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Sediment Export from Forest Road Turn-outs: A Study Design and Preliminary Results

by

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Summary:

This paper reports the design and preliminary results of a study that evaluates the effects of commonly prescribed forest road runoff control treatments. A study design which utilizes runoff samplers, runoff diversion walls, sediment filter bags, and erosion stakes to evaluate sediment transport through runoff control treatments is documented. The study design will evaluate the effectiveness of four road turn-out ditch treatments: vegetation, rip-rap, sediment fences, and settling basins, in reducing sediment export onto the forest floor. Turn-out erosion control treatments were installed on a site located in central Alabama on the Tuskegee National Forest. Preliminary data show that the settling basin is most effective in filtering sediment laden runoff and yields the least sediment deposition downslope of treatment areas.

Keywords:

Forest roads, Soil Erosion, Conservation Practices, Surface Runoff

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INTRODUCTION

Roads have been identified as the major source of sediment from forest lands that reach streams (Hoover 1952; Patric 1976; Anderson et al. 1976). Roads which interrupt natural drainage channels are cited as the major source of sediment reaching the streams by Packer (1967). Components such as location and construction of forest roads are elemental in controlling sediment and runoff water emanating from roads. Careful and considerate road construction and design is an important aspect in reducing the environmental impact of road management practices.

Removal of water from the road system with minimal soil movement is a major concern in road research. Swift (1985) cites two methods for improving road designs to protect water quality: keeping sediment from flowing into intermediate stream channels and removing runoff from the roadway with minimal soil erosion. One of the most important design principles involved in accomplishing these two goals is flow dispersion to slow runoff to non-erosive velocities.

Two primary areas of concern and problems due to erosion and sedimentation is the turn-out ditch and the roadside ditch. These areas serve as zones of flow concentration in which runoff from the traveledway, cutslope, and upland forest converge. Ditches have increased potential for erosion due to large volumes of water at high velocity. The kinetic energy of runoff water is greatly increased with increasing runoff volume and velocity, since kinetic energy is defined as half the product of mass and the square of velocity.

Specifically, four commonly used erosion control techniques (vegetation, rip-rap, sediment fences, and settling basins) will be compared. The study will evaluate the effectiveness of turn-out ditch treatments on capacity to filter runoff and reduction of sediment export from the road.

PREVIOUS WORK

Erosion and sedimentation from forest land are minimal if the forest is not disturbed by forest operations. Forest litter generally protects the underlying soil from the damaging effects of surface flow. Once this litter has been disturbed, erosion can increase causing degrading effects to stream water quality due to sedimentation. The most drastic of the disturbances that occur during forest operations is caused by forest roads. Roads have large areas of bare, exposed soil which is vulnerable to erosion caused by surface flow. Roads account for as much as 90 percent of all sediment produced on forest land (Patric 1976). The major source of sediment that reaches stream channels is logging roads that interrupt natural drainage channels (Packer 1967, Haupt 1959, Trimble and Sartz 1957, Weitzman and Trimble 1952).

The impact of forest roads varies from site to site depending on watershed hydrology, soil characteristics, and climatic factors. Major concerns in road management are site degradation due to soil export, water quality, and changes in hydrology. Careful road location, design, and construction can prevent the major impacts of roads on soil erosion and sedimentation of streams. Criteria have been suggested for more environmentally acceptable forest roads (Gardner 1978, Packer 1967, Nagygyor 1984, Reinhart et al. 1963, Swift 1985, Hewlett and Douglass 1968, Murphy 1985). The road design criteria given major emphasis concern water control and drainage structures which are considered the major influences on soil erosion and sedimentation.

One of the main principles of forest road building is to direct water away from the roadway at a non-erosive velocity. Surface runoff water should be diverted into filter strips or some type of dispersion area to reduce runoff volume and velocity (Brinker 1993). Reduced runoff volume and velocity can directly contribute to reduced erosion and sedimentation due to lower kinetic energy of runoff. Design features utilized to channel water from the road surface include: culverts, broad-based dips, turn-out ditches, outsloping, and berms.

Broad-based dips are a design feature recommended on forest access systems in the eastern United States by several researchers (Kochenderfer and Helvey 1987; Cook and Hewlett 1979). The dip is made by constructing a 6-meter-long, 3 percent reverse grade with the trough of the dip outsloped with a 3 percent grade. Specifications for design, construction, and spacing are given by Hewlett and Douglass (1968). Dips are designed to require minimal maintenance and prevent destruction of the roadbed by intercepting surface runoff and dispersing it before serious damage can be caused by increased runoff energy. Roadway and drainage information was collected from 19 sites in the Appalachian region to assess the performance of dips and 0.5-m culverts (Eck and Morgan 1987). Investigators concluded that the performance of dips was substantially inferior to culverts in reducing impacts in this study of 227 culverts and 225 broad-based dips in the Appalachian region. In this investigation neither culverts nor dips were a cure-all for drainage problems, but the performance of culverts was substantially better than broad-based dips based on soil type, geologic formation, and slope.

Alabama's Best Management Practices (BMPs)recommend installation of functional water diversion techniques at the time that roads are constructed (Alabama Forestry Commission 1993). Forest road BMPs state adequate drainage as the most important factor controlling soil erosion. Water diversion devices such as turn-out ditches, outsloped roads, insloped roads, water bars, and broad-based dips should be used to disperse drainage water onto the forest floor whenever possible based on the current BMPs. Turnout ditches at proper spacings are recommended to disperse water collected in roadside ditches into the surrounding forest floor (Table 1) (Alabama Forestry Commission 1993). Water diversion devices allow adequate dispersion to decrease road water and required forest floor filtering.

In a study by Miller et al. (1985), the quantity of sediment delivered to drainage structures and eventually to streams from roads was evaluated. Sediment yields at drainage structure outlets from the five drainage structure classes was greatest for the 5 to 8 percent road gradient class. Sediment yields for direct entry into creeks, culverts into natural drains, culverts onto the forest floor, and turnouts in natural drains, were greatest for the 5 to 8 percent road gradient class yielding 356.2, 859.8, 936.9, and 149.3 tonnes, respectively. Sediment yields for turnouts onto the forest floor were greater than all other drainage structure classes with 2893.5 tonnes of total delivered sediment. Total sediment delivery, the sum of suspended and deposited sediment, for direct entry into creeks, culverts into natural drains, and turnouts in natural drains were also greatest for the 5 to 8 percent road gradient class with 252.2, 356.5, and 61.7 tonnes, respectively.

A study of insloped and outsloped roads in central Idaho forest was conducted by Haupt et al. (1963). The six-month-old road evaluated traversed a steep mountain with slopes generally exceeding 60 percent. All outlets of dips were deeply eroded from concentration of surface flow. Observations suggested that dips should be located to discharge on the outside curves of the road to allow absorption of sediment flows by undisturbed sideslopes before reaching a ravine or stream.

Research has been carried out to determine the length of filter strips required to filter sediment from runoff to acceptable levels before reaching streams. In a study by Haupt (1959), the sediment flow distance ranged from 1 to 113 m, with 12 percent of the values less than 4 m. The distance sediment flows from a road embankment into a filter strip was found to be affected by four factors---the slope obstruction index, cross ditch interval squared, slope length, and road gradient. These factors were incorporated into an equation for determining safe width of filter strips. Trimble and Sartz (1957) measured the distance sediment traveled from a road at 36 open-top log culverts. Rule-of-thumb recommendations were made, based on the assumption that it is acceptable for some sediment to reach the stream, for general situations starting with a strip width of 7.6 m on level land and increasing in width with increased slope. This research made more conservative recommendations for roads constructed in municipal watersheds. Swift (1986) also found that the distance sediment traveled in filter strips was influenced by slope, as well as brush barriers and the type of drainage structure. The deposition distances without grass ranged from 11 to 96 meters; with much shorter distances found below grassed fills. Swift presented an equation for filter strip width: slope distance (ft) = 43 + 1.39 x (slope percent).

Much work on road sediment transport and erosion control has been carried out on the traveledway, road sideslopes, and filter strips. As a result of this work, erosion control techniques are commonly applied to the road prism and adequate filter strip widths are allowed in attempts to filter runoff before it reaches streams. The filtering capacity of the forest floor, however, is not boundless and decreases as sediment is dropped from sediment laden runoff. As the filtering capacity of filter strips decreases, sediment can be delivered to streams causing water quality problems. Effective filtering of sediment laden runoff can be accomplished before it reaches the forest floor, preventing the reduction in the filtering capacity of the forest floor. Erosion control treatments can be applied to the outflow from the forest road prism to reduce sediment transport onto the forest floor and eventually to streams. Erosion treatments applied to turn-out ditches may prove to be an effective control to prevent sediment from leaving the road prism.

OBJECTIVES

Previous research has investigated filter strips used below erosion sources to control erosion, but has not focused on roadside ditch and control techniques that can be applied to reduce sediment transport. The effectiveness of ditch turn-out treatments in reducing sediment exported to the forest floor will be evaluated in this work. Selected techniques used to control sediment transport will be compared on sediment filtering from each associated treatment. The purpose of this experiment is to test the hypothesis that there are differences in the filtering capacity of four roadside erosion control techniques: (1) vegetation, (2) rip-rap, (3) sediment fences, and (4) settling basins. Forest road turn-out ditch treatments' effect on road runoff and sediment export will be evaluated and quantified in order to improve current road management practices.

METHODOLOGY

The study site was identified on the Tuskegee National Forest in Macon County near Tuskegee, Alabama during summer 1997. The forest road evaluated in this study was re-constructed, during a two week period in August 1997, to incorporate proper turn-out design and spacings. The crowned road with ditching had originally been constructed twenty years earlier for forest management activities. Soil on the study site is a Norfolk loamy sand, slope phase, ranging from 6 to 12 percent slope. The Norfolk soils are characterized by a fifteen-cm-deep, gray, loose, sand surface soil. The upper subsoil layer is light brownish-yellow loamy sand, and the lower soil layer, at a depth of 1 .1 m, is yellow friable sandy clay.

Twelve road turn-out ditches with similar topography, road design, soils, and drainage were installed on the Tuskegee National Forest. Three replicates of four sediment control techniques were used in this experiment: (1) vegetation, (2) rip-rap, (3) sediment fences, and (4) settling basins (Figure 1). Turn-out ditch spacing and construction/re-construction followed specifications currently recommended by Alabama's Best Management Practices and used by the Tuskegee National Forest. Turn-out ditches are V-shaped with a minimum cross-sectional width of 1.2 meters and depth varying according to surrounding topography (Figure 2). Turn-out ditch slopes were constrained to 2 to 4 percent grades.

Turn-out ditch treatments were hand seeded with a mixture of Pensacola bahiagrass (Paspalum notatum) at 22.5 kg/ha, annual lespedza (Lespedza cuneataj at 5.6 kg/ha, white clover (Trifolium repens) at 11.2 kg/ha, and Kentucky 31 fescue (Festuca arundinacea) at 28.1 kg/ha. Treatments were hand mulched with fescue hay at a rate of 4.5 t/ha and fertilized with 13-13-13 fertilizer at a rate of 1 .O t/ha. Vegetation treatments consisted of the seeding and mulching scheme mentioned above. Settling basins were designed on the basis of expected runoff from the drainage area supporting the turn-out ditch. Settling basins were designed to hold 38-mm of runoff from drainage areas using the equation:

$$V = A\,d$$

where:

V = Runoff Volume, m^3
A = Drainage Area, m^2
d = Depth of Rainfall, m

The design capacity of basins was 11 m^3 and they had dimensions 3.5 m x 3.1 m x 1 m. Rip-rap ditch treatments consisted of No. 1 course aggregate applied to a thickness of 31-cm and to a length of 3-m from the ditch outlet. Sediment fences, 3-m in length, were placed perpendicular to turn-out ditch outlets for all sediment fence treatments.

Sediment transport from the road prism via the turn-out ditch was measured using two runoff samplers at each turn-out ditch structure, immediately above (inflow) and below (outflow) the mitigation treatments. Runoff samplers collected composite runoff samples for each runoff event and suspended sediment was determined by gravimetric filtration. Filtering accomplished by each associated treatment was determined by comparing inflow and oufflow runoff concentrations.

A secondary measurement method was used to investigate sediment delivery downsiope onto the forest floor. This assessment involved using filter bags of known pore size to collect total sediment delivered to the forest floor. A diversion dam was placed below the turn-out treatment to direct runoff to l-micron filter bags (Figure 3). Filter bags were periodically collected, dried, and weighed to determine delivered sediment onto the forest floor from each associated mitigation treatment. The collected sediment gave valuable information on the quantity of sediment exported into filter strips below each turn-out treatment. Erosion stakes, on a uniform grid, were utilized in order to quantify sediment deposited on the forest floor prior to entering filter bags. Changes in forest floor elevations obtained from erosion stakes were used to calculate equivalent sediment weight. Total exported sediment was determined as a combination of sediment collected in filter bags and sediment deposited on the forest floor above filter bags. Turn-out treatments were compared based on reduction of sediment exported to the forest floor.

Response variables were analyzed using a repeated measures analysis of variance (ANOVA). The hypothesis for this comparison was that treatments were not equal in capacity to filter sediment laden runoff. Change in runoff concentration and sediment yield were used as dependent variables for investigation. Independent variables considered in the analysis of variance were treatment method, road grade, and runoff volume. Comparisons of treatment means were made to test within subject effects (a = 0.05), where analysis of variance indicated significant differences.

Rainfall amount and intensity, ambient temperature, and soil moisture were recorded by a weather station located on site. The weather station used a data logger to record input signals from a tipping bucket rain gauge sensor, temperature probe, and soil moisture sensor. Runoff volumes in turn-out sections were estimated based on runoff emanating from road sections, taking into account infiltration rates for each associated road section and roadside ditch.

RESULTS AND DISCUSSION

Turn-out ditch treatments and monitoring stations were installed between July 28, 1997 and August 15, 1997. Study monitoring began on August 28, 1997, before any rain had fallen on the newly treated turn-out ditches. The treatments were intensively monitored between August 28, 1997 and January 3, 1998. Sixteen rain events were observed during this initial study period (Table 2). Storm intensities ranged from 1.3 to 7.4 mm/hour with an average intensity of 3.2 mm/hour. Inflow and outflow runoff concentrations for each associated mitigation treatment were collected for each rain event observed during the study period.

Runoff Concentration

The change in runoff concentrations from inflow sampling points to outflow sampling points from the treatments was not as drastic as expected. The settling basin treatment was most effective in acting as a sink for transported sediment by retaining 57.9 percent of the input concentration. The sediment fence treatment was the second most effective sink for sediment with 28.7 percent reduction in runoff concentration from inflow to outflow. The vegetation treatment retained 13.5 percent of the inflow concentration. The rip-rap treatment had a 10.4 percent increase in outflow concentration, behaving as a. source for sediment transport. The increase in rip-rap outflow concentration was unexpected and likely resulted from large flow events flushing deposited sediment through the treatment area. Outflow runoff concentrations for the rip-rap treatment were greater than inflow concentrations during three storm events during the study events 3, 10, and 16 (Table 2). These events were characterized by higher rainfall amounts and intensity which could have flushed sediment deposited during previous storm events.

Repeated measures analysis of variance (a = 0.05) indicated treatment effects and sampler location were significant variables in runoff concentrations. Treatment effects on reduction in runoff concentration, however, was not detected as significant by the ANOVA (Table 3). The analysis also detected a significant time effect on runoff concentrations, but this effect was accounted for with the repeated measures analysis. Tests, by sampler location, on individual treatment means for within subjects effects (a = 0.05) detected no significant concentration differences in inflow runoff samples taken immediately before runoff entered treatment areas, for treatments used in this investigation (Table 4). Outflow runoff samples taken leaving the treatment areas, followed a different trend than the inflow runoff. Outflow runoff concentration from the sediment basin was significantly less than all other treatments in this investigation. The sediment fence had significantly lower outflow runoff concentrations than the vegetation treatment. The rip-rap treatment had similar runoff concentrations to that of the vegetation treatment and sediment fence treatments.

Sediment Deposition

Sediment transported from the road surface and through the individual treatments was measured as deposited sediment. The effectiveness of each associated turn-out treatment in filtering sediment laden runoff had an effect on the amount of sediment deposited'below treatment areas. The treatments with the highest reductions in runoff concentrations from inflow to outflow yielded the least amount of sediment below treatment areas.

Sediment deposition data was analyzed as a single factor ANOVA. No significant treatment effects were detected (Table 5). The hypothesis that there were differences in the filtering capacity of four roadside erosion control treatments could not be proven with these preliminary sediment deposition data. Even though no significant treatment effects were found, trends in sediment deposition were observed. The settling basin, as mentioned earlier, had the greatest reduction in runoff concentration and the lowest quantity of sediment deposited below the treatment area. The settling basin was followed by the sediment fence and vegetation treatments, respectively, in quantity of deposited sediment. The rip-rap treatment had the greatest amount of sediment deposited below the treatment area which was expected due to its inability to filter sediment laden runoff.

CONCLUSIONS

This paper details a study to evaluate ability of four erosion control techniques to control sediment export from forest roads. Erosion control treatments, including rip-rap, settling basin, sediment fence, and vegetation, were evaluated based on effectiveness in filtering sediment-laden runoff from the road.

Analysis of variance detected no significant treatment effects on the filtering capacity of four erosion control techniques. The settling basin provided the greatest reduction from inflow runoff concentrations with 57.9 percent reduction in concentrations exiting the treatment area. The sediment fence and vegetation with 28.7 and 13.5 percent reductions in sediment concentrations, respectively, retained a smaller percentage of exported sediment than the settling basin. The rip-rap treatment acted as a source for sediment, likely resulting from large flow events which flushed sediment deposited during previous events, with a 10.4 percent increase in outflow runoff concentrations.

Sediment deposition below each associated treatment showed no significant differences. However, the rip-rap treatment had the greatest amount of deposited sediment with 80.7 kg/ha. The vegetation and sediment fence treatments were the next two highest deposition amounts with 61 .O and 37.9 kg/ha of sediment, respectively. The settling basin with 1.7 kg/ha of deposited sediment yielded the least of all treatments in the experiment.

LITERATURE CITED

Alabama Forestry Commission. 1993. Alabama's best management practices for forestry. Alabama Forestry Commission. Montgomery, Alabama.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forest and water: effects of forest management on floods, sedimentation, and water supply. USDA Forest Service, General Technical Report PSW-18, San Francisco, California.

Brinker, R.W. 1993. Best management practices for timber harvesters. Alabama Cooperative Extension Service, Agriculture and Natural Resources, Circular ANR-539, Auburn University, Alabama.

Cook, W.L.Jr. and J.D. Hewlett. 1979. The broad-based dip on Piedmont woods roads. *Southern Journal of Applied Forestry; 3:* 77-81.

Eck, R.W. and P.J. Morgan. 1987. Culverts versus dips in the Appalachian Region: a performance-based decision-making guide. In: *Fourth International Conference* on *Low-Volume Roads.* Volume 2; Transportation Research Record 1106; p. *330-340.*

Gardner, R.B. 1978. Some environmental and economic effects of alternative forest road designs. *Transactions of the ASAE;* Vol. 22, No. 1: 63-68. ASAE, St. Joseph, Ml.

Haupt, H.F. 1959. Road and slope characteristics affecting sediment movement from iogging roads. Journal *of Forestry,* 57(5): *329-332.*

Haupt, H.F., H.C. Rickard, and L.E. Finn. 1963. Effect of severe rainstorms on insloped and outsloped roads. USDA Forest Service, Research Note INT-1 , Ogden, Utah.

Hewlett, J.D. and J.E. Douglass. 1968. Blending forest uses. USDA Forest Service, Research Paper SE-37, Asheville, NC.

Hoover, M.D. 1952. Water and timber management. *Journal of Soil* and Water *Conservation;* Vol. 7: 75-78.

Kochenderfer, J.N. and J.D. Helvey. 1987. Using gravel to reduce soil losses from minimum-standard forest roads. *Journal of Soil and Water Conservation*; 42(1): *46-50.*

Miller, EL., R.S. Beasley, and J.C. Covert. 1985. Forest road sediments: production and delivery to streams. In: Blackman, B.G., ed. *Proceedings of Forestry and Water Quality: A mid-South Symposium;* 1985 May 8-9: Little Rock, AR. University of Arkansas Montecello, School of Forestry. p. 164-176.

Murphy, A.A. 1985. Minimizing forest road construction envirorimental impact. *Presented at the New England Regional Council on Forest Engineering, NER.COFE Roads and Structures Workshop,* University of Maine at Orono, March 21-22, 1985. p. 5-10.

Nagygyor, S.A. 1984. Construction of environmentally sound forest roads in the Pacific Northwest. Presented at 1984 COFE/IUFO Conference, August 12-14 1984 in Orono, Maine, USA. p. 143-147.

Packer, P.E. 1967. Criteria for designing and locating logging roads to control sediment. Forest Science; 13(1): 2-l 8.

Patric, J.H. 1976. Soil erosion in the eastern forest. Journal of *Forestry*; 74(10): 671-677.

Reinhart, K.R., A.R. Eschner, and G.R. Trimble, Jr. 1963. Effect of streamflow of four forest practices in the mountains of West Virginia. USDA Forest Service, Research Paper NE-l, 79 p.

Swift, L.W. Jr. 1985. Forest road design to minimize erosion in the southern Appalachians. In: Blackman, B.G., ed. *Proceedings of Forestry and Water quality: A mid-south Symposium;* 1985 May 8-9: Little Rock, AR. University of Arkansas, Montecello School of Forestry. p. 141-l 51.

Swift, L.W. Jr. 1986. Filter strip widths for forest roads in the southern Appalachians. *Southern Journal of Applied Forestry, 1 0(1): 27-34.*

Trimble, G.R.Jr. and R.S. Sartz. 1957. How far from a stream should a logging road be located? *Journal of forestry;* 55(5): *339-342.*

Weitzman, S. and G.R. Trimble, Jr. 1952. Skid-road erosion can be reduced. *Journal of Soil and Water Conservation; 7: 122-l 24.*

Table 1. Recommended spacing for turn-out ditches and broad-based dips.

Road Gradient (%)	Turn-out ditch* (m)	Broad-based dip** (m)
3	72	71
5	55	55
10	43	43
15	38	39

* Alabama Forestry Commission 1993
** Hewlett and Douglass 1968.

Table 2. Precipitation at the Tuskegee site during study period .

Obs. #	Obs. Date	Precipitation (mm)	Intensity (mm/hr)
1	Aug. 28 - Sept. 29	27.9	3.2
2	Sept 29 - Oct. 24	5.1	2.3
3	Oct. 24 - Oct. 27	71.4	5.8
4	Oct. 27 - Oct. 31	14.0	3.6
5	Oct. 31 - Nov. 5	24.1	3.0
6	Nov. 5 - Nov. 12	14.0	2.5
7	Nov. 12 - Nov. 13	35.6	3.0
8	Nov. 13	25.1	5.3
9	Nov. 13 - Nov. 21	34.3	3.2
10	Nov. 21 - Nov. 24	37.3	7.4
11	Nov. 24 - Nov. 29	31.2	4.6
12	Nov. 29 - Dec. 1	29.2	3.6
13	Dec. 1 - Dec. 4	24.4	3.2
14	Dec. 4 - Dec. 9	34.0	1.3
15	Dec. 9 - Dec. 15	8.3	1.8
16	Dec. 15 - Jan. 3	104.4	6.4

Table 3. Mean runoff concentration reductions for turn-out treatments.

Treatment	N	Runoff Concentration Reductions* (%)
Vegetation	45	13.5a
Rip-rap	45	-10.4a
Sediment Fence	45	28.7a
Settling Basin	45	57.9a

* Means with the same letter are not significantly different (a = 0.05).

Table 4. Mean runoff concentrations for turn-out treatments.

Treatment	N	Inflow Concentration* (ppm)	Outflow Concentration** (ppm)
Vegetation	39	265a	229a
Rip-rap	40	203a	224a
Sediment Fence	39	238a	169ab
Settling Basin	39	142a	60b

* Means with the same letter are not significantly different (a = 0.05).
** Means with the same letter are not significantly different (a = 0.05).

Table 5. Mean sediment deposition and runoff for turn-out treatments.

Treatment	N	Flow Distance (m)	Drainage Area (ha)	Deposited Sediment* (kg/ha)	Runoff (m^3)
Vegetation	3	60	0.024	61 .Oa	75.5
Rip-rap	3	60	0.021	80.7a	65.0
Sediment Fence	3	50	0.016	37.9a	51.1
Settling Basin	3	50	0.017	1.7a	54.6

* Means with the same letter are not significantly different (a = 0.05).

Figure 1. Study Experimental Design and Field Layout.

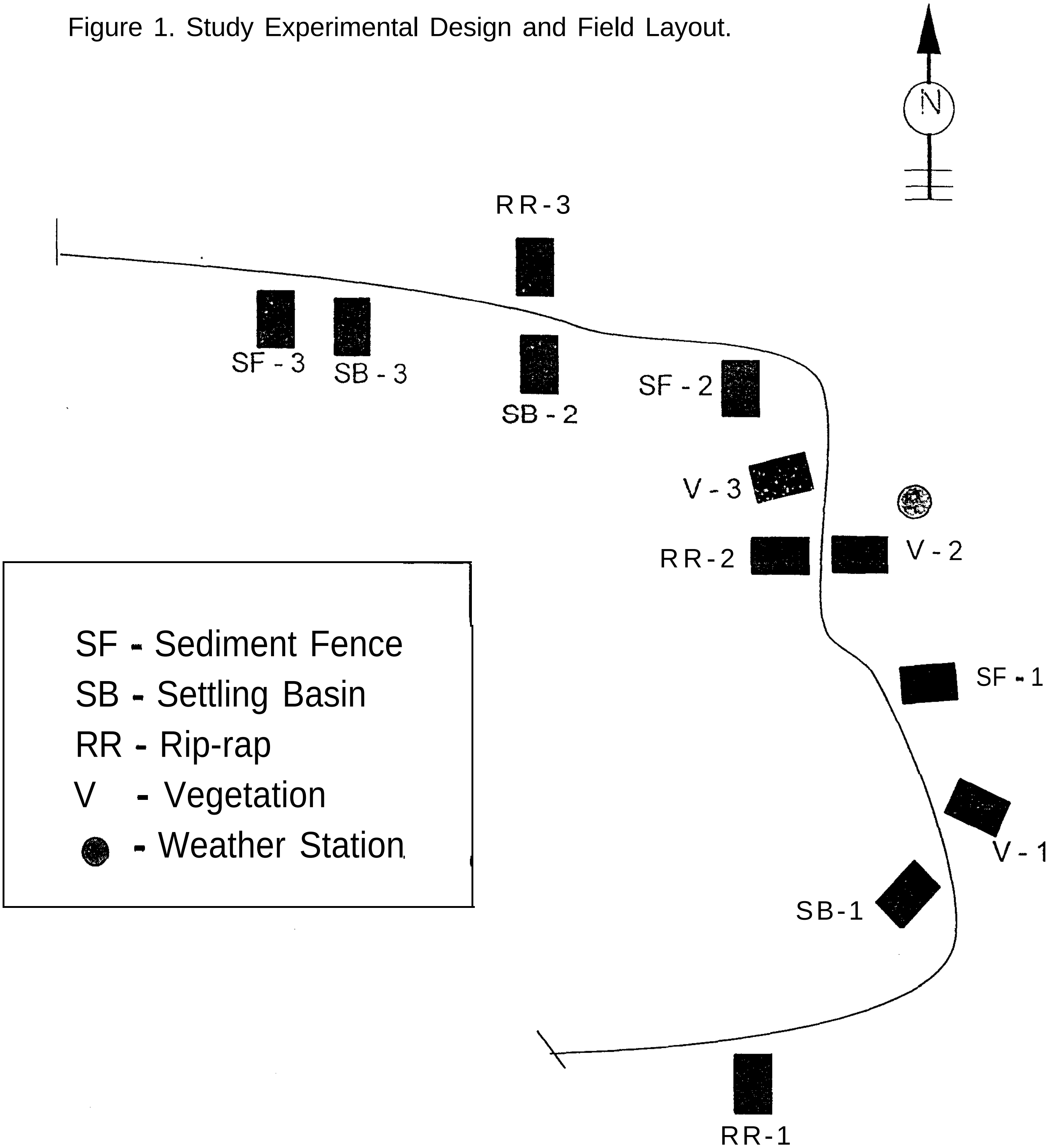

Figure 2. Turn-out ditch cross-section (not to scale).

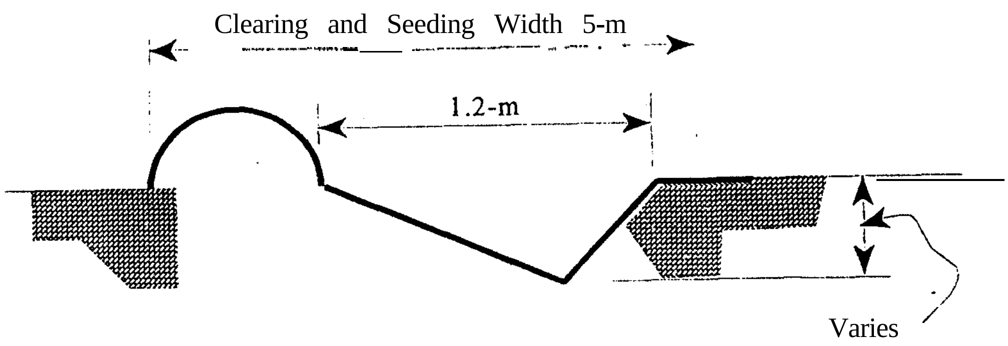

Figure 3. Schematic of Individual Test Area.