Measurement and Prediction of Sediment Yields in Wisconsin Streams

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

in cooperation with
CITY OF MADISON
CITY OF MIDDLETON
DOUGLAS COUNTY
UNIVERSITY OF WISCONSIN-EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY
U.S. ARMY CORPS OF ENGINEERS
WISCONSIN DEPARTMENT OF NATURAL RESOURCES
# Measurement and Prediction of Sediment Yields in Wisconsin

**Sediment data** have been collected by the U.S. Geological Survey at 118 stream-gaging sites throughout the State beginning in 1935. Enough data were collected at 84 of these sites to calculate an **average annual suspended sediment**. Measured average annual yields range from about 680 tons per square mile (238 tonnes per square kilometre) in the "Driftless Area" to 3.1 tons per square mile (1.1 tonnes per square kilometre) in the Northern Highland province. The average suspended-sediment yield for Wisconsin is about 80 tons per square mile per year (28 tonnes per square kilometre per year).

Sediment-yield prediction equations for four geographic provinces make it possible to predict average annual sediment yield at any point on 95 percent of the streams in the State. The prediction technique involves regression equations that relate average annual suspended-sediment yields to the controlling physical factors. The standard error of estimate for these four equations, which only represent the accuracy of an estimated sediment yield at an ungaged site, ranges from 28 to 38 percent.

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**Key Words and Document Analysis**

- Sediment yield
- Prediction
- Measurement
- Wisconsin
- Particle size
- Regression analysis
- Estimating equations
- Sedimentation

**Identifiers/Open-Ended Terms**

- Regionalize
- Geographic provinces
- Geography

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**Availability Statement**

No restriction on distribution
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S. M. Hindall

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City of Madison,
City of Middleton,
Douglas County,
University of Wisconsin-Extension,
Geological and Natural History Survey,
U.S. Army Corps of Engineers,
Wisconsin Department of Natural Resources
UNITED STATES DEPARTMENT OF THE INTERIOR
Thomas S. Kleppe Secretary

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V.E. McKelvey Director

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1815 University Avenue
Madison, Wisconsin 53706
Conversion Factors

For the use of those readers who may prefer to use metric units rather than English units, the conversion factors for terms used in this report are listed below.

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Measurement and Prediction of Sediment Yields in Wisconsin Streams

S.M. Hindall

Abstract

Sediment data of some form have been collected by the U.S. Geological Survey at 118 stream-gaging sites throughout Wisconsin, beginning in 1935. The average concentration of suspended sediment for Wisconsin streams is low in comparison with that of many streams in the United States—110 milligrams per litre for Wisconsin, as compared with 600 milligrams per litre for 50 percent of the United States (Rainwater, 1962). Enough data have been collected at 84 of the 118 sites to calculate an average annual suspended-sediment yield at those sites.

Measured average annual yields range from about 680 tons per square mile (238 tonnes per square kilometre) in the "Driftless Area" to 3.1 tons per square mile (1.1 tonnes per square kilometre) in the Northern Highland province. The average suspended-sediment yield for Wisconsin is about 80 tons per square mile per year (28 tonnes per square kilometre per year). Only three areas in the State may be considered to have a sediment problem. They are sections of the "Driftless Area" of southwestern Wisconsin, the Lake Superior red-clay area, and areas of expanding urbanization in southeastern Wisconsin.

Sediment-yield prediction equations have been developed for the Northern Highland province, the Central Plain province, the Eastern Ridges and Lowlands province, and the "Driftless Area" (Martin, 1932 and Thwaites, 1956). These four equations make it possible to predict average annual suspended-sediment yields at any point on about 95 percent of the streams in the State. The prediction technique involves regression equations that relate average annual suspended-sediment yields to factors, such as topography, soils, land use and cover, stream hydraulics, and climatic conditions. The standard error of estimate for these equations, which only represents the accuracy of an estimated sediment yield at an ungaged site, ranges from 28 to 38 percent.
INTRODUCTION

The U.S. Geological Survey has been collecting fluvial sediment data at various points throughout Wisconsin for about 20 years. Most of these data have been published in the "Water Resources Data for Wisconsin" annual reports.

This report presents practical and useful sediment-yield information for Wisconsin. Measured and estimated sediment yields are supplemented by information on suspended-sediment concentration and particle size of suspended and bed material for 84 sites in the State. To expand the usefulness of these data, an additional section in the report presents a method to estimate or predict sediment yields in ungauged streams.

SEDIMENT DATA AND YIELDS OF WISCONSIN STREAMS

Various amounts and types of sediment data have been collected by the U.S. Geological Survey in cooperation with the city of Madison, the city of Middleton, Douglas County, the University of Wisconsin-Extension, Geological and Natural History Survey, the U.S. Army Corps of Engineers, and the Wisconsin Department of Natural Resources at 118 stream-gaging sites throughout the State beginning in 1935. Figure 1 shows the sites that are being monitored along with all active and inactive sites that have enough sediment data to calculate an average annual sediment yield.

Three types of sediment data are available for the State. The most common type of data are suspended-sediment concentration. These data, when used with stream discharge, make it possible to determine the amount of suspended sediment transported by the stream. Particle size of both suspended and bed material helps describe the physical characteristics of the transported sediments. Both types of data, if collected concurrently, can be used with hydraulic data at the collection site to estimate total sediment transport. There are limited data on chemical characteristics of the transported sediments.

Sediment yields were calculated for all sites where sufficient concentration data have been collected to define sediment discharges over the complete range of water discharge. The relation between sediment and water discharge is used with streamflow-duration curves to calculate the average annual suspended-sediment yield.

Sediment-yield, suspended-sediment concentration, and some particle-size data for 84 stream-gaging stations in the State were compiled in table 1. The short-term average annual suspended-sediment yields were computed for the period of sediment record through the 1973 water year. The long-term, suspended-sediment yields were determined by adjusting the short-term yields to a 10-year base period, 1961-70. The average annual sediment yields include an estimate of bed-material discharge.
TABLE I.—Sediment yield, concentration, and particle-size data for Wisconsin streams.

Type of sediment data: SC, suspended-sediment concentration; SM, suspended-sediment particle size; BM, bed-material particle size; CC, chemical characteristics

Average annual sediment yield: Short term, period of sediment record through 1973 water year; Long term, ten year base period, 1961-70

Estimated bed material yield: M, minimal transport (less than 5 percent); P, possible significant transport (5 - 15 percent); S, significant transport (greater than 15 percent of total sediment load)

Maximum observed concentration: if blank, insufficient number of samples collected.

Particle size: average of all samples; if blank, no samples collected

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<th>Station number</th>
<th>Period of sediment record</th>
<th>Type of sediment data</th>
<th>Average annual sediment yield (tons/sq mi)</th>
<th>Estimated bed material yield</th>
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TABLE 1.—Sediment yield, concentration, and particle-size data for Wisconsin streams—CONTINUED.

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<th>Type of sediment data</th>
<th>Average annual sediment yield (tons/sq mi)</th>
<th>Estimated bed material yield</th>
<th>Maximum observed concentration (mg/l)</th>
<th>Minimum observed concentration (mg/l)</th>
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*Note: SC = Suspended, BM = Bed material, CC = Concentrated, P = Peak, M = Median, S = Seasonal, L = Long-term*
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Note: The table contains data on number of species and fish counts for each year range.
Particle-size data presented in table 1 give the percentage of suspended and bed material that is finer than 0.062 mm (millimetre), the division between silt and sand sizes.

The regionalized suspended-sediment yield (fig. 2) was based on measured yields adjusted to the 10-year (long-term) base period plotted at the centroid of the drainage basin. This regionalized map is only a general estimate of sediment yields and should be treated as such. Sediment yields for some basins do not fit into any regional pattern. This is partly due to local actions, partly to an inherent variability in sediment transport, and partly to a lack of detailed sediment data.

As of October 1, 1974, there were 60 sites in the State where sediment data were being collected at intervals ranging from daily to intermittent (table 2). Ten stations were sampled daily and nine were sampled weekly. The remaining 41 were sampled at frequencies varying from individual storms to approximately monthly. During high-water periods the sampling frequency for all stations was increased to at least daily where possible. Twenty-four of these stations were operated for special sedimentation-related projects. Particle-size data of both suspended and bed material were being collected at every site on an "event" basis.

Recently a small program to determine chemical as well as physical characteristics of the transported sediments was begun in the State. The amounts of certain chemical constituents that are sorbed on the sediments and transported "piggy-back" by the sediments greatly exceed, in some instances, the amounts dissolved in the water. This property of some types of sediments to sorb large amounts of chemical makes sediment a tremendous potential carrier for possible contaminants.

Wisconsin is fortunate to have no serious overall sediment problem as is indicated by generally low measured yields. Local or point-source problems may cause high yields in some areas, but their effect on regional sediment yields is minimal. The average annual suspended-sediment yield for Wisconsin is only 80 tons/mi$^2$ (28 tonnes/km$^2$). The average discharge-weighted concentration of suspended sediment for Wisconsin streams is about 110 mg/l (milligrams per litre). This is very low when compared to that of streams throughout the United States. Ninety percent of the streams in the United States have a discharge-weighted suspended-sediment concentration of less than 8,000 mg/l, and only 50 percent of the streams have a suspended-sediment concentration of less than 600 mg/l (Rainwater, 1962). The 110 mg/l definitely puts Wisconsin streams in the lower percentage of the United States streams.

The highest yields in the State are in the "Driftless Area" (fig. 3). Measured average annual suspended-sediment yields range from 34 to 680 tons/mi$^2$ (12 to 238 tonnes/km$^2$) for this area with the median yield being 200 tons/mi$^2$ (70 tonnes/km$^2$). Here the silty soils on very steep slopes promote high sediment yields.
FIGURE 2. REGIONALIZED SUSPENDED-SEDIMENT YIELD IN WISCONSIN.

Line of equal suspended-sediment yield, approximately located, September, 1974. Interval irregular, in tons per square mile per year.
Table 2.—Sediment-data site network for Wisconsin

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The lowest average annual suspended-sediment yields are in the Northern Highland province of the State (fig. 3). Large areas of heavy forests, very little crop farming, and gentle topography all combine to keep yields low. Measured average annual suspended-sediment yields range from 3.1 to 31 tons/mi² (1.1 to 11 tonnes/km²) in this area with the median yield being 8.3 tons/mi² (2.9 tonnes/km²).

Measured average annual suspended-sediment yields in the Eastern Ridges and Lowlands province (fig. 3) range from 2.7 to 410 tons/mi² (0.9 to 144 tonnes/km²). The median yield in this area is 18 tons/mi² (6.3 tonnes/km²). This large range of yields is normal for some agricultural areas and for agricultural areas that are being converted to urban areas. Most of the extremely high yields are due to point-source erosion problems that are local and generally of short duration. For example, when an area or sub-division is developed, sediment yields increase drastically during the construction period, but generally return to near preconstruction levels after construction is completed. Point-source erosion problems are the easiest to correct and have the most immediate effect on sediment yields and therefore should receive the greatest attention.

Similar midrange average annual suspended-sediment yields are found in the Central Plain province (fig. 3). The measured yields range from 2.1 to 50 tons/mi² (0.7 to 17 tonnes/km²) with a median yield in this area of 17 tons/mi² (5.9 tonnes/km²).
FIGURE 3. GEOGRAPHIC PROVINCES AND 'DRIFTLESS AREA' IN WISCONSIN.

EXPLANATION

'Driftless Area'

Geographic provinces from Martin, 1932, and geology from Thwaites, 1956.
The Lake Superior Lowland province (fig. 3), which approximately outlines the red-clay soils in northwestern Wisconsin, has fairly high sediment yields. Data from stream basins only partly in the area give average annual suspended-sediment yields ranging from 140 to 220 tons/mi$^2$ (49 to 77 tonnes/km$^2$). A yield of 480 tons/mi$^2$ (168 tonnes/km$^2$) was obtained for the one area that is completely in the red-clay area (Young and Skinner, 1974). Sufficient data are not available for the area to develop a meaningful median yield or to determine a really representative maximum yield. The high yields in this geologically young area are due in part to the easily erodible red clay that retards infiltration and promotes rapid surface runoff. Also, the rapid downcutting of stream channels leaving steep exposed red-clay streambanks that continually erode and fall into the streams is a major cause of the high yields.

PREDICTING SEDIMENT YIELDS IN WISCONSIN STREAMS

Because sediment-yield data are available for only a small percentage of Wisconsin streams and at only a few points on the streams, a method to predict sediment yields in the remaining streams of the State has been developed. The procedure is simple and requires only data that are readily available. It consists of equations that relate sediment yield to the geographic or physical factors that control sediment production and transport.

Geography is important in explaining difference in sediment yield between areas. Most of the physical factors that control sediment yields of streams are in some way related to geography. Physical factors such as geology, topography, soils, land use and cover, stream hydraulics, and climatic conditions all have a direct effect on sediment yields but are also all part of the geography of an area. The State has been divided into five geographic provinces as shown in figure 3 (Martin, 1932, p. 33). The "Driftless Area" of southwestern Wisconsin (Thwaites, 1956) provides an additional geographic division. (See fig. 3.) This is an area of the State that was not glaciated during Pleistocene time and that has very distinct surface features. These divisions make it possible to group streams according to geography, therefore lessening geographic differences between streams. Equations for predicting the sediment yields within each geographic division were developed by regression techniques that relate sediment yields to the physical factors that control sediment production and transport.

The regression equations were developed through a three-step procedure. The first step was selecting and grouping the stations to be used in the analyses. Only stations with drainage areas less than 1,000 mi$^2$ (2,590 km$^2$) and a sediment-transport curve well defined over the entire range of discharge were used. The 60 stations that met these requirements were then grouped according to their geographic province or geologic area. Next, the physical geographic factors that control sediment yield in each stream were defined, measured, and entered into
the regression analysis as independent variables. The 14 physical factors used for this regression analysis were drainage area, average discharge, 2-year recurrence-interval flood, 25-year recurrence-interval flood, main-channel slope, percentage lake and marsh area, main-channel length, percentage forest cover, soil index, precipitation-intensity index, flood runoff, vegetative factor, mean frost depth, and duration factor. (See glossary for definitions of the variables.) The dependent variable used in the regression analysis was the previously calculated suspended-sediment yield (table 1).

The final step was the computation of the regression equations by computer. The results of the computer analyses were examined to determine the most significant independent variables and best equation for each province or area. In the four regression equations developed for Wisconsin streams, the number of statistically significant independent variables ranged from 1 in the equation for the Northern Highland province to 9 for the Eastern Ridges and Lowlands province equation. Independent variables that were not statistically significant were not included in the equations shown in table 3.

The regression equations, relating sediment yield to physical factors that control sediment yield, are in the form

\[ Q_s = a + b_1A + b_2Q_a + b_3Q_{25} + b_4S \]

where "Q_s" is a statistical sediment yield; "A", "Q_a", "Q_{25}", and "S" are sediment-yield controlling factors as defined in the glossary; "a" is the regression constant; and "b_1", "b_2", "b_3", and "b_4" are coefficients obtained by regression. In the regressions presented in this report the computer calculated the regression equation, the standard error of estimate, and the significance of each geographic factor.

A principal measure of the accuracy of the regression analysis, hence the accuracy with which sediment yield can be estimated, is the statistical measure of error, "standard error of estimate". Even though standard error is only a measure of the accuracy of a regression equation, not actual sedimentation methods, it represents the accuracy of an estimated sediment yield using the regression equation at an ungaged site. It is the estimated limit above and below the average within which about 67 percent of future sediment-yield values are expected to fall. Conversely, there is only one chance in three that future values will differ from the average by more than one standard error.

The regression equations, 1 through 4, standard error of estimate, and statistical significance for four geographic provinces of the State are shown in table 3. The computed versus measured sediment yields of streams in these four geographic provinces are given in table 4. There is no regression equation available for the Lake Superior Lowland province because enough data were not available to run a regression. In this area
Table 3.—Equations for prediction of suspended-sediment yield

<table>
<thead>
<tr>
<th>Number</th>
<th>Equation</th>
<th>Geographic province</th>
<th>Standard error of estimate (percent)</th>
<th>Level of statistical significance (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$Q_s = 51.1 \cdot St^{-0.72}$</td>
<td>Northern Highland</td>
<td>35</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>$Q_s = 2.82 \cdot 10^{10} \cdot Q_a^{1.43} \cdot Q_{25}^{0.43} \cdot L^{-3.29} \cdot S^{-3.26} \cdot I^{-1.52}$</td>
<td>Central Plain and glaciated Western Upland</td>
<td>29</td>
<td>95</td>
</tr>
<tr>
<td>2</td>
<td>$Q_s = 4.37 \cdot 10^{-12} \cdot Q_a^{2.63} \cdot Q_2^{-5.83} \cdot Q_{25}^{5.92}$</td>
<td>Eastern Ridges and Lowlands</td>
<td>38</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>$Q_s = 197.7 \cdot A^{2.38} \cdot Q_a^{-3.14} \cdot S^{2.01} \cdot St^{0.19}$</td>
<td>&quot;Driftless Area&quot; (Unglaciated Western Upland)</td>
<td>28</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>$Q_s = 4.14 \cdot Fd^{-4.48} \cdot D^{-1.43}$</td>
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</table>
Table 4.—Observed versus computed average annual long-term suspended-sediment yields

<table>
<thead>
<tr>
<th>Station number</th>
<th>Average annual suspended-sediment yields (tons/mi$^2$)</th>
</tr>
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<tbody>
<tr>
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<td><strong>Central Plain Province</strong></td>
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Table 4.—Observed versus computed average annual long-term suspended-sediment yields—Continued

<table>
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<tr>
<th>Station number</th>
<th>Average annual suspended-sediment yields (tons/mi²)</th>
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<th>Computed</th>
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</table>

"Driftless Area"

<table>
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<tr>
<th>Station number</th>
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<th>Observed</th>
<th>Computed</th>
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<tr>
<td>05436000</td>
<td>39</td>
<td>43</td>
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of the State other methods of sediment-yield estimation must be used. The "Driftless Area" was substituted for the Western Upland province. The "Driftless Area" and Western Upland province have similar boundaries except in the glaciated area of the Western Upland province. The effects of glaciation or lack of glaciation created two distinct geographic areas and are treated as such. To predict sediment yields in that part of the Western Upland province outside the "Driftless Area", the regression equation for the Central Plain province is applicable and gives very good results.

Different combinations of the 14 independent variables were found to be statistically significant for each of the four regression equations. The only significant independent variable in the equation for the Northern Highland province was percentage lake and marsh area. The remaining 13 variables used in the analysis were found to be statistically insignificant. The average discharge, 25-year recurrence-interval flood, main-channel length, soil index, and precipitation-intensity index are the only independent variables that were statistically significant in the equation for the Central Plain province. The remaining nine variables were disregarded. In the equation for the Eastern Ridges and Lowlands province the average discharge, 2- and 25-year recurrence-interval floods, main-channel slope, main-channel length, 10-year runoff, soil index, frost depth, and duration factor are the significant independent variables. Five remaining variables were found to be statistically insignificant for this province. The equation for the "Driftless Area" had seven statistically significant independent variables: drainage area, average discharge, main-channel slope, percentage lake and marsh area, main-channel length, frost depth, and duration factor. The remaining seven independent variables were insignificant and not included in the equation.

These regression equations make it possible to predict sediment yields for about 95 percent of Wisconsin streams. Use of the sediment-yield equations is illustrated below by a practical application to the Manitowoc River at Lake Michigan.

1. Determine from figure 3 the major geographic province of the Manitowoc River. In this example it falls completely in the Eastern Ridges and Lowlands province and therefore equation number 3 is applicable. Equation number 3 is as follows:

\[
Q_s = 4.37 \times 10^{-12} Q_a^{2.63} Q_2^{2.63} Q_{25}^{5.92} S_i^{1.94} L^{-2.52} \\
* Ro^{1.31} S_{ld}^{6.35} P_d^{8.26} D^{0.59}
\]

2. To calculate average discharge \(Q_a\), in cubic feet per second, first determine the size of the contributing drainage area \(A\) from the best maps available. For the Manitowoc River it is about 530 mi\(^2\) \(1,373 \text{ km}\(^2\).\)
Next, estimate the average runoff for the basin from figure 4. (See glossary.) In this example it is about 7.5 in (19 cm). Finally, multiply the drainage area by the average runoff and apply the necessary conversion factor (0.074) to get average discharge.

\[ Q_a = 7.5 \times 530 \times 0.074 = 290 \text{ ft}^3/\text{s} (8.21 \text{ m}^3/\text{s}) \]

3. Compute the 2-, 10-, and 25-year recurrence-interval floods \((Q_2, Q_{10}, Q_{25})\) from previously developed equations (Conger, 1971). (The 10-year recurrence-interval flood will be used in a later step.) For the Manitowoc River they are as follows:

\[ Q_2 = 3,900 \text{ ft}^3/\text{s} (110 \text{ m}^3/\text{s}) \text{ and } \]

\[ Q_{25} = 8,100 \text{ ft}^3/\text{s} (229 \text{ m}^3/\text{s}). \]

4. Determine the main-channel length \((L)\) and slope \((S)\) from topographic maps as follows: (a) Measure the river length, in miles, from the desired location to the basin divide. If the stream forks, follow the fork with the greater drainage area. This is channel length \((L)\). (b) Determine altitudes at points that are 10 and 85 percent of the total river length. (c) Determine the difference between these altitudes and divide by the distance in miles between these points. The Manitowoc River is approximately 70 mi (113 km) long and has a slope of about 5 ft/mi (0.95 m/km).

5. The 10-year runoff \((R_o)\) is calculated by dividing the \(Q_{10}\) by the drainage area from step 1.

\[ Q_{10} = 6,500 \text{ ft}^3/\text{s} (184 \text{ m}^3/\text{s}) \text{ and } \]

\[ A = 530 \text{ mi}^2 (1,373 \text{ km}^2). \]

For the Manitowoc River it is approximately 12 \((\text{ft}^3/\text{s})/\text{mi}^2 \{0.13 \text{ (m}^3/\text{s})/\text{km}^2\}.\)

6. The soil index figure \((S_i)\) of 2.90 in (7.4 cm) for the Manitowoc River was determined by the U.S. Department of Agriculture, Soil Conservation Service, upon request.

7. Frost depth \((F_d)\) for the Manitowoc River is determined from figure 6 and is about 24 in (610 mm). (See glossary.)

8. The duration term \((D)\) was determined through a correlation procedure with nearby U.S. Geological Survey continuous-record stations. The Manitowoc River is between the Kewaunee and Sheboygan Rivers, both of which have continuous-record gaging stations. By comparing the hydrologic and geographic characteristics of all three basins, an estimate of 23 was made for the duration term for the Manitowoc River.
9. The final step in the example is substituting the calculated or estimated factors in equation number 3 and performing the necessary calculations. For the Manitowoc River the final equation is:

\[
Q_s = 4.37 \cdot 10^{-12} \cdot 290^{2.63} \cdot 3,900^{-5.83} \cdot 8,100^{5.92} \cdot 5^{-1.94} \\
\cdot 70^{-2.52} \cdot 12^{1.31} \cdot 2.9^{-6.35} \cdot 24^{8.26} \cdot 23^{0.59}
\]

\[
Q_s = 9.88 \cdot 10^1 = 99.
\]

Solving the equation gives an estimated average annual suspended-sediment yield for the Manitowoc River of 99 tons/mi² (35 tonnes/km²). This calculated yield appears to be somewhat high when compared to the regionalized sediment-yield map (fig. 2), but the map shows that Manitowoc River sediment yield could range from 30 to 100 tons/mi² (11 to 35 tonnes/km²). Considering that equation number 3 has 38 percent standard error of estimate, the calculated yield and the yield map are in good agreement.

These equations are only a first step in developing models for prediction of sediment yields. As additional data become available and new statistical techniques are developed, more accurate and quicker procedures for prediction of sediment yields and even erosion and deposition rates should become available.

GLOSSARY

Dependent variable

1. Sediment yield \(Q_s\), expressed in tons per square mile per year, is the average amount of dry weight of suspended sediment that passes a stream section during 1 year divided by the area of the drainage basin.

Independent variables

1. Drainage area \(A\), in square miles, of a stream at a specified location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point. Drainage areas have been determined for many basins in Wisconsin (Holmstrom, 1972).

2. Average discharge \(Q_a\), in cubic feet per second, is the arithmetic average of daily mean discharges for a period of years. It can be estimated from the drainage area and average runoff of the basin (fig. 4).

3. Two-year flood \(Q_2\), in cubic feet per second, is the discharge of a flood that has a recurrence interval of once in 2 years. Regression techniques are available to determine \(Q_2\) for any stream in the State (Conger, 1971).
Figure 4. Average Annual Runoff in Wisconsin.

EXPLANATION

Line of equal average annual runoff, through 1970, interval 1 inch.
4. Twenty-five year flood ($Q_{25}$), in cubic feet per second, is the
discharge of a flood that has a recurrence interval of once in 25 years.
Regression techniques are available to determine $Q_{25}$ for any stream in
the State (Conger, 1971).

5. Main-channel slope ($S$), in feet per mile, is the slope of the
stream between points that are 10 and 85 percent of the distance along
the channel from the site where yields are to be determined to the basin
divide. It can be determined from U.S. Geological Survey quadrangle maps.

6. Lake and marsh area ($St$), expressed as percent of the drainage
area, includes lakes, ponds, and wetlands determined from U.S. Geological
Survey quadrangle maps and U.S. Department of Agriculture, Soil Conservation
Service, data. To avoid zero values, a constant of 1 percent is added
each value to obtain the value of $St$ to be used in the regression
equation.

7. Main-channel length ($L$), in miles, is measured from the site
where yield is to be determined to the basin divide. It can be determined
from U.S. Geological Survey quadrangle maps.

8. Forest cover ($F$), expressed as a percentage of the basin drainage
area as shown on U.S. Geological Survey quadrangle maps and data from
the U.S. Department of Agriculture, Soil Conservation Service. To avoid
zero, a constant of 1 percent is added to each value to obtain the value
of $F$ used in the regression equation.

9. Soil index ($Si$), in inches, is an index of soil infiltration
capacity. It is available from and calculated by the U.S. Department of
Agriculture, Soil Conservation Service, from information on soil type,
vegetal cover, and agricultural practices (R. W. Akley, written comm. ,
1974).

10. Precipitation-intensity index ($I$) (2-year, 24-hour rainfall),
expressed in inches, is determined from figure 5 (Hershfield, 1961).
This maximum 24-hour rainfall has a recurrence interval of once in 2 years.

11. Flood runoff ($Ro$), in cubic feet per second per square mile,
is the flood discharge that has a recurrence interval of once in 10 years,
$Q_{10}$, divided by the drainage area of the basin. Drainage area data
are from variable 1 above and the flood data can be determined as in
variables 2, 3, and 4 above.

12. Vegetative factor ($V$), in inches per degree F, is the mean
annual precipitation divided by mean annual temperature and may be
determined from maps available from the Wisconsin Statistical Reporting
Service (1967).

13. Mean frost depth on February 28 ($Fd$), 1961–68 average in inches,
is determined from figure 6 (Wisconsin Statistical Reporting Service,
FIGURE 5. PRECIPITATION INTENSITY INDEX IN WISCONSIN.

EXPLANATION

—— 3.0 ——
Line of equal precipitation intensity index (2-year, 24 hour rainfall). Interval 0.1 inches

Data from Hershfield, 1961
FIGURE 6. MEAN FROST DEPTH ON FEBRUARY 28 IN WISCONSIN

EXPLANATION

-18-

Data from Wisconsin Statistical Reporting Service, 1970.
14. Duration factor (D) is the stream discharge that can be expected to occur at least 10 percent of the time divided by the discharge that can be expected to occur 90 percent of the time. Duration data are available from stream-gaging records.

SELECTED REFERENCES


