X-DRAIN AND XDS:
A SIMPLIFIED ROAD EROSION PREDICTION METHOD

by

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Summary:

To develop a simple road sediment delivery tool, the WEPP program
modeled sedimentation from forest roads for more than 50,000
combinations of distance between cross drains, road gradient, soil
texture, distance from stream, steepness of the buffer between the road
and the stream, and climate. The sediment yield prediction from each of
these runs was stored in a data file. Two computer interfaces were
developed to access the results either from a Windows operating system
or over the Internet. Methods are presented to apply these results to
road planning and environmental analysis.

Keywords:
WEPP Roads Erosion prediction Interface

X-DRAIN and XDS: A Simplified Road Erosion Prediction Method

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Abstract

Roads are a major source of sediment in our nation's forests. The Water Erosion Prediction Project (WEPP) model can predict sediment delivery to a stream from a forested buffer below a forest road. The current WEPP interface, however, has been found to be too cumbersome for casual field use. To make the WEPP technology available for field application, WEPP was run to model sedimentation from forest roads for more than 50,000 combinations of distance between cross drains, road gradient, soil texture, distance from stream, steepness of the buffer between the road and the stream, and climate. The sediment yield prediction from each of these runs was stored in a data file. Two computer interfaces were developed to access the results either from a Windows operating system or over the Internet. Methods are presented to apply these results to road planning and environmental analysis.

Introduction

Roads have been identified as the major source of sediment in most forest watersheds due to surface erosion or mass failure. Practices to control sedimentation from roads are well known, and have been incorporated into road designs for many years (for example, see Packer and Christensen 1977). Such guidelines, however, merely provide estimates of percentage of sediment reduction at best, and their application is limited to the specific soils and climates for which each was developed. There have been numerous cases in recent years in which forest planners have wanted to know the sediment yield from a given length of road, but have had no acceptable means to estimate the amount. In some cases, planned forest activities were halted because managers were unable to predict offsite sedimentation from roads.

One of the primary practices to control erosion on forest roads is the inclusion of a means to divert runoff from the road surface or eroding ditch. There are a variety of methods to achieve this including surface cross drains or broad based dips, and ditch relief culverts. Their purpose is to divert concentrated runoff from the road surface or ditch to reduce road traveled way erosion or ditch erosion. In some cases, these methods are meant to reduce sediment delivery to nearby streams. The runoff from the cross drain is routed over the fill slope and across a buffer area to the stream (figure 1). Runoff and erosion occur on the road surface or inside ditch, and downslope infiltration and deposition occur on the hillside buffer below a cross drain.

All insloping roads, flat-surfaced roads, rutted roads, and outsloping roads can be described by figure 1. Only roads that cross streams or drain directly into streams are exceptions to this model (Elliot and others 1994). The current practice in road design is to address each live water crossing as a site-specific problem in order to determine the best practice to minimize sedimentation.

Erosion Prediction Models

USLE—The most common erosion prediction technology is the universal soil loss equation (USLE). This technology has been widely applied to agricultural cropland conditions. Inputs for the USLE also have been developed for forest harvest conditions in the Southeastern U.S. (Dissmeyer and Foster 1981). Input parameters have not, however, been developed for forest roads. A major disadvantage of the USLE for road conditions is that it was developed to predict erosion from the eroding part of the hillside, and is not intended to serve as a sediment delivery model where downslope deposition is a major factor in the sediment delivery process.

WATSED—An approach to estimating sediment delivery from forest roads has been developed in the Northwestern U.S. with a series of watershed cumulative effects models. The variation in erosion and sediment delivery predicted by these models is a value that was determined partially from field research, but often modified for a specific locality by consensus from a group of agency specialists. One of the first of these models was the WATSED model (USDA Forest Service 1990) and one of the most comprehensive methods was developed by the Washington Forest Practices Board (1995). These methods guide the user to estimate a road erosion rate for a part or all of a given watershed road network, based on geology, age of road, and factors related to road use. The erosion rate is then adjusted for delivery, and the resulting sediment yield is calculated. Results from this method are generally reasonable and have been validated for the geologic and climate region for which they were developed, but lose accuracy rapidly for other climates or geologic areas.

WEPP—The Water Erosion Prediction Project (WEPP) model (Flanagan and Livingston 1995, Laflen and others 1997) is a physically-based soil erosion model that can provide estimates of soil erosion and sediment yield considering the specific soil, climate, ground cover, and topographic conditions of a site. WEPP simulates such daily conditions that impact erosion as the amount of vegetation canopy, the surface residue, and the soil water content. For each day that has a precipitation event, WEPP determines whether it is rain or snow, and calculates the appropriate infiltration and runoff. If there is runoff, WEPP routes it over the surface, calculating erosion or deposition rates for at least 100 points on the hillslope. It then calculates the average annual sediment yield from the hillslope. The model has been validated for numerous conditions including forest roads (Elliot and others 1994, Elliot and others 1995, Tysdal and others 1997).

Included in the WEPP technology is the CLIGEN stochastic weather generator. CLIGEN generates a daily climate for any length of simulation from 1 to 999 years, based on the statistics from the selected weather station. CLIGEN has a database of over 1000 climates spaced at a grid of approximately 100 km for the entire USA (Flanagan and Livingston 1995).

Forest Service Applications of WEPP
During the past four years, more than 120 people have been trained in Forest Service workshops to apply the WEPP model to forest roads and disturbed forest conditions. Forest Service scientists have offered to assist these potential users in applying WEPP to local problems, and in numerous consultations the authors have assisted forest managers in such a way (Laflen and others 1997). In spite of these efforts, fewer than 10 percent of the workshop participants have attempted to apply the WEPP model. The reasons given for the low use rate have been the users' lack of time to devote to using WEPP, and the complexity of the current WEPP interface. WEPP requires more than 400 input variables to run. Even though typical templates have been developed for many agriculture, range, and forest conditions (Flanagan and Livingston 1995, Elliot and Hall 1997), users become discouraged when trying to find and adjust the critical variables to describe a given site.

In spite of the modeling difficulties, the Forest Service and other agencies need to predict sediment yield from roads. WEPP can provide the predictions, but the current interface is too complex for the time available for field use. Other prediction methods are limited in scope. To meet this challenge, we need a new technology which can address site-specific sediment risks, and which can be readily learned and applied by field personnel. One technology that we are developing to meet this challenge is incorporated in the X-DRAIN and XDS computer programs. The remainder of this paper describes these programs.

Methods and Results

To exploit the ability of WEPP to predict sedimentation from roads, and to make the results available for field application, more than 50,000 runs of the WEPP model (Version 95.7) were made. We sequentially ran WEPP for each combination of the soil and topography conditions described in table 1 for a 30-year simulated climate for each location described in Table 2. Road erosion rate, runoff amount, sediment plume length, and sediment yield to the stream were saved for each run. Figure 2 shows some typical results. Discussion of the results is given in Morfin and others (1996). The predicted sediment yields from the runs were stored in a data file. Two programs were developed to access the data: a stand-alone version to run in Windows (X-DRAIN 1997) and a version to run over the Forest Service intranet or the Internet via the World Wide Web (XDS 1997).

X-DRAIN and XDS Screens

X-DRAIN and XDS have two main screens: an input screen (figure 3) and an output display screen (figures 4 and 5). On the input screen, the user can select the climate, the soil classification, the steepness of the forested buffer between the road and the nearest stream, and the length of the buffer. A road width between 1 m (3 ft) and 30 m (100 ft) is also specified. Both programs can be run with either metric or English units.

On the output screen (figures 4 and 5), the input selections are presented along with a table of sediment yield values, in kg/m or lb/ft of road length between cross drains for five cross drain spacings and four road gradients. To determine the sediment yield from a road segment with a given gradient and cross drain spacing, multiply the value in the output table by the length of the spacing between cross drains. For example, the output shown in figure 4 predicts a sediment yield of 0.1 kg/m for a 60-m cross drain spacing at a road gradient of 4 percent. The average annual total sediment production from the 60 m of road between cross drains would be 0.1 kg/m x 60 m = 6 kg.

For conditions between the points modeled, interpolation between results appears to be valid. It is not advisable, however, to extrapolate outside the region modeled, as the relationships are not linear.

Discussion

In our field research observations, the range of sedimentation observed will vary from the mean by at least 30 percent of the mean, and the minimum observed values are frequently less than half of the maximum values (Elliot and others 1989, Elliot and others 1994, Elliot and others 1995, Tysdal and others 1997). Our WEPP validation work has shown that the erosion rates predicted by WEPP generally fall within the range of observed values (Elliot and others 1991, Elliot and others 1994, Elliot and others 1995, Tysdal and others 1997). Because of the magnitude of natural variability in soil erosion processes, users should not place too much emphasis on small differences between predicted values.

We assumed that the user would not model a condition where the road gradient was steeper than the slope of the buffer, so for each such combination the output table has a blank entry. The values in the table are rounded to one or two significant digits depending upon the magnitude (Elliot and others 1998b), with a minimum reported value of 0.01 kg/m (0.01 lb/ft). Any value below that limit was treated as zero.

In a sensitivity analysis of sediment yield to the various input factors for X-DRAIN and XDS, Morfin and others (1996) found that the sediment yield was particularly sensitive to cross drain

spacing, road gradient, and buffer length. It was less sensitive to changes in buffer slopes above 25 percent. Their study reported that sediment yield was sensitive to both climate and soil type.

In analyzing the results from this study, we observed that for several climates in which a significant part of the precipitation occurred as snow, WEPP predicted larger sediment yields than it did for climates with similar amounts of precipitation but with no snow. Earlier studies had suggested that WEPP was over predicting snow melt rates (Elliot and others 1996). After the WEPP runs for this study were completed, a revised version (Version 97.3) of the WEPP model (1997) with modified snow melt routines was developed by the Agricultural Research Service and is now available. Runs were made with the new WEPP, and we found that the revised sediment yield values ranged from less than a five percent reduction for most climates to as much as a 90 percent reduction for some of the scenarios for the Deadwood Dam, Idaho, climate. Further analyses of these differences is ongoing. Future versions of X-DRAIN and XDS may be based on the Version 97.3 results. The climates with runoffs that are dominated by snow melt are noted in Table 2.

For this study we assumed that the runoff water followed the road from one cross drain to the next (figure 1). This template can be applied to a variety of conditions for a reasonable estimate of sediment yield (table 3). Outsloping roads without wheel ruts generally have an equivalent cross drain spacing of about 7 m (Foltz 1996), but this figure soon increases as traffic flattens the cross slope, so cross drains are generally recommended on outsloping roads. If the site template presented in figure 1 is not adequate to describe the site conditions, then site-specific runs can be made with the WEPP model with the aid of the templates developed by Elliot and Hall (1997) and Elliot and others (1998a). If the road drains directly into a channel, then the cross drain template is not valid. With WEPP, this condition can be modeled as a simple rutted or insloping road, or as a small watershed (Elliot and Hall 1997, Tysdal and others 1997, Elliot and others 1998a).

Applications
There are several different applications for these programs for a range of road and similar conditions, some of which are listed in tables 3 and 4. Examples of applications are provided in the X-DRAIN documentation (Elliot and others 1998b).

In a typical application, a planner can estimate the average annual sediment from a given road system by determining the sediment yield for each road segment with X-DRAIN or XDS after consulting the road design and a site survey or contour map. The road design generally will specify the distance between cross drains, the appropriate traveled way shape, and the gradient of the road for each segment. The buffer slope and distance to a channel can be determined from a field survey or a contour map. With this information and an appropriate soil type and climate, the sediment yield can be determined for each road segment, and the total sediment yield for the road system can be calculated.

A second application of X-DRAIN and XDS is to evaluate the impact of spacings of cross drains on any road (including skid trails) on sediment delivery. The necessary input information is collected, and the output table is studied to determine what spacing will give an acceptable sedimentation rate.

A third application is as an aid to identifying sections of road that are the best candidates for closure or for mitigation measures. One mitigation measure is the application of gravel to a clay or silt loam, which can be evaluated by selecting a gravelly loam soil. For example, figure 5 shows a sediment yield of zero for all road gradients and cross drain spacings from the same

climate and topographic conditions as figure 4, but with the gravelly loam soil selected. The application of gravel to a sandy loam road can be evaluated by selecting the gravelly sand soil.

Other applications of the model are to determine erosion from footpaths or bike trails—by specifying a narrow width (1 m)—or from log landings, parking lots, or similar cleared areas if the surface is in an eroding state and the width is 30 m (100 ft) or less.

The soil erodibility properties defined for X-DRAIN and XDS are presented in Table 6 for users who may wish to modify the forest template files (Elliot and Hall 1997), or to build soil files with the current WEPP file builders (Flanagan and Livingston 1995).

On The Horizon
Currently, a revised database is under development for X-DRAIN and XDS based on WEPP version 97.3. It will likely be released with XDS once it has been verified. The data are also being studied to see whether regression relationships can be developed to replace the look-up table, which will provide the user with the opportunity to enter any topographic value rather than being limited to those which were part of the underlying WEPP runs.

An interface to the WEPP model similar to these programs is under development for roads. This new interface allows the user to specify any length of road or buffer, as well as incorporate any correctly formatted climate file. Additional help from the input screen, and more information in the output will be part of the interface.

Conclusions
The X-DRAIN and XDS programs offer natural resource managers a method to estimate road sediment yields quickly for a wide range of conditions. The programs are fast, simple to use, and a significant improvement over most current methods that estimate road sediment yields to streams.

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Tables

Table 1. Soil and topography conditions in X-DRAIN and XDS

Variable	Values
Spacing of cross drains	10, 20, 40, 60, and 100 m
Road gradient	2, 4, 8, and 16 percent
Length of forest buffer between road and stream	10, 40, 80, and 200 m
Steepness of forest buffer	4, 10, 25, and 60 percent
Soil classifications (See tables 4 and 5 for details)	Clay loam, silt loam, sandy loam, gravelly loam, and gravelly sand

Table 2. Details of Climate Stations used in the Study

State	Location	Precip (mm)	Latitude °N	Longitude °W	Elevation (m)	Record (yrs)
AK	JUNEAU	1336.1	58.37	134.58	3	43
AL	BIRMINGHAM	1391.8	33.57	86.75	185	62
AR	CLARKSVILLE	1239.1	35.47	93.47	134	39
AZ	HEBER	318.4	34.38	110.58	2029	42
CA	ALTURAS *	306.8	41.50	120.53	1359	61
CA	GLENVILLE	494.0	35.72	118.70	954	41
CA	WILLITS	1282.2	39.42	123.33	411	32
CO	EAGLE	282.4	39.63	106.92	1981	44
ID	DEADWOOD DAM *	822.7	44.32	115.63	1639	47
ID	WALLACE *	922.7	47.50	115.88	899	44
KY	HEIDELBERG	1165.2	37.55	83.77	201	60
LA	RUSTON	1391.8	32.52	92.68	85	62
MI	WATERSMEET	758.8	46.28	89.17	490	44
MO	SALEM	1108.4	37.63	91.55	365	74
MT	LIBBY	454.6	48.40	115.53	633	84
MT	SEELEY *	544.9	47.22	113.52	1228	44
NC	CULLOWHEE	1279.6	35.32	83.18	640	44
NH	LANCASTER	879.9	44.46	71.57	268	42
NM	TAOS	327.1	36.42	105.57	2127	44
NV	TUSCARORA	301.8	41.42	116.23	185	33
OH	NEW LEXINGTON	1009.6	39.73	82.22	271	50
OR	AUSTIN *	517.5	44.58	118.50	1283	44
OR	NORTH BEND	1611.3	43.42	124.25	3	61
OR	WICKIUP *	553.9	43.68	121.70	1319	41
PA	RIDGWAY	1053.7	41.43	78.73	417	66
SD	FORT MEADE	497.1	44.40	103.47	1005	43
TX	LUFKIN	1141.4	31.47	94.72	88	85
UT	HEBER	418.8	40.50	111.42	1703	64
WA	COLVILLE *	470.2	48.53	117.87	566	40
WA	PACKWOOD	1351.3	46.62	121.67	323	42
WA	SAPPHO *	1935.1	48.07	124.12	231	44
WV	LEWISBURG	934.7	37.80	80.43	685	44
WY	LAKE YELLOWSTONE *	415.5	44.57	110.40	2356	64

*   Predicted sediment yields from these stations may be overestimated
due to over prediction of snowmelt rates by the WEPP model (version
95.7)

Table 3. Adapting cross drain inputs to model different conditions.

Condition	Cross drain application
Insloping Roads	
With no ditch treatment and no ruts	Enter width of traveled way plus inside ditch in width box
With rocked or graveled ditch and no ruts	Enter width of traveled way in width box and select 10 m (30 ft) for spacing of cross drains
With ruts and stable ditch	Enter width of traveled way in width box and read output for the spacing of cross drains
With ruts and eroding ditch	Enter width of traveled way plus ditch in width box, and read output for spacing of cross drains
Outsloping Roads	
Without ruts	Enter width of traveled way in width box and select 10 m (30 ft) for the spacing of cross drains
With ruts	Enter width of road contributing runoff to ruts. Read the results for the observed spacing of cross drains
Other	
Road with flat traveled way	Enter width of traveled way in width box and read output directly
Bladed and compacted skid trail	Select appropriate native surface soil and appropriate topographic variables for first year erosion. Subsequent years will decline rapidly as vegetation is reestablished on the skid trail, to near zero by year 5. (Example in Elliot and others 1998b)
More complex conditions	Run the WEPP model for the specific conditions

Table 4. Categories of common forest soils in relation to cross-drain soils

Cross drain soil	Typical field soils	Unified Soil Classification
Clay loam	Native-surface roads on shales and similar decomposing sedimentary rock	MH CH
Silt loam	Ash cap native-surface road. Alluvial loess native-surface road	ML CL
Sandy loam	Glacial outwash areas. Finer-grained granitics	SW SP SM SC
Gravelly loam	Cobbly loam soils. Clay or silt loam surfaces that have been graveled	GC
Gravelly sand	Coarse-grained granitics, and fine-grained granitics that have been graveled	GM

Table 5. X-DRAIN and XDS soil erodibility properties

| Element	Soil				
	Clay	Silt	Sand	Gravelly loam	Gravelly Sand
Road traveled way					
Gravel (%)	20	5	5	60	80
Sand (%)	30	30	60	40	70
Silt (%)	40	55	35	40	25
Clay (%)	30	15	5	20	5
Conductivity (mm/hr)	0.3	0.3	1	2	3
Interrill erodibility	1,000,000	3,000,000	2,000,000	1,000,000	2,000,000
Rill erodibility	0.0002	0.0006	0.0004	0.0003	0.0003
Critical Shear	1.5	1.8	2	1.8	2
Organic Matter (%)	0.01	0.01	0.01	0.01	0.01
Fill slope					
Gravel (%)	20	5	5	40	40
Sand (%)	30	30	60	35	65
Silt (%)	40	55	35	40	30
Clay (%)	30	15	5	25	5
Conductivity (mm/hr)	5	8	10	25	40
Interrill erodibility	1,000,000	3,000,000	2,00,000	1,000,000	2,000,000
Rill erodibility	0.0002	0.0006	0.0004	0.00025	0.00035
Critical Shear	1.5	1.8	2	1.6	2
Organic Matter (%)	2	2	2	2	2
Forest buffer					
Gravel (%)	20	5	5	20	5
Sand (%)	30	30	60	30	60
Silt (%)	40	55	35	40	35
Clay (%)	30	15	5	30	5
Conductivity (mm/hr)	10	15	20	50	80
Interrill erodibility	1,000,000	3,000,000	2,000,000	1,000,000	2,000,000
Rill erodibility	0.0002	0.0006	0.0004	0.0002	0.0004
Critical Shear	1.5	1.8	2	1.5	2
Organic Matter (%)	4	4	4	4	4
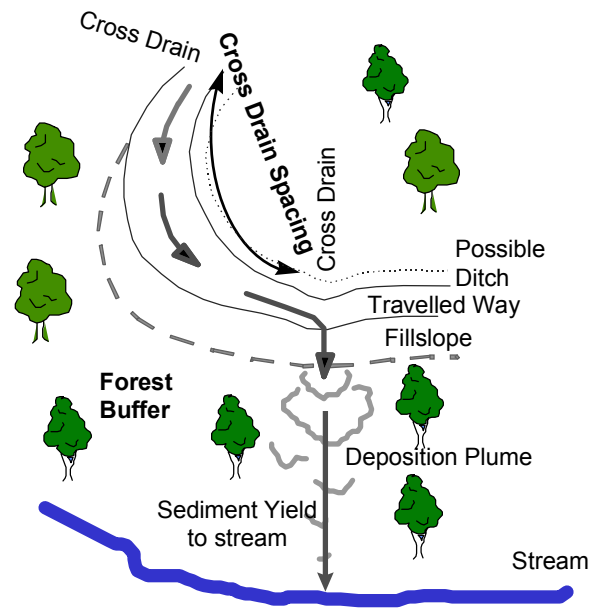
Figure 1. Typical forest conditions associated with road erosion causing stream sedimentation
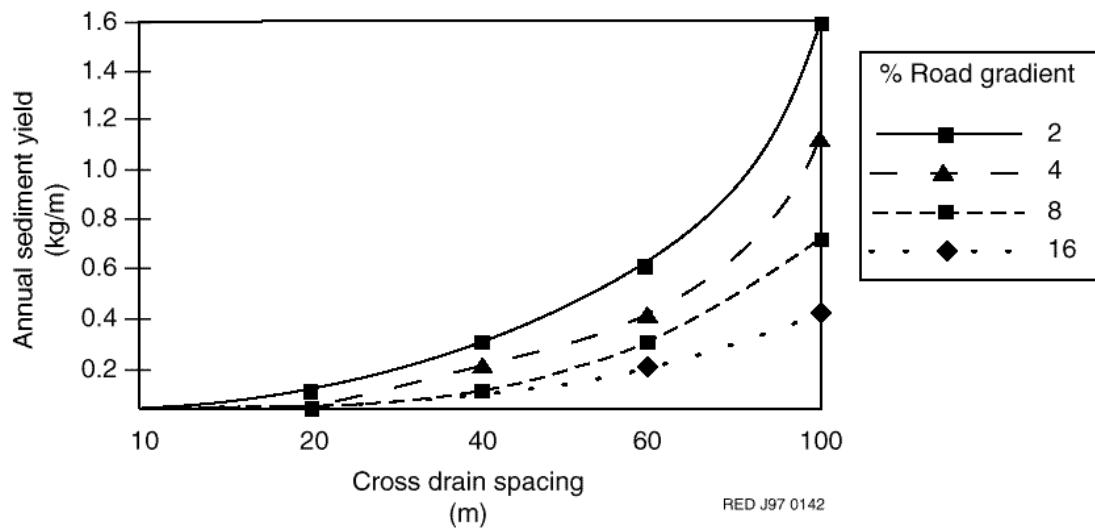

Figure 2. Annual sediment yield versus cross drain spacing for different road gradients for the Wallace, ID climate, with a buffer length of 40 m, a silt loam soil, a buffer slope of 25 percent, and a road width of 4 m.
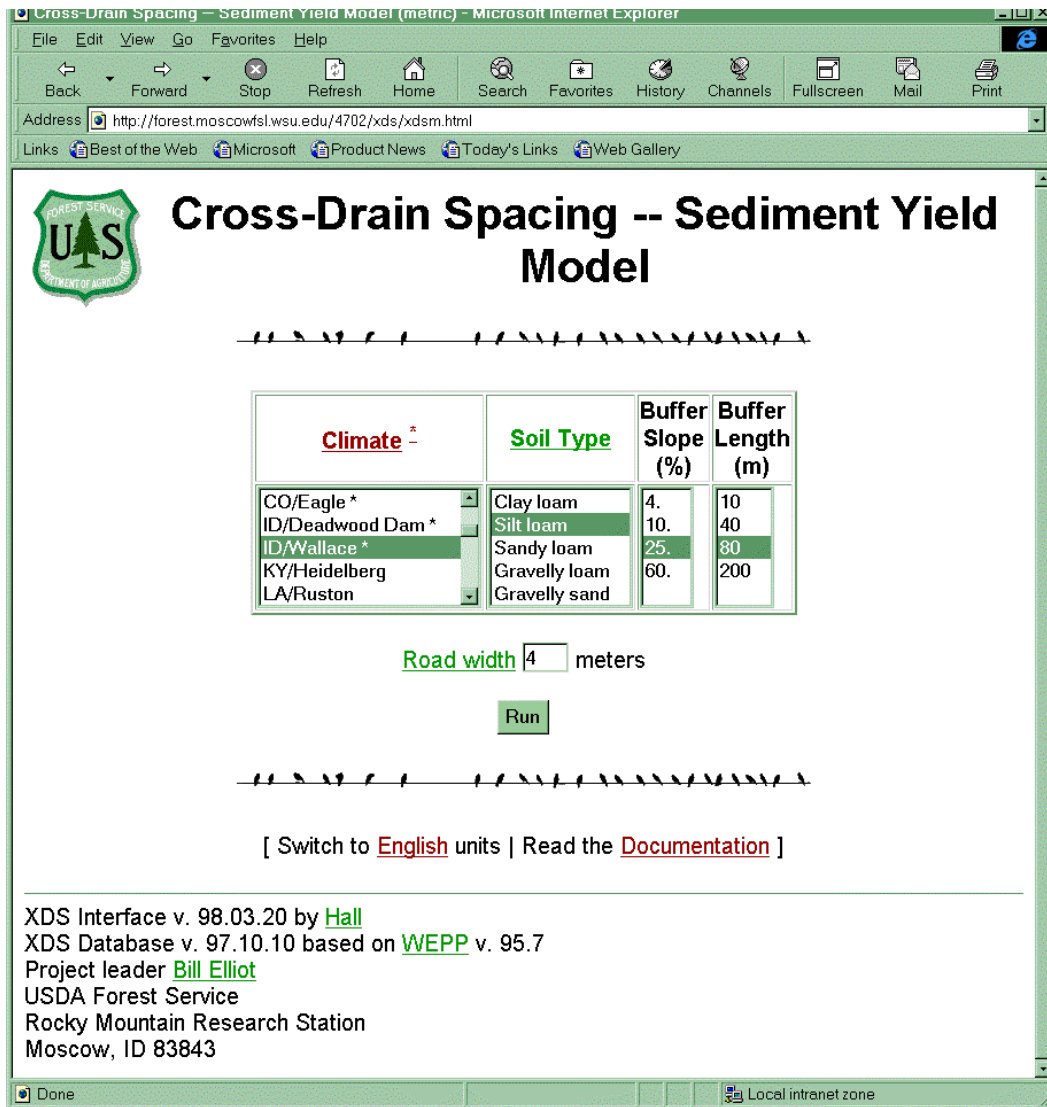
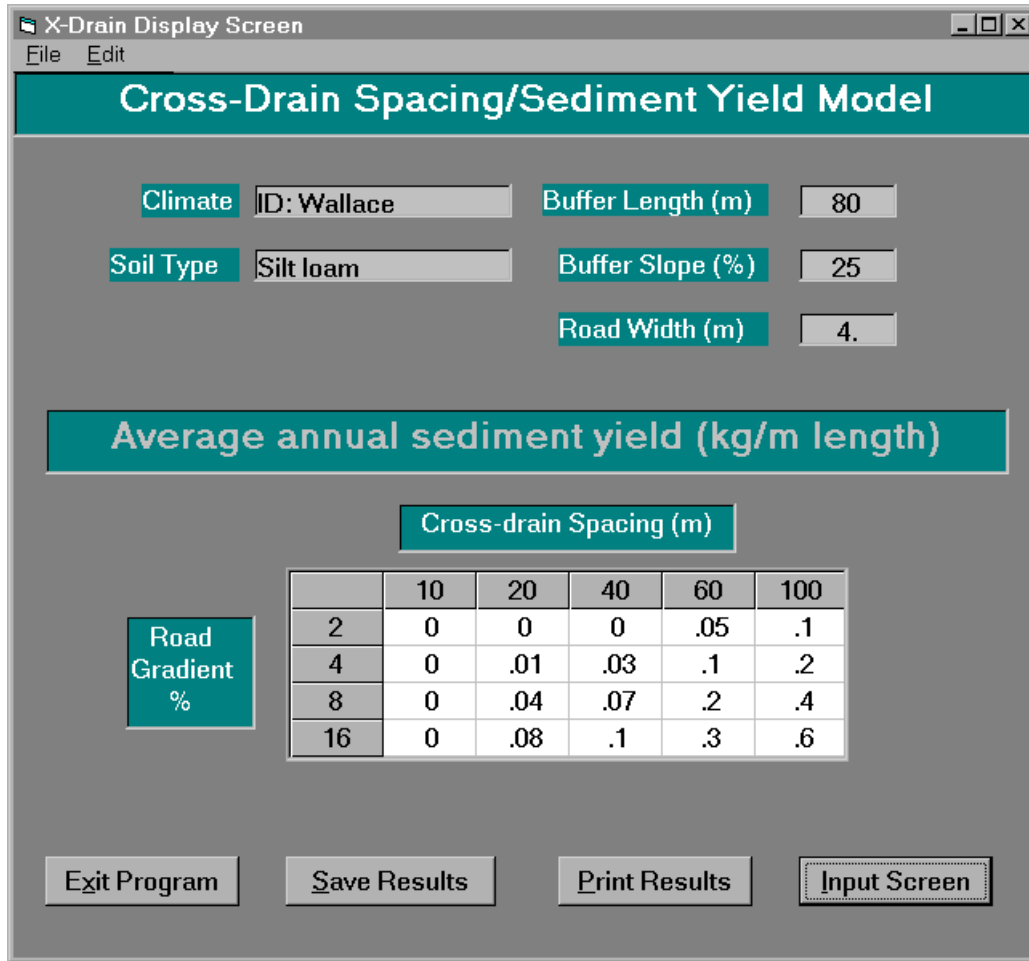**Figure 3**. XDS input screen. X-DRAIN input screen is similar.

Figure 4. X-DRAIN output display screen.

Cross-Drain Spacing -- Sediment Yield Model

Results

Climate: ID/Wallace   **Buffer length:**   80 m
Soil type: gravelly loam   **Buffer gradient:** 25 %
Road width: 4 m

Average annual sediment yield (kg/m length)

Road Gradient	Cross drain spacing				
	10 m	20 m	40 m	60 m	100 m
2 %	0	0	0	0	0
4 %	0	0	0	0	0
8 %	0	0	0	0	0
16 %	0	0	0	0	0

[empty cells indicate unlikely geometrical conditions]

Back

XDS Interface v. 98.03.20 by Hall
XDS Database v. 97.10.10 based on WEPP v. 95.7
Project leader Bill Elliot
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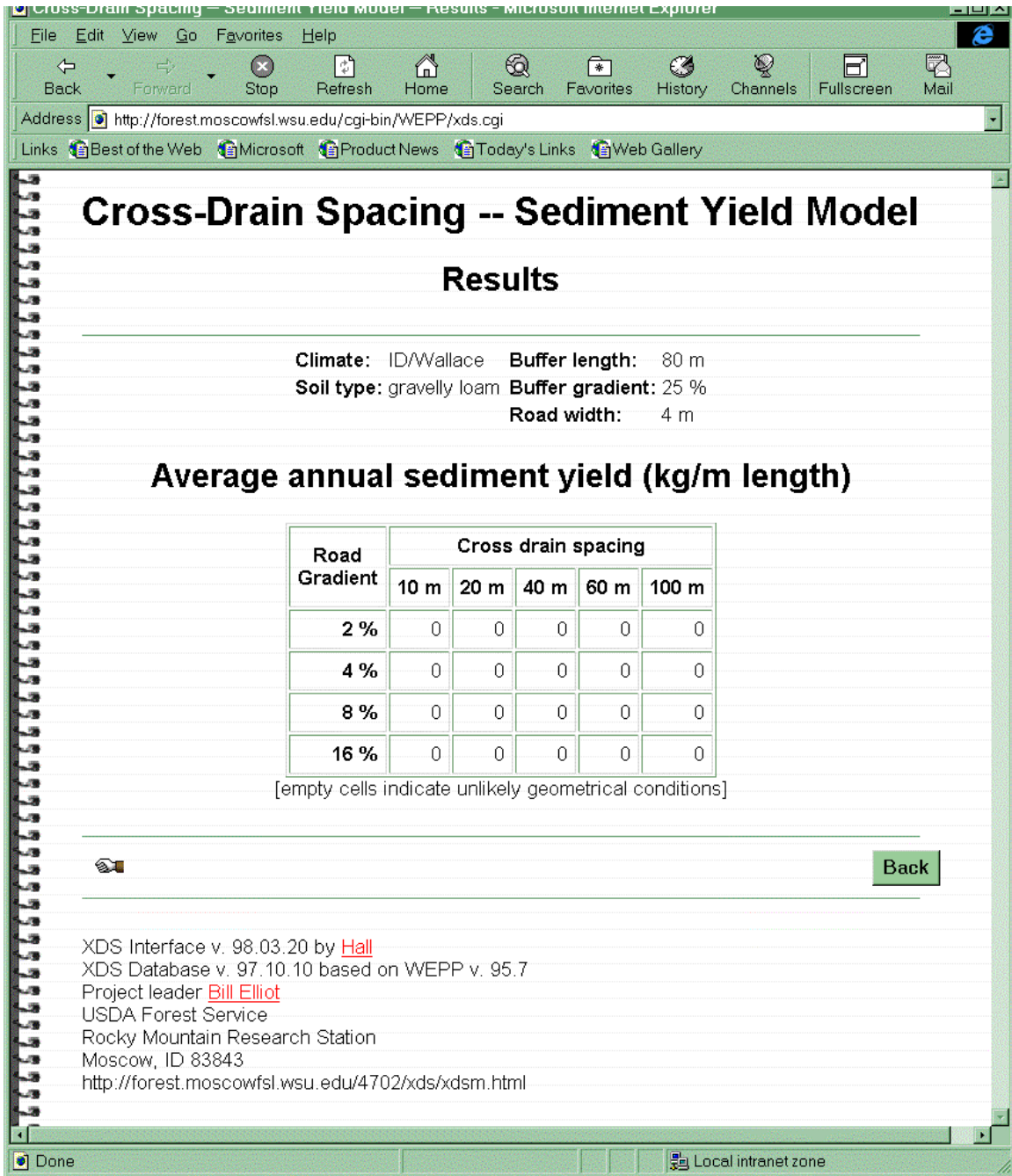http://forest.moscowfsl.wsu.edu/4702/xds/xdsm.html

Figure 5. XDS output display for the same climate and topographic conditions as figure 4, but with a gravelly loam soil.