PATTERNS OF DISCHARGE AND SUSPENDED SEDIMENT TRANSPORT IN THE WALNUT AND SQUAW CREEK WATERSHEDS, JASPER COUNTY, IOWA: WATER YEARS 1996-1998

Geological Survey Bureau
Technical Information Series 42

Iowa Department of Natural Resources
Lyle W. Asell, Interim Director
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Supported, in part, through grants from the U.S. Environmental Protection Agency,
Region VII, Nonpoint Source Program

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Iowa Department of Natural Resources, Geological Survey Bureau
Technical Information Series 42, 2000, 47 p.

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ABSTRACT

Sediment is the major pollutant affecting Iowa's streams. Despite the magnitude of sediment impacts on streams, little research has been conducted to determine the nature of sediment transport in small Iowa watersheds. In the Walnut Creek and Squaw Creek watersheds in Jasper County, Iowa, research as part of the Walnut Creek Nonpoint Source Monitoring Project is focused on monitoring daily discharge and suspended sediment in paired, agricultural watersheds. The Walnut Creek project was established in 1995 as a nonpoint source monitoring program in relation to watershed habitat restoration and agricultural management changes implemented by the U.S. Fish and Wildlife Service (USFWS) at the Neal Smith National Wildlife Refuge. The monitoring program utilizes a paired-watershed approach, with Walnut Creek as the treatment watershed and neighboring Squaw Creek as the control. Standard U.S. Geological Survey gauging facilities are located at upstream and downstream locations on Walnut Creek and downstream on Squaw Creek. The purpose of this report is to present the results of three years of daily discharge and suspended sediment monitoring in Walnut and Squaw Creek watersheds and to examine the timing, frequency and magnitude of discharge and suspended sediment transport.

Daily discharge and suspended sediment transport in both watersheds was very flashy, responding rapidly to precipitation and snowmelt events. This pattern is typical of incised channels where flood events are contained within the channel and rapidly transport suspended sediment downstream. Five days in any given year accounted for 60 to 80% of the annual sediment load in both watersheds. Discharge and suspended sediment loads are highest in May and June, which accounted for 40 to 50% of the annual discharge and approximately 60% of the annual suspended sediment. The February to July period accounted for 98% of the annual sediment total. Maximum peak flows and sediment loads and a higher proportion of annual sediment loads migrating during one- and five-day periods were observed in Squaw Creek than Walnut Creek. Watershed morphology and land use differences, including prairie restoration in Walnut Creek, may contribute to these differences.

A major source of sediment is streambank erosion of Holocene alluvium and post-settlement materials (up to 50% of the annual total). Streambed downcutting contributes little to sediment loads due to base level control provided by resistant Pre-Illinoian till. Other sources of sediment include contributions from upland sheet and rill erosion and concentrated flow

erosion in gullies and tributary channels. Eroded sediment stored within the channel may take many years to exit the watershed. A long-term monitoring record is needed to detect changes in the Walnut Creek watershed resulting from the land restoration efforts. The long timeframe is necessary for factoring out influences of climate, variability in morphology and land use between Walnut Creek and Squaw Creek and the effects of historical sediment storage. The Walnut Creek project may be capable of detecting changes more quickly than other projects due to the type and magnitude of land use change being implemented, the presence of fewer tiles in the watershed and the dual gauges located on the channel.

At a minimum, suspended sediment sampling should be conducted daily during the period February through July to characterize the flashy behavior observed in sediment loading during this time. In the August through January period, reduced sampling frequency, or estimating loads from daily discharge or turbidity can be used to adequately estimate monthly sediment loads.

INTRODUCTION

Sediment has been identified as the major pollutant affecting Iowa's streams (Agena et al., 1990). Approximately 45% of the impaired water bodies on Iowa's 1999 303(d) list were listed because of excessive siltation or turbidity (IDNR, 1999). Silt delivered to streams and rivers through nonpoint source runoff and streambank erosion can degrade aquatic habitat through covering of coarse substrates, deposition in pools and through increased turbidity that can interfere with the growth and reproduction of fish and other aquatic life (IDNR, 1997).

Much of the cause of excess siltation can be traced to the introduction of European farming techniques more than a century ago which forced major channel adjustments in watersheds draining the newly cultivated land (Knox, 1977, Trimble and Lund, 1982, Trimble, 1983). Soil erosion in the uplands from intensive row crop agriculture mobilized a tremendous volume of sediment into the stream valleys. Much of this historical sediment remains stored on the floodplain (Happ et al., 1940; Knox, 1977, Trimble, 1983). In an attempt to increase the number of tillable acres on floodplains, practices such as stream channelization, removal of riparian vegetation and agricultural tiling, also had profound affects on hydraulic characteristics and morphology of alluvial systems (Simon 1989; Hupp, 1992).

As the agricultural community has become more aware of the problems of upland soil erosion and modifications in channel hydrology, farming methods and land use practices have been developed that substantially reduce the amount of sediment delivered to streams. These methods include contour planting, terracing, grassed waterways, no till planting and riparian buffer systems. Although the rate of sediment remobilization and transport down the drainage system can be improved by land management practices, the fact remains that the historical sediment accumulation and hydraulic modifications represent conditions of instability that require time to overcome.

Despite the magnitude of sediment impacts on streams in the agricultural Midwest, relatively little research has been conducted to accurately determine the nature of sediment transport (Waters, 1995). In Iowa, most discharge and suspended sediment monitoring is concentrated in large watersheds and reservoirs. Few studies have examined discharge and sediment transport in watersheds less than 30 mi^2 in area. In the Walnut Creek and Squaw Creek watersheds in Jasper County, Iowa, research as part of the Walnut Creek Nonpoint Source Monitoring Project is focused on monitoring daily discharge and suspended sediment in two small, agricultural watersheds. The Walnut Creek project was established in 1995 as a nonpoint source monitoring program in relation to watershed habitat restoration and agricultural management changes implemented by the U.S. Fish and Wildlife Service (USFWS) at the Neal Smith National Wildlife Refuge. Large portions of the Walnut Creek watershed are being restored from row crop to native tallgrass prairie and savanna (Drobney, 1994). The monitoring program utilizes a paired-watershed approach, with Walnut Creek as the treatment watershed and neighboring Squaw Creek as the control. Upstream/downstream comparisons are also being made in the Walnut Creek watershed (Figure 1). Both Walnut and Squaw Creek watersheds have been intensively row-cropped and tile drained, and both stream channels have been channelized; hence, these watersheds are typical of much of rural Iowa. The paired watershed approach in this study offers the ability to: 1) evaluate natural variations in discharge and suspended sediment between two watersheds with similar morphologies and land use histories; and 2) monitor changes in discharge and sediment transport as a result of recent watershed restoration activities occurring in Walnut Creek.

The purpose of this report is to present the results of three years of daily discharge and suspended sediment monitoring in Walnut and Squaw Creek watersheds and examine the timing, frequency and magnitude of discharge and suspended sediment transport. Although three years of record is not capable of characterizing all system variability, patterns in discharge and sediment transport have emerged which may be consistent on a year-by-year basis. Discharge and sediment monitoring

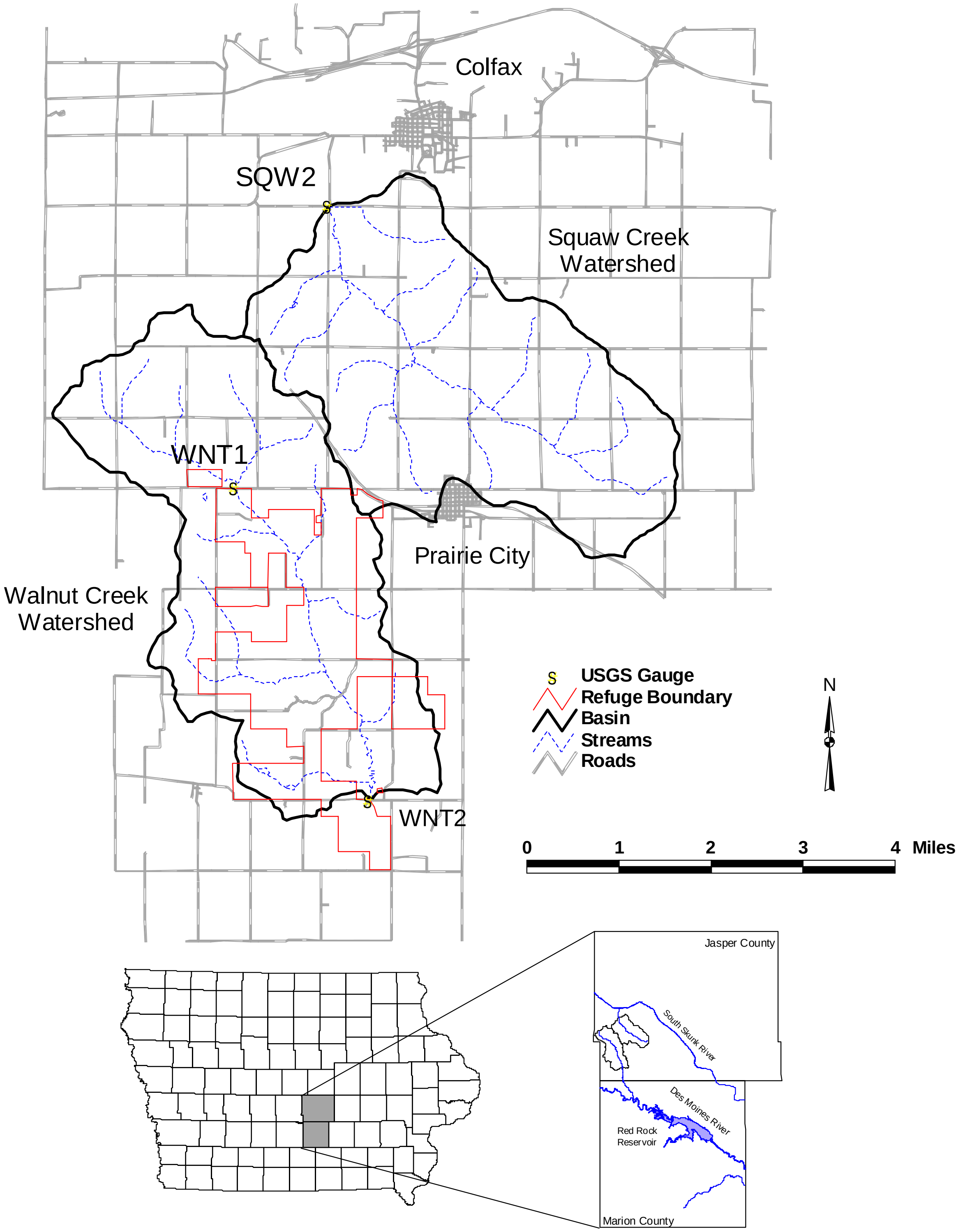

Figure 1. Location map of Walnut Creek and Squaw Creek watersheds.

results are coupled with recent Walnut Creek stream mapping data (Schilling and Wolter, 1999; in press) to examine the effects of stream bank erosion and streambed sediment storage on suspended sediment loads. Discussion focuses on the nature of sediment transport in the Walnut and Squaw Creek watersheds, sources of sediment, seasonal transport patterns, and the potential timeframe for reducing sediment loads in the Walnut Creek watershed. Based on the sediment monitoring record, implications for monitoring suspended sediment loads in small agricultural watersheds like Walnut and Squaw Creek are also examined. Results of this study will contribute to the understanding of the mechanics and pathways of discharge and suspended sediment transport so that realistic sediment reduction goals and monitoring strategies can only be established for these and similar watersheds.

WATERSHED ATTRIBUTES

Walnut and Squaw Creeks are warm-water streams located in southwest Jasper County, Iowa (Figure 1). Walnut Creek drains 30.7 mi.^{2} (19,500 acres) and discharges into the Des Moines River at the upper end of the Red Rock Reservoir. Only the upper part of the watershed (20.1 mi.^{2} or 12,895 acres) is included in the monitoring project because of possible backwater effects from the reservoir. The Squaw Creek basin, adjacent to Walnut Creek, drains 25.2 mi.^{2} (16,130 acres) above its junction with the Skunk River. The watershed included in the monitoring project is 18.3 mi^2 (11,714 acres) and does not include the wide floodplain area near the intersection with the Skunk River. Standard United States Geological Survey (USGS) gauging facilities are located at upstream and downstream sites on Walnut Creek and at a downstream site on Squaw Creek (WNT1, WNT2, and SQW1; Figure 1).

Walnut Creek and Squaw Creek watersheds are well suited for a paired watershed design, as the basin characteristics of both watersheds are very similar (Table 1). Drainage basin characteristics, quantified using a Geographic Information System (GIS) procedure (modified from Majure and Eash, 1991; Eash, 1993), were used to compare the morphology of the two watersheds. Table 1 lists selected basin characteristics, many of which are defined by Strahler (1964). The Walnut Creek basin is larger than Squaw Creek and includes a longer main channel length; however, the Squaw Creek basin includes more relief which results in greater main channel slope (Table 1). Squaw Creek is less sinuous than Walnut Creek.

The watersheds are located in the Southern Iowa Drift Plain, an area characterized by steeply rolling hills and well-developed drainage (Prior, 1991). The soils and geology of the two watersheds are similar (Table 2). Digitized soil maps for Jasper County were evaluated using GIS techniques to quantify percentages of soil parent materials and various soil taxa in the watersheds. Both watersheds are mantled primarily by loess in the upland areas, with outcrops of Pre-Illinoian till occasionally observed in hillslope areas. Recent alluvium dominates the shallow subsurface of the main channels and second order tributaries.

Soils within the Walnut and Squaw Creek watersheds fall primarily within four major soil associations: Tama-Killduff-Muscatine, Downs-Tama-Shelby, Otley-Mahaska, and Ladoga-Gara (Nestrud and Worster, 1979). Dominant soil taxa are indicated in Table 2; these soil taxa account for 82% of the soils found in the Walnut basin and 78% of the soils found in the Squaw basin. Tama and Muscatine soils are found primarily in upland divide areas, whereas Ackmore soils are associated with bottomlands. Killduff, Otley and Ladoga-Gara soils are found developed on hillslopes. Most of the soils are silty clay loams, silt loams, or clay loams formed in loess and till. Many of the soils are characterized by moderate to high erosion potential; both watersheds contain equal amounts of highly erodible land (Table 2).

In the drainageways of Walnut and Squaw creeks, Holocene alluvial deposits of the DeForest Formation (Bettis, 1990; Bettis et al., 1992) consist of stratified sands, silts, clays and occasional peat. The DeForest Formation was designated by Bettis (1990) to contain all the fine-grained Holocene alluvium in the state. In the Walnut and Squaw creek watersheds, two members of the DeForest

Table 1. Basin characteristics of the Walnut and Squaw creek watersheds.

Basin Characteristics	**Walnut Creek**	**Squaw Creek**
Total Drainage Area (sq mi)	20.142	18.305
Total Drainage Area (acres)	12,890	11,714
Slope Class:		
A (0-2%)	19.9	19.7
B (2-5%)	26.2	26.7
C (5-9%)	24.4	25.0
D (9-14%)	24.5	22.2
E (14-18%)	5.0	6.5
Basin Length (mi)	7.772	6.667
Basin Perimeter (mi)	23.342	19.947
Average Basin Slope (ft/mi)	10.963	10.981
Basin Relief (ft)	168	191
Relative Relief (ft/mi)	7.197	9.575
Main Channel Length (mi)	9.082	7.605
Total Stream Length (mi)	26.479	26.111
Main Channel Slope (ft/mi)	11.304	12.623
Main Channel Sinuosity Ratio	1.169	1.141
Stream Density (mi/sq mi)	1.315	1.426
Number of First Order Streams (FOS)	12	13
Drainage Frequency (FOS/sq mi)	0.596	0.710

Formation are commonly observed (Camp Creek Member and Roberts Creek Member). Bettis and Littke (1987) provided a generalized description of these deposits in the nearby Soap Creek watershed (Appanoose, Davis, Monroe and Wapello Counties) (p. 15):

CAMP CREEK MEMBER: Very dark grayish brown to yellowish brown (10YR3/2-5/4) silt loam to loam; can be sandy loam texture if source materials are sandy; noneffervescent; unit is usually horizontally stratified where it exceeds 0.75 m in thickness; base of unit usually overlies buried A horizon of the presettlement soil; thickest in the floodplain area (where it buries the Robert Creek Member) and at the base of steep slopes where row-cropped fields are upslope; ranges in age from 400 years before present (BP) at base to modern at top.

ROBERTS CREEK MEMBER: Very dark gray to dark gray (2.5YR3/0, 10YR3/1-4/1) silt loam, loam or sandy loam; noneffervescent; thick sections are horizontally stratified at depth; unit has relatively thick A-C soil profile developed into its upper part; found within the present low floodplain, usually roughly paralleling the modern channel; unit ranges in age from about 3000 to 500 years BP.

The thickness of the Camp Creek Member was measured at 13 stream bank exposures along the Walnut Creek channel. The thickness ranged from approximately four to six feet and did not vary appreciably from upstream to downstream locations.

Table 2. Soil characteristics in the Walnut and Squaw creek watersheds.

Soil Characteristics	Walnut Creek		Squaw Creek	
	Acres	Percent	Acres	Percent
Soil Parent Material:				
Alluvium	2043.87	15.86	2050.90	17.51
Eolian Sand			245.15	2.09
Weathered Shale	14.88	0.12		
Local Alluvium	192.79	1.50	383.34	3.27
Gray Paleosol	405.27	3.14	157.86	1.35
Loess	6155.89	47.75	6312.66	53.89
Loess and Local Alluvium	24.99	0.19	27.62	0.24
Loess-gray or gray mottles	2073.92	16.09	1245.56	10.63
Paleosol-reddish	13.27	0.10	7.96	0.07
Sandy Alluvium	168.52	1.31		
Till (Pre-Illinoian)	1773.99	13.76	1255.80	10.72
Highly Erodible Land	6935.11	53.78	6226.13	53.57
Dominant Soil Taxa:				
Tama	2528.92	19.61	4018.23	34.29
Killduff	1889.72	14.66	1242.04	10.66
Muscatine	1038.25	8.05	548.54	4.68
Otley-Mahaska	1396.53	10.83	999.57	8.53
Shelby-Adair	508.47	3.94	986.67	8.42
Ackmore, Ackmore-Colo	1612.18	12.50	1309.69	11.17
Ladoga-Gara	1556.96	12.08	40.56	0.35

Pre-Illinoian glacial deposits, predominantly till, underlie the Holocene alluvium and most of both watersheds, ranging from 20 to 100 feet in thickness. Bettis and Littke (1987) described Pre-Illinoian till in the Soap Creek watershed as massive and firm, yellowish brown (10YR5/4-5/6) to dark gray (10YR3/1-4/1) loam with common pebbles. This general description is consistent with observations of Pre-Illinoian till in Jasper County. Bedrock occurs at an approximate elevation of 700 to 850 feet above mean sea level and is primarily Pennsylvanian Cherokee Group shale, limestone, sandstone, and coal. Outcrops of shale and some sandstone can be seen in some portions of the refuge and along roads just south of the study area. A small segment of Walnut Creek flows on top of Pennsylvanian bedrock in the southern portion of watershed.

Walnut Creek Stream Survey

Channel features and morphology of Walnut Creek were described in detail in October 1998 by traversing a seven-mile segment of stream channel, including the channel located between the two USGS stream gauges and a one mile contiguous section downstream of WNT2 (Figure 2). Channel conditions have not been similarly described in Squaw Creek but are believed to be similar to Walnut Creek based on field reconnaissance. Continuous channel conditions (left and right bank erosion rates, streambed materials and thickness at

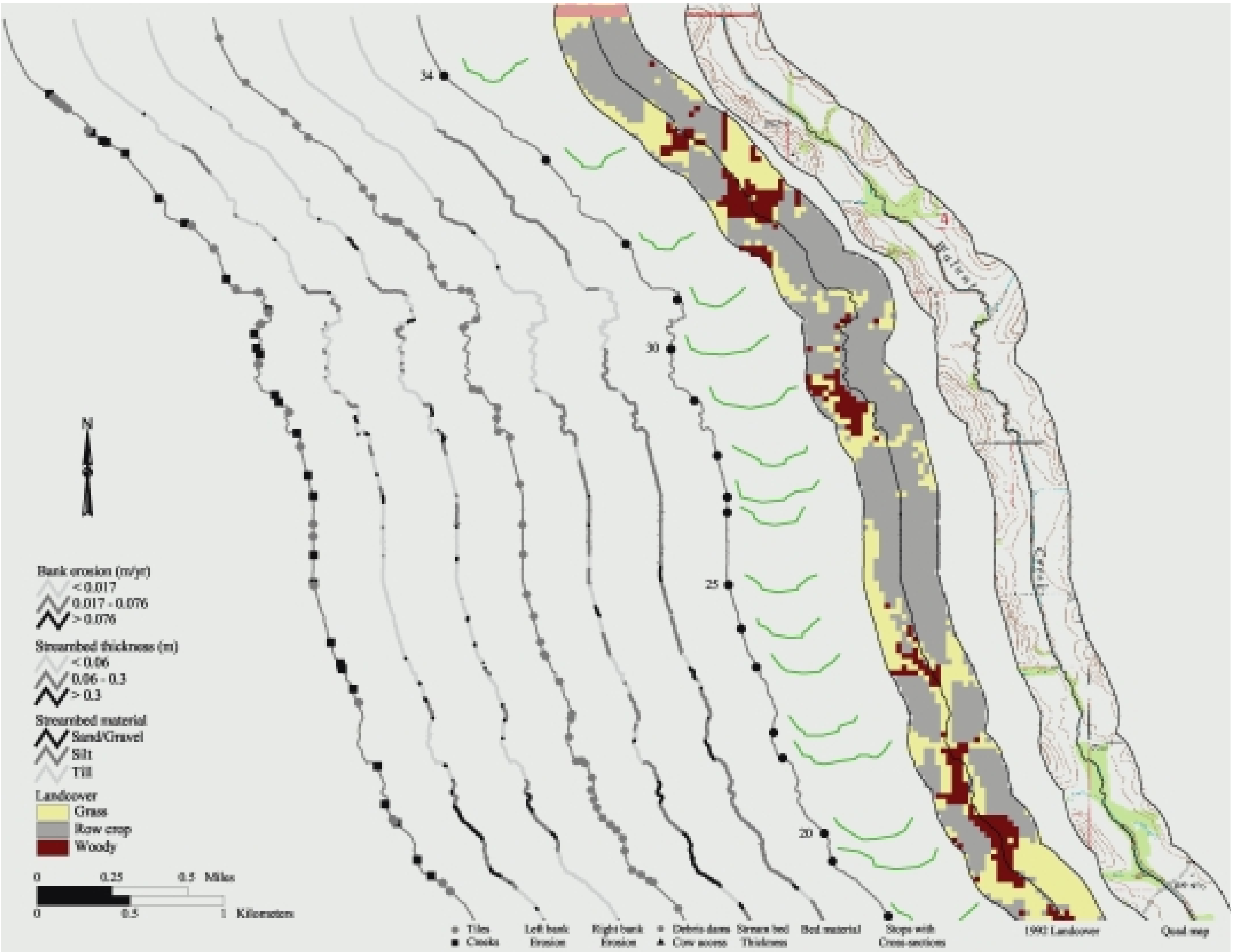

Figure 2. Channel features mapped in Walnut Creek. Figure shows same stream channel depicted side-by-side with different features mapped. Stop numbers provide points of reference and link to cross-section dimensions presented in Table 4. Quadrangle map is from the 1972 Runnels Quadrangle (1:24,000 scale), Jasper County, Iowa. Dark line on the quad map is the actual stream course mapped with GPS.

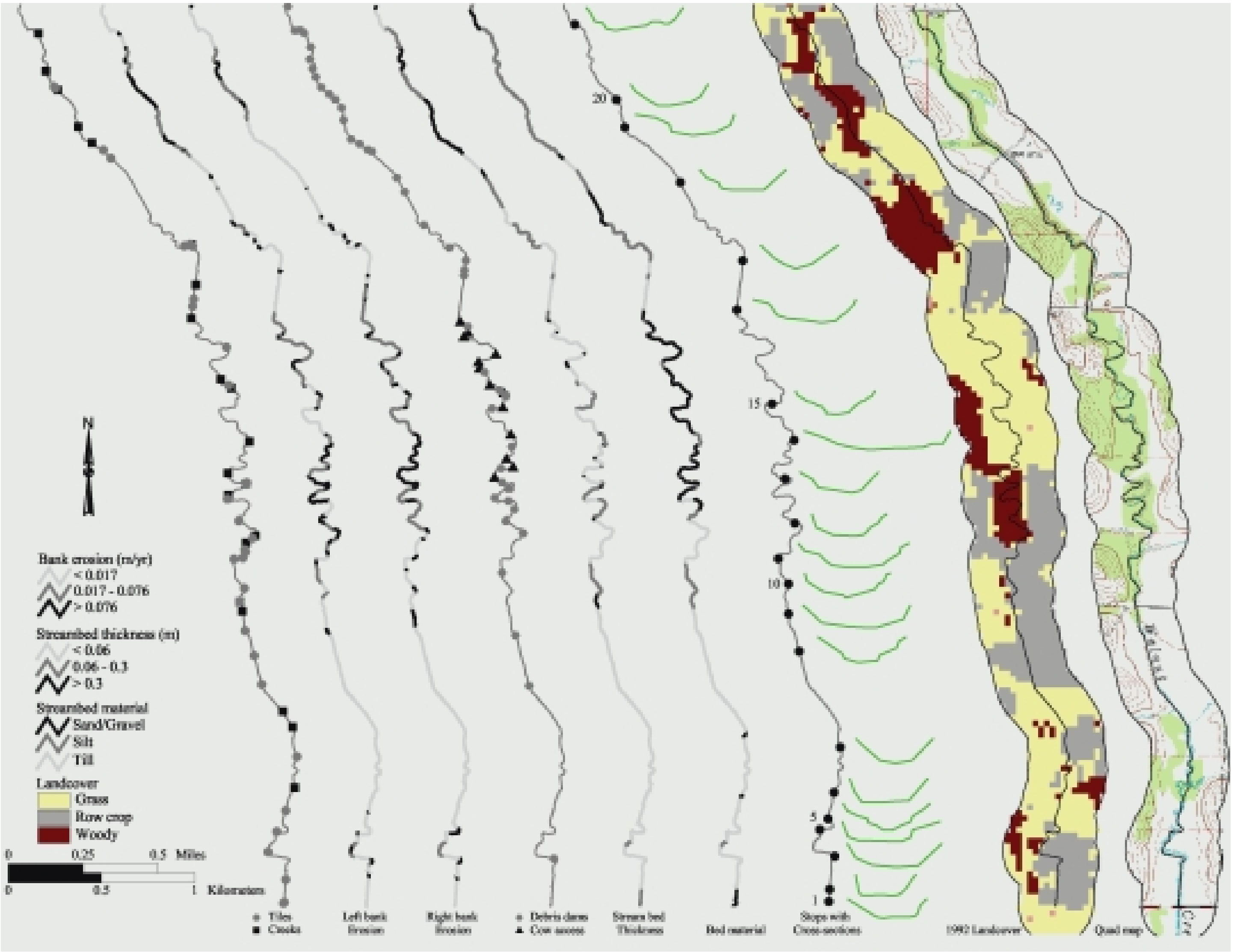

Figure 2. Continued.

Table 3. Descriptive model for estimating streambank erosion rates (from unpublished Iowa Natural Resource Conservation Service worksheet for calculating erosion and sediment delivery).

Streambank Recession Rate (ft/yr)	Category	Description
0.01- 0.05	Slight	Some bare bank, but active erosion not readily apparent. Some rills but no vegetative overhang. Maybe some exposed tree roots.
0.05 – 0.2	Moderate	Bank is predominantly bare with some rills and vegetative overhang. Some exposed tree roots but no slumps or slips.
0.2 – 0.5	Severe	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignments of roads and trails. Channel cross-section becomes more U-shaped.
0.5 – 0.8	Very severe	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains and culverts eroding out and changes in cultural features as above. Massive slips or washouts common. Channel cross-section is U-shaped and stream course or gully may be meandering.

the thalwag) and discrete features (locations of channel cross-sections, drainage tiles, tributary creeks, debris dams) were located using Global Positioning System (GPS) equipment. The GPS data were exported into a GIS format and field descriptions added to create a series of GIS coverages used for spatial analysis. Discrete locations were recorded using GPS to an accuracy of one meter and continuous data were recorded to an accuracy of five meters. Stream mapping procedures and results were reported by Schilling and Wolter (1999) and Schilling and Wolter (in press). The color poster of Schilling and Wolter (1999) is available on the Iowa Department of Natural Resources Geological Survey Bureau web page (http://www.igsb.uiowa.edu/inforsch/walnut/wntpost/wntpost.htm). Some results of the Walnut Creek stream survey are highlighted below.

Bank conditions and erosion rates were characterized using a descriptive model developed by the Iowa Natural Resources Conservation Service (NRCS) (Table 3). Left and right streambank recession rates generally varied from slight, in straightened segments of the channel, to severe at many meander bends, debris dams or cattle access points (Figure 2). Severe bank erosion on many outside meander bends tended to be located immediately downstream of straightened reaches. Average left and right bank erosion rates were similar (0.135 ft/yr and 0.143 ft/yr, respectively) and yielded an average watershed erosion rate of 0.278 ft/yr. Based on the stream survey data, the mass of sediment eroded from Walnut Creek streambanks was estimated to be 7,091 tons per year for the portion of channel located between the two USGS gauging stations. Considering that the average annual sediment load at the downstream Walnut Creek USGS gauging station for the period between 1996 and 1998 was 14,025 tons, the percentage of total annual suspended sediment load derived from streambank erosion is estimated to be 51%.

Streambed materials and bed thickness were described in the field during the traverse. Substrate sediment consisted of bare or thinly mantled Pre-Illinoian till in many areas and thick muck (greater than one foot thick) behind some debris dams and in cattle access areas (Figure 2). Streambed thickness less than 0.2 ft was often found in straightened channel segments with few debris dams. Most streambed sediment was composed of silt locally derived from Holocene alluvium, loess or Pre-Illinoian till. Mapping data from Walnut Creek was used to estimate the mass of sediment stored on the channel bottom and the amount of time needed to remove it from the watershed. Based on the stream survey data, the average channel bottom width of Walnut Creek was 13.24 feet and the average bed thickness was 0.41 feet. Considering that the channel length between the two gauging stations was 32,203 feet, the volume of sediment stored in the channel was estimated to be 174,810 cubic feet. Assuming a specific gravity of 2.70 for the silty streambed material (Spangler and Handy, 1982), the mass of stored sediment would be approximately 14,726 tons. Based on the mean annual flow rate and annual suspended sediment concentration measured at the downstream USGS station for the period between 1996 and 1998 (19.1 cfs and 116.1 mg/l, respectively), flushing the amount of sediment stored in the channel bottom from the watershed would require approximately 9 years, assuming no additional inputs.

Cattle access to Walnut Creek was concentrated in a one mile segment (Figure 2) and this area showed evidence of extensive channel modifications. Severe bank erosion and accumulation of streambed sediment were observed where cattle entered the stream by ramps located primarily at meander bends. Streambed sediment thickness in these areas often exceeded one foot. Sand and gravel were the dominant streambed material in this portion of Walnut Creek. It is hypothesized that excessive cattle trampling in these areas has served to winnow the fine-textured silt and clay from the Pre-Illinoian till, leaving behind accumulations of coarser sand and gravel. Fine textured materials, like the underlying Pre-Illinoian till, are noted to be particularly susceptible to increased erosion from livestock grazing (Trimble and Mendel, 1995). Immediately downstream of cattle access points were the only substantial accumulations of native sand substrate material in the entire stream channel. Other sand and gravel occurrences in Walnut Creek were primarily associated with riprap from bridge crossings.

GPS was used to locate debris dams if the dams appeared to constrict flow or otherwise divert flow into the channel sides, regardless of debris diameter or length. A total of 81 debris dams were located in the stream channel (Figure 2). These dams ranged from fallen trees and beaver dams to several large debris dams. Large debris dams at some locations consisted of dozens of fallen trees blocking the channel and constricting stream flow. Debris dams tended to be more prevalent in the central portion of the mapped area (Figure 2). In a 0.5 mile segment of Walnut Creek, 16 debris dams were mapped, most of which consisted of large debris jams (greater than five trees) severely constricting streamflow. Most of the woody vegetation in this area, as well as other forested areas north of this zone, consist of weak, fast-growing trees (elm, silver maple, box elder, hackberry) that are not native to the area and subject to increased occurrences of disease and blowdown (personal communication: Pauline Drobney, USFWS biologist). The stream channel behind many debris dams in this area showed bed sediment accumulations greater than one foot thick (Figure 2); bed thickness actually exceeded two feet in one area within this reach (Schilling and Wolter, 1999). Where debris dams were less prevalent, streambed thickness was often less than 0.2 feet and Walnut Creek flowed on top of Pre-Illinoian till. Channel cross-sections were measured at 25 locations along Walnut Creek between the two gauging stations (Figure 2).

Channel width varied from 22.93 feet to 61.83 feet and averaged 32.10 feet, whereas channel depth varied from 7.18 feet to 10.36 feet and averaged 8.95 feet (Table 4). Channel width and depth generally decreased from downstream to upstream locations. Channel width-to-depth ratio varied from 2.71 to 7.76 and generally ranged between 3 and 4 (Table 4). Stream sinuosity was less than 1.1 in three segments and greater than 1.5 between stops 11 and 16.

Table 4. Channel dimensions at cross-section locations shown on Figure 2. Sinuosity values determined for approximate 0.5 mile distance between channel stops.

Cross-Section No.	Channel Width (ft)	Channel Depth (ft)	Channel Bottom Width (ft)	W/D ratio	Sinuosity
1	33.39	7.47	18.13	4.46	
2	30.40	8.88	16.46	3.42	
3	39.88	9.97	19.74	4	
4	41.39	8.36	20.13	4.95	
5	36.90	11.34	11.48	3.25	
6	33.71	10.06	14.85	3.35	
7	32.89	10.36	13.44	3.17	1.310
8	37.39	10.85	13.97	3.44	
9	45.46	9.18	22.92	4.95	
10	36.40	10.36	18.95	3.51	
11	46.87	9.87	21.65	4.75	
12	32.80	9.28	14.27	3.53	
13	33.39	8.76	10.96	3.81	
14	61.83	7.97	17.02	7.76	1.792
15	33.39	9.87	9.68	3.38	
16	43.36	9.74	15.35	4.45	1.577
17	32.90	9.97	11.55	3.30	
18	36.60	8.76	17.45	4.18	1.261
19	41.89	8.89	17.94	4.71	
20	32.90	9.09	16.86	3.62	
21	40.87	9.77	10.96	4.18	1.113
22	29.00	8.56	13.64	3.39	
23	28.90	8.07	13.97	3.58	
24	28.40	8.36	13.15	3.40	
25	30.41	7.58	14.96	4.01	1.096
26	26.93	7.58	15.55	3.55	
27	29.91	9.18	18.24	3.26	
28	31.42	8.76	9.97	3.59	
29	32.90	9.25	21.12	3.56	1.129
30	34.90	8.17	19.94	4.27	
31	22.93	8.46	7.28	2.71	
32	28.70	7.18	11.94	4.00	1.448
33	30.41	8.76	12.96	3.47	
34	27.42	9.77	8.76	2.81	1.077
Mean	32.10	8.95	13.24	3.59	

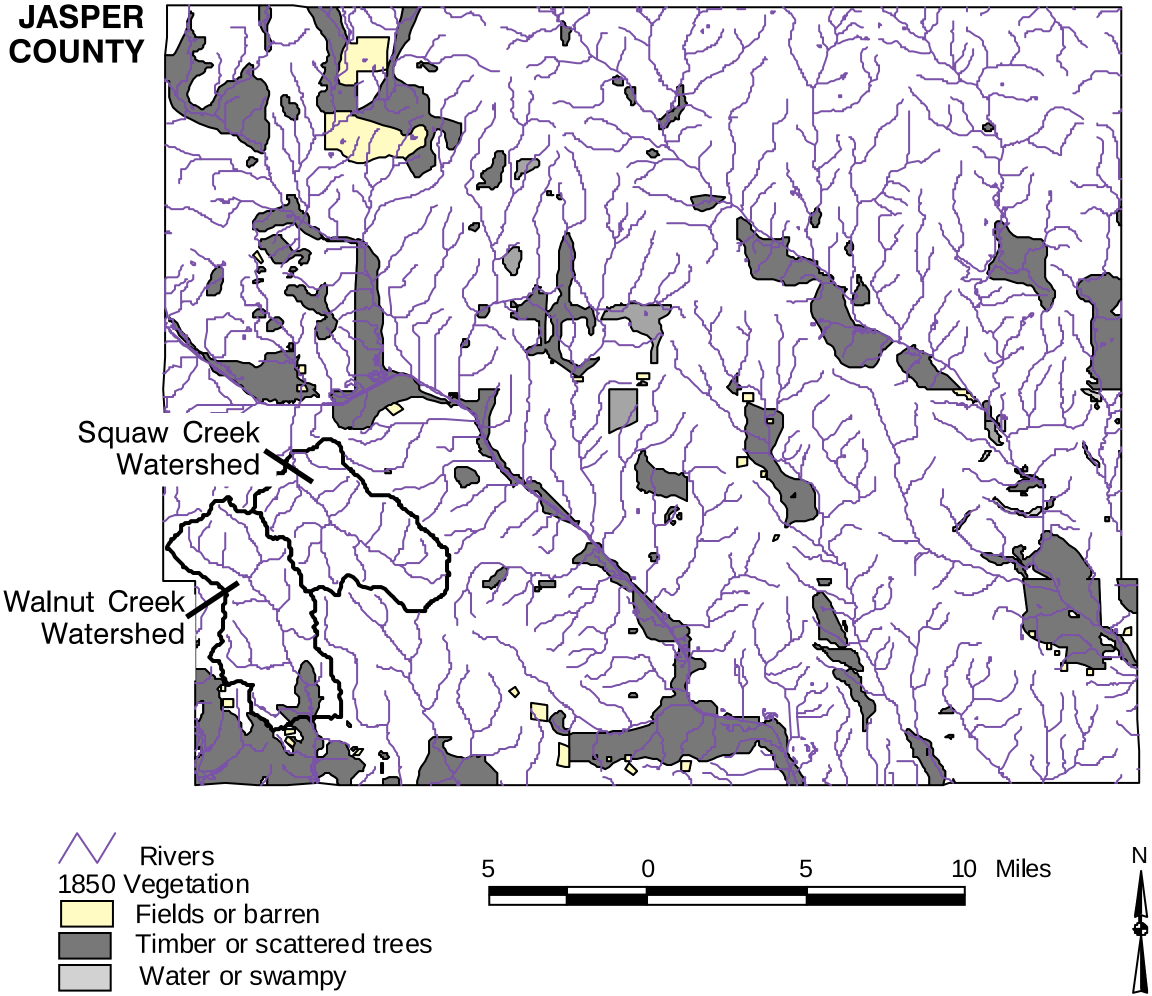

Figure 3. Native vegetation in Jasper County in 1850 at the time of Euro-American settlement.

Land Use

During initial Euro-American settlement in the mid-1800s, land cover in the Walnut and Squaw Creek watersheds was predominantly grassland and savanna (Figure 3). By the 1940s, aerial photographs of the Walnut Creek watershed indicate that most of the watershed was cultivated and sections of the Walnut Creek channel had been artificially straightened (Figure 4). Many farm plots in 1940 appeared to be rectangular in shape with little regard for natural topography or stream boundaries. Land management practices during this time were typically very poor, characterized by poor crop rotations, removal of crop residues, nutrient depletion, lack of cover crops and very active erosion (Trimble and Lund, 1982). Concentrated overland flow from rills and gullies in cropped areas often dissected hillside deposits and eroded downslope. Aerial photographs suggest that by 1971, modern soil conservation practices were common in the Walnut Creek watershed, including terraces, contour planting and riparian buffer strips (Figure 4). Despite the conservation measures, it was evident that between 1940 and 1971, many stream channels were deepened and many gullies formed. Drainage networks appear considerably more developed by 1971 (Figure 4).

Prior to watershed restoration activities commencing in 1992, land use in the Walnut Creek watershed consisted of approximately 69 percent row crop and 27 percent grass (Schilling and Thompson, 1999). The headwater portion of the watershed was most heavily row cropped, averaging more than 80% in 1992. From 1992 to 1997, land use changes implemented by the USFWS have resulted in conversion of 1,729 acres or 13.4% of the Walnut Creek watershed from row crop to native prairie (Figure 5). Another 20.3 percent of the watershed is owned by USFWS but either farmed on a cash-rent basis (6 percent) or unchanged since refuge activities began (14.3 percent). As of 1997, the USFWS controlled 4,343 acres, or 33.7%, of the Walnut Creek watershed above the WNT2 gauging station (Schilling and Thompson, 1999). Overall land use in the Walnut Creek watershed in 1998 consisted of 59.6 percent row crop and 29.9 percent grass or pasture. In the portion of the watershed downstream of the WNT1 gauging station that contains most of the refuge, land use percentages were 42.8 percent row crop and 44.4 percent grass/pasture.

Overall land use in the Squaw Creek watershed in 1998 consisted of 75.5 percent row crop and 15.5 percent grass/pasture with little difference between headwater areas (83.6 percent row crop) versus the remainder of the watershed (76.2 percent row crop).

METHODS

At USGS gauging stations, stage is monitored continuously with bubble-gage sensors (fluid gages) and recorded by data collection platforms (DCP) and analog recorders (Rantz, 1982). The DCPs digitally record rainfall and stream stage at 15-minute intervals. Stevens A-35 strip-chart recorders also register stage continuously. The recording instruments are housed in five feet by five feet metal buildings. The equipment is powered by 12 volt gel-cell batteries which are recharged by solar panels or battery chargers run by external power. Reference elevations for all USGS gauge stations are established by standard surveys from USGS benchmarks. Stage recording instruments are referenced to outside staff plates placed in the streambed, or to type-A wire-weights attached to the adjacent bridges.

Stream discharge is computed from the rating curve developed for each site (Kennedy, 1983). The stream gaging and calibration is performed by USGS personnel, using standard methods (Rantz et al., 1982; Kennedy, 1983). Current meters and portable flumes are used periodically to measure stream discharge and refine the station rating curve.

Suspended sediment samples are collected daily by local observers and weekly by water quality monitoring personnel. The observers collect depth integrated samples at one point in the stream using techniques described by Guy and Norman (1970). Samples are collected daily at all three stations. During storm events, suspended sediment samples are collected with an automatic water-quality sampler installed by the USGS at the gaging stations. Sampling is initiated by the DCP when the stream rises to a pre-set stage, and terminates when the stream falls below this stage. Suspended sediment concentrations are determined by the USGS Sediment Laboratory in Iowa City, Iowa, using standard filtration and evaporation methods (Guy, 1969). Precipitation was measured at the three USGS gauging sites using standard tipping-bucket rain gauges attached to the USGS stream gauges. Discharge, rainfall, and sediment data are stored in the USGS Automatic Data Processing System (ADAPS) and published in Iowa District Annual Water-Data Reports (May et al., 1997; May et al., 1998; May et al., 1999).

RESULTS

Precipitation

Monthly precipitation totals and monthly maximum events measured at gauging stations WNT1, WNT2 and SQW2 are presented in Table 5. Also shown are long-term monthly averages and average annual precipitation for the central Iowa region

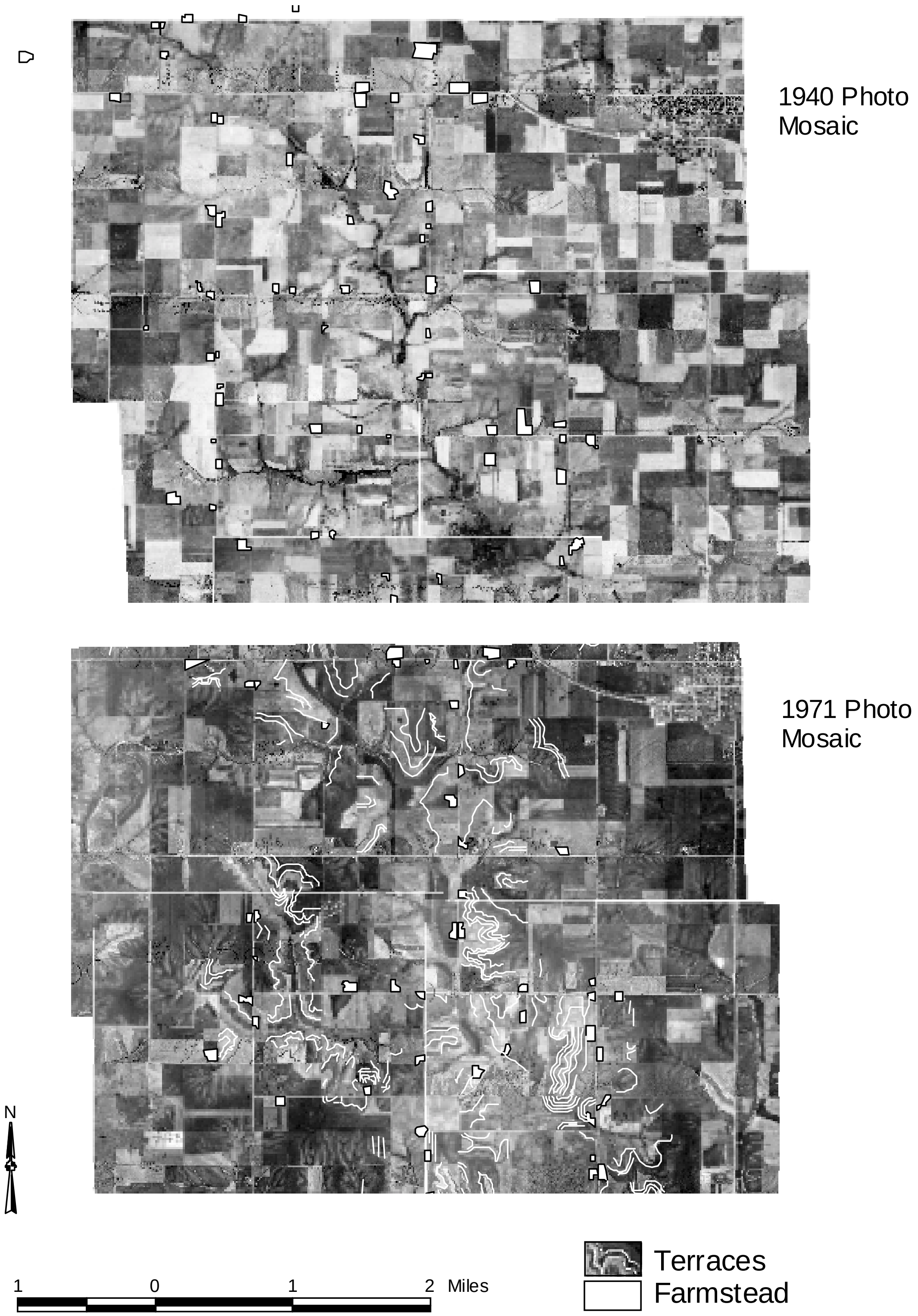

Figure 4. Composite aerial photographs of northern portion of Walnut Creek watershed from 1940 (above) and 1971 (below). Note location of Prairie City in northeastern portion of both photographs.

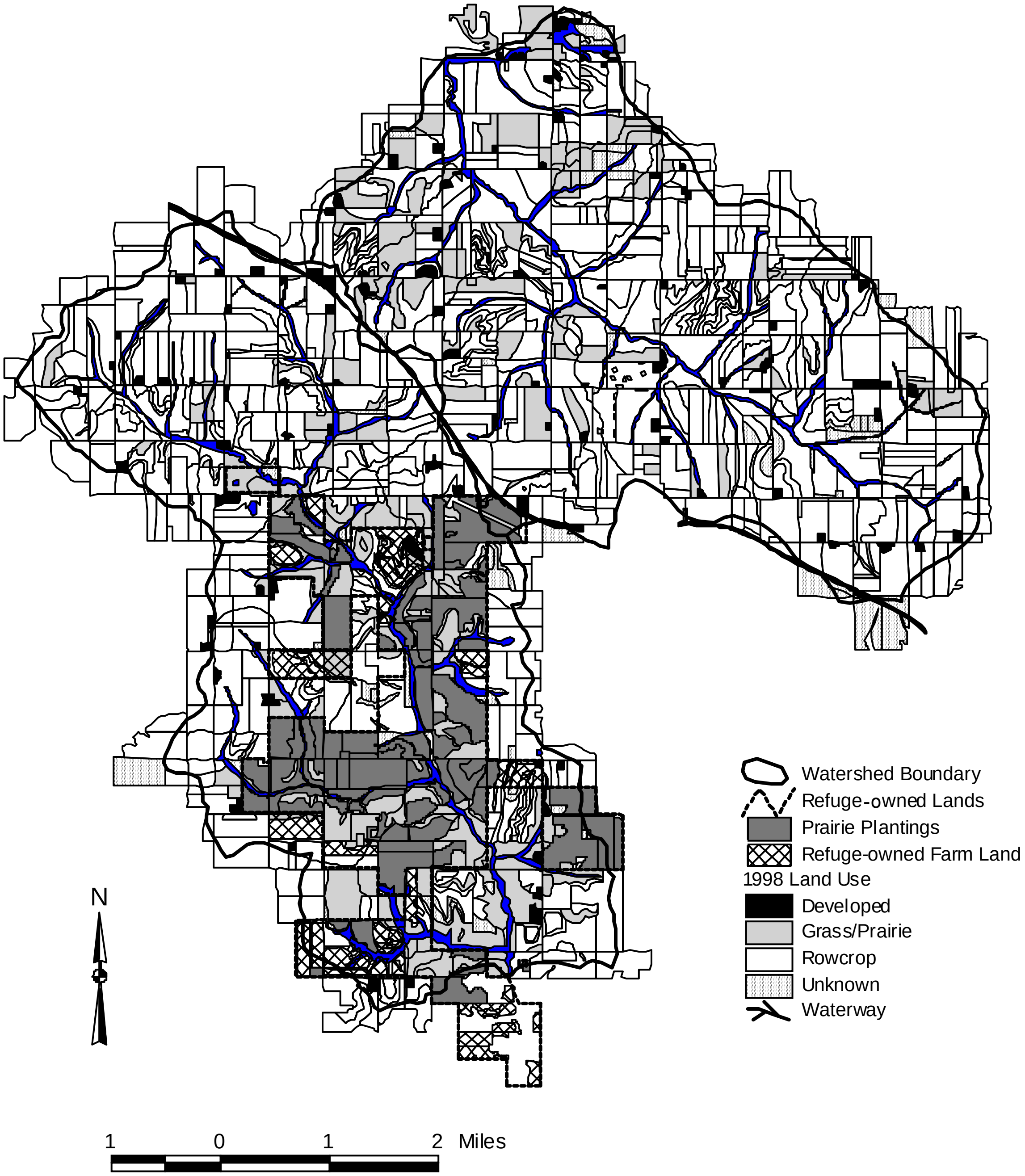

Figure 5. Land use in Walnut Creek and Squaw Creek watersheds in 1998.

(State Climatologist Office, 1998). In general, rain gauges at the three monitoring sites recorded below normal precipitation for the 1996 to 1998 period. Two above normal annual totals were recorded at WNT2 and SQW2 in 1998 (Table 5).

Variable precipitation totals were measured at the WNT2 gauging station, whereas data from WNT1 and SQW2 were similar (Table 5). Two explanations are proposed for the differences between WNT2 data and other stations. The WNT2 site is the southernmost measurement station in the study area, suggesting that perhaps the higher

Table 5. Summary of monthly precipitation totals (in inches) for water years 1996 to 1998. Average values from State Climatologist Office for central Iowa region.

Site	Water Year	Parameter	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year Total	Departure from Avg
WNT2	1996	Total	1.09	1.45	0.1	0.55	0.52	1.26	2.37	11.9	3.79	4.88	1.81	3.04	32.81	-0.62
		Max	0.65	1.07	0.06	0.23	0.18	0.58	1.06	4.72	1	3.04	0.56	1.21		
	1997	Total	3.29	1.79	0.31	0.29	0.63	1.41	2.98	5.29	3.22	2.68	1.54	1.97	25.40	-8.03
		Max	2.03	0.75	0.15	0.23	0.3	1.05	1.56	2	0.71	1.14	0.66	0.52		
	1998	Total	5.60	1.42	0.55	0.64	1.80	2.95	3.07	6.73	8.47	5.47	4.38	0.49	41.57	8.14
		Max	1.75	1.24	0.21	0.30	0.51	1.97	0.49	2.17	2.37	2.21	1.56	0.33		
WNT1	1996	Total	1.44	1.08	0.02	0.54	0.26	0.99	1.64	9.03	2.18	3.34	1.46	2.35	24.33	-9.10
		Max	0.52	0.87	0.02	0.29	0.17	0.47	0.84	2.34	0.63	2.53	0.48	0.91		
	1997	Total	2.9	2.01	0.33	0.23	0.48	1.09	3.1	4.06	3.38	2.49	2.02	2.68	24.77	-8.66
		Max	1.83	0.68	0.18	0.15	0.24	0.58	1.8	1.74	1.26	0.93	0.47	0.83		
	1998	Total	4.55	0.93	0.54	0.41	1.23	2.54	2.21	5.29	2.18	2.98	5.63	0.46	28.95	-4.48
		Max	1.86	0.74	0.24	0.20	0.33	1.69	0.39	1.47	0.77	1.18	1.76	0.25		
SQW2	1996	Total	1.21	1.15	0.06	0.46	0.19	0.92	1.25	7.81	2.81	3.5	1.52	2.5	23.38	-10.05
		Max	0.54	1.06	0.03	0.29	0.15	0.43	0.68	1.91	0.78	2.69	0.54	0.79		
	1997	Total	2.61	1.77	0.43	0.29	0.37	0.91	3.01	3.66	3.31	4.11	3.32	2.9	26.69	-6.74
		Max	1.55	0.72	0.24	0.25	0.18	0.45	1.78	1.26	1.15	1.47	1.05	0.86		
	1998	Total	4.93	0.68	0.24	0.46	1.26	0.81	2.29	7.05	7.77	4.03	4.32	0.56	34.40	0.97
		Max	2.27	0.53	0.07	0.23	0.29	0.35	0.55	1.73	1.46	1.70	1.64	0.29		
Average		Total	2.58	1.71	1.22	0.83	0.97	2.18	3.23	4.06	4.81	4.15	4.10	3.59	33.43	

rainfall totals reflect differences in storm tracking patterns. Alternatively, differences in rainfall totals between the gauging sites may be associated with differences in setting. Both WNT1 and SQW2 are located in relatively flat, wide open areas devoid of trees, whereas WNT2 is located in a moderately closed area with nearby trees (although none directly overhanging the rain gauges). Wind, topography or other environmental factors could cause variability in rainfall totals at WNT2. Therefore, data from WNT1 and SQW2 are considered most representative of local precipitation conditions. Totals from WNT1 and SQW2 weather stations appear comparable in timing and magnitude (Table 5).

Highest monthly precipitation totals occurred in May although large storms can produce totals in excess of 1.5 inches anytime between March and October (Figure 6). Based on data from WNT1 and SQW2, May accounted for about 23 percent of the annual precipitation total, whereas monthly totals from June, July, August and October each accounted for between 10 and 13 percent of the annual total. Long-term averages indicate that May through August typically experience more than 4 inches of rainfall per month.

Discharge and Suspended Sediment

Daily Measurements

Daily discharge and suspended sediment values peaked sharply over a wide range of flows and concentrations in water years 1996 to 1998 (Figure 7). Peaks in discharge and sediment loads most often occurred in February, May and June, although rapid increases also occurred in other months. Streamflow typically decreased from seasonal highs of greater than 100 cfs in May and June to less than 1 cfs in September and October. Discharge in both watersheds was very flashy, responding rapidly to precipitation (Figure 8). Dis-

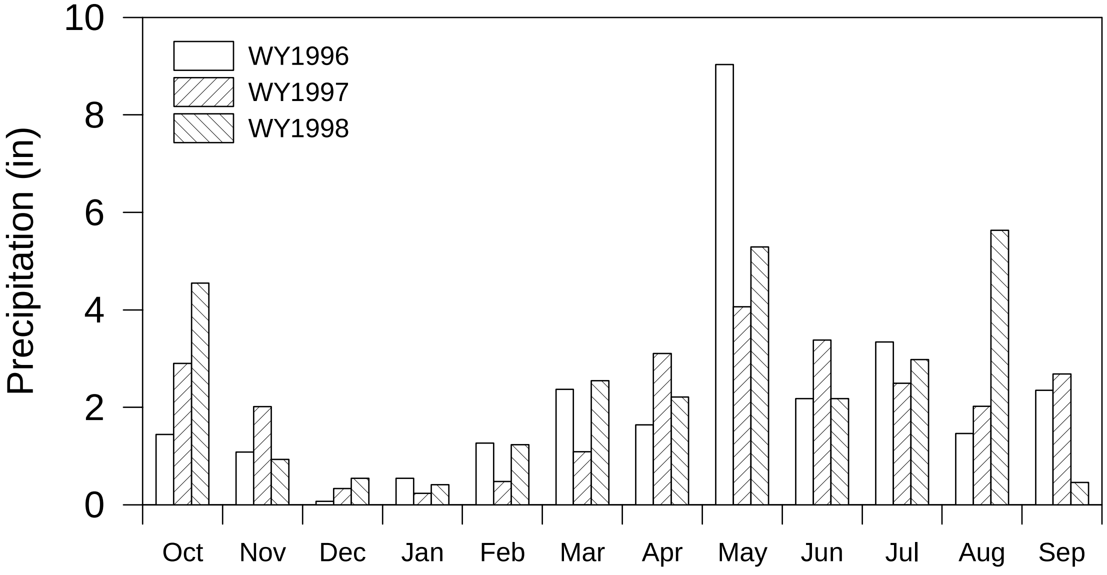

Figure 6. Summary of monthly precipitation totals for water years 1996 to 1998.

charge peaks occurring in February and early March were primarily the result of snowmelt.

Sediment loads followed the same general pattern as discharge, with most suspended sediment discharged during intermittent high flow events. Sediment loads during high flow events exceeded 100 tons/day in the period between February through July. Sediment loads typically decreased more rapidly than discharge following peak events and were generally less than 1 ton/day between August and January (Figure 7).

Examining the temporal pattern of daily discharge and suspended sediment concentration in the two most active months (May and June) shows variability between the two watersheds (Figure 9). Although the timing of events is similar in many instances, there were large differences in the magnitude of various peaks. For example, differences are noticeably evident in data from Water Year 1997. Four main peaks in discharge were observed in both watersheds; two larger peaks occurring on May 8 and May 26 and two smaller peaks occurring on June 21 and June 25 (Figure 9). In the Walnut Creek watershed, the two large peaks showed discharge of 158 and 148 cfs whereas the discharge was 68 and 30 cfs in Squaw Creek. This discharge discrepancy translated to large differences in suspended sediment concentration as well. Sediment concentrations were 2,450 and 1,630 mg/l in Walnut Creek and 1,150 and 283 mg/l in Squaw Creek. However, in June, a relatively small discharge peak in Squaw Creek (14 cfs) produced a high sediment concentration (1,200 mg/l). At the same time in Walnut Creek, a discharge of 17 cfs produced a sediment concentration significantly less (556 mg/l) (Figure 9).

Another example of temporal similarity in event peaks but differences in peak magnitude is illustrated by the June 1998 data (Figure 9). Two large discharge peaks in Walnut Creek were similar in magnitude (447 and 526 cfs), whereas on the same two days in Squaw Creek, there was a large difference in discharge peak magnitude (137 and 847 cfs). The discharge peaks in Walnut Creek produced similar sediment concentrations (551 and 570 mg/l), but events in Squaw Creek showed tremendous variability in concentration (220 and 2,680 mg/l). As a result, differences in suspended sediment loads for the two days were equally large. Total sediment load for the two day period was 1,870 tons in Walnut Creek and 11,518 tons in Squaw Creek. Differences cannot solely be attributable to precipitation considering that the amount of precipitation was similar on both days (2.37

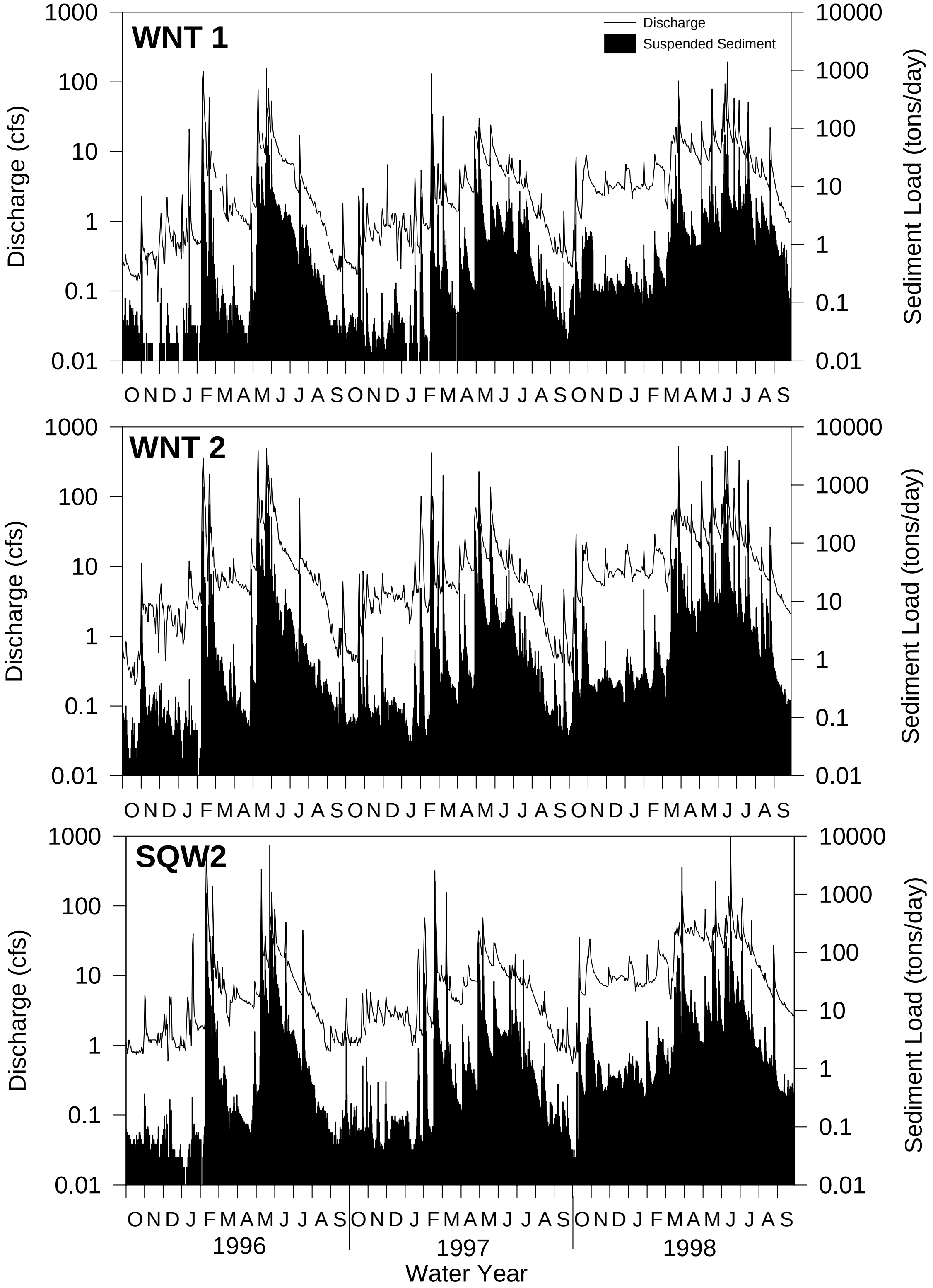

Figure 7. Summary of daily stream discharge and mean suspended sediment loads for sites WNT1, WNT2 and SQW2 water years 1996 to 1998.

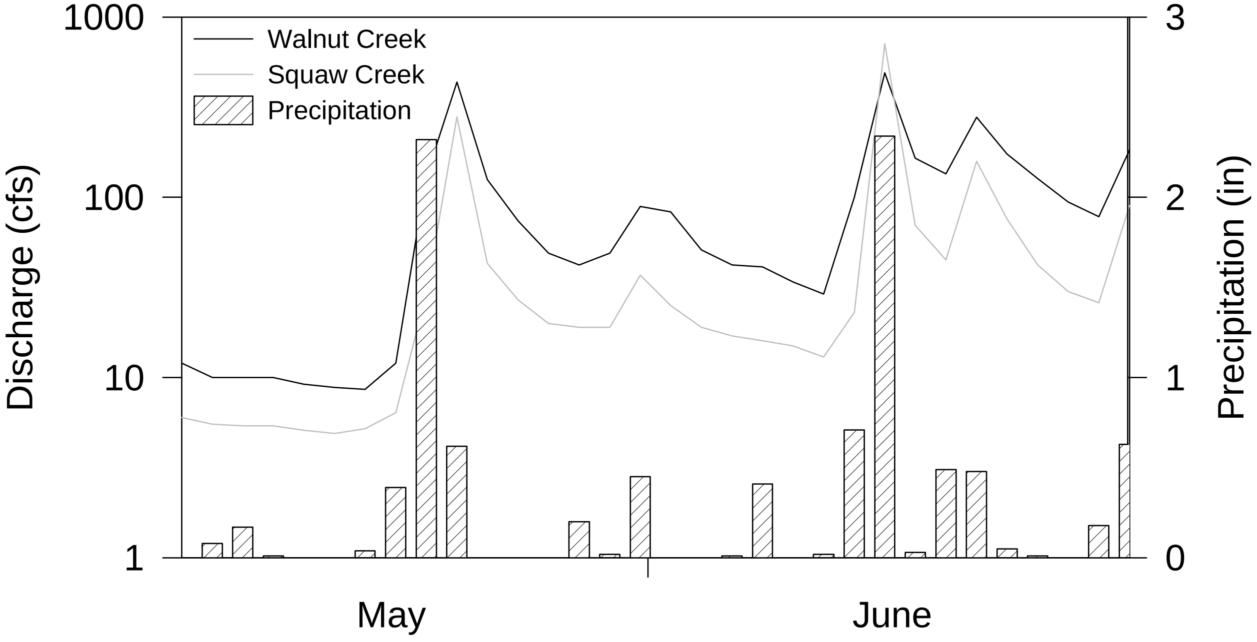

Figure 8. Typical storm hydrograph from May and June 1996.

inches and 1.31 inches in Walnut Creek for the two days; 1.46 and 1.33 inches in Squaw Creek).

The relationship of discharge to suspended sediment concentration is similar in the Walnut and Squaw creek watersheds (Figure 10). Regression analysis indicated that suspended sediment concentration (SS in mg/l) is a linear function of discharge (Q in cfs). Two linear regressions were performed, one a best fit line, and a second regression line forced through the origin. The second regression line satisfies the conceptual model that when there is no discharge in the stream, the suspended sediment concentration would also be zero. The equations for the two regression lines are as follows:

Walnut Creek

Equation 1 (best fit) $SS = 4.06Q + 55.87; r^2 = 0.451$

Equation 2 (origin) $SS = 4.501Q; r^2 = 0.417$

Squaw Creek

Equation 1 (best fit) $SS = 4.00Q + 43.82; r^2 = 0.467$

Equation 2 (origin) $SS = 4.3141Q; r^2 = 0.4424$

Although considerable scatter exists in the data, regression indicates a highly significant relationship for both plots ($p<<0.05$). The slopes of the regression lines are slightly higher for both equations for the Walnut Creek data.

During most of the year, suspended sediment concentrations were less than 100 mg/l (Table 6). For combined water years 1996 to 1998, concentrations were less than 100 mg/l 68.8 percent of the time in Walnut Creek and 77.6 percent in Squaw Creek. Concentrations less than 20 mg/l occurred less frequently in any given year, ranging from 23.2 to 46.2 percent in Walnut and 4.9 to 27.9 percent in Squaw. Concentrations greater than 500 mg/l were measured about 4 to 5 percent of the time in either watershed.

The timing and magnitude of maximum discharge and sediment loads between the two watersheds was evaluated by ranking the top twenty discharge and sediment loads events measured at WNT2 and SQW2 (Table 7). The top two daily discharge events occurred on the same days in both

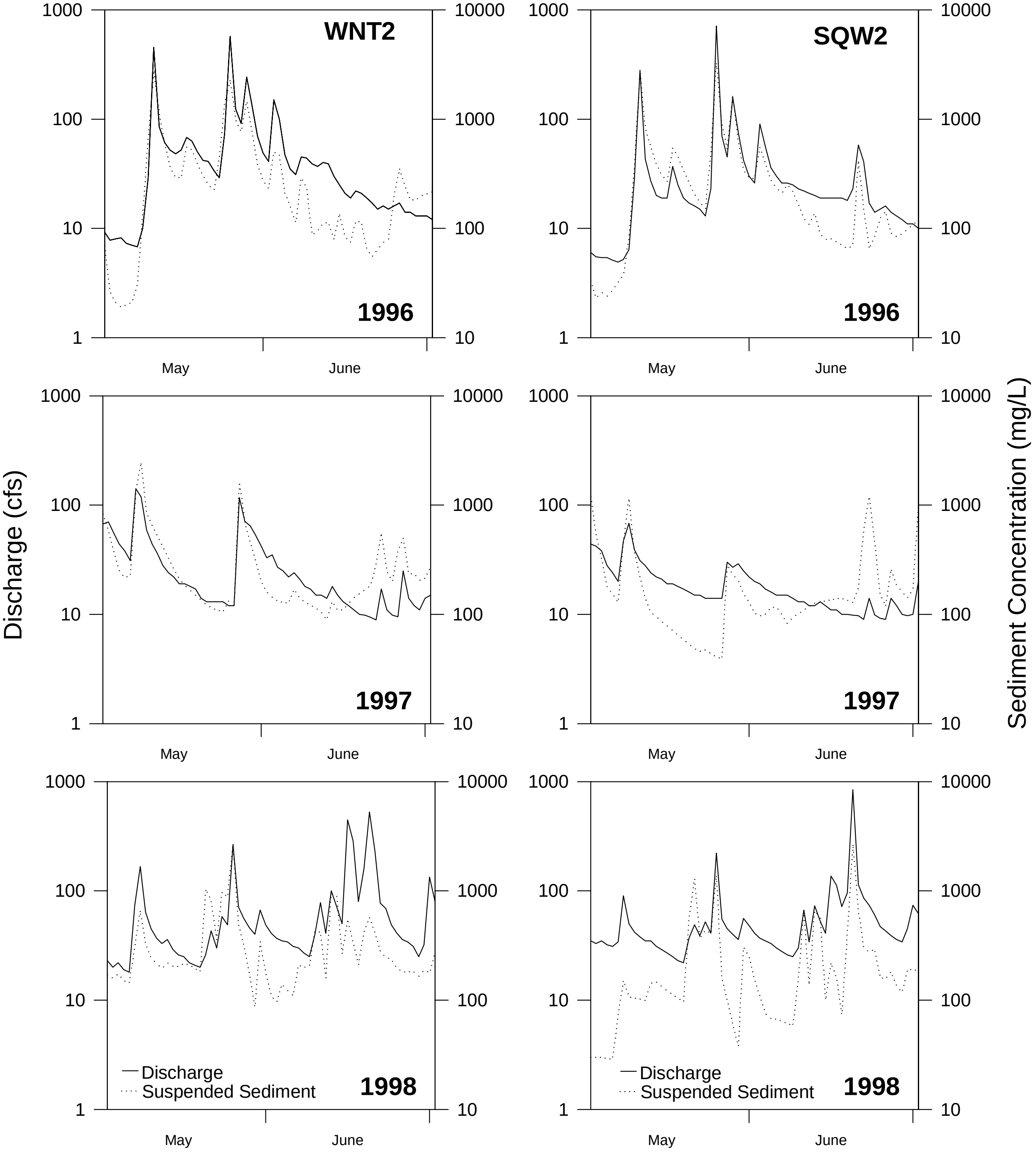

Figure 9. Summary of stream discharge and suspended sediment concentrations for sites WNT2 and SQW2 for months of May and June, water years 1996 to 1998.

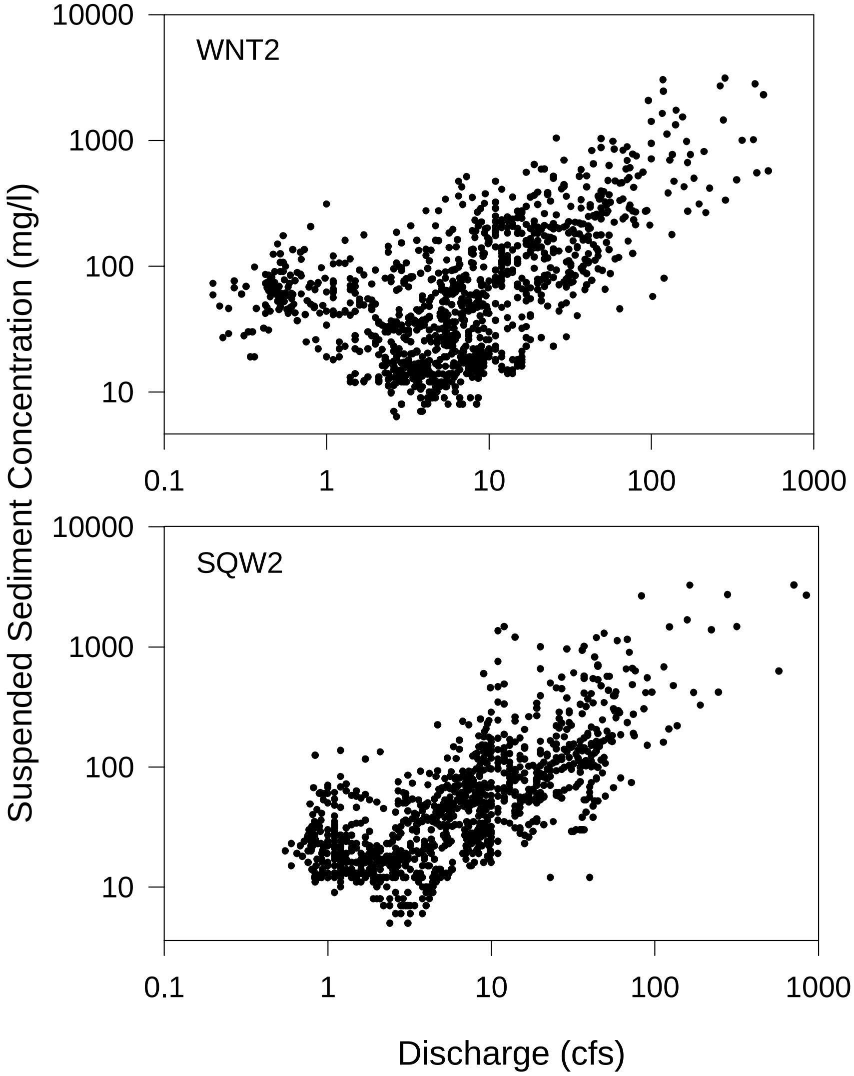

Figure 10. Relationship of stream discharge to suspended sediment concentration.

watersheds (June 18, 1998 and May 24, 1996) although peak flows on these two dates were higher at SQW2. After the highest two events, the rank of other maximum discharge events was similar, although discharge values measured at WNT2 were often higher than SQW2 for the same day. Of the top twenty events, six occurred in February (both watersheds), seven (WNT2) and five (SQW2) occurred in May (WNT2) and five (WNT2) and six (SQW2) occurred in June. Large discharge events occurred most often in 1996 (eleven and nine at WNT2 and SQW2, respectively) and 1998 (eight and ten, respectively). For Water Year 1997, only the February 18, 1997 discharge event in both watersheds ranked among the top twenty (Table 7). Overall, Squaw Creek discharge tended to peak higher and exhibit much greater range in maximum discharge values compared to Walnut Creek.

The timing and magnitude of maximum sediment load was less consistent than discharge (Table 7). The maximum sediment load measured at

Table 6. Frequency of occurrence of various suspended sediment concentrations for water years 1996 to 1998.

	WNT2				SQW2			
Concentration Range (mg/l)	WY96	WY97	WY98	WY 96-98	WY96	WY97	WY98	WY 96-98
<20	23.2%	46.2%	24.7%	23.1%	27.9%	21.4%	4.9%	26.4%
20-50	24.3%	24.0%	22.2%	24.3%	29.3%	26.3%	36.4%	29.9%
50-100	26.5%	10.7%	21.9%	21.4%	21.1%	15.9%	32.1%	21.3%
100-200	11.5%	8.7%	16.7%	14.3%	12.1%	14.8%	16.2%	12.3%
200-300	6.3%	3.8%	6.3%	7.0%	3.6%	8.5%	2.5%	3.3%
300-400	2.2%	1.9%	2.7%	3.1%	1.1%	4.4%	1.6%	1.6%
400-500	1.1%	1.4%	0.8%	1.8%	0.8%	3.6%	2.5%	1.6%
500-1000	3.3%	2.5%	3.0%	3.4%	1.6%	3.8%	2.5%	2.2%
>1000	1.6%	0.8%	1.6%	1.6%	2.5%	1.4%	1.4%	1.6%

Table 7. Rank of top twenty discharge and sediment loads measured in the Walnut and Squaw creek watersheds for water years 1996 to 1998.

	WNT2				SQW2			
Rank	Date	Discharge (cfs)	Date	Sediment Load (tons/day)	Date	Discharge (cfs)	Date	Sediment Load (tons/day)
1	6/18/98	526	3/30/98	4600	6/18/98	847	6/18/98	11400
2	5/24/96	491	5/10/96	3980	5/24/96	710	5/24/96	6880
3	6/14/98	447	5/24/96	3440	2/10/96	575	3/30/98	2930
4	5/10/96	436	5/24/98	3310	2/18/97	318	5/10/96	2720
5	2/18/97	426	5/7/97	1713	5/10/96	279	2/18/97	1657
6	2/10/96	362	3/9/97	1465	2/11/96	245	5/24/98	1520
7	7/7/98	336	2/18/97	1266	5/24/98	222	3/9/97	1062
8	6/15/98	286	5/8/97	1231	2/20/96	190	2/10/96	1030
9	3/30/98	284	7/22/98	1230	2/9/96	173	5/27/96	1010
10	5/27/96	278	6/18/98	1040	3/30/98	164	3/31/98	574
11	5/24/98	266	5/27/96	1030	5/27/96	158	2/20/97	321
12	6/19/98	229	2/10/96	942	6/14/98	137	2/11/96	305
13	2/11/96	217	5/26/97	937	7/7/98	130	2/9/96	244
14	2/20/96	211	6/14/98	830	3/31/98	123	5/8/97	240
15	2/9/96	197	3/31/98	780	2/12/96	122	5/25/96	237
16	6/1/96	183	7/7/98	551	6/19/98	114	6/19/98	227
17	5/28/96	174	2/20/96	463	6/15/98	113	6/1/96	214
18	2/21/96	168	6/11/98	427	6/17/98	96	7/7/98	203
19	5/7/98	167	7/17/96	408	6/1/96	90	7/17/96	194
20	5/25/96	165	6/15/98	334	5/7/98	90	6/11/98	190

Table 8. Maximum daily sediment loads and percentage of annual total (non-consecutive days).

Gauging Site and Water Year	**Maximum Daily Sediment Loads (tons/day) and Percent Annual Total**			
	1-day	5-day	10-day	20-day
WNT 1				
1996	1,080 (42.6%)	1,711 (67.5%)	1,985 (78.3%)	2,188 (86.3%)
1997	874 (44.6%)	1,352 (69.0%)	1,520 (77.5%)	1,647 (84.0%)
1998	654 (23.7%)	1,409 (51.1%)	1,698 (61.6%)	1,994 (72.3%)
WNT 2				
1996	3,980 (27.8%)	9,855 (68.9%)	11,488 (80.3%)	13,111 (91.7%)
1997	1,710 (18.2%)	6,612 (70.4%)	7,692 (81.8%)	8,511 (90.6%)
1998	4,600 (25.0%)	11,010 (60.0%)	13,405 (73.0%)	15,201 (82.8%)
SQW 2				
1996	6,880 (46.2%)	11,945 (80.2%)	13,022 (87.4%)	13,957 (93.7%)
1997	1,657 (33.1%)	3,435 (68.7%)	4,040 (80.8%)	4,444 (88.9%)
1998	11,400 (55.7%)	16,651 (81.4%)	17,493 (85.5%)	18,382 (89.9%)

SQW2 (11,400 tons/day) was nearly 2.5 times greater than the maximum sediment load measured at WNT2 (4,600 tons/day). In fact, on the day of the maximum load at SQW2 (June 18, 1998), sediment load at WNT2 measured an order of magnitude less (1,040 tons/day) and ranked as the 10th highest load. Although 15 of the 20 maximum sediment loads occurred on the same day in both watersheds, seldom were their sediment load total or order of ranking similar. Sediment loads ranked as high as five and nine in Walnut Creek did not appear on the SQW2 list. Although the top two sediment loads measured at SQW2 (total of 18,280 tons/day) were significantly higher than those measured on the same day at WNT2 (total of 8,580 tons/day), on most other dates where sediment load data were compared, Walnut Creek watershed tended to have higher sediment loads. The overall pattern of sediment transport is consistent with discharge. Maximum values and range were higher in Squaw Creek. Of the top twenty sediment loads, the months of May, June and February accounted for most of the maximum values. February accounted for slightly more frequent high loads in Squaw Creek than Walnut (five versus three), whereas frequencies in other months were very similar. Water Year 1996 accounted for 45% of the highest loads in Squaw and 30% of the high loads in Walnut; 20 to 25% of the maximum loads were measured in Water Year 1997 and 35 to 45% of the maximum loads were measured in Water Year 1998 (Table 7).

The trend toward higher maximum sediment loads in Squaw Creek is also shown by data presented in Table 8. In the Squaw Creek watershed, the maximum one-day total of sediment load represented 33.1 to 55.7% of the annual total load, whereas the one-day total measured in Walnut Creek was considerably less (18.2 to 27.8%). Maximum five-day totals also comprised a lower percentage in Walnut Creek, but percentages were more similar in ten-day totals. When maximum 20-day sediment loads were totaled, the percentages were nearly equal (Table 8). Maximum sediment load data from the upstream gauge on Walnut Creek (WNT1) was more variable than measured at the downstream gauge (WNT2). One-day sediment totals ranged from 23.7 to 44.6% of the annual total at WNT1. The five-, ten- and twenty-day total loads at WNT1 generally accounted for a lower

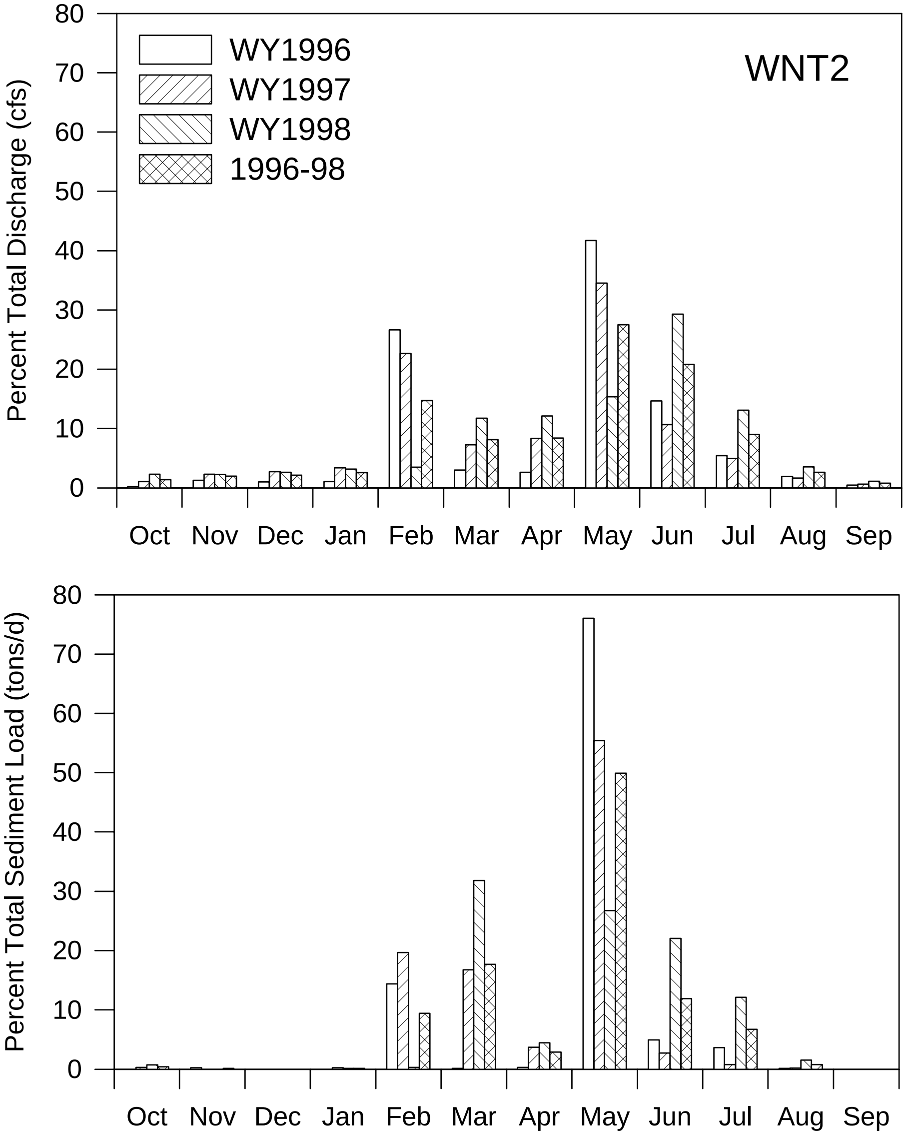

Figure 11. Monthly discharge and suspended sediment loads at WNT2, expressed as percentage of total, for water years 1996 to 1998.

percentage of the annual total than either WNT2 or SQW2 (Table 8).

Seasonal Patterns

Seasonal variations in discharge and suspended sediment loads suggested by daily measurements (Figure 7) were summarized by month in Figure 11 (Walnut Creek) and Figure 12 (Squaw Creek). Table 9 includes mean monthly discharge and sediment concentration data for both watersheds during the three-year monitoring period. Both watersheds showed a similar temporal pattern in monthly discharge and suspended sediment concentrations and loads. Highest monthly discharge totals occurred in May and June when, on average between 1996 and 1998, 48% (Walnut Creek) and 44% (Squaw Creek) of the total discharge for the

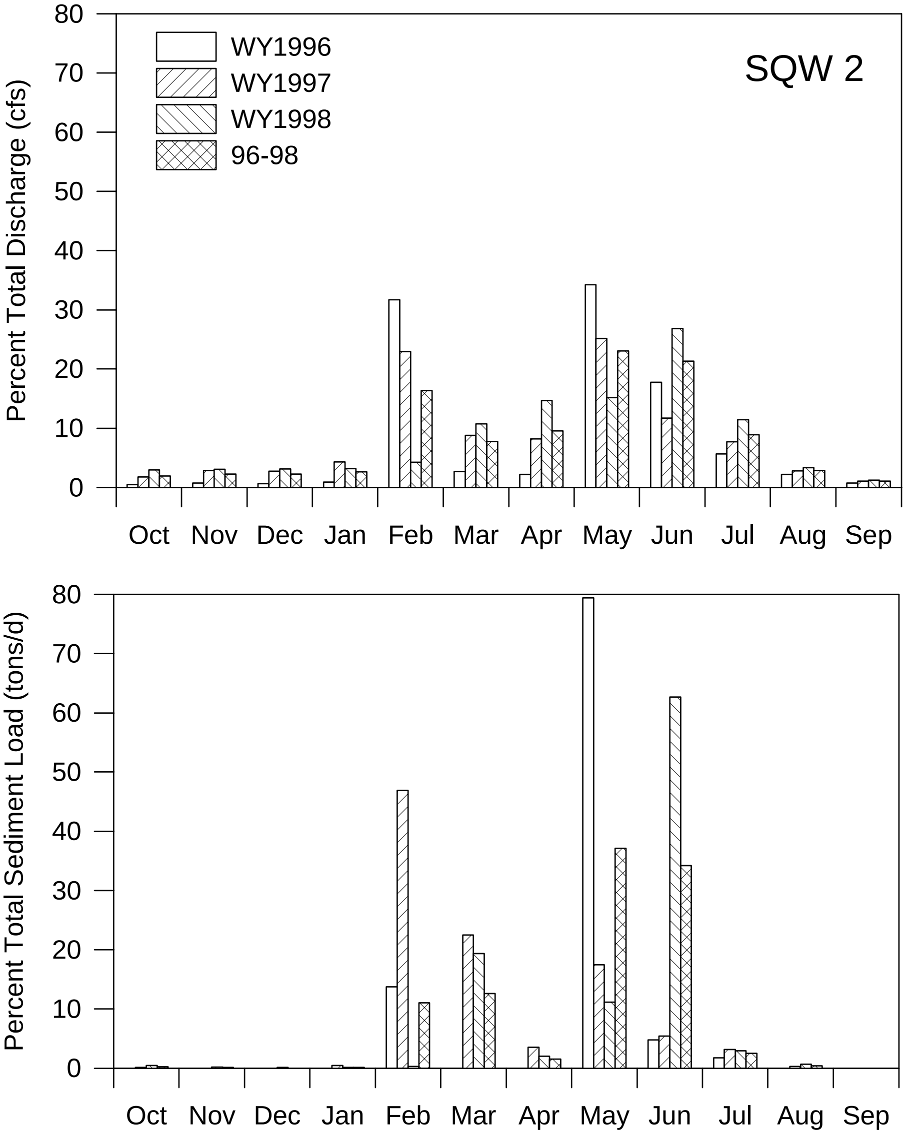

Figure 12. Monthly discharge and suspended sediment loads at SQW2, expressed as percentage of total, for water years 1996 to 1998.

year occurred. Mean discharge was considerably higher in Walnut Creek in May and June (63 and 52 cfs) than Squaw Creek (43 and 40 cfs) but was similar for other months (Table 9). In any given year, discharge in May and June was variable in each watershed, ranging between 11 and 42% of the total discharge (Figures 11 and 12). The next highest mean monthly discharge occurred in February from snowmelt events and averaged approximately 34 to 37 cfs (Table 9). The month of February accounted for approximately 15% of the annual discharge total. March, April and July typically accounted for another 7 to 10% of the total annual discharge, averaging approximately 15 to 21 cfs. The remainder of the year accounted for less than 3 percent of the total discharge each month (Figures 11 and 12). The period from August through January accounted for 11.5% of the total

Table 9. Summary of monthly mean discharge and suspended sediment concentrations for water years 1996 to 1998.

	WNT2				SQW2			
	Suspended Sediment (mg/L)			Q (cfs)	Suspended Sediment (mg/L)			Q (cfs)
Month	Mean	Median	s.d.	Mean	Mean	Median	s.d.	Mean
Oct	84.1	62	89.4	3.12	41.6	28	40.9	3.88
Nov	38.7	21	61.4	4.58	23.8	18.5	18.8	4.65
Dec	20.5	17	10.5	4.84	19.7	18	8.0	4.70
Jan	18.6	16	9.3	6.40	21.6	15	14.7	5.97
Feb	131.6	33	214.9	36.92	160.5	60	255.8	33.73
Mar	168.5	47	479.1	18.49	166.0	53	459.7	15.59
Apr	104.5	35	174.4	19.84	66.9	41	116.6	19.55
May	480.5	261	561.3	63.02	325.4	151	510.6	43.16
Jun	221.7	182	159.6	51.61	243.3	136.5	348.4	40.09
Jul	172.4	100	264.4	21.09	128.6	86	171.6	16.79
Aug	110.3	69	115.1	6.49	62.1	44	92.8	4.97
Sep	76.6	61	50.6	1.98	42.9	36	28.6	2.13

discharge total in Walnut Creek and 13% of the annual total in Squaw Creek.

Suspended sediment concentrations showed large variability but generally followed a similar temporal pattern as discharge (Figure 13). Mean monthly concentrations were highest in May (325 to 481 mg/l) and June (222 to 243 mg/l) in both watersheds (Table 9), but standard deviations indicated significant variability in these months. In all the data, median sediment concentrations were less than mean values, indicating that the means were biased by occasional peak concentrations. Sediment concentrations generally decreased from peak concentrations in June to lowest concentrations measured during December and January (Figure 13). Mean sediment concentrations showed less variability in December and January than other months (Table 9). Squaw Creek showed higher mean concentrations in January, February, and June, whereas Walnut Creek had higher mean values in all other months.

Suspended sediment loads were concentrated in the period between February and July (Figures 11 and 12). Highest monthly totals occurred in May and June when these two months accounted for an average of 61% of the total annual load in both watersheds. Total loads in May and June were highly variable, however, ranging from highs near 80% of the annual total in May WY1996 in both watersheds to less than 3% in June WY1997 in Walnut Creek. Total loads in February and March were similar, on average, in both watersheds (8 to 18%), whereas these two months were typically followed by much lower suspended sediment loads in April (less than 3% of the annual total). Overall, the period between February and July of each year accounted for approximately 98.5 percent of the total annual suspended sediment load in both Walnut and Squaw Creek watersheds. Monthly sediment loads tended to be more variable than total discharge within any given month and were more heavily concentrated in the months between February and July (Figures 11 and 12).

Although total monthly discharge and sediment loads were significantly related to total monthly precipitation in both Walnut and Squaw creek watersheds, considerable scatter exists in the data. In the Walnut Creek watershed, a linear regression of monthly precipitation and discharge was significant at p=0.005 ($r^2 = 0.219$) and monthly precipitation and sediment load was significant at p=0.005 ($r^2 = 0.419$). The relationship of monthly precipitation to discharge and sediment loads was equally significant in Squaw Creek (respectively, p=0.0005,

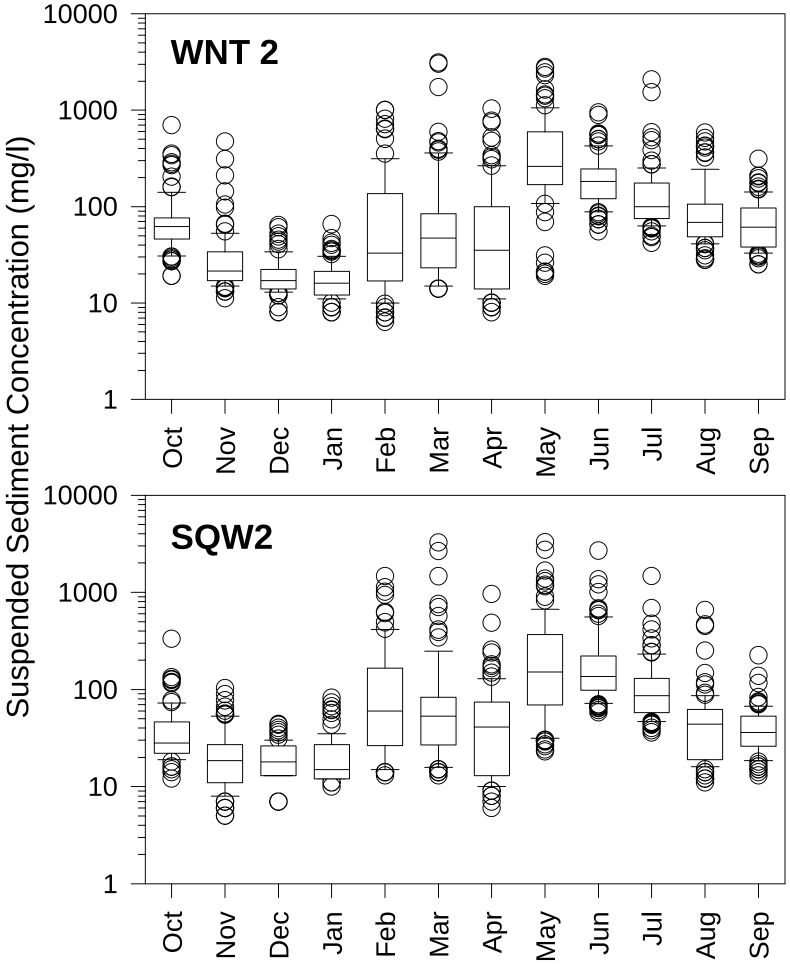

Figure 13. Box plot of suspended sediment concentration values measured at WNT2 and SQW2 sampling sites for water years 1996 to 1998. Box plots illustrate the 25th, 50th and 75th percentiles; the whiskers indicate the 10th and 90th percentiles; and the circles represent data outliers.

r^2=0.321; p=0.0005, r^2=0.381). However, the low r^2 values suggest that precipitation may explain only 20 to 40 percent of the monthly variability of discharge and suspended sediment loads. Although monthly precipitation typically increased from February to May (Figure 6), discharge typically peaked in February then decreased in March and April (Figures 11 and 12). Elevated precipitation totals occurring in August, September and October often did not result in discharge or suspended sediment increases in these months. For example, more than five inches of precipitation in August 1998 did not significantly increase total discharge or sediment loads for the month.

Annual Summary

A summary of three years of discharge and suspended sediment monitoring is shown on Table 10. Mean annual discharge in the Walnut and Squaw Creek was variable, ranging from 8.8 cfs in Squaw Creek in WY 1997 to 27.5 cfs in Walnut Creek in WY1998. On a square mile of drainage basin, discharge was nearly equal between the two watersheds in water years 1996 and 1998 but higher in Walnut Creek in 1997.

Table 10. Summary of annual discharge and suspended sediment data for water years 1996 to 1998.

Parameter	Sample Site	Water Year 1996	Water Year 1997	Water Year 1998
Precipitation (in)	WNT1	24.33	24.77	28.95
	WNT2	32.81	25.40	41.57
	SQW2	23.38	26.69	34.40
Total annual discharge (ft^3/sec)	WNT1	2,090	1,299	3,374
	WNT2	6,400	4,487	10,027
	SQW2	5,945	3,197	9,279
Annual mean discharge (ft^3/sec)	WNT1	5.7	3.6	9.24
	WNT2	17.5	12.3	27.5
	SQW2	16.2	8.8	25.4
Annual mean discharge per square mile drainage (ft^3/sec /mi^2)	WNT1	0.84	0.52	1.36
	WNT2	0.86	0.61	1.35
	SQW2	0.88	0.48	1.38
Maximum daily discharge (ft^3/sec)	WNT1	210	118	192
	WNT2	573	426	526
	SQW2	710	318	847
Baseflow percentage	WNT1	26%	48%	53%
	WNT2	31%	41%	44%
	SQW2	31%	52%	59%
Maximum suspended sediment concentration (mg/l)	WNT1	1,830	1,930	2,130
	WNT2	2,800	3,270	3,020
	SQW2	2,650	3,120	3,250
Annual mean suspended sediment concentration (mg/l)	WNT1	99.6	118.5	127.3
	WNT2	127.8	126.8	153.2
	SQW2	93.5	105.9	119.6
Maximum suspended sediment discharge (tons/day)	WNT1	1,080	874	654
	WNT2	3,980	1,710	4,600
	SQW2	6,880	1,657	11,400
Total suspended sediment discharge (tons/year)	WNT1	2,534	1,961	2,757
	WNT2	14,305	9,403	18,367
	SQW2	14,898	5,001	20,456
Annual suspended sediment load per square mile (tons/mi^2)	WNT1	376	291	409
	WNT2	710	467	912
	SQW2	821	276	1,127
Annual suspended sediment load per acre (tons/acre)	WNT1	0.58	0.45	0.64
	WNT2	1.11	0.73	1.42
	SQW2	1.28	0.43	1.76

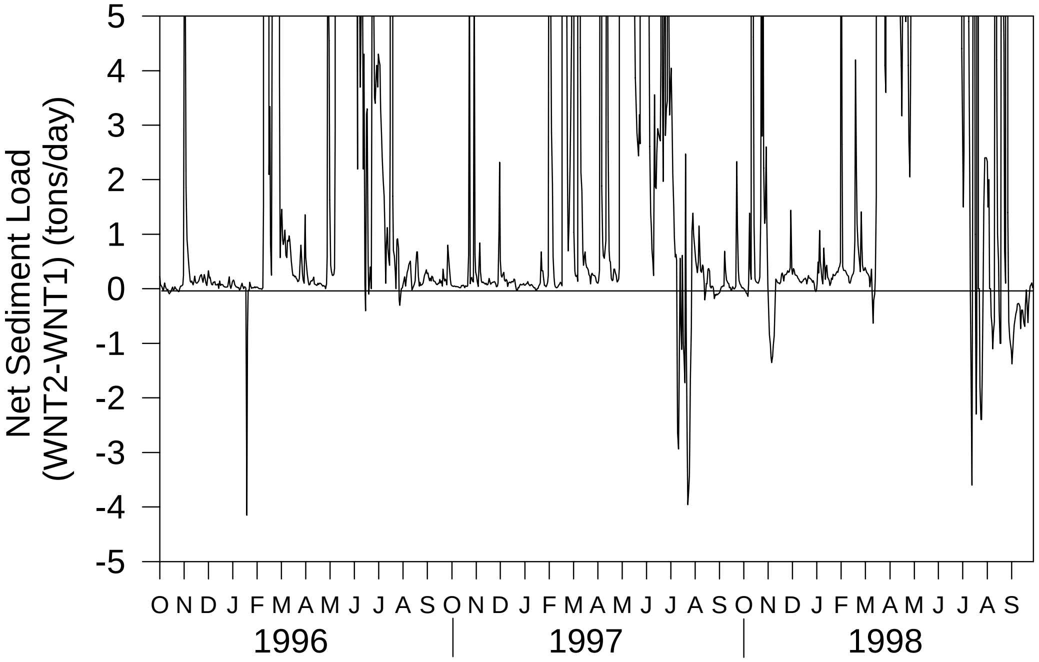

Figure 14. Difference in daily suspended sediment loads measured at upstream (WNT1) and downstream (WNT2) locations. Note top of scale cut off at 5 tons/day.

Perennial streamflow in Walnut and Squaw Creeks is maintained by discharge from groundwater and tile lines. Annualized baseflow percentages show that groundwater and tile line discharge comprised approximately 30 to 60 percent of the total discharge in either watershed (Table 10). The variability in baseflow percentages indicates how difficult it is to generalize on a baseflow percentage from year to year from a limited record. For the three years of daily discharge measurements associated with average to slightly below normal precipitation, baseflow percentages indicate that groundwater contributions to the stream are potentially significant in terms of total discharge.

Like discharge, annual total suspended sediment loads were also variable in the Walnut and Squaw Creek watersheds, ranging from 4,000 tons to more than 20,000 tons (Table 10). Total sediment loads were slightly less at WNT2 compared to SQW2 in water years 1996 and 1998, but Walnut Creek nearly doubled the sediment load in Squaw Creek in 1997. This increase corresponded with the increase in discharge in Walnut Creek in 1997. In Water Year 1998, the total sediment load measured at WNT2 (18,367 tons) and SQW2 (20,456 tons) represented a loss of 912 and 1,127 tons of sediment per square mile of drainage area, respectively (Table 10). This loss of sediment corresponded to 1.42 and 1.75 tons/acre, respectively.

Walnut Creek Upstream Versus Downstream Comparison

Two USGS gauging stations on Walnut Creek provided data on discharge and suspended sediment at upstream and downstream locations (see Figure 1). Discharge and sediment peaks clearly show the relationship between basin size. The timing of daily discharge and sediment peaks was the same as expected, but the peaks measured at WNT2 were considerably larger (Figure 7).

Comparison of daily sediment loads measured at the upstream gauge (WNT1) to sediment load measured at the downstream gauge (WNT2) indicates that most of the time Walnut Creek was exporting more sediment that it received from upstream sources (Figure 14). However, on several days in summer and fall, there were higher incoming sediment loads measured at WNT1 than exporting loads measured at WNT2. This suggests there was, on occasion, net deposition of sediment in the Walnut Creek channel during periods of low flow. In general, net sediment loads between upstream and downstream gauges were relatively equal during the late summer, fall and winter periods except for occasional large increases from individual discharge events (Figure 14). Discharge events in spring and early summer usually resulted in large net export of sediment from the watershed.

Within the Walnut Creek watershed, discharge measured at WNT1 accounted for approximately 29 to 34 percent of the discharge measured at WNT2 (Table 10). This range was consistent with the ratio of land area between the two watersheds (WNT1 comprises 33.4 percent of WNT2 basin). Sediment load measured at WNT1 accounted for approximately 15 to 21 percent of the suspended sediment measured at WNT2. This percentage of total sediment load was less than discharge percentages calculated for the two areas. Normalizing the data on a square mile basis, sediment loss above WNT1 was about one-half of the sediment loss per square mile measured for the entire watershed (Table 9). This indicates greater contribution to suspended sediment loads in the lower portion of the watershed.

DISCUSSION

Nature of Discharge and Suspended Sediment Transport

Daily monitoring indicates that discharge and suspended sediment transport in the Walnut and Squaw Creek watersheds is highly event driven. Single day discharge events typically accounted for 5 to 12 percent of the annual discharge, whereas single day suspended sediment loads accounted for 18 to 56 percent of annual sediment total. A 20-day period in any given water year (non-consecutive days) accounted for as much as 94 percent of the annual sediment total. This pattern of rapid conveyance of discharge and sediment loads is typical of incised channels (Happ et al., 1940; Knox, 1987; Shields et al., 1995; Faulkner and McIntyre, 1996). In incised channels, flood events peak higher and faster as more water is contained within the channel, promoting efficient transport of suspended sediment downstream. Channel incision in the Walnut and Squaw Creek watersheds probably contains all but the most exceptional flood flows and contributes to the rapid downstream conveyance of sediment.

Channel incision of Walnut Creek and Squaw Creek probably occurred quite rapidly after initiation of intensive row crop production and modification of stream channel morphologies. Simon (1989) described the relationship between stream power (discharge and gradient) and the ability to move sediment (sediment discharge) as a "dynamic equilibrium":

$$QS \sim Q_s d_{50} \qquad \text{(Equation 3)}$$

where bankfull discharge (Q) and channel gradient (S) balance with bed-material discharge (Q_s) and median grain size of the bed material (d_{50}). An increase in stream power or changes in sediment discharge quantity or character can disrupt this balance and result in a stream incising into its floodplain. In the case of Walnut Creek and Squaw Creek, this balance was disrupted significantly in the past when stream channels were straightened (resulting in increased stream gradients) and much of the watersheds were row cropped and tile drained (resulting in increased flow to the channel). The stream channels subsequently moved toward equilibrium by incising into their channels and increasing sediment loads through downcutting and widening. If Walnut Creek and Squaw Creek behaved similar to other Midwestern watersheds, much of the disruption probably occurred during the early part of the 20th century. Trimble and Lund (1982) noted that pervasive land deterioration occurred in the Coon Creek watershed in southeastern Wisconsin primarily between 1910 and 1940. Aerial photographs of Walnut Creek watershed showed little evidence of modern conservation by 1940, perhaps suggesting that the period of land disturbance extended to a later time in this watershed.

Considering that both Walnut and Squaw Creek channels are deeply incised into their floodplains how comparable are discharge and suspended sediment loads between the two watersheds? Over a three-year period, peaks in discharge and suspended sediment loads showed temporal consistency but often differed substantially in magnitude. Variations in precipitation patterns and intensity between the two watersheds probably account for some of this difference. The timing, location and magnitude of precipitation events may vary considerably over very small geographic areas, especially during large storms in spring and summer. However, these precipitation variations have been minimized to the extent practicable with the paired watershed approach.

There is evidence to suggest that Squaw Creek exhibits flashier behavior than Walnut Creek. Based on three years of record, Squaw Creek showed greater peak flow and sediment loads and a higher proportion of annual sediment loads migrating during one- and five-day periods. It is possible that watershed morphology and land use differences contribute to higher peak events in the Squaw Creek watershed. Greater basin relief, channel slope and less sinuosity in Squaw Creek would tend to increase hydraulic gradients and result in higher peak discharge. Baseflow percentages indicate surface runoff comprises a larger percentage of annual discharge in Squaw Creek than Walnut Creek. Peak runoff events may be higher in Squaw Creek, in part, due to a higher percentage of row crop land use and greater use of tile drainage in the watershed.

Could some differences in runoff and sediment load characteristics between the two watersheds be attributable to prairie restoration activities in Walnut Creek? Widespread conversion of row crop land to native prairie should, in time, result in reduced surface water runoff and increased infiltration, ultimately leading to lower flood peaks and suspended sediment loads in the watershed. Currently, over 13 percent of the Walnut Creek watershed has been converted from row crop to native prairie. At this point, it is unknown whether this amount of restoration is sufficient to begin to observe reduced flood peaks and suspended sediment loads. Three years of record are obviously too few to make clear distinctions in causal mechanisms, but the limited data record is nonetheless consistent with hypothesized effects of prairie restoration.

Sediment Sources

Research into incised channels in Mississippi and Tennessee indicated that the source of sediment in these states was dominated by streambeds and banks (Shields et al., 1995; Simon, 1989). Mapping data available from Walnut Creek suggest that streambanks also contribute large sediment loads in the Walnut and Squaw Creek watersheds. Mapping streambank erosion rates in Walnut Creek suggested that approximately 50% of the annual sediment load could be accounted for by streambank erosion. This percentage is consistent with data from larger Iowa rivers where it has been estimated that 45% of the total sediment load leaving the state was from in-stream bank erosion. (Odgaard, 1984). In the Walnut and Squaw Creek watersheds, streambanks are particularly susceptible to erosion. Channel incision has occurred primarily through post-settlement materials and Holocene alluvium, which lack the cohesive strength of the underlying till. In particular, historical post-settlement alluvium (Camp Creek Member) would be easily remobilized by streambank erosion because these materials lack internal structure provided by buried soil horizons developed during the Holocene (Bettis and Littke, 1987; Kreznor et al., 1990; Beach, 1994).

Streambed degradation of the underlying till is not believed to be a significant sediment source in the watersheds. Despite evidence for active downcutting in several straightened reaches of Walnut Creek (evidenced by narrow, V-shaped channel cross-sections and a channel bottom consisting of bare or thinly mantled till; Figure 2), base level is controlled by resistant Pre-Illinoian till. Stream mapping in Walnut Creek showed little or no streambank erosion occurring in these straightened reaches. On the contrary, downcutting appears to have been slowed by the resistant till bottom which has allowed streambanks to become relatively stable and well vegetated. Streambanks in channelized segments showed little sign of recent mass wasting or undercutting. Most severe streambank erosion in Walnut Creek was concentrated in active meandering areas, debris dam areas and cattle access points. Reduced sediment loads derived from the streambed may be partially responsible for the high proportion of annual sediment load derived from streambank erosion. In order to achieve sufficient sediment load to balance stream power (Equation 3), less sediment supplied by the streambed would result in a higher proportion of sediment coming from other sources (i.e., streambanks).

Other sources of sediment in the watersheds include concentrated flow erosion from gullies and tributaries and sheet and rill erosion from upland sources. In the Walnut Creek watershed, these sediment sources combine to contribute the remaining 50% of the annual sediment loads. Future work in both Walnut and Squaw Creek watersheds will focus on developing a sediment erosion model that incorporates all sediment sources, including streambanks, gullies and sheet and rill erosion.

Eroded sediment that reaches the main channel of Walnut Creek or Squaw Creek does not necessarily exit the watershed immediately. Stream mapping in Walnut Creek indicated that sediment often accumulates in the channel behind logs, debris dams or other impediments. Others have observed that these features can provide temporary base levels in the stream and temporary storage sites of sediment for long periods (Mosley, 1981; Trimble 1983). When these temporary storage sites are destroyed or disrupted, stored sediment becomes available again for transport and is eventually flushed from the watershed. Thus, streambed sediment stored in the channel bottom can also provide a continuing source of sediment downstream. In Walnut Creek, calculations suggested that up to nine years would be required to flush the bed sediment out of the watershed, assuming a mean annual flow rate and suspended sediment concentration, and no additional sediment inputs. Although stream mapping was not conducted in Squaw Creek, field reconnaissance suggests that bed materials and stream bank conditions are similar between the two watersheds.

Conceptual Model of Seasonal Sediment Transport

Seasonal variation in discharge and suspended sediment between the Walnut and Squaw Creek watersheds was relatively consistent during the monitoring period. Both streams transported most of their discharge and suspended sediment loads during a six month period between February and July. Seasonal sediment loads were particularly pronounced, with the February to July period accounting for more than 98 percent of the annual total. A cyclical pattern of sediment movement downstream is suggested by the seasonal data (Figure 15). Following winter, the first major snowmelt event typically contributes large discharge and sediment loads (Figure 15). Large sediment loads would come primarily from in-channel storage and streambanks. Streambed sediment, which had settled on the channel bottom when the stream was frozen, would be remobilized by flowing meltwater. Streambank failure by mass-wasting processes would introduce additional sediment to the stream system. After the major snowmelt event(s), discharge tended to decrease during early spring (March and April) whereas sediment loads remained elevated (Figure 15). Sediment loads could remain high due primarily to contributions from streambanks (mass-wasting, streamside erosion of exposed and poorly vegetated banks), and increased sediment runoff from sheet and rill erosion from spring plowing.

In May and June, precipitation increased in amount and intensity, resulting in large increases in discharge and sediment loads (Figure 15). Heavy rains and increased discharge during this period would tend to mobilize sediment from a variety of sources, including streambanks, ephemeral gullies and upland sources. Rapidly rising and falling stream levels would result in variable bank saturation levels and lead to increased occurrences of slumps and mass wasting. Undercutting of some streambanks would result in some large failures. In

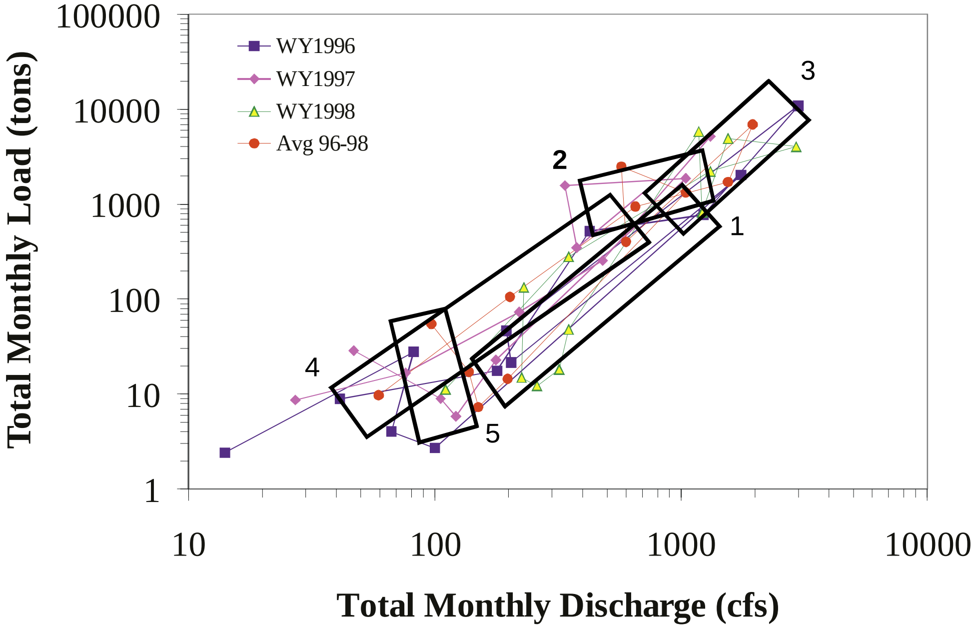

Figure 15. Conceptual model of seasonal sediment transport in Walnut Creek watershed: 1) rapid increase in discharge and sediment during snowmelt; 2) high sediment loads with decreasing discharge after snowmelt; 3) high discharge and sediment loads in May/June rains; 4) major decrease in discharge and sediment loads during summer and early fall; and 5) stable discharge and low sediment loads in late fall and winter.

the uplands, freshly tilled fields and emerging crops would offer little resistance to overland flow and result in increased sheet and rill contributions. Within the stream channel itself, high flow events would destroy many debris dams and rapidly mobilize channel sediment downstream.

Through the summer and early fall, discharge and suspended sediment loads typically decreased (Figure 15). Large precipitation events in late summer and fall did not often result in large discharge events or suspended sediment loads. In the uplands, increased infiltration and evapotranspiration provided by growing crops and grasses would reduce sediment loads resulting from runoff. Along the streambanks, mass wasting would subside as discharge decreases and annual vegetation anchors fresh scarp surfaces and newly formed slump blocks. Within the stream channel, newly formed debris dams from earlier peak flow events would provide temporary storage sites for streambed sediment. In the late fall and winter, discharge was typically stable and sediment transport appeared to enter a storage phase (Figure 15).

Restoration Timeframe in the Walnut Creek Watershed

Given the variability and flashy behavior of discharge and sediment transport in the Walnut and Squaw Creek watersheds, and the continuing sources of sediment, what will be the timeframe needed to detect changes in the Walnut Creek watershed resulting from the land restoration efforts? Discharge and suspended sediment data from water years 1996 to 1998 indicated that maximum flood events and sediment loads were lower in Walnut than Squaw but overall patterns of discharge and suspended sediment loads were indistinguishable between the two watersheds.

Often a long-term monitoring record is needed to factor out influences of climate and historical sediment storage. Potter (1991) looked at a 47-year period of record in southwestern Wisconsin to factor out climatic factors in order to detect changes in watershed hydrology resulting from adoption of conservation measures. Others, such as Trimble (1983), Knox (1977) and Beach (1994), examined historical records dating as far back as the 1830's to prepare sediment budgets needed to estimate changes in sediment transport at watershed scales. Trimble and Lund (1982) looked at more than 100 years of land use and sedimentation records and noted a lag time (or "hysteresis") of 10 years between 1930 and 1940 in the Coon Creek watershed in Wisconsin before improvements in land use resulted in decreases in erosion and sedimentation. In the Buffalo River watershed in west-central Wisconsin, Faulkner and McIntyre (1996) investigated the persistence of high sediment yields despite decades of erosion control and land use changes. They found that channel incision migrating into tributary streams increased conveyance capacities of sediment downstream.

In Iowa, the longest period of record available for a similar size watershed is the Sny Magill/ Bloody Run paired watershed study in northeast Iowa (Seigley et al., 1994). The project is currently in its eighth year of a 10-year monitoring program. Stream morphology and substrate materials differ substantially between the Sny Magill/Bloody Run paired watershed (Seigley, et al., 1994; 1996). The Sny Magill/Bloody Run watersheds are located in the Paleozoic Plateau landform region where the landscape is characterized by thin loess and till overlying bedrock formations (Prior, 1991; Seigley et al., 1994). However, both Sny Magill/Bloody Run and Walnut/Squaw Creek watershed pairs move the majority of sediment during intermittent short-term events. In 1994, for example, seven-days (not consecutive) accounted for 68 to 85% of the total annual sediment load in the Sny Magill watershed (Seigley et al., 1996). Despite 70-80% participation from landowners and the installation of more than 270,000 feet of terraces and other sediment control structures, changes in discharge and suspended sediment have not been detected due to the flashy behavior of the streams (Seigley et al., 1996; unpublished data).

The implication suggested by these studies is that there may a significant time lag before changes in land use in the Walnut Creek watershed translate to reduced discharge and suspended sediment loads downstream. However, aspects of the Walnut Creek project suggest that improvements may be measured more quickly in the Walnut Creek watershed as compared to other watersheds. First, large-scale land use changes involving conversion of row crop acres to native prairie will likely affect discharge and suspended sediment loads in restored areas more than traditional conservation practices (i.e., terraces, contour planting, etc.). Conservation practices have traditionally placed more emphasis on reducing sheet and rill erosion by slowing sheet and rill runoff from upland fields. However, even when runoff is slowed, total discharge from row cropped fields often remains unchanged. Drainage tiles that drain terraces and grassed waterways quickly route runoff and groundwater infiltration to the stream channel. Reducing upland soil erosion without a corresponding decrease in discharge may result in increased downstream erosion of floodplain deposits and no net change in sediment loads (Trimble, 1990). In the case of Walnut Creek, the dense vegetative cover provided by native prairie will increase infiltration and substantially slow runoff and upland erosion. Because restored prairie areas are not tile-drained, discharge during baseflow conditions will also be reduced. Schilling and Wolter (in prep.) noted that baseflow discharge from watersheds dominated by native prairie was about five times less than baseflow discharge from row crop watersheds. Considering the amount of land currently owned by the USFWS and their future acquisition goals, there is potential for a measurable decrease in discharge and subsequent decrease in carrying capacity for suspended sediment loads in the Walnut Creek watershed.

Secondly, as part of their restoration program, the USFWS has removed many drainage tiles that emptied into Walnut Creek. Although stream mapping identified 52 tiles between the two gauging stations, only 19 were flowing sufficiently for measurement. During baseflow, total flow from the 19 flowing tiles was only four percent of the total discharge measured at the downstream gauging station (Schilling and Wolter, in prep.). Prior to restoration, this percentage was undoubtedly much greater when the tiles were actively draining row crop fields. The low percentage of discharge from tiles suggests tile discharge effects are minimal in Walnut Creek and probably considerably greater in Squaw Creek.

A third aspect of the Walnut Creek monitoring program that may enable changes to be more readily detected is the upstream discharge and suspended sediment gauge on Walnut Creek. The upstream gauge may isolate improvements in the lower portion of the watershed, where land use changes are concentrated, from the upstream headwater areas where little or no improvements are anticipated in the near future. The upstream gauge effectively reduces the overall size of the Walnut Creek watershed by one-third and concentrates the land use changes in a smaller area.

However, optimism for detecting changes in the Walnut Creek watershed in a reasonable timeframe must be tempered with caution. First, the effect of climate is a tremendous variable for which there is no control. Climatic effects, including variable location and intensity of precipitation within a watershed or between watershed pairs, can completely overwhelm and mask any reductions in discharge and sediment loads for many years. Climate is a main reason other watershed sediment reduction projects require decades to observe improvements. Compounding climatic variability is the attempt to view improvements between paired watersheds with very similar, yet different morphologies and land use histories. Small differences in channel sinuosity and slope may translate to significant differences in discharge and sediment transport. While similar in a general sense, historical land use in the Walnut and Squaw Creek watersheds has probably resulted in variable amounts and distribution of sediment stored on the floodplain. Considering that streambank erosion can contribute up to 50% of the annual load, and gullies may contribute additional loads, land use changes in the uplands may be difficult to detect above these sediment sources. Most of the sediment available for sediment migration in channels and gullies is derived from sediment storage. Within the channel itself, temporary sediment storage can effect long-term sediment yields. As Schilling and Wolter (in press) noted, based on the amount of sediment stored in the Walnut Creek channel, up to a decade may be needed to remove the sediment from the channel with no additional inputs.

IMPLICATIONS FOR SUSPENDED SEDIMENT MONITORING

Daily suspended sediment monitoring is often an expensive proposition in watershed monitoring projects. For the Walnut Creek 319 monitoring project, sediment sampling at three gauging sites accounts for a large percentage of the annual budget. Based on patterns of suspended sediment transport in the Walnut and Squaw Creek watersheds, are there actions that can be taken to reduce sediment monitoring costs? This issue was evaluated by asking three questions: 1) What would total annual sediment loads look like if samples were collected at reduced frequencies? 2) Can monthly sediment loads be approximated by reduced sampling frequency or can monthly loads be estimated from discharge? 3) Is turbidity a suitable substitute for suspended sediment concentrations?

Reduced Sampling Frequency

To evaluate the first question, daily records of suspended sediment loads measured at the WNT2 and SQW2 gauging stations were subdivided to examine the effects of sampling frequencies on total annual loads. Three sampling frequencies were considered, one sample collected every two days, one sample collected every three days, and one sample collected per week (Table 11). The daily records were sorted, in the case of Table 11-A, by sequentially numbering the daily records as either day 1 or day 2, and then summing all day 1's and day 2's for the water years. For Tables 11-B and 11-C, the days were numbered 1 through 3 or 1 through 7, respectively, and then summed.

In the case of Table 11-A, could total annual sediment loads be approximated by sampling every other day? In a perfect situation, the total annual

Table 11. A. Total annual sediment loads for sediment samples collected at a frequency of one sample every two days. **B.** Total annual sediment loads for sediment samples collected at a frequency of one sample every three days. **C.** Total annual sediment loads for sediment samples collected at a frequency of one sample every seven days.

A.

		Day 1		Day 2		
Site	Data Record	Sediment Load (tons)	Percent of Total	Sediment Load (tons)	Percent of Total	Total Load (tons)
WNT2	WY1996	10,746	75.1%	3,558	24.9%	14,305
	WY1997	4,419	47.0%	4,984	53.0%	9,403
	WY1998	7,941	43.2%	10,425	56.8%	18,367
	Total	23,103	54.9%	18,966	45.1%	42,070
SQW2	WY1996	12,184	81.8%	2,713	18.2%	14,898
	WY1997	2,787	55.7%	2,213	44.3%	5,001
	WY1998	4,310	21.1%	16,146	78.9%	20,456
	Total	19,281	47.8%	21,072	52.2%	40,354

B.

		Day 1		Day 2		Day 3		
	Data Record	Sediment Load (tons)	Percent of Total	Sediment Load (tons)	Percent of Total	Sediment Load (tons)	Percent of Total	Total Load (tons)
WNT2	WY1996	6,076	42.5%	2,162	15.1%	6,067	42.4%	14,305
	WY1997	4,260	45.3%	1,354	14.4%	3,789	40.3%	9,403
	WY1998	6,745	36.7%	3,373	18.4%	8,248	44.9%	18,367
	Total	17,080	40.6%	6,884	16.4%	18,106	43.0%	42,072
SQW2	WY1996	4,584	30.8%	1,403	9.4%	8,910	59.8%	14,898
	WY1997	1,808	36.1%	779	15.6%	2,414	48.3%	5,001
	WY1998	3,333	16.3%	12,728	62.2%	4,396	21.5%	20,457
	Total	9,725	24.1%	14,910	36.9%	15,720	39.0%	40,357

C.

	Day 1 tons/ % of Total	Day 2 tons/ % of Total	Day 3 tons/ % of Total	Day 4 tons/ % of Total	Day 5 tons/ % of Total	Day 6 tons/ % of Total	Day 7 tons/ % of Total	Total Load (tons)
WNT2	6,839	8,207	4,462	5,243	4,977	9,477	2,865	42,070
	16.3%	19.5%	10.6%	12.5%	11.8%	22.5%	6.8%	100.0%
SQW2	13,235	13,220	1,765	3,785	3,974	2,719	1,656	40,354
	32.8%	32.8%	4.4%	9.4%	9.8%	6.7%	4.1%	100.0%

sediment load measured on either day 1 or day 2 could be multiplied by two to estimate the total annual sediment load for the year. Thus, the percentage of the total annual sediment load, as measured once every two days, would be 50 percent. In any given year, sampling either day 1 or day 2 would account for 25 to 75 percent of the annual total in Walnut Creek and 18 to 82 percent of the annual total in Squaw Creek (Table 11-A). Based on a three-year total, the percentage of total load measured on either day 1 or day 2 approached 50 percent.

If sediment samples were collected once every three days, ideally sampling every third day would account for about 33 percent of the annual total. Depending on which day was sampled in either watershed, the percentage of total annual load could range from 9.4 percent to 62.2 percent (Table 11-B). Based on a three-year average, the percentage of total load ranged from 16 to 43 percent in Walnut Creek and 24 to 39 percent in Squaw Creek. Based on the pattern shown by Tables 11-A and 11-B, it is no surprise that the percentage of total load approximated by sampling once per week is highly variable (Table 11-C). Depending on which day was sampled, an individual day could account for seven to 33 percent of the three-year total.

In small, flashy watersheds like Walnut and Squaw creeks, it is clear that sampling sediment at a frequency of one sample every other day or less could potentially provide very misleading results of annual sediment transport. Monitoring data indicates that sampling every other day, in any given year, provides a wide range of annual sediment loads. For example, if the day 1 total for Squaw Creek in water year 1996 were multiplied by two to estimate the annual sediment load, the total estimated load for the year would have been overestimated by nearly 9,500 tons. Conversely, the day 2 total would underestimate the annual total by the same amount. Only by totaling three years of data can reduced sampling frequency approach adequate characterization of sediment loads. However, determination of year-by-year trends would be difficult.

Monthly Comparison

Can sediment loads be estimated on a monthly basis better than an annual basis? Because most of the sediment in the Walnut and Squaw Creek watersheds is transported between February and July each year, how well do estimates characterize sediment transport during the remainder of the year? Four methods were used to estimate sediment loads on a monthly basis (Table 12). Method 1 considered an every other day sampling schedule. Methods 2 and 3 utilized the relationships established between discharge and suspended sediment concentration. Both used previously developed linear regression equations (equation 1 = best fit line; equation 2 = y-intercept equal to zero) to estimate monthly sediment loads from daily discharge measurements. Daily discharge values were used in the two equations to calculate the daily sediment load, which was then summed for each month. Method 4 simply multiplied mean monthly discharge and suspended sediment concentrations (Table 9) to estimate a mean monthly load.

Based on three years of data, all four methods failed to adequately characterize monthly sediment loads for the February and July sediment transport period. Monthly loads varied from 15 to 85 percent based on sampling every other day in Walnut Creek and 11 to 89 percent in Squaw Creek. Monthly estimates based on other estimation methods varied by thousands of tons for several of these months (Table 12). For the remainder of the year (August through January), monthly loads varied considerably less for all methods. Sampling every other day accounted for approximately 37 to 63% of the overall monthly totals in both watersheds. Discrepancies in monthly sediment loads measured from August through January do not substantially contribute to discrepancies in annual sediment load totals. For example in Walnut Creek, the total sediment load measured in either day 1 or day 2 for the August through January period was 264 and 362 tons. Doubling either day 1 or day 2 to estimate the total contribution from these months resulted in an estimated total ranging from 528 to 724 tons, respectively. The difference between these two amounts (196 tons) divided by the total load during

Table 12. Comparison of monthly sediment loads based on sampling once every two days, estimating sediment loads using regression equations 1 and 2 (see text), and estimating loads from mean monthly discharge and sediment concentration.

						Regression Equation 1		Regression Equation 2		Mean Monthly Flow and Sediment Conc.	
WNT2	**Total Load (tons)**	**Day 1 (tons)**	**Percent of Total**	**Day 2 (tons)**	**Percent of Total**	**Estimated Load (tons)**	**Difference from Actual**	**Estimated Load (tons)**	**Difference from Actual**	**Estimated Load (tons)**	**Difference from Actual**
Jan	43	29	67.5%	14	32.5%	172	129	91	48	30	-14
Feb	3,954	3,091	78.2%	863	21.8%	6,473	2,519	6,655	2,701	1,115	-2,839
Mar	7,438	1,096	14.7%	6,341	85.3%	1,899	-5,538	1,819	-5,619	782	-6,655
Apr	1,216	463	38.1%	752	61.9%	960	-255	767	-449	504	-712
May	21,000	14,778	70.4%	6,222	29.6%	11,106	-9,894	11,339	-9,661	7,604	-13,397
Jun	5,014	2,185	43.6%	2,829	56.4%	9,748	4,734	10,036	5,022	2,780	-2,233
Jul	2,824	1,226	43.4%	1,598	56.6%	2,298	-526	2,221	-604	913	-1,911
Aug	314	116	36.8%	199	63.2%	161	-153	79	-235	180	-134
Sep	29	13	45.1%	16	54.9%	34	5	7	-21	37	8
Oct	164	74	45.3%	90	54.7%	86	-78	47	-117	66	-98
Nov	52	21	40.9%	31	59.1%	91	39	32	-20	43	-9
Dec	22	11	48.1%	12	51.9%	99	77	35	13	30	8
Total	42,070	23,103		18,967		33,128		33,128		14,084	

						Regression Equation 1		Regression Equation 2		Mean Monthly Flow and Sediment Conc.	
SQW2	**Total Load (tons)**	**Day 1 (tons)**	**Percent of Total**	**Day 2 (tons)**	**Percent of Total**	**Estimated Load (tons)**	**Difference from Actual**	**Estimated Load (tons)**	**Difference from Actual**	**Estimated Load (tons)**	**Difference from Actual**
Jan	50	31	62.7%	19	37.3%	144	95	85	35	32	-17
Feb	4,450	3,425	77.0%	1,025	23.0%	1,921	-2,528	7,134	2,684	1,242	-3,207
Mar	5,099	874	17.1%	4,225	82.9%	996	-4,103	889	-4,210	650	-4,449
Apr	605	198	32.8%	406	67.2%	935	331	784	180	318	-287
May	14,985	12,440	83.0%	2,545	17.0%	8,660	-6,325	8,829	-6,156	3,527	-11,459
Jun	13,797	1,567	11.4%	12,230	88.6%	9,789	-4,008	10,098	-3,699	2,370	-11,427
Jul	1,016	591	58.2%	425	41.8%	814	-203	678	-338	542	-474
Aug	159	71	44.2%	89	55.8%	99	-60	48	-111	78	-82
Sep	25	11	43.5%	14	56.5%	29	4	7	-18	22	-2
Oct	99	38	37.9%	61	62.1%	103	4	65	-34	41	-58
Nov	41	21	51.7%	20	48.3%	85	44	39	-3	27	-14
Dec	28	14	51.3%	14	48.7%	84	56	36	8	23	-5
Total	40,357	19,281		21,073		23,660		28,692		8,872	

the three-year measurement period (42,070 tons) indicates that the potential error in load estimates utilizing either day 1 or day 2 estimates was 0.46 percent. This would not appear to be a significant deviation over the course of three years.

Other methods compared estimated monthly loads to the actual loads measured at WNT2 and SQW2 (Table 12). Overall, the total loads estimated by these methods substantially underestimated total three-year loads, mainly due to the February through July period. Data from August through January appeared to be better suited for estimating. Data from August appeared to be the most difficult to estimate from linear regression equations or from mean monthly values for the August through January period. The three methods all underestimated the total three-year sediment loads for August by more than 60 tons. October was underestimated by all methods in the Walnut Creek data set and two of the three methods in Squaw Creek. Summing the total positive and negative errors for the August through January period for each method indicated that the range of estimated loads varied from 19 tons overestimated in Walnut Creek using regression equation 1 to 332 tons underestimated in Walnut Creek using regression equation 2. In both watersheds, the best fit regression equation (equation 1) overestimated loads, whereas the other two methods underestimated total loads. The total error for all estimates ranged from 0.04 % to 0.7 % of the three-year total.

Turbidity and Suspended Sediment

Can turbidity be used to estimate suspended sediment concentrations in Walnut and Squaw creeks? Figure 16 shows two plots of this relationship based on available data. The top graph (A) includes all data from both sites, whereas the bottom graph (B) includes only data with an NTU less than 200 and a sediment concentration less than 500 mg/l. A regression line is plotted through the origin on both graphs. It is evident that considerable scatter exists in the data, correlation coefficients were 0.07 in graph A and 0.26 in graph B. The weak relationship shown in graph B suggests that sediment concentration may be estimated by multiplying turbidity by approximately 2.2 for suspended sediment concentrations less than 500 mg/l.

Much of the scatter in the relationship is probably due to differences in timing between collection of a sediment sample and the turbidity measurement. Depending on the timing in relation to high streamflow events, the discrepancies between turbidity and concentration may be exceptionally large. More study of this relationship should be undertaken with specific emphasis on the collection of both measurements simultaneously. Based on data collected to this point, the relationship does not appear strong enough for estimating suspended sediment concentrations on a routine basis in the watersheds.

Summary

Suspended sediment monitoring on a fixed schedule of once every two days (or greater) without regard to season does not provide representative load data on an annual basis. Seasonal patterns should be taken into account so that the period February through July is sampled more intensely (daily) than the remainder of the year. Various methods can be used to estimate sediment loads on a monthly basis in the August through January period. Sampling every other day during this period appears to provide representative results. If a period of monitoring record is developed for the watershed, loads may be estimated by using the relationship between discharge and suspended sediment concentration or mean discharge and concentration values for the various months. The relationship between suspended sediment concentration and turbidity holds promise but should be compared more precisely than the existing data set permits.

CONCLUSIONS

The following conclusions are supported from three years of monitoring discharge and suspended sediment in the Walnut and Squaw Creek watersheds:

1. Daily discharge and suspended sediment transport in Walnut and Squaw creeks is very

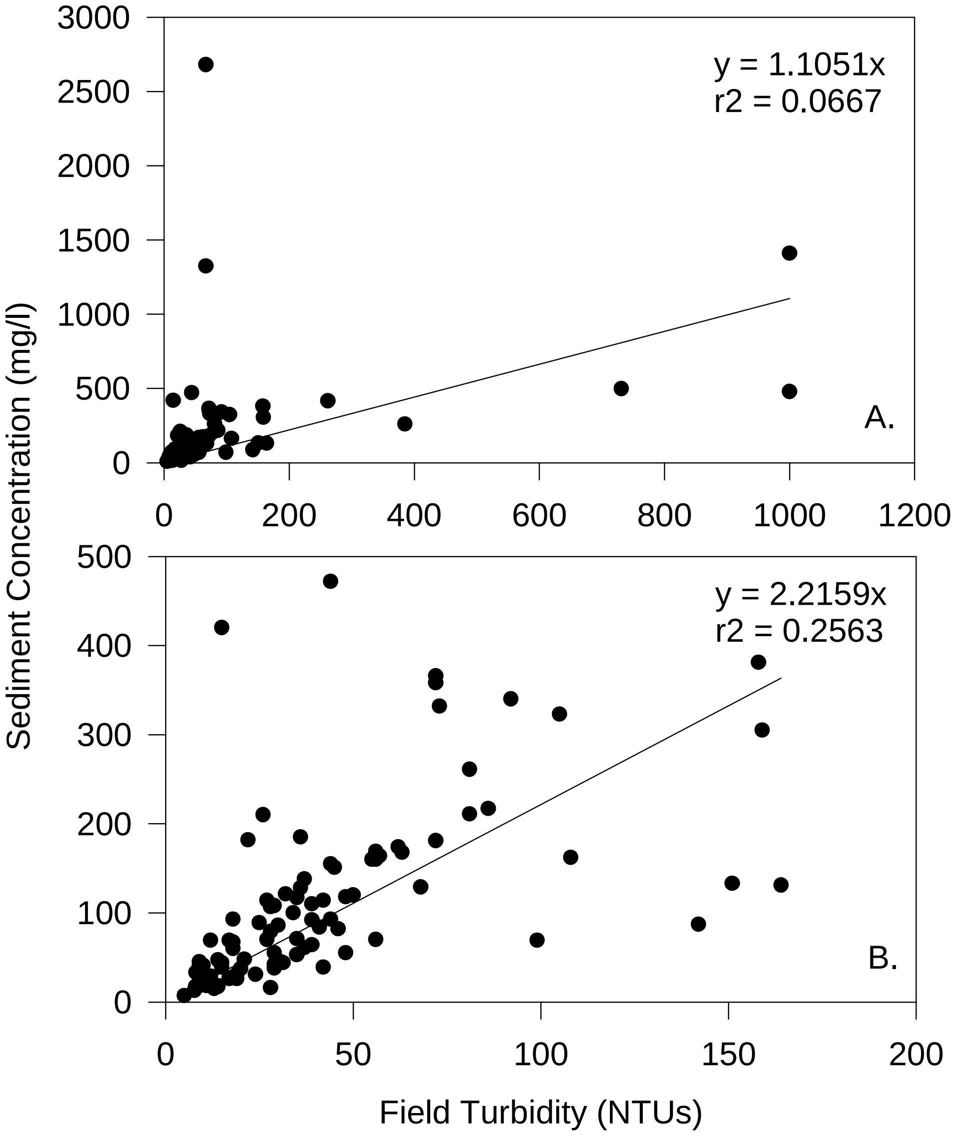

Figure 16. Relationship of sediment concentration to field turbidity; upper plot includes all data collected at Walnut and Squaw creeks, lower plot includes all data points less than 500 mg/l and 200 NTUs.

flashy, responding rapidly to precipitation and snowmelt events. This pattern is typical of incised channels where flood events are contained within the channel and rapidly transport suspended sediment downstream.

2. Maximum peak flows and sediment loads and a higher proportion of annual sediment loads migrating during one- and five-day periods were observed in Squaw Creek than Walnut Creek. Watershed morphology and land use differences may contribute to this flashier behavior in Squaw Creek.

3. Discharge and suspended sediment loads are primarily transported during a six-month period between February and July. Highest monthly totals occurred in May and June,

which accounted for 40 to 50% of the annual discharge and approximately 60% of the annual suspended sediment. The February to July period accounted for more than 98 percent of the annual sediment total.

4. A cyclical pattern of sediment movement downstream was suggested by the seasonal data. The first major snowmelt event in February and early March contributed large discharge and sediment loads. During early spring (March and April) discharge decreased whereas sediment loads remained elevated. In May and June, precipitation increased in amount and intensity, resulting in large increases in discharge and sediment loads. Through the summer, fall and winter seasons, discharge typically decreased and sediment was stored on the land or in the channel.

5. The major source of sediment in the Walnut Creek watershed (and Squaw Creek by analogy) is believed to be streambank erosion of Holocene alluvium and post-settlement materials (up to 50% of the annual total). Because base level is controlled by resistant Pre-Illinoian till, streambed contributions to sediment loads via downcutting are minimal. Eroded sediment is stored within the channel behind debris dams and other impediments and may take many years to exit the watershed. Other sources of sediment include contributions from upland sheet and rill erosion and concentrated flow erosion in gullies and tributary channels.

6. Like other watershed studies, a long-term monitoring record is needed to detect changes in the Walnut Creek watershed resulting from the land restoration efforts. The long timeframe is necessary for factoring out influences of climate, variability in morphology and land use between Walnut and Squaw Creek and the effects of historical sediment storage. The Walnut Creek project may be capable of detecting changes more quickly than other projects due to the type and magnitude of land use change being implemented, the presence of fewer tiles in the watershed and the dual USGS gauges located on the channel.

7. At a minimum, daily suspended sediment sampling should be conducted during the period February through July to characterize the flashy behavior observed in sediment loading during this time. In the August through January period, reduced sampling frequency, or estimating loads from daily discharge can be used to adequately estimate monthly sediment loads.

ACKNOWLEDGEMENTS

The Walnut Creek Nonpoint Source Pollution Monitoring Project is supported, in part, by Region VII of the U.S. Environmental Protection Agency through a 319-Nonpoint Source Program Grant to the Iowa Department of Natural Resources (IDNR). Pauline Drobney, Nancy Gilbertson and staff at the Neal Smith National Wildlife Refuge are gratefully acknowledged for their considerable support of field activities. Calvin Wolter was instrumental in conducting and analyzing the stream survey data. His interest and Geographic Information System skills have contributed greatly to the success of the Walnut Creek project. Editorial reviews and discussions were provided by Mary Skopec, Bernie Hoyer, Calvin Wolter, Carol Thompson, Jean Prior and Bob Libra. Pat Lohmann oversaw the design and layout of the report.

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