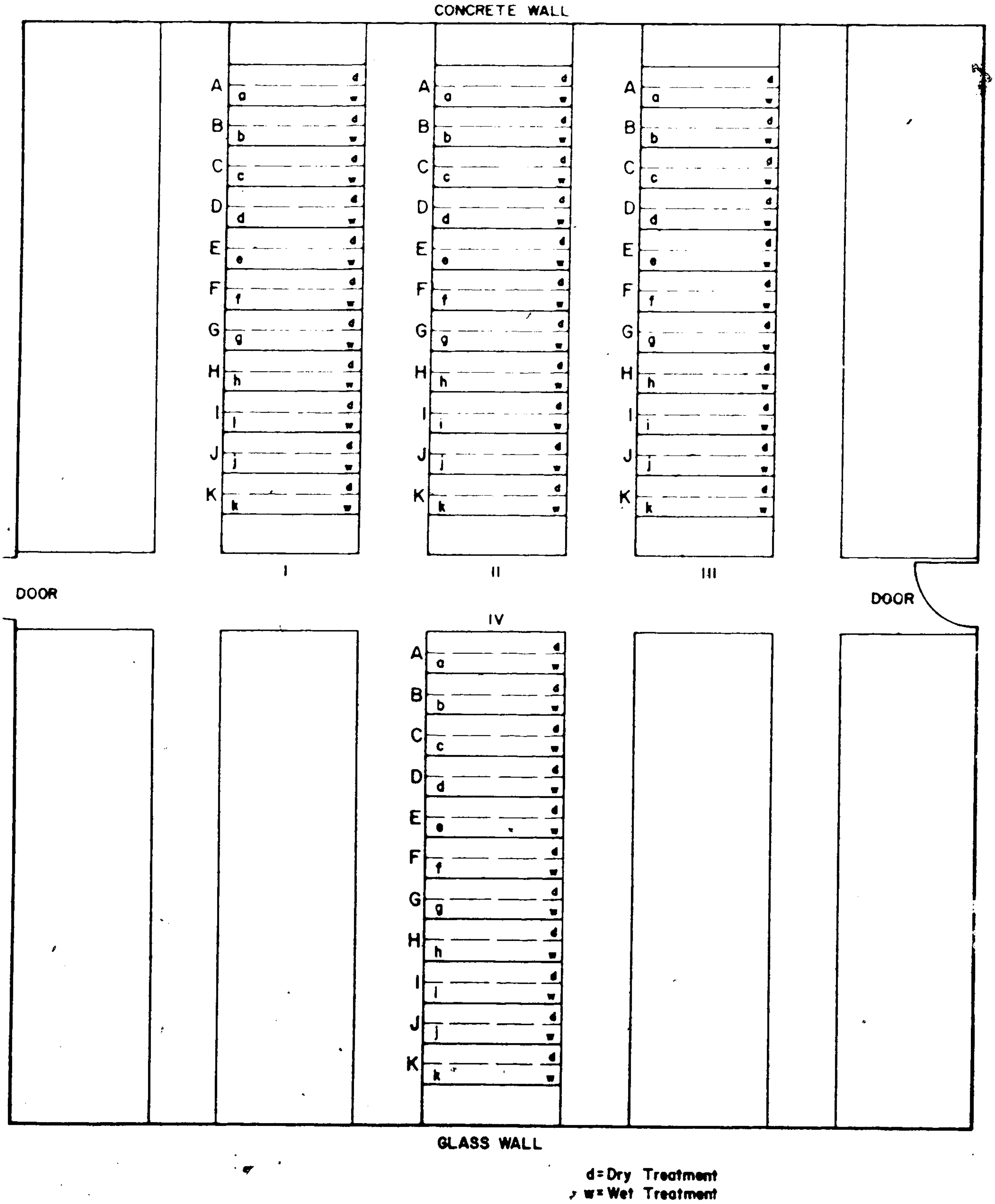
APPENDIX A

GREENHOUSE LAYOUT



GREENHOUSE LAYOUT

FIGURE A-1

I

A	LNL3	LSM3	JNL2	LSU1	LSU4
B	JSU1	JWU2	LSM4	LWL1	LWL2
C	LWL1	LNU1	C	JSL1	LSL4
D	LWM2	LSU3	LSU2	JNU1	JEU1
E	LNU3	JSM1	LWL2	JNM2	JNM1
F	JSM2	JEM2	LEL1	LSM1	LWU1
G	JWL1	JNL1	LSL3	LEL4	LWU2
H	LNM3	JEL2	LEM4	LNM1	JWM2
I	LWM1	LSM2	JSL2	JWL2	JWU1
J	JEU2	JEM1	LEM1	LNL1	JEL1
K	JNU2	LEU1	LEU4	JWM1	JSU2

II

A	LSM4	JWL1	LWU1	LWL1	JEL1
B	JNM1	LSL4	LSU1	JNL2	LNL3
C	JEL2	LSM1	LNU1	JWL2	JSL1
D	JNM2	LSL3	JEM1	LWM1	JSL2
E	JWU2	JSU1	LEU4	LWM2	JNL1
F	LSM2	LWL2	LNM1	LEM1	LSU4
G	JNU1	LEU1	LSL2	LSM3	JEU2
H	LEM4	LNL1	JSM2	JWM1	JWU1
I	JWM2	C	LWU3	LEU1	JEM2
J	LEL4	LNU3	JSM1	LSL1	LWU2
K	LNM3	JNU2	LSU2	LEL1	JSU2

III

A	LSM4	JWL1	LWU1	LWL1	JEL1
B	JNM1	LSL4	LSU1	JNL2	LNL3
C	JEL2	LSM1	LNU1	JWL2	JSL1
D	JNM2	LSL3	JEM1	LWM1	JSL2
E	JWU2	JSU1	LEU4	LWM2	JNL1
F	LSM2	LWL2	LNM1	LEM1	LSU4
G	JNU1	JEU1	LSL2	LSM3	JEU2
H	LEM4	LNL1	JSM2	JWM1	JWU1
I	JWM2	C	LSU3	LEU1	JEM2
J	LEL4	LNU3	JSM1	LSL1	LWU2
K	LNM3	JNU2	LSU2	LEL1	JSU2

IV

A	LSM1	JWL1	LWU1	JSM1	LWL2
B	JWU2	LNU3	LWM1	LEU4	JNM2
C	LWL1	JNL2	LSU1	JSU1	C
D	JEL2	LWM2	JEL1	JSU2	LSM3
E	JNL1	LSL3	JSL2	JNU1	LEM4
F	LNL3	LSL2	LSL4	LEU1	LEM1
G	LSU4	LNU1	JWM2	LWU2	LNM1
H	LEL4	LEL1	LSU3	JNM1	LSM2
I	JSM2	LNU1	JEU1	LSU2	JWM1
J	LSL1	JWU1	LNM3	LSM4	JEM1
k	JNU2	JEU2	JEM2	JWL2	JSL1

POT ARRANGEMENT ON BENCHES

FIGURE A-2

APPENDIX B

DATA AND STATISTICS

TABLE B-1

SUMMARY OF PRODUCTION CHARACTERISTICS

VARIABLE	SITE	UNITS	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
FIELD STUDIES								
Initial Harvest of Standing Crop and Litter	Little Bow	gm/m²	25	448	138.4	84.2	0.9	2.6
	Jensen		118	833	405.6	115.4	0.28	0.35
Log_{10} Initial Harvest	Little Bow	gm/m²	1.69	2.95	2.37	0.27	-0.36	0.64
	Jensen		2.37	3.22	2.87	0.20	-0.84	1.01
Topsoiled Plot Harvest	Little Bow	gm/m²	1.3	999	174.7	247.0	2.4	5.9
	Jensen		21.9	220.6	72.7	49.8	1.4	2.1
Stripped-Plot Harvest	Little Bow	gm/m²	0.0	176	31.4	44.2	1.9	3.7
	Jensen		9.4	202.3	50.2	42.2	2.1	6.5
GREENHOUSE TRIALS								
Wet Treatment	Little Bow	gm/pot	1.18	3.91	2.12	0.58	1.03	2.10
	Jensen		1.44	3.51	2.49	0.60	0.07	-1.06
Dry Treatment	Little Bow	gm/pot	1.10	2.59	1.73	0.29	0.49	1.94
	Jensen		1.06	2.57	1.71	0.38	0.23	-0.19

TABLE B-2

SUMMARY OF TOPOGRAPHIC CHARACTERISTICS

VARIABLE	SITE	UNITS	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
Slope	Little Bow	percent	2	12	6.08	2.99	0.44	-0.94
	Jensen		2.3	37	18.43	11.04	-0.07	1.14
Length	Little Bow	metres	57	270	133	80.7	0.95	-0.89
	Jensen		30	82	48.4	18.14	1.06	-0.50
Horizontal Shape	Little Bow		2	4	2.9	0.75	0.17	-1.28
	Jensen		2	4	2.8	0.59	-0.24	-0.70
Vertical Shape	Little Bow		2	4	2.7	0.82	0.50	-1.39
	Jensen		1.5	3.5	2.5	0.74	-0.07	-1.54
Aspect	Little Bow	degrees from SW	20	143	75.7	41.5	0.22	-1.46
	Jensen		6	126	70.8	40.6	-0.07	-1.76
Proportion of Slope Length	Little Bow		0.09	0.94	0.53	0.27	0.08	-1.078
	Jensen		0.11	0.75	0.44	0.21	0.01	-1.321

SUMMARY OF SOIL CHARACTERISTICS

VARIABLE	SITE	UNITS	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
Nitrogen	Little Bow	ppm	4	51	34.9	13.9	-0.30	-0.24
	Jensen		25	51	48.7	5.5	-1.94	8.39
Phosphorus	Little Bow	ppm	7	26	14.8	4.0	0.41	0.80
	Jensen		8	18	12.8	3.2	0.13	-0.66
Potassium	Little Bow	ppm	160	488	315	80	0.02	-0.02
	Jensen		377	664	548	73	-0.14	-0.11
Sulphur	Little Bow	ppm	11	200	30	45.9	1.80	5.9
	Jensen		--	--	--	--	--	--
pH	Little Bow		6.8	6.8	7.26	0.38	-0.17	-0.75
	Jensen		6.4	7.5	7.05	0.33	-0.56	-0.78
Electrical Conductivity	Little Bow	mmhos	0.3	1.0	0.59	0.18	0.74	0.21
	Jensen		0.6	2.3	1.29	0.39	0.67	0.60
Sodium	Little Bow	-*	1	2	1.03	0.18	5.5	30
	Jensen		1	1	1	0		
Lime	Little Bow	-*	0	2	0.1	0.4	4.3	18.8
	Jensen		0	4	0.6	1.2	2.3	4.8
Texture	Little Bow	-**	1	3	1.9	0.40	-0.88	3.2
	Jensen		2	4	3.3	0.53	0.34	-0.10
Organic Matter	Little Bow	percent	1.2	5.7	3.2	1.28	0.002	-0.64
	Jensen		5.6	12.6	8.1	2.00	0.88	-0.37

NOTE: N, P, K, S - expressed as elemental concentration.
* Scale of 0 (none) to 9 (very high)
** Scale of 1 (very course) to 5 (very fine)

TABLE B-4

REGRESSION ANALYSIS RESULTS
PRODUCTION WITH TOPOGRAPHY AND SOIL VARIABLES

DEPENDENT VARIABLE	SITE	REGRESSION EQUATION	r^2 VALUE OF EQUATION
TOPOGRAPHIC VARIABLES ONLY			
Initial Harvest	Little Bow	125H - 85	0.31
	Jensen	303H - 42	0.29
		415H + 14D - 658	0.53
Log$_{10}$ Initial Harvest	Little Bow	0.2H + 1.8	0.33
	Jensen	0.19H + 2.3	0.30
		0.26H + 0.0094D + 1.95	0.58
SOIL AND TOPOGRAPHIC VARIABLES			
Initial Harvest	Little Bow	125H - 85	0.31
	Jensen	97M + 24	0.34
		99M + 709P - 301	0.54
Log$_{10}$ Initial Harvest	Little Bow	0.2H + 1.8	0.33
		0.24H - 0.8M + 1.93	0.34
	Jensen	0.19H + 2.3	0.30
		0.26H + 0.0094D + 1.95	0.58
Topsoiled Harvest	Little Bow	96M - 136	0.25
	Jensen	37V - 22	0.30
		33V + 0.55A - 48	0.50
Stripped-Plot Harvest	Little Bow	0.41A + 0.077	0.15
		0.625A + 0.36D - 41	0.40
	Jensen	13M - 53	0.36
		10M + 25V - 97	0.54

A = Aspect
D = Distance from Top of Slope
H = Horizontal Shape
M = Soil Organic Matter Content
P = Proportional Distance Downslope
V = Vertical Shape

TABLE B-5

REGRESSION ANALYSIS RESULTS
PRODUCTION WITH PRINCIPLE COMPONENTS FACTOR SCORES

DEPENDENT VARIABLE	SITE	REGRESSION EQUATION	r^2 VALUE OF EQUATION
Initial Harvest	Little Bow	91.73 PC1(Shape) + 276.74	0.31
	Jensen	183.71 PC1(Soil) + 817.59	0.34
		183.71 PC1(Soil) + 161.59 PC2(Position) + 817.59	0.54
Logged Initial Harvest	Little Bow	0.143 PC1(Shape) + 2.3704	0.30
		0.143 PC1(Shape - 0.091 PC3(Soil) + 2.3704	0.42
	Jensen	0.104 PC1(Soil) + 2.8721	0.26
		0.104 PC1(Soil) + 0.101 PC2(Position) + 2.8721	0.51
Topsoiled Harvest	Little Bow	123.25 PC3(Soil) + 174.71	0.25
	Jensen	27.46 PC1(Soil) + 73.52	0.29
		27.46 PC1(Soil) + 23.18 PC2(Position) + 73.52	0.50
Stripped-Plot Harvest	Little Bow	20.24 PC3(Soil) + 31.44	0.21
	Jensen	26.16 PC1(Soil) + 49.77	0.37
		26.16 PC1(Soil) + 17.26 PC2(Position) + 49.77	0.53

TABLE B-6

REGRESSION ANALYSIS RESULTS
SOIL ORGANIC MATTER CONTENT AND SOIL TEXTURE WITH TOPOGRAPHIC VARIABLES

DEPENDENT VARIABLE	SITE	REGRESSION EQUATION	r^2 VALUE OF EQUATION
Organic Matter	Little Bow	0.80V + 1.0491	0.26
	Jensen	0.0356A + 5.5954	0.53
	Little Bow	0.63 PC1(Shape-Position) + 3.2433	0.25
	Jensen	1.03 PC3(Slope-Aspect) + 8.1512	0.26
		0.98 PC3(Slope-Aspect) + 0.86 PC1(Horizontal Shape-Length) + 8.1839	0.45
Texture	Jensen	0.0087A + 2.6326	0.44
	Jensen	0.27 PC3(Slope-Aspect) + 3.2423	0.24
		0.26 PC3(Slope-Aspect) + 0.24 PC1(Horizontal Shape-Length) + 3.2516	0.44

A = Aspect
V = Vertical Slope Shape

CORRELATION MATRIX

LITTLE BOW RESERVOIR DATA

KEY

Slope	Percent Slope
SWBear	Aspect SW rotated
Dist	Distance from summit
Length	Length of slope
Hor	Horizontal slope shape
Vert	Vertical slope shape
Biomas	Biomass of intial harvest
Logbio	Log_{10} Biomass
Tpsl	Topsoiled plot harvest
Notpsl	Stripped-plot harvest
Mwet	Mean of biomass values for four replicates from wet treatment from greenhouse trials
Mdry	Mean of biomass values for four replicates from dry treatment from greenhouse trials
N	Nitrogen concentration in soil
P	Phosphorus concentration in soil
K	Potassium concentration in soil
S	Sulphur concentration in soil
pH	pH of soil
Cond	Electrical conductivity of soil
Na	Sodium concentration in soil
Lime	Free lime in soil
Text	Soil texture
OM	Soil organic matter content

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- - - - - - - - - - - - - - - -  P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S  - - - - - - - - - - - - - - - -

                SLOPE      SWBEAR        DIST      LENGTH         HOR        VERT      BIOMAS      LOGBIO        TPSL      NOTPSL        MWET

SLOPE          1.0000       .3227      -.3489      -.1862      -.0732      -.2865      -.0937       .0708      -.2377       .0402      -.0269
             (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
              P=          P= .041     P= .029     P= .162     P= .350     P= .062     P= .311     P= .355     P= .103     P= .416     P= .444

SWBEAR          .3227      1.0000      -.3550      -.4455      -.1651      -.1622      -.2700      -.2720       .2995       .3889       .0706
             (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
              P= .041     P=          P= .027     P= .007     P= .192     P= .196     P= .071     P= .073     P= .054     P= .017     P= .355

DIST           -.3489      -.3550      1.0000       .7180       .4797       .7546       .3854       .2705       .1630       .3258       .3770
             (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
              P= .029     P= .027     P=          P= .000     P= .004     P= .000     P= .018     P= .074     P= .195     P= .039     P= .020

LENGTH         -.1862      -.4455       .7180      1.0000       .0433       .3512       .0782       .0056      -.0031       .2459       .5323
             (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
              P= .162     P= .007     P= .000     P=          P= .410     P= .028     P= .341     P= .488     P= .494     P= .095     P= .001

HOR            -.0732      -.1651       .4797       .0433      1.0000       .7170       .5539       .5703       .0857       .0192       .1317
             (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
              P= .350     P= .192     P= .004     P= .410     P=          P= .000     P= .001     P= .000     P= .326     P= .460     P= .244

VERT           -.2865      -.1622       .7546       .3512       .7170      1.0000       .4170       .4069       .3035       .1730       .3048
             (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)
              P= .062     P= .196     P= .000     P= .028     P= .000     P= .        P= .011     P= .013     P= .051     P= .180     P= .051

BIOMAS         -.0937      -.2700       .3854       .0782       .5539       .4170      1.0000       .9125       .0157       .0369       .1199
             (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)
              P= .311     P= .074     P= .018     P= .341     P= .001     P= .011     P=          P= .000     P= .467     P= .423     P= .264

LOGBIO          .0708      -.2720       .2705       .0056       .5703       .4069       .9125      1.0000      -.1189      -.0948       .0359
             (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)
              P= .355     P= .073     P= .074     P= .488     P= .000     P= .013     P= .000     P=          P= .266     P= .309     P= .425

TPSL           -.2377       .2995       .1630      -.0031       .0857       .3035       .0157      -.1189      1.0000       .3572       .1130
             (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)
              P= .103     P= .054     P= .195     P= .494     P= .326     P= .051     P= .467     P= .266     P=          P= .026     P= .276

NOTPSL          .0402       .3889       .3258       .2459       .0192       .1730       .0369      -.0948       .3572      1.0000       .5058
             (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)
              P= .416     P= .017     P= .039     P= .095     P= .460     P= .180     P= .423     P= .309     P= .026     P=          P= .002

MWET           -.0269       .0706       .3770       .5323       .1317       .3048       .1199       .0359       .1130       .5058      1.0000
             (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)
              P= .444     P= .355     P= .020     P= .001     P= .244     P= .051     P= .264     P= .425     P= .276     P= .002     P=

(COEFFICIENT / (CASES) / SIGNIFICANCE)          " . " IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED
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- - - - - - - - - - - - - - - -  P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S  - - - - - - - - - - - - - -

           SLOPE      SWBEAR     DIST       LENGTH     HOR        VERT       BIOMAS     LOGBIO     TPSL       NOTPSL     MWET

MORY       -.1745      .0930      .2035      .3608      .0697      .1979      .0401     -.0452      .2001      .4546      .7940
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .178    P= .312    P= .140    P= .025    P= .357    P= .147    P= .417    P= .406    P= .144    P= .006    P= .000

N           .0294     -.2050      .0478     -.0639      .3867      .1963      .1718      .2516     -.0978     -.2713     -.0012
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .439    P= .138    P= .401    P= .369    P= .017    P= .149    P= .182    P= .090    P= .304    P= .073    P= .498

P          -.2306     -.3951      .1705      .1733      .1767      .2193      .3316      .3459      .1815     -.1621      .2238
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .110    P= .015    P= .184    P= .180    P= .175    P= .122    P= .037    P= .030    P= .168    P= .196    P= .117

K          -.3443     -.0281      .5037      .4314      .3864      .5324      .1433      .0125      .1684      .3053      .6770
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .031    P= .441    P= .002    P= .009    P= .017    P= .001    P= .225    P= .474    P= .187    P= .050    P= .000

S          -.0505      .0631     -.0505     -.1528      .3473      .1111     -.0141      .0450     -.0733      .0589     -.0065
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .395    P= .370    P= .395    P= .210    P= .030    P= .279    P= .471    P= .407    P= .350    P= .379    P= .486

PH          .3588      .3651     -.7477     -.7249     -.3139     -.5875     -.2228     -.1160     -.2214     -.2081     -.5052
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .026    P= .024    P= .000    P= .000    P= .045    P= .000    P= .118    P= .271    P= .120    P= .135    P= .002

COND       -.0313     -.0535     -.0488     -.2103      .4744      .1652      .2932      .3611     -.0716     -.1109     -.0182
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .435    P= .389    P= .399    P= .132    P= .004    P= .191    P= .058    P= .025    P= .353    P= .280    P= .462

NA         -.0683     -.0943      .0276     -.0723      .2780      .0616     -.0771     -.0378     -.1042     -.1194     -.0649
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .360    P= .310    P= .442    P= .352    P= .068    P= .373    P= .343    P= .421    P= .292    P= .265    P= .367

LIME        .1931      .1939     -.1465     -.2206     -.2521     -.2306     -.1581     -.2128     -.1268     -.1053     -.1753
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .153    P= .152    P= .220    P= .121    P= .089    P= .110    P= .201    P= .129    P= .252    P= .290    P= .177

TEXT       -.1216      .2914      .3583      .3162      .2521      .3354      .1520     -.2105      .4365      .2722      .4412
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .261    P= .059    P= .026    P= .044    P= .089    P= .035    P= .211    P= .132    P= .008    P= .073    P= .007

OM         -.2671      .1865      .4633      .2956      .3318      .5139     -.0261     -.1760      .4954      .3586      .5680
          (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)    (   30)
          P= .077    P= .162    P= .005    P= .056    P= .037    P= .002    P= .446    P= .176    P= .003    P= .026    P= .001

(COEFFICIENT / (CASES) / SIGNIFICANCE)          " . " IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED
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- - - - - - - - - - - - - - - -  P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S  - - - - - - - - - - - - - - -

              MDRY        N           P           K           S           PH          COND        NA          LIME        TEXT        OM

SLOPE         -.1745       .0294      -.2306      -.3413      -.0505       .3588      -.0314      -.0683       .1931      -.1216      -.2671
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .178     P= .439     P= .110     P= .031     P= .395     P= .026     P= .435     P= .360     P= .153     P= .261     P= .077

SWBEAR         .0930      -.2050      -.3951      -.0281       .0631       .3651      -.0535      -.0943       .1939       .2914       .1865
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .312     P= .138     P= .015     P= .441     P= .370     P= .024     P= .389     P= .310     P= .152     P= .059     P= .162

DIST           .2035       .0478       .1705       .5037      -.0505      -.7477      -.0489       .0276      -.1465       .3583       .4633
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .140     P= .401     P= .184     P= .002     P= .395     P= .000     P= .399     P= .442     P= .220     P= .026     P= .005

LENGTH         .3608      -.0639       .1733       .4314      -.1528      -.7249      -.2103      -.0723      -.2206       .3162       .2956
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .025     P= .369     P= .180     P= .009     P= .210     P= .000     P= .132     P= .352     P= .121     P= .044     P= .056

HOR            .0697       .3867       .1767       .3864       .3473      -.3139       .4741       .2780      -.2521       .2521       .3318
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .357     P= .017     P= .175     P= .017     P= .030     P= .045     P= .004     P= .068     P= .089     P= .089     P= .037

VERT           .1979       .1963       .2193       .5324       .1111      -.5875       .1652       .0616      -.2306       .3354       .5139
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .147     P= .149     P= .122     P= .001     P= .279     P= .000     P= .191     P= .373     P= .110     P= .035     P= .002

BIOMAS         .0401       .1718       .3316       .1433      -.0141      -.2228       .2932      -.0771      -.1584      -.1520      -.0261
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .417     P= .182     P= .037     P= .225     P= .471     P= .118     P= .058     P= .343     P= .201     P= .211     P= .446

LOGBIO        -.0452       .2516       .3459       .0125       .0450      -.1160       .3611      -.0378      -.2128      -.2105      -.1760
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .406     P= .090     P= .030     P= .474     P= .407     P= .271     P= .025     P= .421     P= .129     P= .132     P= .176

TPSL           .2001      -.0978       .1815       .1684      -.0733      -.2214       .0716       .1042       .1268       .4365       .4954
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .144     P= .304     P= .168     P= .187     P= .350     P= .120     P= .353     P= .292     P= .252     P= .008     P= .003

NOTPSL         .4546      -.2713      -.1621       .3053       .0589      -.2081      -.1109      -.1194      -.1053       .2722       .3586
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .006     P= .073     P= .196     P= .050     P= .379     P= .135     P= .28[illegible] P= .265 P= .290     P= .073     P= .026

MWET           .7940      -.0012       .2238       .6770      -.0065      -.5052       .182[illegible] .0649   .1753       .4412       .5680
             (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)     (   30)
             P= .000     P= .498     P= .117     P= .000     P= .486     P= .002     P= .162     P= .361     P= [illegible] P= .007  P= .001

(COEFFICIENT / (CASES) / SIGNIFICANCE)          " . " IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED
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            MDRY        N           P           K           S           PH          COND        NA          LIME        TEXT        OM

MDRY        1.0000      -.0482      .1875       .5902       .1580       -.4681      .0224       -.1512      -.1726      .4534       .5219
           (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
            P= .        P= .400     P= .160     P= .000     P= .202     P= .005     P= .453     P= .213     P= .181     P= .006     P= .002

N           -.0482      1.0000      .3908       .0249       .2485       -.2007      .7494       .0564       -.5355      .0223       -.0578
           (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
            P= .400     P= .        P= .016     P= .448     P= .093     P= .144     P= .000     P= .384     P= .001     P= .454     P= .381

P           .1875       .3908       1.0000      .0366       -.0531      -.4116      .1764       -.1785      -.2855      -.0980      .0380
           (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
            P= .160     P= .016     P= .        P= .424     P= .390     P= .012     P= .176     P= .173     P= .063     P= .303     P= .421

K           .5902       .0249       .0366       1.0000      .1907       -.6478      .1465       .0230       -.2147      .5901       .8120
           (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
            P= .000     P= .448     P= .424     P= .        P= .156     P= .000     P= .220     P= .452     P= .127     P= .000     P= .000

S           .1580       .2485       -.0531      .1907       1.0000      .0740       .6452       -.0213      -.0812      .0924       .1379
           (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)
            P= .202     P= .093     P= .390     P= .156     P= .        P= .319     P= .000     P= .456     P= .335     P= .314     P= .234

PH          -.4681      -.2007      -.4116      -.6478      .0740       1.0000      -.0552      .0980       .2573       -.5053      -.5411
           (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)    (    30)
            P= .005     P= .144     P= .012     P= .000     P= .349     P= .        P= .386     P= .303     P= .085     P= .002     P= .001

COND        .0224       .7494       .1764       .1465       .6452       -.0552      1.0000      .0071       -.3273      .0385       -.0351
           (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)    (    30)
            P= .453     P= .000     P= .176     P= .220     P= .000     P= .386     P= .        P= .485     P= .039     P= .420     P= .427

NA          -.1512      .0564       -.1785      .0230       -.0213      .0980       .0071       1.0000      -.0469      .0469       .1268
           (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)    (    30)
            P= .213     P= .384     P= .173     P= .452     P= .456     P= .303     P= .485     P= .        P= .403     P= .403     P= .252

LIME        -.1726      -.5355      -.2855      -.2147      -.0812      .2573       -.3273      -.0469      1.0000      -.1489      -.0892
           (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)    (    30)
            P= .181     P= .001     P= .063     P= .127     P= .335     P= .085     P= .039     P= .403     P= .        P= .216     P= .320

TEXT        .4534       .0223       -.0980      .5901       .0924       -.5053      .0385       .0469       -.1489      1.0000      .7066
           (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)    (    30)
            P= .006     P= .454     P= .303     P= .000     P= .314     P= .002     P= .420     P= .403     P= .216     P= .        P= .000

OM          .5219       -.0578      .0380       .8120       .1379       -.5411      -.0351      .1268       -.0892      .7066       1.0000
           (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (    30)    (     0)
            P= .002     P= .381     P= .421     P= .000     P= .234     P= .001     P= .427     P= .252     P= .320     P= .000     P= .

(COEFFICIENT / (CASES) / SIGNIFICANCE)          " . " IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED
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CORRELATION MATRIX

JENSEN RESERVOIR DATA

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- - - - - - - - - - - - - - - -  P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S  - - - - - - - - - - - - - - - -

            SLOPE       SWBEAR      DIST        LENGTH      HOR         VERT        BIOMAS      LOGBIO      TPSL        NOTPSL      MWET

SLOPE       1.0000       .5203       .3578       .1423       .0029       .1409       .3038       .3029       .3985       .2723      -.0700
           (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
            P=          P= .005     P= .043     P= .254     P= .495     P= .256     P= .074     P= .075     P= .027     P= .099     P= .373

SWBEAR       .5203      1.0000      -.3055      -.3223       .6997       .1438       .1911       .4827       .5188       .5165       .2293
           (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
            P= .005     P=          P= .073     P= .062     P= .000     P= .251     P= .002     P= .008     P= .005     P= .005     P= .140

DIST         .3578      -.3055      1.0000       .5825      -.3733       .3388       .2569       .2878       .1205       .1412      -.2277
           (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
            P= .043     P= .073     P=          P= .001     P= .036     P= .053     P= .113     P= .086     P= .287     P= .255     P= .142

LENGTH       .1423      -.3223       .5825      1.0000      -.6902      -.3579      -.1556      -.1518      -.2942      -.2287       .0911
           (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
            P= .254     P= .062     P= .001     P=          P= .000     P= .043     P= .234     P= .239     P= .081     P= .141     P= .335

HOR          .0029       .6997      -.3733      -.6902      1.0000       .4471       .5375       .5453       .5381       .5914       .1367
           (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
            P= .495     P= .000     P= .036     P= .000     P=          P= .014     P= .003     P= .003     P= .003     P= .001     P= .262

VERT         .1409       .1438       .3388      -.3579       .4471      1.0000       .5067       .5072       .5504       .5690      -.1684
           (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)
            P= .256     P= .251     P= .053     P= .043     P= .014     P=          P= .006     P= .006     P= .003     P= .002     P= .216

BIOMAS       .3038       .4914       .2569      -.1556       .5375       .5067      1.0000       .9538       .7897       .8146       .1586
           (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)
            P= .074     P= .007     P= .113     P= .234     P= .003     P= .006     P=          P= .000     P= .000     P= .000     P= .229

LOGBIO       .3029       .4827       .2878      -.1518       .5453       .5072       .9538      1.0000       .6666       .7013      -.2339
           (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)
            P= .075     P= .008     P= .086     P= .239     P= .003     P= .006     P= .000     P=          P= .000     P= .000     P= .136

TPSL         .3985       .5188       .1205      -.2942       .5381       .5504       .7897       .6666      1.0000       .8485      -.1110
           (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)
            P= .027     P= .005     P= .287     P= .081     P= .003     P= .003     P= .000     P= .000     P=          P= .000     P= .303

NOTPSL       .2723       .5165       .1412      -.2287       .5914       .5690       .8146       .7013       .8485      1.0000      -.0146
           (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)
            P= .099     P= .005     P= .255     P= .111     P= .001     P= .002     P= .000     P= .000     P= .000     P=          P= .473

MWET        -.0700       .2293      -.2277       .0911       .1367      -.1684       .1586      -.2339      -.1110      -.0146      1.0000
           (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)
            P= .373     P= .140     P= .142     P= .335     P= .262     P= .216     P= .229     P= .136     P= .303     P= .473     P=

(COEFFICIENT / (CASES) / SIGNIFICANCE)          " . " IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED
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- - - - - - - - - - - - - - - -  P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S  - - - - - - - - - - - - - - - -

              SLOPE        SWBEAR       DIST         LENGTH       HOR          VERT         BIOMAS       LOGBIO       TPSL         NOTPSL       MWET

MDRY         -.0683         1969        - 2827       - 0865         1852        - 0530         2663        - 2981       - 1293       - 0420         8939
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  376      P=  178      P=  090      P=  344      P=  193      P=  403      P=  104      P=  078      P=  273      P=  423      P=  000

N             .0515         0948        - 0249         3014       - 0776       - 3111         0527       - 0050         0488         0526         2443
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  406      P=  330      P=  454      P=  076      P=  359      P=  069      P=  403      P=  491      P=  410      P=  404      P=  125

P             .2240         5324        - 3128       - 0479         2924         0047         1486         1121         2425         2075         5093
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  146      P=  004      P=  068      P=  412      P=  083      P=  491      P=  211      P=  301      P=  127      P=  165      P=  005

K            - 1753         0734        - 1561       - 2603         3515         4424       - 0047         0058         1555         0424         2134
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  206      P=  367      P=  233      P=  109      P=  046      P=  015      P=  491      P=  489      P=  234      P=  422      P=  158

S
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=           P=           P=           P=           P=           P=           P=           P=           P=           P=           P=

PH           - 4877       - 7096         0583         0015       - 4366       - 2230         3819       - 3113         4733       - 4469         2169
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  008      P=  000      P=  393      P=  497      P=  016      P=  147      P=  032      P=  069      P=  010      P=  014      P=  122

COND         - 0911       - 0086       - 0447         2579       - 1588       - 1120       - 1357       - 2132       - 2055       - 1091         4977
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  336      P=  484      P=  418      P=  112      P=  229      P=  301      P=  261      P=  159      P=  168      P=  306      P=  [illegible]

NA
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=           P=           P=           P=           P=           P=           P=           P=           P=           P=           P=

LIME           0395       - 2436         0828         1034       - 3388       - 4059         0979       - 1023       - 2062       - 1964       - 3458
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  427      P=  126      P=  350      P=  315      P=  053      P=  [illegible] P=  321    P=  316      P=  167      P=  179      P=  [illegible]

TEXT           2995         6661         0152       - 2987         6452         3056         5451         4067         1802         5810         1193
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  077      P=  000      P=  472      P=  078      P=  000      P=  [illegible] P=  [illegible] P=  [illegible] P=  [illegible] P=  001  P=  [illegible]

OM             3198         7253       - 1418         1139         5684         2698         5835         4969         5485         5978         3121
            (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)      (   24)
            P=  064      P=  000      P=  254      P=  251      P=  002      P=  [illegible] P=  [illegible] P=  [illegible] P=  [illegible] P=  [illegible] P=  [illegible]

(COEFFICIENT / (CASES) / SIGNIFICANCE)          " . " IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED
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- - - - - - - - - - - - - - -  P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S

           MDRY        N           P           K           S            PH          COND        NA           TIME        TEXT        OM

SLOPE     -.0683       .0515       .2240      -.1753                   -.4822       .0911                    .0395       .2995       .3198
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .376     P= .406     P= .146     P= .206     P=           P= .008     P= .336     P=           P= .427     P= .077     P= .064

SWBEAR     .1969       .0948       .5324       .0734                   -.7096      -.0086                    .2436       .6661       .7253
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .178     P= .330     P= .004     P= .367     P=           P= .000     P= .484     P=           P= .126     P= .000     P= .000

DIST      -.2827      -.0249      -.3128      -.1561                    .0583      -.0111                    .0829      -.0152       .1418
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .090     P= .454     P= .068     P= .233     P=           P= .393     P= .418     P=           P= .350     P= .472     P= .254

LENGTH    -.0865       .3014      -.0479      -.2603                    .0015       .2520                    .1034       .2987      -.1439
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .344     P= .076     P= .412     P= .109     P=           P= .497     P= .112     P=           P= .315     P= .078     P= .251

HOR        .1852      -.0776       .2924       .3515                   -.4366       .1588                    .3388       .6452       .5684
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .193     P= .359     P= .083     P= .046     P=           P= .016     P= .229     P=           P= .051     P= .000     P= .002

VERT      -.0530      -.3111       .0047       .4424                   -.2230       .1127                   -.4059       .3056       .2608
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .403     P= .069     P= .491     P= .015     P=           P= .147     P= .301     P=           P= .024     P= .073     P= .109

BIOMAS    -.2663       .0527       .1486      -.0047                   -.3849       .1357                    .0979       .5451       .5835
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .104     P= .403     P= .244     P= .491     P=           P= .032     P= .264     P=           P= .324     P= .003     P= .001

LOGBIO    -.2981      -.0050       .1121       .0058                   -.3113       .2132                    .1029       .4960       .4969
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .078     P= .491     P= .301     P= .489     P=           P= .069     P= .159     P=           P= .316     P= .007     P= .007

TPSL      -.1293       .0488       .2425       .1555                   -.4733       .2055                    .2062       .4502       .5485
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .273     P= .410     P= .127     P= .234     P=           P= .010     P= .168     P=           P= .167     P= .014     P= .003

NOTPSL    -.0420       .0526       .2075       .0424                   -.4461       .1091                   -.1964       .5810       .5928
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .423     P= .404     P= .165     P= .422     P=           P= .014     P= .306     P=           P= .179     P= .001     P= .001

MWET       .8939       .2443       .5090       .2134                    .2469       .4971                   -.3158       .1193       .3323
          (   24)     (   24)     (   24)     (   24)     (    24)     (   24)     (   24)     (    24)     (   24)     (   24)     (   24)
          P= .000     P= .125     P= .005     P= .158     P=           P= .122     P= .007     P=           P= .049     P= .289     P= .059

(COEFFICIENT / (CASES) / SIGNIFICANCE)          " " IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED
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- - - - - - - - - - - - - - - -  P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S

           MDRY         N           P           K           S          PH          COND        NA          LIME        TEXT        OM

MDRY      1.0000       .2905       .5291       .2127                  -.2396       .4658                  -.3919       .1534       .2675
         (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
          P=          P= .084     P= .004     P= .159     P=          P= .130     P= .011     P=          P= .029     P= .237     P= .103

N         .2905       1.0000       .4378      -.2441                  -.4047       .4729                   .0153       .2144       .3348
         (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
          P= .084     P= .        P= .016     P= .125     P=          P= .025     P= .010     P=          P= .472     P= .157     P= .055

P         .5291        .4378      1.0000       .0484                  -.5618       .3029                  -.5712       .3258       .4954
         (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
          P= .004     P= .016     P=          P= .411     P=          P= .002     P= .075     P=          P= .002     P= .060     P= .007

K         .2127       -.2441       .0484      1.0000                  -.0937       .0114                  -.4714      -.1304       .1145
         (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
          P= .159     P= .125     P= .411     P=          P=          P= .332     P= .421     P=          P= .010     P= .272     P= .297

S                                                        1.0000
         (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)
          P=          P=          P=          P=          P=          P=          P=          P=          P=          P=          P=

PH       -.2396       -.4047      -.5618      -.0937                  1.0000      -.4647                   .4718      -.6953      -.8537
         (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)    (    24)
          P= .130     P= .025     P= .002     P= .332     P=          P=          P= .011     P=          P= .010     P= .000     P= .000

COND      .4658        .4729       .3029       .0114                  -.4647      1.0000                  -.3575       .2614       .4229
         (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)    (    24)
          P= .011     P= .010     P= .075     P= .424     P=          P= .011     P=          P=          P= .043     P= .109     P= .020

NA                                                                                            1.0000
         (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)    (    24)
          P=          P=          P=          P=          P=          P=          P=          P=          P=          P=          P=

LIME     -.3919        .0153      -.5712      -.4714                   .4718      -.3575                  1.0000      -.2433      -.4841
         (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)    (    24)
          P= .029     P= .472     P= .002     P= .010     P=          P= .010     P= .043     P=          P=          P= .126     P= .008

TEXT      .1534        .2144       .3258      -.1304                  -.6953       .2614                  -.2433      1.0000       .7488
         (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)    (    24)
          P= .237     P= .157     P= .060     P= .272     P=          P= .000     P= .109     P=          P= .126     P=          P= .000

OM        .2675        .3348       .4954       .1145                  -.8537       .4229                  -.4841       .7488      1.0000
         (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (    24)    (     0)
          P= .103     P= .055     P= .007     P= .297     P=          P= .000     P= .020     P=          P= .008     P= .000     P=

(COEFFICIENT / (CASES) / SIGNIFICANCE)          " . " IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED
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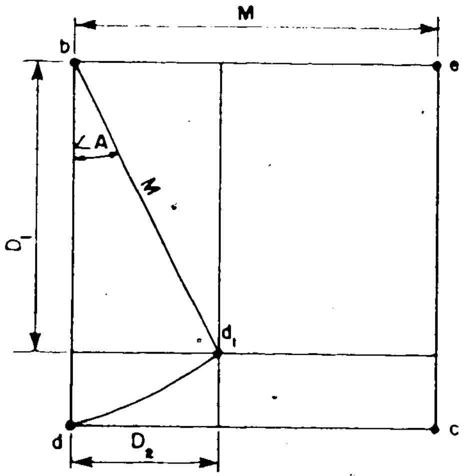
APPENDIX C

PROOF FOR CORRECTION FOR ASPECT FOR SLOPE ANALYSIS

$$D_1 = M \cos A$$

$$D_2 = M \sin A$$

$$d_1 = \frac{[\frac{D_1}{M}(\frac{D_2}{M} e + \frac{M - D_2}{M} d) + \frac{M - D_1}{M}(\frac{D_2}{M} c + \frac{M - D_2}{M} x)]}{2} + \frac{[\frac{M - D_2}{M}(\frac{D_1}{M} d + \frac{M - D_1}{M} x) + \frac{D_2}{M}(\frac{D_1}{M} e + \frac{M - D_1}{M} c)]}{2}$$



$$= x + \frac{D_1}{M}(d - x) + \frac{D_2}{M}(c - x) + \frac{D_1 D_2}{M^2}(e + x - c - d)$$

$$= x + \cos A\ (d - x) + \sin A\ (c - x) + \sin A \cos A\ (e + x - c - d)$$

CORRECTION FOR ASPECT

FIGURE C-1