However, the limitations as well as the capabilities of the procedural guide and the interactive program must be recognized and addressed. Both methods are limited regionally to the soils tested and the sites evaluated during the study. Furthermore, the interactive program and the procedural guide are limited to assessing the erosion from relatively simple road geometries. In spite of these limitations, however, it is conceivable that, with an expanded field data collection program, improved methodologies similar to those presented in this paper could be produced for any selected geographic region.

ACKNOWLEDGMENT

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REFERENCES

1. D.B. Simons, R.M. Li, and B.A. Anderson. Soil Erosion and Sedimentation Analysis of Forest Roads in Northern California. Colorado State Univ., Fort Collins, Rept. CER81-82DBS-RML-BAA74, 1982.
2. D.B. Simons, R.M. Li, and T.J. Ward. Simple Procedural Method for Estimating On-Site Soil Erosion. Colorado State Univ., Fort Collins, Rept. CER76-77DBS-RML-TJW38, 1977.
3. D.B. Simons, R.M. Li, T.J. Ward, and K.G. Eggert. Estimation of Input Parameters for Modeling of Water and Sediment Yields. Department of Civil Engineering, Colorado State Univ., Fort Collins, Draft Rept. CER-79DBS-RML-TJW-KGE50, April 1979.
4. W.H. Wischmeier and D.D. Smith. Rainfall Energy and Its Relationship to Soil Loss. Trans., American Geophysical Union, Vol. 39, No. 2, 1958, pp. 285-291.
5. W.H. Wischmeier. Rainfall Erosion Potential. Agricultural Engineering, April 1962.
6. R.A. Young and R.E. Burwell. Prediction of Runoff and Erosion from Natural Rainfall Using a Rainfall Simulator. Proc., Soil Science Society of America, Vol. 36, 1972.
7. D.B. Simons, R.M. Li, and B.A. Anderson. Procedural Guide for Estimating Water and Sediment Yield from Forest Roads. Colorado State Univ., Fort Collins, Rept. CER81-82DBS-RML-BAA4, 1981.
8. L.D. Meyer. Soil Erosion by Water on Upland Areas. In River Mechanics, Volume 2 (H.W. Shen, ed.), Colorado State Univ., Fort Collins, 1971.
9. R.M. Li, D.A. Collette, and B.A. Anderson. Users Guide for SIMAK: Interactive Program for Estimating Soil Erosion from Forest Roads. Colorado State Univ., Fort Collins, Rept. CER81-82RML-DAC-BAA75, 1982.

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Roadside Erosion Causes and Factors: Minnesota Survey Analysis

ROXANNE SULLIVAN AND LAWRENCE E. FOOTE

A roadside erosion survey was conducted along all state, county, and township roads in Minnesota. The locations and estimated volumes of roadside erosion, cross-sectional road designs, roadway ownership, type and causes of erosion, and history of the road (time since construction disturbance) were noted. The total estimated soil loss was 116,203,336 ft^3 at 17,902 sites located along 115,570 miles of roadway. The cross-sectional design that resulted in the most soil loss was the cut-fill design. The fill design had the lowest soil-loss volume. Erosion occurred most often along at-grade roads and least often along fill roads. Volumes and occurrences were slightly more along township than along county roads and much less along state roads. Ditch bottoms were the most common location of erosion on roadsides and water-related erosion was the major type. Although erosion occurred more often along older roads, eroded sites were larger along newer roads. The larger sites were generally caused by (a) inadequate design in areas with rough terrain or poor soils or near waterways and (b) lack of administrative direction and emphasis on establishment of cover and control of unauthorized activities, including farming the right-of-way and use of roadsides as borrow areas or for recreation. Erosion was often associated with drainage from adjacent areas, steep slopes, inadequate design, and lack of administrative direction and emphasis. Corrective measures were recommended, and many counties fully implemented such measures. However, some sites remain uncorrected and others have increased. Lack of funds is the main reason for the absence of corrective measures, particularly on township roads. More construction of roads with a fill cross-sectional design and less of cut-fill roads, especially in rough terrain, should reduce the potential for future erosion.

The potential for erosion is ever present. The process of detachment, transportation, and redeposit of sediment is by far the greatest contributor of pollution to streams and lakes. Sediment in waterways increases turbidity, inhibits photosynthesis, interferes with respiration of aquatic organisms, tends to destroy habitat, and degrades water quality. Sedimentation in culverts, ditches, stream channels, reservoirs, and other conveyance or storage structures decreases capacity and reduces the effectiveness of such structures. The removal of sediment from these structures and public water supplies is costly. Loss of topsoil by erosion reduces vegetation productivity and increases rainfall runoff.

Significant erosion occurs most frequently on agricultural and other disturbed lands (i.e., borrow pits and recreational areas); along stream banks, drainage ditches, and lakeshores; and at or near construction sites, including those of roads, bridges, and other transportation facilities.

Highway construction often drastically disturbs natural soil deposits and formations. It includes removal of vegetation, displacement of topsoil, and alteration of natural slopes and drainages. Sediment eroding along the roadside originates from the roadbed itself, from areas within the roadside right-of-way, and from areas outside the right-of-way. Loss of soil from the roadbed itself or from in-slopes results in structural instability of the roadway and a potential safety hazard for the motoring public. Loss of topsoil along the right-of-way lowers soil fertility, which reduces the ability of slopes and ditches to revegetate and control future erosive action. Erosion that begins on land adjacent to the right-of-way often continues unchecked onto the right-of-way. Such erosion scars the landscape, mars the aesthetic appeal of the area, and reduces the capacity of roadside ditches.

The cost of repair and maintenance for erosion sites is proportional to the quantity of erosion involved. Unless proper measures are taken to prevent and control erosion during construction or reconstruction of roads and during maintenance on existing roads, serious erosion and sedimentation problems often develop. Uncontrolled erosion can lead to the need for structural corrections to the road itself or installation of costly control structures.

A roadside erosion survey was conducted along all state, county, and township roads in Minnesota to identify and document the location and amount of erosion occurring along these roads. Reports of the survey results were prepared and published by the Minnesota Department of Transportation for each of the 87 counties in the state.

In this paper, various general facts, problems, conditions, and relationships concerning roadside erosion in Minnesota are identified and analyzed. Recommendations are made that should have wide application and be of general use for the prevention of roadside erosion through design as well as control and repair. Basic causes and factors associated with the occurrence of roadside erosion are discussed. Greater knowledge and consideration of these causes should make it possible to design and construct or reconstruct roadways that avoid or provide control measures so as to decrease the potential for erosion.

PROCEDURES

Data forms, maps, and procedures used in the survey were distributed at a series of instructional meetings. Then an organizational meeting of participating groups was held in each county to help acquaint personnel with the survey methods. Before starting, the county groups made trial runs and erosion site estimates were checked by actual measurements.

Roadside survey field work was conducted in the spring after snowmelt but before extensive vegetative growth or in the fall after growth had stopped and had been affected by frost. The survey was conducted by two- or three-person teams within each township of each county. Instructions were to report all eroded areas larger than 100 ft^2 in surface area, at least 6 in. deep, or more than 50 ft^3 total volume. The teams recorded the location of each erosion occurrence and its volume on the survey data form (see Figure 1). Data on road design (see Figure 2), roadway ownership, type and cause of erosion, history of the roadway, and control measures needed were also requested. Roadside erosion sites were located on aerial photographs and on new plat books.

On a county-by-county basis, volumes and occurrences of roadside erosion were tabulated according to road design (at-grade, fill, cut, cut-fill, and other); roadway ownership (township, county, state, forest, and private); location of erosion (ditch bottom, in-slope, backslope, adjacent areas, and other as well as combinations thereof); type of erosion (slide, wash, and blowout); cause (disturbance, inadequate design, and other); history of the roadway (3 years or less since construction and more than 3 years since construction); and control needed (till and establish cover; slope, shape, till, and establish cover; or slope, shape, till, and establish cover and structure). County totals were summed for similar statewide totals and averages.

Data on volume and occurrence were then tabulated on a per-mile basis for each category of roadway ownership. These per-mile data normalized erosion for the purpose of comparing counties or roadway ownerships with unequal mileages. The average volume per mile and occurrence rate were calculated for each county. The average volume per occurrence for each road design and ownership category and average volume per occurrence countywide and statewide were calculated.

RESULTS

Erosion on All Roadways

The total estimated volume of erosion reported in the roadside survey was 116,203,336 ft^3 distributed over 17,702 sites located along 115,570 miles of roadway (see Table 1). As the following table indicates, the volume of erosion per county ranged from 20,895 to 23,444,632 ft^3:

	Volume (ft^3)	
Range	Per County	Per Mile
Low	20,894	17
High	23,444,632	27,173
Median	521,681	433

The total statewide volume was 116,203,336 ft^3.

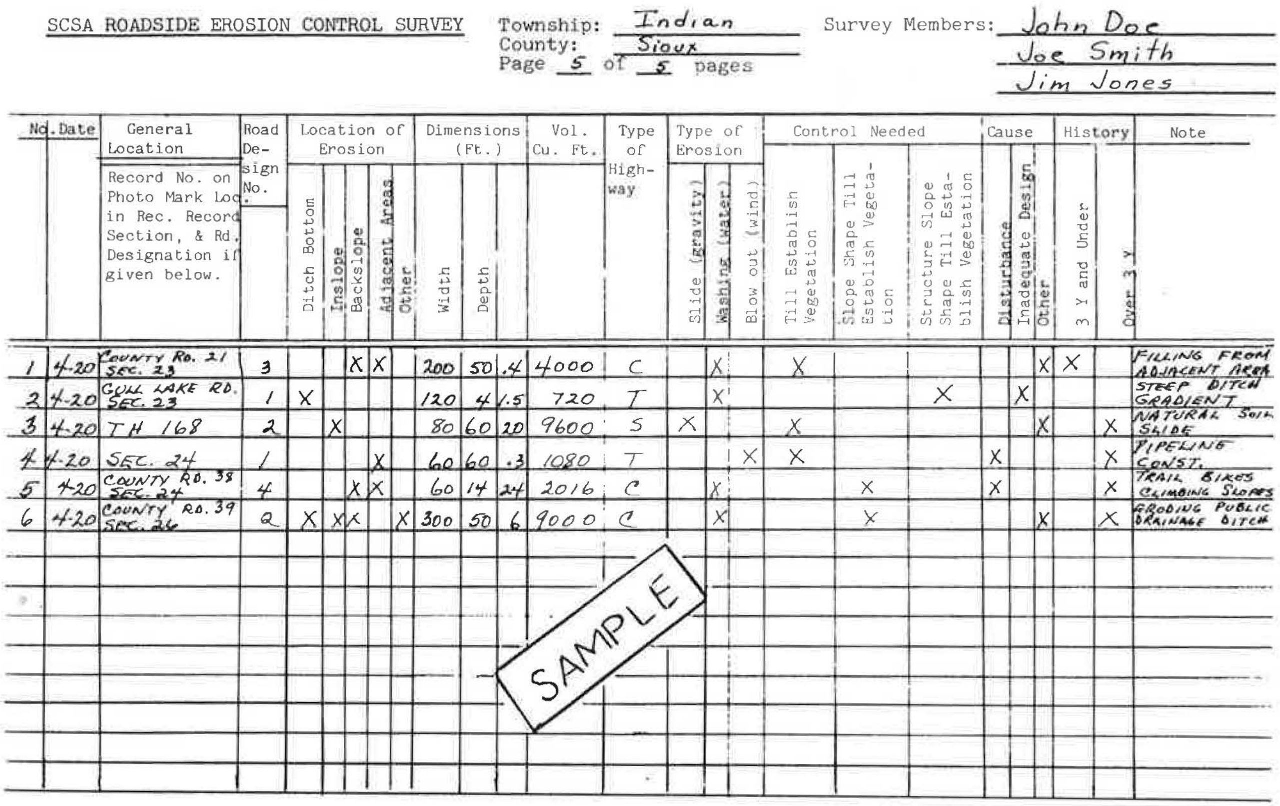
The average volume of soil lost per county was 1,335,728 ft^3; however, only 15 percent of the counties had more than the average estimate (see Figure 3). Specific causes of soil loss in counties with the most severe roadside erosion included lack of vegetative cover, rough terrain, use of roadsides as borrow areas, lack of erosion control during development, recreational activities, lack of past administrative emphasis on erosion control and repair, and lack of funds to correct existing problems.

Occurrences of erosion per county ranged from 9 to 1,015, as the following table indicates (one site every 8.3 miles = 0.12):

	No. of Occurrences	
Range	Per County	Per Mile
Low	9	0.006
High	1,015	0.87
Median	166	0.12

The total number of occurrences for the state was 17,902. The average number of sites per county was 206. Of the counties, 36 percent had more than the average number of sites inventoried (see Figure 4). The major causes of erosion in counties that had the most numerous occurrences included agricultural drainage or drainage from ditches mandated by statute, poor vegetative cover, inadequate road design, and use of roadsides as borrow areas.

Figure 1. Sample data sheet used in gathering information on the survey.



SCSA ROADSIDE EROSION CONTROL SURVEY

Township: Indian
County: Sioux
Page 5 of 5 pages

Survey Members: John Doe
Joe Smith
Jim Jones

No.	Date	General Location (Record No. on Photo Mark Loc. in Rec. Record Section, & Rd. Designation if given below.)	Road Design No.	Location of Erosion: Ditch Bottom	Inslope	Backslope	Adjacent Areas	Other	Dimensions (Ft.): Width	Depth		Vol. Cu. Ft.	Type of Highway	Type of Erosion: Slide (gravity)	Washing (water)	Blow out (wind)	Control Needed: Till Establish Vegetation	Slope Shape Till Establish Vegetation	Structure Slope Shape Till Establish Vegetation	Cause: Disturbance	Inadequate Design	Other	History: 3 Y and Under	Over 3 Y	Note
1	4-20	COUNTY RD. 21 SEC. 23	3			X	X		200	50	.4	4000	C		X		X					X	X		FILLING FROM ADJACENT AREA
2	4-20	GULL LAKE RD. SEC. 23	1	X					120	4	1.5	720	T		X				X		X				STEEP DITCH GRADIENT
3	4-20	TH 168	2		X				80	60	20	9600	S	X			X					X		X	NATURAL SOIL SLIDE
4	4-20	SEC. 24	1				X		60	60	.3	1080	T			X	X			X				X	PIPELINE CONST.
5	4-20	COUNTY RD. 38 SEC. 24	4			X	X		60	14	2.4	2016	C		X			X		X				X	TRAIL BIKES CLIMBING SLOPES
6	4-20	COUNTY RD. 39 SEC. 26	2	X	X	X		X	300	50	6	9000	C		X			X				X		X	GRADING PUBLIC DRAINAGE DITCH

SAMPLE

Figure 2. Identification of roads by cross-sectional design and location of erosion.

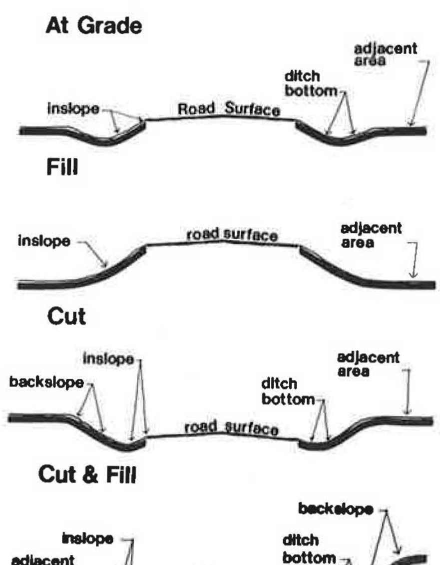


Table 1. Summary of survey results: volume estimates and occurrences of roadside erosion.

Category	No. of Occurrences[a]	Volume (ft³) Total	Per Occurrence
Road design			
At-grade	7,181	35,751,365	4,934
Fill	1,602	8,155,015	5,091
Cut	4,672	31,484,429	6,739
Cut-fill	4,199	39,470,568	9,400
Other	184	9,502,009	51,641
Ownership			
Township	8,660	45,859,258	5,296
County	7,962	44,522,514	5,591
State	1,080	22,773,360	21,689
Location			
Ditch bottom	11,390		
Inslope	9,223		
Backslope	7,394		
Adjacent areas	9,329		
Other	406		
Type			
Slide (gravity)	3,183		
Wash (water)	15,309		
Blowout (wind)	284		
History			
<3 years[b]	2,217	34,490,843	15,557
>3 years[b]	13,747	88,698,250	6,452
Control needed			
Till and establish cover	4,471		
Till, establish cover, slope, shape cover	10,099		
Till, establish cover, slope, shape, structural control	2,668		

Note: Data not available for volume and volume per occurrence for ditch bottom, inslope, backslope, adjacent areas, and other locations. Data not available for volume and volume per occurrence for slide (gravity), wash (water), and blowout (wind) types.

[a] Because some sites occurred on more than one portion of the cross section and some data were omitted, some totals vary.
[b] Time since construction or reconstruction.

Figure 3. Distribution of total volume ratings of erosion on all roads by county.

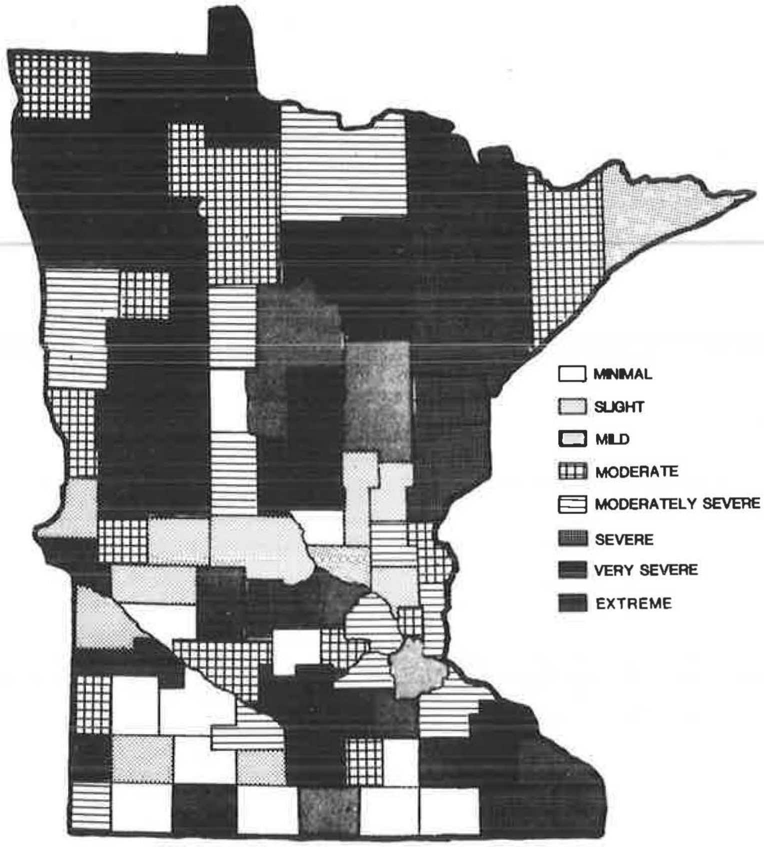
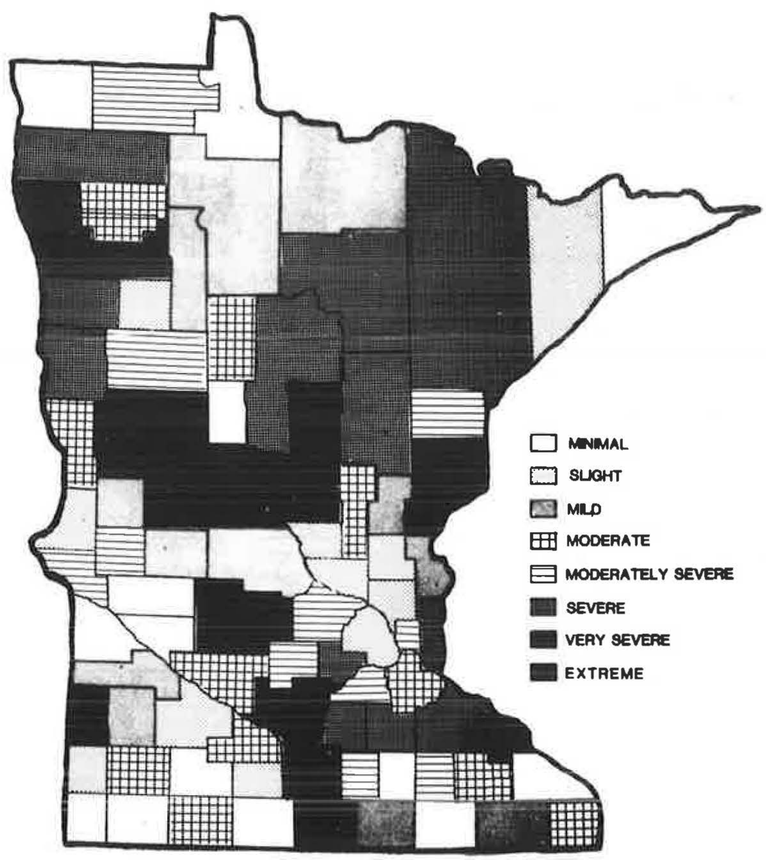


Figure 4. Distribution of total occurrence ratings of erosion on all roads by county.



Mileage per county ranged from 432 to 4,390. The average mileage per county was 1,329 miles. Volume per mile estimates per county ranged from 17 to 27,173 ft^3. The average volume per mile statewide was 1,006 ft^3. Erosion was less severe than the volume estimates indicated in counties that had more miles of road than the average and was more severe in counties that had many fewer miles of road than the average. About 27 percent of the counties had more than the average volume of erosion per mile.

The frequency of erosion sites per county ranged from one site every 167 miles to one site every 1.15 miles. The average frequency of erosion sites statewide was 0.17, or one site every 5.88 miles. Approximately 32 percent of the counties had more than the average number of sites per mile. As with the estimates of volume per mile, counties with many more miles than the average had less frequent occurrences of erosion per mile than indicated by the occurrence data and counties with many fewer miles had more frequent occurrences of erosion per mile than indicated by the occurrence data.

Volumes per occurrence indicate the average size of erosion sites in the various counties:

Range	Avg Volume per Occurrence (ft^3)
Low	230
High	37,006
Median	3,008

The average size of erosion sites ranged from 230 to 37,006 ft^3/county. The statewide average size of a site was 6,492 ft^3. In general, counties that had low volumes and few occurrences had low volumes per occurrence. Some counties had low volume estimates but a high number of sites. In these counties, erosion is more a potential problem than an actual one. A few counties had high volume estimates but a low number of occurrences. In these counties, large erosion sites were generally found in proximity to waterways. Counties in which both volume and number of occurrences were high produced high estimates of volume per occurrence. Causes of erosion at these sites included proximity to rivers and streams, rough terrain, lack of vegetative cover, and lack of past administrative emphasis on prevention, control, and repair of erosion sites.

Erosion According to Road Design

Data on mileage of individual road designs are not available. However, the at-grade design is the most common and thus has the most mileage (any cross section with less than 4 ft of vertical variance up or down was defined as at-grade). The next most commonly constructed roadway cross sections are the fill design and the cut design. The cut-fill roadway design has the least mileage. The cut-fill cross-sectional design had been perceived as the most economical to build in areas of rough terrain. Other cross-sectional designs (as noted in the survey forms) were generally a combination of or a transition between the preceding types.

The greatest volume of erosion was found on roadways built according to the cut-fill design. An estimated 39,470,568 ft^3 of soil was lost along roadways of this design (Table 1). More soil and drainage patterns, both surface and subsurface, are distributed along the roadway during construction with the cut-fill design than with any other design. Soils and rock are exposed during the cut and moved to the lower fill areas, which often produces unevenly consolidated heterogeneous soil mixtures.

In the construction and maintenance of cut-fill-design roads, problems often result from the use of heterogeneous roadbed materials, introduction of less stable materials, and the intersection of groundwater. Other problems relate to altered drainage ways, differential soil consolidation resulting from nonuniform compaction of the fill slope during construction, and related structural instabilities. The potential for erosion appears higher along newly constructed cut-fill-design roads than along roadways of any other age or design.

In one county, Wabasha, 17,650,000 ft^3 of soil had been lost along cut-fill roads (probably an overestimate). Most of the roads in the rough terrain of Wabasha County were constructed as cut-fill roads. Deletion of the data for this county reduces the total volume of soil loss along cut-fill roads to 21 million ft^3. This volume is still significant because the cut-fill design is much less frequently constructed than the at-grade, fill, or cut design.

The total volume of erosion recorded on at-grade-design roads was 35,751,365 ft^3. Early roads in Minnesota were often constructed as at-grade roads. Ditches were generally V-bottomed with steep slopes that tended to slide, slump, and cave. As these early at-grade roads are reconstructed, inadequate ditch designs are corrected and the potential of future erosion should be reduced. However, problems associated with agricultural drainage generally occur on at-grade roads and are difficult to correct. Because many more miles have been constructed with the at-grade design than with other designs, actual erosion on the at-grade road is less severe than the total volume estimate indicates.

The total estimated volume of erosion on cut-design roads was 31,484,429 ft^3. Because the cut design is considered to be less common than either the at-grade or the fill road, the volume of erosion noted for the cut design is more severe than comparison of volumes by design indicates. Deletion of the Wabasha data does not significantly reduce the amount of soil lost along cut-design roads.

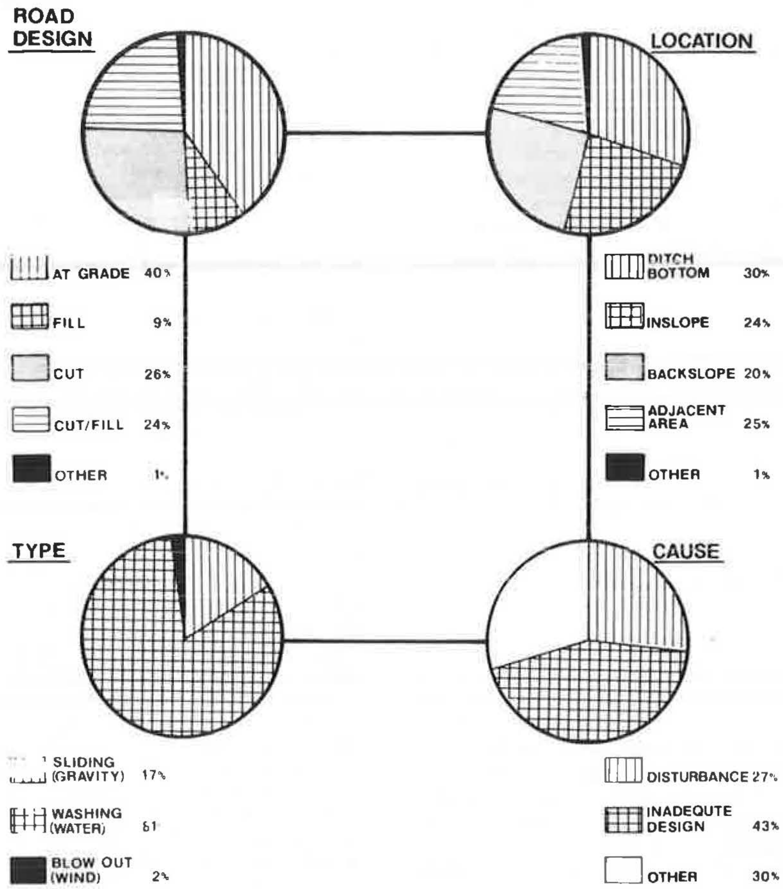
An estimated soil loss of 9,502,009 ft^3 was noted for all other road designs. Considering the infrequency with which other designs was noted (just 184 occurrences), the magnitude of this volume mostly associated with transitions should be emphasized.

The lowest estimated volume of erosion--8,155,015 ft^3--was along the fill-design road. During selection of material to be used as fill, undesirable soils are rejected and only stable, more granular soils are accepted. A reduction in the amount of heterogeneous soils used in constructing the roadbed reduces the potential of erosion. Problems relating to the design and construction of fill roads usually involve the availability of suitable materials and the proximity of these materials to the construction site. Because the fill design is the second most commonly used road design, the low volume of erosion recorded along fill-design roads is important to note.

Erosion occurred most frequently on at-grade roads (Table 1 and Figure 5). A total of 7,181 sites, or 40 percent of all occurrences noted by design, were on at-grade roads. This is expected because there are many more miles of at-grade roads than of any other cross-sectional road design and the sites on at-grade roads are, on the average, the smallest in size.

A total of 4,672 sites, or 26 percent, were along cut-design roads and 4,199 sites, or 24 percent, were along cut-fill roads. There were fewer sites along both cut and cut-fill roads than along at-grade roads. However, cut-fill roads are less common than cut roads and both are much less common than at-grade roads. Because of this, erosion was considered more frequent on cut-fill roads than on cut roads and more frequent on both than on at-grade roads.

Figure 5. Erosion factors according to occurrences of roadside erosion.



Erosion sites along fill roads constituted only 9 percent of the total--1,602 sites. Because fill roads are the second most commonly constructed cross-sectional design type, the infrequent occurrence of erosion along roads of this design is important.

There were 184 occurrences of erosion on roads of other designs. This represented about 1 percent of the total sites, but the average volume per occurrence was high: 51,641 ft^3, the highest of any road design type. Lack of vegetation is the most common cause of erosion at the largest sites. The road design with the second largest average site was the cut-fill design (9,400 ft^3); this was followed by the cut, fill, and at-grade designs (6,739; 5,091; and 4,934 ft^3/site, respectively) (Table 1).

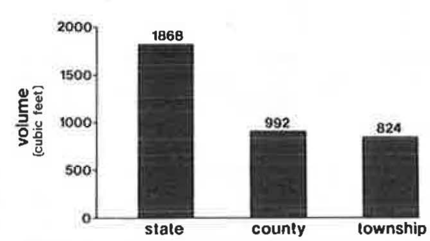
Erosion According to Ownership

On a statewide basis total estimated volume and occurrence of erosion were slightly more along township roads than along county roads. The results estimated 45,859,258 ft^3 of soil, or 41 percent of the total volume, to have been eroded along township roads. An estimated 44,522,514 ft^3, or 39 percent, was recorded along county roads. The total reported along state roads was less: 22,773,360 ft^3, or 20 percent. The number of sites on township roads was 8,660, or 49 percent of the occurrences. Along county roads 7,962, or 45 percent of the sites, were noted. A total of 1,080 sites, or 6 percent, were along state roads.

Minnesota has 55,367 miles of township roads, 44,683 miles of county roads, and 12,189 miles of state roads. The statewide erosion volume per mile was 1,004 ft^3. Because of an extremely large volume of erosion noted on state roads in Wabasha County, 18,337,000 ft^3, the estimated volume per mile by ownership was largest along state roads: 1,868 ft^3. Exclusion of the Wabasha data reduces this estimate for state roads to 326 ft^3/mile. The estimated volumes per mile for township and county roads were 824 and 992 ft^3, respectively (see Figure 6).

The average occurrence per mile by ownership was 0.157, or one site every 6.42 miles. The frequency of erosion along both township and county roads was similar to the statewide average--0.156, or one site every 6.53 miles, along township roads and 0.177, or one site every 5.65 miles, along county roads. The average frequency of erosion along state roads was 0.086, or one site every 11.63 miles (see Figure 7).

Figure 6. Average volume of erosion per mile of roadway by ownership.



Volume per Occurrence

Again, because of the extremely large volume of erosion noted on state roads in Wabasha County, the estimated volume per occurrence was highest along state roads: 21,689 ft^3/site (see Figure 8). If the erosion data for Wabasha County are deleted, the estimated volume per occurrence along state roads is 4,274 ft^3/site. The average size per site is somewhat more along both county and township roads: 5,591 and 5,296 ft^3, respectively. The estimated average volume per occurrence statewide was 6,428 ft^3.

Location and Type of Erosion

Each occurrence was analyzed according to location of the erosion on the roadway cross section and to type of erosion. Because erosion occurred in more than one location on the cross section or was of more than one type, the totals according to location and type of erosion differ from the grand total compiled according to occurrence.

The most frequently noted location of erosion was ditch bottoms (11,390 sites, or 30 percent). Loss of soil from adjacent areas and in-slopes was noted somewhat less (9,339 occurrences, or 25 percent, and 9,223 sites, or 24 percent). Erosion from backslopes was less frequent (7,394 sites, or 20 percent). Other areas were identified 406 times (Figure 5).

The type of erosion sited most frequently was washing or water-related. Erosion by water accounted for 15,309 occurrences, or 81.5 percent of the roadside sites. Sliding or gravity-related soil loss accounted for 3,183 occurrences, or 16.8 percent of the sites. Wind-related erosion accounted for 1.7 percent, or 284 occurrences (Figure 5).

History of Roads

In general, erosion tended to occur more frequently on older roads (more than 3 years since construction or reconstruction), but the size of erosion sites was larger along new roads [3 years or less since construction or reconstruction (Table 1)]. Present road standards require more disturbance of the landscape.

Figure 7. Occurrences of erosion per mile of roadway by ownership.

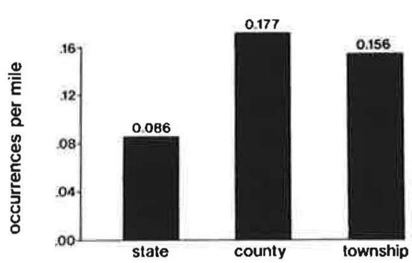
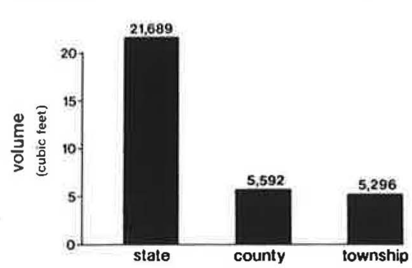


Figure 8. Volume of erosion per occurrence by ownership.



Causes of Erosion

The causes of erosion noted on the data forms were inadequate design, disturbance, or other. The greatest part of the volume--43.7 percent--was attributed to inadequate design of the road. Disturbance was responsible for 26.7 percent, and other causes for 29.5 percent (Figure 5).

In addition to the causes noted on the survey forms, more specific causes were identified under a note or comment column for 24 percent of the total volume. According to the comments, lack of vegetation was the single most important cause of erosion along roadsides. Loss of topsoil from roadsides lowers soil fertility and reduces the ability of slopes and ditches to revegetate and control future erosive action. The second most frequent cause related to agricultural activities, including drainage ditches, unauthorized farming of roadsides, surface drainage or field wash, livestock, and tile outlets. These causes of erosion are often beyond the control of the road authorities.

Other important reasons for erosion identified from the survey notes include steep slopes and rough topography; river fall; improper design of roads, especially near streams; poor soils; use of roadsides as borrow areas; lack of funds for correcting existing erosion problems; and lack of past administrative emphasis on controlling erosion.

Corrective Measures

Three levels of corrective measures were recommended. The first level, tillage and establishment of vegetation, was recommended for 27 percent of the sites (Table 1). This form of control is least costly and easiest to implement. The second level includes the first level plus slope shaping and is more costly, requiring some physical alteration of the roadside slope. Second-level controls were recommended for 58 percent of the sites. Third-level controls are most costly, involving the greatest modification of existing conditions. Third-level measures include secondary controls plus installation of some type of structural correction and were suggested for 15 percent of the sites.

The counties were also asked to identify corrective measures needed to control erosion and corrective measures implemented after completion of the survey and to discuss special problems regarding the control of erosion in each county. According to responses regarding the need for and implementation of corrective measures, the need for structural correction was overestimated by the survey and the importance of vegetative cover was significantly underemphasized. Of the 55 counties that responded regarding implementation, 18 had completed second-level controls, 10 had implemented first-level controls, and 14 had installed structures. Most controls had been completed on county and state roads. Townships did not have the funds to correct many erosion problems, especially those that required the more costly reshaping and structural controls. Lack of funds was identified as the major factor preventing correction of many erosion problems.

CONCLUSIONS

Differences in the amount and occurrence of roadside erosion do exist. The larger sites of roadside erosion in Minnesota are generally caused by

1. Inadequate design of the roads, especially in areas of rough terrain or poor soils and near streams or rivers, and
2. Lack of administrative direction and emphasis, especially in the establishment of vegetative cover, maintenance repair of erosion sites, and control of unauthorized activities along the roadside, such as farming and use of the roadside for borrow or for recreational purposes.

In the design of new or reconstructed roads, a reduction in the construction of cut-fill-design roads and an increase in the construction of fill roads, especially in areas of rough terrain, should significantly reduce the potential of future roadside erosion. Special consideration is needed to control erosion in areas of transition between cross-sectional designs. If vegetative cover can be established during or soon after construction, erosion can be minimized. Technical emphasis and administrative direction are also important in the control of erosion. This emphasis and direction has been identified as the major factor producing differences in erosion between counties with similar topography, soils, climate, and land use.

Frequent occurrences of erosion are often associated with

1. Drainage from ditches mandated by statute, agricultural lands, and private developments;
2. Rough terrain or steep slopes;
3. Inadequate design of roads in areas of rapid changes in topography; and
4. Lack of technical emphasis and administrative direction.

Because road authorities in Minnesota are required by statute to accept natural drainage from adjacent areas into the road ditch system (including drainage ditches), it is difficult for the road authorities to control erosion associated with drainage from adjacent areas. A cooperative effort by all authorities involved will be needed to control this type of erosion problem. Selection of the fill-design road in areas of rough terrain and administrative emphasis on the need for erosion control should reduce the occurrences of erosion along roadsides.

Many corrective measures were recommended, and in many counties these recommendations have been implemented. However, some erosion sites have remained unchecked and other sites have increased in size. Lack of funds is the most frequently identified reason for not repairing or correcting erosion. Townships in particular do not have money available for erosion control. An increase in funds and technical assistance for controlling and preventing erosion is needed on the township level.

The results of this survey have made it possible to

1. Determine the extent and type of roadside erosion,
2. Evaluate the present application of erosion control techniques,
3. Determine the corrective measures required,
4. Determine highway alignment and design deficiencies and the roadway cross sections with the greatest erosion potential,
5. Determine and locate conditions and situations that are apt to result in severe roadside erosion,
6. Locate problem soil types,
7. Locate private roads and other land use contributing to the sedimentation problem, and
8. Note other factors contributing to the roadside erosion problem.

The county surveys, data sheets, and maps have served to help develop township or county programs for additional action on controlling erosion. The results should be reduced sedimentation and pollution, improved highway safety and roadway stability, reduced highway operations and maintenance costs, improved water quality and wildlife habitat, and enhanced aesthetics in the rural landscape.

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The Minnesota roadside erosion survey resulted from interagency coordination on the state, county, and township levels. It is an excellent example of what can be accomplished through such an effort. The survey was a joint effort of the county engineers, the Agricultural Extension Service, the Minnesota Department of Transportation (DOT), the Soil Conservation Service, and the Soil and Water Conservation Districts. The Minnesota chapter of the Soil Conservation Society of America initiated the survey by establishing a special committee to plan and guide the statewide erosion survey. Lawrence E. Foote was chairman. John Bedish and Maynard Scilley of the State Soil Conservation Service were vice-chairmen. The support of W.S. Ekern (retired) and Gordon Fay of the Minnesota DOT greatly helped in starting the survey. Chapter presidents of the Soil Conservation Society of America continue to support the effort. Appreciation is extended to all who conducted the survey or helped compile or write the county reports.

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