WATER RESOURCES INVESTIGATIONS
54-75

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

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle MEASUREMENT AND PREDICTION OF SEDIMENT YIELDS IN WISCONSIN			5. Report Date January 1976 6.
7. Author(s) S. M. Hindall			8. Performing Organization Rept. No. USGS/WRI-54-75
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division 1815 University Avenue Madison, Wisconsin 53706			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 1815 University Avenue Madison, Wisconsin 53706			13. Type of Report & Period Covered Interim 14.

15. Supplementary Notes Prepared in cooperation with the city of Madison, the city of Middleton, Douglas County, the University of Wisconsin-Extension, Geological and Natural History Survey, the Army Corps of Engineers, and the Wisconsin Department of Natural Resources.

16. Abstracts

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.

17. Key Words and Document Analysis. 17a. Descriptors

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

17b. Identifiers/Open-Ended Terms

Regionalize, Geographic provinces, Geography

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	33
	20. Security Class (This Page) UNCLASSIFIED	22. Price

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Water-Resources Investigations 54-75

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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.

Multiply English unit	By	To obtain metric unit
in (inches)	25.40	mm (millimetres)
ft (feet)	.3048	m (metres)
mi (miles)	1.609	km (kilometres)
mi^2 (square miles)	2.590	km^2 (square kilometres)
ft/mi (feet per mile)	.1894	m/km (metres per kilometre)
gal/min (gallons per minute)	6.309×10^{-2}	l/s (litres per second)
$tons/mi^2$ (tons per square mile)	.3503	$tonnes/km^2$ (tonnes per square kilometre)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic metres per second)
$(ft^3/s)/mi^2$ (cubic feet per second per square mile)	1.093×10^{-2}	$(m^3/s)/km^2$ (cubic metres per second per square kilometre)

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 south-eastern 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 ungaged 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.

FIGURE 1. SEDIMENT DATA NETWORK IN WISCONSIN.

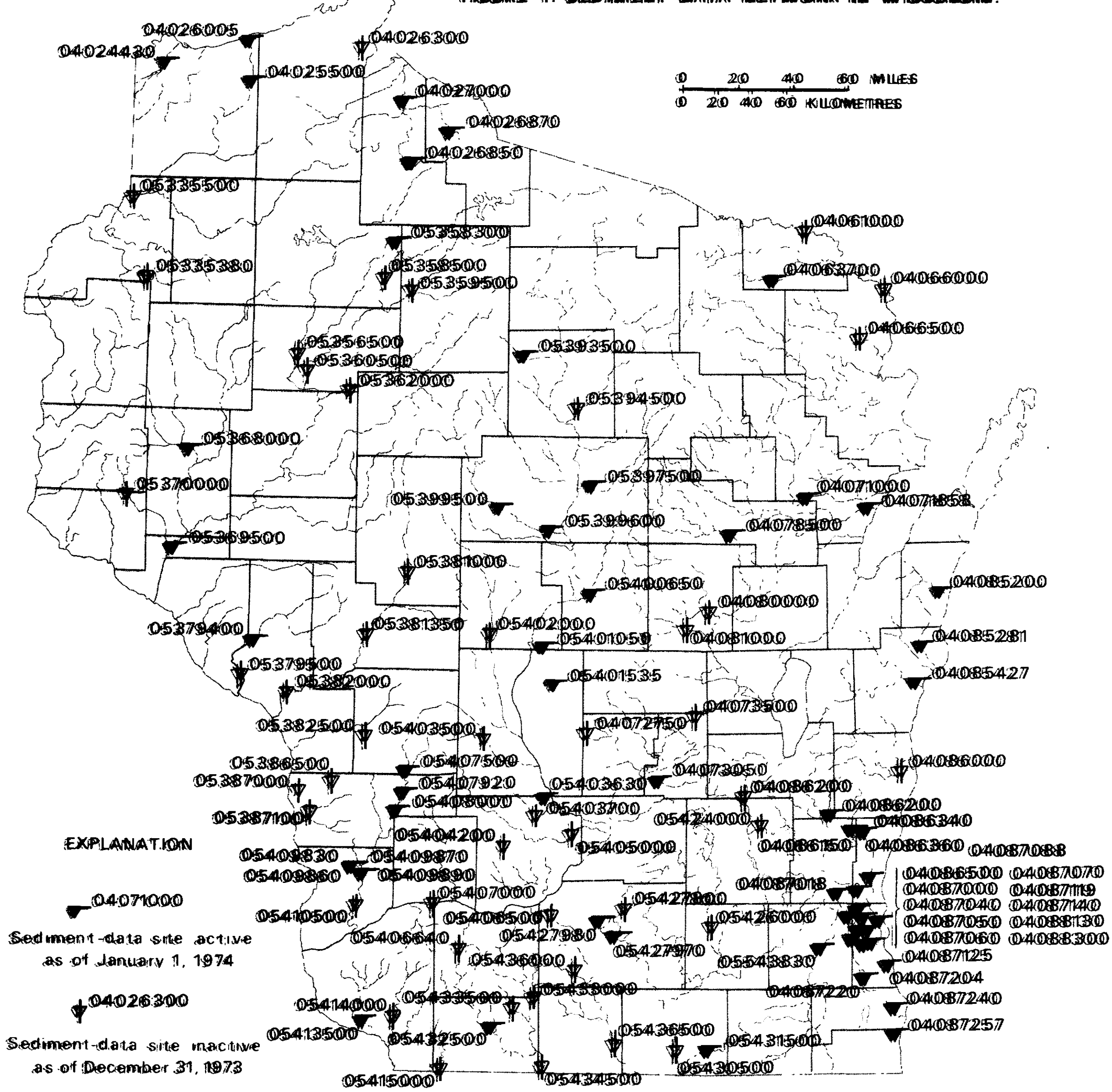


TABLE 1.—*Sediment yield, concentration, and particle-size data for Wisconsin streams.*

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

Station number	Period of sediment record	Type of sediment data	Average annual sediment yield (tons/sq mi)			Estimated bed material yield	Maximum observed concentration (mg/l)	Minimum observed concentration (mg/l)	Computed average concentration for period of record (mg/l)	Particle size (percent finer than 0.062 mm)	
			Suspended		Estimated total					Suspended material	Bed material
			Short term	Long term							
04025500	1964-74	SC,SM,BM	10	9.6	11	P	198	1	7	73	0
04026005	1970-74	SC,SM,BM	157	140	148	M	618	8	127	56	1
04026300	1968-70	SC,SM,BM	190	220	310	P	698	2	191	44	0
04026870	1973-74	SC,BM	10	10	11	M	15	2	5		3
04027000	1964-67 1971-74	SC,SM,BM	300	164	190	P	1,920	2	304	65	2
04061000	1964-67	SC	11	10	11	P	30	4	12		
04063700	1963-74	SC,SM,CC	3.9	3.3	3.5	M	27	1	4	59	
04066000	1964-67	SC	22	17	19	P		3	24		
04066500	1964-67	SC	6.9	6.9	7.7	P	96	2	8		
04071000	1971-74	SC	6.6	3.1	3.4	P	22	0	8		
04071858	1972-74	SC,BM	56	17	18	P	93	2	51		1
04073050	1968-74	SC,SM,BM	26	15	17	P	454	2	35	99	2
04073500	1964-70	SC,BM	27	34	38	P	63	15	36		5
04078500	1971-74	SC,SM,BM	13	8.1	9.0	P	2,420	2	18	67	0
04080000	1964-70	SC,BM	19	30	33	P	266	1	25		0
04081000	1964-66	SC	31	31	33	P		4	36		
04085200	1968-74	SC	15	16	18	P	611	2	28		
04085281	1973-74	SC	38	17	19	P	110	4	39		

04086000	1964-68	SC	76	62	69	P	1,420	7	149		
04086150	1968-70 1973-74	SC,BM	10	11	12	M	100	0	24		5
04086200	1968-74	SC,BM	3.5	4.8	5.1	M	50	2	7		1
04086340	1968-70 1973-74	SC,BM	11	10	11	M	249	3	24		1
04086360	1968-70	SC	28	18	23	S	149	7	40		
04086500	1968-70 1973-74	SC,BM	30	45	50	P	152	2	60		1
04087000	1964-70 1972-74	SC,SM,CC	12	8.5	9.0	M	156	4	15	82	
04087120	1973-74	SC	59	53	56	M	979	48	99		
04087204	1972-74	SC	114	38	40	M	678	12	155		
04087220	1971-74	SC,SM	51	19	21	P	689	10	66	99	
04087240	1964-74	SC,SM,CC	64	47	52	P	662	13	65	98	
04087257	1972-74	SC,SM	283	81	82	M	2,820	4	264	97	
05333500	1964-67	SC	9.0	8.6	9.6	P	14	7	11		
05335380	1968-70	SC,BM	3.0	2.7	3.0	P	27	2	11		1
05356500	1964-67	SC	9.0	7.3	8.1	P	24	3	10		
05358500	1964-67	SC	10	8.0	8.9	P	48	6	10		
05359500	1968-73	SC,BM	6.0	3.8	4.0	M	200	0	6		0
05360500	1964-67	SC	5.0	4.4	4.9	P	17	1	5		
05362000	1964-67	SC	11	8.9	9.9	P	57	2	13		
05368000	1964-74	SC,SM,BM,CC	30	29	36	S	503	2	29	22	0
05369500	1964-67 1974	SC	15	11	14	S	144	8	19		
05370000	1964-67	SC	31	18	21	S	1,220	6	79		
05379400	1968-74	SC,SM,BM	172	200	222	S	6,785	44	276	25	1
05379500	1964-68	SC	480	450	530	S	3,630	19	799		
05381000	1964-67	SC	70	50	56	P	270	1	93		

TABLE 1.–*Sediment yield, concentration, and particle-size data for Wisconsin streams*–CONTINUED.

Station number	Period of sediment record	Type of sediment data	Average annual sediment yield (tons/sq mi)			Estimated bed material yield	Maximum observed concentration (mg/l)	Minimum observed concentration (mg/l)	Computed average concentration for period of record(mg/l)	Particle size(percent finer than 0.062 mm)	
			Suspended		Estimated total					Suspended material	Bed material
			Short term	Long term							
05381350	1969-74	SC	79	130	144	P		3	145		
05382000	1964-67	SC	48	35	44	S		12	63		
05382500	1935-38	SC	460	270	300	P	11,111	7	780		
05386500	1935-38 1940	SC	850	380	420	P	27,366	2	1,624		
05387000	1935-38	SC	540	400	440	P	23,052	10	956		
05387100	1968-70	SC,BM	250	680	800	S	883	8	410		21
05393500	1964-74	SC,SM,BM	12	8.1	8.5	M	154	0	12	34	0
05394500	1964-70	SC	8.5	8.5	9.4	P	46	1	9		
05397500	1964-74	SC,SM,BM	10	7.8	8.2	M	86	0	10	37	0
05399500	1964-74	SC,SM,BM,CC	39	31	33	M	1,970	0	39	95	0
05403500	1971-73	SC,BM	36	20	22	P	48	1	29		1
05400650	1968-74	SC,SM,BM,CC	3.5	2.1	2.2	M	27	0	5	2	1
05401050	1968-74	SC,SM,BM,CC	56	34	36	M	388	3	65	2	0
05401535	1971-74	SC,SM,CC	7.5	2.4	2.5	M	22	2	7	49	
05402000	1964-68	SC	17	15	17	P	56	4	28		
05403630	1972-74	SC	12	9.4	10	P	34	9	23		
05403700	1957-65	SC,SM	18	16	18	P	438	2	30	98	
05404200	1968-70	SC,BM	240	510	570	P	958	16	357		4
05405000	1964-67	SC	54	62	73	S	523	20	91		
05406500	1954-65	SC,SM	71	34	38	P	4,440	3	117	99	
05407000	1964-67	SC	34	33	55	S	299	11	42		
05408000	1972-74	SC,SM,BM,CC	300	280	330	S	2710	2	447	88	5
05409890	1966-74	SC,SM,BM	204	204	214	M	5,166	1	465	87	4

05410000	1970-74	SC,SM	280	270	300	P	970	10	425	91	
05410500	1964-71	SC	340	410	430	P	3,520	3	529		
05413500	1964-67	SC,SM,BM,CC	656	636	707	P	10,300	38	1,125	100	28
05414000	1964-67	SC,SM	143	164	182	P	4,780	14	215	95	
05415000	1942-67	SC	600	180	200	P	5,490	19	1,066		
05423000	1968-70	SC	150	410	460	P	236	42	318		
05424000	1964-68	SC	17	18	20	P	254	2	37		
05426000	1964-68	SC	35	40	44	P	290	10	79		
05427800	1968-70	SC	130	340	35	M	656	47	96		
05430500	1964-67	SC	23	26	31	S	166	14	52		
05431500	1940-42 1973-74	SC,SM	132	12	13	P	2,430	48	258	85	
05432500	1964-67 1971-74	SC,SM,BM,CC	157	178	198	P	3,250	9	160	98	40
05433000	1964-67	SC	190	140	160	P	1,200	10	316		
05433500	1954-59	SC,SM	280	76	80	P	9,040	7	509	98	
05434500	1940-42	SC,SM	260	320	360	P	7,170	39	407		
05436000	1954-60 1964	SC,SM,BM	96	39	46	S	6,080	82	95	96	
05436500	1964-67	SC	45	44	55	S	2,580	17	73		
05543830	1968-74	SC,BM	7.1	2.7	3.0	P	198	2	13		25

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.

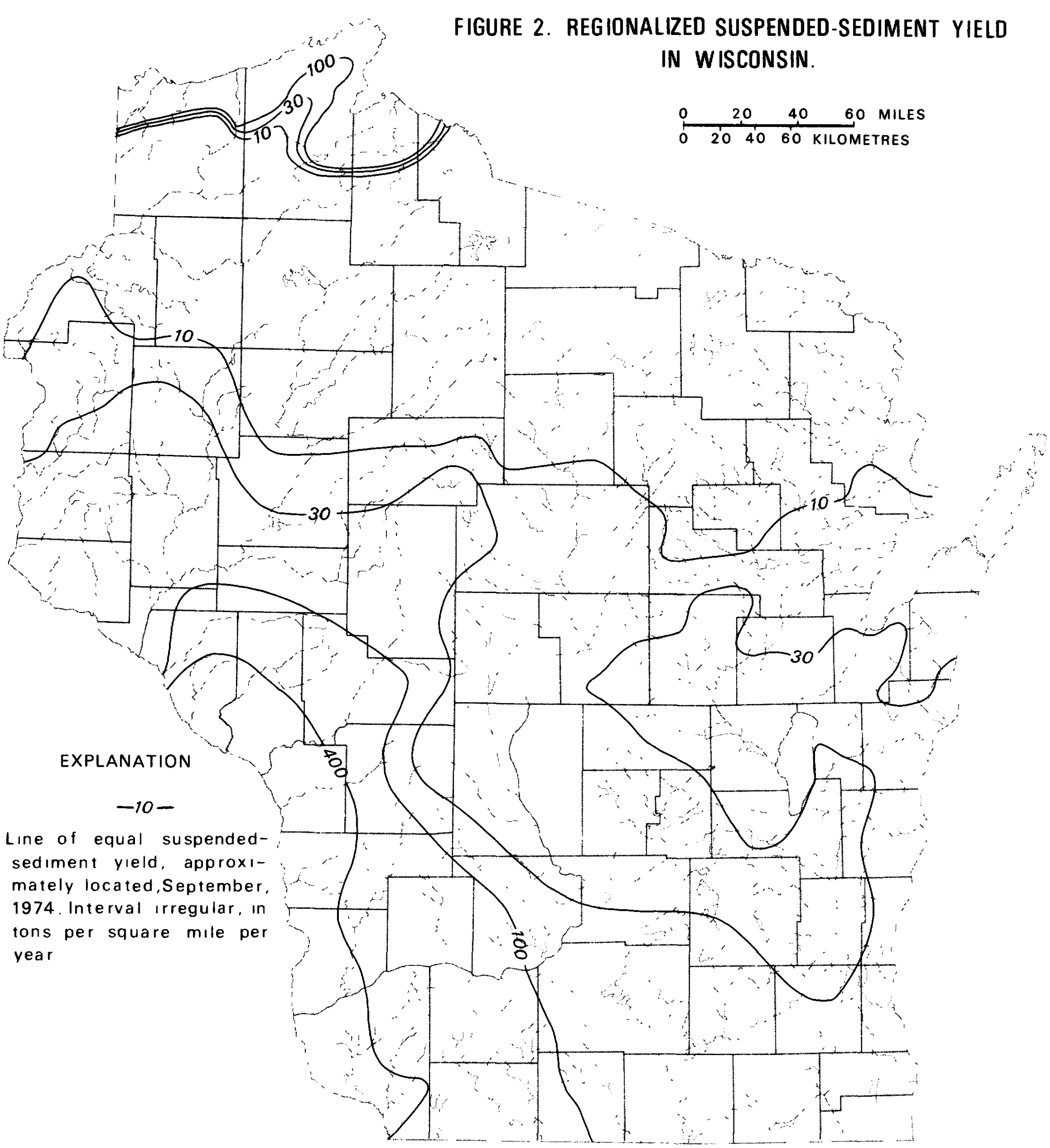
As of October 1, 1974, there were 60 sites in the State where sediment data were being collected at intervals ranging from daily to intermittent (table 2). Ten stations were sampled daily and nine were sampled weekly. The remaining 41 were sampled at frequencies varying from individual storms to approximately 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 contaminates.

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.



EXPLANATION

—10—

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

Site number	Site name	Site status
04024430	Nemadji River near Superior	Active
04025500	Bois Brule River at Brule	Active
04026005	Bois Brule River near Lake Superior	Active
04026300	Soix River near Washburn	Discontinued
04026450	Bad River near Mellen	Active
04026870	Alder Creek near Upson	Active
04027000	Bad River near Odanah	Active
04061000	Brule River near Florence	Discontinued
04063700	Popple River near Fence	Active
04066000	Menominee River near Pembine	Discontinued
04066500	Pike River at Amberg	Discontinued
04071000	Oconto River near Gillett	Active
04071858	Pensaukee River near Pensaukee	Active
04073050	Grand River near Kingston	Active
04073500	Fox River at Berlin	Discontinued
04078500	Embarrass River near Embarrass	Active
04080000	Little Wolf River at Royalton	Discontinued
04081000	Waupaca River at Waupaca	Discontinued
04085200	Kewaunee River at Kewaunee	Active
04085281	East Branch Twin River at Mishicot	Active
04086000	Sheboygan River at Sheboygan	Discontinued
04086150	Milwaukee River at Kewaskum	Active
04086200	East Branch Milwaukee River near New Fane	Active
04086340	North Branch Milwaukee River near Fillmore	Active
04086360	Milwaukee River at Waubeka	Discontinued
04086500	Cedar Creek near Cedarburg	Active
04087000	Milwaukee River at Milwaukee	Active
04087018	Menomonee River at Germantown	Active
04087030	Menomonee River at Menomonee Falls	Active
04087040	Menomonee River at Butler	Active
04087050	Little Menomonee River near Friestadt	Active
04087060	Noyes Creek at Milwaukee	Active
04087070	Little Menomonee River at Milwaukee	Active
04087088	Underwood Creek at Wauwatosa	Active
04087119	Honey Creek at Wauwatosa	Active
04087120	Menomonee River at Wauwatosa	Active
04087125	Schoonmaker Creek at Wauwatosa	Active
04087130	Hawley Road Storm Sewer at Wauwatosa	Active
04087140	Menomonee River at Milwaukee	Active
04087204	Oak Creek near South Milwaukee	Active
04087220	Root River near Franklin	Active
04087240	Root River at Racine	Active
04087257	Pike River near Racine	Active
05333500	St. Croix River near Danbury	Discontinued
05335380	Bashaw Brook near Shell Lake	Discontinued

Table 2.--Sediment-data site network for Wisconsin--Continued

Site number	Site name	Site status
05356500	Chippewa River near Bruce	Discontinued
05358300	Pine Creek near Oxbo	Active
05358500	Flambeau River at Babbs Island near Winter	Discontinued
05359500	South Fork Flambeau River near Phillips	Discontinued
05360500	Flambeau River near Bruce	Discontinued
05362000	Jump River at Sheldon	Discontinued
05368000	Hay River at Wheeler	Active
05369500	Chippewa River at Durand	Active
05370000	Eau Galle River at Spring Valley	Discontinued
05379400	Trempealeau River at Arcadia	Active
05379500	Trempealeau River at Dodge	Discontinued
05381000	Black River at Neillsville	Discontinued
05381350	Levis Creek near Black River Falls	Discontinued
05382000	Black River near Galesville	Discontinued
05382500	Little La Crosse River near Leon	Discontinued
05386500	Coon Creek at Coon Valley	Discontinued
05387000	Coon Creek at Stoddard	Discontinued
05387100	North Fork Bad Axe River near Genoa	Discontinued
05393500	Spirit River at Spirit Falls	Active
05394500	Prairie River near Merrill	Discontinued
05397500	Eau Claire River at Kelley	Active
05399500	Big Eau Pleine River near Stratford	Active
05399600	Big Eau Pleine River near Mosinee	Active
05400650	Little Plover River at Plover	Active
05401050	Tenmile Creek near Nekoosa	Active
05401535	Big Roche a Cri Creek near Adams	Active
05402000	Yellow River at Babcock	Discontinued
05403500	Lemonweir River at New Lisbon	Discontinued
05403630	Hulburt Creek near Wisconsin Dells	Active
05403700	Dell Creek near Lake Delton	Discontinued
05404200	Lawrence Creek near Westfield	Discontinued
05405000	Baraboo River near Baraboo	Discontinued
05406500	Black Earth Creek at Black Earth	Discontinued
05407000	Wisconsin River at Muscoda	Discontinued
05407500	Kickapoo River at Ontario	Active
05407920	Kickapoo River near Rockton	Active
05408000	Kickapoo River at La Farge	Active
05409830	North Fork Nederlo Creek near Gays Mills	Active
05409860	South Fork Nederlo Creek near Gays Mills	Active
05409870	Nederlo Creek near Gays Mills	Active
05409890	Nederlo Creek near Gays Mills	Active
05410000	Kickapoo River at Gays Mills	Active
05410500	Kickapoo River at Steuben	Discontinued
05413500	Grant River at Burton	Active
05414000	Platte River near Rockville	Discontinued

Table 2.--Sediment-data site network for Wisconsin--Continued

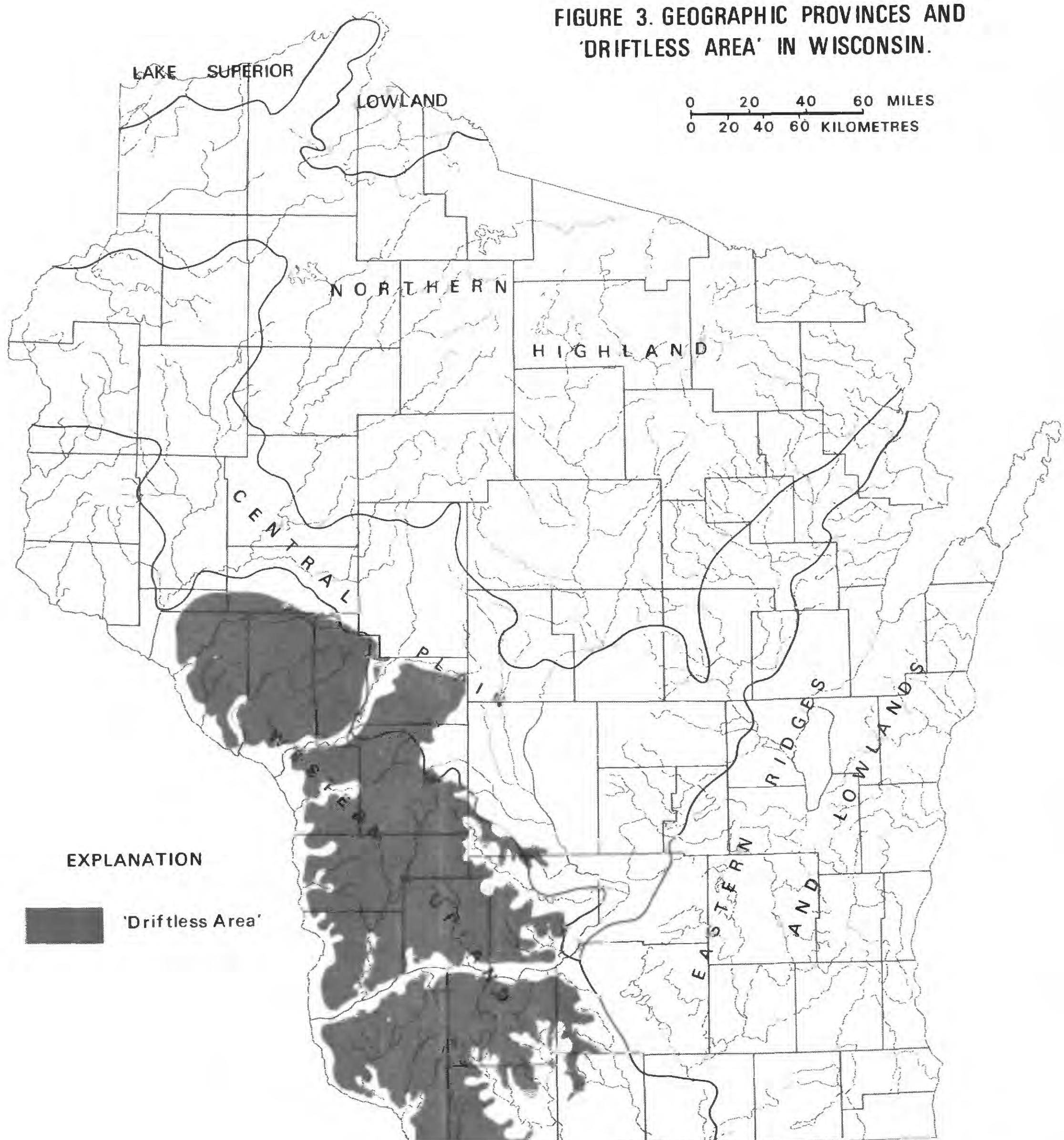
Site number	Site name	Site status
05415000	Galena River at Buncombe	Discontinued
05423000	West Branch Rock River near Waupun	Discontinued
05424000	East Branch Rock River near Mayville	Discontinued
05426000	Crawfish River at Milford	Discontinued
05427800	Token Creek near Madison	Discontinued
05427948	Pheasant Branch at Middleton	Active
05427970	Willow Creek at Madison	Active
05430500	Rock River at Afton	Discontinued
05431500	Turtle Creek near Clinton	Active
05432500	Pecatonica River at Darlington	Active
05433000	East Branch Pecatonica River near Blanchardville	Discontinued
05433500	Yellowstone River near Blanchardville	Discontinued
05434500	Pecatonica River at Martintown	Discontinued
05436000	Mount Vernon Creek near Mount Vernon	Discontinued
05436500	Sugar River near Brodhead	Discontinued
05543830	Fox River at Waukesha	Active

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/mi^2 (1.1 to 11 tonnes/km^2) in this area with the median yield being 8.3 tons/mi^2 (2.9 tonnes/km^2).

Measured average annual suspended-sediment yields in the Eastern Ridges and Lowlands province (fig. 3) range from 2.7 to 410 tons/mi^2 (0.9 to 144 tonnes/km^2). The median yield in this area is 18 tons/mi^2 (6.3 tonnes/km^2). 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 subdivision 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/mi^2 (0.7 to 17 tonnes/km^2) with a median yield in this area of 17 tons/mi^2 (5.9 tonnes/km^2).

FIGURE 3. GEOGRAPHIC PROVINCES AND 'DRIFTLESS AREA' IN WISCONSIN.



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

$$Q_s = a \cdot A^{b_1} \cdot Q_a^{b_2} \cdot Q_{25}^{b_3} \cdot S^{b_4} \; . \; . \; . \; . \; .$$

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

Number	Equation	Geographic province	Standard error of estimate (percent)	Level of statistical significance (percent)
1	$Q_s = 51.1 \cdot St^{-0.72}$	Northern Highland	35	99
2	$Q_s = 2.82 \cdot 10^{10} \cdot Q_a{}^{1.43} \cdot Q_{25}{}^{0.43} \cdot L^{-3.29} \cdot Si^{-3.26} \cdot I^{-1.52}$	Central Plain and glaciated Western Upland	29	95
3	$Q_s = 4.37 \cdot 10^{-12} \cdot Q_a{}^{2.63} \cdot Q_2{}^{-5.83} \cdot Q_{25}{}^{5.92} \cdot S^{-1.94} \cdot L^{-2.52} \cdot Ro^{1.31} \cdot Si^{-6.35} \cdot Fd^{8.26} \cdot D^{0.59}$	Eastern Ridges and Lowlands	38	99
4	$Q_s = 197.7 \cdot A^{2.38} \cdot Q_a{}^{-3.14} \cdot S^{2.01} \cdot St^{0.19} \cdot L^{4.14} \cdot Fd^{-4.48} \cdot D^{-1.43}$	"Driftless Area" (Unglaciated Western Upland)	28	99

Table 4.--Observed versus computed average annual long-term suspended-sediment yields

Station number	Average annual suspended-sediment yields (tons/mi^2)	
	Observed	Computed
	Northern Highland Province	
04025500	9.6	7.2
04026870	10.0	10.0
04061000	10.0	9.9
04063700	3.3	4.8
04066500	6.9	6.6
04071000	3.1	6.7
05359500	3.8	4.1
05362000	8.9	6.5
05393500	8.1	6.6
05394500	8.5	5.3
05397500	7.8	8.9
05399500	31	32
	Central Plain Province	
04078500	8.1	9.3
04080000	30	36
04081000	31	21
05368000	29	30
05370000	18	17
05381000	50	47
05401050	34	34
05402000	15	17
05403500	20	22
05403630	9.4	12
05403700	16	12
	Eastern Ridges and Lowlands Province	
04071858	17	18
04073050	15	19
04085200	16	23
04085281	17	17
04086000	62	47
04086150	11	9.5
04086340	10	9.7
04086360	18	12
04086500	45	44

Table 4.--Observed versus computed average annual long-term suspended-sediment yields--Continued

Station number	Average annual suspended-sediment yields (tons/mi^2)	
	Observed	Computed
Eastern Ridges and Lowlands Province--Continued		
04087000	8.5	14
04087120	53	29
04087204	38	40
04087220	19	17
04087240	47	76
04087257	81	76
05424000	18	18
05426000	40	41
05431500	12	17
05436500	44	34
05543830	2.7	2.7
"Driftless Area"		
05379500	450	423
05381350	130	105
05382500	270	367
05386500	380	373
05387000	400	540
05387100	680	540
05405000	62	69
05406500	34	29
05408000	280	230
05409890	204	185
05410500	410	503
05413500	636	419
05415000	180	187
05432500	178	188
05433000	140	150
05433500	76	100
05436000	39	43

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:

$$Q_s = 4.37 \cdot 10^{-12} \cdot Q_a^{2.63} \cdot Q_2^{-5.83} \cdot Q_{25}^{5.92} \cdot S^{-1.94} \cdot L^{-2.52}$$

$$\cdot Ro^{1.31} \cdot Si^{-6.35} \cdot Fd^{8.26} \cdot D^{0.59}$$

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 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.

$$Q_a = 7.5 \cdot 530 \cdot 0.074 = 290 \text{ ft}^3/\text{s } (8.21 \text{ m}^3/\text{s})$$

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 (Ro) 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 (Si) 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 (Fd) 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/mi^2 (35 tonnes/km^2). 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/mi^2 (11 to 35 tonnes/km^2). 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.

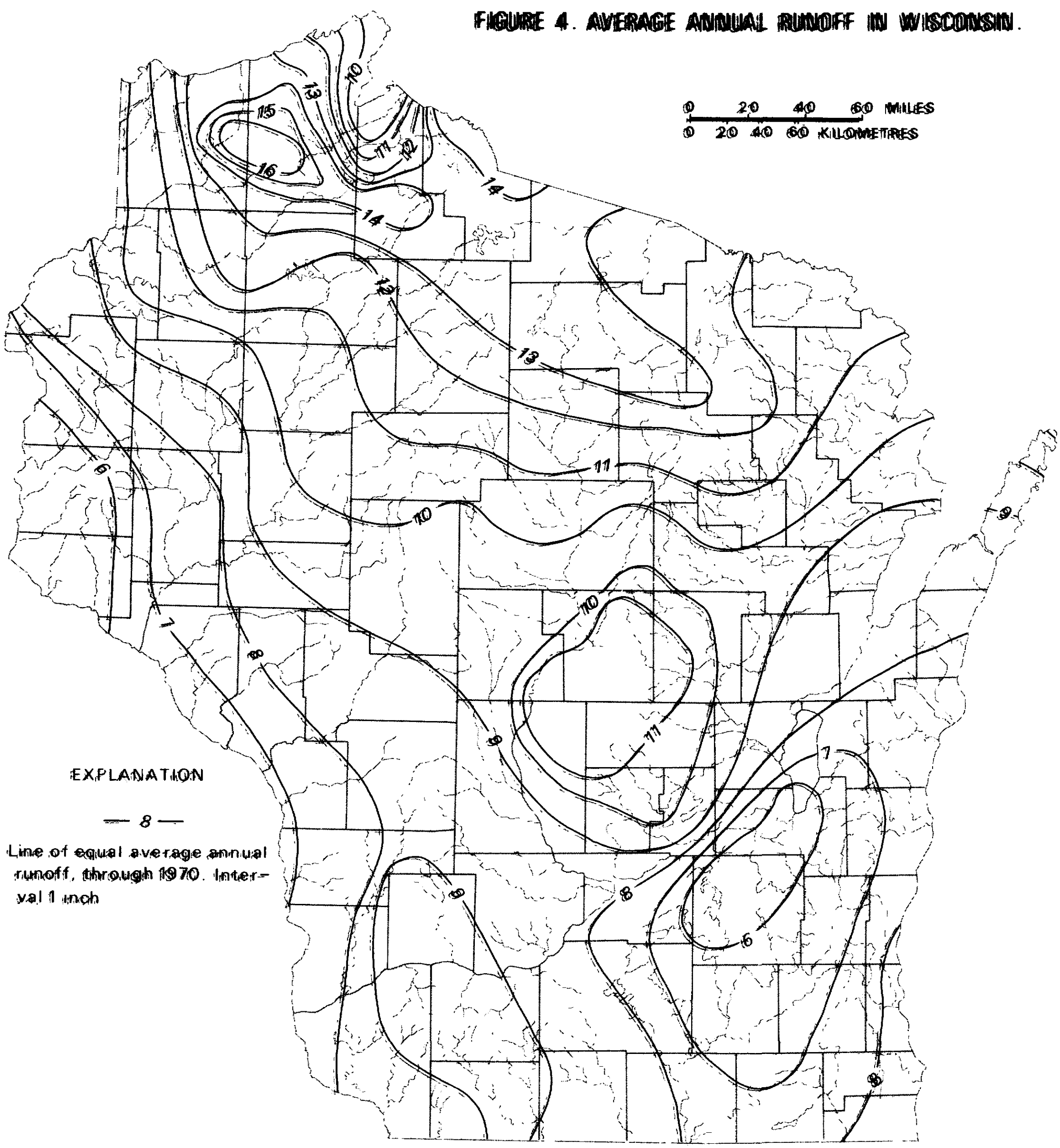
Independent variables

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.



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 to 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. Akeley, written commun., 1974).

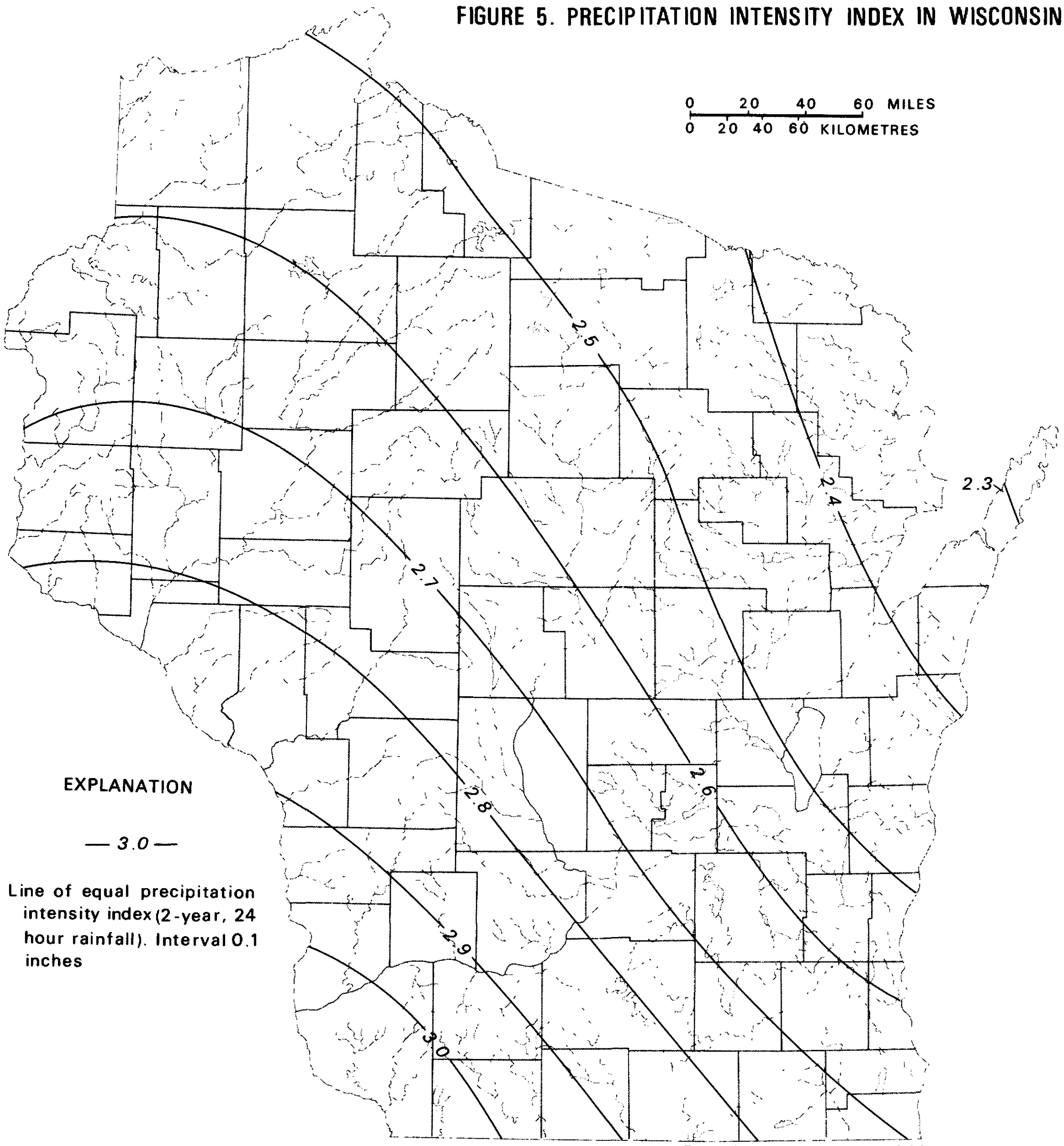
10. Precipitation-intensity index (I) (2-year, 24-hour rainfall), expressed in inches, is determined from figure 5 (Hershfield, 1961). This maximum 24-hour rainfall has a recurrence interval of once in 2 years.

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).

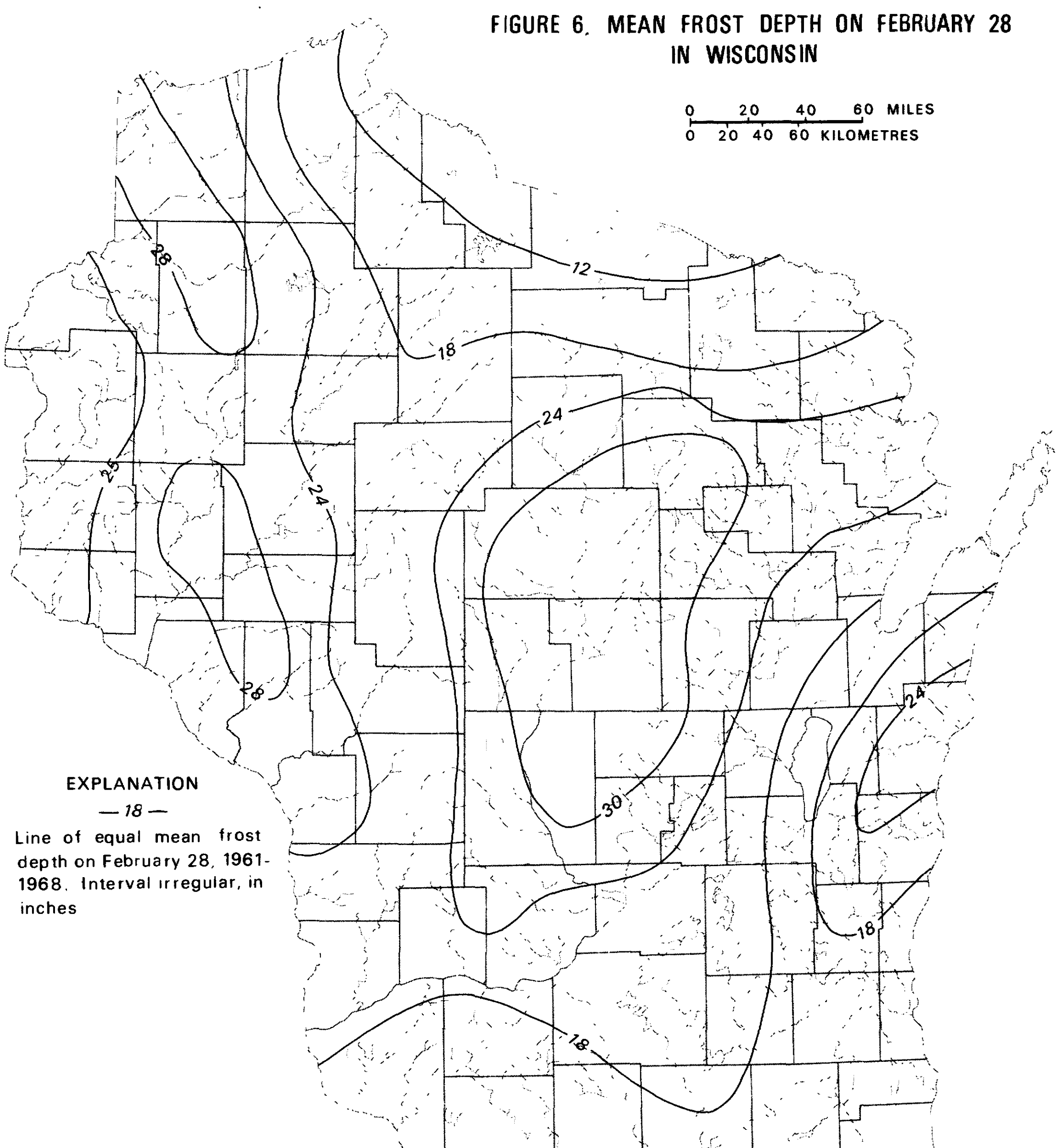
13. Mean frost depth on February 28 (Fd), 1961-68 average in inches, is determined from figure 6 (Wisconsin Statistical Reporting Service, 1970, p. 13).

FIGURE 5. PRECIPITATION INTENSITY INDEX IN WISCONSIN.



Data from Hershfield, 1961

FIGURE 6. MEAN FROST DEPTH ON FEBRUARY 28 IN WISCONSIN



EXPLANATION

— 18 —

Line of equal mean frost depth on February 28, 1961-1968. Interval irregular, in inches

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.

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*U.S. GOVERNMENT PRINTING: 1976 653-339

MEASUREMENT AND PREDICTION OF SEDIMENT YIELDS IN WISCONSIN STREAMS WRI 54-75