CHARACTERISTICS AND PREDICTION OF SOIL EROSION ON A WATERSHED IN THE PALOUSE

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AUTHORIZATION TO PROCEED WITH THE FINAL DRAFT:

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ABSTRACT

The objective of this project was to study the process of soil loss by water on this one watershed and determine the effect of various hydrologic parameters.

The 1971-72 wateryear provided good data and 3.71 tons/acre soil loss was measured on a storm basis. The annual figure is estimated to be 4 tons/acre which would include unmeasured events and low flow periods with minimal losses. The 1972-73 wateryear was a poor year from the standpoint of erosion data as it was quite dry. However, three of the events which occurred were of the frozen ground type which provided valuable hydrologic data. Frozen ground events were deleted from the erosion data analysis.

The soil loss events that were not on frozen ground were analyzed on a storm basis and a predictive equation for use on this watershed was developed by multiple regression techniques using several hydrologic parameters. Soil loss was found to depend mainly on amounts and timing of precipitation, volume of runoff, snow melt, and the conditions of the soil.

The data collected yielded good results but left unanswered the question of the effect of cropping patterns, tillage practice, slope, slope length, and slope aspect on soil erosion. These parameters are all very important to amount of soil loss but did not vary in this case because the work was done on one watershed with one cropping practice.

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INTRODUCTION

Heavy spring runoff has long caused serious soil erosion and depletion of soil nutrients on agricultural watersheds in the Palouse region. Three types of events which normally occur from December through March provide the source for this runoff. These are:

1. Precipitation storage in snow being melted by warming temperatures and rainfall.
2. Prolonged precipitation on ground previously frozen by a period of low temperature.
3. Rainfall on bare, unfrozen ground when soil moisture is very high and the infiltration rate is low.

The first event is the most common in this area for generating large sediment yields. The moisture stored in the snow pack increases as snow occurs until a warming trend causes the snow to change to rain and the pack begins to ripen and melt. If the rain is of sufficient duration to produce more water than can be stored in the pack, water will begin to drain from the snow. If water drains from the snow at a rate greater than the infiltration rate of the soil, runoff will occur. The erosion process will then commence and continue as long as the precipitation persists.

The second event occurs less frequently, and though often not a significant contributor to the problem of soil erosion, it can account for very high rates of runoff. In this case sub-zero weather lasting up to a week when there is no snow cover for insulation will freeze the ground to such a depth as to effectively eliminate soil infiltration. Precipitation occurring on this impermeable frozen ground will then cause runoff as soon as surface storage is satisfied bringing about an accompanying loss of soil. A variation of the frozen ground event which does produce significant sediment yield is rainfall on thawing ground. In this situation the thawing soil is subjected to a rainfall event. The underlying soil is frozen and the thawed portion of the soil becomes saturated. This leaves the soil in a soupy condition with practically no resistance to erosive action. If sufficient rainfall occurs to produce runoff large amounts of soil loss are possible.

The third situation can usually be coupled to the first or the second in that one or the other has usually occurred within a short time period prior to this type of event. As stated, runoff occurs because the rainfall rate is greater than the infiltration rate into the soil. In this case the soil moisture is increased to the point that the soil can no longer take in water as fast as it is supplied so runoff and erosion occur.

A fourth type of event should be mentioned although it is highly isolated and the relative contribution to soil loss is small in this area. During the summer months isolated high intensity thunder storms sometimes occur which on summer fallow or freshly cultivated ground can cause great amounts of erosion.

In the Palouse region 95 per cent of the soil erosion occurs in the period of December through March and approximately 90 per cent of the annual discharge of water, nitrogen, and phosphorous (ARS, 1972). The amounts of soil and nutrients eroded due to this runoff are a very significant problem of the agricultural industry in the Palouse.

The problem of runoff and erosion not only affects the land on and around which it occurs, but also affects streams and reservoirs into which the watersheds drain. Land damage includes productivity loss, roadway and drainage ditch siltation, slope disturbance, and esthetic loss; while stream and reservoir damages include flooding, nutrient and organic matter pollution, stream channel siltation, loss of recreational value, disruption of stream ecology, loss of reservoir capacity, and again esthetic loss (Brandt and others, 1972). These problems are all prevalent in the Palouse region.

It is not possible to determine precisely the costs of these damages to our environment and productivity. Some of the damages could be estimated but these are really only secondary costs and vary greatly in different areas of the Palouse. The true cost is the loss of a non-renewable resource, top soil, and the ecological disruption caused by the sediment.

Impetus for erosion control is coming from legislation at the federal, state, and local level to provide means to control those who waste this resource. Therefore, better means to predict such losses must be available so that guidelines for soil erosion have a sound basis.

FIGURE 1a: Thompson watershed and surrounding area (summer 1972).

FIGURE 1b: North facing slope of Thompson watershed (summer 1972).

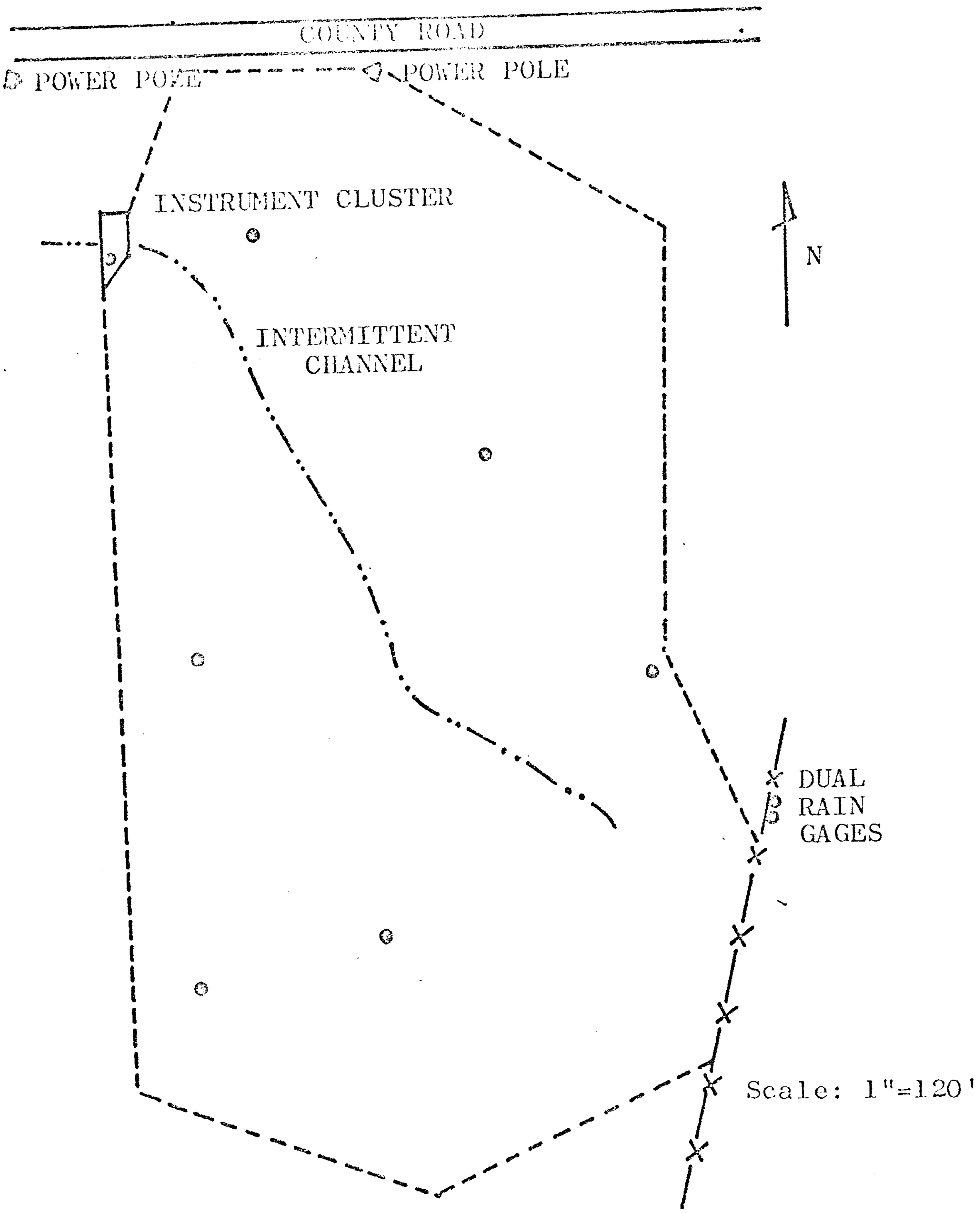


FIGURE 2: Map of Thompson watershed, Moscow, Idaho.

PURPOSE

The objective of this study was to collect and analyze information related to sediment yield from individual runoff events. The process of soil erosion and parameters involved therein was the primary interest of this thesis. At the present time there is no workable method by which to predict or measure amounts of soil erosion which occur on a watershed in this area.

Two basic objectives were pursued in this thesis: The first was to qualitatively describe the soil erosion process in the Palouse area and second, to obtain a quantitative description of soil erosion on the study watershed. This information will facilitate the development of soil erosion prediction methods in the Palouse area.

LITERATURE REVIEW

Physical Process of Erosion

There are two definitions that are integral to the understanding of this study. They are:

Erosion: detachment and removal of rock particles by the action of water and wind.

Fluvial sediment: an accumulation of rock and mineral particles transported or deposited by water.

(From: Committee on Sedimentation, 1965)

The scope of this thesis encompasses the erosion of soil by water and the accompanying transport of the fluvial sediment. In this thesis the term soil erosion is used to describe the detachment and transportation of the soil by water.

As stated there are two mechanical processes that must take place to have soil erosion. First, the particle must be detached from its surroundings. The energy required to accomplish this may come from two general sources; runoff water and/or raindrop impact. Secondly, the detached particle must be moved which involves transportation. The same two sources of energy are available to transport the detached particles.

The relative amounts of soil detached and/or transported by each of the energy mechanisms is dependent mainly on the intensity of the rainfall. East of the Rocky

Mountains where very high rainfall intensities are characteristic, most soil detachment and some transportation are attributable to raindrop impact. However, in the Pacific Northwest (characterized by the study area), rainfall intensity is usually very low and raindrop impact contributes little to the detachment or transportation of the soil. In this region almost all detachment and transportation is the direct result of runoff water. The basic difference between these two areas is the two different forms of energy release. High intensity rainfall releases its energy through impact while during low intensity rainfall, runoff creates a shear stress which detaches the soil particles. The difference in the energy mechanisms which generate soil erosion seems to be the reason why universal empirical soil loss equations have been unsatisfactory.

Erosion Equations

To develop a soil loss predictive equation that would be truly universal would require a complete understanding of all physical parameters involved in the mechanics of sediment detachment and transport. This would indeed be an extremely complex undertaking. However, research has been conducted to find the most important variables involved in the transport and detachment phenonema and soil loss equations have been developed.

The general categories of variables which must be considered in any predictive equation are climatic factors, watershed characteristics, and land use and treatment (Williams and others, 1971).

There have been two common types of predictive equations developed. The first is the gross-erosion equation. This type is characterized by the Musgrave Method (Musgrave, 1947), the Soil Conservation Services TP-97 (Gottschalk and Brune. 1950). and Wischmeier and Smith's "Universal Soil Loss Equation" (USLE) (ARS, 1961). These equations are based on plot or field data and a delivery ratio must be included to predict soil loss on a watershed basis. The USLE is by far the best developed and is the result of thousands of plot years of data.

Using the USLE as an example, the gross sediment yield from the entire area of the watershed in question is predicted then a delivery ratio is computed and used to predict actual sediment yield leaving the watershed. This was done with success using a modified USLE and delivery ratio in the Texas Blacklands by Williams and Berndt (1972). However, Beer tested the three aforementioned unmodified equations with data from 24 reservoirs and concluded they were not applicable to these watershed complexes because of inability to develop a satisfactory delivery ratio and difficulty in adapting plot parameters to watershed characteristice (Beer and others, 1966).

The second type of predictive equation establishes mathematical relationships between watershed and hydrologic parameters and soil loss. To develop this equation, it is necessary to solve a series of complex equations. The use of a digital computer simplifies this task. Flaxman (1972), Williams (1971), and Anderson and Wallis (1965) have all used statistical methods such as multiple correlation, multiple regression, and factor analysis to predict sediment yield in this way. Williams (1971) felt by use of these and other statistical procedures better sediment yield equations and a better insight into the relative importance of physical parameters involved could be obtained.

In summary, there are several observations to be made. As for the first type of equation, in particular the USLE, these were developed from data taken from east of the Rocky Mountains (high intensity rainfall area). It is difficult to apply this equation to this area because of the difference in the source of energy input and the lack of data to use in developing the climatological and watershed characteristic parameters. As an example of the energy input problem, one of the most important parameters in the USLE is the rainfall factor R which is the number of erosion index units in the annual rainfall. This R value is a measure of the level of kinetic energy imparted on the soil annually. Representative values are: Mississippi-600, Texas-100 to 500, and Colorado-50 to 100. Pullman, which is representative of the Palouse region, has a computed R value of 9. Supposedly this would indicate little erosive force whereas high rates of erosion are apparent. Another problem is that these equations were developed on an annual basis thus using this type of approach does not take into account the timing of the events. Erosion events that occur close together will produce more sediment than those spread out over a longer period of time. This is because soil moisture will remain high if there is insufficient time for the water to percolate or evaporate; and, therefore, soil will be more easily eroded.

In lieu of an equation encompassing all variables that predicts erosion from the dynamic particle point of view, it would seem the best approach is the statistical one for the watershed or area in question. However, because of its wide use, the parameters from the USLE will be explained and values for the Palouse country will be given as close as possible in the section on analysis of data.

Erosion in the Palouse

The Palouse region is an area of low intensity rainfall where rainfall rate is rarely greater than 0.1 inch per hour except for very brief periods. Also, continuous rainfall events during the peak erosive period (December through March) seldom exceed one inch. Since both amount and intensity of rainfall are small, soil must be eroded by runoff and not rainfall impact.

Runoff occurs when the water input (including snow melt) is greater than the infiltration and evapotranspiration (ET). Since ET on a short-term basis is very small in comparison to the input, especially in the winter months, the runoff is directly related to the infiltration capacity of the soil. In the Palouse infiltration is limited by four main factors:

1. Crust development on pulverized wheat fields (McCool and Johnson, 1973).
2. Soil moisture at relatively high levels due to summer fallow.
3. Surface condition-frozen or unfrozen ground.
4. Soil saturated due to previous events.

Excluding frozen ground, it is usually difficult to determine which of the remaining three have the largest effect on infiltration in a particular situation. Usually it is a combination of all limiting factors (except frozen ground) that restricts the infiltration and thus increases runoff. Frozen ground does cause impermeable conditions if the soil is nearly saturated before freezing. However, frozen ground events in the Palouse are not frequent and their contribution to sediment yield is small. From observations, then, it would seem that runoff waters provide the majority of energy for detachment and transportation of soil in the Palouse.

Sediment yield is directly dependent on the cropping and tillage practices in effect on the watershed if all other things are equal. The type of crop, crop rotation, seed bed preparation, and general tillage work all greatly influence the ability of the soil to resist erosion.

Kaiser (1961) gives a relative soil loss for different cropping systems in the Palouse (Table 1). These values are relative in that field management can greatly influence these figures. By far the worst contributor to soil loss on a per acre basis is the practice of summer fallowing. The practice was developed to conserve soil moisture, control weeds, and provide soil nutrients. However, the continuous cultivation of this soil during the summer and fall prior to planting leaves it devoid of organic matter

Cropping System	Soil Loss (tons/acre)
Alfalfa & Grass (4-6 years): Grain (1-2 years)	1.8
Alfalfa & Grass (3-5 years): Grain & Peas (3-5 years)	4.4
Alfalfa & Grass (3-5 years): Grain & Peas (6-10 years)	4.9
Clover & Peas:Green Manure: Grain	5.0
Recropping with Grain*	5.0
Clover & Peas:Green Manure: Grain:Peas:Grain	6.0
Grain:Peas	7.5
Grain:Fallow	12.0

*Corresponds to Thompson watershed cropping.

Table 1: Soil loss in the Palouse from water and tillage for different cropping systems.

that would increase infiltration and in a pulverized, smooth surface condition which is highly susceptible to erosion. Most good farm managers recognize the problem and summer fallowing is slowly being phased out since soil moisture is adequate without it; herbicides can control weeds, and fertilizers will replenish soil nutrients.

There have been prior studies of erosion in this area. During the period of 1932 to 1947 data from the Pacific Northwest Conservation Experiment Station were collected (Horner and others, 1942). Much of this work dealt with soil loss as it was part of a nation wide data acquisition system on soil erosion. However, the data collected were not found to be compatible with the rest of the erosion research stations and much have since been lost or destroyed. Some of this information can be obtained (Horner and Naffziger, 1942). However, even this information is fragmentary and soil treatment during the experiment was not standardized or listed. This information is currently being re-analyzed by Don McCool (ARS, Pullman, Washington) in hopes that it can be useful in an attempt to develop a soil loss equation generally applicable to this area.

There is and will be a problem of soil erosion as long as present day agricultural practices are in effect. The only sure solution is to plant the Palouse hills back to its natural grasses. Only a hard core environmentalist would consider this a solution. Combative measures such as terraces, control structures, and slope reduction are not economically or physically practical in most cases. Soil stabilization must be brought about by biological, mechanical, or chemical means at an economically feasible level. This, however, is another problem and is being studied by many scientists. The aforementioned analysis of the mechanics of soil erosion conducted by Don McCool (ARS, Pullman, Washington) is progressing; however it is slow because of the large amount of data required to give reasonable results. In the meantime, work must continue towards developing a usable soil loss equation for this area so that soil erosion and its accompanying problems can be designed for and reduced.

DESCRIPTION OF STUDY AREA

Watershed Description and Characteristics

Thompson watershed is located on the eastern edge of the Palouse agricultural region approximately six miles northeast of Moscow, Idaho. The watershed is somewhat oval in shape and covers an area of 8.2 acres. The slope of the watershed ranges from nearly level at the instrument shelter to 20 per cent. Average slope as computed from the equation given by Williams and Berndt (1972) gives a value of 15 1/2 per cent for the entire watershed. The slope areas are approximately evenly divided between north facing and south westerly facing segments. Because of continuous cropping no permanent stream channel exists. However, by the conclusion of spring runoff, rills of sizable dimensions may exist. (Note Figure 3).

The soil is basically a silt loam which ranges from a sandy silt to a clayey silt and has a depth of approximately 5 feet to restricted permeability (Neff, 1966). Davis (1971) gave a good review of the soil characteristics on Thompson watershed. This paper should be referred to for additional soil data.

The geographic location of the watershed (close to Moscow Mountain) is such that the area receives slightly more rainfall than other segments of the Palouse region to the west. This must be considered when comparing it to the rest of the Palouse area. Other than the higher amount of

FIGURE 3a: Typical erosion on upper portion of Thompson watershed (1971-1972).

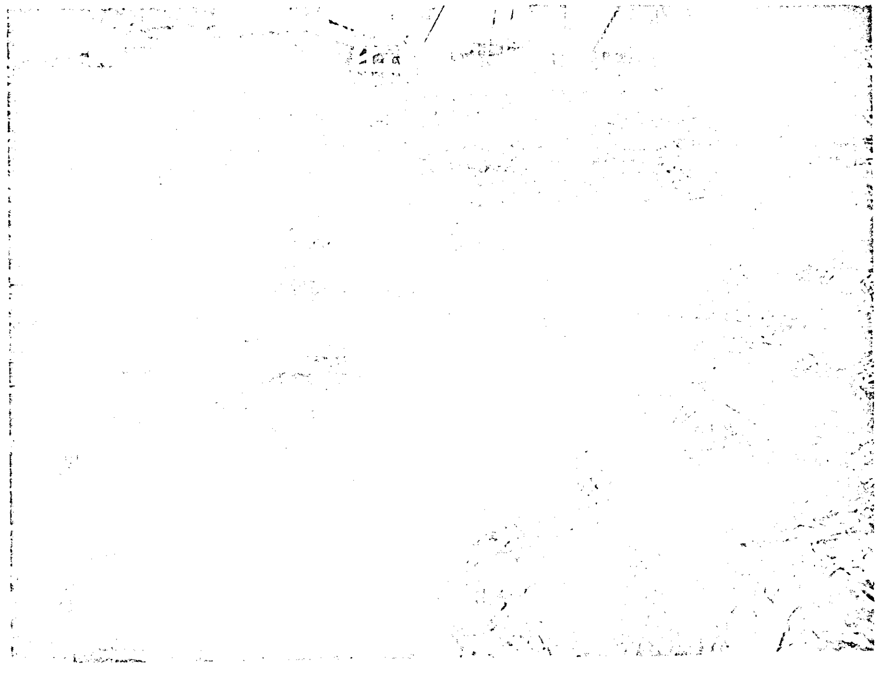


FIGURE 3b: Severe erosion on lower portion of Thompson watershed (1971-1972).

annual percipitation, Thompson watershed is fairly representative of the rolling Palouse hills hydrologically and physiographically.

The watershed is farmed by a local resident and has been planted to spring barley for the past four years. The barley is usually planted in late April or early May, harvested in August. and the ground is then plowed. This practice leaves the ground in a good state for erosion prevention as the field is contour plowed and large amounts of organic matter are incorporated in the top six inches of soil. However, in spite of this, sufficient erosion occurs as to be detrimental to the long range productivity of the watershed.

Instrumentation

Complete hydrologic data were collected during the course of the project. Some of this information was extraneous to the erosion study but was obtained in order to complie additional hydrologic information. The actual data and instrumentation used in the erosion analysis will be described in detail. The additional data and instrumentation taken will be listed for future use.

Precipitation. There were four rain gages on the watershed during the project. The standard can type used by Davis (1971) was maintained and gave reasonably accurate data for gross weekly precipitation during the winter months. Data from this gage were used as a check on total precipitation.

However, precipitation data for a storm-by-storm analysis of erosion events for a particular time period could not be determined from this gage. During the spring and summer months a large portion of the precipitation catch evaporated before measurement so the use of this gage was discontinued until late fall.

The second gage was a heated tipping bucket gage installed in March, 1972, at the instrument cluster. This gage was coupled to a Rustrack 4-channel recorder and gave a very good indication of the distribution of rain during the winter months. However, it was discovered when the heat was turned on, significantly less rainfall was recorded than by any of the other gages. This can probably be attributed to the heat evaporating the very small amounts of precipitation in the bucket before it could register. When the heat was off the gage correlated very well with the other gages. Since most of the erosion events took place during the winter months, this precluded the use of the tipping bucket gage to measure precipitation as it would not operate without heating.

The last two rain gages are a dual system of a shielded and an unshielded gage at the crest of the hill. In theory, the dual system should give quite accurate value of moisture caught at the soil surface if values from these two gages were adjusted using the method developed by Hamon (1972). However, during the month of February, 1972, the gages were subjected to extremely high winds (in the range of 50-70 M.P.H.) and the unshielded gage when calibrated in late spring was found to be damaged severely. This left only the shielded gage's record as an accurate and continuous record of precipitation. Neff (1967) suggested that a gage on the crest of a hill would receive 16 per cent less precipitation than the soil because of wind effect which is probably reasonable in most cases. However, very little wind accompanied the rainfall which caused runoff events and therefore the significant data are felt to be accurate within 10 per cent.

Surface Runoff. Runoff was measured with a Stevens dual pen A-35 water level recorder coupled to a drop box weir. The drop box weir is uniquely suited for this type of study in that it is fitted with a sediment sampling plug. This weir was developed to measure flow in heavily sediment laden streams (Johnson and others, 1966). The stage discharge relationship was developed by using a bucket of known volume and a stop watch. Extremely high flows (1-2 cfs), where measurement was impossible, were assumed to follow the theoretical curve developed by Johnson and others (1966). There is a small leak in the cut-off wall estimated to be .003 inches of surface runoff per day (Davis, 1971). This amount was insignificant on an event basis. In order to speed calculations of runoff a computer program was developed to give runoff in inches as computed by the mid-interval method developed by U.S.G.S. (USGS, 1972). This program is easily adaptable to any watershed with a known rating curve and is listed in the appendix.

Sediment Sampling. Sampling of sediment was accomplished by both mechanical and hand sampling techniques. A sediment sampler patterned after the Chickasha sampler (Miller and others, 1969) was put into operation January, 1972, and used in conjunction with the hand samples. There was often a discrepancy between hand samples and the samples from the sediment sampler. This was attributed to the fact that the hand sample was taken from the center of the weir notch while the sample obtained in the sediment sampler was removed from a plug in the side of the weir. Also, the hand sample valve was a gravity sample whereas the sampler used a pump which may have caused bottom agitation as it withdrew the sample. A workable relationship between hand and sediment sampler values was obtained and all samples from the sediment sampler were corrected to hand sample valves. During the 1971-72 season the sediment sampler was set up to take timed integrated samples. Using this technique the most important segment of the storm--the peak--was missed. During the 1972-73 wateryear a reed switch triggered by a notched wheel on the Stevens recorder made possible a better sampling distribution within each event. The samples were obtained and stored in sealed one pint milk bottles until being analyzed. The magnitude of error in sampling would be hard to estimate in that after sampled points were plotted some of the sediment discharge versus time curve had to be

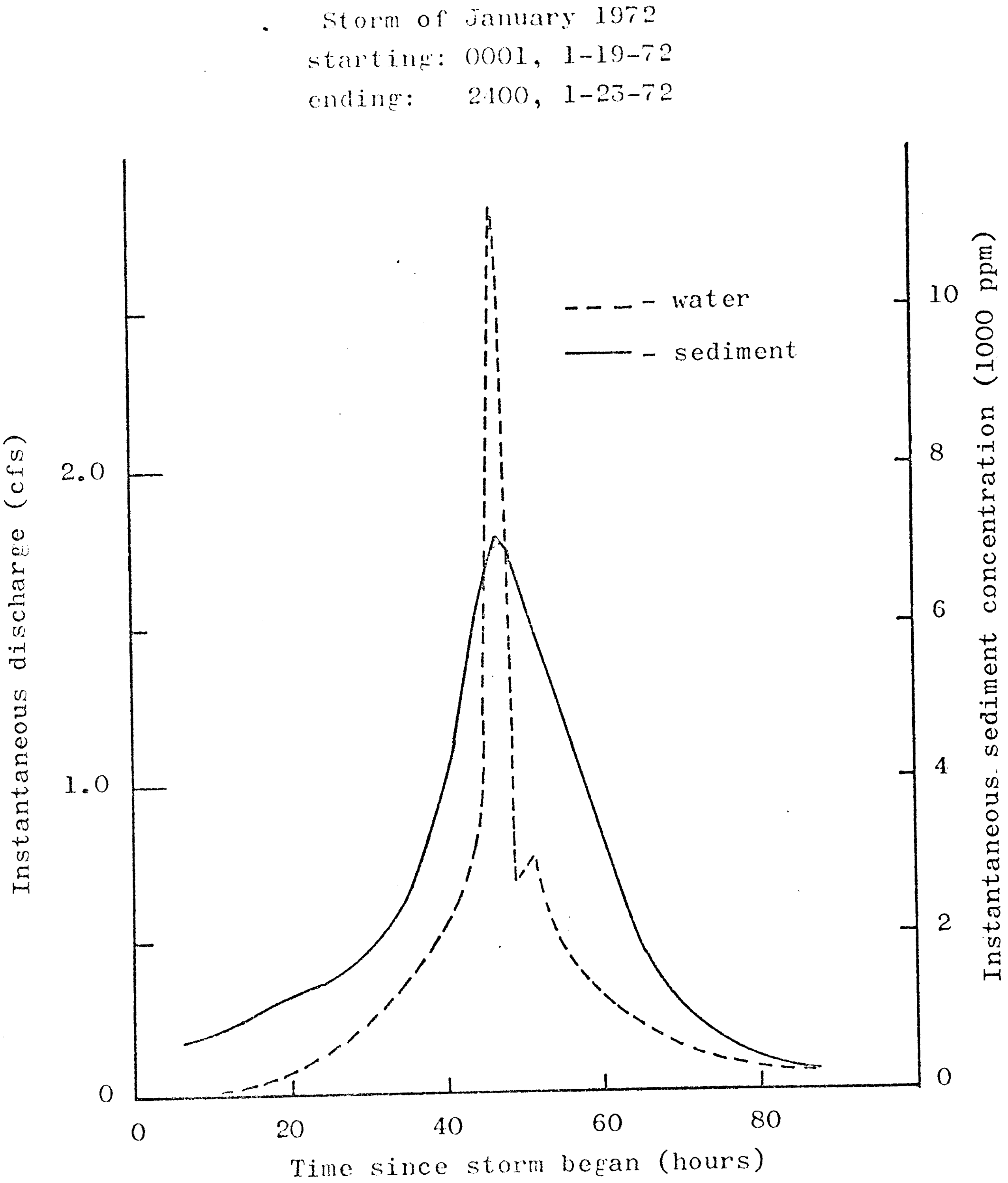


FIGURE 4: Typical relation between sediment concentration, water discharge, and time for Thompson watershed.

estimated. The sample points themselves were probably accurate within 10-15 per cent and the estimated parts of the curve were again reasonably accurate because procedures outlined in the Geological Survey Manual were used (Porterfield, 1972).

Soil Temperature. From a probe buried six inches soil temperature was recorded on a continuous recorder during the winter months. This device was installed during the 1972-73 year and replaced the Honeywell recorder used by Davis (1971). The purpose of this data was to determine the extent and duration of frozen ground during a runoff event (if the ground was frozen).

Additional Data. Data on the following parameters were also obtained, soil moisture, pan evaporation, water temperature, maximum and minimum air temperature, relative humidity, wind movement, and solar radiation. For further details on these parameters consult Davis (1971).

Experimental Procedure

The reliability of the prediction of sediment discharge is directly related to the care taken in analyzing the samples. Two methods were used to evaluate sediment concentration of the samples. For samples of high sediment concentration (greater than 3,000 ppm) the evaporation method was used. In this method the sample was allowed to settle, then the supernatant liquid was decanted and the sediment and remaining liquid were washed into a pre-weighed plate and evaporated in an oven at 105° C. For samples of smaller concentration the filtration method was used. In this system the sample was allowed to settle and the supernatant liquid was decanted. Then the remaining liquid and sediment were washed into a pre-weighed Gooch crucible with filter that was under a small vacuum. After filtration the crucible was put in the oven to dry. Using these systems had the following advantages. With the filtration system no dissolved solids corrections were needed since all dissolved solids in the native water passed through the filter. In the evaporation method, since such large quantities of sediment were present, the dissolved solids were relatively unimportant and thus could be ignored.

After drying, both samples were re-weighed and net sediment yield in ppm (parts per million) was obtained by the following formula:

$$\text{Concentration (ppm)} = \frac{\text{weight of sediment} \times 10^6}{\text{weight of sediment and water}}$$

A correction factor to convert ppm to milligrams/liter for concentrations greater than 16,000 ppm can be applied but was not because very few samples had concentrations in excess of this figure.

Data Collected. The following data were tabulated for each storm: precipitation in inches, runoff in inches, soil loss in tons per acre, average air temperature in degrees Fahrenheit, days since prior event, length of event in hours, difference in snow cover before and after event in per cent of area, maximum discharge in cfs, average antecedent air temperature in degrees Fahrenheit, antecedent precipitation as rainfall in inches, whether or not ground was frozen, and time code for the month occurring. This information was compiled for each event that had significant erosion and is given in Appendix E.

ANALYSIS OF DATA

Qualitative Description of Erosion Process

There have been three types of storm events which were monitored since Thompson watershed was instrumented. These events were:

1. Summer thunder shower;
2. Unfrozen ground (rain on snow and rain on saturated ground); and,
3. Frozen ground.

The only isolated thunderstorm occurred in July of 1966. This event had a peak runoff of 5.5 cfs (0.67 inches of runoff per hour) from .3" of rain and occurred in a five minute time span (Rosa, 1966). The watershed was in summer fallow and erosion was termed severe. Unfortunately, no data on exact losses are available. This event was a very good example of the intense isolated summer storms in this area although they account for very little of the total soil loss (as discussed in the literature review).

The type of events that contribute the greatest erosion on Thompson watershed is the rainfall on snow or rainfall on saturated ground. These events usually occur in the period of December to March and contribute a majority of soil loss from the watershed. Storage occurs in the snow pack until rainfall, during a warming period, melts the snow and causes runoff. Quite often, soon after this event takes place, another event of rain on saturated ground occurs and again soil loss occurs. In both cases precipitation continues until storage requirements are met (snow pack, soil, and/or surface storage) then runoff commences. The first event of the season (in December or January) seems to fill the soil to field capacity or greater. Through the rest of the winter almost any precipitation input will cause a runoff event and resulting soil loss. The moisture condition of the soil is important to the amount of soil that will be lost. The more saturated the soil the more easily it erodes. This cycle of snow build-up and melting or rain on saturated soil continues until about mid-March when precipitation events are less frequent and spring sun and wind begin to dry the soil. When the soil is dry on the surface it takes a very prolonged or intense storm to start the runoff process.

The amount of soil loss on the watershed for spring runoff events is dependent on several factors. An examination of the data together with some intuitive reasoning indicates that the most important factors are length of event, amount of precipitation during event, area covered by snow before and after event, and time since prior event. The length of the event coupled with the amount of precipitation gives an indication as to the relative intensity of the rainfall. An event of short duration and given amount of precipitation will be more intense and flashy than one of longer duration and the same amount of precipitation. Although rainfall intensity is rarely greater than .05-.15 iph, even small variations within this range give markedly differing results in storm characteristics.

The surface area covered by snow gives an index to the amount of surface water storage in the form of snow. A better measure would possibly have been actual snow course measurements but these would have to be measured on a daily basis to be of use. The time since the prior event indicates the condition of the soil. The longer the time between rainfall events the drier the soil will be and thus more resistant to erosion. These parameters do not include the physical characteristics (i.e. slope, soil type, channel length, etc.) or agricultural practices (i.e. type and method of cultivation, crops and crop rotation, etc.) on the watershed. This is because only one watershed was used, so no physical characteristics changed; and, since the watershed was farmed in the same manner every year, no agricultural practice parameters varied. This is not to say these parameters are unimportant. As discussed in the literature review, the physical characteristics and the farming practices utilized on a watershed are probably the most important variables in determining the amount of erosion occurring. Also, these parameters can be somewhat controlled by man and can make the difference between severe and moderate soil loss. However, inclusion of such variables in this study would require a much more detailed analysis plus data from many other watersheds.

The third type of event that occurred and was of interest was the frozen ground event. During the study period three frozen ground events occurred. These were all in the 1972-73 wateryear and all occurred in a one month period following December 21, 1972. Frozen ground events did not contribute a significant amount of erosion in comparison to other events but were of interest because of their large amount of runoff. Factors which most affect freezing of ground are amount of snow cover (insultative effect), soil moisture, temperature, and duration of cold. On the watershed each event was preceded by a period of subfreezing weather (-12° F to +7° F) for a length of several days. There was no snow cover and soil moisture was high, enabling the ground to be frozen to a depth in excess of 12 inches. A warming trend followed this cold spell and rain fell on the impermeable frozen ground. Although a significant amount of runoff occurred, relatively little soil loss was experienced. When the data from these events were analyzed there was very poor agreement between frozen and unfrozen ground events. For this reason the frozen ground data were not included in the forming of the predictive equation. Although there were insufficient data to perform a separate analysis of the frozen ground events, it is felt that they are not significant on this watershed as far as soil loss is concerned. The results of this study and a separate study of frozen ground events performed in this area in which only one occurred in five years show that the probability of occurrence of frozen ground events is small (Bloomsburg, 1969).

The types of erosion were approximately evenly divided between rill and gully erosion. The rill erosion occurred on the upper parts of the slope and the gully erosion occurred on the lower sections of the watershed.

Figure 5 is a topographic map of the watershed. Slope ranges from 21 per cent on the north facing side to approximately 5 per cent by the entrance to the A-frame shelter at the outlet of the watershed. There was very little settling out on the small slopes so no delivery ratio was used.

Development of the Predictive Equation

During the study period there were 12 events for which good information could be obtained. These events ranged in magnitude of soil loss from 0.02 tons/acre to 1.54 tons/acre. This, however, includes three frozen ground events that were excluded from the analysis (discussed in previous section). This left 9 events that could be analyzed. Only one event could be obtained from records prior to the 1971-72 wateryear. All events which had significant erosion during the study period from September, 1971, to March, 1973, were considered.

The events were analyzed on a storm basis and were considered to begin when suspended sediment was measurable, (usually greater than 500 ppm). After the sediment samples were analyzed and all other hydrologic data reduced, the following variables were considered for a predictive

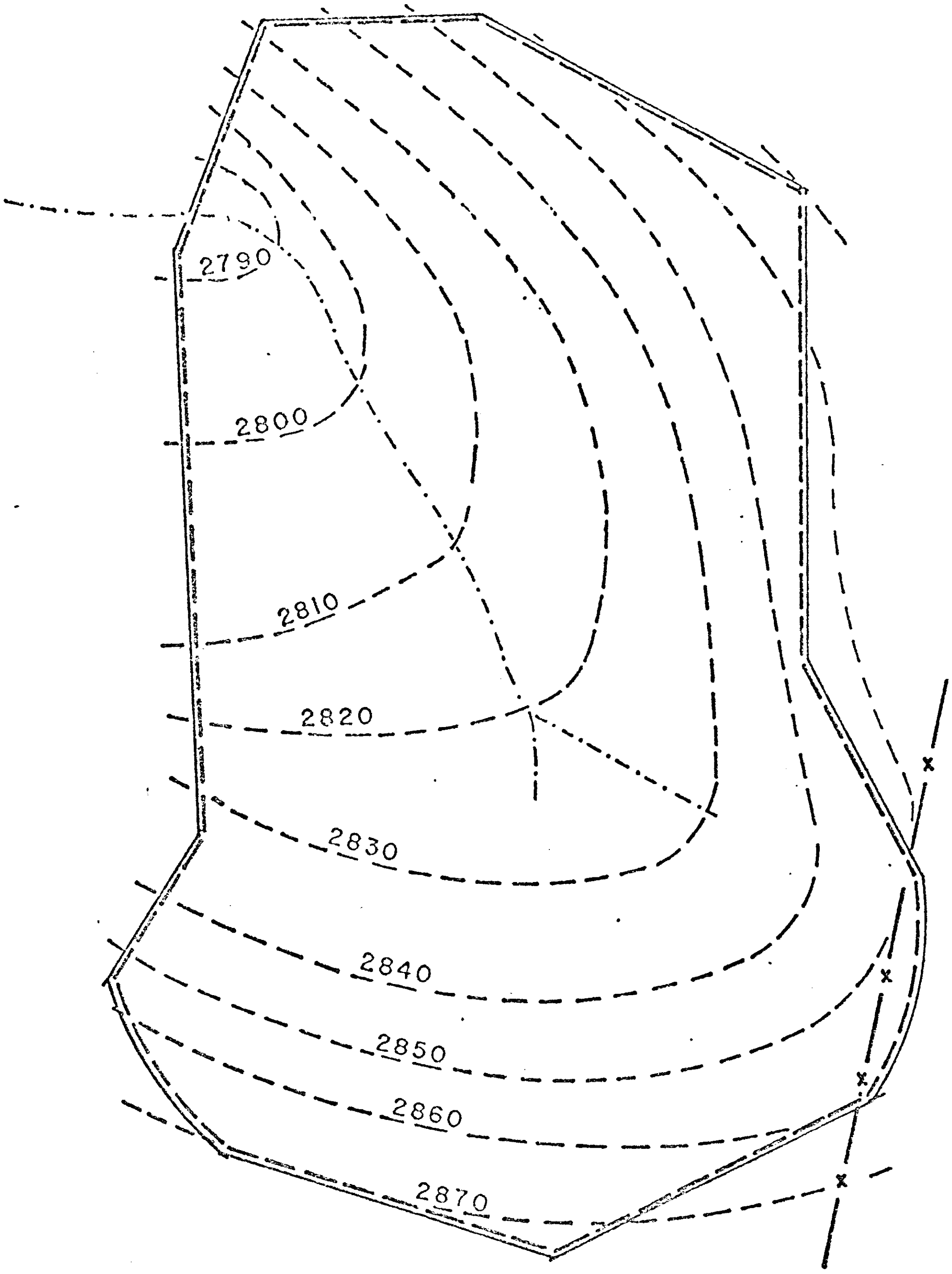


FIGURE 5: Topographic map of Thompson watershed (elevation in feet above mean sea level).

equation. The variables listed were selected because of their apparent effect on soil loss. These variables are:

1. Soil loss (tons/acre).
2. Soil loss (tons/inch of runoff).
3. Precipitation since runoff began (inches).
4. Antecedent precipitation as rainfall (inches).
5. Surface runoff (inches).
6. Maximum discharge (cfs).
7. Maximum discharge divided by total runoff (cfs/inches).
8. Average air temperature during event (°F).
9. Twenty-four hour antecedent air temperature (°F).
10. Difference in snow cover before and after event (% of area).
11. Days since prior event.
12. Length of storm (hours).
13. Time code for month occurring.

All of these parameters were obtained from the data taken from the instruments listed in the description of experiment section.

A multiple correlation matrix was derived from the data to find the variables which were highly correlated to soil loss. The following variables were found to be significantly correlated to soil loss (in tons/acre) and had correlation values above 0.5 (Table 2).

1. Precipitation since runoff began (inches).
2. Runoff (inches).
3. Difference in area of snow coverage (%).
4. Days since prior event.
5. Length of event (hours).

	Erosion	Precipitation	Runoff	Snow Diff.	Days Since Prior Event	Length of Storm
Erosion	1.000	0.962	0.869	0.543	0.743	0.759
Precipitation	0.962	1.000	0.831	0.410	0.806	0.800
Runoff	0.869	0.831	1.000	0.798	0.762	0.934
Snow Diff.	0.543	0.041	0.798	1.000	0.370	0.702
Days Since Prior Event	0.743	0.806	0.762	0.370	1.000	0.689
Length of Storm	0.759	0.800	0.934	0.702	0.689	1.000

TABLE 2: Correlation coefficients for significant variables (frozen ground data removed).

As explained earlier, these variables are intuitively significant in that they describe watershed characteristics that dominate soil loss. None of the other variables thought to be correlated to soil loss were statistically significant. The values of the significant variables for each event are given in Table 3. A similar correlation matrix was run on the logarithms of the data. The results were

Date Started	Erosion (Tons/Acre)	Precipitation (Inches)	Runoff (Inches)	Snow Difference (% Area)	Time Since Prior Event (Days)	Length of Storm (Hours)
3-23-71	0.23	0.11	0.09	0	10	4
1-19-72	1.54	1.66	3.20	70	300	120
2-15-72	0.96	0.87	2.42	95	21	108
2-27-72	0.60	0.67	0.98	5	7	60
3-05-72	0.61	0.38	1.34	99	4	48
3-12-72	1.07	1.00	0.65	0	5	30
12-21-72*	0.53	0.89	0.21	0	1	11
12-22-72*	0.02	0.53	0.04	0	1	6
1-12-73*	0.06	0.51	0.43	100	21	21
1-13-73	0.22	0.16	0.20	0	0	24
1-15-73	0.38	0.39	0.31	0	0	30
2-28-73	0.19	0.40	0.09	0	7	48

* Frozen ground events (excluded from regression analysis)

TABLE 3: Values of the significant variables used in regression analysis to form example predictive equation.

no better so for simplicity, the data were left untransformed. Noting Figure 6, except for frozen ground events, either independent variable (runoff or precipitation) has a fairly good graphical correlation to soil loss. This indicates that they should be included in the predictive equation. However, the two variables are not independent for this study (a fairly high cross correlation between runoff and precipitation) and, therefore, only one should be used in the predictive equation. Precipitation is much easier to measure and was chosen over runoff. The other variables were not cross correlated or were thought to be independent of each other.

Various combinations of these variables were used to form an equation through the use of multiple linear regression. For each iteration, soil loss was the dependent variable and various groups of independent variables were chosen from the significant parameters.

The Predictive Equation

A predictive equation with highly significant parameters is presented. Other combinations of parameters and their complete statistical tables are listed in the appendix. These also gave good results. The example equation and its variables are as follows:

$$SL = 1.13\ P + .0037\ SD - .00039\ DSP - .0047\ L + .087$$

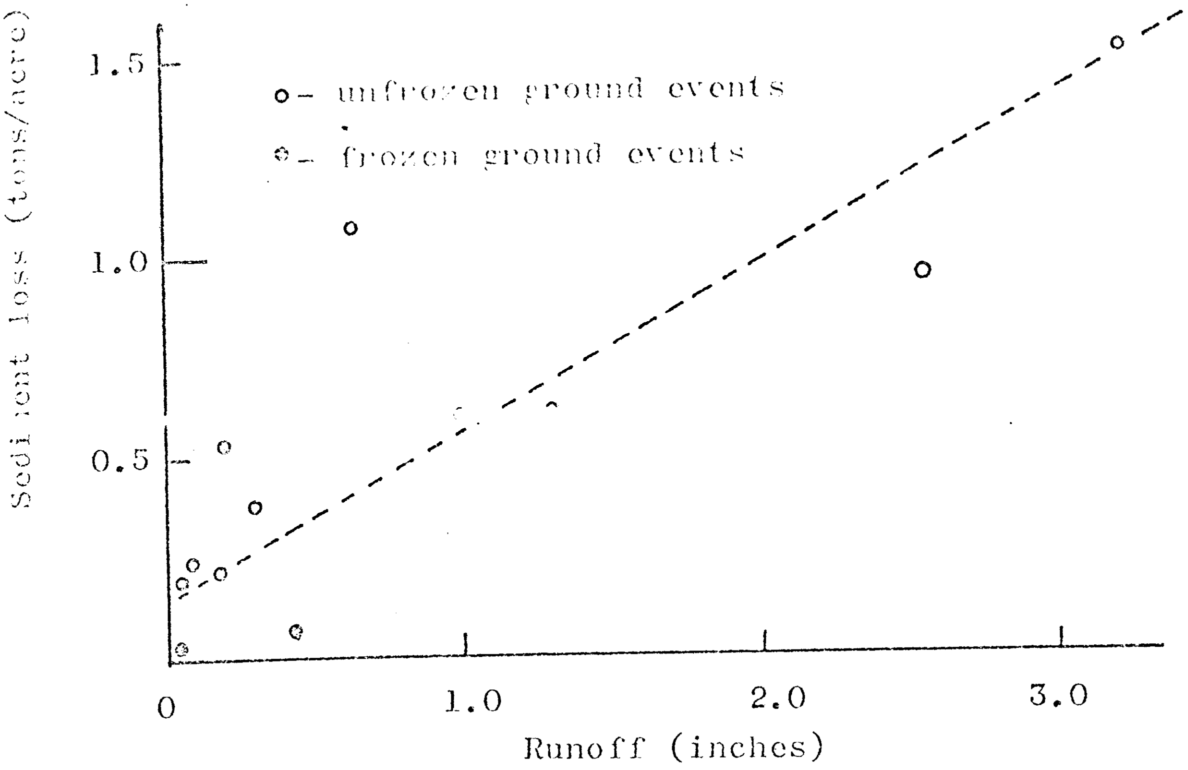
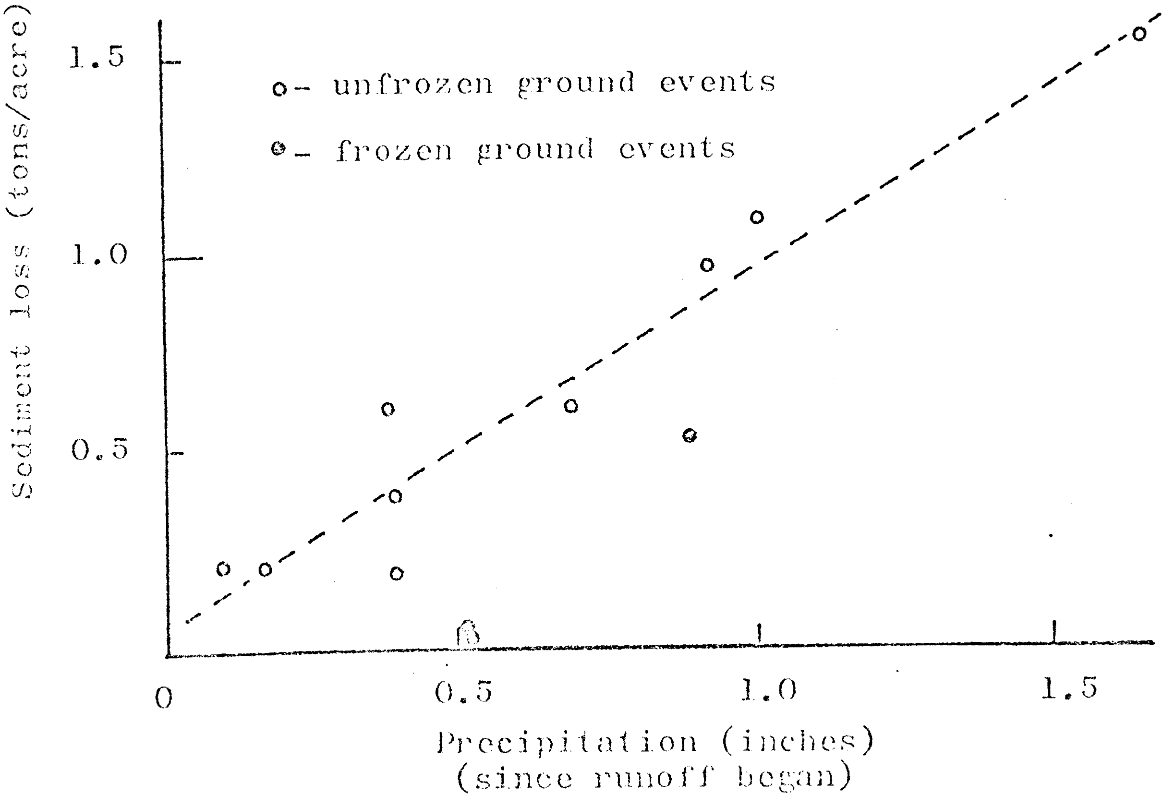


FIGURE 6: Runoff, precipitation, and soil loss relationships for events on Thompson watershed.



Where:

SL = soil loss (tons/acre).

P = precipitation since storm began (inches).

SD = difference in snow cover before and after event (% of area).

DSP = days since prior event.

L = length of storm (hours).

Statistical analysis of the equation is below:

Variable	Mean	Standard Deviation	Computed T Value	Level of Significance	Significant T at 4 degrees of Freedom
P	0.626	0.490	9.030	0.005	4.600
SD	29.880	44.300	3.860	0.010	3.700
DSP	39.330	97.950	0.770	Not	Significant
L	52.400	38.580	2.770	Not	Significant
SL	0.640	0.460			

R^2 = .984 for regression equation.

Computed R value = .99 (significant at the .01 level is .97).

Computed F value = 64.8 (significant F value at the .005 level is 23.155).

TABLE 4: Statistical analysis of the example predictive equation.

In words the above statistics indicate that the variables P and SD are significant while DSP and L are not. R squared = .98 means 98 per cent of the variation is explained by the regression equation. The computed F value (68.82) is greater than the corresponding F value listed in a table (23.155) indicating the equation is linear. Even though DSP and L are shown to be "non-significant", they can be included in the equation to improve the overall data fit. As can be seen from the statistical tests and their

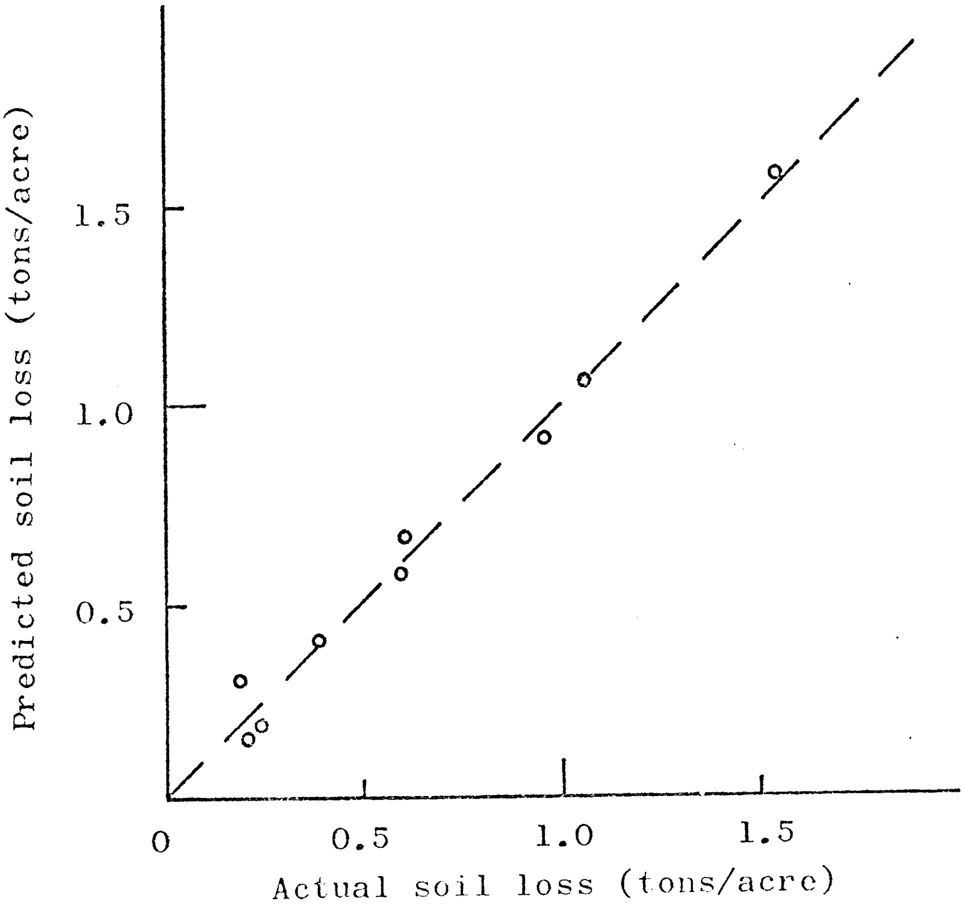


FIGURE 7: Computed versus actual soil loss for example prediction equation.

explanation, this equation fits the soil loss data very well on the watershed over this period of time (Figure 7). However, it is not always this easy to fit this type of data. As can be seen in Figure 8 which was taken from the Pullman SCS erosion data (McCool and Johnson, 1973), the relationship between runoff and soil loss (also precipitation and soil loss) is not always easily related (as compared to Thompson data).

It must be remembered that there are several limitations to this equation and others like it. To reiterate, since there are no parameters which involve watershed characteristics, only soil loss from this watershed can be predicted (or watersheds identical to it). For the same reason since no cropping or tillage practice factor is included, only watersheds of like management can be dealt with. This obviously limits the use of the equation to a great extent. There is a possibility that by using Kaiser's data (Table 1) as a base, relative magnitudes of soil loss could be predicted for differing cropping practices. However, with further research, precise information on the effect of watershed characteristics and cropping and tillage practices could be obtained for the Palouse region. These variables, which would possibly include such items as slope, slope length, slope aspect, soil type, cropping patterns, tillage practices, and erosion prevention measures, could be included in this type of equation to make it applicable to a more general area.

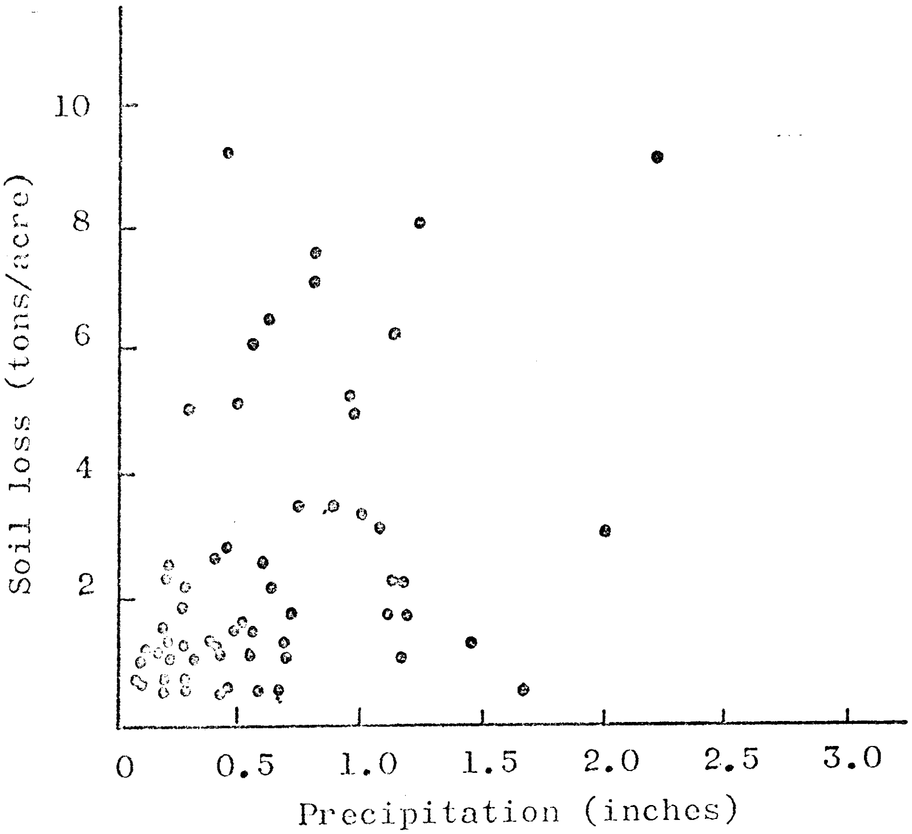
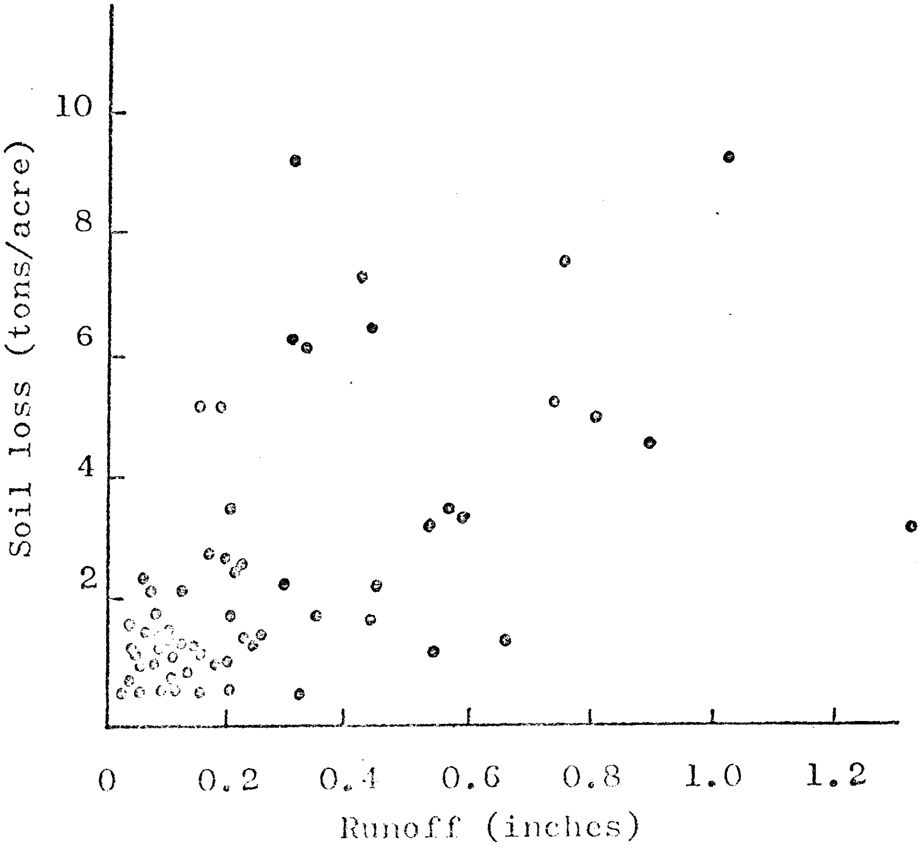


FIGURE 8: Selected events from Pullman Erosion Lab data (for non-frozen ground, no snow pack, and greater than 0.5 tons/acre).



Error Analysis

Since the equation was developed to fit the data, the equation has no error other than a lack of a perfect fit. All error for this equation comes from the error in the data collected. The relative magnitudes of these errors were discussed in the section on instrumentation and experimental procedure. However, this does not mean that the equation will predict future events as well as it fit past data. As more data are collected, a better equation can be developed using the same parameters. Statistically, the more data used, the more reliable is the equation developed.

USLE Comparison

Because of its wide use and continuing efforts to apply it to this area, the Universal Soil Loss Equation and its variables are presented and explained. Also, where possible, values for the variables will be given (or what data are necessary to obtain the values) for Thompson watershed. The Universal Soil Loss Equation is as follows:

$$A = R\ S\ K\ L\ C\ P$$

where: A = computed soil loss per unit area.

R = Rainfall Factor, number of erosion-index units in a normal year's rain. Reflects amount of kinetic energy dissipated by raindrops on the soil surface.

K = Soil-Erodibility Factor, erosion rate per unit of erosion-index for a specific soil in cultivated continuous fallow, on a 9 per cent slope 72.6 feet long.

L = Slope-Length Factor, the ratio of soil loss from the field slope length to that from a 72.6 foot length on the same soil type and gradient.

S = Slope-Gradient Factor, the ratio of soil loss from the field gradient to that from a 9 per cent slope.

C = Cropping-Management Factor, the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the factor K is evaluated.

P = Erosion-Control Practice Factor, the ratio of soil loss with contouring, strip-cropping, or terracing to that with straight-row farming, up and down slope.

A value of R = 9 will be used. This value was taken from work done at the Pullman Erosion Lab and is reasonable for the very low intensity rainfall in this area (McCool and Johnson, 1973). The K value will be equal to 0.33 (Wischmeier and Smith, 1965). This corresponds to an Ida silt loam which is similar to the Palouse silt loam. The

L and S values can be computed in two ways. One is:

$$LS = \text{sqrt}(\lambda)*(0.0076 + 0.0053\ s + 0.000765\ s^2)$$

λ = slope length as determined by method proposed by Williams and Berndt (1972)

λ = 277. ft. (See Appendix D)

s = average slope as determined by method proposed by Williams and Berndt (1972)

s = 15.5 per cent (See Appendix D)

This method is used by Wischmeier and gives an LS value of 4.53. However, Wischmeier suggests this equation is not valid at slopes greater than 10 per cent, and therefore, an alternative to this is a separate calculation of each variable. L is calculated from an equation proposed by Zingg (1940) and S by an equation developed by Wischmeier.

$$L = \frac{(\lambda)}{(72.6)}^{M}$$

M = 0.6 (for slopes greater than 10 per cent)

λ = 277. ft. (Same as previous λ)

L = 2.23

$$S = \frac{0.43 + 0.30\ s + 0.043s^2}{6.613}$$

s = 15.5%

S = 2.33

LS = 5.19

The P value for a practice of farming on the contour and slope between 12 and 18 per cent is 0.8. This leaves only the C value to evaluate. Values for C are tabulated for differing cropping patterns and tillage practices. However, finding one to fit conditions on Thompson watershed is quite difficult. Therefore, the equation will be solved using C as 1.0 and then the value of total annual soil loss that was obtained during the 1971-72 wateryear (4 tons/acre) will be put into the equation and C will be determined.

with $LS = 5.19$

$$A = R * K * L * S * P$$

$$= 9.0 * 0.33 * 5.19 * 0.08$$

$$= 12.34 \text{ tons/acre}$$

$A' = 4$ tons/acre (soil loss for 1971-72 wateryear on Thompson watershed)

$$C = \frac{A'}{A} = \frac{4.0}{12.34} = 0.32$$

for $LS = 4.53$

$$A' = R * K * L * S * P$$

$$= 9 * 0.33 * 4.53 * 0.8$$

$$= 10.76 \text{ tons/acre}$$

$$C = \frac{A'}{A} = \frac{4.0}{10.76} = 0.37$$

Examining the Table of Wischmeier and Smith (1965) for values of C that corresponds to this value, C = 0.36 is the closest. This C value is for ground in its second year of small grain, tilled conventionally, with residue left on surface and in a rough fallow during the erosion process. The conditions seem to closely resemble the conditions at Thompson; however, before it was computed it was not possible to find this value. Also there is a great range in these C values and finding one that corresponds so well is quite lucky.

This comparison to the USLE seems to give good results other than the difficulty in selecting the C value. However, there are some serious problems and the seemingly close correspondence of actual soil loss to predicted soil loss is more luck than anything else. The R value does not account for any water input as snow melt. Since this is an area of very low rainfall intensity, the R value is low; however, large amounts of precipitation may be stored on the watershed as snow and released by melting during a runoff event. This imparts a much greater amount of energy than reflected by this R value. Another problem with this equation is that it does not take into account timing of the event. As discussed in the Literature Review, events which occur close together will cause more soil loss because of the high soil moisture. In this area a majority of the events occur in the spring months when soil moisture is high. Little erosion occurs the rest of the year. Another problem is in developing a relation between length of slope, slope gradient, and soil loss (LS). The L and S relationship in the USLE is for straight, uniform slopes (non-convex or concave slopes). In this case a relationship developed by Williams and Berndt (1972) was used to compute average slope(s) and length of channel (λ) and thus L and S. However, these relationships were not tested for data of the type found in the Thompson watershed and thus are unproven in this area. The last problem is that of a delivery ratio. For Thompson watershed the delivery ratio was assumed to be 1.0 (what is eroded leaves the watershed). On other watershed complexes this would definitely not be true and would necessitate the calculation of delivery ratios.

These problems illustrate the fact that accurate prediction of soil loss in the Palouse by the "Universal Soil Loss Equation" is not feasible at the present.

RECOMMENDATIONS

Since it is doubtful that data will be collected in the near future on Thompson watershed, the recommendations are in the form of possible new research projects to be undertaken. These were developed while analyzing data from this study and in discussions with persons involved in erosion work. Some have been mentioned in other parts of this thesis.

1. Study of how watershed characteristics such as slope, slope length, slope aspect, soil type, elevation, and other hydrologic and watershed parameters influence soil loss in the Palouse region.
2. Study of how crop, cropping patterns, and tillage practices affect soil loss in the region. This should especially be undertaken for the most popular crops in the area such as wheat, barley, dry peas, and alfalfa. Other less common crops could be studied later.
3. Comparison of data collected on Thompson watershed to data from other watersheds to determine whether Thompson watershed and the data collected are truly representative of this area.

4. Study of the amounts of erosion attributable to sheet, rill, and gully erosion and a determination as to where each occurs on a typical Palouse watershed.
5. Study of cohesive strengths of soil in fluid shear. This information could possibly be used in developing a soil loss equation from an open channel point of view.
6. Develop improved remote sampling equipment which would facilitate data collection. A unit which could be easily transported to different locations and take accurate samples would be especially useful.
7. Study of raindrop size and possible raindrop affect on detachment of soil particles. Before any type of physical model could be developed for this area such information is necessary.
8. Build a physical model of a watershed to study overland flow, soil detachment, soil transportation, and other hydrologic parameters.

CONCLUSIONS

The following conclusions can be drawn from the analysis of the data collected:

1. Soil loss can be predicted from hydrologic parameters for a watershed. On Thompson watershed and the Palouse region the following varaibles are important in predicting soil loss: amount and timing of precipitation, runoff, snow melt, and the moisture condition of the soil.

2. The most severe and consequental erosion in the Palouse occurs during winter and spring runoff events when soil moisture is high and soil resistance to erosion low.

3. Soil detachment and transportation seem to be accomplished by running water. A detachment of soil by freeze-thaw cycles is also possible.

4. Thompson watershed data from pre-1971-72 records and the 1972-73 data were sparse but seemed to substantiate the date for 1971-72.

6. Frozen ground events on this watershed contributes less to soil loss than a similar event on unfrozen ground.

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APPENDIX A

Project Data (1971-73)

MONTHLY PRECIPITATION (1968-1973)**

Thompson Watershed, Moscow

(inches)

MONTH	68-69	69-70	70-71	71-72	72-73
OCT	----	0.72	1.42	1.14	1.41
NOV	----	0.28	2.71	3.01	1.40
DEC	1.43	1.91	1.39	4.10	4.41*
JAN	3.60	5.97	2.36	3.49	2.13*
FEB	0.21*	1.83	1.75	2.23	0.89
MAR	0.66	1.58	1.64	4.03	1.14
APR	1.76	0.15*	1.08	1.28	----
MAY	1.06	0.84	1.59	2.42	
JUN	1.20	1.83	3.78	0.62	
JUL	0.00	1.77	0.67	0.82	
AUG	0.00	0.00	1.00	0.72	
SEP	0.66	1.07	1.81	0.98	
sum	----	17.95	21.20	24.84	----

* Some Estimated Values

** Data From Shielded Rain Gage

DAILY SNOW COVER (1971-1972)

Thompson Watershed, Moscow

(percent of area)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				100	100	1						
2				100	100	100						
3				100	100	100						
4				100	100	--						
5				100	100	70						
6			100	100	100	1						
7			100	100	100	--						
8			100	100	100	0						
9			100	100	100	0						
10			100	100	99							
11			100	100	--							
12			100	100	90							
13			100	100	80							
14			100	100	100							
15			100	100	85							
16			100	100	15							
17			100	100	--							
18			100	100	--							
19			100	100	--							
20			100	90	5							
21			100	45	5							
22			100	40	5							
23			100	--	4							
24			100	100	2							
25			100	100	--							
26			100	100	--							
27			100	100	--							
28			100	100	2							
29			100	100								
30			100	100								
31			100	100								

DAILY SNOW COVER (1972-1973)

Thompson Watershed, Moscow

(percent of area)

AY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1												
2												
3				0								
4				10								
5				100								
6				100								
7				100								
8				100								
9				100	0							
10				100	100							
11			0	90	100							
12			100	80	90							
13			100	50	80							
14			100	10	75							
15			100	0	--							
16			100		--							
17			100		--							
18			50		--							
19			0		--							
20					--							
21					10							
22				0	0							
23				25								
24				0								
25												
26												
27												
28												
29												
30												
31												

DAILY SURFACE RUNOFF (1971-1972)

Thompson Watershed, Moscow

(inches)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1					.005	.026						
2					.004	.121						
3					.003	.116						
4					.002	.069						
5						.450	.002					
6						1.272	.003					
7						.088	.002					
8						.050						
9						.028						
10						.024						
11						.045						
12				.005*	.013	.109	.004					
13				.005*	.283	.572						
14				.005*	.129	.163						
15				.005*	.373	.073						
16				.005*	1.153	.045	.004					
17				.005*	.137	.023						
18				.007	.567	.141						
19				.166	.196	.051						
20				1.470	.117	.031						
21				1.12	.077	.020						
22				.302	.109	.022						
23				.175	.078	.013						
24				.099	.069	.024						
25				.066	.036	.017						
26				.036	.025	.009						
27				.024	.609	.005						
28				.016	.225	.003						
29				.013	.105	.001						
30				.012								
31				.007								
SUMS				3.543	4.315	3.611	.015					

* Estimated Runoff

DAILY SURFACE RUNOFF (1972-1973)

Thompson Watershed, Moscow

(inches)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1						.070						
2						.002						
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13				.430								
14				.200								
15				.100								
16				.210								
17												
18			.070									
19			.190									
20			.080									
21			.290		.010*							
22			.040									
23												
24												
25												
26												
27												
28					.010*							
29												
30												
31												
sums			0.670	0.940	0.020	0.072						

* Estimated Runoff

MAXIMUM DAILY TEMPERATURE (1971-1972)

Thompson Watershed, Moscow

(Fahrenheit)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	58	40	36	37	14	33	54	59	70	74	86	83
2	64	43	35	33	17	39	44	63	76	77	84	83
3	68	44	36	19	25	35	52	69	62	77	86	86
4	75	45	32	22	29	41	51	70	74	90	93	88
5	80	40	42	30	32	46	55	68	80	92	96	66
6	80	38	32	40	34	45	50	67	89	95	100	65
7	77	40	23	36	41	40	44	56	76	85	102	71
8	78	44	31	36	38	51	44	45	75	81	104	78
9	79	56	34	36	38	64	43	50	76	68	96	64
10	77	53	32	29	38	55	49	57	62	70	95	67
11	63	52	25	37	35	52	41	64	58	69	90	70
12	62	48	31	29	39	46	41	68	--	89	85	51
13	55	43	29	25	37	57	40	76	63	81	82	67
14	48	42	33	28	33	50	47	71	74	81	90	76
15	51	37	29	36	40	57	47	67	84	83	76	79
16	54	35	35	37	44	64	40	70	63	87	77	76
17	53	36	39	36	35	65	39	54	65	84	68	69
18	54	34	37	36	49	49	44	56	67	79	85	74
19	43	41	33	39	50	45	51	74	73	54	76	57
20	49	49	33	41	40	52	53	67	73	72	91	68
21	51	45	37	39	42	56	46	49	69	64	89	67
22	57	41	42	38	42	62	46	57	74	82	69	57
23	44	35	37	34	38	43	66	57	61	86	72	51
24	46	42	42	29	39	47	58	54	52	81	81	42
25	45	41	34	30	40	33	48	63	54	86	89	52
26	46	36	32	13	35	35	57	71	63	87	92	56
27	34	46	24	16	51	37	71	78	74	88	97	51
28	34	36	21	15	55	43	54	83	87	95	98	54
29	34	39	24	22	42	46	44	86	85	97	93	61
30	35	38	27	26	--	54	49	86	81	94	78	75
31	32	--	34	22	--	61	--	75	--	87	79	--
AVG	55.7	42.0	32.6	30.5	37.7	48.5	48.9	65.5	71.1	81.8	87.1	66.8

MAXIMUM DAILY TEMPERATURE (1972-1973)

Thompson Watershed, Moscow

(Fahrenheit)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	71	42	48	36	39	44						
2	73	47	40	34	40	47						
3	74	53	25	28	39	47						
4	70	51	14	19	36	43						
5	64	47	16	23	36	45						
6	66	48	15	13	36	53						
7	71	50	12	16	42	52						
8	74	43	3	19	36	53						
9	63	47	7	18	40	46						
10	48	49	9	26	35	42						
11	64	52	16	34	38	44						
12	71	40	17	38	39	39						
13	49	47	16	45	40	36						
14	57	48	24	49	42	43						
15	60	48	28	48	39	52						
16	63	51	36	43	41	54						
17	62	41	37	42	39	38						
18	64	42	42	40	40	45						
19	61	44	44	34	40	55						
20	62	36	43	33	45	44						
21	60	40	46	35	50	46						
22	65	38	40	37	50	50						
23	56	32	40	37	51	54						
24	55	37	39	--	45	58						
25	61	40	40	35	49	56						
26	46	40	47	31	53	45						
27	46	35	45	33	53	--						
28	37	37	34	39	50	--						
29	35	35	31	39		--						
30	41	37	31	40		--						
31	38		31	37		--						
avg	58.9	43.2	29.5	33.4	42.3	47.0						

MINIMUM DAILY TEMPERATURE (1971-1972)

Thompson Watershed, Moscow

(Fahrenheit)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	32	31	28	22	-9	27	42	27	47	38	52	43
2	34	29	31	8	-1	31	25	42	45	53	50	45
3	38	37	21	9	12	21	26	37	46	51	46	47
4	44	24	27	14	19	24	42	39	45	56	50	50
5	48	18	29	21	21	33	43	40	46	49	53	51
6	44	26	6	28	30	26	32	48	50	57	56	41
7	41	26	--	26	33	26	32	45	57	47	59	39
8	40	24	14	23	29	35	30	35	55	47	58	42
9	45	39	26	26	24	45	26	39	59	41	63	38
10	41	41	22	23	27	40	31	40	45	36	55	33
11	39	44	11	26	30	37	33	39	40	49	54	41
12	37	39	22	16	34	41	30	43	38	55	54	44
13	31	33	22	10	28	40	27	45	44	48	51	44
14	28	30	25	12	25	34	33	51	42	42	52	41
15	25	34	6	27	32	35	38	47	49	47	49	43
16	27	32	13	30	29	41	28	47	38	46	46	50
17	23	32	33	27	30	41	27	37	36	47	47	43
18	26	31	29	26	35	40	25	38	45	49	43	40
19	36	33	26	35	39	37	27	37	42	46	49	43
20	34	38	29	30	29	33	33	49	44	45	52	41
21	30	34	29	35	30	43	29	44	45	46	51	35
22	43	26	31	30	30	40	25	41	42	46	49	32
23	36	30	30	23	30	31	37	36	45	55	43	35
24	31	33	33	22	30	29	38	37	39	51	47	31
25	31	31	25	13	31	24	32	34	40	46	50	31
26	28	32	11	4	30	26	29	40	40	47	54	35
27	22	32	6	-6	34	26	42	54	43	50	53	31
28	14	33	10	-6	41	30	31	59	50	47	56	32
29	12	34	16	1	29	28	24	59	46	55	55	31
30	26	30	17	13	--	31	23	56	44	59	45	45
31	26	--	25	5	--	33	--	56	--	60	38	--
AVG	32.6	31.9	21.1	18.5	26.9	33.2	31.3	43.3	44.9	48.7	51.0	39.9

MINIMUM DAILY TEMPERATURE (1972-1973)

Thompson Watershed, Moscow

(Fahrenheit)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	39	37	32	25	25	33						
2	40	38	16	17	31	31						
3	42	41	11	12	32	32						
4	35	40	-4	3	23	30						
5	30	31	-1	8	22	31						
6	30	34	8	-7	18	34						
7	36	38	-8	-8	20	36						
8	40	32	-12	0	16	31						
9	44	35	-12	-1	27	35						
10	42	33	-5	11	24	32						
11	41	36	9	24	25	27						
12	40	35	-3	33	20	28						
13	42	35	-5	35	21	30						
14	38	37	5	39	24	27						
15	33	36	7	39	29	29						
16	36	37	24	31	32	31						
17	38	36	33	31	32	28						
18	36	32	35	31	28	27						
19	33	31	38	23	28	37						
20	32	30	38	22	25	38						
21	43	26	39	19	28	36						
22	40	26	36	25	30	32						
23	33	29	37	31	32	32						
24	26	31	31	--	37	31						
25	38	31	32	26	37	34						
26	34	27	39	19	39	31						
27	29	23	34	19	34	--						
28	27	24	28	27	38	--						
29	26	25	20	31		--						
30	24	30	26	31		--						
31	28		18	25		--						
avg	35.3	32.5	17.6	20.7	27.8	33.0						

MEAN DAILY HUMIDITY (1971-1972)

Thompson Watershed, Moscow

(percent)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	66	84	84	90	93	87	78	45	58	45	46	44
2	70	72	66	70	80	100	57	44	52	38	48	46
3	64	54	44	64	59	91	47	50	90	41	45	43
4	68	62	98	85	60	83	64	55	70	40	37	43
5	58	70	100	96	98	88	86	51	53	50	32	62
6	66	54	78	90	100	72	87	54	49	56	30	53
7	64	70	86	89	93	69	73	80	77	60	33	60
8	65	76	88	86	92	65	69	100	84	60	33	57
9	60	46	94	82	90	50	70	87	77	69	37	65
10	66	66	98	91	70	81	64	81	96	64	31	53
11	78	46	96	88	81	90	96	78	77	78	41	47
12	68	95	92	85	92	96	95	70	--	63	30	97
13	70	96	98	67	93	96	90	60	66	68	31	67
14	84	94	100	93	94	86	88	65	68	60	35	60
15	56	100	98	70	96	83	89	65	66	55	57	49
16	34	100	96	63	74	81	82	64	76	50	46	45
17	46	100	81	90	91	75	86	89	68	53	52	49
18	48	100	88	96	86	88	74	66	67	65	60	43
19	68	94	96	92	65	85	62	59	63	92	54	62
20	68	84	100	92	88	71	76	64	70	72	49	66
21	60	88	88	89	73	57	78	99	74	90	47	66
22	55	88	84	94	86	69	58	85	70	65	70	69
23	94	82	76	94	88	75	37	72	80	52	62	81
24	88	94	58	95	94	75	58	75	95	67	60	95
25	74	90	92	97	83	87	76	70	91	55	58	70
26	70	96	94	81	85	83	67	50	75	48	--	59
27	70	94	94	82	93	80	45	47	73	42	--	62
28	48	97	92	93	82	84	65	42	54	37	--	56
29	63	100	98	90	75	80	69	42	50	36	--	52
30	66	96	96	79	--	70	59	60	46	38	45	39
31	92	--	97	82	--	65	--	58	--	44	42	--
AVG	66.0	82.9	88.7	85.7	84.6	79.4	71.5	65.4	70.2	56.6	44.5	58.7

MEAN DAILY HUMIDITY (1972-1973)

Thompson Watershed, Moscow

(percent)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	59	86	68	75	65	73						
2	61	98	98	77	47	63						
3	61	93	84	79	49	56						
4	62	99	76	76	68	76						
5	60	91	86	79	70	68						
6	56	83	90	78	65	57						
7	55	73	92	71	40	72						
8	56	99	94	52	56	64						
9	81	87	92	56	56	71						
10	99	86	87	51	77	72						
11	84	88	85	79	78	68						
12	81	99	89	81	76	76						
13	88	84	87	83	74	80						
14	76	87	88	71	69	72						
15	80	95	69	67	80	56						
16	80	89	85	85	67	54						
17	84	99	96	81	76	71						
18	80	99	96	70	73	57						
19	82	94	100*	74	63	42						
20	83	99	100*	77	67	69						
21	82	96	100*	77	63	73						
22	80	90	100*	67	62	57						
23	77	90	98	45	55	58						
24	86	99	97	49	52	52						
25	78	99	85	72	73	49						
26	95	98	--	72	55	62						
27	87	93	--	58	66	--						
28	97	89	68	47	74	--						
29	99	98	71	46		--						
30	93	90	75	68		--						
31	92		78	79		--						
avg	78.5	92.0	87.4	69.0	65.0	64.0						

* Estimated

AVERAGE SOIL TEMPERATURE (1972-1973)

Thompson Watershed, Moscow

(Fahrenheit at 6")

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1			29	28	27	36						
2			30	27	27	35						
3			29	26	27	--						
4			28	26	27	34						
5			27	26	27	35						
6			26	25	27	35						
7		--	24	24	28	37						
8		36	22	23	25	38						
9		37	21	23	27	37						
10		37	20	24	27	35						
11		38	21	26	28	34						
12		36	22	27	27	32						
13		37	23	28	26	31						
14		38	24	28	27	35						
15		37	25	28	28	--						
16		37	26	28	28	--						
17		37	27	28	28	35						
18		36	28	28	28	--						
19		35	28	27	28	--						
20		33	--	27	28	37						
21		33	30	27	28	38						
22		31	30	27	28	--						
23		30	30	28	28							
24		30	--	28	--							
25		30	--	28	29							
26		32	32	27	32							
27		30	33	27	36							
28		29	30	26	38							
29		29	28	26								
30		29	27	26								
31			28	27								

CORRECTED PAN EVAPORATION (1971-1972)

Thompson Watershed, Moscow

(inches)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1									.26	.30	.32	.30
2									.26	.33	.29	.29
3									.08	.32	.33	.32
4									.19	.30	.36	.32
5									.25	.26	.38	.14
6									.32	.29	.37	.22
7									.19	.30	.38	.16
8									.14	.26	.36	.28
9									.16	.17	.41	.26
10									.04	.17	.32	.19
11									.05	.11	.26	.17
12									.05	.25	.29	.03
13									.05	.26	.28	.13
14									.20	.28	.26	.19
15									.24	.30	.16	.25
16									.25	.16	.26	.34
17									.21	.32	.17	.29
18									.17	.14	.22	.21
19									.21	.08	.17	.19
20									.16	.07	.26	.14
21									.17	.09	.26	.17
22									.33	.22	.20	.09
23									.09	.30	.16	.07
24									.11	.14	.19	.01
25									.03	.29	.25	.07
26								.30	.13	.30	.30	.19
27								.36	.16	.26	.33	.13
28								.42	.29	.36	.37	.13
29								.46	.28	.34	.36	.14
30								.28	.29	.33	.37	.22
31								.36	--	.26	.25	--
SUMS								2.18	5.35	7.56	8.89	5.64

DAILY AVERAGE WATER TEMPERATURE (1971-1972)

Thompson Watershed, Moscow

(Fahrenheit)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1									68	69	75	67
2									68	68	73	65
3									57	69	70	67
4									66	75	73	68
5									71	78	74	59
6									--	80	76	55
7									71	74	78	55
8									72	73	79	61
9									74	65	80	57
10									58	62	76	52
11									57	67	75	57
12									52	73	73	50
13									59	74	71	57
14									65	72	73	61
15									75	73	69	60
16									66	71	68	60
17									63	74	65	59
18									64	64	67	57
19									67	54	66	49
20									65	60	74	48
21									67	59	74	48
22									68	69	61	47*
23									61	72	62	43
24									53	67	68	41*
25									52	72	73	46*
26									56	73	75	48
27									68	74	76	46*
28									75	74	76	43*
29									74	77	73	48*
30									73	77	67	55
31									--	73	63	--
SUMS									1882	2182	2223	1629
MEANS									65	70	72	54

* Air temperature lower than 32°F during day

DAILY WIND MOVEMENT IN MILES (1971-1972)

Thompson Watershed, Moscow

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1									38	25	41	42*
2									30	41	43	42*
3									39	38	35	42*
4									32	26	21	42*
5									31	7	14	91
6									29	25	26	86
7									15	19	22	34
8									29	39	16	69
9									28	43	19	101
10									50*	12	13	39
11									50*	18	19	49
12									50*	50	22	53
13									50*	69	40	52
14									50*	29	18	36
15									26	25	25	55
16									59	36	22	137
17									33	27	29	145
18									43	33	10	38
19									26	32	5	183
20									31	30	15	101
21									30	10	11	107
22									14	33	33	77*
23									39	46	14	77*
24									28	25	13	77*
25								--	--	23	5	77*
26								76	23	26	7	77*
27								90	19	31	9	50*
28								64	30	20	13	50*
29								83	16	7	53	50*
30								--	21	17	71	50*
31								--	--	19	42*	--
SUMS								313	959	881	726	2129
MEANS								78	33	28.	23	71

*Total miles for this period was distributed uniformly over these days.

APPENDIX B

Computer Programs

```
                                 BIG G

                        PROGRAM     BY LEE DRUFFEL 1972


      DIMENSION DATE(80),T(80),QI(80),GH(80),DT(80),Q(80),RI(80),TC(80),
     .TK(80),DAY(10),X(50),Y(50)
C
C  .... THE FOLLOWING DATA IS THE CALIBRATION FOR THE WEIR IN USE
C           X=GAUGE HEIGHT (FT.)  Y=DISCHARGE (C.F.S.)
C
      CALL INPUT (X,NX)
      CALL INPUT (Y,NY)
C  ***************************************************************
C
C       THIS PROGRAM IS USED TO COMPUTE RUNOFF IN INCHES
C      ON A DAY BASIS FOR ANY WATERSHED WHEN THE CORRECT PHYSICAL
C      PARAMETERS ARE INTRODUCED.
C
C       THE METHOD OF COMPUTATION IS THE MIDINTERVAL TYPE
C       CALCULATION TAKEN FROM THE U.S.G.S. PUBLICATION
C       ON COMPUTATION OF SEDIMENT YEILD.
C
C       ALL INPUT TO THIS PROGRAM IS OF THE FREEFORM TYPE (CALL INPUT)
C
C        REQUIRED INPUT:
C
C             1) DISCHARGE RATING CURVE
C             2) IDENTIFICATION CARD (DATE)
C             3) DATE OF EVENT (DAY)
C             4) CLOCK TIME (TC)
C             5) GAUGE HEIGHT (GH)
C
C      THE DATA IS INPUT IN THE FOLLOWING MANNER
C
C         DATA CARD SET ONE- GAUGE HEIGHTS FOR WEIR CALIBRATION
C         DATA CARD SET TWO- CORRESPONDING DISCHARGES FOR WEIR
```

```
C       DATA CARD THREE- IDENTIFICATICN NEEDED
C                        (I.E. WATERSHED NAME, WATER YEAR, ETC.)
C       DATA CARC FOUR- MONTH AND DAY CF EVENT
C                        (I.E. JAN 21)
C       DATA CARC SET FIVE- CLCCK TIME AND GAUGE HEIGHT
C                        (FOR EACH DATE THE CLCCK TIME AND
C                        GAUGE HEIGHT TAKEN FRCM THE HYDROGRAPH
C                        CN SAME SET OF DATA CARCS ALTERNATING
C                        CLOCK TIME AND GAUGE HEIGHT (I.E.
C                        0000 11.55 240C 11.65 )
C
C     FCR MORE THAN CNE CAYS DISCHARGE REPEAT CATA SETS FCUR
C     AND FIVE FOR EACH CAY
C
C
C     THE FOLLOWING VARIABLES ARE USED IN THE PRCGRAM:
C          TK - INPUT VECTOR OF CLCCK TIMES AND GAUGE HEIGHTS
C          TC - CLCCK TIME SINCE STCRM BEGAN
C          GH - GAUGE HEIGHT
C           X - GAUGE HEIGHT CALIBRATION
C           Y - DISCHARGE CALIBRATICN
C           T - CLCCK TIME IN DECIMAL FCRM
C          CI - INSTANTANEOUS DISCHARGE
C          CT - DIFFERENCE IN TIME INTERVALS
C        DATE - ICENTIFICATICN
C         DAY - MCNTH AND DAY OF EVENT
C          RI - RUNOFF IN INCHES (INSTANTANEOUS)
C        RSUM - TCTAL RUNOFF FOR DAY
C        AREA - WATERSHED AREA IN ACRES
C
C      REF: "CCMPUTATICN OF FLUVIAL SEDIMENT DISCHARGE", BY GEORGE
C           PORTERFIELD. U.S.G.S. PUBLICATICN. 1972
C
C***************************************************************
      READ(1,1)DATE
    1 FCRMAT(8CA1)
      WRITE(3,75)CATE
```

```
   75 FCRMAT('1',//,2X,'RUNCFF FOR TIME PERICD (CATES) :',80A1)
      WRITE(3,80)
   80 FCRMAT(//,2CX,'CATE',7X,'CLCCK TIME',4X,'TIME INTERVAL',4X,'GAUGE
     .HEIGHT',4X,'CISCHARGE',6X,'RUNCFF',/,23X,'(HOURS)',8X,'(HOURS)',11
     .X,'(FT.)'8X,'(C.F.S.)',6X,'(IN.)',// )
      CC 66 K=1,1CC
      READ (1,2) CAY
    2 FCRMAT(1CA1)
      WRITE(3,85) DAY
   85 FCRMAT(16X,1CA1,/)
      CALL INPUT (TK,N)
        KI=N-1
      L=N/2
      DC 1C I=2,N,2
   10 GH(I/2)=TK(I)
      DC 20 I=1,KI,2
   20 TC((I+1)/2)=TK(I)
C
C  .... T(I) IS THE TIME IN DECIMAL FORM
C
      DC 15 I=1,L
      ZIP=(TC(I)*C.C1)
      T1=AINT(ZIP+C.C1)
   15 T(I)=T1+((ZIP-T1)*1.666666666)
      LL=L-1
      DC 3C I=2,LL
   3C CT(I)= (T(I+1)-T(I-1))*0.5
      DT(1)=T(2)*C.5
      CT(L)=(T(L)-T(L-1))*0.5
C
C  .... COMPUTE THE INSTANTANEOUS CISCHARGE FOR EACH GAUGE HEIGHT
C
       DO 40 N=1,L
      J=2
   69 IF (GH(N)-X(J))122,121,12C
  120 J=J+1
      GC TO 69
```

```
  121 QI(N)=Y(J)
      GO TO 40
  122 QI(N)=Y(J-1)+(Y(J)-Y(J-1))/(X(J)-X(J-1))*(GH(N)-X(J-1))
   40 CONTINUE
C
C  .... COMPUTE THE DISCHARGE (CUBIC FEET) FOR EACH TIME INTERVAL
C
      C=3600.
      DO 50 I=1,L
   50  Q(I)=C*QI(I)*DT(I)
C
C  .... COMPUTE THE RUNOFF IN INCHES FOR EACH TIME INTERVAL
C
C  .... AREA = DRAINAGE AREA IN ACRES
C
      AREA=8.20
      AI=12./(AREA*43560.)
      DO 60 I=1,L
   60 RI(I)=Q(I)*AI
C
C  .... COMPUTE THE TOTAL RUNOFF FOR THE TIME PERIOD
C
      RSUM=0.0
      DO 70 I=1,L
   70 RSUM=RI(I)+RSUM
       DO 100 I=1,L
      WRITE(3,90)TC(I),DT(I),GH(I),QI(I),RI(I)
   90 FORMAT(33X,F7.0,8X,F7.3,10X,F7.3,5X,F12.3,8X,F8.6)
  100 CONTINUE
      WRITE(3,110)RSUM
  110 FORMAT(//,66X,'TOTAL RUNOFF IN',/,65X,'INCHES FOR PERIOD=',F10.5,/
     ./)
   66 CONTINUE
  200 STOP
      END
```

```
RUNOFF FOR TIME PERIOD :
        *** THOMPSON WATERSHED RUNOFF DATA 1972-73 WATER YEAR ***

  DATE        CLOCK TIME    TIME INTERVAL    GAUGE HEIGHT    DISCHARGE      RUNOFF
               (HOURS)         (HOURS)          (FT.)        (C.F.S.)       (IN.)

JAN 20

                    1.          1.125          11.800          0.150         0.020
                  215.          3.492          11.820          0.186         0.079
                  700.          2.375          11.820          0.186         0.053
                  700.          1.000          11.830          0.206         0.025
                  900.          3.125          11.860          0.280         0.106
                 1315.          2.875          11.870          0.310         0.109
                 1445.          1.125          11.890          0.376         0.051
                 1530.          1.375          11.920          0.512         0.085
                 1730.          2.000          11.940          0.611         0.148
                 1930.          1.250          11.940          0.611         0.092
                 2000.          0.750          11.950          0.660         0.060
                 2100.          0.750          11.990          0.928         0.084
                 2130.          0.625          11.990          0.928         0.070
                 2215.          1.125          12.200          2.820         0.384
                 2345.          0.875          11.980          0.856         0.091
                 2400.          0.125          11.990          0.928         0.014

                                               TOTAL RUNOFF IN
                                               INCHES FOR PERIOD=    1.47002
```

```
                              DIRTMCVE

                       PROGRAM    BY LEE DRUFFEL 1972

      DIMENSICN TC(2CO),GH(2CO),SED(2CC),X(5C),Y(5C),T(200),QI(200),
     .RS(2CO),CT(2CC),IC(80)
C
C ..... THE FCLLOWING CATA IS THE CALIBRATICN FOR THE WEIR IN USE
C
C         READ IN VALLES FOR GUAGE HEIGHT VS. DISCHARGE
C           X=GAUGE HEIGHT (FT.)  Y=DISCHARGE (C.F.S.)
      CALL INPUT (X,NX)
      CALL INPUT (Y,NY)
C
C     ******************************************************************
C
C     THE FOLLOWING IS A PROGRAM TO COMPUTE THE INSTANTANEOUS
C     SEDIMENT YIELC (TCNS/HCUR) ANC WATER DISCHARGE (C.F.S.) PLUS
C     THE TOTAL RUNCFF (INCHES) ANC THE TCTAL SOIL LCSS (TONS/ACRE)
C     FCR THE WATERSHED CN A STORM BASIS USING THE MICINTERVAL METHOC.
C
C     THE FOLLCWING CATA IS NEEDED:
C            A) FOR DISCHARGE RATING CURVE
C
C                1) GAUGE HEIGHT (X)
C                2) CORRESPCNDING DISCHARGE (Y)
C
C            B) FCR SEDIMENT-RUNOFF PRCGRAM
C                 ( IN CRDER OF INPUT )
C
C                1) IDENTIFICATION (ID)
C                2) CLOCK TIME (HOURS)
C                3) GAUGE HEIGHT (FT)
C                4) SEDIMENT CONCENTRATICN (PPM)
C
C     ALL INPUT IN THIS PROGRAM IS FREE FCRM (CALL INPUT) AND EACH
```

```
C     DATA SET MUST BE ON ONE CARD CARD SET (I.E. ALL CLOCK TIMES ON
C     ONE SET, THEN ALL CORRESPONDING GAUGE HEIGHTS ON NEXT SET, ETC.)
C         ( THE TIME IS THE TIME SINCE THE STORM STARTED IN HOURS )
C
C     FOR EACH STORM THE DATA IN PART B MUST BE COMPLEATED
C
C
C     THE FOLLOWING VARIABLES ARE USED IN THE PROGRAM:
C
C            CH - GAUGE HEIGHT
C            TC - CLOCK TIME SINCE STORM BEGAN
C             Y - DISCHARGE CALIBRATION
C             X - GAUGE HEIGHT CALIBRATION
C            CT - DIFFERENCE IN TIME INTERVALS
C            QI - INSTANTANEOUS DISCHARGE
C             T - CLOCK TIME IN DECIMAL FORM
C            RO - TOTAL STORM RUNOFF
C        TOTSED - TOTAL STORM SEDIMENT YIELD
C            RS - INSTANTANEOUS SEDIMENT DISCHARGE
C          AREA - WATERSHED AREA IN ACRES
C           SED - SEDIMENT CONCENTRATION
C            ID - IDENTIFICATION
C
C     REF: "COMPUTATION OF FLUVIAL SEDIMENT DISCHARGE", BY GEORGE
C          PORTERFIELD. U.S.G.S. PUBLICATION. 1972
C
C    ***************************************************************
   10 CONTINUE
      READ(1,1)ID
    1 FORMAT (80A1)
      WRITE (3,75) ID
   75 FORMAT('1',//,10X,'SEDIMENT AND RUNNOFF DATA FOR :',80A1)
C
C ....  CALL IN TIME GUAGE HEIGHT AND SEDIMENT CONCENTRATION
C
      CALL INPUT (TC,NC)
      CALL INPUT (GH,NG)
```

```
      CALL INPUT (SED,NS)
C
C  ....  CCNVERT CLCCK TIME INTO DECIMAL TIME
C
      DC 15 I=1,NC
      ZIP=(TC(I)*C.C1)
      T1=AINT(ZIP+C.01)
   15 T(I)=T1+((ZIP-T1)*1.6666)
C
C  ....  FIND THE DECIMAL DIFFERENCE IN TIME INTERVALS
C
      LL=NC-1
      DC 30 I=2,LL
   30 DT(I)=(T(I+1)-T(I-1))*0.5
      DT(1)=T(2)*C.5
      DT(NC)=(T(NC)-T(NC-1))*0.5
C
C  .... CCMPUTE THE INSTANTANEOUS DISCHARGE FOR EACH GAUGE HEIGHT
C
      DC 4C N=1,NC
      J=2
   69 IF(GH(N)-X(J))122,121,120
  120 J=J+1
      GC TC 69
  121 QI(N)=Y(J)
      GC TO 4C
  122 QI(N)=Y(J-1)+(Y(J)-Y(J-1))/(X(J)-X(J-1))*(GH(N)-X(J-1))
   40 CCNTINUE
C
C  .... COMPUTE THE SEDIMENT RATE (INSTANTANEOUS) FOR EACH TIME
C
      BIGK=0.C0011232
      DC 16 I=1,NS
   16 RS(I)=QI(I)*SED(I)*BIGK
C
C  .... COMPUTE THE RUNCFF FOR THE STORM
C
```

```
      C=3600.
C
C  .... THE FOLLOWING IS THE AREA OF THE WATER SHED IN ACRES
C
      AREA=8.2
      AI=12./(AREA*43560.)
      RO=0.0
      DO 17 I=1,NS
   17 RO=(C*QI(I)*DT(I)*AI)+RO
C
C  ....  COMPUTE THE TOTAL SEDIMENT IN TONS/ACRE FOR THE STORM
C
      TOTSED=0.0
      DO 18 I=1,NS
   18 TOTSED=((RS(I)*DT(I))/AREA)+TOTSED
      WRITE(3,80)
   80 FORMAT(//,20X,'CLOCK TIME',4X,'TIME INTERVAL',4X,'GAUGE HEIGHT',4X
     .,'DISCHARGE',6X,'SEDIMENT',6X,'SOIL LOSS',/,22X,'(HOURS)',8X,'(HOU
     .RS)',11X,'(FT.)',8X,'(C.F.S.)',8X,'(PPM)',8X,'(TONS/HOUR)',//)
      DO 19 I=1,NS
      WRITE (3,90) TC(I),DT(I),GH(I),QI(I),SED(I),RS(I)
   90 FORMAT (24X,F7.0,8X,F7.3,10X,F7.3,6X,F8.4,8X,F6.0,8X,F9.4)
   19 CONTINUE
      WRITE(3,100) RO,TOTSED
  100 FORMAT(//,39X,'TOTAL RUNOFF FOR STORM',1X,F5.3,1X,'INCHES',/,37X,'
     .TOTAL SEDIMENT FOR STORM',1X,F5.2,1X,'TONS/ACRE')
      GO TO 10
      STOP
      END
```

CLOCK TIME (HOURS)	TIME INTERVAL (HOURS)	GAUGE HEIGHT (FT.)	DISCHARGE (C.F.S.)	SEDIMENT (PPM)	SOIL LOSS (TONS/HOUR)
1.	1.500	11.550	0.0	0.	0.0
300.	2.492	11.590	0.0016	500.	0.0001
500.	1.500	11.630	0.0064	7000.	0.0050
600.	2.000	11.650	0.0112	10000.	0.0126
900.	2.250	11.640	0.0084	5000.	0.0047
1030.	1.000	11.630	0.0064	5000.	0.0036
1100.	0.500	11.660	0.0140	19000.	0.0299
1130.	0.500	11.680	0.0225	45000.	0.1137
1200.	0.375	11.780	0.1172	70000.	0.9215
1215.	0.250	11.750	0.0760	55000.	0.4695
1230.	0.375	11.740	0.0664	45000.	0.3356
1300.	0.500	11.730	0.0568	30000.	0.1914
1330.	0.500	11.710	0.0409	23000.	0.1057
1400.	0.750	11.700	0.0335	23000.	0.0865
1500.	0.750	11.700	0.0335	20000.	0.0753
1530.	0.500	11.730	0.0568	42000.	0.2680
1600.	0.750	11.710	0.0409	26000.	0.1194
1700.	1.000	11.700	0.0335	22000.	0.0828
1800.	2.000	11.690	0.0280	19000.	0.0598
2100.	3.000	11.700	0.0335	10000.	0.0376
2400.	3.000	11.680	0.0225	5000.	0.0126
2700.	3.000	11.660	0.0140	3000.	0.0047
3000.	3.000	11.650	0.0112	2500.	0.0031
3300.	3.000	11.630	0.0064	2000.	0.0014
3600.	3.000	11.610	0.0032	1200.	0.0004
3900.	3.000	11.600	0.0019	1000.	0.0002
4200.	3.000	11.590	0.0016	500.	0.0001
4500.	3.000	11.570	0.0008	400.	0.0000
4800.	1.500	11.550	0.0	0.	0.0

TOTAL RUNOFF FOR STORM 0.085 INCHES
TOTAL SEDIMENT FOR STORM 0.19 TONS/ACRE

APPENDIX C

Other Predictive Equations

"Statistics for Other Predictive Equations"

The following pages give the mathematical and statistical components for assembling and analyzing several predictive equations. These are different combinations of the significant variables which could be used to form a predictive equation.

The variables are given by number and their corresponding physical parameters are as follows:

Variable Number	Variable
1	Soil loss (tons/acre)
2	Precipitation since storm began (inches)
3	Runoff (inches)
4	Difference in snow cover before and after event (% area)
5	Days since prior event
6	Length of event (hours)

```
MULTIPLE REGRESSION.....EROSION DATA WITH FROZEN GROUND DATA REMOVED

     SELECTION..... 1


VARIABLE      MEAN        STANDARD        CORRELATION     REGRESSION      STD. ERROR      COMPUTED
  NO.                     DEVIATION         X VS Y        COEFFICIENT     OF REG.COEFF.   T VALUE
   2        0.62667        0.49005         0.96180         0.90851         0.09774        9.29517
DEPENDENT
   1        0.64444        0.46290


INTERCEPT                  0.07511

MULTIPLE CORRELATION       0.96180

R SQUARED                  0.92505

STD. ERROR OF ESTIMATE     0.13547


                  ANALYSIS OF VARIANCE FOR THE REGRESSION

   SOURCE OF VARIATION        DEGREES      SUM OF         MEAN          F VALUE
                             OF FREEDOM    SQUARES       SQUARES
ATTRIBUTABLE TO REGRESSION       1         1.58574       1.58574        86.40021
DEVIATION FROM REGRESSION        7         0.12847       0.01835
     TOTAL                       8         1.71422
```

```
MULTIPLE REGRESSICN.....ERUSION DATA WITH FROZEN GROUND DATA REMCVED

     SELECTICN..... 2


VARIABLE      MEAN        STANDARD        CORRELATICN       REGRESSICN      STD. ERROR       COMPUTED
  NO.                     DEVIATICN         X VS Y          COEFFICIENT     CF REG.COEF.     T VALUE
   3        1.03144        1.10978         0.86867          0.36233         0.07810          4.63936
DEPENDENT
   1        C.64444        C.46290


INTERCEPT                  0.27C72

MULTIPLE CORRELATICN       C.86867

R SQUARED                  C.75459

STD. ERROR OF ESTIMATE     C.24515


                  ANALYSIS OF VARIANCE FOR THE REGRESSICN

    SCURCE OF VARIATICN          DEGREES        SUM OF           MEAN            F VALUE
                                OF FREEDOM      SQUARES         SQUARES
 ATTRIBUTABLE TC REGRESSICN         1           1.29353         1.29353         21.52364
 DEVIATICN FROM REGRESSION          7           C.42C69         0.C601C
       TCTAL                        8           1.71422
```

```
MULTIPLE REGRESSION.....EROSION DATA WITH FROZEN GROUND DATA REMOVED

     SELECTION..... 3


VARIABLE      MEAN        STANDARD       CORRELATION      REGRESSION     STD. ERROR      COMPUTED
  NO.                     DEVIATION        X VS Y         COEFFICIENT    OF REG.COEF.    T VALUE
   2         0.62667       0.49005        0.96180          0.83954        0.09319        9.00896
   4        29.88889      44.31546        0.54253          0.00186        0.00103        1.80479
DEPENDENT
   1         0.64444       0.46290


INTERCEPT                  0.06274

MULTIPLE CORRELATION       0.97541

R SQUARED                  0.95142

STD. ERROR OF ESTIMATE     0.11781


                   ANALYSIS OF VARIANCE FOR THE REGRESSION

    SOURCE OF VARIATION      DEGREES      SUM OF         MEAN            F VALUE
                            OF FREEDOM    SQUARES        SQUARES
 ATTRIBUTABLE TO REGRESSION      2        1.63095        0.81547        58.75870
 DEVIATION FROM REGRESSION       6        0.08327        0.01388
      TOTAL                      8        1.71422
```

```
MULTIPLE REGRESSION.....EROSION DATA WITH FROZEN GROUND DATA REMOVED

     SELECTION..... 4


VARIABLE      MEAN       STANDARD        CORRELATION      REGRESSION      STD. ERROR       COMPUTED
  NO.                    DEVIATION         X VS Y         COEFFICIENT     OF REG.COEF.     T VALUE
   2         0.62667      0.49005         0.96180          0.92254         0.15333         6.01665
   4        29.88889     44.31546         0.54253          0.00192         0.00108         1.77306
   5        39.33333     97.95131         0.74337         -0.00052         0.00075        -0.70094
DEPENDENT
   1         0.64444      0.46290

INTERCEPT                0.02984

MULTIPLE CORRELATION     0.97763

R SQUARED                0.95577

STD. ERROR OF ESTIMATE   0.12314


               ANALYSIS OF VARIANCE FOR THE REGRESSION

   SOURCE OF VARIATION        DEGREES      SUM OF        MEAN          F VALUE
                             OF FREEDOM    SQUARES      SQUARES
ATTRIBUTABLE TO REGRESSION        3        1.63840      0.54613       36.01411
DEVIATION FROM REGRESSION         5        0.07582      0.01516
     TOTAL                        8        1.71422
```

5

```
MULTIPLE REGRESSION.....EROSION DATA WITH FROZEN GROUND DATA REMOVED

      SELECTION..... 5


VARIABLE       MEAN          STANDARD         CORRELATION       REGRESSION       STD. ERROR        COMPUTED
  NO.                        DEVIATION         X VS Y           COEFFICIENT      OF REG.COEF.      T VALUE
   2        0.62667           0.49005         0.96180           1.12749          0.12485           9.03107
   4       29.88889          44.31546         0.54253           0.00374          0.00097           3.86485
   5       39.33333          97.95131         0.74337          -0.00039          0.00050          -0.77701
   6       52.44444          38.58466         0.75366          -0.00469          0.00170          -2.76525
DEPENDENT
   1        0.64444           0.46290


INTERCEPT                    0.08739

MULTIPLE CORRELATION         0.99238

R SQUARED                    0.98481

STD. ERROR OF ESTIMATE       0.08069


                     ANALYSIS OF VARIANCE FOR THE REGRESSION

    SOURCE OF VARIATION        DEGREES       SUM OF          MEAN             F VALUE
                              OF FREEDOM     SQUARES        SQUARES
ATTRIBUTABLE TO REGRESSION       4           1.68818        0.42204          64.82755
DEVIATION FROM REGRESSION        4           0.02604        0.00651
     TOTAL                       8           1.71422
```

```
MULTIPLE REGRESSION.....EROSION DATA WITH FROZEN GROUND DATA REMOVED

     SELECTION..... 6

                                                                                    COMPUTED
                                                     REGRESSION     STD. ERROR      T VALUE
VARIABLE     MEAN        STANDARD     CORRELATION    COEFFICIENT    OF REG.COEF.    1.59479
  NO.                    DEVIATION      X VS Y         0.62447        0.39157       3.33168
   2        0.62667       0.49005       0.83088        0.01010        0.00303       1.30542
   4       29.88889      44.31546       0.79809        0.00203        0.00156       1.65667
   5       39.33333      97.95131       0.76207        0.00882        0.00532
   6       52.44444      38.58466       0.93393
 DEPENDENT
   3        1.03144       1.10978

INTERCEPT                     -0.20411

MULTIPLE CORRELATION           0.98691

R SQUARED                      0.97400

STD. ERROR OF ESTIMATE         0.25306


               ANALYSIS OF VARIANCE FOR THE REGRESSION
                                                                          F VALUE
                                DEGREES      SUM OF          MEAN
     SOURCE OF VARIATION       OF FREEDOM    SQUARES        SQUARES       37.46251
                                   4         9.59668        2.39917
  ATTRIBUTABLE TO REGRESSION       4         0.25617        0.06404
  DEVIATION FROM REGRESSION        8         9.85284
       TOTAL
```

```
MULTIPLE REGRESSION.....EROSION DATA WITH FROZEN GROUND DATA REMOVED

     SELECTION..... 7


VARIABLE      MEAN       STANDARD        CORRELATION     REGRESSION     STD. ERROR       COMPUTED
  NO.                    DEVIATION        X VS Y         COEFFICIENT    OF REC.COEF.     T VALUE
   4        29.88889      44.31546        0.79809         0.01353        0.00258         5.24804
   2         0.62667       0.49005        0.83088         1.00957        0.36596         2.75872
   5        39.33333      97.95131        0.76207         0.00230        0.00180         1.27895
DEPENDENT
   3         1.03144       1.10978


INTERCEPT                 -0.09599

MULTIPLE CORRELATION       0.97784

R SQUARED                  0.95616

STD. ERROR OF ESTIMATE     0.29391


               ANALYSIS OF VARIANCE FOR THE REGRESSION

    SOURCE OF VARIATION        DEGREES      SUM OF        MEAN          F VALUE
                              OF FREEDOM    SQUARES       SQUARES
ATTRIBUTABLE TO REGRESSION         3        9.42093       3.14031       36.35356
DEVIATION FROM REGRESSION          5        0.43191       0.08638
     TOTAL                         8        9.85284
```

```
MULTIPLE REGRESSION.....EROSION DATA WITH FROZEN GROUND DATA REMOVED

     SELECTION..... 8


VARIABLE       MEAN         STANDARD       CORRELATION      REGRESSION     STD. ERROR       COMPUTED
  NO.                       DEVIATION        X VS Y         COEFFICIENT    OF REG.COEF.     T VALUE
   2         0.62667          0.49005        0.83088         0.90892        0.34749         2.61568
   4        29.88889         44.31546        0.79809         0.01003        0.00224         3.09818
   6        52.44444         38.58466        0.93393         0.00954        0.00565         1.69700
DEPENDENT
   3         1.03144          1.10978


INTERCEPT                    -0.33819

MULTIPLE CORRELATION          0.98129

R SQUARED                     0.96292

STD. ERROR OF ESTIMATE        0.27030


                     ANALYSIS OF VARIANCE FOR THE REGRESSION

   SOURCE OF VARIATION        DEGREES       SUM OF          MEAN            F VALUE
                             OF FREEDOM     SQUARES        SQUARES
ATTRIBUTABLE TO REGRESSION       3          9.48754        3.16251         43.28618
DEVIATION FROM REGRESSION        5          0.36530        0.07306
     TOTAL                       8          9.85284
```

APPENDIX D

Computation of λ and s

Computing λ and s Parameters For Use in the Universal Soil Loss Equation

In order to adapt the Universal Soil Loss Equation to a watershed, the average flow length (λ) and the average slope (s) must be computed so the LS factor can be obtained. A method developed by Williams and Berndt (1972) for the Texas Blacklands was employed. The average flow length (λ) is considered to be the length of a channel in a rectangular watershed of equal area. The average slope (s) is a weighted average of slopes over the area of the watershed.

The values were computed as follows:

(1) $$\lambda = \frac{1}{2}\,\frac{A}{LCH}$$

λ = Average flow length

A = area of watershed (ft^2)

LCH = length of channels (taken to be length of intermittent channel) (ft)

$$\lambda = \frac{1}{2}\,\frac{8.2*43560.}{645.}$$

$\underline{\lambda = 277'}$

(2) $$s = \frac{\underline{\text{summation }(s'(i)*DA(i)}}{DA}$$

s = average slope

s'(i) = slope over area (i)

DA(i) = area (i)

DA = total watershed area

S'(i) values were computed by calculating the area (DA) between contours (i) and (i + 1), measuring the length (LC) of contours (i) and (i + 1), and calculating the difference in elevation (H) between the two contours. Then for eact set of contours with this information the average slope s'(i) was computed by:

$$(3)\quad s'(i) = \frac{H(LC(i) + LC(i+1))}{105.6 * DA(i)}$$

with these values of s'(i) and equation (2), the average slope was computed to be 15.5%. (s = 15.5%)

APPENDIX E

Values of Parameters Considered in Soil Loss Equation

	(in.)	(in.)	LOSS (T/A)	TEMP. (F)	DIFF. (% area)	EVENT	EVENT (hr.)	DIS. (cfs)	TEMP. (F)	(in.)		
3-23-71	0.11	0.09	0.23	41	0	10	4	0.72	33	0.03	no	4
1-19-72	1.66	3.20	1.54	34	70	300	120	2.80	31	0	no	2
2-15-72	0.87	2.42	0.96	38	95	21	108	0.93	29	0	no	3
2-27-72	0.67	0.98	0.60	42	5	7	60	1.65	32	0.14	no	3
3-5-72	0.38	1.34	0.61	38	99	4	48	6.55	32	0.06	no	4
3-12-72	1.00	0.65	1.07	47	0	5	30	0.86	44	0.20	no	4
12-21-72	0.89	0.21	0.53	43	0	1	11	0.51	41	0	yes	1
12-22-72	0.53	0.04	0.02	38	0	1	6	0.15	43	0	yes	1
1-12-73	0.51	0.43	0.06	40	100	21	21	0.41	36	0.15	yes	2
1-13-73	0.16	0.20	0.22	44	0	0	24	0.12	40	0	no	2
1-15-73	0.39	0.31	0.38	40	0	0	30	0.19	44	0	no	2
2-28-73	0.40	0.09	0.19	42	0	7	48	0.12	44	0	no	3

* Time Code is defined as : 1 - December, 2 - January, etc.