THESIS

ALPINE SURFACE SOIL MOVEMENT

Submitted by

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In partial fulfillment of the requirements

for the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

August, 1969

COLORADO STATE UNIVERSITY

August, 1969

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY MOUINE F. ZOGHET ENTITLED ALPINE SURFACE SOIL MOVEMENT BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF THESIS

ALPINE SURFACE SOIL MOVEMENT

During 1967 and 1968 a study was conducted to determine the rate and type of alpine surface soil movement in the vicinity of Crown Point, Roosevelt National Forest in northcentral Colorado.

Five different colors of fluorescent pigments were used successfully to index the movement of soil particles quantitatively and qualitatively.

Sediment was collected from 32 micro-runoff collectors over the winter and snowmelt period of 1968, and over the summer period of the same year. Rates and patterns of actual soil particle movement were obtained from 15 transects (each about 15 meters long), representing the different site characteristics.

Results indicated that creep erosion was the most important mechanism of soil movement in the alpine. On sites exposed to wind action, wind erosion was responsible for movement of soil particles less than 2 mm in size.

Snow deposition, frost, rain-drops, wind, grazing, slope, vegetation and microtopography were the most important factors in accounting for surface soil movement in this alpine area.

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ACKNOWLEDGMENTS

I extend my gratitude to Drs. Robert E. Dils and William D. Striffler for their patient advice, help and encouragement throughout the period of my graduate study at Colorado State University.

I express sincere appreciation to the other members of my committee, Dr. F. Ward Whicker, Dr. Edwin W. Mogren and Dr. Robert E. Danielson, for their advice, interest, and generous investment of time on my behalf.

Appreciation is also extended to the Institute of International Education, University of Damascus, Colorado State University and the Office of Water Resources Research (Allotment Project A-022-Colorado) for their help and support during my residence here.

Finally, I wish to thank many others of the university community who have made this return to student life a very valuable experience for myself and family.

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Chapter I

INTRODUCTION

The alpine tundra areas of the central Rocky Mountain highlands represent an important ecosystem and are a major landscape component of the region. Paulsen (1960) estimates that these areas cover over 2 million hectares in the central Rocky Mountains. Some 900,000 hectares occur in Colorado (Shwan and Costello, 1951).

Severe climate and short growing season, limit alpine tundra vegetation to low growing shrubs, grasses, forbs and sedges. Although moisture is seldom limiting, the high winds characteristics of the high mountain slopes, and the high incidence of days with freezing temperature, even during the summer, permit only the hardiest species to survive.

Although the vegetation of the alpine is hardy, it offers only slight protection to the site. In spite of this fact however, alpine vegetation plays an important role in stabilizing slopes and in most undisturbed sites a delicate balance exists between the vegetation and the often highly erodable soils.

Alpine areas have traditionally served as summer grazing lands for domestic sheep. Although grazing of public lands is now controlled, and the number of sheep has been reduced, alpine range lands still constitute an important source of forage. Each summer, thousands of sheep graze on high elevation ranges. This use, plus rapidly increasing use of alpine areas for recreational purposes has caused some concern and much interest in the stability of the alpine tundra and in the amount of use which is practical in these areas. In addition, general problems of watershed deterioration under the unique environment of such alpine areas have also stimulated the attention of many investigators to overcome the amazing lack of knowledge of the characteristics of these areas and the interrelation of their physical environments.

In this connection it is important to study field methods of investigating surface soil erosion. The use of fluorescent pigments is a practical field marking technique for qualitative and quantitave estimates of surface soil movement. It is rapid and inexpensive. It eliminates the health hazard present in the use of radioactive particles.

This study was designed to answer some of the questions posed by concern about land use in alpine areas. Specifically, the objectives of the study were:

1. To determine natural rates of surface soil pacticle movement in a relatively undisturbed alpine environment.
2. To determine the influence of site factors such as topography, vegetation, and soils on soil particle movement.
3. To determine the effect of grazing on soil particle movement.
4. To evaluate fluorescent pigments as tags for tracing soil particle movement in an alpine environment.

Chapter II

REVIEW OF LITERATURE

ALPINE AREAS OF COLORADO

Alpine refers to the mountainous region lying above the coniferous forests and below the permanent snow. This region is influenced by local conditions of available moisture, prevailing winds, exposure and topography (Nelson, 1953 and Weaver and Clements, 1929).

The alpine areas of Northern Colorado are predominately grassland areas. Its lower limit is the tree line which occurs, approximately, at 3350 meter (11,000 ft) above sea level. In some places it extends higher than 3520 meters (Johnson and Cline, 1965).

Geology

The structure of the Northern Colorado range is essentially crystalline Pre-Cambrian granites, schists, and gneisses, with the Tertiary period represented mainly by clastics. Associated with the lavas are intrusive rocks representing the middle Tertiary period (Lovering and Goddard, 1949).

According to Retzer (1956) the Rocky Mountains originated as an upthrust of igneous and metamorphic rocks through many thousand meters of sedimentary rocks. Subsequent erosion exposed primary rocks to dominantly granites, and the accompanying metamorphic rocks. Pockets of sedimentary rock, such as, shale, limestone, sandstone remain in places. Basalt, andesite and rhyolite also occur.

Soils

Retzer (1956) has proposed that alpine soils be classified into the three great soil groups: (1) Alpine turf, (2) Alpine meadow, and (3) Alpine bog. This classification is based on the degree of drainage present in each soil group.

Alpine turf, the most dominant group, is well drained and has well developed horizons. These soils occur on the higher convex slopes. They vary in depth from 35 to 82 cm., are black to brown in color and have a high content of organic residues.

Alpine meadow soils are closely associated with alpine turf soils, and the two occur commonly in complexes. Generally speaking, alpine meadow soils occupy the lower and concave slopes of the alpine on alluvium or glacial till. Being imperfectly drained they are intrazonal and have A-C profiles. They vary in thickness, color, and texture. They are wet or moist year-long.

Alpine bog soils are undrained and are developed from organic residues in small depressions or basins. They are extremely acid and intrazonal without distinct horizons and consist of a fibrous peat mixed with silt about one half meter deep.

In a more recent report, Retzer (1962) described the Ptarmigan, Vasquez and Nystrom series as members of the alpine turf, meadow and bog groups, respectively. Johnson and Cline (1965) have classified the turf group as a Cryothod, the alpine meadow group as a Cryaquod and the alpine bog group as Histosols.

Not correct — Johnson + Cline goofed!

Most alpine tundra soils are high in organic matter regardless of the internal drainage (Nimlos and McConnell, 1965). This characteristic, plus high carbon-nitrogen ratios, indicates that the organic matter is quite resistant to breakdown in the alpine tundra environment.

The climate of alpine soils is cold and moist. In alpine areas of Northern Colorado the average annual soil temperature ranges from -2 to 0°C, and the average summer temperature ranges from 4.5 to 7.2°C. The effect of soil temperature on soil genesis is extreme in this area. It influences the type, intensity and duration of biological and chemical processes (Johnson and Cline, 1965).

Climate

The alpine climate of Colorado is a unique one. The average temperature is low and the effect of cold air drainage is apparent in many alpine localities. Precipitation is almost equally distributed during all months of the year. Rainfall occurs as a result of convectional activity during the summer months. Snow comes with major frontal disturbances during all winter months. Because snow accumulates during the cold season (about 8 months of the year), effective soil moisture recharge occurs almost entirely during the short growing season. The mean monthly precipitation in mm. for four areas in Colorado alpine tundra is shown in table 2.1.

Temperature is a very important factor in the total alpine environment. An increase in elevation up a mountain slope is accompanied by a general decrease in air temperature. Baker (1944) and Whitfield (1933) reported that the average lapse rate is between 0.8-2.0°C for every 1000 feet depending on the time and season.

The mean yearly temperature is between -2.8 to -7.2°C, the mean maximum temperatures for the summer period range from 15 to 26°C and mean minimum temperatures range from -4 to -3.6°C in various alpine tundra areas in Central Rocky Mountains (Baker, 1944; Johnson and Billings, 1962 and Marr, 1961).

Table 2.1

Mean monthly precipitation in Colorado alpine tundra (in mm)

	1*	2*	3*	4*
Jan.	20.3	40.6	61.0	97.0
Feb.	27.9	38.1	40.6	129.0
Mar.	48.3	53.3	55.9	119.4
Apr.	81.3	88.9	71.1	213.4
May	76.2	91.4	81.3	123.0
June	66.0	66.0	45.7	40.6
July	114.3	106.7	76.2	66.0
Aug.	94.0	94.0	76.2	55.9
Sep.	50.8	43.2	25.4	55.9
Oct.	50.8	33.0	30.4	73.7
Nov.	27.9	43.2	50.8	66.0
Dec.	27.9	63.5	50.8	86.4

*1. Central Colorado Mountains (Baker, 1944)
2. Pikes Peak, Colorado (Clement, 1920)
3. Niwot Ridge, Colorado (Osburn, 1963)
4. Corona pass, Colorado (U.S. Weather Bureau, 1930)

Wind is an important environmental factor in the alpine areas. According to Bates (1924), Brochert (1950) and Osburn (1963) wind reaches its highest intensities during the winter. Wind speed averages 32 to 48 kph in winter and 8 to 16 kph in summer. Bliss (1956) reported that the velocity is greatly reduced near the ground within the foliage crowns of the plants. Wind plays a very significant role in snow drifting and deposition.

Vegetation

Holway (1962), Spomer (1962), USFS (1961), Billings and Bliss (1959), Billings and Mooney (1959), Clement (1920), Marr (1961), Osburn (1963) and

Whitfield (1933) have discussed plant community characteristics in the alpine tundra of the central Rocky Mountains.

Due to the extreme diversity of the environment on a microscale, sites and communities may change within a very short distance. Differences in alpine tundra communities may be related to the interaction of changes in soil moisture and temperature, topography, length of growing season, presence or absence of a snow cover during the winter months, stability of the strata on which the plants grow, and protection from the prevailing wind and air temperature.

Snowmelt and Hydrology

Snow disappearance is largely a function of direct solar radiation, (Garstka et al., 1958). Melting begins at the surface of snowpack when temperature of the snow has been increased to or above 0°C. Initially melt water percolates into the snowpack. Runoff begins only when the water-holding capacity of snowpack has been satisfied (Foster, 1948). Cool temperature, porous soils and sparse vegetation give low evapotranspiration losses (Martinelli, 1966).

Martinelli also reported that about 40 cm of water per hectare as a water yield potential for July and August of 1956 in the alpine. Schwan and Costello (1951) estimated that 3.5 percent of Colorado, as alpine type, produces 20 percent of the state's runoff. Evans et al. (1964) stated that the alpine area of the Lake Creek watershed in Central Colorado produces the most water per unit area. Here the yield was about 6000 m^3 per hectare per year.

NATURE OF SOIL MOVEMENT

The geological erosion takes place as a result of the action of water, wind, gravity, and glaciers while accelerated erosion is associated with changes in natural cover or soil conditions and is caused primarily by water and wind (Schwab et al., 1966).

Weaver (1929), Quincy (1936), Osburn (1950), Andre (1961), Stallings (1964) and Baver (1965) concluded that the surface soil erosion is a function of running water, raindrop splash, wind, gravity, glaciers, topography, soils, vegetation, drainage, and land use.

Water Erosion

Water erosion is the most important single erosive force in nature. Water picks up, carries, and deposits huge quantities of material. It is an effective agent in both chemical and physical weathering. Raindrop and surface flow are the two principal agents of surface soil movement.

Rain-drop Erosion

When falling raindrops strike the ground surface or the thin films of water covering it they splash small bits of soil into the air. These splashed particles reach varying heights, ranging up to about one meter and may move horizontally about two meters on level surfaces (Ellison, 1944).

Mihara (1952) stated that "The amount of damage done by falling raindrops is proportional to their kinetic energy, which ranges from 1,000 to 100,000 times the work capacity of surface flow". Energy of falling raindrops is determined by raindrop mass, size distribution, shape, velocity and direction.

Raindrops vary in diameter from about 0.51 to 6.35 mm. Their terminal velocities vary with their diameter from 3.6 to 7.6 meters per second, and their kinetic energy is proportional to $d^3 v^2$ (Linsley, 1958). The kinetic energy increases at the rate of 1.2 powers of the intensity (Stallings, 1964).

Wischmeir et al. (1958), developed the following equation for the energy of rain-drop:

$$E = 916 + 331 \log i$$

K = kinetic energy in ft-tons per acre inch of rain
i = Intensity in iph

Osburn (1950) indicated that the raindrops are relatively unimportant in the transportation of detached material on a level ground and assuming vertical direction of rainfall. Kohnke and Bertrand (1959) and Linsley (1958) explained the effect of raindrop direction in soil movement. Delp (1968) stated that measurements on an open field of 10 percent slope showed three times as much downhill movement as uphill movement of splashed soil. However, slope of land surface, wind, and surface conditions are important factors affecting the direction and distance of soil splash.

Surface-flow Erosion

Flowing surface water is usually the major transporting agent of soil particles. USFS (1961) described the flow of water in three ways:

1. Laminar movement, relatively rare in nature.
2. Turbulant movement, the most common one.
3. Shooting movement as the water moves with spurts and jets that are often seen in rapids and waterfalls. It is rare.

Surface flow erosion is related to the watershed characteristics, such as the drainage area, soil characteristics, the alignment, size and shape of the gully and the slope in the channel (Schwab et al., 1966).

Surface erosion can occur only when the force of the current exerted on the land surface exceeds the resistance of the soil particles to be moved. The force needed to cause dislodging must exceed the submerged weight of the particle times the sine of the angle. This is generally expressed by the sixth-power law which states that the weight of a particle lifted at a given velocity of flow is proportional to the sixth power of velocity (V^6) (USFS, 1961). This law does not refer to the quantity of material that can be moved or its rate of movement. Soil-detachment processes in surface flow erosion occur in the forms of rolling, lifting or abrading (Stallings, 1964; Ellison, 1947; and USFS, 1961). Soil materials deposited by moving water are usually separated by particle sizes. The first materials to be deposited will be those of lowest transportability, whereas the materials of highest transportability will be deposited last. The velocity of flow, the slope gradiant, the breaks in the slopes along with the size of particles are important factors in soil deposition

Factors Effecting Water Erosion

Baver (1965) summarized the factors affecting soil erosion by the following equation:

$$E = f(C, T, V, S, H)$$

C = Climate
T = Topography
V = Vegetation
S = Soils
H = Human factors

The Effect of Climate

Climatic factors affecting erosion are precipitation, temperature, wind, humidity, and solar radiation. Baver (1965), Stallings (1964), and Dortignac and Hickey (1936) indicated that the surface soil erosion is proportional to the amount, intensity, and duration of precipitation. Neal (1937) talked about the increase in erosion as the power function of intensity (1.2 power). Jugo (1963) discussed the action of climate with parent material, relief, vegetation, soil and land use. He stressed the quantity and intensity of precipitation, and the drought period as an important factor in erosion. Wischmeir et al. (1958) working with 19 independent variables showed that the relationship between precipitation characteristics and runoff and soil loss is very complex.

The Effect of Soil

Baver (1965) has considered the soil as one of the very important factors in soil erosion. The effects of soil properties on water erosion are manifested in two ways: first, there are those properties that determine the rate with which rainfall enters the soil; and second, there are those properties that resist dispersion and erosion during rainfall and runoff. Baver summarized the effect of soil factors on erosion by the following descriptive equation:

$$E = K \frac{D}{AP_p}$$

Where K refers to a proportionality constant involving the other factors affecting soil erosion, (D) is an index of the ease of dispersion, (A) is an expression of the infiltration capacity of soil surface, (P) characterizes the permeability of the soil profile (p) denotes the size of soil particles.

Andre' and Anderson (1961) concluded the following:

1. The surface-aggregation ratio was somewhat more significantly related to soil erodibility than was the dispersion ratio.
2. Soil of acid igneous rock was about 2.5 times as erodible as soil developed on basalt.
3. Erodibility was highest for soils under brush, next under trees, and least under grass.
4. In elevation there was no clear cut relation of erodibility.
5. The interaction of zone and geologic rock type showed significant variation in erodibility.

Willen (1965) reported that soil texture and erodibility indexes were significantly related to variation in parent rock type, vegetation cover type, aspect, slope, and elevation. He notes also that granitic forest soils at high elevations may be twice as erodible as soil developed under similar soil forming conditions at low elevations.

The Effect of Topography

The degree and length of the slope are the two essential features of topography (Baver, 1965; Miladin, 1963; Cook, 1936; Schwab et al., 1966; USFS, 1961; and others). Baver mentioned that the degree is more important from the standpoint of the severity of erosion.

Zingg (1940) considering the degree of the slope, found the following equation:

$$X_c = 0.065\ S^{1.49}$$

X_c = the coded total soil loss

S = the land slope in percent

In considering the length of slope he also gives the equation:

$$X_c = 0.0025\ L^{1.53}$$

X_c = the coded total soil loss

L = the length of land slope in feet.

He combined the effect of degree and length of slope and expressed them in the following equation:

$$X = C\ S^{1.4}\ L^{1.6}$$

C = constant that depends upon infiltration rate physical properties of soil and duration of the rainfall and other factors.

The effect of length of slope on erosion seems to vary considerably with type of soil (Brost et al. 1945, Smith et al. 1945, Musgrave 1935, and Deeter and Hopkins 1936). The size and shape of a watershed along with the degree of slope and length of slope are important features in water erosion (Schwab et al. 1966).

Kohnke and Bertrand (1959) concluded that slopes that face south and west suffer more from erosion than from north or east facing areas. They also considered microtopography, as it has some effect in reducing erosion and runoff on slopes of less than 20 percent gradiant.

The Effect of Vegetation and Grazing

Erosion is inversly proportional to ground cover and there is no doubt that vegetation constitutes the most unique ground cover.

Baver (1965) stated that the major effects of vegetation as a ground cover in reducing erosion are:

1. Interception of precipitation by absorbing the energy of raindrops.
2. Decreasing the velocity of runoff and the action of water.
3. The root effects in increasing granulation and porosity.
4. Biological activities associated with vegetative growth and their influence on soil porosity.
5. Transpiration of water leading to subsequent drying out of the soil.
6. Physical restraint of soil movement.

The vegetative influences vary with the season, crop, degree of maturity, soil, and climate as well as with the kind of vegetative material, namely roots, plant tops and plant residues (Schwab et al. 1966). Munns, Preston and Sims (1938) stated that soil losses from forests is much less than cultivated or bare areas.

Kotok (1931) reported that an increase of erosion 1000 times after the vegetative and litter cover have been burned. Anderson (1951) in California estimated that if cover density increased on a watershed from 31-47 percent, erosion would be reduced to 44 percent of the original rate. Baver stated that a good vegetative cover, such as a thick sod or a dense forest, offsets the effects of climate, topography and soil on erosion. Weaver and Harmon (1935) stated that other factors being equal, the intensity of erosion is directly proportional to the decrease in vegetation, both above and below ground.

Grazing is related very much to the vegetative cover and to activation of soil movement. Strickler (1961) showed that grazing can destroy the vegetative cover by utilizing the important forage plants, and the trailing sheep breaks down the sod and pulverized soil, in which, eroded trenches that run both across and down slopes can result very easily. With heavy utilization and concentrated trailing continuing annually, the roots of dead and weakened plants cannot hold soil and much soil erosion by wind or water can result.

The Australian Academy of Science (1957) was convinced that the greater part of damage in soil erosion in grassland and alpine areas is due to heavy grazing, especially during the periods of drought. The effect of grazing on alpine vegetative cover is of significance, but there is a lack of knowledge of the characteristics of alpine areas where, little is known about the influence of grazing by domestic livestock and other factors (Johnson, 1962).

Wind Erosion

USFS (1961), Chepil (1950) and FAO (1960) stated that erosion by wind may occur wherever the following conditions of soil, vegetative and climate are favorable:

1. The soil is loose, dry and reasonably finely divided;
2. The soil surface is somewhat smooth and vegetative cover absent or sparse;
3. The field is sufficiently large, and
4. The wind is sufficiently strong to initiate soil movement.

The mechanics of wind erosion are broken into three simple but distinct phases:

1. Initiation of movement: The minimum velocity of wind required to initiate soil movement is known as threshold velocity. The threshold velocity required to initiate movement of the most erodible soil particles is about 16 kilometers per hour at a height of 30.5 cm. for particles of 0.1 mm. in diameter (FAO, 1960).
2. Transportation: It is very much related to particle size, gradation of particles, wind velocity and distance across the eroding area.

   The estimated potential carrying capacity for one cubic mile of the atmosphere is up to 126,000 tons of soil depending on the wind velocity (Schwab et al. 1966). As much as 230 Kg of soil per hectare were depostied in Iowa in 1937 from a dust storm originated in Texas (Stalling, 1964).
3. Deposition: Deposition of sediment occurs when the gravitational force is greater than the forces holding the particles in the air. The accumulation of aeolian material over wide areas depends in the most complex way upon climatic factors, not only as they influence the path and velocity of the wind, but also as they control the presence or absence of vegetation and its nature and permanence.

According to Stallings (1964), FAO (1960), and Chepil (1960, 1946, 1945) there are three types of soil movement by wind:

1. Saltation
2. Suspension
3. Surface creep

According to their explanations figure (2.1) has been sketched.

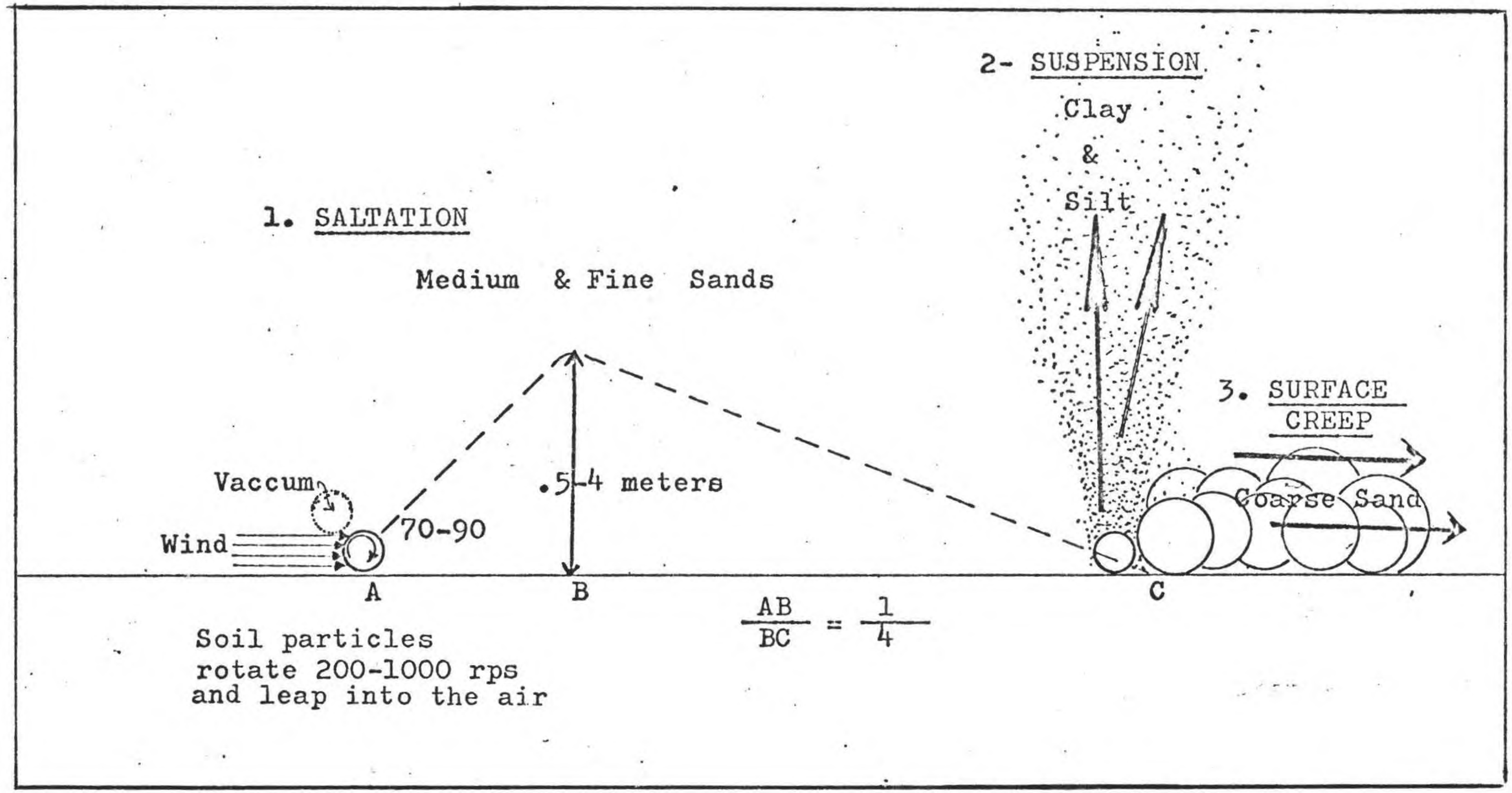


Fig. 2.1- Types of soil movement by wind

Factors Effecting Wind Erosion

Climatic factors; (wind itself, precipitation, temperature, humidity, density of air, and viscosity), Soil factors; (texture, structure, density of particles, density of soil mass, organic matter, moisture content and surface roughness), Topography; (the length of the eroding surface) and Vegetation are related directly or indirectly to wind erosion (Chepil 1950, 1945).

Soil texture, state and stability of consilidation (crust or clods) of soil particles are the major soil factors related to wind erosion. Moisture, compaction, organic matter, clay content, time, micro-organism activity and cementing materials affect consolidation and stability of soil in wind erosion. The degree of consolidation is greatly affected by climatic factors and the mechanical action on the surface. The surface roughness and barriers may trap and stop the build up of eroding material (FAO, 1960).

Vegetation and vegetative residue are of importance to retarding wind erosion, especially, the living plants by the action of their roots and their above ground barriers function.

Soil Movement at Higher Elevation

Soil formation in the alpine environments is accompanied by much internal soil disturbance and movement, both horizontal and vertical. Such disturbance is the result of freezing and thawing (Johnson, ? soof 1961).

Water increases about 9 percent in volume when frozen. The resultant force about 9000 kg per square meter is great enough to split and break rocks into smaller sizes, and create soil movement (USFS, 1961).

Sharp (1938), Gibbs et al. (1945), Shumm (1964), Dils (1965) and Soons (1967 and 1968) have written about the frost action as a major factor contributing to erosion problems at high elevation.

Frost features such as circles, nets, polygons, steps, and stripes, have been discussed by Richmond (1949), Johnson (1961), Billings and Mooney (1959).

Washburn (1965, 1967) during his observations in Northeast Greenland from 1956-1961, found that frost creep is the ratchetlike down slope movement of particles. Frost creep in most places is due mainly to the annual freeze-thaw cycles. He said also, that the frost creep tends to exceed gelifluction (flow of soil associated with frozen ground) about 3 to 1 over a period of years, and either process can predominate in a given year. He also found mass-wasting (the slow down slope movement of rock debris) due to frost creep and gelifluction on a gradient of 10-14, ranged from a mean of 0.9 cm per year in sectors subject to desiccation during summer to mean of 3.7 cm per yr. in sectors remaining saturate.

Sharp (1938) stated the following:

> "Recognition of the importance of mass movement in the shaping of the land has lagged far behind our knowledge of the action of running water, glaciers, winds and waves. Many individual land slides, creeps and other examples of mass movement have been described. Most of these, however, have been recorded by casual observers who have had only a passing interest in such phenomena."

Rapp (1961) called the mass-movements as exogene processes due to gravity, without the direct influence of transporting agents such as running water, glaciers, wind...etc.

In the Swiss Alps, the actual average denudation is .58 mm per year as a result of mass-movement and glacial activity (Jackli, 1957).

Starkel (1959) in the Polich Carpathians Upland, calculated the average total amount of postglacial denudation as .05 mm per year. In modern times this denudation is about .05 to .15 mm per year indicating an increase in the removal probably due to deforestation and land use by man.

Rapp (1961) talked about the rockfalls, rockslides, earthslides, mudflows and gullying as very significant agents in the process of soil movement in the high lands. He also considered snow avalanches as another important factor in soil movement, he talked about the dirty avalanches which consist of snow and waste of rock, earth, plants...etc.., and the ground avalanches that move in direct contact with ground, as they erode and grow dirty. Judson (1967) discusses in more detail the avalanches in the high alpine zones of Colorado and other parts of Western U.S.

Glaciers are another phase ofhigher elevations affecting soil movement and erosion (Karol, 1964 and Daubenmire, 1959).

TRACING SOIL MOVEMENT

Radioactive tracers

The use of radioisotopes extends only over a few decades. In forestry, soils, water and other natural sciences there are over one hundred radioisotopes that can be produced in the reacter and used in research and peaceful application.

Arlmanet al. (1958) give a complete history of the search for an effective particle marking and sampling technique in which radioactive methods are stressed.

According to Hubbell and Sayre (1963, 1964), Arlman et al. (1958), McDowell (1963), Feely et al. (1961), and McHenry and McDowell (1962) radioisotopes are very good tools for tracing sediment transport and deposition in the water. S_c^{46}, Ag^{110}, p^{32}, and $BaLa^{140}$ were used.

According to Goldberg and Inman (1955), Inman and Chamberlain (1959), Crikmore (1961) and Crikmore and Lean (1962) slow neutron irradiation has been utilized in the activation of sediments, especially to study beach sand movement after applying autoradiography techniques on very sensitive films.

Silver 110 was used by Gilbert et al. (1958) to investigate sand movement using a solution of Ag^{110} nitrate. Cr^{51} was also used by Davidson (1958) in studying sand movement. He concluded that the low gamma emissions and poor penetrating ability are of disadvantages in using Cr^{51}. McHenry and McDowell (1962) used Sc^{46} on the surface of quartz grains, by applying a solution of $Sc^{46}Cl$ in which case, it was absorbed on the surface. Slow heating with an infrared light to 800-1000^{o}C was sufficient to bond the isotope to the quartz.

Surface labeling has also been used by Delp (1968). He used Cs^{134} to tag soil at point methods. Rates and patterns of actual soil particle movement were established by measuring changes in radiation intensity following three summer thunder-storms, in which the effect of raindrop effect was mainly of concern in his study on soil movement.

Wooldridge (1965) using Fe^{59} as $Fe^{59}Cl_3$, in which the Fe reacts with existing ferric compounds on clay and silt particles, to tag surface soil movement on bare slopes, in 5 foot lines along a contour (300 uc were used). He concluded that Fe^{59} offers a usable method for tracing soil particles movement.

Fluorescent Pigment Tracers

Long before the advent of modern science certain natural pigments, minerals, and bacterial cultures such as those found in decaying animal and vegetable matter, were known to emit characteristic radiation when irradiated by visible light. Later it was found that fluorescence also occurred in the nonvisible wavelengths, and that the exciting agent need not necessarily be visible light. The fluorescence under ultraviolet energy of chlorophyll, quinine, and other plant materials was known to Stokes as early as 1852 (Udenfriend, 1962). Since then the use of fluorescence in assay work has had constant attention, although Udenfriend was surprised that the procedure has not had greater application before 1962.

It is well to distinguish this phenomennon of fluorescence from that of two other commonly confused terms, phosphorescence and luminescence. Fluorescence is the emission of radiant energy from matter, under the influence of an exciting agent. Phosphorescence is the continuation of radiant energy emission after the removal of the exciting agent. Luminescence is a loose term covering both phenomena.

Udenfriend (1962) described the actual phenomenon of fluorescence as follows: A molecule of the fluorescent substance absorbs a photon of energy and an electron is raised to a higher energy level placing the molecule in an excited state. Provided the molecule does not decompose as a result of the increase in energy and/or all the energy is not dissipated by subsequent collisions with other molecules, then after a short period of time characteristics of atom or molecule the electron returns to the original lower energy level, emitting a photon in the process. The difference between the energy of the initial state and final state determines the energy of the emitted radiation, and it is this emitted radiation that is called fluorescence. This radiation has a longer wavelength or lower energy than the light which is absorbed (Stoke's law). Udenfriend (1962) and Koller (1965) cover the aspect of fluorescence in greater detail.

Use of fluorescence tracer coatings in sediment transport and soil movement studies has interested many investigators dealing with natural conditions of transport or with laboratory models.

In general, the marked natural particles under the natural environment should exactly reproduce the transport characteristics of unmarked particles for which they are substituted. To date the marking technique which most fully complies with the requirement is that of induced radioactivity in the natural particles. Search for naturalness may be futile if the particle population from which sediment is taken for irradiation has changed by the time the irradiated particles are reintroduced. In view of surface soil movement much can be learned by using a marking technique which allows rapid and relatively inexpensive field marking and reintroduction at a slight expense to grainsize, shape, density and abrasion resistance. Russell (1960) has summarized previous work on formulation of ultraviolet tracers.

Since the end of World War II an interesting assortment of daylight and near-ultraviolet fluorescent dyes has become commercially available. Thus far they have achieved their widest use in art, advertising and safety marking. Yasso (1962) has reported a successful search has been for a particle marking technique with coastal geomorphology investigations, using these fluorescent dyes applied as a surface coating to sandsize sediment. Rapid and inexpensive field marking for qualitative and quantitative estimate of transport, during the day or night, now becomes possible and eliminates the health hazard present in the use of radioactive particles.

Yasso (1965) tested seven formulations for suitability as tracer coatings. These formulations represent only a partial list of the various combinations of dye and coating vehicle which are available. He also stated that the use of a sensitive photometer with fluorescent tracer particles will allow the simulation or supplementation of conventional field sampling procedures. He also stated that all coatings are insoluble in fresh or saline water, and single-application coating thicknesses range between 0.0076 and 0.0610 mm. Air drying time at room temperature for separated particles varies from 40 seconds to 14 minutes depending on coating mixture used. Laboratory calibration indicates that 5 percent differences in aerial concentration of marked particles at given sampling locations can be determined.

USGS (news release, July 24, 1967), using fluorescent sand reported that one fluorescent grain can be detected when mixed with 10,000,000 non-fluorescent grains, so the grains are easily found in samples of stream sediment when scanned under ultraviolet light.

Recent study by Young and Holt (1968) reported that fluorescent glass particles with density similar to that of natural soil particles appeared to be potentially useful in tracing soil particle movement.

Personal communicatons with Mr. H. W. Berndt, reported that fluorescent Willenite ore (zinc silicate with a manganese activator) with specific gravity of 3.83, was used as a tracer. The ore was crushed and graded to sizes equivalent to soil fractions, as sand (0.2-2.0 mm), gravel (2-5 mm) and stonesized used on the soil surface of six study plots to study soil erosion. This ore is yellowish-green in color, response to ultraviolet light (2500 Angstrom units) emitted by inexpensive mineral-prospecting lamps.

Chapter III

DESCRIPTION OF THE STUDY AREAS

The main study area is located between Crown Point, 3495 meters in elevation (11463 ft.), Crown Mountain, 3548 meters in elevation (11637 ft.) and Browns Lake, T8N, R74W, Sec. 34, 6th PM, in the Roosevelt National Forest, Larimer County, Colorado (Fig. 3.1). The plots under study were located between 3400 to 3480 meters in elevation and not far above timberline.

Another secondary study was conducted in the Hourglass watershed. This area is south of the main study area and closer to the north edge of the Rocky Mountain National Park than Crown Point (Fig. 3.1 and 3.5). Cerillo (1967) and Hubbard (1968) have described this area in detail.

CLIMATE

Holway (1962), Marr (1961) and Osburn (1963) give a general climatic picture of the Northern Colorado Front Range alpine tundra. The Alpine tundra climate typically consists of cold, snowy, windy winters, in which, many sites are swept clear of snow, while others, notably depressions, act as natural snow accumulation areas. Heavy wet snow may occur during the spring, often with little or no wind - this snow will stay in place, even on exposed sites. Rain, sleet of graupel (a pellet snow) may occur during the early summer months as a result of convective precipitation. Convective precipitation is spotty, and its intensity may range from light showers to cloud bursts. Summer mornings are generally

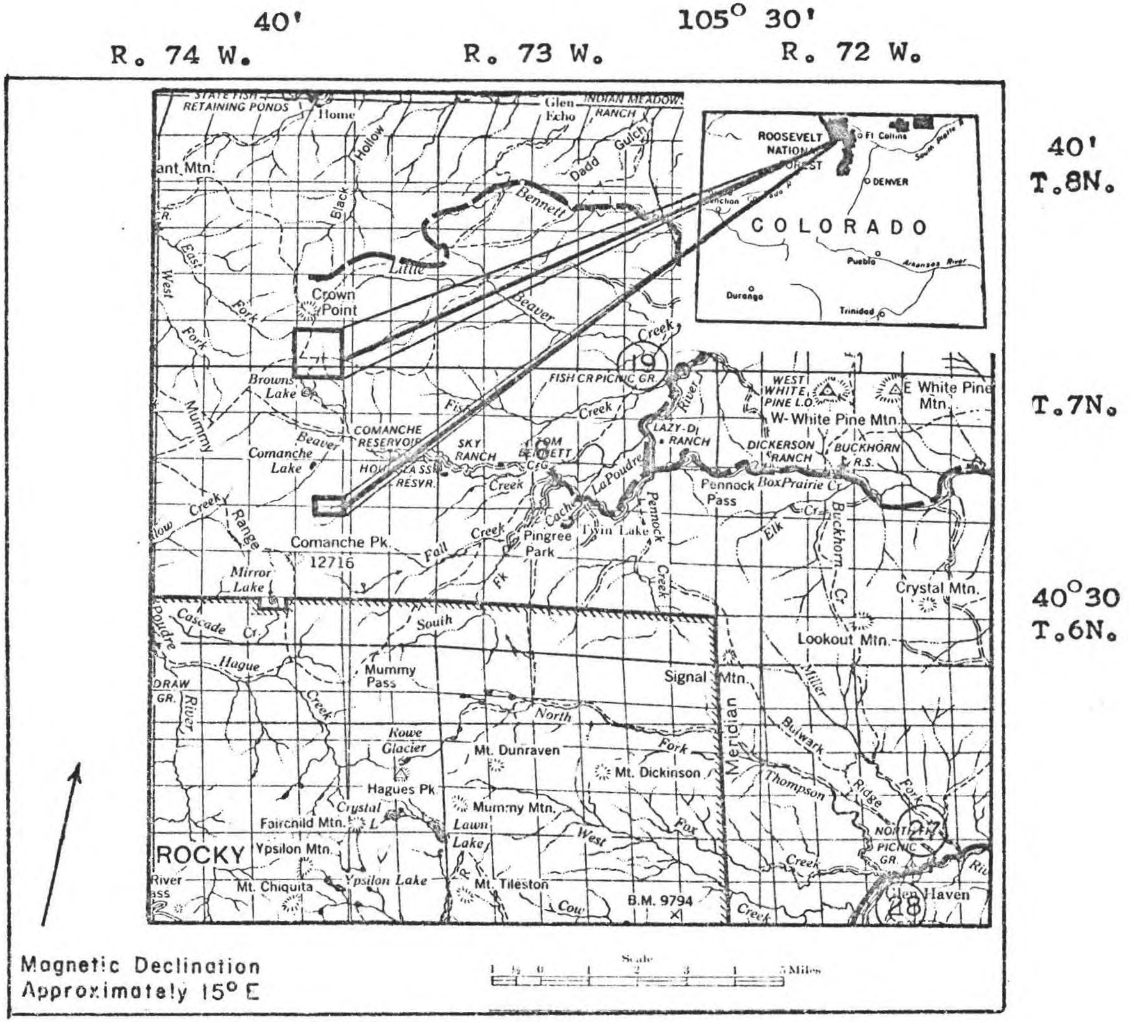


Fig. 3.1 Location of study areas

calm and clear, but wind and thundershower activity often increase sharply in the early afternoon. Frosts may occur at any time during the summer period. July is usually a warm, moist month. August is warm and dry while September and October are the driest months of the year. The first winter snow usually occurs in October.

Precipitation

Johnson (1963) estimated the mean annual precipitation in the Little South Fork Watershed as between 457-508 mm. The Pingree Park rain gage, at an elevation of 2750 meters measured an average of 550 mm. per year from 1961 to 1967. In all probability annual precipitation on the study area is somewhat in excess of 550 mm.

Summer precipitation, mostly in the form of convective precipitation, averaged 186 mm. from 1961 to 1967 at Pingree Park. The average monthly precipitation was 62 mm. for June, 66 mm. for July and 58 mm. for August.

The Colorado Game, Fish and Parks Division recorded precipitation from 1962 to 1964, near the Crown Point at an elevation of about 3350 meters, somewhat lower than the study area on the North-east side of Crown Point (Table 3.1).

Temperature

The Pingree Park weather station, and the Colorado Game, Fish and Parks Division recorded the air temperature at Pingree Park and near Crown Point as shown in Table 3.2.

Holway (1962) presented the air temperature for the summer periods of 1960 and 1961 on False Mummy Pass, Colorado at the northern edge of the

Table 3.1

Total Precipitation Near Crown Point (mm.)

	1962	1963	1964
J	46	65	43
F	65	39	35
M	31	34	48
A	79	41	66
M	33	14	53
J	38	81	34
J	31	54	46
A	17	136	52
S	38	46	31
O	14	14	5
N	21	11	24
D	31	27	64
Year	444	56~~6~~ 2 2	501

Table 3.2

Air Temperature in °C at Pingree Park and near Crown Point

	Average 3 years (1965–67) at Pingree Park			Average 3 years (1962–1964) near Crown Point		
	Mean Monthly	Mean Maximum	Mean Minimum	Mean Monthly	Mean Maximum	Mean Minimum
J	-5.8	-1.7	-11.9	-10	6	-25
F	-9.6	-3.0	-16.4	-12	5	-24
M	-5.2	2.4	-12.9	- 9	7	-22
A	.5	5.8	- 5.0	- 8	11	-14
M	3.6	11.2	- 4.0	4	16	- 6
J	8.1	16.3	0.0	9	23	- 2
J	12.5	21.4	3.3	14	26	5
A	10.1	19.4	.8	11	24	- 2
S	5.8	12.4	- 1.4	8	20	- 4
O	3.9	11.6	- 3.6	5	17	- 9
N	-1.3	4.8	- 7.0	- 1	10	-15
D	-6.4	- .3	-10.0	-10	4	-26

Rocky Mountain National Park, at an elevation of 3350 meters and about 10 kilometers south of the study area (Table 3.3).

Table 3.3

Summer Air Temperature in °C at False Mummy Pass, Colorado

	1960 6/5-10/12	1961 5/22-9/19
Mean Minimum	3.6	2.2
Mean Maximum	18.4	17.6

Wind

The prevailing wind in the area is from the west. The average wind velocity during the summer 1968 obtained from two anemometers located on the site of the Crown Point study area, is shown in Tabl e 3.4.

Salisbury et al. (1968) reported the presence of extreme high turbulence of wind in the alpine area at False Mummy Pass, Colorado (elevation of 3350 meters).

Table 3.4

Average Summer Wind Velocity in kph
on Crown Point Study area
1968

Anemo-meter	Aspect	Slope %	Average wind velocity in kph 7/30-8/5	8/5-8/20	8/20-9/7
1	North	30	8.55	9.80	14.65
2	South	20	9.24	9.35	16.75

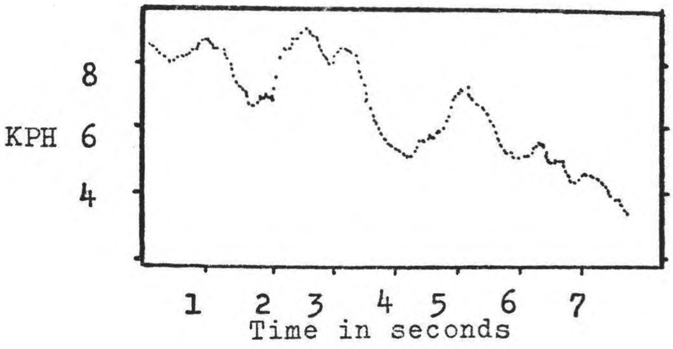


Fig. 3.2

Wind Velocity during 8 seconds in the Alpine at False Mummy Pass

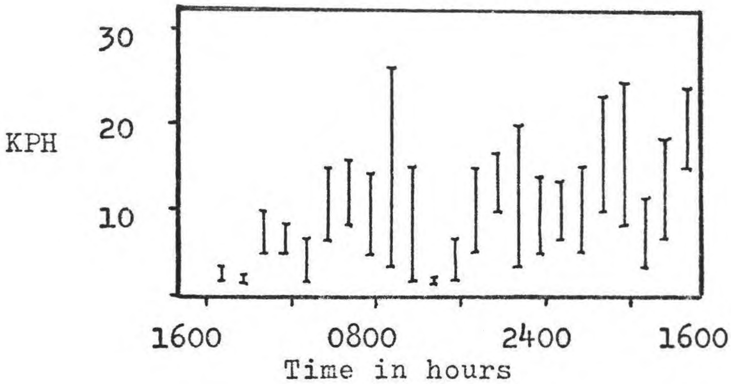


Fig. 3.3

Wind ranges over 1-2 minute intervals measured every 2 hours during a 48-hr study carried out on August 20,21,22, 1960 at False Mummy Pass.

(After Salisbury,1968)

The range of wind velocity in the alpine during 8 second observation periods was between 3-10 kph, and the bi-hourly wind ranges over 1-2 minute spans during a 48-hour study showed extremes of 3-27 kph in wind velocity (Fig. 3.2 and 3.3).

GEOLOGY AND PHYSIOGRAPHY

The geology of the Colorado Front Range has been described by Lovering and Goddard (1956). These mountains are thought to have been formed during the Larimide revolution, during which time igneous rocks were intruded as the core of the mountain range. The main geological component of the area was the Silver Plume granite. It consists of pinkish-grey feld spars, quartz and slightly proply-ritic biotite (Fig. 3.4.). The percentage of the biotite varies and muscovite may be present in some facies (Johnson, 1963; Murray, 1968). Weathering and erosion have carried away the overlying sedimentary materials on the tops of the mountains, exposing the dominant Precambrian granite, while shists and gneisses derived from granite are locally exposed with a corresponding mixture of the rock types.

Retzer (1962) stated that "Glaciation has been extensive and beyond a doubt has played a major role in the shaping of the landscape as it is today." Cirque basins are common, and outcrops of granite rock are generally the high points in the area (Fig. 3.5).

The southern end of the Crown Point study area was covered by glaciers extending beyond the Hour-glass study area (Johnson, 1963). The prominent physiographic features of the area resulted from the great Larimide period of

Figure 3.4. Rocks samples on Crown point study area, showing the ignous origin of these Feldspar and Quartz minerals and the Gneiss metamorphic rocks.

Figure 3.5. Physiography of Colorado Front Range, showing Hourglass watershed study area and a cirque in the middle of the photograph.

of mountain building which occured in the upper Cretaceous and lower Tertiary. Due to deformation, faults and folds are common.

The area is extremely rocky with such distinct features as rock-fields, stone stripes (Fig. 3.6) or rocks simply distributed throughout the area (Fig. 3.7).

SOILS

The soil of the alpine tundra of the Rocky Mountains have been classified by Retzer (1956) into three categories which are comparable to great soil groups: Alpine Turf, Alpine Meadow and Alpine bog.

The Alpine Turf soils occur on the higher convex slopes that are well drained. They are a black-to-brown mineral soil with the surface containing 5-20 percent organic matter. Black organic residues form beneath stones. The soil is internally and externally well drained with well defined horizons, the A horizon being separable into two parts (A_{11} & A_{12}).

Retzer (1956) described the Alpine Meadow soil as black-to-dark brown mineral soil developed under imperfect-to-poor internal drainage. Profiles with A through C horizons are present with varying degrees of mottling. The organic content usually exceeds 20 percent. These soils occupy the lower concave portions of the slope where drainage is slowed and water may accumulate from areas above.

The third group, the Alpine bog soils, were described as black or brown soils high in organic matter and peat due to their development in bogs and wet areas. These soils are often strongly worked by frost action and occur where water is ponded for long periods of time.

Figure 3.6. Stone stripes are common in the study areas.

Figure 3.7. Rocks are a predominant ground cover feature.

Two soil profiles, one on the south aspect and one on the north aspect of the Crown Point study area, were studied (Fig. 3.8). The soil on both sites can be classified as a zonal alpine turf. The horizon is a dark brown, silt loam, about 7.5-12.5 cm. thick with a high organic matter content and thickly matted with roots of grasses and mat-like vegetation. The B horizon is a sandy loam, about 25-35 cm. thick which contains many roots. The C horizon is yellowish, gravelly and mixed with stones and rocks. The parent material is residium derived from weathered gneiss.

The Colorado Game, Fish and Parks Division recorded soil temperature and moisture near Crown Point as noted below:

		1962	1963	1964
Soil Temperature: (average)	Max.	15	19	19
	Min.	-8	-3	-5
°C	Mean	3	4	3
Range of soil moisture (% of dry weight)		5.2-22.2	8.8-18.7	6.9-18.5

VEGETATIONS AND GROUND-COVER

The alpine turf soils are covered with a short, low density vegetative cover. This cover is made up of grasses, sedges, forbs and shrubs. On certain sites, well protected from prevailing winds, short shrubby trees may also exist. Many sites contain mixtures of grasses, sedges and forbs as co-dominants, while other sites may have a single dominant species. Plants are generally short, many of them prostrate; some of them form cushions. Alpine tundra plants have the ability to

Figure 3.8a. Soil Profile on the south aspect, and 7 percent slope.

Figure 3.8b. Soil profile on the north aspect, and 30 percent slope.

complete their life cycle rapidly. During their period of growth and reproduction they can withstand below freezing temperatures and snow cover. These adaptations, as well as their short growth form, enable them to survive the rigors of the alpine environment. Bliss (1962) considered that air and soil temperature are of major importance to the time of plant emergence in the spring on all but boggy sites, while the end of the growing season is determined by the loss of available soil moisture.

A preliminary survey of ground cover and vegetation on the Crown Point study area showed that 45 to 49 percent of the area was exposed soil, and classified as bare ground, while vegetative cover was about 45 to 49 percent.

The most common plant species occurring within the study area were: Antennaria alpina (L.) Gaertn, Arenaria obtusiloba (Rydb) Fern, Artemisia scoplorum A. Gray, Aster alpinus L., Carex supp., Dryas octopetala ssp. hookeriana (Juz) Hulten, Eritrichum elongatum (Rydb) Wight, Festuca spp., Geum rosii (R. Br.) Ser., Hymenoxys grandiflora (Pursh) Parker, Luzula spicata (L.) D C., Poa glauca M. Vahl, Polemonium viscosum Nutt, Potentilla concinna Rich, Sedum laneolatum Torr., Selaginella densa Rydb., Trifolium nanum Torr., Trifolium parryi A. Gray, LICHEN, and SALIX.

HYDROLOGY AND SNOW-MELT

The melting of snow in alpine areas depends largely on solar radiation, warm air and wind. Direct solar radiation is the most important factor. Snow melting commences in early June. Most melt water will percolate down into the soil although surface runoff may occur for short distances below a melting snowpack when soils are saturated.

Johnson (1963) in a study of runoff distribution for the Little Beaver watershed which includes Crown Point, showed a large increase in runoff during the month of June. This was attributed to snowmelt. The annual water yield averaged 45-55 percent of the annual precipitation. During the period of 1961-1966, annual yield ranged from 127-305 area mm. (Murry, 1968).

GRAZING AND LAND USE

During the summers of 1967 and 1968, the Crown Point study area was subject to heavy grazing by about 4500 sheep. The sheep begin grazing in late July and stayed on the area for about two months before they were removed in early September. The area is also subject to recreational use. Many people with four-wheel drive vehicles, motorcycles, horses, or on foot were observed during the period. Recreational attractions at the area include fishing, hiking, and unsurpassed scenery.

Chapter IV

METHODS

SELECTION OF PLOT LOCATIONS

During the summer of 1967 study plots and transects were selected with the aid of aerial photographs. Eight locations were selected as shown in Figure 4.1. Plot characteristics are given in Table 4.1. An Abney level was used to measure the slope in percent. The total length of slope was measured in the field. The cosine of the angle of the slope was used to calculate the horizontal distance between locations. Plot locations with respect to Crown Point are show in Figure 4.2.

Table 4.1

Plot Characteristics, Crown Point Sampling Area

Plot No.	Aspect	Ave. Slope %	Position on Slope	Max. Slope distance (meters)1/	Max. Horz. distance (meters)2/	Slope Dist. between upper & lower (meters)
1	North	9	Lower	75	74	51
2	North	9	Upper	24	23	
3	North	30	Lower	301	260	203
4	North	30	Upper	98	85	
5	South	7	Upper	25	25	51
6	South	7	Lower	76	75	
7	South	20	Upper	103	96	204
8	South	20	Lower	307	298	

1/ Slope distance is the ground distance between the plot location and the upper end of the slope.

2/Horizontal distance = Slope distance x Cosine of the angle of the slope.

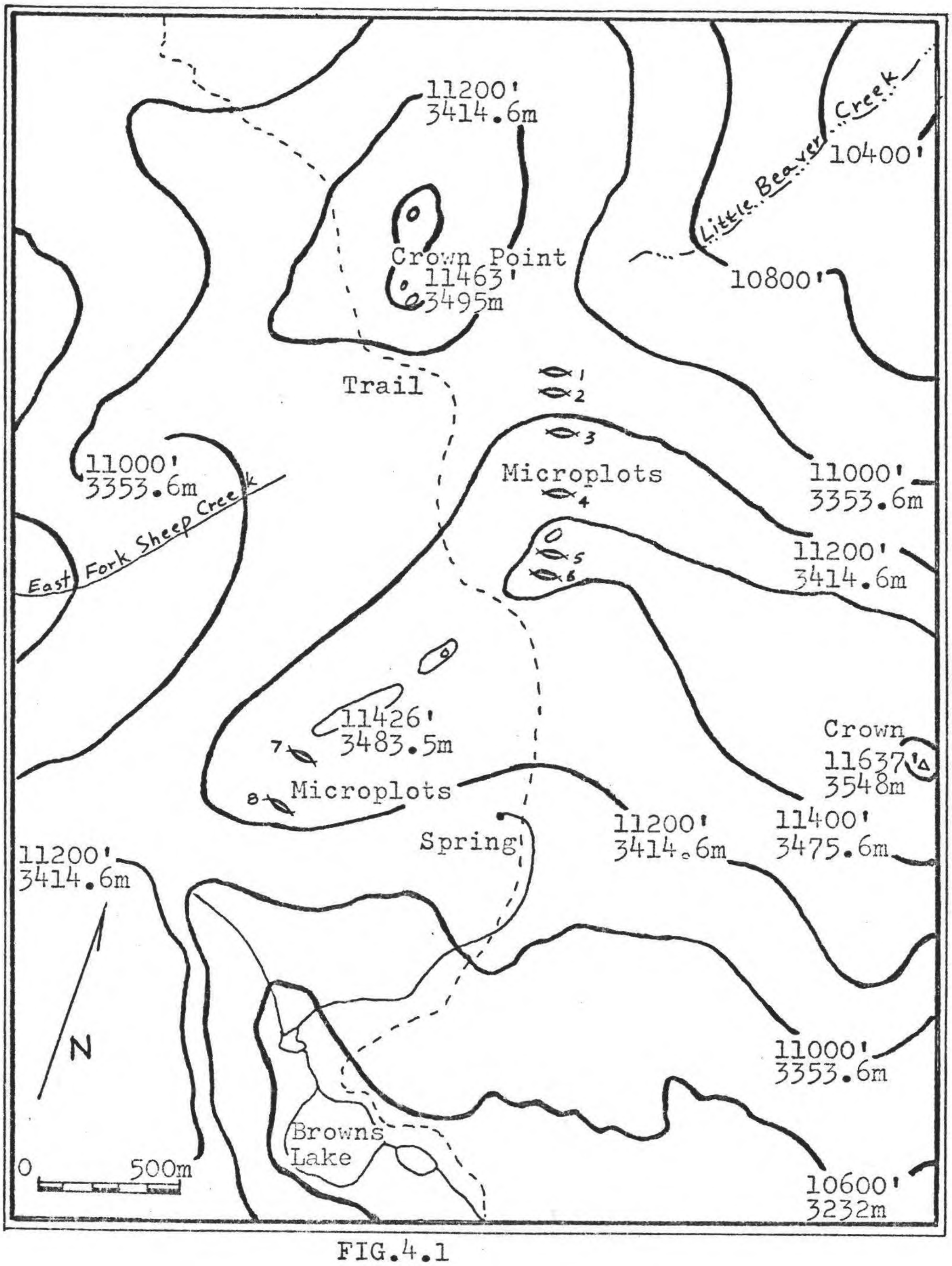


FIG.4.1

CROWN-POINT STUDY AREA

Figure 4.2. Crown-Point study area showing the north aspect with more than 20 percent slope on the left and the south aspect with less than 10 percent slope on the right.

INSTALLATION OF MICRO-RUNOFF COLLECTORS

In late September 1967, four micro-runoff collectors were installed at each location to measure both runoff and sediment. Collectors were installed at 5 meter intervals along the contour. Thus, a total of 32 collectors were installed on the Crown Point study area, representing 2 aspects, 2 slopes, 2 positions on slopes, and 4 replicants.

Micro-runoff collectors consisted of small sheet metal collection troughs, designed to lie flat on the soil surface (Fig. 4.3 and 4.4). Surface runoff and water borne sediments originating up slope from the trough were free to enter the trough. The trough was fastened to the ground by two-30cm spikes and the upper lip of the trough was sealed with bentonite along the 12cm edge of the collector so as to prevent water and sediment from seeping under the trough. The lower portion of the trough was a funnel which led into a double container in which the sediment was trapped. All containers had lids so as to eliminate trapping of any wind borne debris. A large flat rock was placed over each collector in order to protect it from sheep or other disturbance.

APPLICATION OF FLUORESCENT PIGMENTS

After the micro-runoff collectors were installed, six lines of different colored fluorescent dye solution were sprayed at varying intervals above the collector (Fig. 4.5). Dye solution consisted of one gram of Day-Glo fluorescent pigment powder dissolved in 10ml. of acetone, a volume sufficient to cover 30 square cm. Colors used included signal green (SG) at 4.0cm above the collector, Blaze orange (BO) at 11.5cm above the collector, Arc yellow (AY) at 21.0cm above the

Figure 4. 3. Micro-runoff collector.

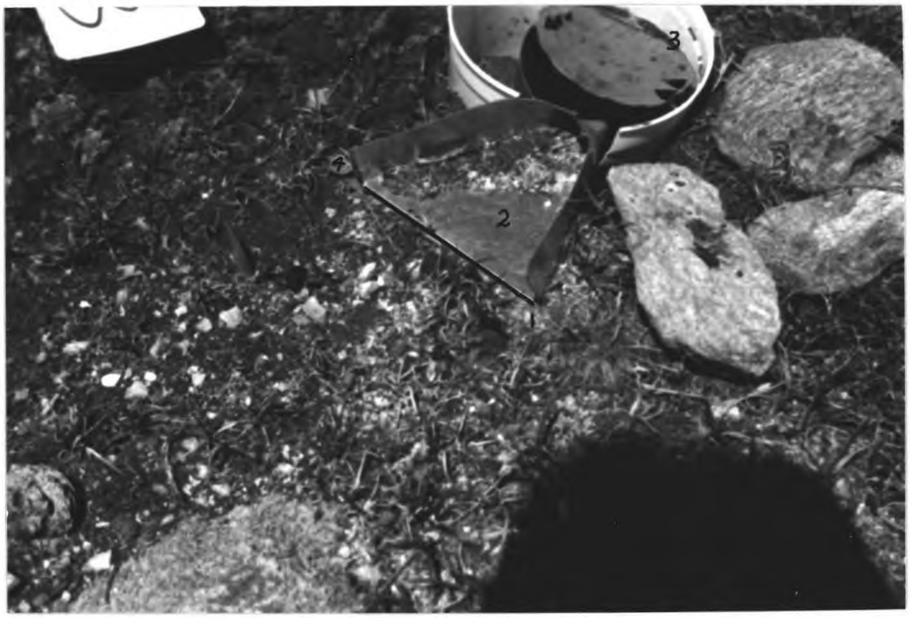


Figure 4. 4. Micro-runoff collector showing
1. Bentonite 2. Trough
3. Double container 4. Spike

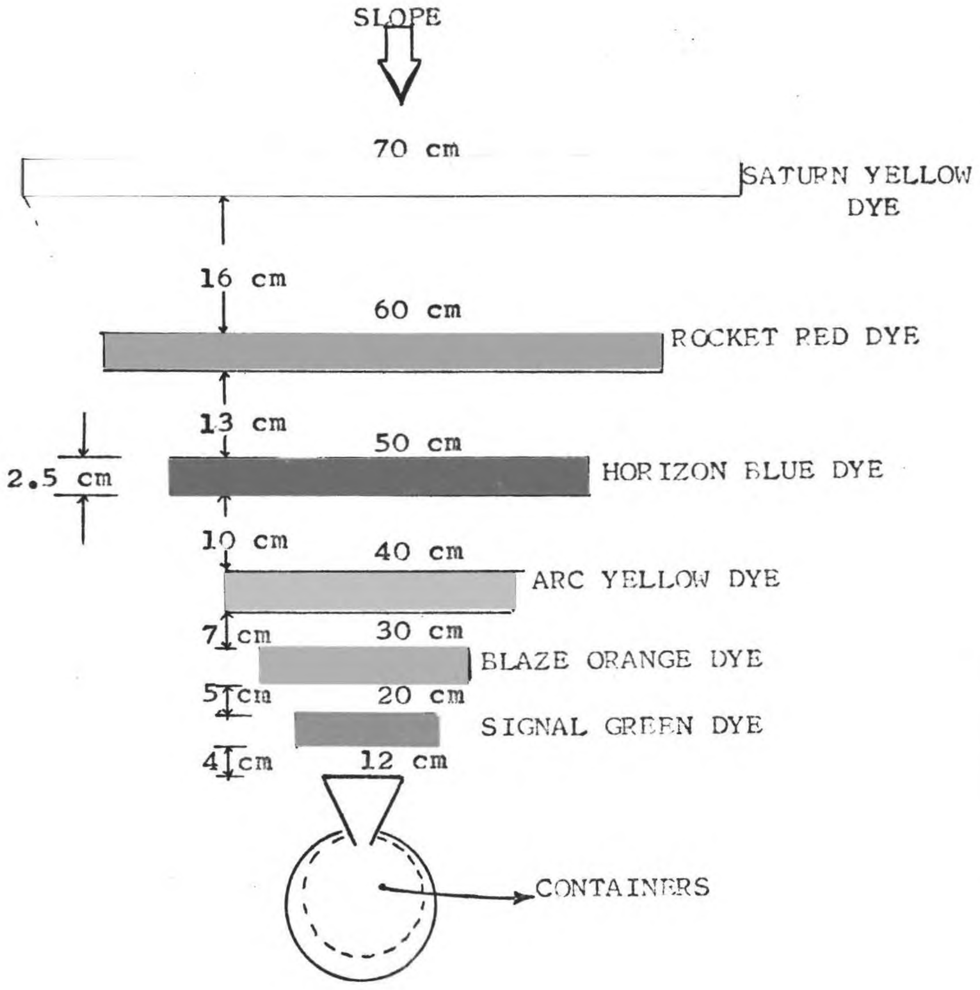


Fig. 4.5- Six lines of different fluorescent dye solution were sprayed at varying intervals above the collector

collector, Rocket Red (RR) at 44.0cm above the collector, Saturn Yellow (SY) at 67.5cm above the collector. Properties of the Day-Glo day light fluorescent pigments used in this study are given in Appendix A.

Flourescent dyes were applied to the soil using an orchard sprayer and a wooden template lined with sponge so that the length and width of the sprayed transect could be rigidly controlled.

In addition to the six dye lines, 10 spots, 10cm in diameter were sprayed with Arc Yellow flourescent pigment on a level area, within the study area, in order to observe the effect of rain drop splash and grazing on surface soil particle movement.

GROUND COVER STUDIES

In early July, 1968, 35 mm. colored pictures of each microplot were taken. A frame with an area of .49 square meter was used as a micro-plot boundary to determine the percentage cover of vegetation, rocks, litter, erosion pavement and bare area (Fig. 4.6). Field observations were necessary to interpret the picture more precisely.

All soil particles above 20 mm. diameter were considered rocks. Erosion pavement was considered as a layer of stones or gravel less than 20 mm. on the surface of the ground after the fine particles have been removed by erosion. Three samples of erosion pavement cover were collected and analyzed in the lab. Exposed soil within the plot was classified as bare area. Soil particles under 5 mm. were classified as soil (USFS 1964).

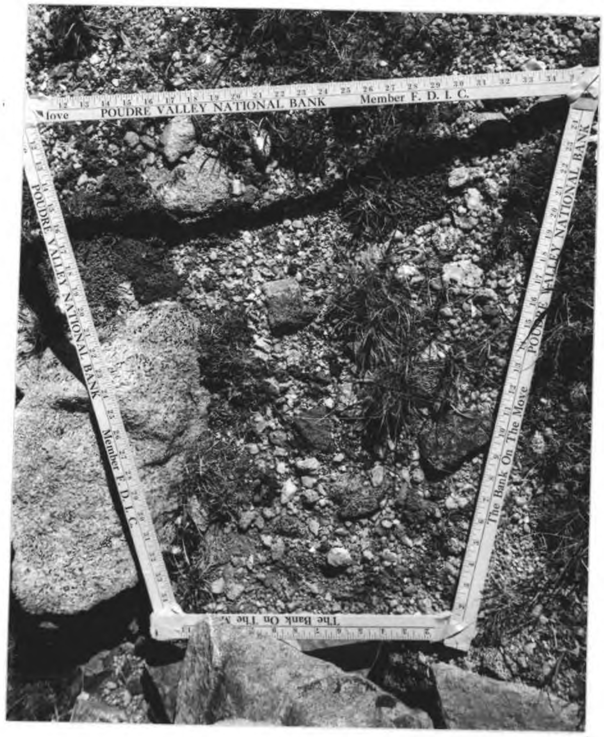


Fig. 4.6a. Frame for ground cover studies.

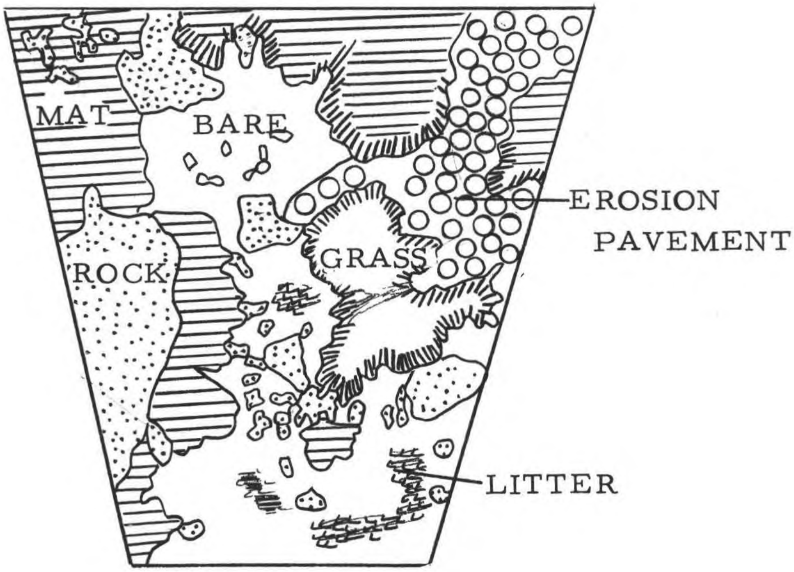


Fig. 4.6b. Interpretation of ground cover.

Only the basal area of herbaceous plant were considered in determining ground cover. Exceptions were mat-forming plants such as Antennaria, Trifolium, moss and lichen, where the entire plant was counted.

All litter was classed as ground cover, and was considered as complete cover only when no bare soil was exposed. Litter cover, also, was based on past years' accumulation and not on current material.

The study of vegetation on each microplot was concerned mainly with the total percentage of vegetative cover within the boundary of the frame. Vegetative cover was further subdivided into percentages of grasses and grass-likes, mats and mat-likes, and forbs. The distribution of vegetation was also considered as:

1. Aggregated: when the vegetative cover was complete and no bare soil was showing.
2. Dispersed: when the vegetative cover was not complete and bare soil was showing.
3. Aggregated and dispersed: when the vegetative cover was partly aggregated and partly dispersed.

MICRO-TOPOGRAPHY

The Micro-topography on each microplot was classified according to a system developed by Hubbard (1968) as:

1. Micro-depression - a closed depression in which water accumulates and infiltrates the soil.

2. Micro-channel - a small furrow-like depression in which water concentrates and flows turbulently. These are often active only with snowmelt and intense storms.

3. Surface Runoff - melt water or rainwater flows relatively uniformly across the area surface. It may flow to a channel or infiltrate the soil surface.

The local slope of each microplot was measured in the field by the use of an Abney level and a ruler.

INFILTRATION RATE, BULK DENSITY AND MOISTURE CONTENT OF SOIL

A USGS hand portable rainfall-simulator infiltrometer (McQueen, 1963), was used to measure the infiltration rate for one-half hour only.
Eight measurements were taken for the eight locations of each set of four microplots. At the same time, bulk density was measured by using a rubber-balloon apparatus (Volu-meter) (Black, 1965) (Fig. 4.7). Sixteen readings, two for each set of four microplots were taken. At the same time, the moisture content of these samples were obtained.

PRESENCE OF SNOW AND RAINFALL MEASUREMENT

The prevailing westerly wind in winter is very important in sweeping the snow from exposed sites and redepositing it in natural accumulation areas. Using aerial photographs taken in April 1967, the sites on the study area showed great variation in snow depostion (Fig. 4.9). Some of them are clear and have no snow at all, others are covered to a considerable depth. Accordingly, the following classification was developed for the sample areas:

Figure 4.7. Volu-meter for measuring soil bulk density.

Figure 4.8. Trough rain-gage.

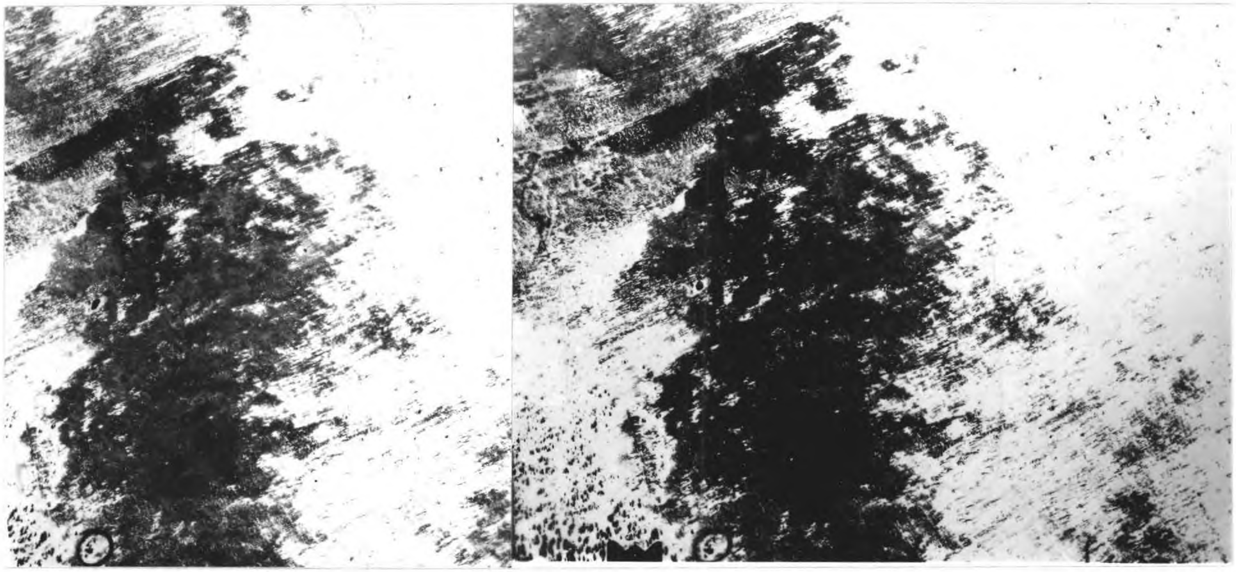


Figure 4.9. Presence of snow during winter on Crown Point study area as seen from the aerial photographs. (These two photos are set in a stereoscopic position for better observation.

0 = 100 percent bare area, clear of snow

1 = 50 percent bare area, 50 percent snow cover

2 = 100 percent snow cover, tall grasses can be seen in the snow

3 = 100 percent snow cover, bushes and shrubs can be seen in the snow

4 = 100 percent show cover, no bushes or shrubs can be seen.

In late July snow had not melted completely from category 4, as shown in Figure 4.10.

Four trough rain gages were used to measure variation in summer precipitation (Fig. 4.8). Two gages were located on the south aspect and two on the north aspect with each one a different slope.

WIND MEASUREMENT

Two anemometers, one on each aspect, were used to measure the total passage of wind during the summer of 1968 (Fig. 4.11).

In the late summer, 1968 a sensitive portable wind meter was available to measure the wind speed and profile for many locations on the study area. Readings, in meters per minute, were taken at ground level and breast height (1.5 m.) at locations representing north and south aspects and various slope positions (Fig. 4.12).

SEDIMENT TREATMENT

Sediment caught in the micro-runoff collectors were collected twice during the summer of 1968, in late June and in late September. All sediment samples were oven-dried, weighed, and sieved into greater than 5mm, 2-5mm, 1-2mm, .5-1mm, .25-.5mm, and less than .25mm size classes.

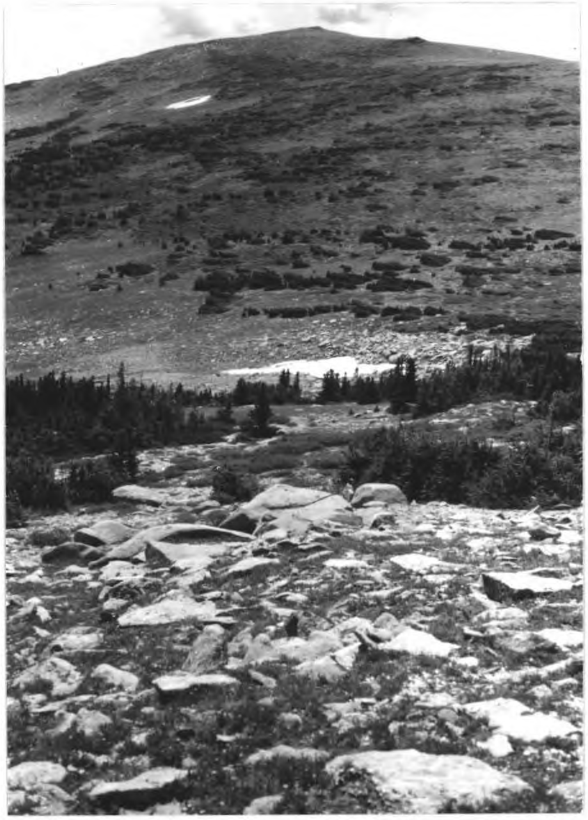


Figure 4.10. General view of the north aspect on the Crown-Point study area in late July showing the presence of snow.

Figure 4.11. Totalizing wind anemometer used to measure the total passage of wind on Crown-Point study area.

Figure 4.12. A portable wind meter, very sensitive at ground level used to measure the wind profile and speed.

The weight of particles colored with fluorescent pigments was determined for each sample. Separate determinations were made for each particle size class. Weights of colored particles were determined on the basis of the total number of colored particles as a percentage of the total number of soil particles in each sample.

The weight of the organic matter content in each sample was determined by combustion in a muffle furnace at 600-900°C.

A Bonus-line Mercury Ultraviolet Lamp with filter (3600°A) was used in photographing the colored soil particles in the dark room for 90 seconds exposure, using a natural color film in order to show the effectiveness of fluorscent pigments in soil erosion studies (Fig. 7.4).

In addition to the micro-runoff collectors, eight transects, 15.2 m. (50 feet) long, were sprayed withArc Yellow fluorescent pigments in the middle of July, 1968, on the Crown Point study area. A transect was located adjacent to each set of four microplots (Fig. 4.13).

In addition to the Crown Point transects, sixteen transects had been installed on the Hour-glass study area in the summer of 1966. These transects were 100 feet long and had been installed on three slope positions (upper, middle, lower), and two aspects (north and south). Half of each 100 foot transect had received <u>in situ</u> spray application of fluorescent dye solution similar to the Crown Point transects. The other half had been excavated with the soil removed from a 2.5 cm wide by 2.5 cm trench. The soil removed was taken to the laboratory and sorted into the various size portions by sieving. Each size class was then dyed a different color,

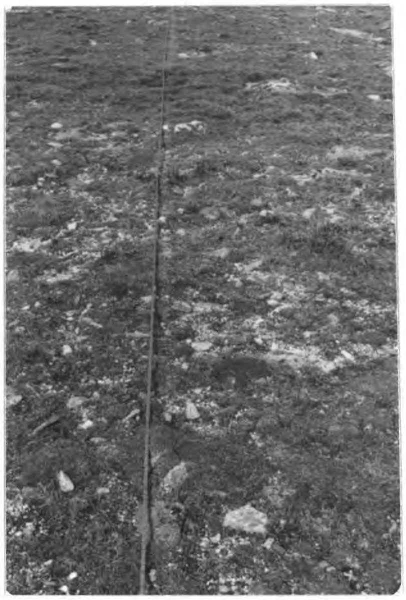


Figure 4.13. A 15.2 meter long transect sprayed with Arc Yellow Fluorescent dye on Crown Point study area.

the soils were re-mixed, and returned to the original sites in the field. In this study, one gram of dye in 10 ml of acetone was sufficient to color 50 grams of soil.

Soil particle size classes were colored as follows:

>5mm - Horizon blue

2-5mm - Blaze orange

1-2mm - Rocket red

.25-1mm - Arc yellow

.05-.25mm - Saturn yellow

<.05mm - Signal green

Of the 16 transects, only seven were observed during the summers of 1967 and 1968. Three of them on the north aspect at 30-40 percent slope, and four of them on the southest aspect at 30-60 percent slope (Fig. 4.14).

During the summer of 1968, a preliminary survey of ground cover and vegetation had been done using a nine inch (23 cm.) loop. The frequency of species and an estimation of ground cover were obtained at one foot intervals along each transect. Thus 50 measurements were taken on each transect. Fifteen transects were investigated: eight on the Crown Point study area and seven on the Hour Glass study area.

In late September, the displacement of soil particles down the slope was determined at night by placing a red flag mark next to each particle moved. A portable ultraviolet light (2537°A) was used to detect the displacement of soil particles. Direct measurement of the distances from the main transect were taken in daylight the following day.

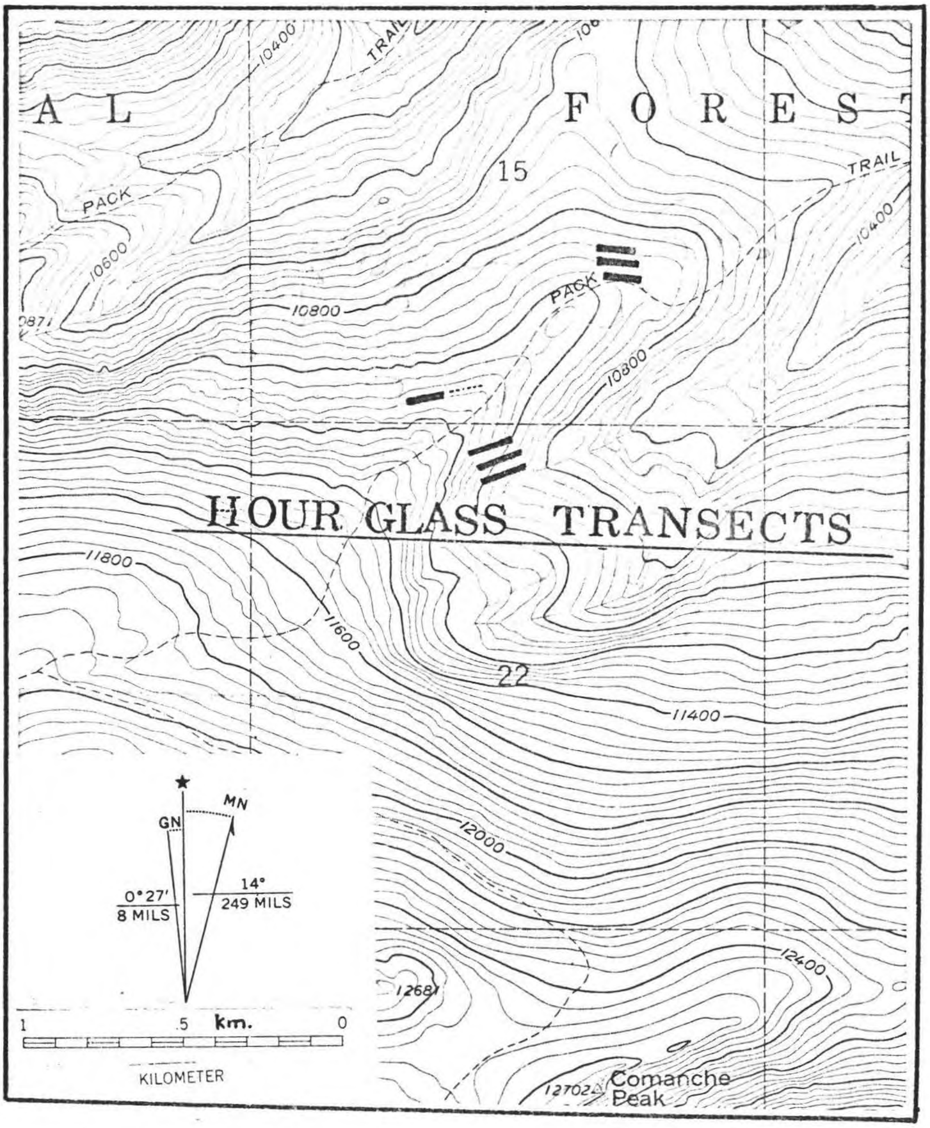


Fig. 4.14- Hour Glass study area

STATISTICAL ANALYSES

A multiple regressio analyses, BMDO2R stepwise regression program was carried out through the facilities of the Colorado State University Computer Center on the Control Data Corporation computer Model number 6400. This program computes a sequence of multiple linear regression equations in a stepwise manner. At each step one variable is added to the regression equation. The variable added is the one which makes the greatest reduction in the error sum of squares. Equivalently it is the variable which has the highest partial correlation with the dependent variable partialed on the variables which have already been added, and it is also the variable which, if it were added, would have the highest F-value. In addition, variables can be forced into the regression equation. Non-forced variables are automatically removed when their F-values become too low.

The output from this program includes:

A. At each step

  1. Multiple R
  2. Standard error of estimate
  3. Analysis of variance table
  4. For variable in the equation:
     a. Regression coefficient
     b. Standard error
     c. F to remove
  5. For variables not in the equation:

a. Tolerance

b. Partial correlation coefficient

c. F to enter

B. Optional output prior to performing regression:

1. Means and standard deviations

2. Covariance matrix

3. Correlation matrix

C. Optional output after performing regression:

1. List of residuals

2. Plots to residuals vs. input variables

3. Summary table

Two statistical parameters were used to determine the degree of variable interrelation in the final prediction equation. These parameters are the standard error of the estimate (SE est.) and the Coefficient of determination (R^2). Increase in R^2 as associated with decrease in SE est. will indicate that the prediction equation will be more accurate.

The variables used in this study included 23 independent variables and 17 dependent variables. They will be discussed in chapter 6.

Chapter V

RESULTS OF FIELD INVESTIGATION

CLIMATE

Results obtained on Crown Point study area, concerning the variation in summer precipitation, and wind speed are shown in tables 5.1 5.2 and 5.3.

Wind speed measurements in kph were obtained by the use of two totalizing anemometers, while the wind speed in meters per minute (mpm) was obtained during the late summer of, 1968 by the use of a portable, sensitive wind meter as a part of measuring the wind profile in the Crown Point study area (Fig. 5.1).

Due to macrotopography, wind profile measurement showed some variation in wind speed between the upper and lower position of the slope. At the same time, due to vegetation and microtopography, variation existed between the wind speed at ground and 1.5m levels.

Total wind passage showed, also, some variation in wind speed between measurements in early July and in early September 1968

Summer precipitation was measured from four trough rain gages, and the final figures were corrected for slope. Precipitation showed some variation from one spot to another, due to the action of convective thunder shower activities.

The presence of snow, or the deposition of snow, on each set of microplots, showed some variation between the north and south aspects and the upper and the

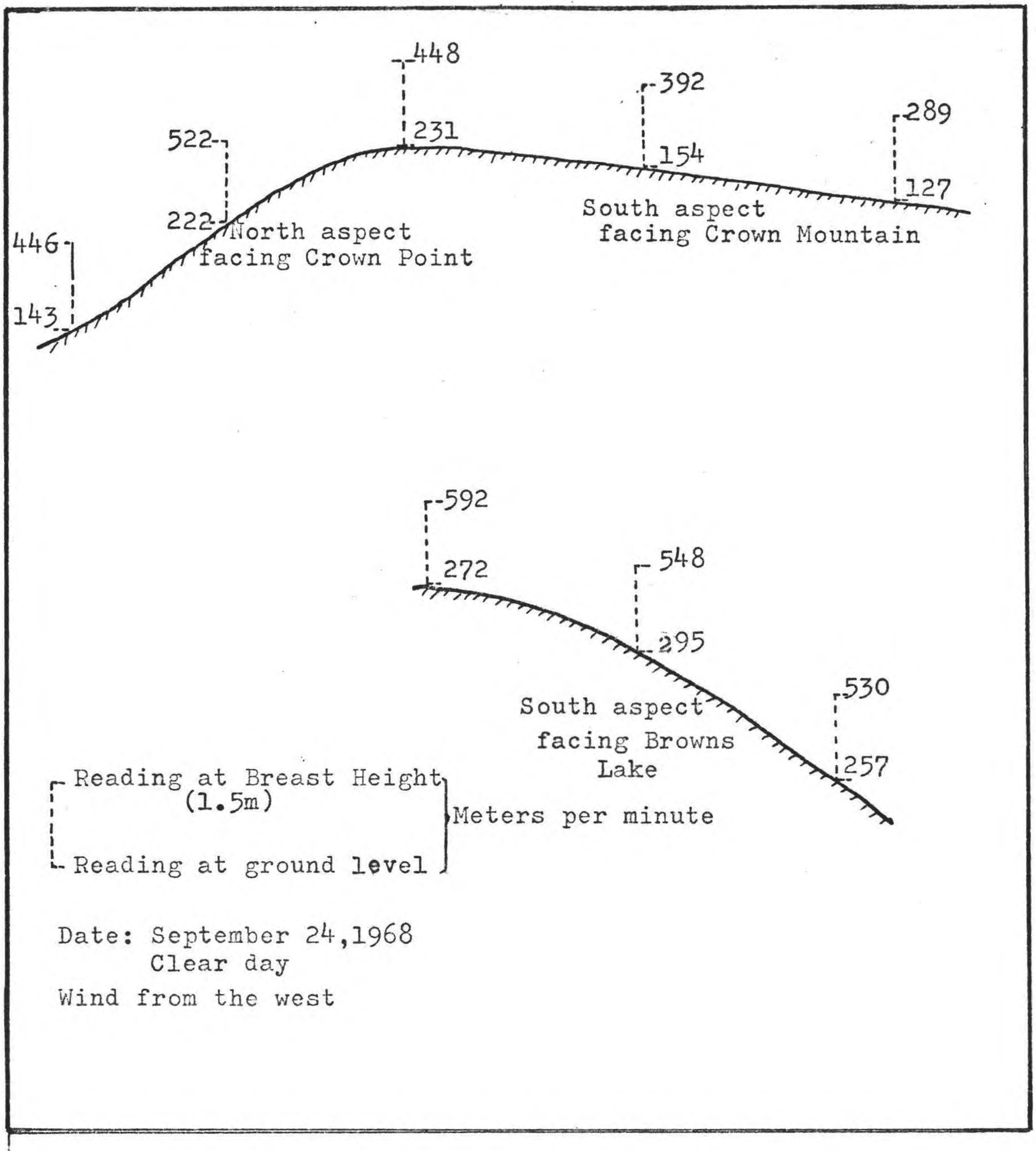


Fig. 5.1

Wind profile measurement on Crown Point study area, by the use of a sensitive portable wind meter.

Table 5.1

Summer Precipitation in mm on Crown Point study area
from July 23 to September 15, 1968

Reading date	Rain gage No. 1	Rain gage No. 2	Rain gage No. 3	Rain gage No. 4
	N-aspect 9% slope	N-aspect 30% slope	S-aspect 7% slope	S-aspect 20% slope
July 23	00.0	00.0	00.0	00.0
July 30	10.2	10.2	10.2	10.2
Aug. 5	26.9	26.7	27.9	39.9
Aug. 27	35.6	33.0	34.3	39.4
Sept. 7	23.4	15.6	22.1	26.9
Sept. 15	15.8	15.5	12.9	7.9
Total	111.9	101.0	107.4	124.3
Total precipitation after Correction for slope*	114	117	108	132

*Correction for slope was based on the following equation:

$$\frac{\text{Collected Rainfall}}{\text{Cosine angle of slope}} = \text{Actual Rainfall}$$

Table 5.2

Wind speed on Crown Point study area, based on total wind passage
during the summer of 1968

Aspect	Slope %	Wind Speed in kph (Summer 1968)		
		7/3 - 8/5	8/5 - 8/20	8/20 - 9/7
South	20	9.20	9.35	16.75
North	30	8.55	9.80	14.65

Table 5.3

Wind speed on Crown Point study area based on short period measurement in late summer 1968

Aspect	Slope %	Wind speed in mpm (in late summer 1968)	
		at ground level	at 1.5 meter level (BH)
North	9	152	398
North	9	143	446
North	24	224	492
North	39	237	489
South	7	154	392
South	7	127	289
South	25	282	606
South	20	291	590

Table 5.4

Deposition or presence of snow on Crown Point study area (April 1967)

Aspect	Slope %	Presence of snow		Remarks
		type 1/	% snow cover	
North	9	4	100 covers bushes	Presence of some trees
North	9	4	100 covers bushes	
North	24	3	100 covers grasses	Presence of nearby depression
North	39	1	50	
South	7	1	50	
South	7	1	50	
South	25	0	0 clear of snow	
South	20	1	50	

1/ Refers to the type of presence of snow cover classification (see methods).

lower position on slopes. The presence of snow was obtained from the aerial photographs of the area, taken in April, 1967 as shown, in the results, in table 5.4.

SOILS

The soil of Crown Point study area was classified as a zonal alpine turf soil. The A horizon is a dark brown, silt loam about 7.5-12.5 cm thick with a high organic matter content, and thickly matted with roots of grasses and mat-like vegetation. The B horizon is a sandy loam, about 24-34cm thick. The C horizon is yellowish, gravelly and mixed with stones and rocks. The parent material is residium formed from weathered gneiss.

Surface characteristics of the microplots study area is shown in table 5.5. The total distribution of ground cover, before and after grazing by sheep on Crown Point study area is shown in table 5.6.

The total distribution of ground cover on Hour Glass study area was about 47 percent vegetation, 6 percent litter, 17 percent rocks, 5 percent erosion pavement and 25 percent bare area.

Three samples of erosion pavement were collected from Crown Point study area, at a depth of 1 to 1.5 cm, showed that about 90 percent of the samples consisted of soil particles greater than 2 mm (table 5.7).

Surface characteristics showed some variation in local slope and microtopography features. The microtopography were classified as surface runoff in 14 microrunoff plots, as micro-channel in 11 microrunoff plots and as

Table 5.5

Surface characteristics on Crown Point study area
Summer 1968

Micro-plot No.	Aspect	Total Slope %	Slope Posit.	Local Slope %	Micro-topography	Ground cover V* %	L* %	R* %	EP* %	B* %
1	North	9	Lower	7	SRO*	25	0	10	50	5
2	North	9	Lower	3	MD*	25	5	30	10	30
3	North	9	Lower	5	SRO	60	10	10	5	15
4	North	9	Lower	10	MC*	70	10	10	0	10
5	North	9	Upper	15	MC	55	5	5	5	30
6	North	9	Upper	8	SRO	65	5	0	15	15
7	North	9	Upper	12	SRO	50	10	5	20	15
8	North	9	Upper	10	MC	40	0	25	30	5
9	North	24	Lower	7	SRO	30	15	5	20	30
10	North	24	Lower	7	SRO	65	5	5	5	25
11	North	24	Lower	6	SRO	10	5	5	60	20
12	North	24	Lower	20	SRO	10	15	15	40	20
13	North	39	Upper	20	MC	75	10	10	0	5
14	North	39	Upper	5	MC	45	15	25	0	15
15	North	39	Upper	20	SRO	50	10	10	20	10
16	North	39	Upper	25	MC	45	5	35	5	10
17	South	7	Upper	0	MD	90	5	5	0	0
18	South	7	Upper	1	MD	60	10	20	0	10
19	South	7	Upper	3	MD	70	10	10	0	10
20	South	7	Upper	6	MC	45	5	40	0	10
21	South	7	Lower	8	SRO	25	20	0	30	25
22	South	7	Lower	1	SRO	5	5	10	65	15
23	South	7	Lower	5	SRO	55	15	0	10	20
24	South	7	Lower	1	MD	50	5	5	10	30
25	South	25	Upper	25	MC	65	10	10	0	15
26	South	25	Upper	10	MD	65	15	5	0	15
27	South	25	Upper	20	MD	60	15	10	0	15
28	South	25	Upper	15	MC	45	5	30	5	15
29	South	20	Lower	5	MC	30	5	0	60	5
30	South	20	Lower	20	SRO	15	5	25	50	5
31	South	20	Lower	10	SRO	35	5	0	55	5
32	South	20	Lower	10	MC	25	10	30	25	10

* SRO = surface runoff
MD = Micro-depression
MC = Micro-channel
V = Vegetation
L = Litter
R = Rock
EP = Erosion pavement
B = Bare area

micro-depression in 7 micro-runoff plots. Local slope has ranged from 1 to 25 percent in the two aspects and the two positions on the slope.

Results of infiltration rate showed a range of 4.0 to 9.9 cm per half hour. This rate is high enough to absorb most of the melt water from snow.

The bulk density was somewhat typical, ranging from 1 to 1.8 and having a mean of 1.25. The moisture content of the top soil was about 20 percent. Results of infiltration rate, soil bulk density and soil moisture content are shown in table 5.8.

Table 5.6

Survey of Vegetation on Crown Point Study area before and after grazing during summer of 1968

Type of Cover	Percent of Cover Before Grazing	 After Grazing	 Effect of Grazing
Vegetative Cover*	45.62	44.84	- .78
Grass Likes	19.50	17.22	-2.28
Mat Likes	20.81	23.28	+2.47
Forb Likes	5.15	4.20	-1.05
Vegetative Cover**	59.27	57.52	-1.75
Litter Cover	3.01	3.58	+ .57
Rock Cover	17.96	17.83	- .13
Erosion Pavement	11.48	10.22	-1.26
Bare Area	8.28	10.85	+2.57

*Survey of Micro-plots
**Survey of transects

Table 5.7

Erosion Pavement analyses on Crown Point Study area

Sample No.	Slope %	Aspect	Organic Matter	Percent of Dry Weight >5mm	2-5mm	1-2mm	.5-1mm	.25-.5mm	<.25mm
1	25	N	.6	51.8	36.3	7.5	1.8	.8	1.2
2	20	S	.5	46.4	44.8	7.0	1.2	.3	.2
3	35	N40W	0	65.5	32.4	1.5	.4	.2	0

Table 5.8

Infiltration rate, Bulk density, Moisture content of soil on Crown Point study area

Location No.	Aspect	Slope %	Infilt. Rate cm/ $\frac{1}{2}$ hr. June	Sept.	Bulk Density* of soil gm/cm^3 June	Sept.	Soil Moisture* content (%) June	Sept.
1	North	9	7.0	6.6	1.41	1.11	18	20
2	North	9	4.0	6.9	1.56	.98	17	30
3	North	24	6.3	6.3	1.27	1.79	25	10
4	North	39	5.5	7.4	.99	1.24	35	21
5	South	7	6.6	7.4	1.33	1.19	10	17
6	South	7	6.6	7.0	1.46	.96	8	31
7	South	25	8.9	7.9	1.11	1.04	18	31
8	South	20	9.9	7.2	1.37	.97	19	32

*A and B horizons

VEGETATION

The average vegetative cover on Crown Point study area was about 59 percent of the total transects, ground cover, and 45 percent of the total micro plots ground cover, and on Hour Glass study area was about 47 percent.

The vegetative cover was broken to three types: grasses and grass-likes, such as: Carex spp., Poa spp., Fustuca spp. mats and mat-likes, such as Trifolium spp., Antennaria spp. moss and lichen, and forbs and forb-likes such as Artemisia spp., Aster spp. Hymenoxys spp. The average distribution of these three groups as percentage of vegetative ground cover per microplot was determined to be 17-19 percent grasses and grass-likes, 20-23 percent mats and mat-likes and 4-5 percent forbs and forb-likes.

Survey of vegetative cover, frequency and list of species are shown in table 5.9.

The vegetative cover distribution was determined to be aggregated in 14 microplots, dispersed in 9 microplots and both in 9 microplots.

MICRO-RUNOFF PLOT INVESTIGATION

Results of sediment analyses, collected from Crown Point micro-runoff collectors, as of weights, grain size, colored particles, organic matter residues are shown in Appendix B. 1 for sediments collected over winter and the snow melt period, and in Appendix B. 2 for sediments collected over the summer season.

The results of average sediments collected per microplot over the winter and snow melt, over summer season, and over a one year period, are shown in table 5.10 and Figure 5.2. This table and this figure give an idea of the particle size distribution and the movement of soil particles down a slope.

The final results showed that the soil particles over 2 mm in diameter were moved from a maximum distance of 23.5 cm after one year up a slope, and about 80 percent of these particles were moved from a distance of 6.5 cm up slope.

Table 5.9

Vegatative survey of the micro-plots on Crown Point study area

Plot	Veg. Cover*				Frequency of Species (Presence or absence)																						
No.	GL	ML	FL	Dist.*	GL*				ML*					FL*													
	%	%	%		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	08	15	02	3		X	X			X	X				X									X			
2	10	10	05	2	X	X			X	X	X				X											X	
3	40	20	00	1		X	X	X			X		X												X		
4	50	18	02	1		X		X		X		X															
5	15	30	10	1				X		X				X				X		X		X		X	X		
6	10	50	15	3	X			X	X					X				X									
7	20	25	05	3		X		X		X		X	X	X													
8	15	15	10	3	X	X				X	X														X		
9	03	25	02	3	X			X			X		X											X		X	
10	03	50	12	1	X		X	X	X	X		X								X	X				X		
11	02	00	08	2		X		X						X						X							
12	01	02	07	2		X						X															
13	35	35	03	1				X		X	X		X					X				X		X			
14	15	20	10	1		X		X	X	X			X														
15	20	20	10	3	X	X	X		X		X		X														
16	12	25	08	1	X	X			X	X					X					X	X				X		
17	78	10	02	1		X		X	X			X		X													
18	33	25	02	1	X			X	X					X	X	X		X				X	X				X
19	40	25	05	1	X			X	X	X		X		X	X								X				
20	40	05	00	1	X	X			X		X		X	X							X						
21	12	08	05	2		X		X					X	X				X	X								
22	00	03	02	2		X		X					X		X			X									
23	25	25	05	3	X		X	X				X						X									
24	20	25	05	3	X			X				X						X									
25	15	45	05	1		X			X		X		X														
26	30	30	05	1	X	X	X	X	X		X			X	X		X		X		X		X				
27	15	30	15	2		X			X	X		X		X													
28	10	30	05	1	X	X		X		X		X	X	X													
29	20	05	00	2	X	X	X	X			X	X	X	X							X						
30	05	10	00	3	X		X	X																X			
31	15	15	05	2	X			X						X										X			
32	07	15	03	2		X		X					X	X							X						

*GL = grass-likes Dist. = Vegetation distribution: (1) aggregated (2) dispersed
ML = mat-likes FL = forb-likes (3) both 1 & 2

1 - Carex spp.
2 - Poa glauca M. Vahl
3 - Luzula spicata (L.) DC.
4 - Festuca spp.
5 - Trifolium parryi A. Gray
6 - Trifolium nanum Torr.
7 - Selaginella densa Rydb
8 - Arenaria obtusiloba (Rydb) Fern
9 - LICHEN
10- Geum rosii (R. Br.) Ser.
11- Dryas octopetala ssp. hookeriana (Juz.) Hultern
12- Antennaria alpina (L.) Gaertn
13 - Artemisia scoplorum A. Gray
14 - Polemonium viscosum Nutt
15 - Aster alpinus L.
16 - Sedum lanceolatum Torr.
17 - Potentilla concinna Rich.
18 - Erigeron simplex Greene
19 - Hymenoxys grandiflora (Pursh) Parker
20 - Saxifraga rhomboides (Greene
21 - Polygonum bistortoides Pursh
22 - Mertensia alpina (Torr.) G. Don
23 - Castilleja occidentalis Torr.

Table 5.10

Average Percent of Sediment Yield per Micro-plot

Collected Sediment	Distance of Movement cm.	Sediment Yield per micro-plot June %	Sept. %	After 1 yr. %
TSY (total sediment yield)		100	100	100
>5MM (particle size)		38	49	41
2-5MM (particle size)		40	32	38
1-2MM (particle size)		12	11	12
.5-1MM (particle size)		4	5	5
.25-.5MM (particle size)		2	2	2
<.25MM (particle size)		3	1	1
TCSY (total colored sediment yield		100	100	100
>5MM (particle size)	14.0	39	37	38
2-5MM (particle size)	23.5	51	45	49
1-2MM (particle size)	36.0	7	14	10
.5-1MM (particle size)	36.0	1	3	2
.25-.5MM (particle size)	70.0	1		
<.25MM (particle size)	70.0	1	1	1
SG (Signal Green particle size)	6.5	79	74	77
BO (Blaze Orange particle size)	14.0	16	20	18
AY (Arc Yellow particle size)	23.5	3	4	4
HB (Horizon Blue particle size)	36.0	1	1	
RR (Rocket Red particle size)	51.5	1	1	1
SY (Saturn Yellow particle size)	70.0			

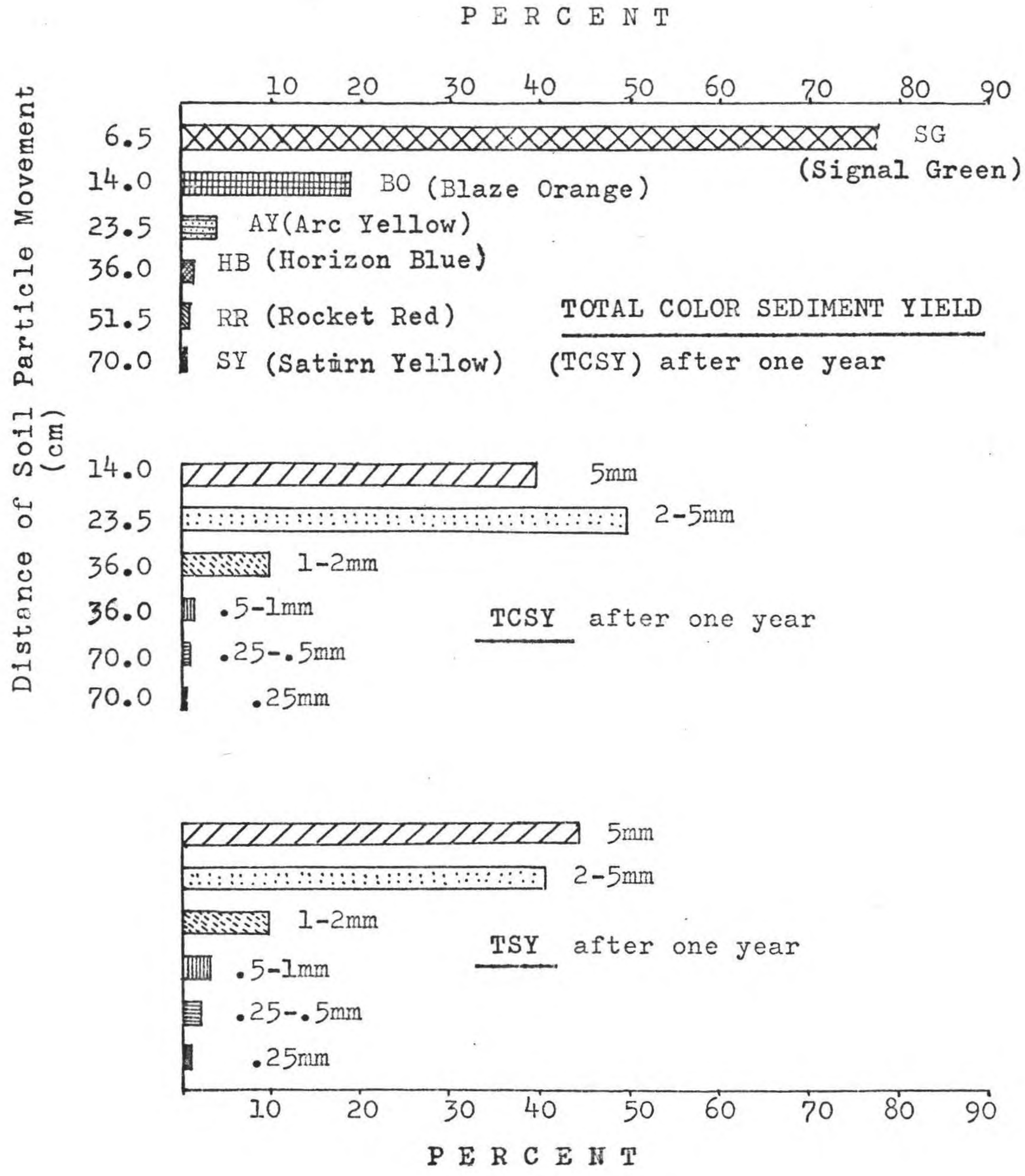


Fig. 5.2

Distribution of Soil Sediment as of size and color

At the same time, about 90 percent of the collected sediment in the micro-runoff collectors consisted of soil particles larger than 2 mm in diameter.

TRANSECTS AND DYE SPOT STUDIES

Results of pattern and distance of soil particle movement as related to slope, aspect, type of drainage, in Hour Glass, and Crown Point study areas are shown in Appendix B.3, B.4, B.5, and B.6 and Figures 5.3, 5.4, 5.5 and 5.6

Surface runoff drainage was the most important factor related to movement of soil particles in the transect study. Figure 5.5 gives the relationship between soil particle size and slope. Increase in slope will lead to an increase in the movement of soil particles.

The effect of rain drops on the movement of soil particles is shown in Appendix B.7. The movement of soil particles was more toward the east and south than to the west or to the north. This is due to the effect of wind and the direction of falling raindrops. The average movement was about 38 cm in any direction during the summer period, when three big summer storms occurred on the Crown Point study area.

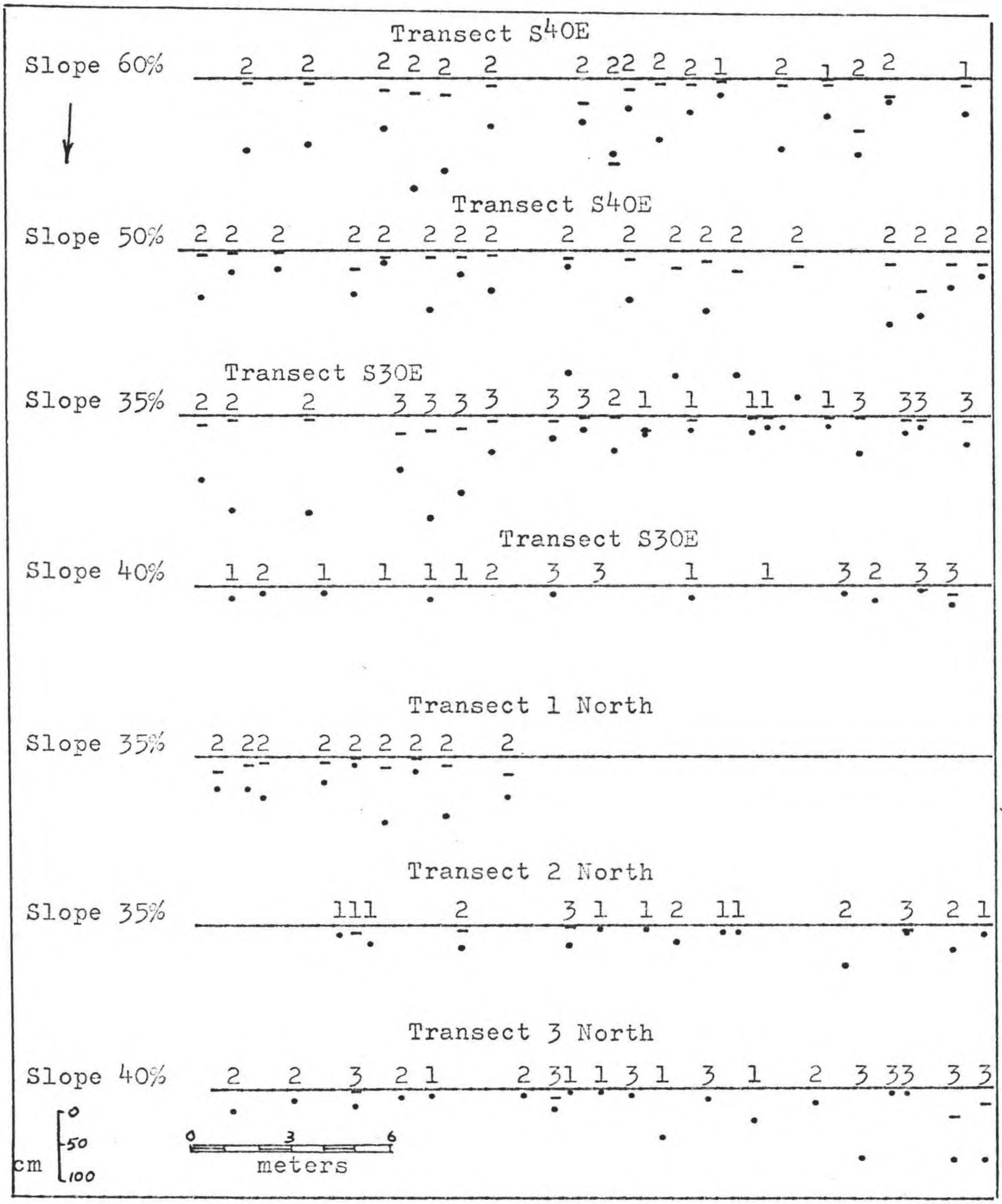


Fig. 5.3 Pattern and distance of soil particles movement during Two-yrs. period(Sept.,1966 to Sept.,1968) on Hour-glass study area.

- = Soil particle larger than 5mm colored with Blue Horizon dye
• = Soil particle .25-1mm colored with Arc Yellow dye
1 = Microdepression 2=Surface runoff 3=Micro-channel

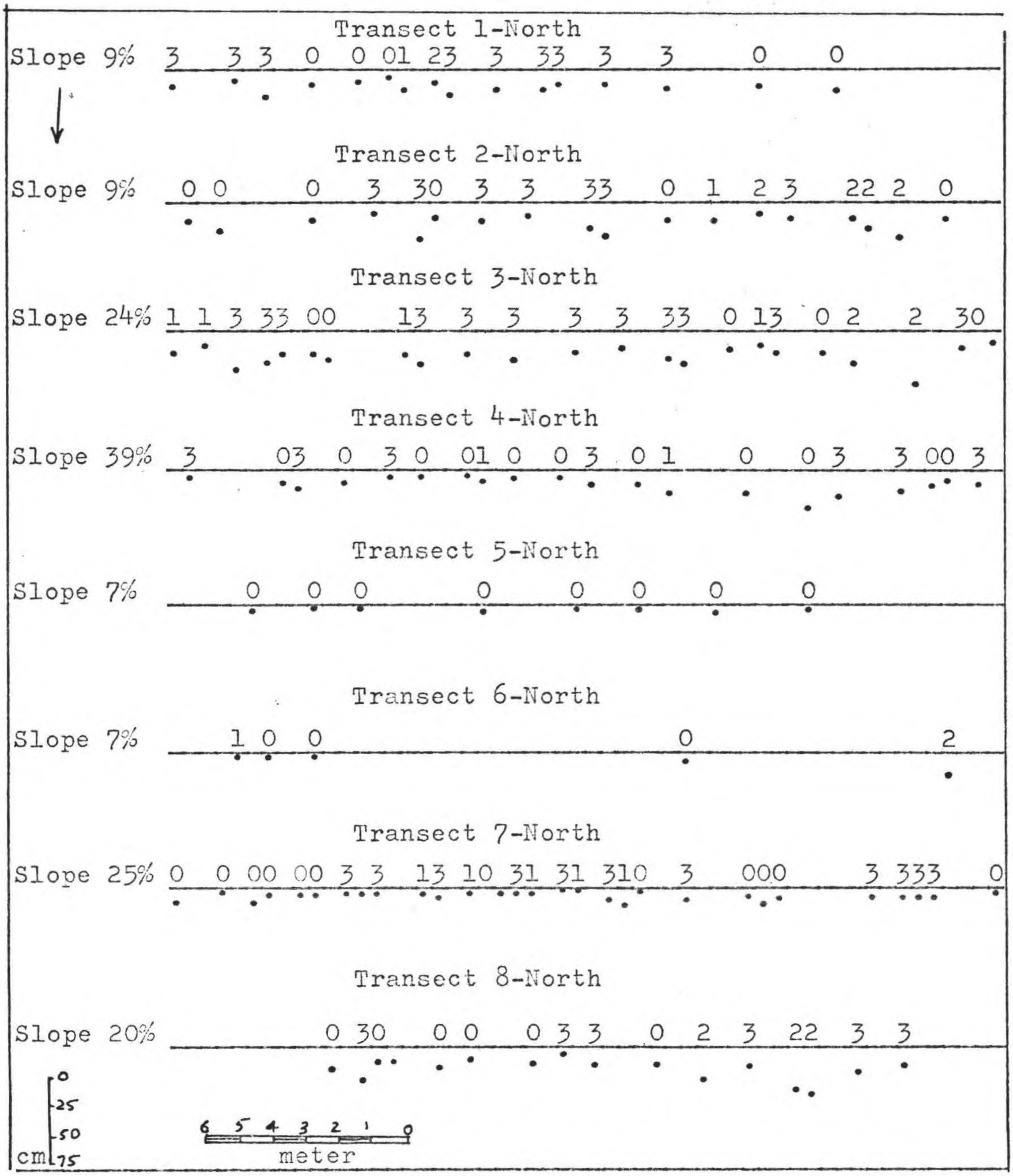


Fig. 5.4 Pattern and distance of soil particles movement during the summer period of 1968, on Crown-point study area

• = Colered soil particle with Arc Yellow dye

1= Microdepression 2=Surface runoff 3=Micro-channel

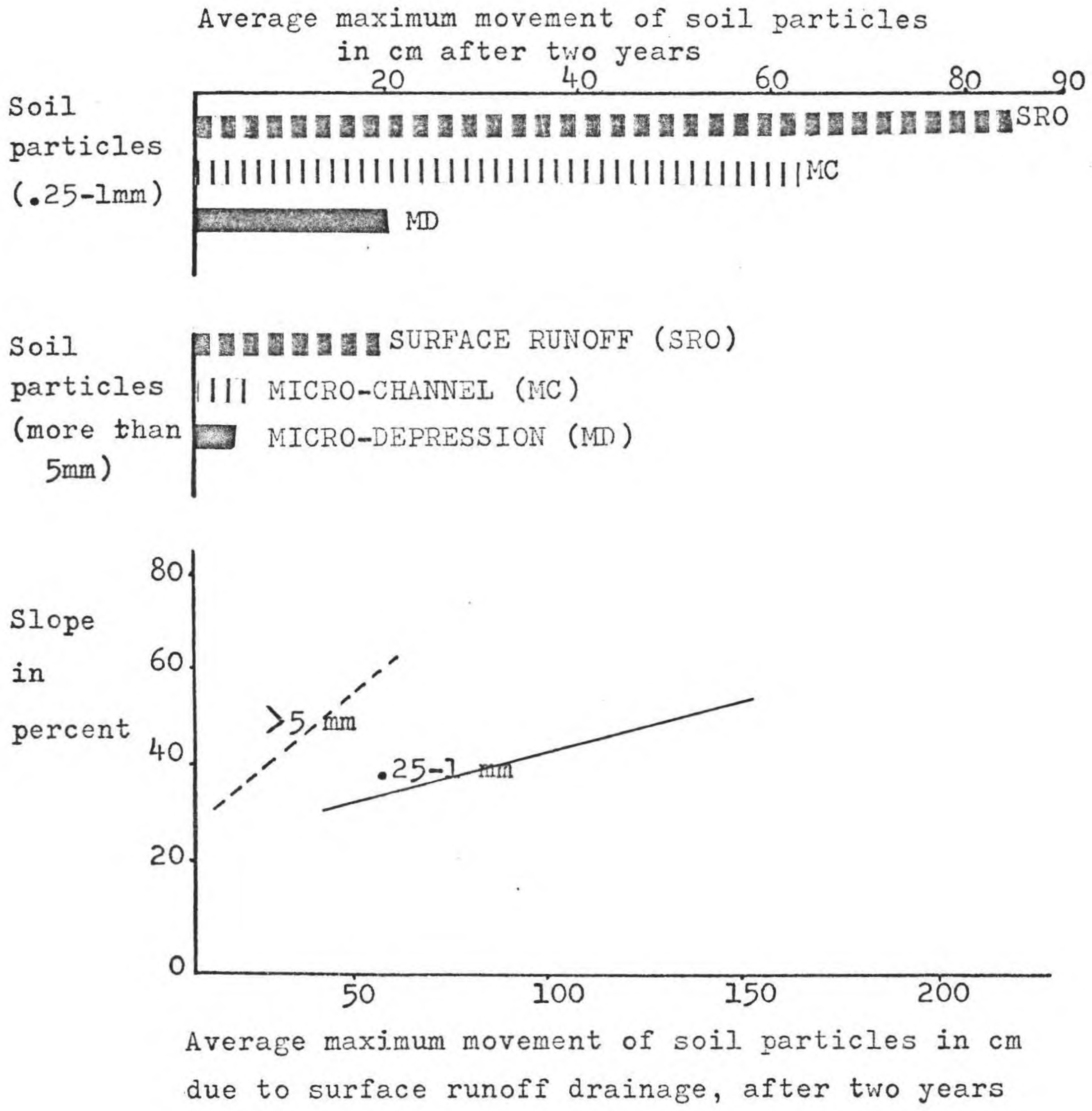


Fig. 5.5- Average maximum movement of soil particles on Hour Glass study area

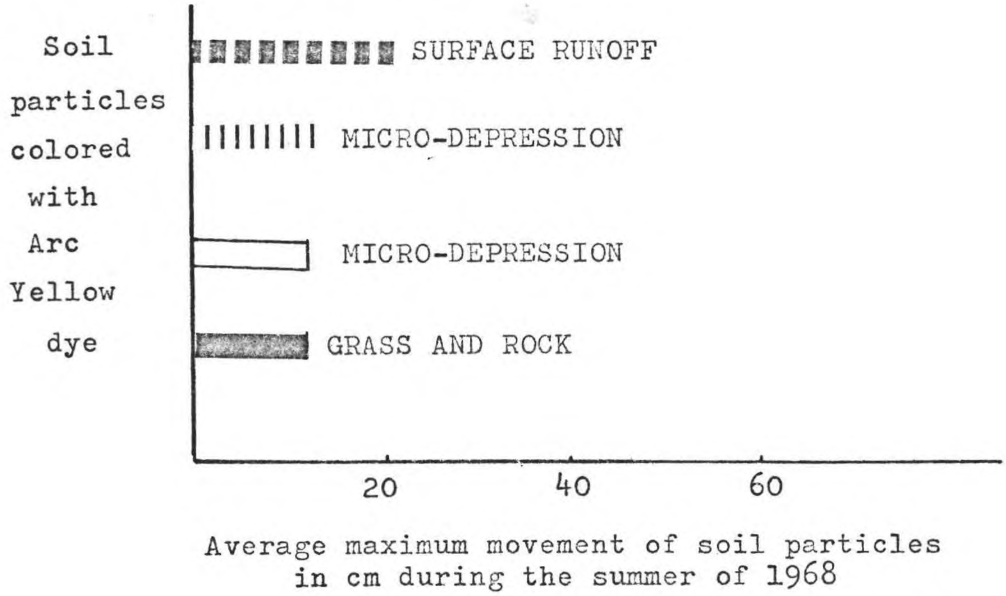


Fig. 5.6- Average maximum movement of soil particles on Crown Point study area

Chapter VI

RESULTS OF STATISTICAL ANALYSES

VARIABLES

The dependent and independent variable used in the statistical analyses of this study, with their designation, are listed in table 6.1.

RELATIONS BETWEEN VARIABLES

Simple correlation coefficient (R) for the relation of every or any two variables over one year period, over the winter and snow melt period, over the summer period, and for transect studies are shown in Appendix C.1, C.2, C.3, and C.4.

At 1% level of significance, the following variables were correlated significantly:

Snow, wind, rain and plant organic matter residues were related with each other.

Vegetation was related to microtopography.

Erosion pavement cover was related to surface runoff drainage, vegetation cover and litter cover.

Slope was related to grass cover, forb cover, local slope and bulk density.

Aspect was related to distribution of vegetation, forb cover, micro-depression and surface runoff drainage.

Bare area (exposed soil) was related to grass cover and microtopography.

Mats and mat-like vegetation was related to the position on slope and erosion pavement cover.

Total sediment yield (TSY) was related to plant organic matter residues, aspect, and distribution of vegetative cover (aggregated) and sizes of sediment analyses. Total colored Sediment Yield was related to the total sediment yield.
Plant Organic matter residues was related to the aspect, infiltration rate, snow, wind, rain, and total sediment yield.

MULTIPLE REGRESSION ANALYSES

A total of 45 multiple regression subproblems were run on the University Computer. These subproblems tested various combination of the independent factors against the dependent variables. The predictive equations derived are presented in tables 6.2, 6.3, 6.4 and 6.5

The final derivation of each prediction equation based on the following:

1. Highest multiple (R)
2. Lowest Standard Error of Estimate
3. Highest F-value
4. Highest Partial Correlation
5. Keeping the formula as short as possible.
6. Considering the independent variables, their measurement, and their practical application.

The sub-problems that were concerned with the various combinations after snowmelt (June), have 36 variables, while those of late summer (September), have 37 variables. In the transects study 16 variables (one dependent) were used on Crown Point study area, and 12 variables (2 dependents) were used on Hour-glass study area.

Table 6.1

Variables Designation

No.	Symbol	Independent Variables
1	NA	North aspect (presence or absence)
2	SA	South aspect (presence or absence)
3	TS	Total slope of the site (percent)
4	PS	Position on Slope (meters) - slope distance from the upper end of slope
5	VC	Vegetation Cover of the plot (percent)
6	LC	Litter Cover of the plot (percent)
7	RC	Rock Cover of the plot (percent)
8	EP	Erosion Pavement Cover of the plot (percent)
9	BA	Bare Area of the plot (percent)
10	GR	Grass Cover (percent of vegetation cover)
11	MA	Mats and Mat-like Cover (percent of vegetation cover)
12	FO	Forbs cover (percent of vegetation cover)
13	LS	Local Slope of the plot (percent)
14	VA	Vegetative cover Aggregated (presence or absence)
15	VD	Vegetative cover Dispersed (presence or absence)
16	VA & D	Vegetative cover Aggregated and Dispersed (presence or absence)
17	IR	Infiltration Rate (CM/ $\frac{1}{2}$ hour)
18	BD	Soil Bulk Density (gm/cm^3)
19	MD	Micro-depression drainage (presence or absence)
20	SRO	Surface Run-off drainage (presence or absence)

Table 6.1 (Continued)

No.	Symbol	Independent Variables
21	MC	Micro-channel drainage (presence or absence)
22	SR	Summer rain (in mm.)
23	GW	Ground Wind velocity (meter/minute) near the plot
24	HW	Wind Velocity at 1.5 meter level (meters/minute) above the plot
25	SN	Snow deposition (presence or absence) from aerial photos
26	VS	Frequency of vegetation species per micro-plot
		Dependent Variables
1	POMR	Plants Organic Matter Residues (gms) per microplot
2	>5MM	Soil Particles more than 5 mm. in size (gms) per microplot
3	2- 5MM	Soil Particles between 2-5 mm. in size (gms) per microplot
4	1- 2MM	Soil Particles between 1-2 mm. in size (gms) per microplot
5	<.25MM	Soil Particles less than .25 mm. in size (gms) per micorplot
6	>5 MMC	Colored soil particles 5 mm. in size (gms) per microplot
7	2-5 MMC	Colored soil particles 2-5 mm. in size (gms) per microplot
8	1-2 MMC	Colored soil particles 1-2 mm. in size (gms) per microplot
9	<.25 MMC	Colored soil particles .25 mm. in size (gms) per microplot
10	SG	Colored soil particles with Signal Green dye. (gms) per microplot
11	HB	Colored soil particles with Horizon Blue dye. (gms) per microplot
12	SY	Colored soil particles with Saturn Yellow dye. (gms) per microplot
13	TCSY	Total Colored Soil Particles (gms) per microplot
14	TSY	Total Sediment Yield (gms) per microplot

Table 6.1 (Continued)

No.	Symbol	Dependent Variables in Transects Studies
15	AYCP	Movement of soil particles, colored with Arc Yellow dye, on Crown Point (cms)
16	AYHG	Movement of Colored soil Particles with Arc Yellow dye. Particles of .25-1 mm size on Hour-Glass study area (cms)
17	HBHG	Movement of Colored soil Particles with Horizon Blue dye. Particles of more than 5 mm in size on Hour-Glass study area (cms)

Table 6.2

Selected Regression Equations for Crown-Point Micro-runoff Collectors after the snow melt period

Dependent Variable		R	R^2	Standard Error of Est.
POMR	= -1.189+.701NA-.005PS+.0199LS+.028IR-.075BD+.81OSN	.95	.90	.431
TSY	= -22.478+.904LC+.229RC+.160IR+4.382MC+8.760SN	.79	.63	8.769
>5MM	= -15.452+.009PS+.498LC+.156RC+.120IR+3.379SN	.67	.45	4.950
2-5MM	= 5.107+.407LC+.088RC+.035EP+1.956MC+2.713SN	.78	.61	3.332
1-2MM	= 2.974-.019VC-.026EP+.318VA&D-.141BC+.949SN	.89	.79	.751
<.25MM	= -.342+.407SA+.009BA+.007MA+.008LS-.006IR+.176MC+.278SN	.86	.73	.288
TCSY	= -.473+.005PS+.076LC-.019EP-.089FO+.377SN	.69	.48	.828
>5MMC	= .526-.019SL+.006PS-.018EP-.017LS-.278MD	.71	.50	.456
2-5MMC	= -.733+.375NA+.048LC-.043FO+.007IR+.161SN	.65	.42	.431
1-2MMC	= .313+.243NA+.113SA+.003LC-.001EP-.004FO-.003LS+.003IR+.016SN	.72	.52	.068
<.25MMC	= -.034+.046NA+.013SA-.001SL+.001BA+.0002MA-.0006FO+.005VD+.004IR-.003SN	.81	.66	.007
SG	= -.615+.005PS+.075LC-.015EP0.076FO+.238MC+.308SN	.68	.46	.740
HB	= -.012+.015NA+.00003PS+.0009LC+.003BA-.001FO+.005VA+.006MC	.66	.43	.009
SY	= -.0010.00006SL+.0001LC+.00002BA-.0001FO-.00002LS-.0005VD+.0003SN	.73	.53	.0008

Table 6.3

Selected Regression Equations for Crown-Point Micro-runoff Collectors after summer observation period

Dependent Variable		R	R^2	Standard Error of Est.
POMR	= .304-.149NA+.007SL-.007LC+.008RC+ .002MA+.013FO0.014LS0.115MD	.71	.50	.138
TSY	= -16.848-.338SL+.043PS+.421RC+.208BA+ .265GR+.291LS-5.622VA-.057SR+.074GW	.88	.77	3.750
>5MM	= 21.297-.351SL+.041PS+.093RC-.048MA- .251FO+.374LS-11.564VD0.125IR-.835BD+ 10.421SRO	.88	.77	1.935
2-5MM	= 5.436-.241SL+.022PS-.659VC+.039RC- .052EP+.692GR+.583MA+.645FO-.235BD- 2.557MD+.065SR+.032GW	.91	.82	1.467
1-2MM	= .111+.005SL+.005PS+.043LC+.012GR+.029LS +.680MC-.005GW	.81	.65	.517
<.25MM	= -.909-.037NA+.004LC-.002BA+.006FO+ .282VA+.260VD-.045MD+.251MC+.008SR- .001GW	.90	.81	.048
TCSY	= -2.692-.087SL+.007PS+.057RC+.022GR+ .030LS+.409VD-.397MD+.011GW	.79	.63	.777
>5MMC	= -1.8410.041SL+.003PS+.036RC+.012BA+ .014GR-.600VA-.320MC+.008GW	.83	.69	.316
2-5MMC	= -2.160-.029SL+.002PS+.043RC+.015GR+ .001FO-.591VA+.003IR+.018BD-.294MC+ .008GW	.79	.62	.398
1-2MMC	= -.063-.007SL+.001PS+.005RC+.004GR+ .006LS-.063MD	.71	.50	.089
<.25MMC	= -.004+.00001PS+.0002LC+.001VA-.005VA&D -.001MD+.004MC+.0002SR	.73	.54	.001
SG	= -.859-.010VC+.023RC-.074FO+.0003SR+ .008GW	.70	.49	.651
HB	= .043-.0005SL+.0004VC+.0008RC+.0005EP+ .0001BA-.013VA-.009MC+.001GW	.79	.63	.007
SY	= -.004+.0006NA+.00002RC-.0001FO+.000BD +.00002GW	.63	.40	.001

Table 6.4

Selected Regression Equations for Crown-Point Micro-runoff Collectors after one year period

Dependent Variable		R	R^2	Statement Error of Est.
POMR	= -.112-.001PS+.235MC+.004SR+.709SN	.89	.79	.453
TSY	= -9.142-2.288SA+.287LC+.153LS+.075IR+ .033GW+7.693SN	.83	.69	6.221
>5MM	= .876-.0005PS-.006SR+.099SN	.81	.65	.338
2-5MM	= .123+.01OPS-.019EP+.077FO+1.168MC+ .004GW+.940SN	.66	.43	1.892
1-2MM	= -3.286+.095SL+.094LC+.017GR=.032LS- 2.241VA&D+.158BD+3.407MC+1.423SN	.84	.70	1.462
<.25MM	= -.240+.263NA+.337SA+.004LS+.082SN	.59	.35	.180
TCSY	= -.823+.004PS+.057LC+.021RC-.072FO+ .003GW+.374SN	.59	.35	.866
>5MMC	= -.631-.037SL+.005PS+.042LC+.021RC+ .011MA-.137MD+.059SN	.64	.62	.517
2-5MMC	= -3.938-.193SL+.023PS+.165LC+.103RC+ 2.962VA&D+.045IR-.009SN	.48	.23	5.714
1-2MMC	= -.334+.061NA+.002RC+.002BA+.002GR+ .029VD+.002IR-.035MD+.0003GW+.025SN	.57	.32	.090
<.25MMC	= -.018+.005NA-.00003PS+.00007MA- .0003FO+.004VD+.0002IR+.00002GW+ .004SN	.75	.56	.005
SG	= -.719+.002PS+.045LC+.011RC-.039FO+ .003GW+.311SN	.55	.30	.697
HB	= .003+.00001PS-.0003FO-.005VA+.00003GW +.003SN	.42	.18	.010
SY	= .0007+.0008NA+.00002SL+.00005LC-.0001FO- .0001MD-.00003SR+.00002GW	.52	.28	.001

Table 6.5

Selected Regression Equation for Transect Studies

Dependent Variable		R	R^2	Statement Error of Est.
AYCP	= 20.884-10.801NA+7.113PS+.604SRO+.067RC -.052BA-.397SR+.086HW	.74	.50	6.078
AYHG	= -30.212+.987SL+8.673SRO+.125RC+.375EP- -1.655VS	.70	.49	15.698
HBHG	= -18.952+.466SL+1.393SRO+.245LC	.48	.23	8.871

SUMMARY OF RESULTS

As indicated before, sediments studies were divided into the following categories:

1. Colored Sediments collected from the area defined by sprayed lines of fluorescent dye above the trough of the micro-runoff collector (Fig. 4.5). This area was a trapezoid with a maximum possible size of .490 m^2 and a possible minimum size of .285 m^2 and extended a total linear distance of 70^{cm} up-slope from the trough of the micro-runoff collector.
2. Sediments collected from the same area and distance in category one, or from a larger area or more distance. These sediments include the colored and noncolored soil particles of all sizes.
3. The organic matter residues collected from any distance or area above the trough of the microplot.
4. Sediments collected over the winter and snow-melt period, over the summer period and over one year period.
5. Sediments of different sizes; more than 5 mm, 2-5 mm, 1-2 mm, .5-1 mm, .25-.5 mm and less than .25 mm, moved at known distance as they were colored or at any distance as they were not colored.
6. Soil particles of two different sizes; .25-1 mm and more than 5 mm coated with fluorescent dye, moved down slope from the main transects.
7. Soil particles of all sizes colored with Arc yellow, moved down the slope from the main transects.

Accordingly, tables 6.6, 6.7, 6.8, and 6.9 give a better and brief picture of these seven categories in which the amounts of sediment moved are functions of the particle size, distance and area with regard to the most important independent variables in each case.

However, statistical analyses of the collected sediment yield data, in Crown Point study area, indicated that snow (presence and accumulation) was the most important variable, and the final multiple R^2 (due to all independent variables) indicated that a large part of the relation, between the dependent and independent variables, was explained.

Table 6.6

Summary of Results for the Micro-runoff Collectors over the winter and snow melt period

Depend. Variab.	Avg. wt. of Sed. per micro-plot gms.	Max. Dist. moved cms.	Area covered sq. meter	Most Important Independent Variables 1	2	3	4	5
TSY	16.494			SN	LC	MC	IR	RC
>5MM	5.433			SN	IR	LC	RC	PS
2-5MM	5.780			SN	LC	MC	RC	EP
1-2MM	1.781			SN	BD	EP	VC	VA&D
<.25MM	.458			SN	IR	SA	MA	LS
TCSY	.825	4.0-70.0	.300-.500	SN	LC	PS	FO	EP
>5MMC	.319	6.0-14.0	.007-.016	PS	EP	LS	MD	SL
2-5MMC	.424	6.5-23.5	.008-.017	SN	LC	IR	FO	NA
1-2MMC	.060	22.5-36.0	.027-.043	SA	FO	LC	IR	SN
<.25MMC	.006	4.0-70.0	.300-.500	SN	FO	MA	SA	SL
SG	.649	4.0-6.5	.005-.008	LC	SN	PS	FO	EP
HB	.008	33.5-36.0	.040-.043	NA	LC	FO	PS	MC
SY	.001	67.5-70.0	.081-.085	PS	LC	SN	FO	SL
POMR	1.153			SN	PS	BD	IR	NA

Table 6.7

Summary of Results for the Micro-runoff Collectors
over the summer period

Depend. Variab.	Avg. wt. of Sed. per micro-plot gms.	Max. Dist. moved cms.	Area covered sq. meter	Most Important Independent Variables 1	2	3	4	5
TSY	7.142			SR	RC	VA	GR	PS
>5MM	3.247			LS	PS	RC	FO	IR
2-5MM	2.131			SR	FO	MD	MA	RC
1-2MM	.762			SL	MC	PS	LC	GW
<.25MM	.080			SR	VA	MC	VA	MD
TCSY	.610	6.5-70.0	.30-.50	PS	RC	SL	LS	GW
>5MMC	.219	6.5-14.0	.008-.017	PS	RC	SL	GW	VA
2-5MMC	.264	14.0-23.5	.017-.028	RC	FO	GW	VA	BD
1-2MMC	.084	23.5-36.0	.028-.043	RC	PS	GR	MD	SL
<.25MMC	.001	51.5-70.0	.300-.500	SR	LC	VA&D	MC	MD
SG	.444	4.0-6.5	.005-.008	VC	FO	RC	GW	VA
HB	.007	33.5-36.0	.040-.043	EP	BA	RC	VD	SL
SY	.001	67.5-70.0	.081-.085	BD	FO	GW	NA	RC
POMR	.305			RC	LS	SL	MD	NA

Table 6.8

Summary of Results for the Micro-runoff Collectors over one year period

Depend. Variab.	Avg. wt. of Sed. per micro-plot gms.	Max. Dist. moved cms.	Area covered sq. meter	Most Important Independent Variables 1	2	3	4	5
TSY	23.640			SN	GW	LS	LC	RC
> 5MM	8.680			SR	SN	PS	GW	SA
2-5MM	7.811			SN	PS	MC	FO	GW
1-2MM	2.542			SN	SL	MC	VA&D	LC
<.25MM	.540			SN	SA	LS	NA	MA
TCSY	1.440	6.5-70.0	.300-.500	PS	SN	FO	LC	GW
>5MMC	.540	6.5-14.0	.008-.017	PS	RC	SL	LC	MA
2-5MMC	.688	14.0-23.5	.017-.028	IR	VA&D	GW	PS	SL
1-2MMC	.140	23.0-36.0	.028-.043	MD	IR	NA	GR	GW
<.25MMC	.007	51.5-70.0	.300-.500	SN	GW	FO	MA	VD
SG	1.100	4.0-6.5	.005-.008	PS	SN	GW	LC	FO
HB	.014	33.5-36.0	.040-.043	VA	SN	GW	PS	FO
SY	.002	67.5-70.0	.081-.085	PS	MD	LC	FO	IR
POMR	1.460	-	-	SN	SR	PS	MC	BD

Table 6.9

Summary of Results in Transects Investigation

Dependent Variable	No. of Soil Particle	Particles Size	Average Movement in cm	Most Important Indep. Variable 1	2	3	4	5
AYCP	134	different	11-23	AS	PS	HW	BA	RA
AYHG	112	.25-1MM	21-87	SL	VS	SRO	EP	RC
HBHG	65	5MM	3-21	SL	LC	SRO	VS	BA

Chapter VII

DISCUSSION AND CONCLUSIONS

Alpine surface soil erosion have been observed by Cumberland (1944), Richmond (1949), Retzer (1956), Johnson and Cline (1965), Leaf (1966) and others. Johnson (1962), after observing the erosion process above timerline, concluded that there is an amazing lack of knowledge of the erosion characteristics of alpine areas. Very little is known about soil erosion and land use in alpine areas. Past experience on other sites is the basis for most management practices. Many questions must be answered in relation to alpine surface soil erosion, the controlling factors, and their interrelations. This study was designed to answer some of the following questions: what are normal rates of erosion from alpine areas, what factors control the rate of soil particle movement, and what effect does grazing by sheep have on soil particle movement?

ALPINE EROSION

Alpine erosion in the study area was a natural and continuous process whereby freezing and thawing, snow, wind, water, and gravity removed soil particles and rock fragments from one part of the soil surface and deposited them in another. This process of normal, or geological erosion, was slow and was the result of climatic forces operating on the land surface under natural ground cover, such as vegetation, litter, rocks, and erosion pavement. But when the ground cover was disturbed, and the soils were bared to the direct attack of climatic forces the erosion here was of an entirely different order, and the soil was subject to accelerated erosion. The types of soil erosion recognized in the study area were wind erosion, sheet or water erosion, and creep erosion.

Wind erosion takes place by the removal and transport of soil loosened by the abrasive action of wind or the removal of soil loosened by freezing and thawing, and subsequent drying. Wind was one of the most important factors in alpine soil erosion. It was related directly or indirectly to the whole problem of soil erosion in alpine areas. Its direct action was concerned mainly with the removal of soil particles from the sites, and with causing the abrasive action of soil particles and rock fragments. Its indirect action was concerned mostly with its effect on snow drifting and deposition, its effect on vegetation and ground cover, and its effect on the intensity and size of rain drops.

In the study area wind blows at varying intensities with maximal velocities (over 40 kph) occurring primarily during winter. Any soil particle that could not resist this high intensity may be picked up and moved from the soil surface.

According to the results obtained in this study, less than 8 percent of the total collected sediments in the micro-plots were 1 mm or less and about 2 percent of the surface soil to a depth of 1.5 cm was of the 1 mm size class while about 7 percent of the surface soils were of less than 2 mm size class. This suggests that the wind may be responsible for the absence of the fine soil particles in the collected sediment.

The high intensities of wind during the winter season were more than enough to sweep snow, organic residues and soil particles less than 2 mm in diameter from exposed windy sites of the study area.

Snow deposition, due to wind, was also an important factor in alpine surface erosion. It appears to accelerate and enforce creep erosion (slow movement of surface soil particle down-slope).

Organic matter residues were strongly related to snow accumulation. The high correlation between snow deposition, wind, organic matter residues, and soil particles less than 2 mm in size in this study also suggests the importance of wind action in the removal of surface soil particles and the presence of a prominent erosion pavement.

Variation in vegetative conditions (vegetative cover, vigor, height, density, distribution, and phenology) between the windy and protected sites, showed the strong action of wind in the alpine areas on Crown Point. The transects on locations 3, 4, 7 and 8 had different vegetative characteristics, than the protected transects, such as 1, 2, 5 and 6. This variation is shown below:

	Exposed sites	Protected sites
Vegetative cover	56-58%	61-64%
Mats and Mat-like vegetation	24%	19%
Grass and Grass-likes vegetation	13%	26%
Erosion pavement	10-12%	5-7%
	Vegetation mostly dispersed and aggregated	Vegetation mostly aggregated

Vegetation also effected soil erosion and development in the study area. Vegetation was related to alpine soil erosion by intercepting precipitation, absorbing the energy of falling raindrops, decreasing the velocity of runoff and action of flowing water, holding the soil with its root mass, its aggregation and porosity, reducing the wind speed at the surface, etc.

On the Crown Point study area, the dispersion of vegetative cover was observed to be inversely proportional to surface soil movement. The average yield of soil particles, for example, was about 5 grams per micro-plot on the south aspects while it was 30 gm on north aspect, after the snow melt period (Fig. 7.1 and 7.2).

The size, speed and intensity of falling rain drops were affected by wind speed and direction. The energy of falling rain drops during the summer period was important in soil movement from one spot to another. As indicated by the results, the soil particles were shifted more toward the east and south direction rather than the other directions, because winds blow mostly from the west and northwest, the angle of impact of falling rain drops tended to move soil particles more toward the east and south.

During the summer time, the energy of falling raindrops and the energy of blowing wind, seemed to be the only two forces affecting the slow movement of large soil particles into the micro-runoff collectors. Grazing also may have distributed some sediment in the micro-runoff collectors as a result of trailing, trampling and disturbing the surface soil.

Figure 7.1. Sediment yield was about 5 grams per micro-runoff collector, from this site.

Figure 7.2. Sediment yield was about 30 grams per micro-runoff collector, from this site.

Sheet erosion is the removal of a thin covering of soil more or less uniformly from the surface by running water, so that the surface suffers a gradual reduction.

Severe water erosion did not occur on the alpine turf soil of the study area, as was the case in the alpine bog soils (Fig. 7.3) on the lower parts of the watershed. This can be explained by the fact that the alpine turf soils are located on the upper position of the slope, have high infiltration rates, and are poorly developed. The area is subject to direct wind action, and is clear of snow most of the year. Thus, water erosion on the study area is a microscale phenomenon. Areas classified as surface-runoff (SRO) areas were the most important with respect to alpine surface soil erosion and more particularly sheet erosion.

Creep erosion is the slow movement of surface soil particles down a slope. It is associated with the thawing and freezing cycles of the high altitudes of the study area, snow movement down a slope, wind, energy of falling raindrops, and the effect of gravity.

About ninety percent of the collected sediments in this study consisted of soil particles larger than 1 mm in diameter, and were moved within an area of one half square meter, and from a maximum distance of .7 meters up slope. Creep erosion seems to be the most logical explanation for the movement of these particles. This erosion is probably the major form of soil particle movement in the alpine area. Creep erosion was also related to the slow movement of snow on the soil surface, as snow accumulated and became more compacted, it pressed the soil particles and moved them short distances.

Litter cover, an important variable in the final prediction equations of soil movement during the winter time, was observed to be correlated with snow

Figure 7.3. Soil movement on alpine bog soil of Crown Point study area is more severe than alpine turf soil.

deposition. It has been observed that during and after snow melt, the organic matter residues mixed with soil particles and accumulated in the form of a litter cover. The deposition and composition of litter by the snow pack formed a protective cover on the soil which helped to stabilize the soil surface.

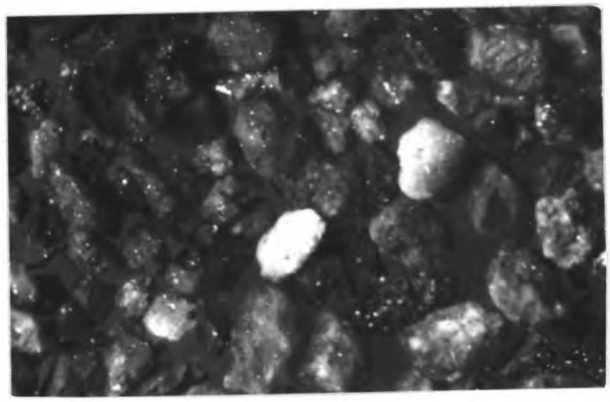
FLUORESCENT PIGMENTS IN TRACING SOIL MOVEMENT

Commercially available ultraviolet fluorescent pigments can be used in short or long lived surface coating or spraying to index soil surface movement quantitavely and qualitatively under natural environments of the alpine areas.

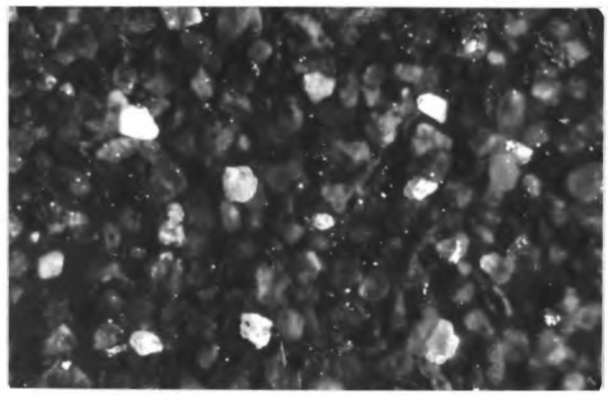
Yasso (1965) gave a complete list of manufacturers and product designations with the recommended mix, drying time, thickness of a single coat, abrasion loss, relative clumping tendency and day light visibility. The Day-Glo fluorescent pigments used in this study were included. Yasso's work was only on coarse sediments in rivers and beaches. In this study the application of fluorescent pigments was on coarse and fine soil grains. Quantitave analysis was possible and satisfactory (Fig. 7.4a, b, c). Fluorescent pigments were insoluble in water, the color did not fade much under natural conditions, and the technique of application was simple, inexpensive, and not hazardous. Spraying fluorescent dyes directly on the surface of the soil has the advantages of not disturbing the soil, as in the case in coating the soil samples completely. Since it is impossible to coat the total surface of the soil particles by spraying in situ, some of the particles could not be traced properly after transportation.

Under field conditions the finest particles treated with fluorescent dyes were very difficult to trace, but in the laboratory study there was no difficulty

a. Soil particles 2-5mm (X7)



b. Soil particles 1-2mm (X7)



c. Soil particles less than .25 mm (X7)

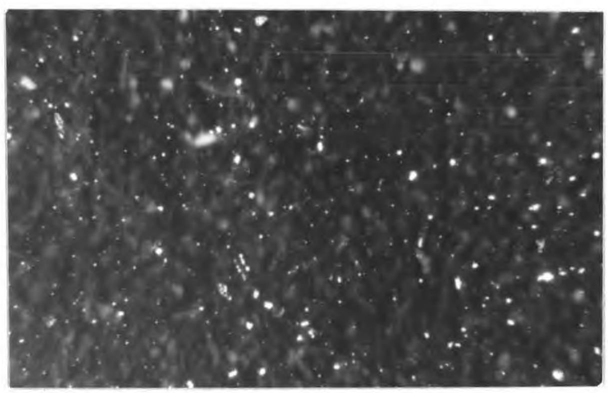


Figure 7.4. Tracing soil movement under ultraviolet light.

in quantitave or qualitative analysis. Fading of color was observed after one year of application. Visibility was poor during the daytime for large soil particles and very poor for fine soil particles, but excellent during the night under ultraviolet light. On the Hour-Glass study area, two years after application, the coated particles showed color fading during the day-time, but during the night, under ultraviolet light, the visibility was excellent.

The analyses of fluorescent pigments applied to the finest soil particles (less than .5 mm) was of importance. Particles with similar colors were very difficult to distinguish, as was the case with Arc Yellow, Saturn Yellow, Blaze Orange and Signal Green. Therefore, it is recommended that one color to be used, or colors with greatly different wave-lengths, in the study of clay or silt.

GRAZING EFFECT

On the alpine grassland ranges of the Crown Point study area, the volume of forage production, the number of sheep that can be grazed, and the adequacy of the dependent watershed and recreation services are largely determined by the existing soil and vegetative cover conditions. In order that a satisfactory condition of the resources may be maintained and further developed, it is important that range-condition trends, particularly if they indicate deterioration, be recognized promptly and correctly interpreted.

During the summers of 1966, 1967, 1968 about 4500 sheep grazed in the Crown Point study area.

Figure 7.5. Trailing of sheep resulted in eroded trenches.

Observations were taken in late summer, 1968, to determine the effect of grazing on the area. Changes due to grazing such as increase in mats and mat-likes vegetation (Trifolium, Antennaria, etc.) were observed in the vegetation of the grazing sites. Some of this variation was undoubtly related to past grazing use by sheep. Individual site characteristics may also have been important causes of this variation. Investigation of the vegetative ground cover on the Crown Point study area, before and after grazing showed an increase in exposed soil of about 2.5 percent, a decrease in erosion pavement cover of about 1.25 percent, a decrease in vegetative cover of about .75-1.75 percent, an increase in mats and mat-like vegetative cover of about 2.5 percent, an increase in litter cover of about .50 percent and a decrease of grasses and grass-like cover of about 2.3 percent. Mats and mat-like plants were negatively correlated with grasses and grass-like plants. Where grasses and grass-likes and forbs were abundant, as on the south aspect, the mats and mat-like plants were relatively less abundant.

In the transect investigations, it was evident that sheep disturbed the soil on the Crown Point study area. Studies of surface characteristics showed that the sheep disturbed the bare areas very severely due to trailing, compacting, trumpling and stirring the soil within a very short period of two months (Fig. 7.5). The movement of soil particles on the Hour Glass study area where no grazing was permitted was mostly related to surface runoff, while the movement of soil particles on the Crown Point study area, where grazing was permitted, was not related to any specific microtopography effect, but moved in many directions, up slope and down slope.

CONCLUSIONS

The conclusions of this study may be as follows:

1. The normal erosion rates of undisturbed alpine slopes are very slow. The degree of slope was more important than the length of the slope.
2. Alpine creep erosion due to freezing and thawing cycles, snow pack movement, wind and raindrops action is the most important erosion mechanism.
3. Wind erosion is a natural and continous process in the alpine. Wind picks and moves soil particles, less than 2 mm in size from windy to protected sites.
4. Soil erosion by water on the alpine turf soil does not go beyond the microscale. Surface runoff was the most important type of microtopography affecting the soil movement.
5. Fluorescent dyes were demonstrated to be effective tool in tracing soil movement. Application of dyes is easy, inexpensive, and not hazardous.
6. Soil particle movement in alpine sites were related to presence of snow, frost, effect of raindrops, wind, grazing, slope, vegetation and microtopography. These factors were very important in determining the following average rates of alpine surface siol movement:

   370 kg of sediment moved a maximum distance of 4-6.5 cm/hec./yr.

   85 kg of sediment moved a maximum distance of 11.5-14 cm/hec./yr.

   25 kg of sediment moved a maximum distance of 23.5-70 cm/hec./yr.

Suggestions for Future Studies

This study has given rise to many specific questions relating to alpine surface erosion. Many of the following are in apparent need of further study:

1. The presence of snow appeared to be the most important factor in this study. It is recommended that an actual snow measurement in the field be made in the future.
2. The interrelation of snow, organic matter residues, soil particles and wind in the alpine areas, suggests that snow samples be collected, in early June, examined and studied, in order to determine the quantity of organic matter residues or soil particles present within the snow pack.
3. Wind is a very important variable in alpine soil erosion. It is recommended that studies be made to investigate the effect of wind only upon soil erosion, as it is independent from water or frost action in soil erosion.
4. West and east aspects should be investigated with respect to alpine surface soil movement.
5. Studying the effect of grazing on soil disturbance and erosion by means of exclosures will be of more significance in land use and management.
6. The presence of an erosion pavement cover in the alpine with a very high percentage of larger particles (7% less than 2 mm in size) is an indication of a correlation between the erosive force, such as wind, and the size of gravels. An Erosion Index might be obtained in this respect.

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APPENDIX

Appendix A

DAY-GLO Daylight Fluorescent Pigments*

Colors and Series used in this study		Specifications Luminance factor (min)	Purity (min)	Dominant wave-length (millimicrons)
Signal Green	A-18+	55%	65%	540-547
Blaze Orange	D-15	64%	90%	598-603
Arc Yellow	D-16	85%	88%	588-591
Horizon Blue	A-19+	17%	65%	475-480
Rocket Red	D-13	35%	77%	620-627
Saturn Yellow	D-17	95%	80%	566-568

* According to the technical booklet No. 1170, Day-glo color division, Switzer Brothers, Inc., Cleveland, Ohio.

+ Are not available in D-series. D-series are more suitable for out of door works.

Physical Proporties of A and D series Pigments

Specific gravity	1.36
Average particle size	3.5-4.0 microns
Softening point	115 C-120 C
Decomposition point	Approx. 195 C
Oil obsorption	49 lbs. oil/100 lbs

General solubility: Insoluble in water, aliphatic and most aromatic hydrocarbons.
Soluble in acetone and many other Ketones

A-series are stable for 2-3 months of continuous direct sunlight exposure.

D-series are stable up to a full year of use out of doors and more resistance to sunlight

APPENDIX B.1

Sediment analyses in grams collected over the snowmelt or winter period (June,1968)

Plot No.	TCSY	TSY	PLAN OM	ANIM OM	>5mm	2-5 mm	1-2 mm	.5-1 mm	.25-.5mm	<.25 mm	>5mmc	2-5 mmc	1-2 mmc	.5-1 mmc
	0.6689	16.05	3.15	1.50	01.25	3.75	3.05	1.25	0.35	1.75	0.0000	0.4870	0.1328	0.0106
2	0.5348	27.85	2.20	1.00	03.75	11.00	5.50	1.75	0.80	1.85	0.0000	0.4400	0.0066	0.0560
3	3.6958	42.00	2.35	1.25	13.50	17.25	5.15	1.35	0.40	0.75	0.8100	2.3978	0.4120	0.0270
4	0.3430	28.90	4.50	1.65	08.15	09.75	3.10	1.10	0.15	0.50	0.0000	0.2925	0.0449	0.0052
5	0.9168	20.95	3.15	1.05	02.55	06.70	4.25	1.35	0.25	1.65	0.1530	0.6030	0.0892	0.0364
6	0.4006	30.15	3.05	1.15	09.85	09.45	3.50	1.55	0.45	1.15	0.2955	0.0472	0.0175	0.0108
7	0.5775	41.10	3.45	1.85	15.55	15.95	1.95	0.85	0.45	1.05	0.1555	0.3510	0.0237	0.0170
8	1.6164	42.35	2.50	1.25	16.90	15.60	3.35	1.35	0.70	0.70	0.3380	1.1700	0.0770	0.0243
9	3.5043	28.15	1.35	1.05	12.50	07.75	3.85	0.65	0.45	0.55	1.8750	1.3950	0.2150	0.0098
10	1.7556	16.10	0.95	0.45	07.85	04.35	1.65	0.35	0.25	0.25	1.1775	0.4350	0.1320	0.0077
11	0.6678	18.00	0.75	0.55	06.75	07.05	1.75	0.75	0.25	0.15	0.3375	0.2820	0.0327	0.0112
12	0.4885	16.20	0.95	0.85	05.15	07.15	1.25	0.30	0.25	0.30	0.0000	0.4540	0.0169	0.0115
13	1.9073	12.25	0.75	0.75	01.25	06.05	2.10	0.85	0.15	0.35	0.4375	1.3310	0.1260	0.0013
14	0.4383	22.15	1.25	1.05	06.25	09.35	2.65	0.85	0.30	0.45	0.1875	0.0935	0.1404	0.0110
15	0.0130	05.05	1.05	1.45	00.00	01.25	1.05	0.10	0.05	0.10	0.0000	0.0075	0.0032	0.0007
16	0.1341	10.75	1.25	1.15	02.70	03.50	1.55	0.25	0.15	0.20	0.0000	0.1050	0.0077	0.0137
17	0.4916	04.05	0.15	1.20	00.75	01.20	0.55	0.10	0.05	0.05	0.3750	0.1080	0.0082	0.0001
18	0.1825	01.95	0.00	0.90	00.55	00.20	0.10	0.10	0.05	0.05	0.1815	0.0000	0.0000	0.0010
19	0.8285	09.90	0.45	1.15	02.35	03.85	1.60	0.25	0.10	0.15	0.3290	0.3850	0.1120	0.0025
20	0.1229	02.05	0.00	0.25	00.00	01.55	0.10	0.10	0.05	0.00	0.0000	0.0930	0.0270	0.0017
21	0.5995	04.05	0.25	0.00	02.35	01.45	0.00	0.00	0.00	0.00	0.1645	0.4350	0.0000	0.0000
22	0.1592	04.05	0.25	1.75	00.00	01.55	0.25	0.15	0.10	0.00	0.0000	0.1550	0.0025	0.0010
23	0.0475	07.95	0.35	1.85	01.05	01.55	1.05	0.15	0.90	1.05	0.0000	0.0232	0.0052	0.0009
24	0.2573	06.00	0.20	0.95	00.00	03.15	0.85	0.25	0.30	0.30	0.0000	0.2205	0.0097	0.0097
25	0.5385	05.95	0.10	1.05	01.75	02.25	0.55	0.25	0.00	0.00	0.0000	0.4375	0.0900	0.0110
26	0.1592	06.85	0.50	0.95	02.65	02.05	0.25	0.20	0.25	0.00	0.0000	0.1435	0.0075	0.0040
27	0.3826	09.80	0.45	1.15	04.35	02.45	0.55	0.40	0.30	0.15	0.1340	0.2200	0.0203	0.0046
28	0.4612	08.10	0.15	0.15	05.25	01.65	0.15	0.25	0.30	0.20	0.3670	0.0825	0.0105	0.0012
29	0.0697	06.15	0.15	0.50	03.15	02.10	0.15	0.05	0.00	0.05	0.0000	0.0630	0.0060	0.0005
30	0.2868	13.30	0.10	0.45	04.95	05.55	1.35	0.85	0.00	0.05	0.1485	0.1110	0.0229	0.0042
31	0.2518	11.05	1.15	0.35	03.40	03.45	1.65	0.65	0.15	0.25	0.0000	0.2070	0.0204	0.0136
32	3.9052	48.60	0.00	1.50	27.35	15.05	2.15	1.10	0.85	0.60	2.7350	0.9933	0.1182	0.0165

APPENDIX B.1 (continued)

Sediment analyses in grams collected over the snowmelt or winter period (June, 1968)

Plot No.	.25-.5mmc	<.25 mmc	SG	BO	AY	HB	RR	SY
1	0.0061	0.0324	0.3601	0.3011	0.0050	0.0014	0.0012	0.0001
2	0.0300	0.0022	0.2010	0.3010	0.0210	0.0101	0.0012	0.0005
3	0.0040	0.0450	2.9000	0.6110	0.1600	0.0218	0.0020	0.0010
4	0.0003	0.0001	0.1100	0.2050	0.0150	0.0120	0.0009	0.0001
5	0.0145	0.0207	0.8005	0.1000	0.0100	0.0039	0.0021	0.0003
6	0.0103	0.0193	0.3000	0.0900	0.0050	0.0050	0.0004	0.0002
7	0.0082	0.0185	0.4813	0.0800	0.0090	0.0040	0.0030	0.0002
8	0.0035	0.0036	1.3016	0.2131	0.0530	0.0330	0.0146	0.0011
9	0.0048	0.0047	2.9120	0.3800	0.1200	0.0539	0.0334	0.0050
10	0.0022	0.0012	1.5010	0.2300	0.0202	0.0030	0.0010	0.0004
11	0.0033	0.0011	0.5810	0.0422	0.0320	0.0101	0.0018	0.0007
12	0.0043	0.0018	0.1022	0.3622	0.0132	0.0090	0.0013	0.0006
13	0.0028	0.0087	1.7000	0.1101	0.0621	0.0301	0.0029	0.0021
14	0.0032	0.0027	0.3900	0.0245	0.0142	0.0080	0.0011	0.0005
15	0.0006	0.0010	0.0050	0.0062	0.0008	0.0008	0.0001	0.0001
16	0.0045	0.0032	0.0490	0.0775	0.0070	0.0004	0.0001	0.0001
17	0.0002	0.0001	0.4110	0.0534	0.0254	0.0012	0.0004	0.0002
18	0.0000	0.0000	0.1700	0.0110	0.0004	0.0007	0.0003	0.0001
19	0.0000	0.0000	0.6800	0.0920	0.0520	0.0023	0.0021	0.0001
20	0.0012	0.0000	0.0703	0.0500	0.0020	0.0003	0.0002	0.0001
21	0.0000	0.0000	0.5122	0.0730	0.0100	0.0034	0.0008	0.0001
22	0.0007	0.0000	0.1000	0.0410	0.0110	0.0070	0.0001	0.0001
23	0.0067	0.0115	0.0205	0.0230	0.0030	0.0008	0.0001	0.0001
24	0.0126	0.0048	0.1270	0.1230	0.0040	0.0031	0.0001	0.0001
25	0.0000	0.0000	0.2801	0.2441	0.0060	0.0060	0.0002	0.0001
26	0.0042	0.0000	0.0780	0.0700	0.0100	0.0009	0.0002	0.0001
27	0.0028	0.0009	0.3550	0.0200	0.0030	0.0032	0.0009	0.0005
28	0.0000	0.0000	0.4100	0.0118	0.0302	0.0090	0.0001	0.0001
29	0.0000	0.0002	0.0100	0.0300	0.0220	0.0005	0.0001	0.0001
30	0.0000	0.0002	0.2618	0.0199	0.0040	0.0009	0.0001	0.0001
31	0.0056	0.0052	0.1006	0.1350	0.0103	0.0050	0.0008	0.0001
32	0.0306	0.0116	3.5000	0.2500	0.1300	0.0131	0.0086	0.0035

APPENDIX B.2

Sediment analyses in grams collected over the summer period (September,1968)

Plot No.	TCSY	TSY	PLANT OM	ANIM OM	>5mm	2-5mm	1-2 mm	.5-1 mm	.25-.5mm	<.25 mm	>5mmc	2-5 mmc	1-2mmc
1	0.6915	03.05	0.20	0.05	01.75	00.75	0.10	0.10	0.05	0.05	0.0000	0.0615	0.0520
2	0.1700	01.50	0.35	0.15	01.00	00.00	0.00	0.00	0.00	0.00	0.1700	0.0000	0.0000
3	0.1102	03.70	0.20	0.10	01.00	01.30	0.55	0.45	0.05	0.05	0.0000	0.0280	0.0770
4	0.3635	11.80	0.10	0.10	03.65	03.75	2.65	1.25	0.15	0.15	0.0000	0.0300	0.3312
5	0.8146	08.90	0.50	0.25	06.00	01.75	0.20	0.10	0.10	0.00	0.3000	0.3850	0.1140
6	0.1190	01.70	0.10	0.05	01.00	00.45	0.05	0.05	0.00	0.00	0.0000	0.0540	0.0380
7	0.0907	04.60	0.10	0.05	01.25	02.05	0.60	0.40	0.10	0.05	0.0000	0.0020	0.0020
8	0.2980	05.30	0.25	0.20	02.25	02.15	0.20	0.10	0.10	0.05	0.0000	0.1265	0.1280
9	0.3232	09.20	0.50	0.20	03.75	02.50	1.00	0.75	0.25	0.25	0.0000	0.0000	0.2000
10	0.1320	06.30	0.75	0.25	02.50	01.15	1.00	0.50	0.10	0.05	0.0000	0.0000	0.0920
11	0.2700	11.80	0.25	0.10	05.50	03.50	2.00	0.25	0.10	0.10	0.1650	0.1050	0.0000
12	0.9456	04.45	0.20	0.15	02.55	00.75	0.60	0.10	0.05	0.05	0.4600	0.3150	0.1560
13	0.3794	09.40	0.10	0.05	02.75	03.00	2.10	1.25	0.10	0.05	0.0000	0.3600	0.0150
14	0.0045	05.35	0.45	0.40	01.30	01.25	1.50	0.25	0.10	0.10	0.0000	0.0000	0.0030
15	0.9375	05.95	0.30	0.20	03.05	01.25	0.75	0.25	0.10	0.05	0.3355	0.4250	0.1575
16	0.2747	16.10	0.40	0.20	13.30	01.20	0.75	0.20	0.05	0.00	0.0000	0.2532	0.0075
17	0.6450	07.30	0.30	0.15	03.05	02.45	0.25	0.20	0.05	0.05	0.0000	0.4410	0.1620
18	0.0000	00.45	0.45	0.00	00.00	00.00	0.00	0.00	0.00	0.00	0.0000	0.0000	0.0000
19	0.0000	00.35	0.35	0.00	00.00	00.00	0.00	0.00	0.00	0.00	0.0000	0.0000	0.0000
20	0.0000	00.45	0.45	0.00	00.00	00.00	0.00	0.00	0.00	0.00	0.0000	0.0000	0.0000
21	0.4510	03.90	0.30	0.20	02.25	00.60	0.40	0.05	0.05	0.05	0.2700	0.1440	0.0200
22	0.4125	02.15	0.55	0.15	01.15	00.25	0.05	0.00	0.00	0.00	0.2530	0.1225	0.0370
23	0.1945	01.40	0.15	0.05	00.75	00.35	0.10	0.00	0.00	0.00	0.1875	0.0000	0.0070
24	0.0245	03.25	0.10	0.00	02.25	00.75	0.10	0.05	0.00	0.00	0.0000	0.0225	0.0000
25	0.4469	08.15	0.15	0.15	03.15	02.55	1.15	0.75	0.20	0.05	0.1575	0.2800	0.0034
26	0.1101	04.75	0.10	0.05	03.05	00.95	0.35	0.10	0.10	0.05	0.0000	0.0760	0.0245
27	0.3265	06.55	0.30	0.10	03.00	01.55	0.55	0.25	0.50	0.30	0.0000	0.2950	0.0170
28	0.9545	12.55	0.55	0.20	03.95	04.85	1.15	0.85	0.60	0.40	0.1975	0.2910	0.3680
29	0.0984	05.10	0.45	0.15	01.65	01.90	0.55	0.20	0.10	0.10	0.0000	0.0760	0.0165
30	3.8539	29.15	0.35	0.05	13.85	11.25	1.90	1.55	0.05	0.15	1.6620	1.8000	0.2660
31	0.7807	08.45	0.05	0.05	03.65	02.35	1.35	0.55	0.20	0.25	0.5480	0.2115	0.0135
32	5.2945	25.50	0.40	0.30	09.55	11.60	2.45	0.90	0.15	0.15	2.2920	2.5520	0.3920

APPENDIX B.2
(continued)

Sediment analyses in grams collected over the summer period (September, 1968)

Plot No.	.5-1 mmc	.25-.5 mmc	< .25 mmc	SG	BO	AY	HB	RR	SY
1	0.0224	0.0015	0.0006	0.0310	0.3300	0.0300	0.0201	0.0012	0.0002
2	0.0000	0.0000	0.0000	0.1700	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0050	0.0001	0.0001	0.0500	0.0589	0.0010	0.0001	0.0001	0.0001
4	0.0020	0.0002	0.0001	0.2000	0.1500	0.0100	0.0020	0.0010	0.0005
5	0.0150	0.0060	0.0000	0.6975	0.1150	0.0025	0.0025	0.0015	0.0010
6	0.0270	0.0000	0.0000	0.0585	0.0405	0.0050	0.0080	0.0045	0.0025
7	0.0260	0.0006	0.0001	0.0500	0.0300	0.0050	0.0050	0.0005	0.0002
8	0.0410	0.0020	0.0005	0.2010	0.0400	0.0310	0.0250	0.0008	0.0002
9	0.0900	0.0260	0.0072	0.1600	0.1500	0.0066	0.0040	0.0023	0.0003
10	0.0400	0.0000	0.0000	0.0715	0.0510	0.0040	0.0034	0.0020	0.0001
11	0.0000	0.0000	0.0000	0.2000	0.0607	0.0044	0.0040	0.0007	0.0002
12	0.0110	0.0021	0.0015	0.8000	0.1000	0.0351	0.0056	0.0039	0.0010
13	0.0034	0.0005	0.0005	0.2000	0.1600	0.0105	0.0050	0.0036	0.0003
14	0.0015	0.0000	0.0000	0.0017	0.0010	0.0010	0.0003	0.0000	0.0000
15	0.0140	0.0030	0.0025	0.8160	0.0890	0.0190	0.0082	0.0045	0.0008
16	0.0120	0.0020	0.0000	0.1601	0.1009	0.0060	0.0050	0.0025	0.0002
17	0.0360	0.0040	0.0020	0.3140	0.2310	0.0100	0.0050	0.0045	0.0005
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	0.0060	0.0080	0.0030	0.3951	0.0500	0.0000	0.0013	0.0045	0.0001
22	0.0000	0.0000	0.0000	0.3505	0.0300	0.0202	0.0102	0.0015	0.0001
23	0.0000	0.0000	0.0000	0.1210	0.0303	0.0203	0.0213	0.0015	0.0001
24	0.0020	0.0000	0.0000	0.0100	0.0070	0.0043	0.0023	0.0008	0.0001
25	0.0045	0.0010	0.0005	0.4000	0.0400	0.0060	0.0009	0.0000	0.0000
26	0.0090	0.0004	0.0002	0.0650	0.0390	0.0033	0.0020	0.0007	0.0001
27	0.0050	0.0035	0.0060	0.2000	0.1100	0.0106	0.0030	0.0026	0.0003
28	0.0680	0.0240	0.0060	0.8802	0.0540	0.0104	0.0035	0.0054	0.0010
29	0.0040	0.0015	0.0004	0.0510	0.0384	0.0060	0.0020	0.0009	0.0001
30	0.1240	0.0007	0.0012	3.1000	0.6010	0.0804	0.0510	0.0185	0.0030
31	0.0050	0.0004	0.0023	0.6500	0.0750	0.0300	0.0170	0.0080	0.0007
32	0.0450	0.0090	0.0045	3.8050	1.0200	0.4203	0.0230	0.0205	0.0057

Appendix B.3

Soil Movement from Transects on Hour-Glass Study area

Transect No.	Stat. No.	Drainage*	Movement of particles (cms) AY*	HB*
1	1	SRO	150	13
	2	SRO	135	17
	3	SRO	114	23
	4	SRO	244	25
	5	SRO	208	30
	6	SRO	102	10
	7	SRO	102	63
	8	SRO	155	198
	9	SRO	96	25
	10	SRO	59	13
	11	SRO	130	25
	12	MD	59	13
	13	SRO	130	33
	14	MD	18	8
	15	SRO	59	109
	16	MD	81	5
	17	MD	51	13
2	18	SRO	71	15
	19	SRO	58	3
	20	SRO	89	8
	21	SRO	59	15
	22	SRO	114	13
	23	SRO	66	96
	24	SRO	107	15
	25	SRO	183	3
	26	SRO	96	5
	27	SRO	180	13
	28	SRO	107	30
	29	SRO	190	98
	30	SRO	228	15
	31	SRO	124	89
	32	SRO	104	48
	33	SRO	51	30
	34	SRO	66	0
	35	SRO	86	5
	36	SRO	140	0

Appendix B.3 (Continued)

Transect No.	Stat. No.	Drainage*	Movement of particles (cms) AY*	HB*
3	37	SRO	132	15
	38	SRO	84	0
	39	SRO	152	3
	40	MC	0	0
	41	MC	152	0
	42	MC	0	3
	43	MC	81	0
	44	MC	33	17
	45	MC	18	0
	46	SRO	46	0
	47	MD	15	23
	48	MD	23	0
	49	MD	5	0
	50	MD	20	3
	51	MD	76	3
	52	MC	30	0
	53	MC	71	0
	54	MC	76	15
	55	MC	10	0
4	56	SRO	15	0
	57	MD	8	0
	58	MD	0	0
	59	MD	17	0
	60	MD	0	0
	61	SRO	0	0
	62	MC	12	0
	63	MC	3	0
	64	MD	5	0
	65	MD	5	0
	66	MD	28	0
	67	SRO	20	0
	68	MD	10	3
	69	MD	25	13
	70	SRO	59	46

Appendix B.3 (Continued)

Transect No	Stat No.	Drainage*	Movement of particles (cms) AY*	HB*
5	71	SRO	58	3
	72	SRO	66	5
	73	SRO	63	13
	74	SRO	23	20
	75	SRO	104	20
	76	SRO	59	3
	77	SRO	79	51
	78	SRO	79	51
	79	MD	0	7
6	80	MD	0	0
	81	MD	43	0
	82	SRO	0	0
	83	MC	17	10
	84	MD	8	0
	85	MD	17	5
	86	SRO	3	0
	87	MD	17	0
	88	MD	8	0
	89	SRO	23	0
	90	MC	81	13
	91	SRO	23	0
	92	MD	13	0
	93	MC	114	3
	94	SRO	20	0
7	95	SRO	23	0
	96	MC	43	3
	97	SRO	10	0
	98	MD	5	0
	99	SRO	10	0
	100	MC	48	3
	101	MD	13	0
	102	MD	13	0
	103	MC	43	10
	104	MC	96	5
	105	MC	33	0

Appendix B.3 (Continued)

Transect No.	Stat. No.	Drainage*	Movement of particles (cms) AY*	HB*
7 (Continued)	106	MD	43	0
	107	SRO	33	7
	108	MC	102	13
	109	MC	91	3
	110	MC	91	7
	111	MC	76	15
	112	MC	99	5

*MD - Micro-depression
MC - Micro-channel
SRO - Surface runoff
AY - Arc Yellow Fluorescent dye
HB - Horizon Blue Fluorescent dye

Appendix B.4

Movement of Soil particles from Transects on Crown Point Study area

Transect No.	Stat. No.	Drainage*	Distance of soil movement cm
1	1	MC	17
	2	MC	16
	3	MC	27
	4	GR	10
	5	GR	11
	6	GR	19
	7	MD	22
	8	SRO	19
	9	MC	26
	10	MC	19
	11	MC	26
	12	GR	10
	13	GR	11
2	14	GR	13
	15	GR	12
	16	GR	22
	17	GR	12
	18	GR	27
	19	GR	16
	20	MC	11
	21	MC	23
	22	GR	21
	23	MC	21
	24	MC	15
	25	MC	23
	26	MC	30
	27	GR	10
	28	MD	13
	29	SRO	9
	30	MC	14
	31	SRO	28
	32	SRO	34
	33	SRO	36
	34	GR	19

Appendix B.4 (Continued)

Transect No.	Stat. No.	Drainage*	Distance of soil movement cm
3	35	MD	9
	36	MD	11
	37	MC	24
	38	MC	25
	39	MC	21
	40	GR	17
	41	GR	24
	42	MD	13
	43	MC	22
	44	MC	22
	45	MC	34
	46	MC	20
	47	MC	20
	48	MC	30
	49	MC	26
	50	MC	27
	51	GR	22
	52	MD	12
	53	MC	19
	54	GR	22
	55	SRO	16
	56	SRO	45
	57	MC	13
	58	GR	22
4	59	MC	8
	60	GR	6
	61	MC	8
	62	GR	13
	63	MC	13
	64	GR	10
	65	MD	10
	66	GR	6
	67	GR	11
	68	GR	6
	69	MC	13
	70	MD	16
	71	GR	2
	72	GR	28
	73	GR	27

Appendix B.4 (Continued)

Transect No.	Stat. No.	Drainage*	Distance of soil movement cm
4 (Continued)	74	MC	21
	75	MC	24
	76	GR	10
	77	GR	7
	78	MC	10
5	79	GR	1
	80	GR	2
	81	GR	1
	82	GR	1
	83	GR	3
	84	GR	1
	85	GR	1
	86	GR	2
6	87	GR	6
	88	GR	4
	89	GR	2
	90	GR	10
	91	GR	2
7	92	GR	11
	93	GR	5
	94	GR	9
	95	GR	7
	96	GR	5
	97	GR	4
	98	MC	4
	99	MC	4
	100	MD	4
	101	MC	3
	102	MD	3
	103	GR	3
	104	GR	4
	105	MC	6
	106	MD	8
	107	MC	6
	108	MD	10
	109	MC	16
	110	MD	13
	111	GR	7

Appendix B.4 (Continued)

Transect No.	Stat. No.	Drainage*	Distance of soil movement cm
7 (Continued)	112	MC	5
	113	GR	9
	114	GR	5
	115	GR	3
	116	MC	5
	117	MC	4
	118	MC	4
	119	GR	18
8	120	GR	20
	121	MC	7
	122	GR	13
	123	GR	12
	124	GR	12
	125	GR	8
	126	GR	14
	127	MC	10
	128	MC	17
	129	MC	12
	130	GR	29
	131	SRO	19
	132	SRO	15
	133	SRO	14
	134	MC	11

*MD - Micro-depression
MC - Micro-channe
SRO - Surface runoff
GR - Ground or rock

Appendix B.5

Average Movement of Soil particles from Transects on Crown Point Study Area after one summer

No. of Transects	No. of Readings	Drainage Type	Drainage No.	Average movement of soil particles (cms)
8	134	SRO	10	23
		MC	47	16
		MD	22	11
		GR	62	11

Appendix B.6

Average Movement of Soil particles from Transects on Hour-Glass Study Area after two years

No. of Transects	No. of Readings	Drainage		Average movement of soil particles (cms)	
		Type	No.	.25-1 mm	>mm
7	112	SRO	56	87 cm	21 cm
		MC	32	58 cm	5 cm
		MD	25	21 cm	3 cm

Appendix B.7

Effect of falling raindrops on the movement of soil particles

Spot No.	Maximum distance of soil particles[1/] moved from the center of the spot (cm)									
	E	W	N	S	NE	SE	SW	NW	% slope	Remarks
1	38		24	48		69			2 E	
2			13				13		3 SE	
3	33		33	41		30			2 S	
4	20	38	38	81					0	
5	56	40						41	1 W	
6	28		25		38		28		2 SE	
7			31	38	49			37	0	Some sheep effect
8	41	23	33		43	18			0	
9		21		40		43		20	0	
10	25	58					38		0	

[1/] Size of soil particle, can be of any size.

APPENDIX C-1

CORRELATION MATRIX OVER ONE YEAR PERIOD

VARIABLE NUMBER	1 NA	2 SA	3 SL	4 PS	5 VC	6 LC	7 RC	8 EPC	9 BA	10 GR
1 NA	1.000	-.969	.331	-.019	-.066	-.086	.052	-.061	.273	-.166
2 SA		1.000	-.347	-.003	.036	.064	.003	.048	-.226	.151
3 SL			1.000	.652	-.255	.177	.179	.103	.015	-.438
4 PS				1.000	-.566	-.089	-.017	.574	-.006	-.497
5 VC					1.000	.227	-.285	-.795	-.246	.732
6 LC						1.000	-.110	-.445	.178	.085
7 RC							1.000	-.137	-.162	-.172
8 EPC								1.000	-.115	-.475
9 BA									1.000	-.415
10 GR										1.000

OVER ONE YEAR PERIOD

n = 64

d.f. = 62 corrected

R at 5% = .246

R at 1% = .320

APPENDIX C-1 (continued)

VARIABLE NUMBER	11 MA	12 FO	13 LS	14 VA	15 VD	16 VD, A	17 IR	18 BD	19 MD	20 SRO
1 NA	-.002	.487	.193	-.505	.252	.202	-.654	.156	-.443	.318
2 SA	-.029	-.480	-.125	.487	-.280	-.156	.546	-.181	.428	-.344
3 SL	-.005	.467	.485	-.285	.105	.154	.150	-.341	-.158	.082
4 PS	-.322	.005	.115	-.336	.344	-.054	.507	-.144	.033	.239
5 VC	.700	.072	-.140	.435	-.412	.035	-.164	-.110	.190	-.371
6 LC	.189	.127	.056	.109	-.137	.044	.065	-.169	.005	-.093
7 RC	-.204	-.028	.362	.047	-.347	.327	.001	-.041	-.217	-.280
8 EPC	-.665	-.164	-.059	-.438	.524	-.151	.276	.088	-.003	.415
9 BA	.059	.167	.008	-.082	.198	-.136	-.317	.199	-.174	.257
10 GR	.052	-.312	-.340	.400	-.396	.050	-.068	.015	.227	-.370
11 MA	1.000	.239	.110	.235	-.175	-.032	-.111	-.162	.047	-.144
12 FO		1.000	.335	-.108	.001	.100	-.379	-.124	-.063	.003
13 LS			1.000	-.253	-.098	.341	-.026	-.173	-.246	-.094
14 VA				1.000	-.509	-.389	.224	-.011	.512	-.478
15 VD					1.000	-.595	-.068	.118	-.137	.938
16 VD, A						1.000	-.136	-.116	-.332	-.558
17 IR							1.000	-.251	.340	-.173
18 BD								1.000	-.516	.348
19 MD									1.000	-.408
20 SRO										1.000

APPENDIX C-1 (continued)

VARIABLE NUMBER	21 MC	22 SR	23 GW	24 SN	25 POM	26 > 5mm	27 2-5mm	28 1-2mm	29 <.25mm	30 5mm C
1 NA	.033	-.019	-.073	.405	.459	.133	.233	.389	.094	-.102
2 SA	-.056	-.012	.043	-.336	-.411	-.109	-.225	-.413	-.005	.088
3 SL	.214	.032	.099	-.094	-.110	-.071	.285	.219	.015	.178
4 PS	.067	.045	.100	-.044	-.166	-.137	.369	.161	.016	.443
5 VC	.020	.000	-.014	-.068	.038	.031	-.180	-.026	-.069	-.262
6 LC	-.026	-.013	.009	-.129	-.099	-.024	.015	.065	-.026	.110
7 RC	.301	-.038	-.035	-.041	-.047	-.008	.072	-.031	.119	.193
8 EPC	-.058	.017	.038	.059	-.043	-.031	.105	-.000	-.046	.141
9 BA	-.258	-.005	-.038	.155	.127	.035	.084	.082	.153	-.006
10 GR	.002	-.028	-.071	-.034	.007	.043	-.260	-.042	-.162	-.211
11 MA	.016	.025	.046	-.071	.035	.014	-.020	-.007	.074	-.102
12 FO	.064	.015	.039	.080	.130	.006	.207	.137	.110	-.182
13 LS	.336	-.024	.039	.011	.066	.008	.218	.097	.173	.010
14 VA	-.282	.066	.055	-.285	-.258	-.127	-.263	-.299	-.063	-.159
15 VD	-.529	-.010	-.028	.176	.091	.016	.022	.074	-.038	.037
16 VD, A	.830	-.050	-.022	.079	.144	.101	.222	.200	.099	.109
17 IR	.162	.105	.142	-.387	-.376	-.175	.056	-.102	-.140	.294
18 BD	-.351	-.010	-.062	.197	.104	.084	.016	.047	-.015	.014
19 MD	-.061	.057	.068	-.208	-.177	-.150	-.184	-.209	-.111	-.115
20 SRO	-.620	-.018	-.046	.197	.101	.059	.010	.074	-.035	.039
21 MC	1.000	-.001	.046	-.060	.055	-.016	.259	.229	.079	.123
22 SR		1.000	.981	-.670	-.440	-.780	-.166	-.525	-.385	-.086
23 GW			1.000	-.648	-.423	-.750	-.117	-.493	-.342	-.045
24 SN				1.000	.854	.661	.396	.701	.515	.099
25 POM					1.000	.592	.399	.652	.397	-.041

APPENDIX C-1 (continued)

VARIABLE NUMBER	21 MC	22 SR	23 GW	24 SN	25 POM	26 >5mm	27 2-5mm	28 1-2mm	29 <.25mm	30 > 5mm C
26 >5mm						1.000	.175	.515	.552	.148
27 2-5mm							1.000	.615	.386	.437
28 1-2mm								1.000	.423	.200
29 <.25mm									1.000	.349
30 5mm C										1.000

APPENDIX C-1 (continued)

VARIABLE NUMBER	31 2-5mm C	32 1-2mm C	33 <.25mm C	34 SG	35 HB	36 SY	37 TCSY	38 TSY
1 NA	-.153	.186	.261	.081	.180	.106	.040	.416
2 SA	.148	-.206	-.267	-.092	-.173	-.107	-.045	-.366
3 SL	.069	.110	-.152	.161	.114	.214	.158	.080
4 PS	.250	.171	-.131	.291	.216	.311	.356	.070
5 VC	-.172	-.021	.033	-.159	-.233	-.180	-.223	-.100
6 LC	.033	.037	-.077	.130	-.014	.101	.103	-.008
7 RC	.185	.137	-.129	.088	.020	.091	.158	.078
8 EPC	.096	-.057	.000	.074	.227	.076	.116	.030
9 BA	-.065	-.006	.134	.031	-.006	.086	.008	.084
10 GR	-.113	.040	.011	-.120	-.154	-.176	-.148	-.083
11 MA	-.088	-.032	.078	-.072	-.155	-.030	-.116	-.068
12 FO	-.185	-.100	-.090	-.081	-.038	-.101	-.161	.118
13 LS	.018	.063	-.037	.090	.082	.104	.093	.191
14 VA	-.063	-.142	-.171	-.198	-.305	-.190	-.222	-.337
15 VD	-.137	.058	.244	.136	.212	.099	.091	.135
16 VD, A	.206	.071	-.102	.039	.058	.072	.110	.170
17 IR	.260	.108	-.132	.120	-.041	.061	.196	-.260
18 BD	.016	.093	.096	.025	.004	.034	.046	.055
19 MD	-.093	-.231	-.110	-.153	-.136	-.147	-.176	-.224
20 SRO	-.127	.092	.245	.147	.194	.108	.103	.143
21 MC	.222	.128	-.096	.037	.034	.060	.098	.076
22 SR	-.167	.165	-.290	-.015	.018	.102	-.049	-.326
23 GW	-.157	.173	-.269	.043	.048	.150	.003	-.279
24 SN	.019	.075	.600	.237	.208	.065	.231	.747
25 POM	-.094	.118	.613	.169	.164	.026	.139	.753

APPENDIX C-1 (continued)

VARIABLE NUMBER	31 2-5mm C	32 1-2mm C	33 .25mm C	34 SG	35 HB	36 SY	37 TCSY	38 TSY
26 >5mm	.204	-.042	.426	.061	.030	-.036	.124	.464
27 2-5mm	.270	.272	.116	.337	.159	.270	.423	.596
28 1-2mm	.119	.262	.436	.269	.258	.158	.282	.692
29 <.25mm	.398	.123	.385	.146	.133	.100	.272	.483
30 >5mm C	.753	.337	.049	.582	.399	.537	.798	.217
31 2.5mm C	1.000	-.054	-.035	-.020	-.051	-.019	.309	-.099
32 1-2mm C		1.000	.392	.731	.448	.596	.687	.440
33 <.25mm C			1.000	.350	.121	.077	.321	.561
34 SG				1.000	.731	.836	.934	.592
35 HB					1.000	.715	.680	.513
36 SY						1.000	.798	.402
37 TCSY							1.000	.537
38 TSY								1.000

<u>OVER ONE YEAR PERIOD</u>

n = 64

d.f. = 62 corrected

R at 5% = .246

R at 1% = .320

APPENDIX C-2

CORRELATION MATRIX FOR JUNE

INDEPENDENT VARIABLE NUMBER	1 NA	2 SA	3 SL	4 PS	5 VC	6 LC	7 RC	8 EPC	9 BA	10 GR
1 NA	1.000	-.939	.337	-.022	-.047	-.035	-.000	-.061	.280	-.166
2 SA		1.000	-.369	-.021	-.013	-.011	.099	.036	-.186	.136
3 SL			1.000	.652	-.243	.248	.124	.101	.033	-.442
4 PS				1.000	-.550	-.013	-.067	.574	-.003	-.494
5 VC					1.000	.264	-.264	-.788	-.229	.718
6 LC						1.000	-.158	-.462	.192	.033
7 RC							1.000	-.170	-.219	-.104
8 EPC								1.000	-.106	-.475
9 BA									1.000	-.421
10 GR										1.000

OVER THE WINTER PERIOD

n = 32

d.f. = 30 corrected

R at 5% = .349

R at 1% = .449

APPENDIX C-2 (continued)

INDEPENDENT VARIABLE NUMBER	11 MAT	12 FORB	13 LS	14 VA	15 VD	16 VD, A	17 IR	18 BD	19 MD	20 SRO
1 NA	.022	.505	.224	-.529	.252	.197	-.653	.136	-.451	.318
2 SA	-.082	-.490	-.094	.497	-.308	-.111	.457	-.184	.423	-.371
3 SL	.016	.493	.433	-.232	.101	.097	.165	-.329	-.117	.078
4 PS	-.294	.039	.068	-.296	.346	-.104	.501	-.132	.070	.241
5 VC	.693	.074	-.166	.460	-.400	.017	-.102	-.096	.197	-.359
6 LC	.276	.200	.011	.120	-.084	-.016	.093	-.167	.005	-.038
7 RC	-.232	-.083	.401	-.035	-.365	.412	-.084	-.061	-.264	-.301
8 EPC	-.641	-.146	-.090	-.410	.524	-.190	.274	.095	.029	.415
9 BA	.089	.188	.069	-.103	.204	-.124	-.365	.165	-.186	.262
10 GR	.023	-.338	-.340	.393	-.396	.071	-.037	.024	.213	-.370
11 MAT	1.000	.266	.071	.273	-.153	-.078	-.049	-.146	.069	-.123
12 FORB		1.000	.333	-.121	.030	.074	-.352	-.130	-.069	.032
13 LS			1.000	-.219	-.152	.349	-.126	-.185	-.224	-.145
14 VA				1.000	-.467	-.383	.241	-.025	.488	-.438
15 VD					1.000	-.638	-.017	.135	-.095	.938
16 VD, A						1.000	-.192	-.119	-.326	-.599
17 IR							1.000	-.193	.340	-.116
18 BD								1.000	-.529	.363
19 MD									1.000	-.373
20 SRO										1.000

APPENDIX C-2 (continued)

INDEPENDENT VARIABLE NUMBER	21 MC	22 SN
1 NA	-.000	.775
2 SA	-.049	-.684
3 SL	.175	-.187
4 PS	.039	-.080
5 VC	.036	-.106
6 LC	-.064	-.276
7 RC	.335	-.135
8 EPC	-.086	.112
9 BARE	-.294	.306
10 GR	.040	-.065
11 MAT	.003	-.104
12 FORB	.034	.167
13 LS	.275	-.061
14 VA	-.254	-.475
15 VD	-.553	.336
16 VD, A	.798	.062
17 IR	.185	-.614
18 BD	-.327	.400
19 MD	-.039	-.340
20 SRO	-.641	.378
21 MC	1.000	-.156
22 SN		1.000

OVER THE WINTER PERIOD

n = 32
d.f. = 30 corrected
R at 5% = .349
R at 1% = .449

APPENDIX C-3

CORRELATION MATRIX FOR SEPTEMBER

INDEPENDENT VARIABLE NUMBER	1 NA	2 SA	3 SL	4 PS	5 VC	6 LC	7 RC	8 EPC	9 BA	10 GR
1 NA	1.000	-1.000	.325	-.015	-.084	-.135	.113	-.061	.267	-.166
2 SA		1.000	-.325	.015	.084	.135	-.113	.061	-.267	.166
3 SL			1.000	.652	-.266	.110	.243	.104	-.002	-.434
4 PS				1.000	-.582	-.161	.042	.574	-.010	-.500
5 VC					1.000	.194	-.311	-.802	-.263	.745
6 LC						1.000	-.059	-.429	.165	.134
7 RC							1.000	-.100	-.094	-.254
8 EP								1.000	-.125	-.475
9 BA									1.000	-.409
10 GR										1.000

OVER THE SUMMER PERIOD

n = 32

d.f. corrected 30

R at 5% = .349

R at 1% = .449

APPENDIX C-3 (continued)

INDEPENDENT VARIABLE NUMBER	11 MA	12 FO	13 LS	14 VA	15 VD	16 VD, A	17 IR	18 BD	19 MD	20 SRO
1 NA	-.027	.469	.162	-.487	.252	.209	-.665	.176	-.438	.318
2 SA	.027	-.469	-.162	.487	-.252	-.209	.665	-.176	.438	-.318
3 SL	-.025	.440	.541	-.335	.109	.215	.135	-.353	-.197	.086
4 PS	-.352	-.032	.164	-.376	.341	-.001	.522	-.157	-.004	.237
5 VC	.707	.069	-.112	.412	-.424	.056	-.243	-.125	.182	-.382
6 LC	.107	.053	.100	.103	-.187	.103	.035	-.172	.007	-.146
7 RC	-.170	.042	.310	.145	-.328	.217	.129	-.015	-.161	-.258
8 EP	-.691	-.184	-.027	-.466	.524	-.112	.282	.080	-.034	.415
9 BA	.028	.143	-.057	-.064	.192	-.148	-.261	.233	-.163	.252
10 GR	.081	-.286	-.342	.410	-.396	.027	-.105	.006	.241	-.370
11 MA	1.000	.210	.156	.197	-.198	.021	-.190	-.180	.023	-.165
12 FO		1.000	.340	-.098	-.031	.132	-.419	-.119	-.059	-.027
13 LS			1.000	-.280	-.042	.326	.110	-.159	-.263	-.042
14 VA				1.000	-.552	-.391	.203	-.001	.531	-.517
15 VD					1.000	-.552	-.131	.101	-.178	.938
16 VD, A						1.000	-.058	-.110	-.335	-.517
17 IR							1.000	-.328	.342	-.245
18 BD								1.000	-.506	.333
19 MD									1.000	-.442
20 SRO										1.000

APPENDIX C-3 (continued)

VARIABLE NUMBER	21 MC	22 GW	23 SR
1 NA	.066	-.254	-.379
2 SA	-.066	.254	.379
3 SL	.253	.491	.537
4 PS	.097	.557	.500
5 VC	.006	-.253	-.166
6 LC	.009	.057	.128
7 RC	.259	.204	.085
8 EPC	-.030	.224	.195
9 BA	-.221	-.200	-.247
10 GR	-.036	-.373	-.369
11 MA	.031	.011	.114
12 FO	.098	.018	.136
13 LS	.398	.555	.533
14 VA	-.306	-.077	-.073
15 VD	-.506	-.139	-.142
16 VD, A	.864	.230	.230
17 IR	.139	.729	.505
18 BD	-.375	-.400	-.421
19 MD	-.080	.103	.104
20 SRO	-.599	-.243	-.239
21 MC	1.000	.430	.401
22 GW		1.000	.832
23 SR			1.000

OVER THE SUMMER PERIOD

n = 32
d.f. corrected 30
R at 5%= .349
R at 1% = .449

APPENDIX C-4

CORRELATION MATRIX FOR HOUR GLASS TRANSECTS

INDEPENDENT VARIABLE NUMBER	1 AS	2 SL	3 SP	4 SRO	5 VC	6 LC	7 RC	8 EP	9 BA	10 VS
1 AS	1.000	.503	-.270	-.036	-.286	-.102	.105	.086	.286	-.160
2 SL		1.000	.471	-.110	-.456	-.069	.249	.283	.250	-.226
3 SP			1.000	-.063	-.286	-.179	.183	.210	.132	-.060
4 SRO				1.000	-.100	-.006	-.057	.093	.153	-.112
5 VC					1.000	.073	-.500	-.398	-.627	.724
6 LC						1.000	-.304	-.109	-.085	.134
7 RC							1.000	-.035	-.224	-.496
8 EP								1.000	.192	-.364
9 BA									1.000	-.298
10 VS										1.000

HOUR GLASS TRANSECTS

n = 112

d.f. = 110 corrected

R at 5% = .186

R at 1% = .244

APPENDIX C-4 (continued)

VARIABLE NUMBER	11 SGHG	12 HBHG
1 AS	.305	.184
2 SL	.529	.426
3 SP	.278	.183
4 SRO	.263	.048
5 VC	-.520	-.248
6 LC	-.121	.157
7 RC	.315	.045
8 EP	.371	.108
9 BA	.208	.165
10 VS	-.440	-.149
11 AYHG	1.000	.429
12 HBHG		1.000

HOUR GLASS TRANSECTS

n = 112
d.f. = 110 corrected
R at 5% = .186
R at 1% = .244

APPENDIX C-5

CORRELATION MATRIX FOR CROWN POINT TRANSECTS

VARIABLE NUMBER	1 NA	2 SL	3 SP	4 SRO	5 VC	6 LC	7 RC	8 BA	9 EPC	10 VS
1 NA	1.000	-.150	-.154	-.199	-.014	.031	.198	-.019	-.112	.115
2 SL		1.000	-.249	.046	-.130	.046	-.000	.314	-.192	-.114
3 SP			1.000	.107	-.069	.028	-.046	.223	-.076	-.170
4 SRO				1.000	-.226	-.203	.464	-.131	.190	-.098
5 VC					1.000	-.091	-.487	-.461	-.403	.781
6 LC						1.000	-.104	.052	-.109	-.009
7 RC							1.000	-.143	.022	-.300
8 BA								1.000	-.265	-.453
9 EP									1.000	-.285
10 VS										1.000

n = 134

d.f. = 130 corrected

R at 5% = .171

R at 1% = .224

APPENDIX C-5 (continued)

VARIABLE NUMBER	11 IR	12 BD	13 SR	14 GW	15 HW	16 AYCP
1 NA	.802	-.362	.631	.628	.546	-.574
2 SL	.024	.261	.273	.411	.199	-.046
3 SP	.122	.194	-.142	-.313	-.248	.380
4 SRO	-.073	.119	.080	.030	.114	.364
5 VC	-.172	.085	-.290	-.202	-.283	-.100
6 LC	.130	-.157	.110	.010	.064	-.049
7 RC	.250	-.140	.334	.245	.322	.105
8 BA	.180	.148	.195	.163	.134	-.031
9 EP	-.187	-.103	-.105	-.081	-.018	.137
10 VS	-.070	-.210	-.153	-.115	-.141	-.153
11 IR	1.000	-.100	.799	.526	.562	-.397
12 BD		1.000	-.218	-.229	-.366	.137
13 SR			1.000	.813	.920	-.244
14 GW				1.000	.874	-.268
15 HW					1.000	-.149
16 AYCP						1.000

n = 134

d.f. = 130 corrected

R at 5% = .171

R at 1% = .224

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