



Development and testing of a modified ground sediment trap  
by Leslie Carol Bush

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in  
Range Science

Montana State University

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Abstract:

A modified version of a ground sediment trap was tested in a greenhouse study for its effectiveness in collecting overland flow and soil loss. Four degrees of slopes, three ground cover levels, varying rainfall and overland flow conditions, and one soil type were used in erosion studies to determine their interactions and influences on overland flow and soil loss. Overland flow and soil losses (a) increased with slope steepness, storm intensity, and storm duration; and (b) decreased with increasing ground cover. Rate of soil loss increased during the first 40 minutes and then decreased as overland flow continued while rate of overland flow increased during the first 40 minutes and then remained constant. The traps were more efficient and less variable in collecting overland flow and soil losses on slopes steeper than 10%. The traps worked more effectively under storms of moderate to high intensities, and with storms of 40 minutes to extended durations; consequently, they should function adequately during semi-arid and arid region natural precipitation events over rangelands in moderate to poor conditions.

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MONTANA STATE UNIVERSITY  
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26 August 1985  
Date

Clayton Marburn  
Chairperson, Graduate Committee

Approved for the Major Department

August 26, 1985  
Date

William C. Hunter  
Head, Major Department

Approved for the College of Graduate Studies

8-26-85  
Date

W. Malone  
Graduate Dean

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## ABSTRACT

A modified version of a ground sediment trap was tested in a greenhouse study for its effectiveness in collecting overland flow and soil loss. Four degrees of slopes, three ground cover levels, varying rainfall and overland flow conditions, and one soil type were used in erosion studies to determine their interactions and influences on overland flow and soil loss. Overland flow and soil losses (a) increased with slope steepness, storm intensity, and storm duration; and (b) decreased with increasing ground cover. Rate of soil loss increased during the first 40 minutes and then decreased as overland flow continued while rate of overland flow increased during the first 40 minutes and then remained constant. The traps were more efficient and less variable in collecting overland flow and soil losses on slopes steeper than 10%. The traps worked more effectively under storms of moderate to high intensities, and with storms of 40 minutes to extended durations; consequently, they should function adequately during semi-arid and arid region natural precipitation events over rangelands in moderate to poor conditions.

## INTRODUCTION

Soil erosion, "a process of detachment and transportation of soil materials by erosive agents" (Ellison 1947a), is "one of the three components in the overall sedimentation process (erosion, transport, and deposition)" (Ekern 1950). There are two basic categories of erosion (a) normal erosion, degradation of the soil at a rate equivalent to the geological normal, and (b) accelerated erosion, degradation of the soil at a rate greater than geologic normal (Croft et al. 1943).

Accelerated erosion occurs through the destructive modification or removal of soil resulting from impairment of the protective influence exerted by the plant and litter cover (Croft et al. 1943). It has been recognized that erosion is a serious problem of farm- and rangelands over a large part of the earth (Smith and Wischmeier 1962). Consequently, proper land management practices are needed to reduce, rectify, and solve erosional problems on noncultivated and cultivated land bases. An important facet of these management practices is the evaluation of their effectiveness; consequently, there are demands for accurate means of quantitative erosion measurement and monitoring.

Ideally, methods of quantifying normal and accelerated erosion on semi-arid rangelands should alter natural ecosystem processes as little as possible. The use of ground sediment traps may be one way to meet this requirement. This study analyzed the feasibility and effectiveness of such traps. There were three primary objectives in this study:

(a) to design and develop a versatile ground sediment trap, (b) to test the effectiveness of prototype traps in controlled erosion studies and (c) to evaluate the influences of ground cover, slope and overland flow conditions on overland flow and soil loss. Hypothetically, sediment collection by in-situ traps varies with changes in slope, storm conditions, soil characteristics, and ground cover. Four slopes, three different ground covers, varying rainfall and overland flow conditions, and one soil type were used in the erosion study to determine their interactions and influences on overland flow and sediment production, and to analyze trap effectiveness.

The study was conducted in the United States Forest Service's Intermountain Forest and Range Experiment Station greenhouse on Montana State University's campus in Bozeman, Montana. Test dates were September 1983 through July 1984.

## LITERATURE REVIEW

Erosion Analysis

Studies dealing with soil erosion problems need to take into account the four factor classes involving erosion. These factor classes are (a) pedologic; including texture, structure, and other soil characteristics involving erodibility; (b) physiographic; including slope, length of overland flow, surface roughness, depression storage, etc.; (c) hydrologic; including precipitation intensity and duration, infiltration capacity, and surface runoff characteristics; and (d) hydraulic; including fluid conductivity, routing and physical characteristics (Horton 1938). The physiographic and hydrologic factors operate indirectly through hydraulic factors and independent variables such as depth and velocity of overland flow, and type of overland flow. Erosion studies which simulate natural conditions need accurate representation of these factor classes in order to obtain results applicable to those expected from studies done under natural climatic and environmental conditions. Erosion studies also need runoff and soil loss collection apparatus which operate efficiently and accurately. Several methods have been developed to better understand the influences and interactions of factors influencing erosion.

Ellison (1944) developed devices that measured overland flow and splash erosion under natural and simulated storms. His overland flow sampler was adjustable for slope and could be carried around for use on

random plots or used on permanent transects. Debris was troublesome in the collection slots, and erosion by overland flow only could not be determined if there was any raindrop erosion (Ellison 1944). Ellison's splash sampler was as portable as the overland flow sampler, and together they could help determine the distribution and nature of the erosional activity occurring over a watershed (Ellison 1944).

Numerous studies have been done under natural and/or simulated storm conditions through use of plots with barriers, troughs, flumes, recording gages, and collection containers for the collection and measurement of surface runoff (SRO) and soil loss. Erosion plots with wood barriers and wood catchment troughs of variable dimensions were used by Lowdermilk (1930), Marston (1952), Rowe and Reimann (1961), and Osborn et al. (1964). Natural rainfall events were used in all these studies. Troughs used by Marston and Rowe and Reimann did not have flumes, recording gages, or collection containers. Lowdermilk's plots (1930) had pipes which transported surface runoff and seepage water from the plots into tipping bucket gages to obtain rates of flow. Osborn et al.'s (1964) troughs had pipes which transferred runoff into silt tanks. Van Doren et al.'s (1940) plots had wood barriers and metal troughs with flumes from which iron pipes transported surface runoff of natural rainfall events into silt tanks. Various modifications of plots equipped with metal sidewalls and metal catchment troughs have been used by Pearse and Woolley (1936), Dunford (1954), Haupt (1967), and Orr (1970). Pearse and Woolley's plots (1936) were supplied by simulated overland flow. The overland flow was funneled through a metal spout into collection cans and jars placed beneath the



downslope frame side. Dunford's plots (1954) were supplied by natural rainfall. Metal flumes were incorporated into Dunford's troughs from which pipes fed runoff into silt tanks. Haupt (1967) used plots with metal sidewalls and metal troughs on which natural and simulated precipitation was supplied. Orr (1970) used plots with metal sidewalls and troughs supplied by natural rainfall. Runoff was funneled from the troughs into buried pipes which emptied into collection tanks. Erosion plots equipped with concrete sidewalls and troughs have been used. Nichols and Sexton (1932) delineated plots with concrete sidewalls and applied simulated rainfall. Surface runoff was collected in concrete cisterns which fed into collection cans at the end of each slope. Leopold (1964) used plots equipped with concrete sidewalls and concrete troughs that fed natural rainfall runoff into collection tanks.

Although there are many advantages of using delineated erosion plots, there are several disadvantages. Advantages are (a) controlled collection of runoff leading to accurate measures of SRO and soil loss; (b) simplified manipulation of vegetal and soil conditions; (c) capabilities for simulating precipitation events over controlled plot conditions resulting in regulated erosion events; and (d) potential correlation of plot erosion conditions to those expected on unaltered areas. Major disadvantages in using constructed erosion plots are (a) alteration of natural erosion patterns over areas where plots were placed; (b) alterations of vegetal and soil conditions which changed erosion patterns and potentials; (c) slow availability of data and variability of data under natural precipitation events; and (d) variability in control of simulated precipitation and other drawbacks

with the use of precipitation simulators. Runoff and erosion data vary greatly due to dissimilar precipitation conditions (Martson 1952).

#### Simulated Rainfall Studies on Natural Terrain

Similar SRO and soil loss collection apparatus as those described in the proceeding section have been used in simulated rainfall studies on smaller erosion plots on natural terrain. Smaller erosion plots were used primarily due to the higher costs, more frequent inaccuracies of measurement, and greater disturbance to natural erosion patterns which were common with large erosion plots. Six infiltrometer models used often in studies on natural terrain are (1) Type-F infiltrometer, (2) Rocky Mountain infiltrometer, (3) modified North Fork equipment, (4) Pearse square foot apparatus, (5) "raindrop applicator", and (6) "rainulator" (Wilm 1941). Their predominant designs involved non-adjustable metal plot frames with metal troughs usually equipped with gages. Runoff may or may not be funneled from the troughs into collection jars and cans depending on the model. Precipitation was supplied by type-F nozzle sprinklers, or a suspended graduated container which fed into a perforated pipe. Dortignac's Rocky Mountain infiltrometer (1951) had a frame with troughs which were adjusted to slope and had fly screen trash collectors to prevent clogging of SRO flows. SRO and soil loss were then passed from each trough through garden hose and drain pipe into 1 gallon containers. Osborn (1952) and Rauzi (1960) used "raindrop applicators" and metal plot frames for erosion study. Osborn's (1952) frame had splash collection troughs on the left and right frame sides and a SRO collection jar positioned at

the end of a metal spout on the downslope frame side. In contrast, Rauzi's (1960) frame had a metal spout covered with burlap which funneled runoff into a collection jar. Meyer and McCune (1958) and Meyer (1960) used a "rainulator" on plots with metal barriers. SRO was collected in metal troughs, measured by gages, and funneled into collection cans. Their trough flumes had water level recorders, and sampling wheels.

As mentioned in the preceding section, there were advantages and disadvantages prevalent with the use of simulated rainfall. Many of these will be discussed in the following section.

#### Natural Rainfall Studies vs Simulated Rainfall Studies

There has been much debate over the need and use of natural vs simulated rainfall in erosion studies. Although natural rainfall studies provide the most direct means of correlating erosion and precipitation actions they also (a) are slow to yield results, (b) are less efficient than simulated rainfall studies, and (c) are less controlled than simulated rainfall studies (Mech 1965). Simulated rainfall studies have been found to yield SRO volumes comparable to those from natural rainfall of similar intensity and duration. However, simulated rainfall studies tend to yield underestimations of expected SRO and erosion from similar natural rainfall conditions (Mech 1965, and Barnett and Dooley 1972). There are other drawbacks to the use of simulated rain. Raindrop energy remains constant with changing simulated intensities while it changes with changes in natural rainfall intensities. There is variation in height of fall of raindrops, rate

of delivery, and rainfall distribution (Dortignac 1951). Rainfall simulators have operational limitations due to their expense and operation complexities (Mech 1965, Young and Burwell 1972). There are limitations on the modeling of environmental and climatic condition constraints in simulated rainfall studies (Mech 1965, Young and Burwell 1972). Natural erosion patterns are altered by plot boundary construction. The results of simulated rainfall studies have also been found to be primarily qualitative (Meyer and McCune 1958). Consequently, there is a need for more effective and efficient erosion analysis methods to be used under natural rainfall conditions since simulated rainfall studies have numerous drawbacks.

#### Simulated Rainfall Studies on Constructed Microsites

The number and variation of factors affecting soil erosion are such that it is difficult to determine the importance of each individual factor. In order to determine the effect of any one factor, the other factors need to be held constant or measured while the variable being studied is altered (Neal 1937). The manipulation and control of factors affecting soil erosion is very difficult under natural conditions. Consequently, microsites have been used in erosion studies so factors affecting soil erosion could be controlled.

Neal (1937) constructed a wood soil tank to use in analyzing the interactions of various factors on SRO, soil loss, and infiltration. He studied (a) the influences that slope, precipitation intensity and duration, initial soil moisture, soil surface condition, and infiltration had on SRO and soil loss; and (b) the influences that slope,

rainfall intensity, initial soil moisture, and rate of infiltration had on infiltration. No ground cover was used while Neal controlled soil conditions, slope, and precipitation intensities and durations. Six slopes were used. Five rainfall intensities and seven rainfall durations were provided with an oscillating nozzle sprinkler system. SRO was collected in a galvanized iron trough at the tank base which fed into collection cans. Soil loss per can was determined for each 10 minute period. Percolation water was collected in a can fed from a trough on the box bottom. Three infiltration cylinders placed in the soil surface were used for obtaining infiltration rates during each run.

Relative density of runoff material increased as slope and rainfall intensity increased (Neal 1937). Soil loss from a saturated soil increased as the 0.7 power of slope, the 2.2 power of rainfall intensity, and directly to rain duration. Neal concluded that rainfall intensity was the most important factor affecting runoff and soil loss in that it (a) had a greater effect on soil loss than on runoff, and (b) had a greater effect on soil loss than percent slope.

Meyer and Monke (1965) used a microsite to establish basic relationships between soil erosion and various factors influencing it: slope length, slope steepness, and soil particle size. No ground cover was used while they controlled soil and slope conditions, and rainfall intensities and durations. Four particle sizes of glass beads ranging from that of a very fine sand to a medium sand were dried and smoothed prior to each run. Six slope steepnesses and four slope lengths were used. Two rainfall intensities were supplied from a rainfall simulator

for 30 minutes. SRO was collected in a metal trough at the plot base which drained into collection cans.

Runoff erosion was found to increase with slope length and steepness except at small steepnesses and lengths where essentially no erosion occurred (Meyer and Monke 1965). Rainfall plus runoff increased erosion of smaller particle sizes but decreased erosion of larger sizes as compared with runoff alone. Meyer and Monke (1965) determined that increased sediment availability and runoff carrying capacity were dominant for more easily transported small particles whereas decreased carrying capacity of runoff was dominant for larger particles.

Farmer and Van Haveren (1971) used a wood constructed microsite to (a) develop information about the effects of soil, slope, and rainfall variables on the erodibility of bare soil; (b) determine the magnitude of these effects; and (c) identify relationships between these variables. Three surface soil samples were tested. Three slopes were used. Two rainfall intensities were provided from F-type nozzles for 30 minute runs. Soil splash was collected on four concentric interlocking trays on the plot perimeter, and on a large unsegmented pan on the floor at the plot base. All SRO was collected into cans and weighed. One pint SRO samples were periodically collected during the runs to find the concentration of soil material.

Farmer and Van Haveren (1971) found that rainfall intensity, slope steepness, and percent by weight of soil particles greater than 2 mm had the greatest effects on erosion by overland flow (OLF). Slope steepness and rainfall intensity strongly interacted to influence soil

erosion by OLF. The interactive strength of slope and rainfall intensity was at least a full order of magnitude greater than any soil variable.

Although information yielded from these studies are very accurate and reliable sources of soil erosion behavior explanation, more information on rainfall patterns and characteristics, and topographic effects needs to be assembled before real expertise can be developed in explaining soil erosion behavior. These studies and others of similar principle could be used as a basis in future erosion studies under more natural conditions, and to provide increased understanding of the soil-erosion process. For this study, various equipment designs used by formerly discussed researchers were incorporated into a modified ground sediment trap that can be used under natural precipitation events. A rectangular metal frame to be left buried with its surface at ground level and to serve as a support for a removable trough was incorporated from Ellison's (1944) and Dortignac's (1951) designs. Trough or trap shapes used by Dortignac (1951), Meyer and McCune (1958), Haupt (1967) and Orr (1970) were combined into a removable metal-trap design. The trap has its downslope rim slide into a lip of the frame and its upslope rim lie over the frame rim. A metal baffle for reducing downslope overflow potentials was installed on the downslope trap side. Modifications of overflow system designs used by Lowdermilk (1930), Pearse and Woolley (1936), Ellison (1944), Meyer and McCune (1958), Rowe and Reimann (1961) and Orr (1970) were incorporated into trap overflow systems in which collection containers would be placed (a) within the frame beneath the trap for low runoff yielding storms, and

(b) downslope of the traps for high runoff volume yielding storms.

Prototype traps were tested on a constructed microsite (Neal 1937, Farmer and Van Haveren 1971) with three ground cover levels and various simulated rainfall and overland flow conditions.



## METHODS AND MATERIALS

Wood Box and Sediment Trap Construction

Wood Box. An adjustable 2.4 m x 1.2 m x 24.8 cm box was constructed to contain soil and vegetation (Figure 1). The box sides were tapered to facilitate drainage. Four steel braces were nailed to the box front for support. Finally, burlap was placed over the front opening to prevent soil loss. Caulking was added to inner box seams.

Drainage holes were made to facilitate soil drainage (Figure 1). Twenty 0.5 cm holes were made through the front sides and covered on the inside with burlap. Very coarse sand was then spread at a depth of 4.1 cm on the box bottom to further facilitate drainage.

Ground Sediment Trap. A general trap design is shown in Figure 2 with a top view of the removable trap shown in Figure 3. The traps were made of sheet metal with  $i \times 0.3i \times 0.4i$  ( $i$  = frame length) dimensions for the stationary frame and  $i' \times 0.2i' \times 0.3i'$  ( $i'$  = trap length) dimensions for the removable trap where  $i' = 0.95i$ . The frame is designed to be left buried with the surface rim being even with the soil surface. Length of frame,  $i$ , should be the same as desired sample plot width. Three prototype removable traps were used in the greenhouse study in which  $i' = 30.5$  cm. Trap frames were not used in the study due to their expense. Surface runoff (SRO) was manually removed from the traps with pipettes, a handpump, and/or siphons.

















































































































