THE DESIGN OF TEMPORARY SEDIMENT CONTROLS WITH SPECIAL REFERENCE TO WATER QUALITY

by

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ABSTRACT

The laboratory and field trapping efficiencies of several types of flow barriers were ascertained. The materials used to fabricate the barriers were various types of hay, straw, crushed stone, and crushed stone/straw mixes. Field checks of systems of barriers have indicated that flow barriers placed by the contractor have a near zero average efficiency. Experimentally modified flow barriers designed by the Soil Loss Equation have an average efficiency approaching that found in the laboratory tests. Sizeable reduction (77%) in the downstream bottom-dwelling organisms was observed with the currently used flow barriers, while for the experimental barriers a smaller reduction was noted. Field observations appear to indicate that for relatively short-term, non-point sediment sources, such as highway construction, the bedload may have a more important effect on stream ecology than the suspended load. A method for the estimation of the time required for stream rehabilitation was developed and used in the study. For the area studied, rehabilitation appears to be on the order of two to three months after construction stops and vegetation is established. The rehabilitation time appears to be dependent upon stream flow and upstream colonization factors.

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INTRODUCTION

Because of increased concern over the possible degradation of the ecology and water quality of streams from sediment, in 1969 the Virginia Department of Highways and Transportation placed added emphasis on the use of erosion and sediment controls on highway construction sites. The purpose of these measures was to provide an effective temporary means of controlling construction-generated sediment. The overall aim of the program is to trap the sediment on the construction site rather than allowing it to enter nearby streams and thereby degrade downstream water quality. The exact level of effectiveness of these controls was, until recently, unknown. Individual control structures, such as flow barriers, had not been evaluated as to their trapping efficiency and the overall effects of Virginia's present efforts in sediment control had not been evaluated in terms of stream ecology and water quality parameters. Lastly, no rational method of control structure deployment had been used during construction. Commonly, the deployment of the majority of structures had been left to the discrimination of the Department's representatives on the construction project. Without a rational deployment method for control structures, only limited success in controlling construction-generated sediment can be realized.

The successful design of temporary sediment controls at any construction site must take into account an estimate of the sediment loss while construction is under way. This estimate, in turn, must be based upon the temporal variation in the intensity and distribution of the precipitation; the erodibility of the soils; the topographic relief, size, and geometric configuration of the construction area; and the trapping efficiency of the individual structures used.

No system of controlling sediment can be 100% successful, but the most effective attempt can be realized if each of the major construction activities which generates sediment is assessed as to its effect on water quality. Recommendations should be made to reduce, wherever possible, the impact of those construction activities which have a pejorative effect on the environment. These recommendations, used in conjunction with a rational method of design and deployment of control structures, should significantly reduce the impact of highway construction on water quality.

PURPOSE AND SCOPE

The purpose of this study was: (1) to evaluate a number of the most important of the currently used sediment trapping materials in terms of their efficiency; (2) to develop a method of estimating both soil losses and the number and placement of control structures required to trap the sediment on construction sites; (3) to make a field evaluation, in terms of trapping efficiency and water quality, of the effectiveness of both the currently used controls and several controls experimentally designed and placed on the basis of estimated soil losses; (4) to indicate those major highway construction activities having the most direct adverse effect on water quality; and (5) to make recommendations to reduce, wherever possible, the impact of those construction activities or techniques which have an adverse impact on water quality.

The research reported here dealt primarily with non-vegetative methods of sediment control and concentrated on the trapping efficiency of straw, hay, and crushed stone barriers. Experimental combinations of crushed stone and straw were also evaluated in the laboratory.

PROCEDURE

Soil Loss Prediction Method

Research into the relationships of topography, soil, and rainfall for more than 30 years has yielded the Soil Loss Equation developed by the Agricultural Research Service of the U. S. Department of Agriculture(1). The equation provides a systematic procedure for the estimation of soil loss from varying combinations of rainfall, topography, and soil erodibilities(2, 3). It was designed primarily for agricultural applications, however it has been applied to highway construction(4) as represented by highway excavations or embankment slopes considered to be unseeded pseudo-fallow slopes or pseudo-meadows with grasses in various stages of growth.

The Soil Loss Equation is expressed as

$$A = R\ K\ LS \qquad (1)$$

in which

A = computed soil loss, tons per acre

R = rainfall factor - the erosion index units per acre in a normal year's rain. (The erosion index is a measure of the erosive force of a specific rainfall.)

K = soil erodibility factor - the erosion rate per unit of erosion index for a specific soil in cultivated continuous fallow on a 9% slope 72.6 ft. (22 meters) long. (The reason for these dimensions is given in the USDA Handbook 282.(1))

L = slope length factor - the ratio of soil loss from the field slope length to that from a 72.6 ft. (22 meter) length of the same soil type and gradient.

S = slope gradient factor - the ratio of soil loss from the field gradient to that from a 9% slope.

The Soil Loss Equation was initially developed for agricultural areas of low and uniform steepness, and two difficulties arise in its application to highway construction. These are that the typical highway slope is commonly irregularly shaped in cross section, and that at least part of the slope is usually very steep. Recently, a modification of the equation by Foster and Wischmeier allows the prediction of soil loss for such irregular slopes(6).

The rainfall factor, R, and the soil erodibility index, K, have been tabulated for Virginia by the USDA Soil Conservation Service(5). The slope length and gradient factors have been combined into a single factor, LS, and uniform slopes may be evaluated using Figure 1.

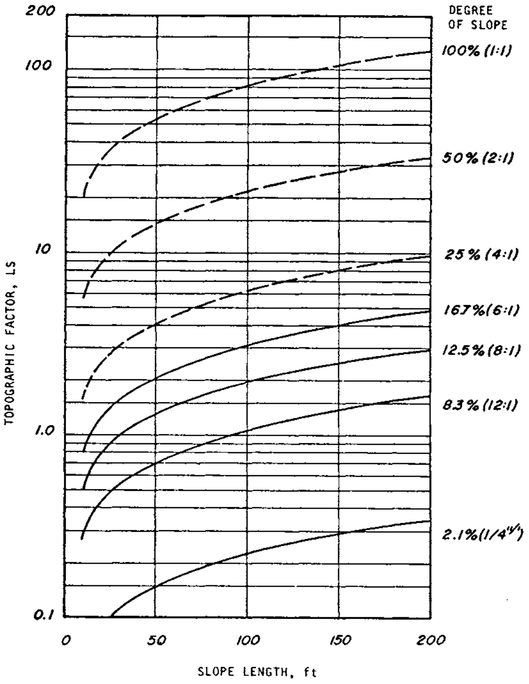


Figure 1. Topographic factor, LS, slope effect. Dashed lines are extrapolated values. (From reference 4.) Basic conversion unit: 1 ft. = .305 meter.

A computer program prepared by Poche(7) takes into account nonuniform slopes for estimating soil loss from a highway slope or median strip. Input for the program consists of a basic description of the slope (location, soil erodibility, slope length, and gradient) and duration of construction. The output consists of an estimated annual soil loss and a peak loss assuming a 2-year, 6-hour storm event during the construction. This rainfall intensity was chosen because it is typical of rainfall events in the eastern U. S. A summary of the method of calculation can be found in Appendix A. The program also outputs the number of straw barriers required to control this peak soil loss.

Laboratory Evaluation of Sediment Trapping Materials

The major laboratory effort was centered around the determination of the filter efficiency of straw, hay, and rock barriers. These particular materials were chosen because they are the ones most commonly utilized in sediment control barriers and berms.

Straw and hay bales of differing fiber composition were first evaluated to determine if there was a material which preferentially had a higher filtering efficiency. Relative bale to bale differences in compaction were measured using porosities of the bales as determined by

$$E = 1 - \frac{\text{Bulk Density}}{\text{Fiber Density}} \tag{2}$$

where E is the porosity and the bulk density of the bale is determined by its weight divided by its volume; the fiber density was determined with a pycnometer.

The determination of the filtering efficiency of various bales was found from

$$\%\text{Eff} = \frac{SS_{in} - SS_{out}}{SS_{in}} \times 100 \tag{3}$$

where Eff is the filtering efficiency or percentage difference between the suspended solids level of the input into the bale (SS_{in}) and the suspended solids level of the output filtered through the bale (SS_{out}). The evaluation consisted of passing known volumes of sediment-laden water at runoff concentrations (10,000 and 20,000 parts per million, or ppm) through bales placed in the flume as shown in Figure 2. Sediment control structures were simulated by single and double thicknesses of straw and hay bales of varying types and bale sized gabions filled with various sizes and combinations of rock fragments and straw. The outflow water was collected and reagitated. A total of 250 liters of 10,000 ppm and 400 liters of 20,000 ppm water-soil mixtures were passed through each simulated control structure. A depth integrated sample of the outflow water was made with a DH-48 hand sampler. The turbid water was then vacuum filtered onto a preweighed, .45 micron filter paper or poured into a preweighed evaporating dish. After drying, it was weighed and the average suspended solids of the outflow was calculated for several runs with the same material. Equation 3 was used to calculate the efficiency.

Figure 2. Flume used in determination of filtering efficiency of flow barriers.

Field Evaluation of Straw Barriers

An evaluation of the filtering efficiency of field barriers was made and the results compared to the findings from the laboratory flume studies. It was also hoped that a barrier system designed to meet the soil losses could be compared in overall efficiency with barriers presently employed by a contractor.

A field test location was selected on U. S. Route 29 south of Charlottesville, Virginia, where two lanes of a four-lane divided highway were being constructed. (See Figure 3.) The project consisted of adding southbound lanes to an existing two-lane facility. Fifteen hundred feet (.5 kilometer) of right-of-way was selected as a test area for the field evaluation. The test section was located upgrade of an unnamed tributary of the north fork of the Hardware River (see Figure 3). The location was selected because of its close proximity to Charlottesville; the simplicity of the drainage basin north of the test location; the proximity to other streams; the high water quality of the crossing tributary as indicated by a pre-test investigation; and the presence of a box culvert across the lower portion of the test location which could be used for stream discharge measurements. The field evaluation site is diagrammatically shown in Figure 4.

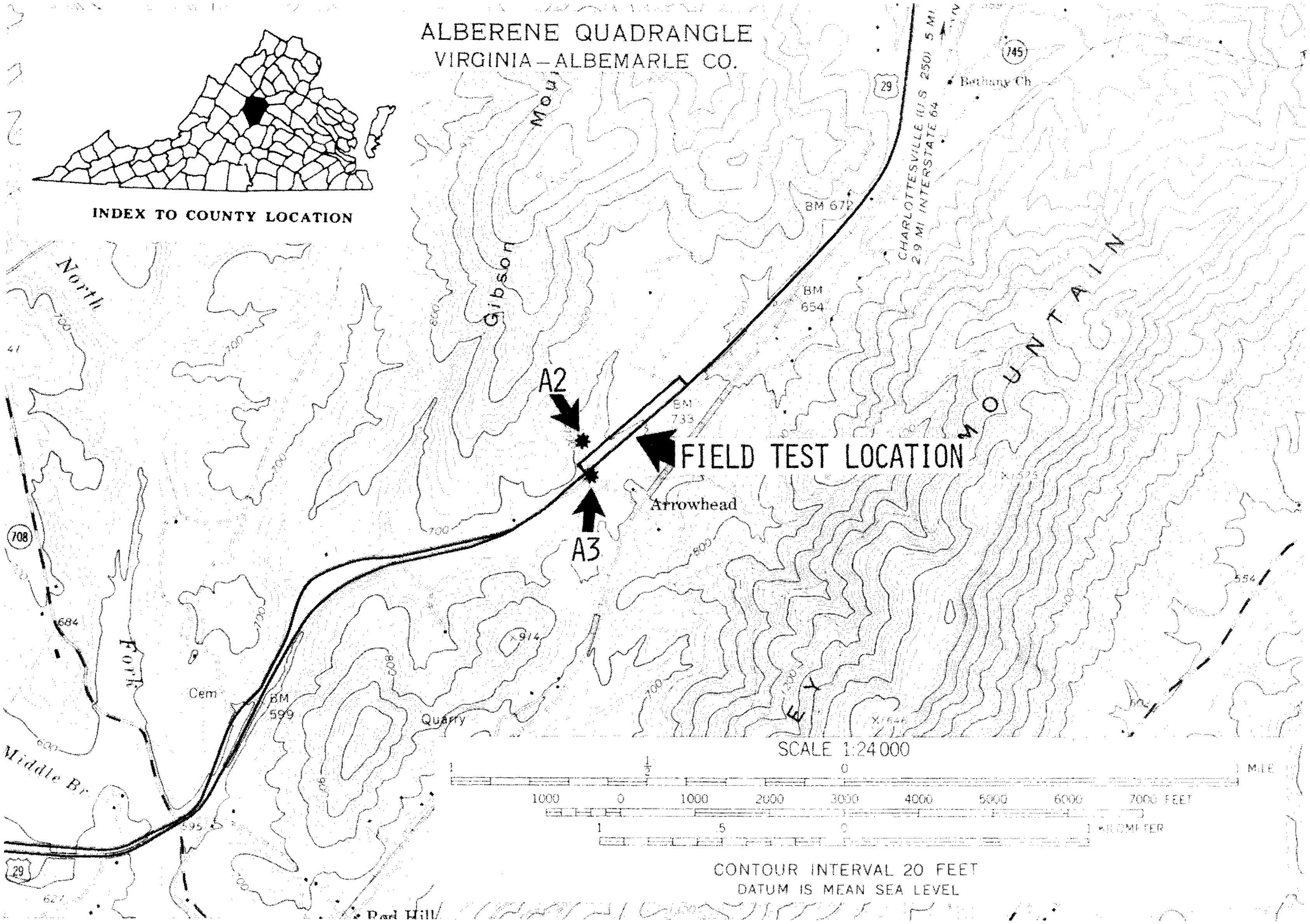


Figure 3. Location of field tests.

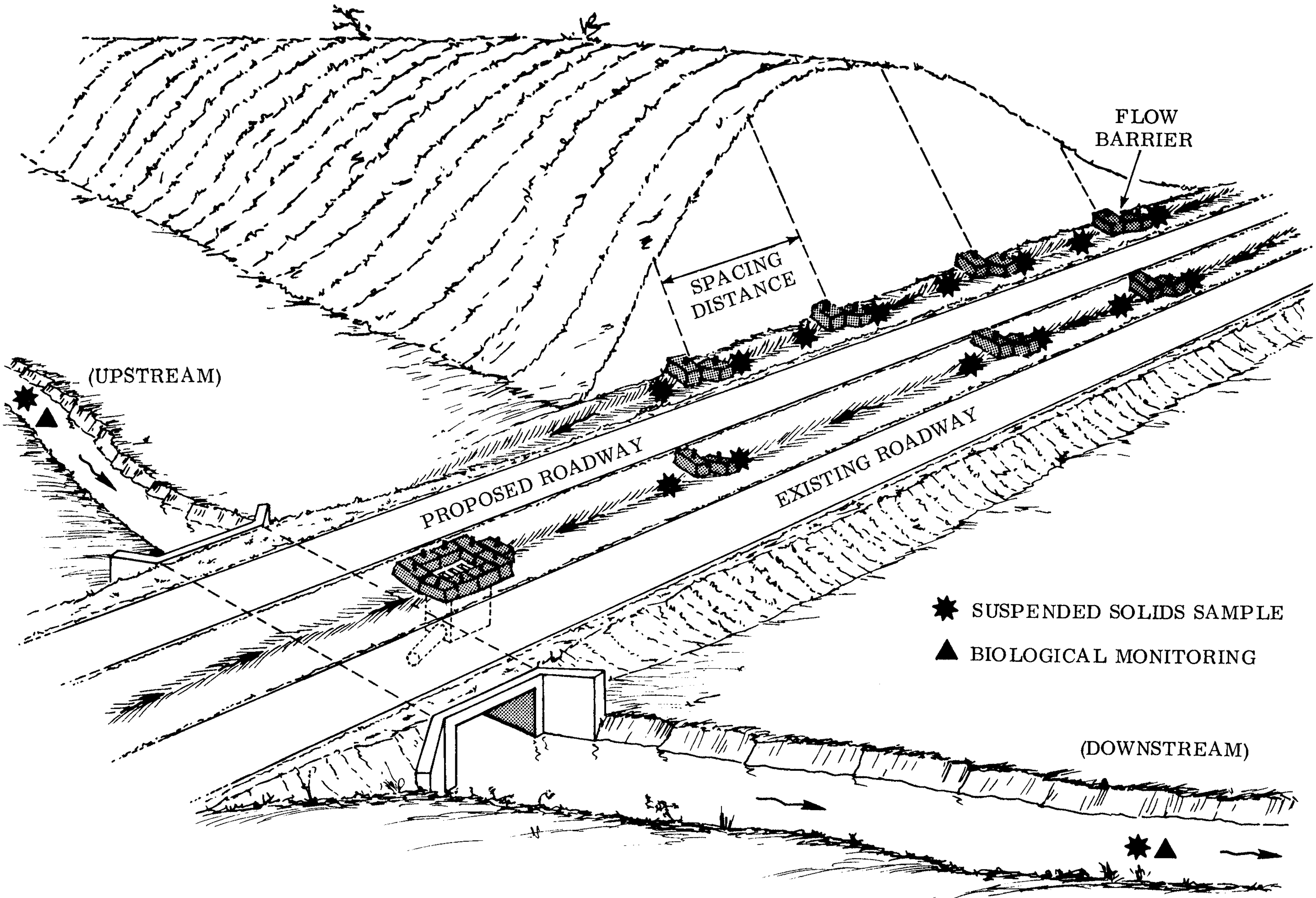


Figure 4. Sampling methodology at field test locations.

Initially no attempt was made to change the normal routine of placing barriers, their location, number etc. The field evaluation first consisted of monitoring the barriers placed by the contractor. Upflow and downflow water samples were taken for each barrier during storm events, and the average percentage loss was calculated and compared with the laboratory results. After storms, barrier failures were identified.

The rainfall intensity was monitored at the test location and was averaged from five gages placed parallel to the construction.

The final field evaluation was made at the test location by replacing the contractor barriers with modified test barriers at predetermined spacings within the ditchline to meet the soil losses predicted by the Soil Loss Equation. The number and kind of bottom-dwelling organisms per square foot were monitored upstream and downstream of the construction using modified HESTER-DENDY biological substrates.(18) Each substrate contained five square feet of surface area. This area was assumed to be statistically valid. Each substrate requires 6 weeks to "grow". During this period it becomes seasoned, and organisms attach themselves and grow. By keeping three substrates at each station, each separated in time by two weeks, it was possible to monitor the construction activity quite closely by relating suspended solids measurements to organism counts.

Biological monitoring, although not a common practice in highway research and engineering in the past, is very desirable because it is a sensitive index to water quality and thereby to sediment pollution in streams. It is a measure of the long-term environmental effects of sediment.

Other Field Studies for Baseline Evaluations

After six weeks of measurements at the two stations associated with the test location, the monitoring program was expanded to 10 stations (see Figure 5). Biological monitoring was located at nine of these stations and water samples were collected from all stations on a weekly basis. The decision to expand the program was made because it was realized that an excellent opportunity existed to gather "baseline" information on the effects of construction on water quality. An overall view of the drainage system was desired so that effects of individual construction phases (such as culvert construction or slope dressing) could be studied, not only at the local station level but also throughout the system, to see if downstream degradation was significant. This study also aided in the determination of regrowth rates of organisms and aquatic plants disturbed by construction. The biological effects of rain induced sediment versus in-stream construction induced sediment were also studied.

Statistical Analysis of Water Quality Data

Since the quality of water is manifested through its biotic component, an ecological evaluation of an aquatic environment involving a comparison of the living community at one time or location with that of another should be an important indicator of water quality.

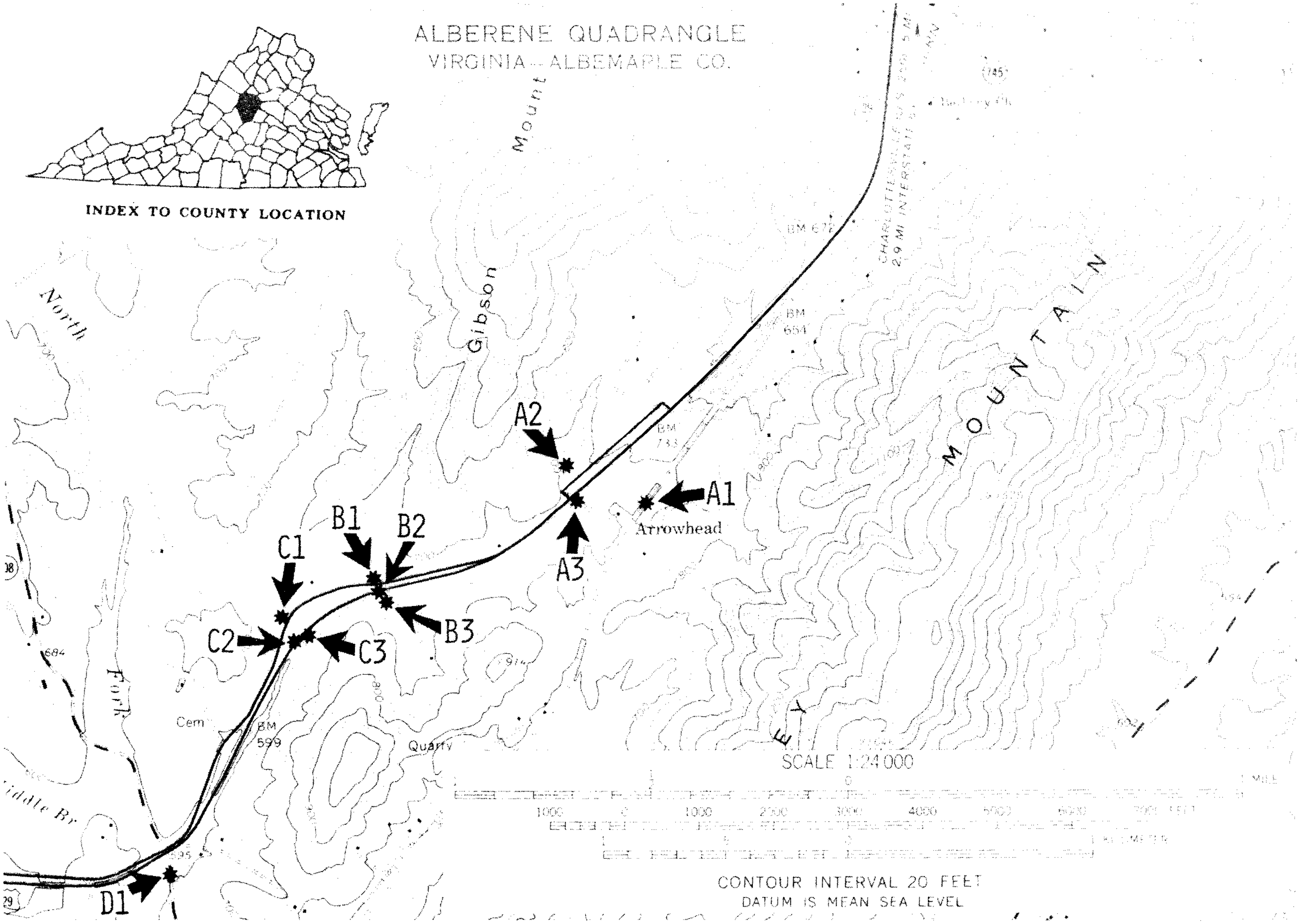


Figure 5. Drainage basin monitoring locations.

Biological analyses of the initial two stations associated with the test location yielded biweekly information on the number and type of organisms per square foot of stream bottom. This index of stream productivity was related to the corresponding measurements of stream suspended solids. It was hoped that a comparison of the biologic data with the suspended solids measurements could be made into a graph relating the percentage of downstream organisms as compared with upstream organisms to suspended solids levels in the stream. Such a graph should allow a recommendation to be made regarding a safe suspended solids level which will not do significant harm to the aquatic environment.

Several additional measurements of the quality of the water within the drainage basin undergoing construction were made possible by the other stations associated with this study. The basic assumption of monitoring is that the biologic community inhabiting any location within a stream is diverse enough to exhibit the physical conditions required for their growth and maintenance. The community present in the stream thus reflects its water quality. The organisms are the food sources for the majority of the higher organisms of the stream (e.g. fish) and are essential to the ecology of the stream. As the community is stressed, say by some form of pollution, the population responds by increasing the number and kinds of those organisms which are tolerant to the new conditions and by decreasing those which are not. Table 1 shows the principal stresses that can be placed on bottom-dwelling organisms and the resulting population shift. The principal effect of stressing the stream population with silt is to reduce both the numbers and kinds of all organisms. Such a change or shift can, in time, be characterized by changes in two principal measures of the population: its mean diversity and its redundancy(8).

Table 1

Principal Effects on Stream Organism Populations from Pollution

Stress	Numbers	No. of Taxa
Toxic Substance	Reduce	Reduce
Temperature	Variable	Reduce
Silt	Reduce	Reduce
Nutrients Inorganic	Increase	Variable
Organic Waste	Increase	Reduce

Source: U. S. Environmental Protection Agency.

The mean diversity, $\bar{D}$, is a measure of the average diversity among individual organisms, or, put another way, its average "richness" in species or genera of the biologic community. Redundancy, R, on the other hand, arises from having unequal numbers of organisms within the species or genera present. Redundancy can be thought of as the probability that an organism belongs to a specific species or genera. Thus it is inversely proportional to the wealth of species or genera present. Redundancy varies from zero (if each individual belongs to a different species or genera) to a value of one (if all individuals belong to the same species or genera).

The mean diversity(10) was computed from equation 4

$$\bar{D} = \frac{1}{N} \left[\log_2 N! - \sum_{i=1}^{S} \log_2 ni!\right] \tag{4}$$

The redundancy(8) was computed from the equation

$$R = \frac{\sum_{i=1}^{S} \log n_i! - S \log (N/S)!}{\log (N-S+1)! - S \log (N/S)!} \tag{5}$$

where: N = total number of organisms

n_i = number of organisms in i^{th} genera

S = total number of genera

For example, if three genera, each containing one organism, are present at a station, then $R = 0.0^0$ and $\bar{D} = 0.86$. When redundancy is zero, the population of organisms is judged to be in an acceptable condition, but when $\bar{D}$ is less than 3, according to Wilhm(9), the population is approaching an unacceptable condition.

Until recently, whenever a large number of water quality parameters, such as redundancy, mean diversity, and suspended solids, had been measured either over a long period of time or over a large number of samples, there was no way to statistically evaluate (i.e., assign probability levels) shifts in these parameters. Without sophisticated evaluative techniques, such shifts in parameters became the subject of conflicting interpretations. Harkins and Austin have demonstrated a technique for reducing a set of numerical indices into a set of unique values which can be statistically evaluated.(10) Basically, the technique involves nonparametric (distribution-free) discrimination techniques which provide a single index value incorporating several measurements made at a station. The index value is a unique distance value from a fixed reference point or condition. For this study, four variables were used as a control reference point (mean diversity -$\bar{D}$, redundancy -R, number of genera -G and a weighted average suspended solids measure -SS). The reference point ($\bar{D} = 0$, $R = 1$, $G = 0$, $SS = 10,000$) was assumed to be a "biological desert" condition.

The reference point and the station parameters of the four indices were ranked from low to high, and the rank variance of each parameter was computed using the equation

$$\text{Var} = 1/12K \left[(K^3 - K) - \sum (t^3 - t)\right] \qquad (6)$$

where $K = M + 1$ and its summation is over all ties of entent t in the values of the parameter.

The standardized distance (SD) or water quality index between the reference or control point and the sample points$^{(10)}$ is computed from

$$SD_i = \frac{(\text{Rank } R_i - \text{Rank } R \text{ control})^2}{\text{VAR } (R)} + \frac{(\text{Rank } \bar{D}_i - \text{Rank } \bar{D} \text{ control})^2}{\text{VAR } (\bar{D})} + \frac{(\text{Rank } S_i - \text{Rank } S \text{ control})^2}{\text{VAR } (S)} + \frac{(\text{Rank } SS_i - \text{Rank } SS \text{ control})^2}{\text{VAR } (SS)} \qquad (7)$$

where $i = 2, 3, \ldots M + 1$, sample points. SD for the case of three parameters is shown diagramatically in Figure 6.

The value SD is normally distributed and may be used to test hypotheses and set probability levels using standard parametric techniques. In addition, SD values mask station to station differences in number of organisms by using mean diversity and redundancy. Generally the larger in magnitude the SD value, the greater the station differs from the desert condition and, thus, the better its water quality.

Two computer programs from the U. S. Environmental Protection Agency were modified and converted so that water and biological measurements could be evaluated simultaneously.

RESULTS OF RESEARCH

Laboratory Results

Relative bale to bale differences in compaction and fiber content were measured by bale porosity. The measured porosities (equation 2) of 21 bales ranged from .838 to .928. The data are shown in Table 2. Single bale suspended solids losses range from 4,600 ppm for barley straw to 8,900 ppm for timothy-orchard grass hay mixture. Using equation 3, the corresponding filtering efficiencies were computed and ranged from 46% to 88%. Double bale thicknesses are generally about 66% more efficient in filtering than are single bale thicknesses.

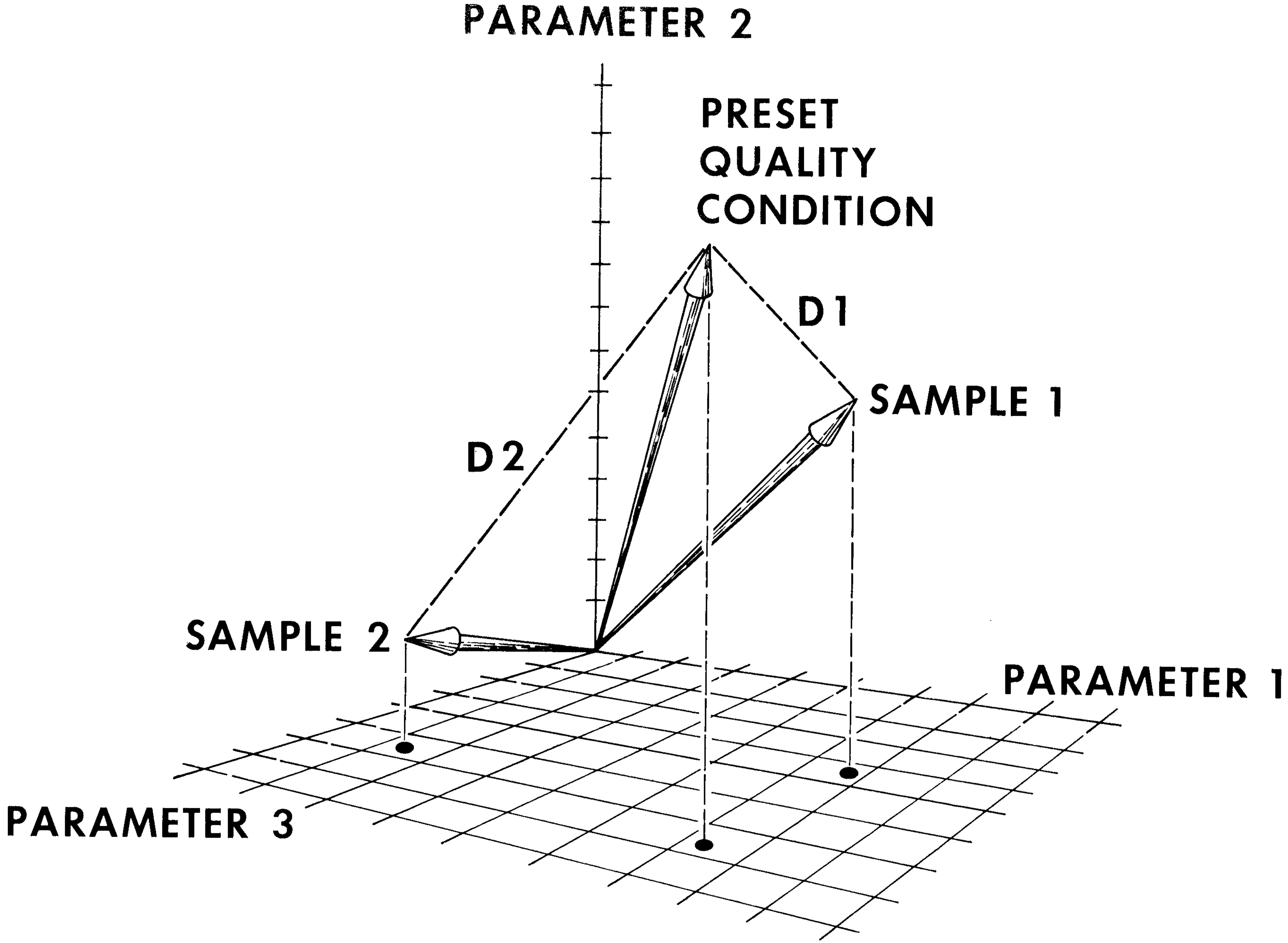


Figure 6. Calculation of distances (D1 and D2) of samples from a reference quality condition (biological desert). When D1 and D2 are divided by the variances of parameters 1, 2, and 3, they become standardized. D2 is farther than D1 from the desert condition and thus has better water quality. See equation 7 of text.

Table 2

Porosity and Filtering Efficiency of Various Bales

Bale Type	Bulk Density g/cc	Fiber Density g/cc	Porosity	% Efficiency
Hay, Orchard Grass	.087	1.43	.838	78
	.086	1.43	.838	78
	.127	1.30	.902	56
	.124	1.19	.894	—
	.153	1.35	.887	66
	.120	1.43	.916	64
	.183	1.16	.842	64
Straw, Barley	.104	1.45	.928	46
Straw, Wheat	.094	1.20	.921	65
	.104	1.31	.921	65
	.071	1.37	.948	62
	.087	1.47	.941	62
Hay, Fescue	.111	1.45	.923	56
	.101	1.59	.936	71
	.103	1.35	.942	74
Hay, Timothy, Orch. Mixed	.130	1.24	.895	88
	.137	1.33	.897	—
	.125	1.15	.891	83
Straw, Oats	.078	1.07	.927	76
	.089	1.16	.924	72
	.079	1.12	.929	—

Statistical t tests of the porosities indicated that there was no significant difference in the compaction between the hay and straw bales, and that no significant differences existed between the filtering efficiencies of the two general types of materials. In other words, straw is just as good as hay as a filter-retention material. Thus neither material should be used in preference to the other for flow barriers.

Both porosity and bulk density have a very low correlation with the filtering efficiency of bales. Thus any scheme to pretest the efficiency of bales with the determination of porosity or bulk density would meet with little success.

During the flume tests it was observed that there is a linear decrease with distance in the cross section of the bale exposed to the water-silt mixture (see Figure 7). The suspended solids loss and thus the filtering efficiency remained nearly constant with repeated treatment with the water-silt mixture. It appeared that as the lower portion of the bale became clogged with mud, flow corridors were found in the higher, cleaner portions of the bale. A similar profile of flow can be seen in the case of double bale thicknesses of straw or hay.

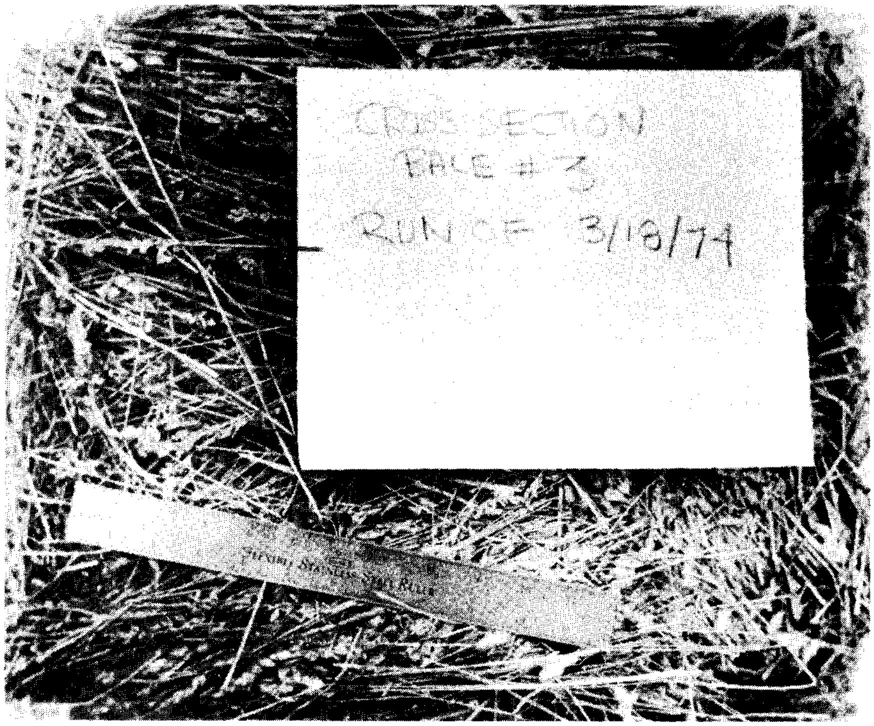


Figure 7. Profile of flow through hay bale. Flow is from left to right and bottom of ruler approximates top of flow profile.

It was also observed that allowing a wet bale to set for an extended period allowed the fibers to expand and a growth of fungus to develop internally, which increased the filtering efficiency. A pre-wetted bale was first tested for its efficiency in the normal way. After several weeks, it was tested again and its efficiency had increased from 74% to 98%. It might be well to recommend wetting of the bales after placement on a project. This would be an inexpensive means of improving the filtering efficiency and if the bale was properly bound, it should not shorten the effective life of the barrier.

In addition to the straw and hay bale tests, four experiments were performed using bale sized gabions filled with crushed stone and crushed stone/straw mixes. Two sizes of crushed stone with and without straw were used: a fine mix (3/8 to 3/4 inches (0.95 to 1.91 cm) in diameter) and a coarse mix (1 1/2 to 2 1/2 inches (3.81 to 6.35 cm) in diameter). The results are shown in Table 3.

Table 3

Gabion Trapping Efficiency

	Without Straw	With Straw*
Fine Mix	32%	62%
Coarse Mix	29%	58%

* Approximately 1 inch (2.54 cm) of straw (compressed) was placed in each gabion with crushed stone placed on top.

It may be concluded that the efficiencies of the gabions without straw were low, even when fine, small crushed rock was used. However, the efficiency approximately doubled when straw was used, approaching that of a straw barrier. The effect of the straw in the gabion is to provide a better bottom seal than rock alone. The majority of the void to void flow is also through the more efficient straw. Even though their efficiency is low, crushed stone barriers are excellent for use in streams because they impede bedload sediment and inhibit increased runoff effects (channel and bank erosion). They also serve as habitat for bottom dwelling organisms. Field observations of crushed stone barriers indicate that little or no ecological damage occurs with their use.(17)

Field Evaluation of Straw Barriers

A field evaluation of the filtering efficiency of straw was made at the test location to (1) compare the results of the laboratory flume studies with field measurements, and to (2) compare various methodologies for the design of flow barrier systems.

Observations of the average percentage efficiencies of the flow barriers placed by the contractor are shown in Table 4. Negative values for efficiencies indicate that in some cases suspended sediment was a higher downflow from the barrier than in the storm water reaching the barrier from upflow areas. Each barrier consisted of three wheat straw bales as shown in Figure 8. The barrier spacing distance was 200 feet (61 meters). While the average laboratory wheat straw barrier was 64% efficient, those in the field showed a grand average of nearly zero. Observations made during the rainfall events of August 4 and September 6, 1974, indicated that, on the average, only a small percentage of the flow barriers placed by the contractor approached the efficiencies measured in the laboratory. Most startling were the measurements of August 4, which indicated the average efficiency of the barriers was a negative 7%. This finding means that on the average the barriers contributed to the suspended solids load rather than reducing it.

Table 4

Percentage Efficiency of Contractor's Barriers
(Wheat Straw Barriers 200 feet (61 meters) Apart)

Flow Barrier	Rainfall Event	
	8/4/74	9/6/74
A*	+56	0
B	-35	- 7
C	-83	-10
D	- 1	-23
E	+ 1	+61
F	+25	+25
Average	- 7	+ 8

* Flow was from barrier F to Barrier A in the ditchline.

Barrier failure may result from a number of factors. The utilization of low numbers of barriers (Figure 9) results in large amounts of sediment and runoff simply bypassing the available barriers. Improper construction practices include improper placement that allows undercutting of the bales and flow around the ends of the barrier. These latter problems are probably the most significant contributor to barrier inefficiency. Improper maintenance only worsens the problem through time (Figure 10) and directly contributes to barrier inefficiency.

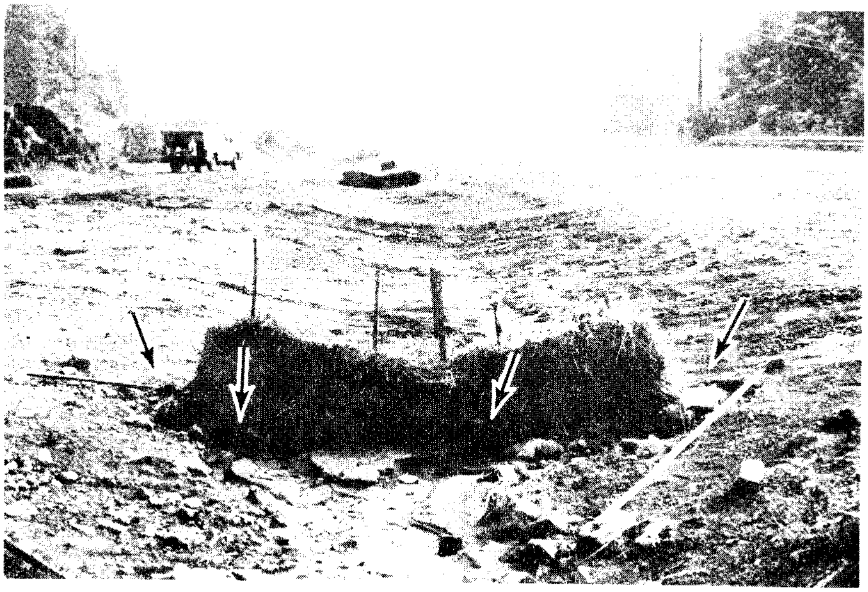


Figure 8. Currently used flow barriers placed by contractor. Arrows indicate barrier failure by undercutting and end flow.

Figure 9. Examples of end flow and sediment bypassing of a contractor's barrier in test location (9/6/74).

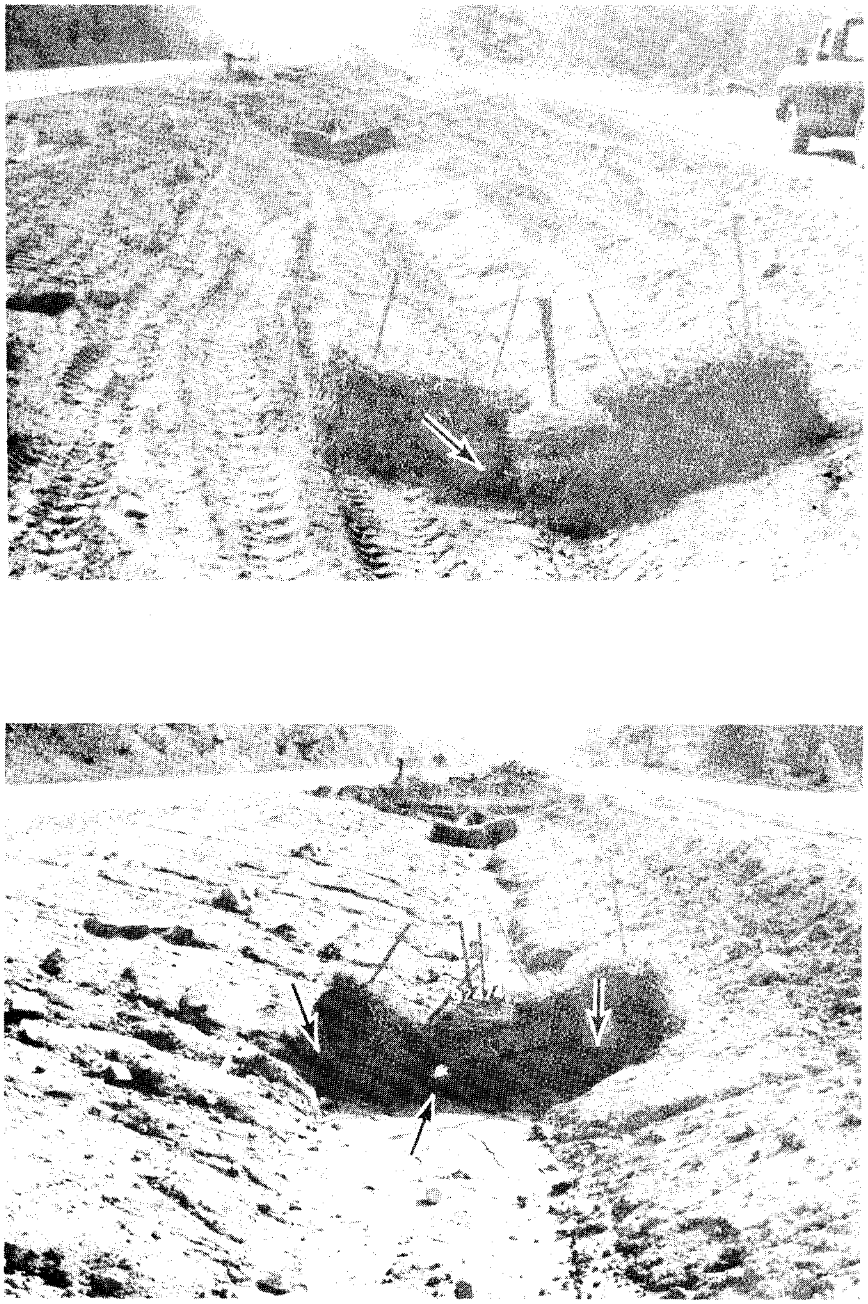


Figure 10. Improper construction and lack of maintenance of flow barriers. Bottom photograph taken 10 weeks after top photograph. Arrows indicate barrier failures and results of lack of maintenance.

Field experiments aimed at overcoming the most common failures were initiated by designing a system of flow barriers (Figure 11) in the test location which would meet the estimated soil loss using the Soil Loss Equation (equation 1). The predicted barrier spacing distance was 100 feet (30.5 meters). Endflow was reduced by making the barriers wider. This widening ensured that runoff would either run over the top or through the barrier. Undercutting was reduced by wedging the bale joints and the barrier bottom with additional straw. Finally, an additional straw bale was broken up and spread upflow of the barrier. This added material had the effect of increasing the filter travel length of the barrier. It also reduced runoff velocities and allowed settling of suspended load, while at the same time it facilitated the removal of sediment trapped behind the barrier.

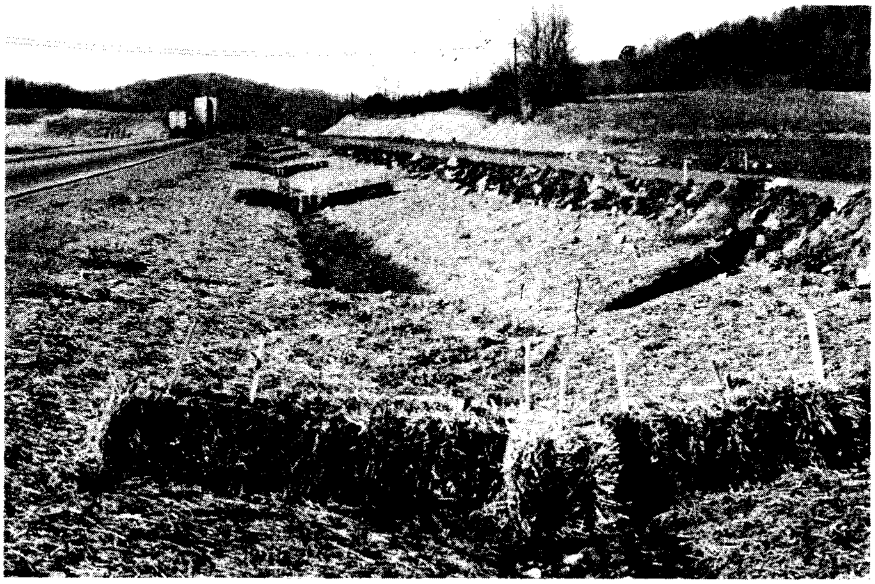


Figure 11. Modified flow barriers in test section. Barrier spacing is 100 feet (30.5 meters) — compare with Figure 8.

Runoff measurements (November and December 1974) taken for the modified barrier are shown in Table 5. There was a 2- to 8-fold increase in the average trapping efficiency when compared with the efficiencies of the contractor's barriers. The 57% average efficiency for each barrier of the system (November) falls in the range of values obtained in the laboratory for single bale efficiencies.

Table 5

Percentage Efficiency of Experimental Barriers Designed by Soil Loss Equation
(Wheat Straw Barriers 100 feet (30.5 meters) apart)

Flow Barrier	Rainfall Event	
	11/6/74	12/1/74
A*	67	-11**
B	76	30
C	79	- 5
D	98	46
E	35	37
F	64	50
G	34	19
H	28	-38
I	32	--
Average	57	16

* Flow is from Barrier I to Barrier A in the ditchline.

** Resulted from significant undercutting or endflow.

The suspended solids in the stream due directly to construction runoff for both the contractor's barriers and the modified barriers are shown in Table 6. The net addition in suspended solids levels due to construction runoff associated with the contractor's barriers is very high (978 and 4400 ppm) as compared with those of the experimental barriers (106 and 680 ppm). The runoff values associated with the experimental barriers (December measurements) actually diluted by 166 ppm the ambient stream levels with cleaner water from the project.

Another important function of straw barriers is the detention of runoff in such a manner that it does not seriously add to the peak discharge of the receiving stream. The level of discharge in a stream can be very closely correlated with its erosive power. Thus runoff should be detained on the project until peak flow in the receiving stream occurs or severe downstream bank and channel erosion will take place. For light rains (less than 1.0 inch total) field observation indicated that the average detention time of runoff behind the experimental barriers was approximately 45 minutes. For heavier rains detention time would probably be even longer. Thus significant amounts of runoff are being detained on the construction site by using the experimental barriers and runoff is being added to the stream at a low rate. The long detention time also aids the natural trapping of sediment behind the barriers by sedimentation.

Table 6

Suspended Solids from Construction, PPM

	Dates			
	8/4*	9/6*	11/11**	12/1**
Upstream	20	76	52	1326
Downstream	998	4476	158	2030
Net Addition Due to Construction Runoff	978	4400	106	680

*Contractor's Barriers **Experimental Barriers

Biological substrates from the stream, located in the lower portion of the test section, were taken approximately four days after the rainfall events of September 6 (contractor's barriers in test location) and November 11 (experimental barriers). The organisms were identified and subdivided into three major tolerance groups. The three groups are (1) sensitive to pollution, (2) intermediate, and (3) tolerant to pollution. One would expect that with the introduction of pollutants into a stream, the pollution sensitive organisms would be reduced some distance downstream and would not reappear until dilution was at a nontoxic level, as is shown in Figure 12.

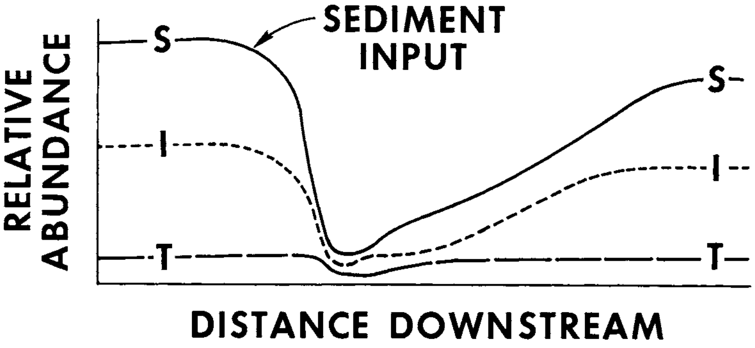


Figure 12. Effect upon organism tolerance groups of downstream sediment introduction. S, I, and T refer to pollution sensitive, intermediate, and pollution tolerant groups.

Under normal circumstances, representatives of all three tolerance groups would be present in any stream. However, the relative proportions of these groups is an excellent index to environmental degradation. With the introduction of sediment into a stream the sediment intolerant members of the community may be replaced downstream by more tolerant forms of organisms which can withstand the new water quality conditions. This can be more clearly seen in Figure 13, which represents percentages of the tolerance groups found on the upstream and downstream biological substrates removed shortly after the barrier efficiency measurements were taken in the test location. A predominance of sensitive forms is found upstream of the construction. However, downstream of construction, large amounts of sediment have been introduced as a result of the inefficiencies of the unmodified controls, and there is a corresponding shift to a predominance of more intermediate forms downstream. The disposition of the forms associated with the modified controls remains essentially unchanged downstream. This latter finding indicates that the water quality was essentially unchanged and reinforces the efficiency measurements taken.

The introduction of sediment to a stream should also affect the number of organisms per unit area. There was a 77% downstream reduction in total organisms after the September rainfall event (contractor's barriers). Measurements associated with the modified barriers in the test section indicate that there was only a 14% downstream loss in organisms from construction generated sediment,

Using the previously outlined procedure, water quality indices were calculated for both the upstream station A2 and downstream station A3 (see Figure 3). The results are shown in table B-1 of Appendix B. The index value is the standardized distance from the reference point, or biological desert condition. The larger the magnitude of the distance between the desert condition and the station point, the better the water quality at the station (Figure 6). Consistently, the largest values are associated with the A2 (upstream) station. The index values ranged from 33.004 to 0.300. Because the station values are correlated in time, paired t statistics were used to test for significant differences in the station mean values. The paired t test has the advantage of eliminating all of the influences which affect both stations such as organism variability due to seasonal growth, drift rate, and meteorological influences. The statistical tests were significant at the .001 level, which implies that, on the average, significant environmental degradation was found downstream during construction 99.9% of the time.

An index of environmental damage (SD_{A2} - SD_{A3}) for the stream associated with the test location was plotted (Figure 14) with data on rainfall, culvert construction activity and stream flow alteration. The variation of the index of environmental damage with time can be correlated with construction and in-stream activity. As the index approaches zero, there is no difference in the water quality indices of the two monitoring stations and no environmental damage is indicated from construction. The reverse is also true; as the index gets large, more environmental damage is occurring. As can be seen in Figure 14, the index rises sharply over the first three measurement periods. This rise corresponds with the time of principal culvert construction and maximum stream disturbing activity. Although some rain did fall during the period (late June and early July) much more fell later in the summer (late July through early September). Since the environmental damage index is free of the influences of rainfall, it may be concluded that the early changes in the index are due principally to culvert construction, and probably directly to the damming and stopping of stream flow in late June and early July (labelled S on Figure 14). The weighted suspended solids (see section on Other Field Studies) measure for July 14 at the downstream station was only 23.4 ppm, and was only 7.8 ppm above the upstream value. These suspended solids levels are far below the U. S. Environmental Protection Agency proposed minimum suspended solids level of 80 ppm and the Virginia Water Control Board's proposed safe level of 60 ppm. Thus something else must have been influencing bottom-dwelling organism populations other than suspended solids. Field observations taken during this time indicated that large amounts of bedload were generated by in-stream construction. It would appear then that high bedload levels and stream flow interruption were the principal causes of downstream degradation of water quality as evidenced by severe reductions in organisms. Organisms were suffocated under a heavy blanket of bedload, partly created by construction and partly mobilized from existing bottom material as stream velocity increased when holding dams were periodically released. Following the principal culvert construction and stream disturbing activity, the index of damage progressively fell toward zero, or complete rehabilitation and regrowth. Occasional subsequent increases in the index probably indicate the influence of runoff from the test location rather than damage due to culvert construction. Figure 15 shows a regression of the index of environmental damage with time. Beginning with the largest value (most damage) and continuing to the last measurement period, the time required for stream rehabilitation occurs when the regression of the environmental damage index crosses the time axis. At this point, the index is zero and the water quality levels at the two stations are the same. Figure 15 shows that the rehabilitation time is 92 days for the stream traversing the test location. No permanent damage to the stream is indicated and approximately 90 days after all work is completed and vegetation has been reestablished, the stream should be completely rehabilitated.

Any downstream station experiences not only the sediment generated from in-stream construction but also that generated from highway construction and draining into the stream. The rehabilitation time of the stream could be decreased by reducing sediment from the latter source through the proper deployment of temporary sediment controls. Even though flow barriers were first placed on the test project early in the construction phase (see Figure 14) by the contractor, efficiency measurements indicate that the barriers were essentially valueless in stopping sediment. Mulching and seeding in the test location did not take place until three months after culvert construction was completed. Earlier seeding and mulching undoubtedly could have also decreased the rehabilitation time significantly.

The principal sediment contributors which affect stream ecology are in-stream activities such as culvert construction and channel modification and runoff from highway construction. Both can produce undesirable levels of suspended sediment and bedload.

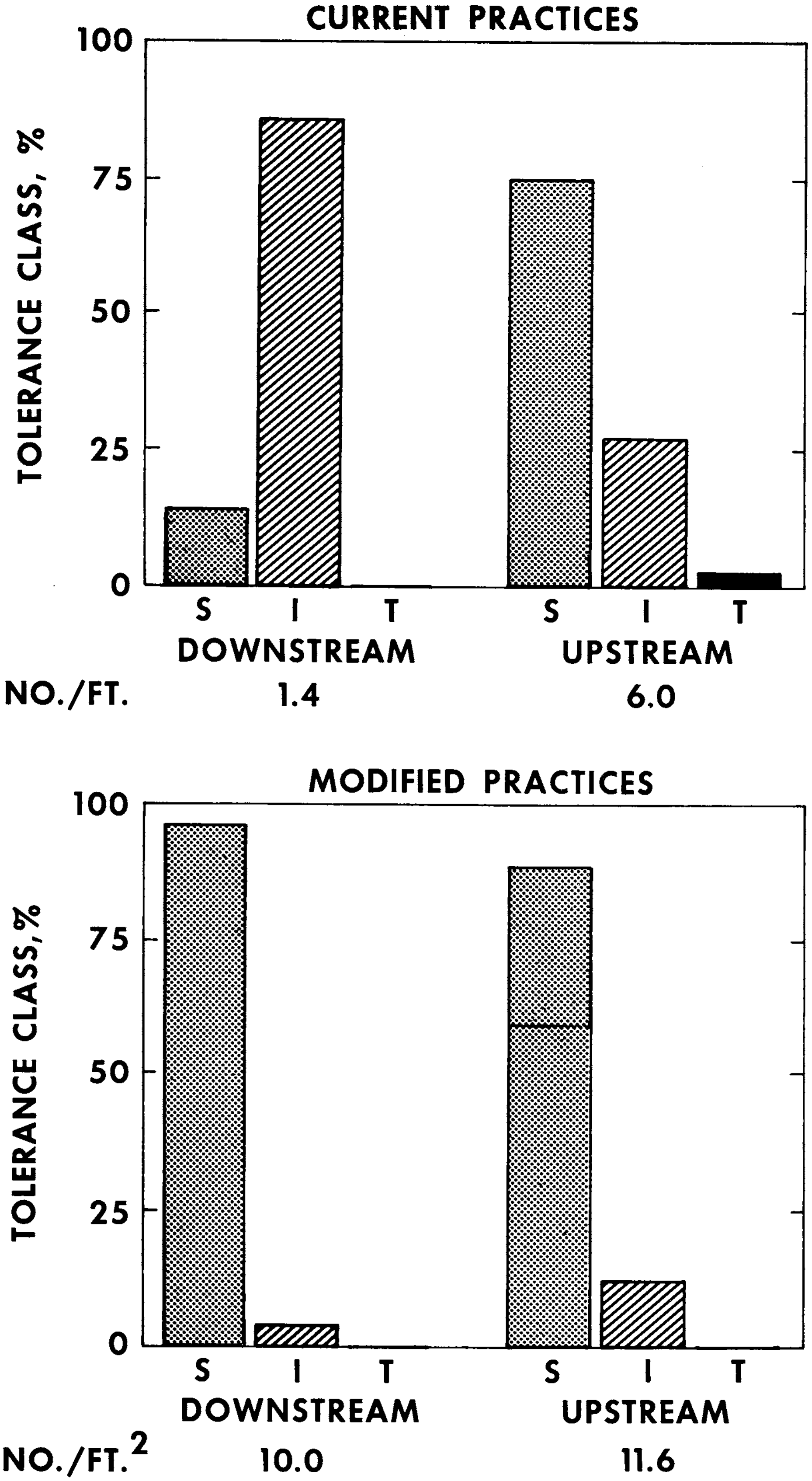


Figure 13. Ecological evaluation of straw barriers of differing methodologies. The numbers of organisms per ft.^{2} are shown under each graph. S refers to percentage of pollution sensitive organisms, I refers to intermediate, and T refers to tolerant forms.

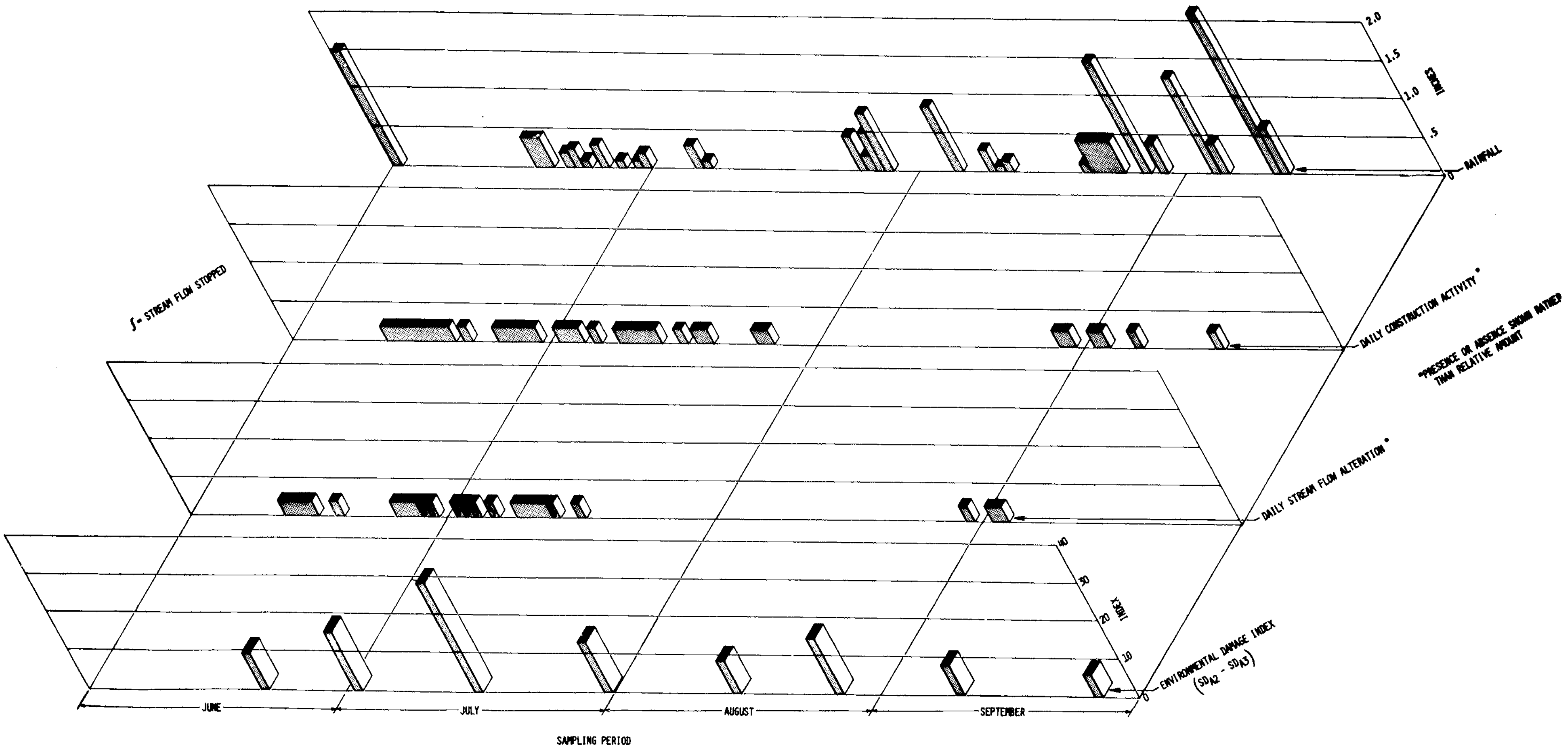


Figure 14. Environmental damage index for the stream associated with the test location. See Figure 5 for station locations.

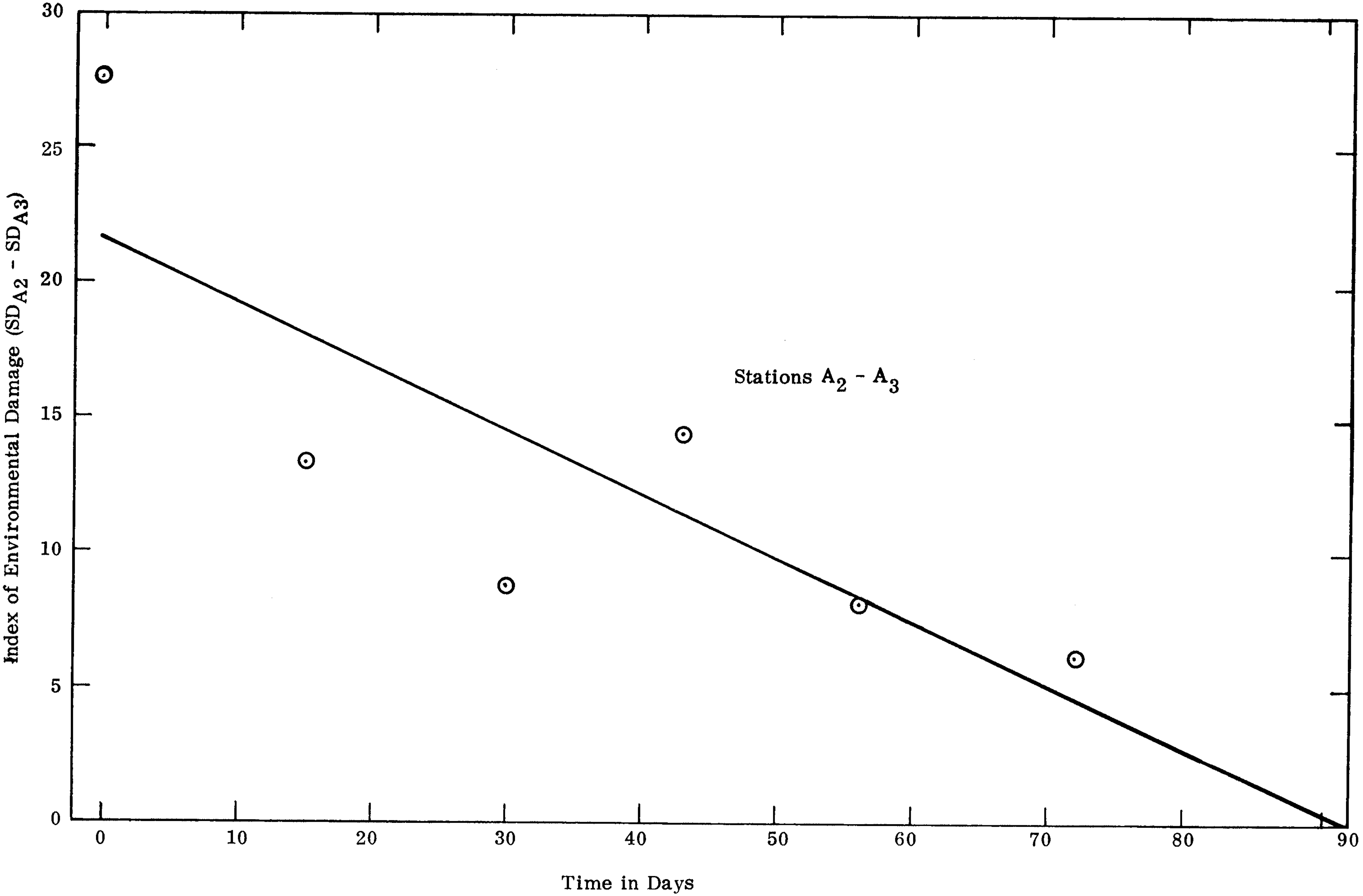


Figure 15. Rehabilitation time of test location stream.

Other Field Studies for Baseline Evaluations

To obtain more information on the effects of highway construction on stream ecology and water quality, several other stations were set up on streams crossed or affected by the construction. Each major drainage tributary was monitored (see Figure 5) in a method similar to that used at the test location. Each tributary was labelled with an alphanumeric designation to show its relative position in the drainage. Stations associated with "A" are found in the headwaters of the drainage. Progressively, the streams are identified "B" and "C", and a single station, D1, is located on the mainstream right before it empties into the Hardware River.

Sediment in the form of suspended solids generated from nonpoint sources such as highway construction contributes to the degradation of the populations of bottom dwelling organisms. An attempt to determine a rational relationship between suspended sediment concentrations and organism populations was undertaken with a literature search of such effects. Several aquatic biologists(11, 12, 13, 14, 15) have studied the effects of long-term suspended solids sources including placer mining, quarrying, and sand and gravel dredging on bottom dwelling organisms. It was observed that these long-term sources could affect aquatic life up to 11 miles downstream from the sediment source. The percentages of organisms lost downstream compared with upstream have been regressed against the suspended solids levels observed by the various workers and are shown in Figure 16. The regression is given by

$$\log(\%\ \text{diff. upstream—downstream}) = 2.81 - .606(\log(\text{conc. of suspended solids}))$$

The data regressed with a correlation coefficient of .85, which indicated that the suspended solids concentration was a reasonable predictor of the percentage downstream organisms loss. Figure 16 also shows, by vertical lines, those suspended solids levels best suited for the growth and maintenance of fish populations as suggested by the European Inland Fisheries Advisory Commission(16).

It was initially assumed that such a curve could be made for short-term suspended solids sources such as those generated from highway construction. However, a problem arose in trying to characterize the suspended solids level to which the downstream biological substrates had been exposed for their six-week growth period. Unlike a constant sediment source in a stream, the suspended solids generated by highway construction vary in time depending upon in-stream construction activity and runoff from rainfall. It was decided to weigh two-week averages of suspended solids measurements in the stream to the downstream organism losses, and then to regress the data for the curve. It was assumed that rainfall events and construction activity occurring closest in time to the sampling date would have the greatest effect on the organisms. Several weight schemes were regressed with the organism data from the stations (A2 and A3) of the test location. The weights included

.10, .20, .70
.05, .15, .80
.10, .30, .60
.05, .05, .90
.05, .10, .85
.33, .33, .34 (a simple average)
and .16, .33, .50 (a simple step function)

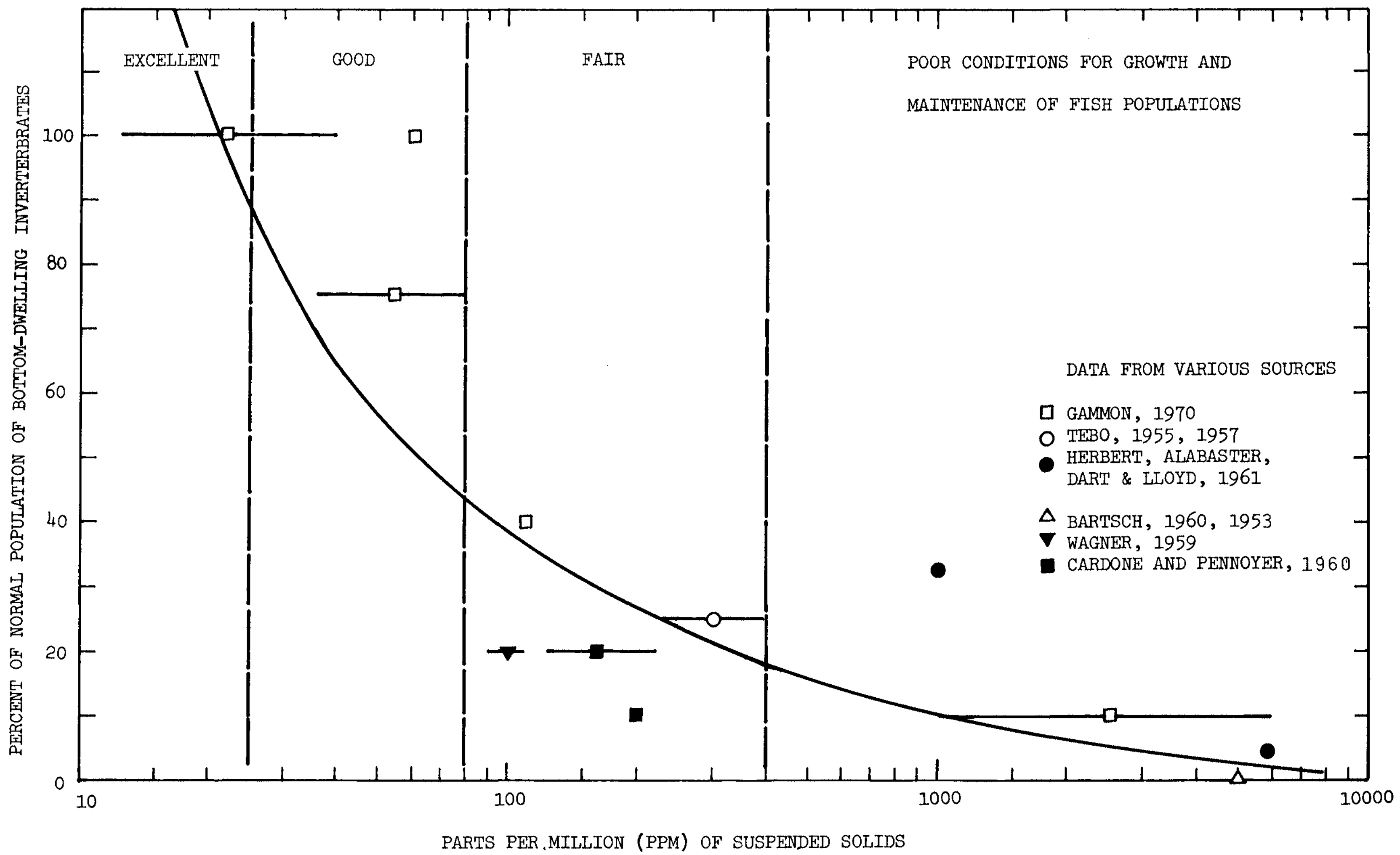


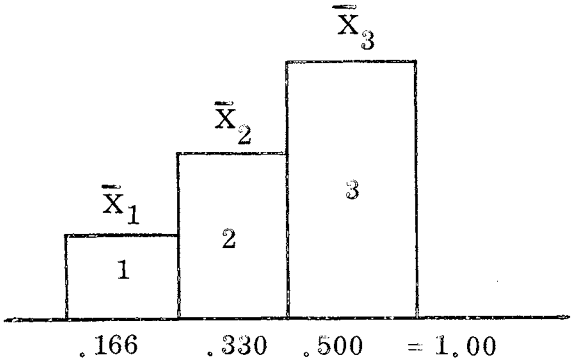
Figure 16. Regression of percentages of downstream organism loss versus suspended solids for long-term sources.

All regressions of the two variables showed little or no correlation. The simple step function scheme shown in Figure 17 was used for one final regression relating a grand average of all upstream stations within the drainage to the number of downstream organisms. The correlation again was very small.

It was concluded that for short-term suspended sediment sources little or no correlation could be found with the percentage loss in downstream organisms. However, as was later observed in the field, bedload generated from construction does affect downstream organism populations. It is also suggested that suspended solids poorly correlate with bedload for short-term non-point sources while correlation may be present for long-term sources.

The standardized distance, or water quality index (equation 1), using the step function weighting for suspended solids was calculated for all stations under study. The data are shown in Table C-1 of Appendix C. The range of values of SD for all stations ranged from approximately less than one to 36 units away from the biological desert condition.

All upstream stations (A1, A2, B1, C1) were compared with all downstream stations (A3, B2, B3, C2, C3, and D1) by a statistical t test. The results were significant at the .10 level, which indicates that the means of the two populations were significantly different and that lower water quality index numbers were found downstream during the majority of the construction.



$$\overline{SS}_{AVE} = .166\bar{X}_1 + .330\bar{X}_2 + .500\bar{X}_3$$

Figure 17. Simple step function weighting scheme for suspended solids measurements. $\bar{X}$, $\bar{X}_2$, and $\bar{X}_3$ refer to the first, second and third 2-week average suspended solids associated with biological substrate growth.

The water quality indices were plotted with respect to time and location (Figure 18). Upstream stations are separated from downstream stations and shaded areas indicate the principal periods during which culvert construction and stream disturbing activities were taking place. As was observed previously, the water quality index approaches zero near the end of high intensity construction periods. For the area of construction studied, three large culverts were constructed in the tributaries to the main stream (see Figure 5). Stations B3 and C3 (located on the mainstream) showed little effects of construction. Their indices are average to slightly above average. These stations were located on the narrow, high velocity portions of the stream where bedload and suspended load would probably have little effect on bottom-dwelling organisms due to bypassing. Station D1 was located further downstream in a pool at the end of the project. Sediment accumulated at this station and all upstream construction influenced the organism counts and suspended solid measurements there. The lowest water quality index for this station occurred during the middle of August at the end of a two-month period of upstream culvert construction and stream disturbing activity. Afterwards, the index slowly climbed for this station, indicating improving water quality conditions for the entire drainage basin.

An indication of the stream rehabilitation of the entire drainage system was calculated by averaging all of the upstream water quality indices. (SD_{A1}, SD_{A2}, SD_{C1}). These values are unaffected by construction and are an excellent measure of the overall water quality of the drainage system. The average upstream index for any one sampling period was subtracted from the appropriate index found at the D1 station, which is the station farthest downstream in the drainage basin. The values at D1 reflect the combined influence of all construction taking place in the basin. As the difference between the average upstream index and the downstream index approaches zero, the water quality of the entire drainage basin is the same. After construction, the time required for the difference between the two measurements to go to zero is taken here as a measure of the time that it takes for the drainage system to rehabilitate itself. Figure 19 shows the regression of the index of rehabilitation versus time. The regression indicates that the drainage should rehabilitate itself in 50 days after construction stops and vegetation is established.

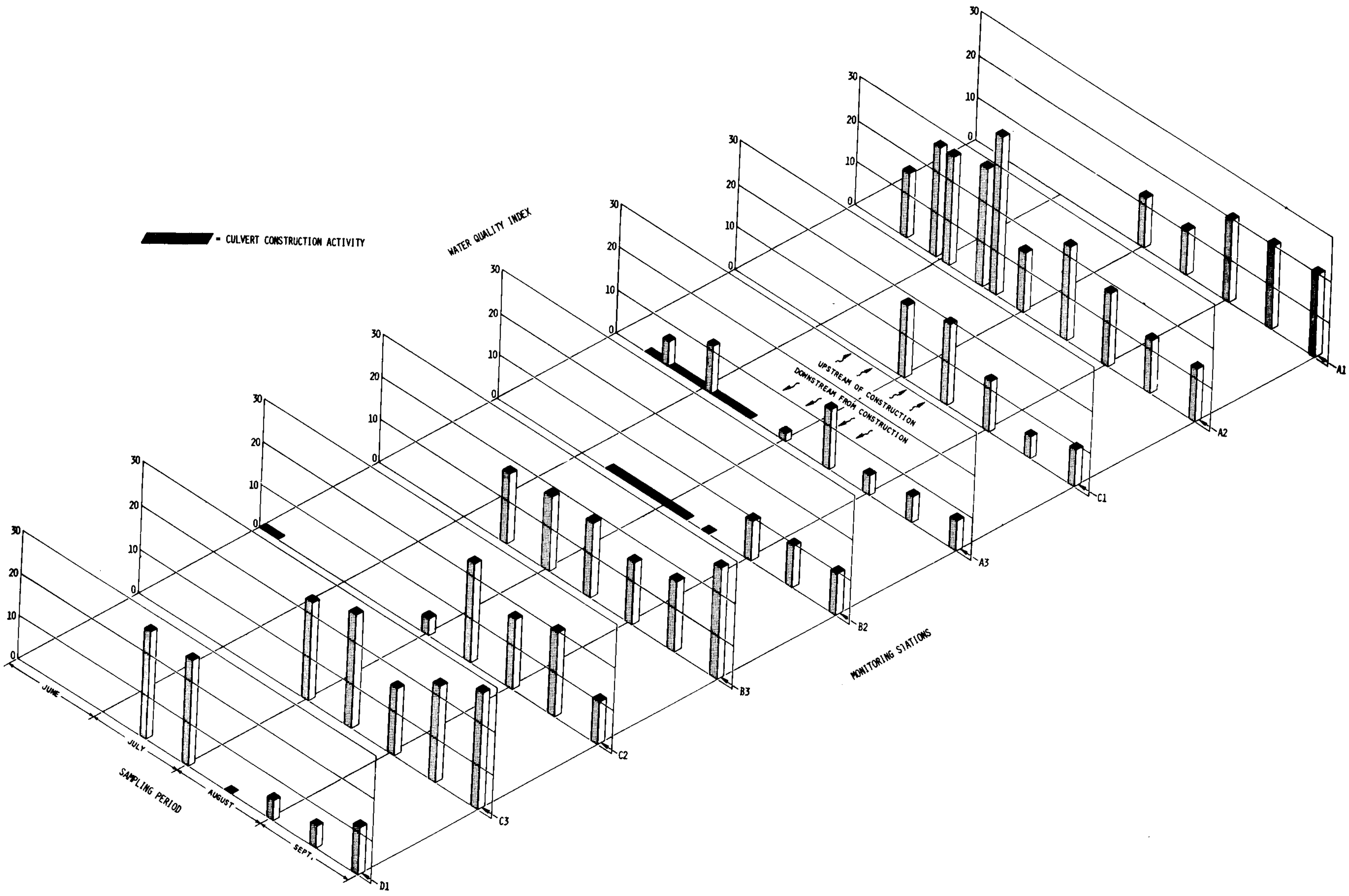


Figure 18. Water quality indices for all monitoring stations within drainage basin plotted with respect to time. Gray areas indicate principal culvert construction periods. See Figure 5 for station locations.

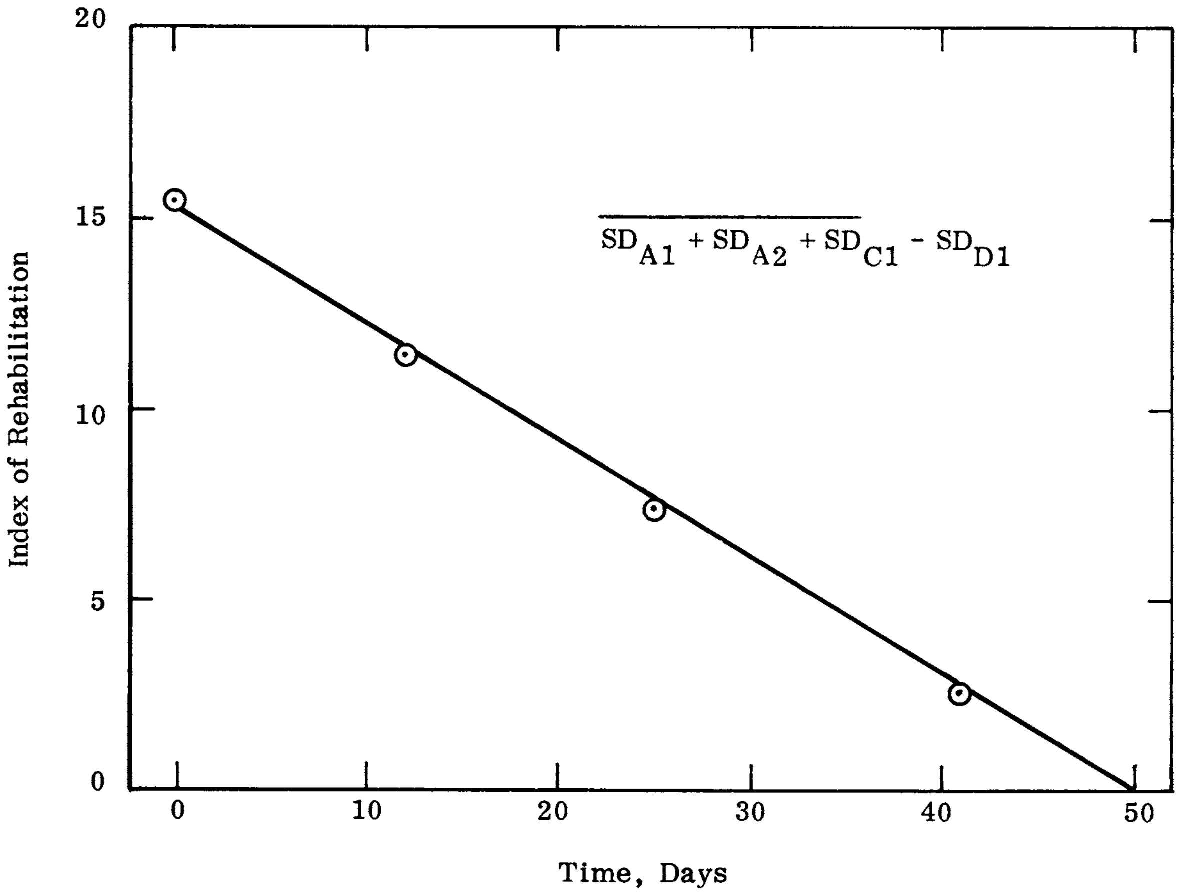


Figure 19. Rehabilitation time for entire drainage. See Figure 5 for station locations.

CONCLUSIONS

No practical method of design and deployment of temporary sediment controls can trap 100% of the suspended sediment but an effective attempt can be realized if such controls are deployed in numbers based on estimated sediment losses. Losses may be easily estimated using the Soil Loss Equation. Proper placement of hay, straw and rock flow barriers results in filtering efficiencies which approach those observed in laboratory tests. No significant difference was observed in the filtering efficiencies of barriers made from hay when compared with those made from straw. The filtering efficiency of bales cannot be predetermined by using tests involving bale porosity or bulk density, as these measures have a very low correlation with filtering efficiency.

Field efficiency tests of currently used flow barrier designs suggest that their average filtering efficiency is nearly zero; thus little material is trapped behind most barriers. In fact, some tests indicate that the currently used barriers actually contribute sediment to the runoff rather than reduce it because of the obstruction to ditchline flow. The principal causes of the barrier inefficiency are undercutting, endflow, and improper placement. Flow barrier design should be modified to eliminate or reduce all inefficiencies (see recommendations). The average detention time behind a currently used barrier is estimated at less than 1 minute while those which had been modified had a detention time of 45 minutes or more, depending on the rainfall intensity.

An indicator of good flow barrier design and deployment can be obtained from an ecological assessment of the nearby streams which receive construction runoff. If downstream environmental degradation has taken place due to inefficient barriers, then it will be reflected in reductions in the overall numbers of bottom-dwelling organisms and/or adoptive organism population shifts. Severe ecological damage occurs with the currently used barriers and little downstream organism reduction exists with the modified barriers because of their better trapping efficiency and detention times. Thus the design and deployment system based on the Soil Loss Equation can maintain good water quality conditions downstream of construction runoff locations.

A far different picture appears when one looks at the effects of in-stream construction. Biological monitoring upstream and downstream of culvert construction revealed that water quality conditions were always impaired downstream. This is seen by the results of statistical testing of the water quality index values. The lowering of the downstream index correlated very closely with stream flow interruptions and construction activities and low average suspended solid values. Average downstream suspended solids were lower than those recommended by the U. S. Environmental Protection Agency and the Virginia Water Control Board. However, large amounts of bedload generated from general construction, bypass pumping, and stream flow interruption were observed to contribute significantly to downstream water quality degradation. Recommendations must be made to reduce as much as possible the adverse impact of those construction operations which create bedload. Rehabilitation of the stream was estimated to be 90 days for the culvert construction studied.

The influence of bedload on organisms was further confirmed by attempts to relate percentage losses in downstream organisms with observed suspended solid averages for a large number of stations within the drainage system. While long-term suspended solids sources, such as quarrying, can account for significant downstream organism losses, no such relationship could be found for short-term sources such as highway construction. Bedload in these cases may have a more important effect on stream ecology than suspended load.

The rehabilitation time of the entire drainage basin was estimated to be 50 days after all construction stopped and grades were stabilized. The rehabilitation time appears to be dependent upon stream flow and upstream colonization factors.

RECOMMENDATIONS

1. It is recommended that soil losses be estimated using the Soil Loss Equation. The number of straw or hay flow barriers to be used on any project should be estimated from the soil losses expected to occur over the period of construction. This estimated number of flow barriers needed should be placed on the construction plans as a suggested guideline.

2. It is recommended that straw and hay flow barrier efficiencies be improved to meet the following criteria:

    (a) Ditchline flow barriers must be widened to prevent flow around the ends of the barrier. The bottoms of the end bales must be higher in height than the top of the keystone or center bale. If the center bale is entrenched then the top of the center bale must be a minimum of 6 inches below the bottom of the end bales to provide a weir for high flow conditions.

    (b) Ditchline flow barriers must have additional straw wedged into the seams of the bales and underneath the bales to prevent undercutting of the barrier at its seams or underside. Alternate to wedging loose straw under the bales is entrenchment of bales to a depth of 2 inches. Or, they must be sprayed with wood cellulose fiber, (concentration: 750 lbs/A) on the upstream side of the barrier.

    (c) A bale must be broken up and spread upstream of the barrier. The purpose of this operation is to help plug voids in the bottom of the barrier and to increase the filtering efficiency by increasing the filtering travel length of the barrier.

3. It is recommended that after flow barriers are deployed the bales be thoroughly wetted in place with water to expand the fibers and initiate the internal growth of fungus. This practice improves the filtering efficiency by as much as 50%.

4. It is recommended that any in-stream construction be done in such a manner as to reduce as much as possible the production of bedload sediment. A reduction in bedload should reduce the rehabilitation time of the stream. Bedload reductions may be accomplished by –

   (a) adopting pumped water management practices;

   (b) constructing culverts "in the dry" where possible;

   (c) constructing rock or rock filled gabion check dams rather than straw to be placed immediately downstream of construction where possible.

The following recommendations are made independently of the research conducted in this study. They are based on observations in the field and evolved out of discussions with department personnel actively working in sediment control:

5. It is recommended that for major construction projects and "environmental" inspector be employed with one of his responsibilities being to supervise the deployment and maintenance of erosion and sediment controls.

6. It is recommended that to reduce soil losses all cut slopes be made concave rather than convex in profile where possible.

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APPENDIX A

METHOD OF CALCULATION

Appendix A contains a very brief mathematical discourse on the method of calculation found in the computer program. For a more detailed treatment of the method used in the computer program the reader is referred to reference 7.

The basic assumptions of the Universal Soil Loss Equation are that the average soil loss per unit area (in this case, of roadside) is a product of a rainfall factor (termed R), a soil erodibility factor (K), a slope length factor (L) and a steepness factor (S). Thus,

$$A = RKLS \tag{1}$$

where A is the soil loss per unit area. For the purpose of calculation the slope length and steepness factors have been combined into a series of tables involving a length-steepness factor (LS).

As indicated by the equation, the calculation of A assumes a uniform steepness. However, Foster and Wischmeier found that in the case of irregular slopes the sediment yields are not accurately estimated by the assumption of a uniform overall average steepness. They observed that the sediment load at any location on an irregular slope must be a function of the slope's erosion characteristics, such as its local soil detachment rate and the transport capacity of the runoff. They proposed that a slope of irregular steepness be divided into a series of N segments such that the slope steepness or gradient and soil type, and thereby the soil detachment rate, within each segment could be considered to be uniform. The total soil loss from the slope is thus the sum of the losses from the N segments.

The Universal Soil Loss Equation then becomes

$$A = RK\left\{\frac{\sum_{j=1}^{N} (S_j \lambda_j^{1.5} - S_j \lambda_{j-1})}{\lambda_e (72.6)^{0.5}}\right\} \tag{2}$$

where the bracketed expression replaces the topographic factor LS in equation 1. The term λ_j is the distance, in feet, from the top of the slope to the lower end of any segment, j; λ_{j-1} is the slope length above segment j; and λ_e is the overall slope length. The term S_j is the value of the factor S from segment j,

where $$S = \frac{0.043\sigma^2 + 0.30\sigma + 0.43}{6.613} \tag{3}$$

and σ is the slope gradient or steepness in percent. The bracketed expression of Equation 2 may be simplified for computation purposes to

$$LS = \frac{1}{\lambda_e} \sum_{j=1}^{N} (U_{2j} - U_{1j}) \tag{4}$$

The LS value determined by this procedure is a function of all the segment lengths and slope gradients or steepnesses and of their particular sequence on the slope. The percentage of the total sediment yield that comes from each of the N slope segments is also obtained by this computational procedure. The relative sediment contribution of segment j to the total soil loss is $(U_{2j} - U_{1j}) / \sum_{j=1}^{N} (U_{2j} - U_{1j})$.

APPENDIX B

BIOLOGICAL ANALYSES FOR 29 SOUTH

Table B-1 shows the redundency (R) and mean diversity ($\bar{D}$) calculated from equations 5 and 4 respectively of the text. Also shown are the number of genera and the number of organisms found within each sample. The first four numbers of the station identification are the month and day of the sample. The following alphanumeric designation refers to the sampling station location within the drainage system (see Figure 5 of the main text).

TABLE B-1

BIOLOGICAL ANALYSES FOR 29 SOUTH

REDUNDANCY INDEX	MEAN DIVERSITY	NUMBER OF GENERA	NUMBER OF ORGANISMS	STATION IDENTIFICATION
.5806	1.664	15	2467.0	617A2
.5274	1.579	6	16.0	617A3
.0759	3.219	13	125.0	617B3
.0914	2.692	9	80.0	617D1
.2413	3.510	25	960.0	628A2
.0739	4.055	24	260.0	628B3
.5254	2.076	18	525.0	628D1
.2357	2.750	13	63.0	7 3A2
0.0000	.862	3	3.0	7 2A3
0.0000	.798	2	10.0	7 9A2
.5456	1.923	17	845.0	7 9B3
.0752	2.534	8	55.0	7 9D1
.2795	2.736	14	103.0	716A2
1.0000	0.000	0	0.0	716A3
.1070	3.050	12	135.0	723A2
.2995	2.097	8	200.0	723B3
.2673	2.304	9	175.0	723D1
.3842	1.281	4	13.0	730A1
.4774	1.540	6	29.0	730A2
1.0000	0.000	1	2.0	730A3
.1346	2.632	11	28.0	8 1B1
1.0000	0.000	0	0.0	730B2
.5201	2.076	13	82.0	730B3
.1820	1.153	3	14.0	730C1
.8164	.306	2	28.0	730C2
.4507	2.560	20	182.0	730C3
.2818	2.370	10	59.0	730D1
.3129	2.309	10	32.0	814A2
0.0000	1.146	4	4.0	814A3
1.0000	0.000	1	1.0	814B2
.5181	2.192	16	129.0	814B3
0.0000	.646	2	4.0	814C1
.1302	1.621	5	10.0	814C2
.2593	2.859	15	71.0	814C3
.9867	.066	3	375.0	814D1
.1684	1.688	5	16.0	827A1
.3817	2.089	9	37.0	827A2
.7131	1.529	6	12.0	827A3
0.0000	.500	2	2.0	827B2
.4995	2.087	14	153.0	827B3
.8287	.587	3	20.0	827C1
.7131	1.529	6	12.0	827C2
.4183	2.220	11	45.0	827C3
.9274	.432	8	228.0	827D1
.4220	2.246	10	19.0	910A1
.4884	1.679	7	30.0	910A2
.4093	1.471	5	7.0	910A3
0.0000	.500	2	2.0	910B2
.5483	2.076	17	195.0	910B3
.7559	.845	4	24.0	910C1
0.0000	1.146	4	4.0	910C2
.1571	2.663	11	38.0	910C3
1.0000	1.415	5	6.0	910D1
.2523	1.956	7	15.0	926A1
.5196	1.699	8	45.0	926A2
.7430	1.313	10	77.0	926A3
0.0000	.500	2	2.0	926B2
.3523	2.770	18	186.0	926B3
.8733	.981	10	83.0	926C1
1.0000	.818	3	6.0	926C2
.1959	2.954	15	42.0	926C3
.7902	1.167	6	25.0	926D1
.5909	1.817	11	61.0	1114A2
.4665	1.898	9	51.0	1114A3

APPENDIX C

STATISTICAL ANALYSIS OF 29 SOUTH

Table C-1 shows the standardized distance (SD) calculated from equation 7 of the text. Input parameter 1 is the redundency (R) of the station; input parameter 2 is the mean diversity ($\bar{D}$); parameter 3 is the number of genera present at the station, and parameter 4 is the weighted suspended solids average of the station. These values are ranked from 1 to the number of samples present using non-parametric ranking techniques. "ID" refers to the station location and time of sampling. For a further description of the statistical technique used, the reader is referred to reference 10.

Table C-2 is similar to Table C-1 except only stations A2 and A3 are used. Ranking is accomplished by a similar procedure and the standardized distance values are different because a smaller number of samples are used.

TABLE C-1
WATER QUALITY INDEX — ALL STATIONS
VIRGINIA HIGHWAY RESEARCH COUNCIL

WATER QUALITY INDEX DATE 06-19-75

29 SOUTH DATA

INPUT PARAMETERS				RANK OF PARAMETERS					
1	2	3	4	1	2	3	4	STANDARDIZED DISTANCE	ID
1.000	0.0	0.0	10000.000	53.00	2.00	1.50	55.00	0.0	CONTROL
0.580	1.664	15.000	36.900	40.00	30.00	49.00	34.00	14.530	617A2
0.527	1.579	6.000	341.900	38.00	28.00	25.00	53.00	5.796	617A3
0.241	3.509	25.000	30.900	16.00	55.00	55.00	32.00	30.109	628A2
0.0	0.862	3.000	342.200	4.00	14.00	11.00	54.00	10.490	7 2A3
0.236	2.750	13.000	22.100	15.00	50.00	44.50	27.00	25.375	7 3A2
0.279	2.736	14.000	14.200	20.00	49.00	46.50	18.00	26.609	716A2
1.000	0.0	0.0	215.900	53.00	2.00	1.50	51.00	0.063	716A3
0.107	3.050	12.000	6.500	8.00	54.00	43.00	3.50	36.184	723A2
0.299	2.097	8.000	20.900	22.00	39.00	31.00	26.00	16.066	723B3
0.267	2.304	9.000	8.200	19.00	43.00	33.50	6.00	24.884	723D1
0.384	1.281	4.000	12.000	26.00	21.00	16.00	13.50	12.007	730A1
0.477	1.540	6.000	12.200	32.00	27.00	25.00	15.00	12.787	730A2
1.000	0.0	1.000	71.400	53.00	2.00	3.00	41.00	0.787	730A3
0.520	2.076	13.000	17.500	37.00	35.50	44.50	22.00	17.167	730B3
0.182	1.153	3.000	8.400	13.00	18.00	11.00	7.00	16.887	730C1
0.816	0.306	2.000	20.000	46.00	5.00	6.00	24.00	4.125	730C2
0.451	2.560	20.000	31.800	31.00	46.00	54.00	33.00	22.520	730C3
0.282	2.370	10.000	10.100	21.00	45.00	37.00	10.00	24.476	730D1
0.135	2.632	11.000	59.100	10.00	47.00	41.00	37.00	22.902	8 1B1
0.442	1.231	4.000	13.600	30.00	20.00	16.00	17.00	9.960	814A1
0.313	2.309	10.000	15.600	23.00	44.00	37.00	19.00	20.752	814A2
0.0	1.146	4.000	23.400	4.00	16.50	16.00	30.00	13.708	814A3

TABLE C-1 CONTINUED

VIRGINIA HIGHWAY RESEARCH COUNCIL

WATER QUALITY INDEX DATE 06-19-75

29 SOUTH DATA

INPUT PARAMETERS				RANK OF PARAMETERS					
1	2	3	4	1	2	3	4	STANDARDIZED DISTANCE	ID
0.518	2.192	16.000	126.000	35.00	40.00	51.00	46.00	17.111	814B3
0.0	0.646	2.000	8.500	4.00	11.00	6.00	8.50	18.538	814C1
0.130	1.621	5.000	6.500	9.00	29.00	20.50	3.50	22.563	814C2
0.259	2.859	15.000	24.500	18.00	52.00	49.00	31.00	26.080	814C3
0.987	0.066	3.000	97.300	50.00	4.00	11.00	44.00	0.892	814D1
0.168	1.688	5.000	12.000	12.00	32.00	20.50	13.50	18.536	827A1
0.382	2.089	9.000	16.500	25.00	38.00	33.50	20.00	17.208	827A2
0.713	1.529	6.000	127.800	41.50	25.50	25.00	47.00	5.174	827A3
0.0	0.500	2.000	198.500	4.00	8.00	6.00	50.00	9.877	827B2
0.499	2.087	14.000	96.200	34.00	37.00	46.50	43.00	14.944	827B3
0.829	0.587	3.000	4.600	47.00	10.00	11.00	1.00	12.330	827C1
0.713	1.529	6.000	6.200	41.50	25.50	25.00	2.00	16.068	827C2
0.418	2.220	11.000	75.100	28.00	41.00	41.00	42.00	15.416	827C3
0.927	0.432	8.000	70.100	49.00	6.00	31.00	40.00	4.489	827D1
0.422	2.246	10.000	13.400	29.00	42.00	37.00	16.00	19.704	910A1
0.488	1.679	7.000	16.900	33.00	31.00	28.50	21.00	12.424	910A2
0.409	1.471	5.000	186.800	27.00	24.00	20.50	49.00	6.193	910A3
0.0	0.500	2.000	230.500	4.00	8.00	6.00	52.00	9.814	910B2
0.548	2.076	17.000	65.000	39.00	35.50	52.00	38.00	16.549	910B3
0.756	0.845	4.000	20.700	44.00	13.00	16.00	25.00	5.213	910C1
0.0	1.146	4.000	8.500	4.00	16.50	16.00	8.50	19.808	910C2
0.157	2.663	11.000	67.600	11.00	48.00	41.00	39.00	22.656	910C3
1.000	1.415	5.000	44.200	53.00	23.00	20.50	35.00	4.777	910D1
0.252	1.956	7.000	11.200	17.00	34.00	28.50	11.00	19.812	926A1

TABLE C-1 CONTINUED

VIRGINIA HIGHWAY RESEARCH COUNCIL

WATER QUALITY INDEX DATE 06-19-75

29 SOUTH DATA

INPUT PARAMETERS				RANK OF PARAMETERS					
1	2	3	4	1	2	3	4	STANDARDIZED DISTANCE	ID
0.520	1.699	8.000	18.100	36.00	33.00	31.00	23.00	12.498	926A2
0.743	1.313	10.000	119.900	43.00	22.00	37.00	45.00	7.407	926A3
0.0	0.500	2.000	135.000	4.00	8.00	6.00	48.00	9.972	926B2
0.352	2.770	18.000	22.200	24.00	51.00	53.00	28.00	26.345	926B3
0.873	0.981	10.000	22.300	48.00	15.00	37.00	29.00	8.477	926C1
1.000	0.818	3.000	7.900	53.00	12.00	11.00	5.00	10.678	926C2
0.196	2.954	15.000	46.100	14.00	53.00	49.00	36.00	26.805	926C3
0.790	1.167	6.000	11.700	45.00	19.00	25.00	12.00	10.942	926D1

TABLE C-2
WATER QUALITY INDEX — STATIONS A2 AND A3

VIRGINIA HIGHWAY RESEARCH COUNCIL

WATER QUALITY INDEX DATE 06-19-75

A2 & A3 29-S

INPUT PARAMETERS				RANK OF PARAMETERS				STANDARDIZED DISTANCE	ID
1	2	3	4	1	2	3	4		
1.000	0.0	0.0	10000.000	18.00	2.00	1.50	19.00	0.0	CONTROL
0.580	1.664	15.000	36.900	14.00	11.00	18.00	11.00	14.502	617A2
0.241	3.509	25.000	30.900	5.00	19.00	19.00	10.00	28.288	628A2
0.236	2.750	13.000	22.100	4.00	17.00	16.00	8.00	25.167	7 3A2
0.279	2.736	14.000	14.200	6.00	16.00	17.00	3.00	27.962	716A2
0.107	3.050	12.000	6.500	3.00	18.00	15.00	1.00	33.004	723A2
0.477	1.540	6.000	12.200	10.00	9.00	8.00	2.00	14.831	730A2
0.313	2.309	10.000	15.600	7.00	15.00	13.50	4.00	22.030	814A2
0.382	2.089	9.000	16.500	8.00	14.00	12.00	5.00	18.393	827A2
0.488	1.679	7.000	16.900	11.00	12.00	10.00	6.00	13.040	910A2
0.520	1.699	8.000	18.100	12.00	13.00	11.00	7.00	13.077	926A2
0.527	1.579	6.000	341.900	13.00	10.00	8.00	17.00	4.527	617A3
0.0	0.862	3.000	342.200	1.50	4.00	4.00	18.00	9.492	7 2A3
1.000	0.0	0.0	215.900	18.00	2.00	1.50	16.00	0.300	716A3
1.000	0.0	1.000	71.400	18.00	2.00	3.00	12.00	1.709	730A3
0.0	1.146	4.000	23.400	1.50	5.00	5.00	9.00	13.160	814A3
0.713	1.529	6.000	127.800	15.00	8.00	8.00	14.00	3.755	827A3
0.409	1.471	5.000	186.800	9.00	7.00	6.00	15.00	4.760	910A3
0.743	1.313	10.000	119.900	16.00	6.00	13.50	13.00	6.695	926A3