SECTION 13

AQUATIC ECOLOGY

VARIATION IN STREAMBED MATERIAL, BEDLOAD, AND BENTHIC INVERTEBRATES

By Paul von Guerard, Hydrologist, U.S. Geological Survey, Pueblo, Colorado

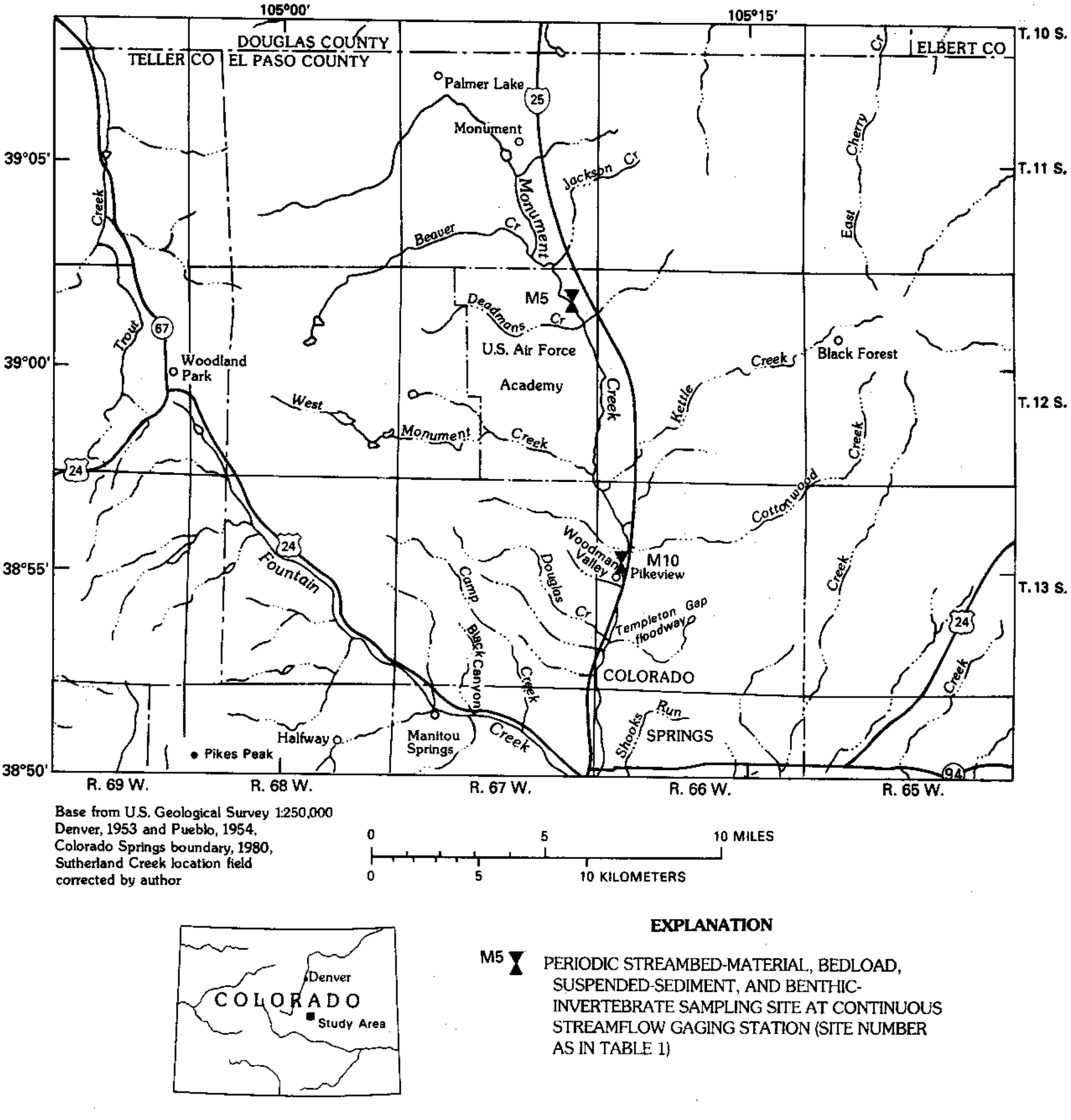
ABSTRACT

Grain-size distribution of streambed material and bedload and the occurrence of benthic invertebrates were determined at two sites on Monument Creek in the Fountain Creek drainage basin in southeastern Colorado. Streambed material, bedload, and benthic-invertebrate samples were collected from 1985 through September 1988 on Monument Creek--above North Gate Boulevard at the U.S. Air Force Academy and at Pikeview, 10.7 river miles downstream. Grain-size distribution of streambed material and bedload differed noticeably at the upstream sampling site but were similar at the downstream sampling site. There was a significant difference between the two sites for average mean values of density for all major taxa of benthic invertebrates. The median density of total organisms was 9,500 organisms per square meter at the upstream sampling site and 370 organisms per square meter at the downstream site. Although other factors affect the density of benthic invertebrates, the analysis presented indicates that as the grain size of streambed material approaches that of bedload, benthic-invertebrate populations might be adversely affected.

INTRODUCTION

The Fountain Creek drainage basin in southeastern Colorado (fig. 1) has been affected by extensive erosion for more than a century. Chapman (1933) cited the Fountain Creek drainage basin as an example of an area that has been affected by greater than normal erosion rates, which he believed began in the late 1870's as a result of agricultural development. Since 1950, much agricultural area in the basin has been replaced by urban development. Monument Creek, the main tributary to Fountain Creek (fig. 1) is affected by greater than normal erosion. The effects of this erosion may affect the suitability of the streambed to provide an adequate physical habitat for a healthy benthic-invertebrate community. The presence or absence of benthic invertebrates may determine the abundance of certain fish populations. Plecoptera (stoneflies), Diptera (trueflies), and Trichoptera (caddisflies) larvae are an important food source for certain fish, especially trout (Pennak, 1978).

This paper describes the longitudinal variation in grain size of streambed material and bedload and in taxa and densities of benthic invertebrates that occur within a relatively short reach of Monument Creek. An empirical association of the effects of streambed material and bedload on the occurrence of benthic invertebrates also is described. From January 1985 through September 1988, periodic streambed-material, bedload, and benthic-invertebrate samples were collected at two sites--Monument Creek above North Gate Boulevard at the U.S. Air Force Academy (site M5) and Monument Creek at Pikeview (site M10), about 10.7 river miles downstream from site M5 (fig. 1).



Base from U.S. Geological Survey 1:250,000
Denver, 1953 and Pueblo, 1954,
Colorado Springs boundary, 1980,
Sutherland Creek location field
corrected by author

Figure 1.--Location of Fountain Creek drainage basin upstream from the confluence of Monument Creek and location of sampling sites.

DESCRIPTION OF STUDY AREA

Monument Creek is a perennial stream that originates in the Front Range of the Rocky Mountains and flows southeast toward the town of Palmer Lake and then parallels the Front Range until it reaches Fountain Creek. The stream reach represented by site M5 is upstream from the junction of Cottonwood Creek. At this location, the stream meanders, has pools and riffles, and the streambed material consists of sand, gravel, and cobbles. The stream reach upstream from Cottonwood Creek is incised into a weakly cemented sandstone and into various unconsolidated stream and wind-laid deposits.

The stream reach represented by site M10, downstream from the junction of Cottonwood Creek, is affected by deposition resulting from upstream erosion. At this site, the stream channel is braided, and sand and gravel comprise the streambed material. The stream reach represented by site M10 is an area of net deposition of sediment immediately downstream from the stream reach represented by site M5. The Monument Creek flood plain is narrow and intermittent throughout, and active streambank cutting is evident along most of the creek (von Guerard, 1989a).

Streamflow in Monument Creek is characterized by base flow during November through February, snowmelt runoff during March through June, and rainfall runoff during May through October. During most years, there is some overlap of the snowmelt and rainfall-runoff periods. Instantaneous minimum, maximum, and mean annual streamflow and mean annual suspended-sediment load for the two sites on Monument Creek are listed in table 1. Peak streamflow at site M10 was about eight times that recorded at site M5. The drainage basin upstream from site M5 is mostly rural. Land use in the drainage basin between sites M5 and M10 is in transition from rural to urban; the Cottonwood Creek drainage basin is affected by urbanization (von Guerard, 1989a).

Table 1.--*Summary of streamflow and suspended-sediment load for selected sites on Monument Creek*

Site number in figure 1	U.S. Geological Survey station number	Drainage basin area (square miles)	Period of record	Streamflow for period of study, water years 1985-88 (cubic feet per second)			Mean annual suspended-sediment load for period of study, water years 1985-88 (tons)
				Instantaneous		Mean annual	
				Minimum	Maximum		
M5	07103780	25.9	April 19, 1985 to September 1988.	1.1	372	17.5	4,990
M10	07104000	81.9	Water years 1939-49; January 1976 to September 1988.	7.1	3,020	39.5	88,100

The size distribution of streambed material is in part dependent upon the prevailing flow regime and on the size of sediment available for transport. Information about the characterization of streambed material and bedload can be used to determine the relative health of a stream habitat (Molles, 1985; Sagar, 1986). Generally, the larger the grain size of streambed material the more diverse are benthic-invertebrate populations (Hynes, 1970).

Streambed material is sediment composing the streambed. Streambed material may be mobile sediments, which are sampled as suspended load or bedload. Streambed-material samples collected in conjunction with benthic-invertebrate samples were scooped and composited from three, 1-square-foot areas where benthic invertebrates were sampled (von Guerard, 1989b).

Suspended sediment is the sediment transported in suspension by the turbulent forces of streamflow or by Brownian movement. Suspended sediment can be described as either fine (silt and clay) or coarse (usually sand). Once suspended in the water column, fine sediments--sediments with particle diameters smaller than 0.062 millimeter--will stay in suspension for long periods of time and are transported at most stream discharges. Suspended-sediment samples were collected by methods described by Edwards and Glysson (1988).

Bedload is sediment moving on or near the streambed. A Helley-Smith sampler with a 3- by 3-inch orifice (Helley and Smith, 1971; Emmett, 1980) was used to collect the bedload samples by the single-equal-width increment method (Edwards and Glysson, 1988). Stream discharge measured at the times of bedload-sample collection ranged from 33 to 199 cubic feet per second at site M5 and 57 to 321 cubic feet per second at site M10. Bedload discharge ranged from 2.6 to 695 tons per day at site M5 and from 78.3 to 839 tons per day at site M10.

The size distributions of streambed material and bedload samples collected at sites M5 and M10 are plotted in figure 2. The average grain size of streambed-material samples from site M5 ranged from about 0.062 millimeter (very fine sand) to about 128 millimeters (small cobbles) and for bedload samples ranged from about 0.125 millimeter (fine sand) to about 32 millimeters (coarse gravel). At site M5, the grain-size distribution of streambed-material and bedload samples is similar for very fine to coarse sands (0.062 millimeter to 0.50 millimeter). For grain sizes larger than coarse sand, the grain-size distribution of streambed-material samples differs noticeably from bedload samples. Bedload samples generally are finer grained than streambed-material samples at site M5 (fig. 2). The larger substrate at site M5 is not usually transported as bedload. Because of the small maximum streamflows (table 1) and the coarser grain sizes present in streambed material, stream-channel scour and fill at site M5 is uncommon (von Guerard, 1989b).

At site M10, grain sizes of streambed material ranged from about 0.125 millimeter (fine sand) to about 64 millimeters (very coarse gravel). At site M10, the grain-size distribution of streambed material is similar to bedload samples. Except for the coarsest streambed material (very coarse gravel), bedload samples included all of the grain sizes sampled in the streambed material (fig. 2). The similarity between streambed material and bedload grain-size distributions indicates that most of the streambed material at

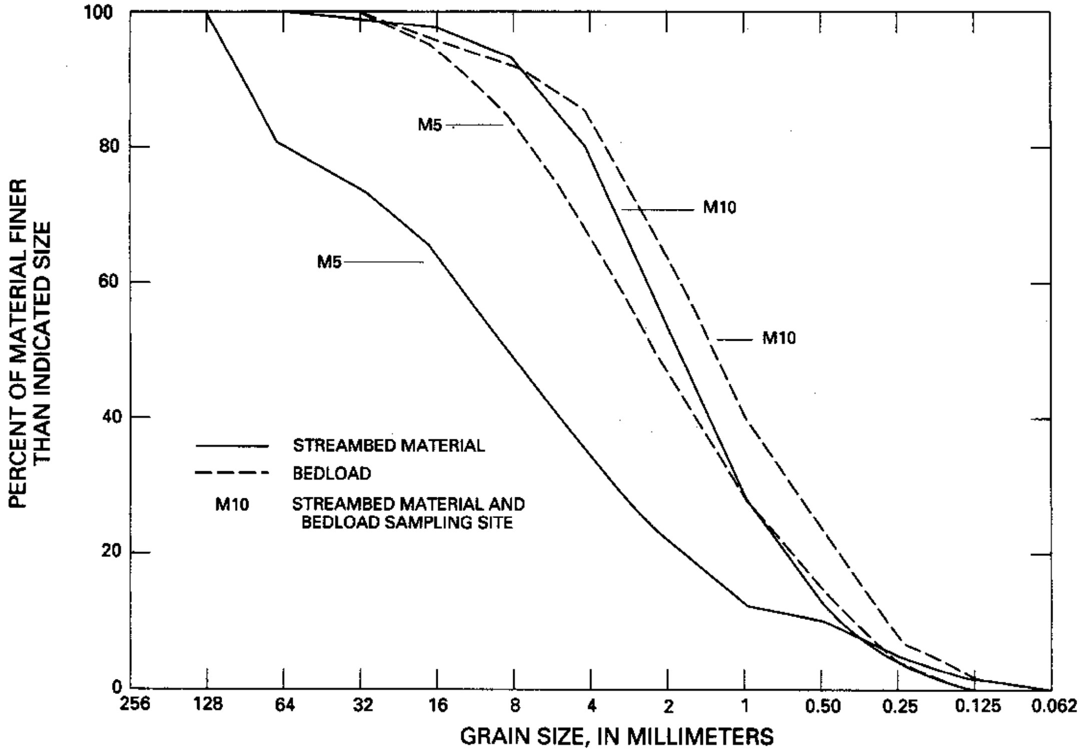


Figure 2.--Average grain-size distribution of streambed-material and bedload samples at Monument Creek above North Gate Boulevard at the U.S. Air Force Academy (site M5) and Monument Creek at Pikeview (site M10).

site M10 is readily transported. Stream-channel scour and fill ranging from -1.0 to +1.0 foot commonly occurs at site M10 (von Guerard, 1989b). The average median grain size of streambed material decreased by about 6.3 millimeters (fig. 2) between sites M5 and M10.

BENTHIC INVERTEBRATES

The streamflow regime, rate of sediment transport, and stream-channel scour and fill are some of the factors that can affect the occurrence and abundance of benthic invertebrates (Canton and others, 1984; Meffe and Minckley, 1986; Sagar, 1986). Understanding the composition of benthic-invertebrate communities is useful for identifying stream reaches that have healthy (large numbers of taxa) or unhealthy (small numbers of taxa) aquatic environments.

From April 1985 to September 1988, benthic-invertebrate samples were collected four times a year at the two sites on Monument Creek, except for 1988, when no samples were collected during the fall. Samples were collected in April (spring) prior to most of the snowmelt runoff, in late June to early July (early summer) after snowmelt runoff, in mid-August to early September (late summer) after periods of rainfall, and in late October to early November (fall).

Benthic-invertebrate samples were collected by using a 1-square foot Surber sampler that has a 210-micrometer mesh net and by using methods described by Britton and Greeson (1989). Three replicate samples were collected in riffle areas at each site. Where no riffles were present, replicate samples were collected in a flowing part of the stream that was representative of the site. According to Canton and Chadwick (1988), three replicate samples provide an acceptable estimate of total density of benthic invertebrates.

Seventy-eight taxa were identified at site M5. Taxa from the orders Diptera (true flies), Ephemeroptera (mayflies), and Trichoptera (caddisflies), and from the class Oligochaeta (worms) accounted for more than 95 percent of total organisms sampled during all sampling periods. The more habitat-sensitive Plecoptera (stoneflies), although not present in large numbers, were collected during all but two sampling periods. Mean density of total organisms ranged from 460 to 20,000 organisms per square meter, and the median was 9,500 organisms per square meter (von Guerard, 1989b).

Forty-one taxa were identified at site M10. Oligochaeta and Diptera were the most frequently collected and the most abundant groups of organisms collected during all sampling periods. The more habitat-sensitive taxa were collected infrequently; mayflies were collected during only six sampling periods; and stoneflies and caddisflies were collected during only two sampling periods. Mean density of total organisms ranged from 42 to 1,200 organisms per square meter, and the median was 370 organisms per square meter or about 25 times less than the median density of total organisms sampled at site M5 (von Guerard, 1989b).

Box plots, which are useful for visually examining the central tendency and dispersion of a group of data, were used to compare mean densities of organisms for all taxa and mean densities of organisms for major taxa at the five sites. Mean densities of organisms for all taxa and mean densities of organisms for major taxa collected at sites M5 and M10 are summarized in figure 3.

Generally, mean densities of organisms are larger at site M5. To test the statistical significance of this difference, mean density of organisms for all taxa and the major taxa groups at sites M5 and M10 were compared using the Wilcoxon rank-sum test (Statistical Analysis System Institute, 1985). Average mean densities of all taxa and major taxa groups were significantly ($p<0.05$) larger at site M5 than at site M10.

CONCLUSION

Within about 10.7 stream miles on Monument Creek, there is a notable change in streambed material and bedload with a corresponding significant difference in the occurrence of benthic invertebrates. Peak streamflow at site M10 was about eight times that recorded at site M5. The average median grain size of streambed material decreased by about 6.3 millimeters (fig. 2) between the upstream and downstream sampling sites. The grain-size distribution of streambed material and bedload samples were substantially different at the upstream sampling site, but at the downstream sampling site the grain-size distribution of streambed material and bedload were similar. Corresponding to the larger peak streamflows, smaller grain sizes, and similarities between the

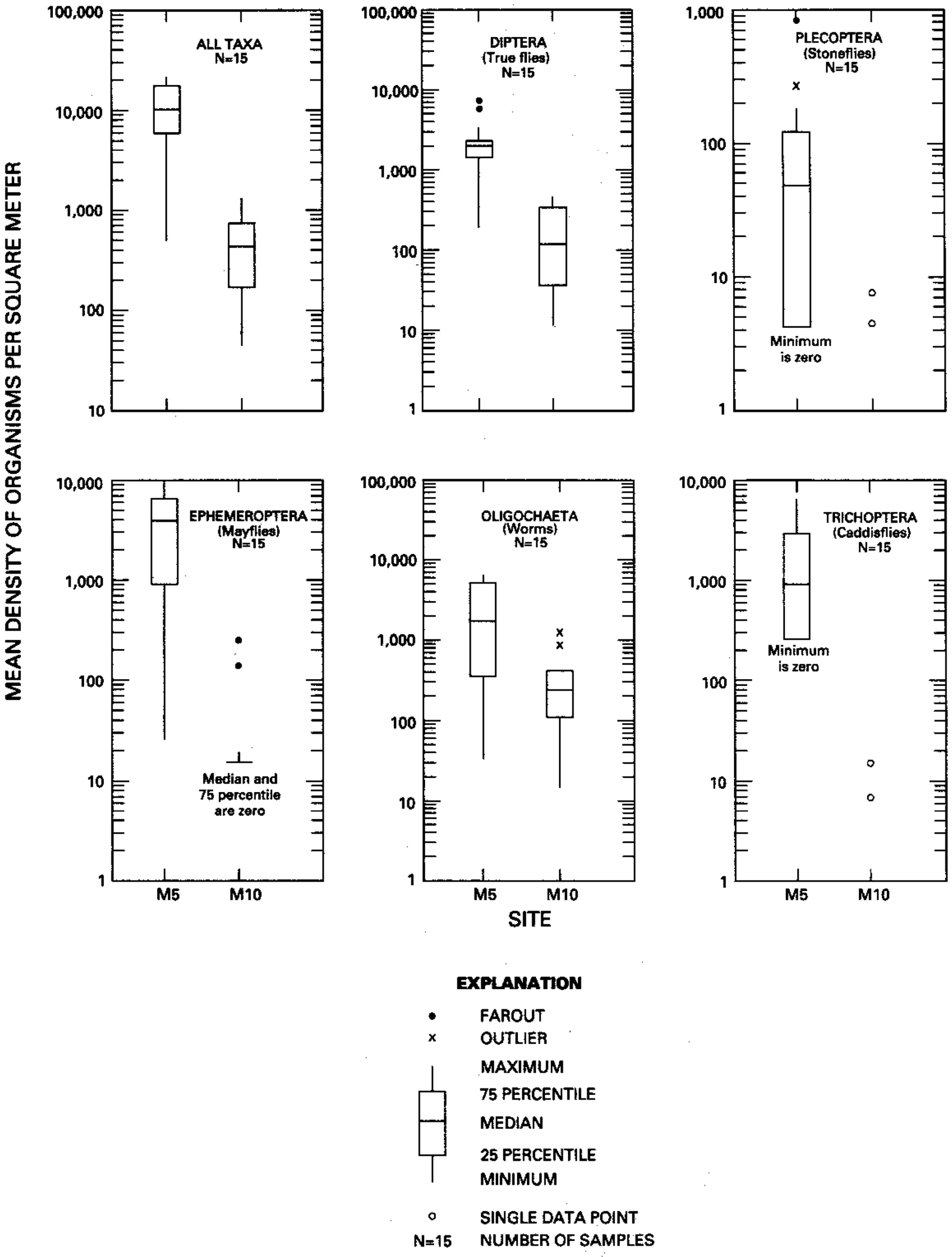


Figure 3.--Mean densities of organisms for all taxa and major taxonomic groups for benthic invertebrates collected on Monument Creek.

grain-size distribution of streambed material and bedload, there was a significant decrease in the occurrence and abundance of benthic invertebrates at the downstream sampling site (site M10). The median density of total organisms was 9,500 organisms per square meter at the upstream sampling site and 370 organisms per square meter at the downstream sampling site. Although other factors can affect the occurrence of benthic invertebrates (Hynes, 1970), the analysis presented indicates that as the grain size of streambed material approaches that of bedload, benthic-invertebrate populations might be adversely affected.

REFERENCES

Britton, L. J., and Greeson, P. E., editors, 1989, Methods for collection and analysis of aquatic biological and microbiological samples. U.S. Geol. Surv. Tech. Water-Resour. Invest. bk. 5, chap. A4.

Canton, S. P., Cline, L. D., Short, R. A., and Ward, J. V., 1984, The macroinvertebrates of a Colorado stream during a period of fluctuating discharge: Freshwater Biology 14, 311-316.

Canton, S. P., and Chadwick, J. W., 1988, Variability in benthic invertebrate density estimates from stream samples. J. Freshwater Ecology 4, 291-298.

Chapman, H. H., 1933, Influence of overgrazing on erosion and watersheds. Civ. Eng. 2, 74-78.

Edwards, T. K., and Glysson, G. D., 1988, Field methods for measurement of fluvial sediment. U. S. Geol. Surv. Open-File Rep. 86-531.

Emmett, W. W., 1980, A field calibration of the sediment-trapping characteristics of the Halley-Smith bedload sampler. U. S. Geol. Surv. Prof. Paper 1139.

Helley, E. J., and Smith, Winchell, 1971, Development and calibration of a pressure-difference bedload sampler.: U.S. Geol. Surv. Open-File Rep. 73-108.

Hynes, H. B. N., 1970, The ecology of running water. Toronto, Canada. Univ. of Toronto Press.

Meffe, G. K., and Minckley, W. L., 1986, Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed sonoran desert stream: The Amer. Midland Natur. 117, 177-191.

Molles, M. C., 1985, Recovery of a stream invertebrate community from a flash flood in Tesuque Creek, New Mexico. The S.W. Natural. 30, 279-287.

Pennak, R. W., 1978, Freshwater invertebrates of the United States (2d ed.). N.Y., John Wiley and Sons.

Sagar, P. M., 1986, The effects of floods on the invertebrate fauna of a large, unstable braided river. N.Z. J. Marine Res. 20.

Statistical Analysis System Institute, 1985, SAS users guide--Statistics (5th ed.). Carey, N.C.

Von Guerard, P., 1989a, Suspended sediment and sediment-source areas in the Fountain Creek drainage basin upstream from Widefield, southeastern Colorado, U.S. Geol. Supv. Water-Resour., Rep. 89-4136.

_____1989b, Sediment-transport characteristics and effects of sediment transport on benthic invertebrates in the Fountain Creek drainage basin upstream from Widefield, southeastern Colorado, 1985-88. U.S. Geol. Surv. Water-Resour. Rep. 89-4161.

TRANSPORT OF INVERTEBRATES AND DETRITUS IN STREAMS

By Larry J. Tilley, Keith V. Slack, and Susan S. Kennelly,
Biologists, U. S. Geological Survey, Menlo Park, California

ABSTRACT

Stream sediment includes living and non-living particulate organic matter along with inorganic particles. Living organisms range in size from bacteria to large plants and animals. Non-living organic matter is mostly of plant origin. Drift, the downstream movement of invertebrates in the water column, is a universal feature of streams and an important component of suspended particulate organic matter. Drift samples, usually collected with nets, contain the invertebrates along with organic and inorganic particles collectively termed detritus. Particulate organic matter is important to stream ecosystem functioning, and is also involved in the transport and fate of plant nutrients, trace metals, pesticides and other substances. This report summarizes studies of some factors affecting drift and detritus abundance and distribution in second and third order streams in the Rocky Mountains. In study areas in Idaho and Colorado, abundances of drift and detritus differed among sampling sites and between day and night. Site differences in Idaho were related to geomorphic factors whereas those in Colorado were related to differences in water quality. Larger drift densities at night compared to day are usual in streams and were observed at five of the six study sites. Similar day-night differences in detritus abundances also were observed, but were not expected. Suspended sediment sampling only during the day may not adequately represent quantities of either organic or inorganic detritus throughout a 24-hour period.

INTRODUCTION

Background

The suspended loads of streams include living and non-living particulate organic matter along with inorganic particles. Living organisms range in size from viruses and bacteria to large plants and animals. The non-living organic matter is mostly of plant origin, and is input to streams in the form of coarse particulate organic matter such as leaves, flowers, fruit, twigs, branches, and even tree trunks from the riparian vegetation. Various physical and biological processes convert the coarse particles to fine particulate organic matter, generally less than 1 millimeter in diameter, which is readily suspended in the flow and transported downstream. In ecological terms, particulate organic matter is the fuel or energy base for headwater stream ecosystems (Cummins, et al., 1989; Cuffney et al., 1990). By helping to reduce the size of coarse particulate organic matter, invertebrate shredders and microbial decomposers make fine particles available to filter feeders and deposit feeders (collectors) in downstream ecosystems. In this way processes in the headwaters enhance biological production downstream.

Ecology is not the only discipline concerned with particulate organic matter. Studies of the movement and fate of plant nutrients, trace metals, pesticides and other substances in streams may require information on organic as well as inorganic loads with which these substances can be associated (e.g., Kuwabara et al., 1989; McKnight et al., 1990).

Table 1. Characteristics of study sites.

Stream/Location	**Order**	**Altitude** (m)	**Gradient** (m per km)	**pH**	**Bed Material**
Idaho					
Little Boulder Cr., Meadow	3	2466	12	7.3-7.8	sand, gravel
Little Boulder Cr., Canyon	3	2362	43	7.3-7.8	cobble, boulder
Colorado					
Deer Cr. above confluence	2	3219	76	6.5-8.0	cobble, boulder
Snake R. 2 above confluence	2	3222	76	3.5-4.3	cobble, boulder
Snake R. 3 below confluence	3	3210	76	5.5-6.5	cobble, boulder
Snake R. 4 at Montezuma, 2km below confluence	3	3135	28	6.4	gravel, cobble

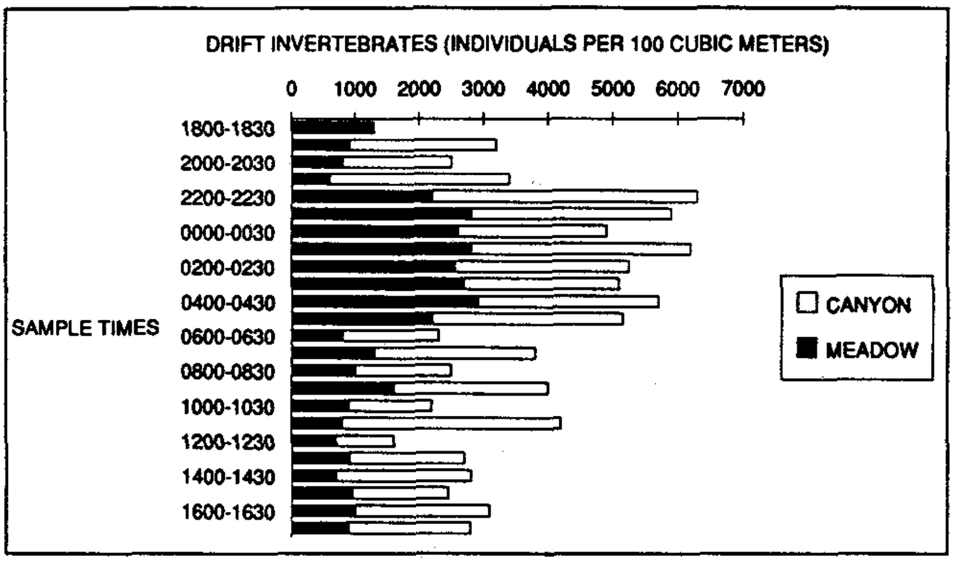


Fig. 1. Drift invertebrate density over a diel cycle in simultaneous samples from two sites, Little Boulder Creek, Idaho.

Particulate organic matter has some properties not shared by inorganic particles. For example, large numbers of benthic invertebrates actively or passively enter the water column from the streambed where they become part of the suspended load. The downstream movement of invertebrates in streamflow, termed "drift", is a universal feature of all but ephemeral streams, and drift rate increases at night (Brittain and Eikeland, 1988). Drift samples, usually collected with nets, contain the invertebrates along with organic and inorganic particles collectively termed detritus. Detritus clogs the collecting nets and interferes with removal of animals from the samples in the laboratory. The amount of detritus collected in a drift net depends on the size of the mesh apertures. The species composition of drift collections also is affected by mesh size (Slack et al., in press), but in general the drift assemblage resembles that of the benthic invertebrate community at the collection site.

Purpose and Scope

This report describes ecological studies of some factors affecting drift abundance and distribution in Rocky Mountain streams. Because the drift samples contained relatively large quantities of detritus as well as invertebrates, we examined the relation between these two components. This work was part of a larger study of the relations between benthic invertebrate communities and water quality of mountain streams. In the present report we show how the results affect sediment-sampling protocols when organic particulate matter is a target constituent.

Study Sites

This work is based on data from drift samples collected during low flows in two areas in the Rocky Mountains (Table 1). In Idaho, two third-order reaches of Little Boulder Creek were sampled. Little Boulder Creek is a tributary of the East Fork Salmon River, Custer County, Southcentral Idaho. The upper study site was near the downstream end of a grassy meadow. The channel gradient increases below the meadow and the flow becomes more turbulent as Little Boulder Creek enters a forested canyon of Douglas fir and Engleman spruce. The lower sampling site was in the canyon, 2.5 km downstream from the meadow.

In Colorado, two second-order streams, Deer Creek and Snake River, were sampled above their confluence; downstream of their confluence, Snake River was sampled at two third-order sites (Table 1). Both streams have steep, rocky channels in the area of their juncture. The area is near Montezuma in Summit County, 2.7 km west of the Continental Divide.

METHODS

Sample Collection

Drift was sampled in both areas during receding streamflows following snowmelt runoff. Sample sizes were determined by constant time periods and not by constant volume quantities. Sample volumes were measured using a flowmeter mounted in the net mouth, and samples were preserved in the field in 70 percent ethanol.

Idaho drift samples -- Twenty-four, 30-minute drift net collections were taken at each site, beginning on the hour, from 18h, 12 July, through 17h Mountain Standard Time (MST), 13 July, 1977. A cylindrical net of monofilament nylon (216 μm square mesh openings) was mounted on a 25 cm square aluminum frame in the center of flow at each site and supported by metal rods driven into the streambed. Additional information about the samples is given by Tilley (1989).

Colorado drift samples -- Drift was sampled simultaneously at each of four sites, August 18-20, 1986. Eight 30-minute collections were made over two diel cycles. Sampling times were 21h, 23h and 09h, 11h MST from the evening of the first day through the morning of the third day. The drift sampler had the same mouth size and method of support described for the Idaho sampler, but three nested nets were used. The sampled water first passed through a 425 μm net, then through a 209 μm net, and finally through a 106 μm net (Slack, et al., in press). Two samplers side-by-side were used, but for this paper, data are reported only for the samples collected nearest maximum depths close to the stream center.

Sample processing.

Drift samples were sorted under a dissecting microscope to separate the invertebrates. The quantity of detritus retained in each net was measured volumetrically for the Colorado study and gravimetrically for some Colorado samples and all Idaho samples. Detritus samples were oven dried at 100° C to determine dry weight, then ashed at 500°, rehydrated and dried at 100° C to determine ash weight. Ash-free dry weight was the difference between dry and ash weights. Samples for volumetric measurement were settled overnight in 70 percent ethanol in a graduated cylinder and measured to the nearest 1 cubic centimeter. Animal and detritus abundances, corrected for the volume of stream water filtered, were expressed as number of invertebrate individuals or quantity of detritus per 100 cubic meters. The drift sampler used in Colorado provided three samples of the invertebrates and detritus per collection, and reported values for a given mesh size include the catch from any larger mesh net(s). Thus, values for the 425 μm net include material (invertebrates and detritus) retained only by that net, values for the 209 μm net include material retained by the 425 μm net plus that retained by the 209 μm net, and values for the 106 μm net include material retained by all three nets.

RESULTS

Drift invertebrates

In both study areas, drift density differed among sites and between day and night. In Idaho, drift density was larger in the canyon than in the meadow for simultaneous collections (Tilley, 1989), although both were third order, pristine reaches (Table 1, Fig. 1). In Colorado, drift density varied with stream-water quality, particularly pH. Deer Creek, the nearly neutral stream, had the largest drift density for a given mesh size net, whereas Snake River 2 above the confluence, the acid stream, had the smallest density (Fig. 2). Immediately below the confluence at Snake River 3, density was intermediate between values for the two upstream sources. At Snake River 4, 2 km downstream, density had partially recovered to the values observed in Deer

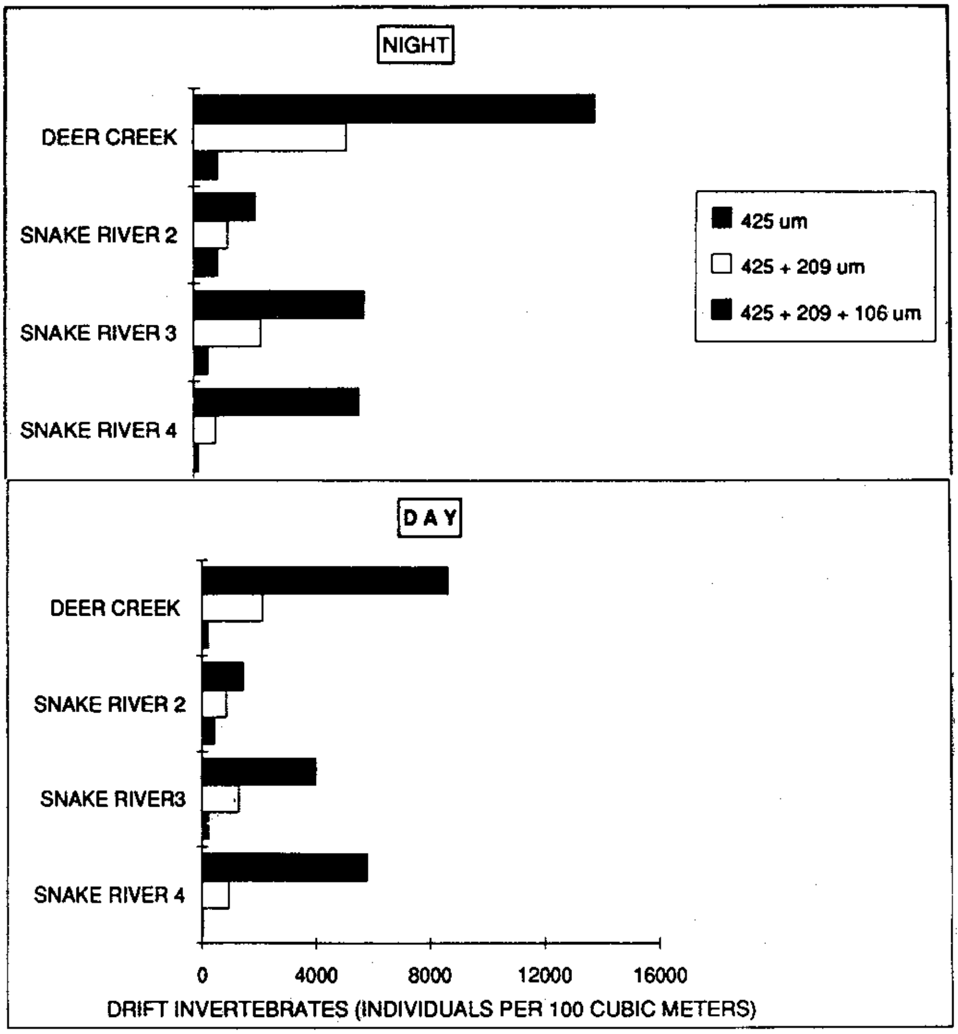


Fig. 2. Drift invertebrate density in simultaneous day and night samples obtained with three mesh sizes of collecting nets at four sites, Deer Creek-Snake River, Colorado.

Creek (Fig. 2). The most notable differences among the drift **samples** in **both** areas was the generally higher drift density at night compared to day.

The effect of net mesh size on drift invertebrate density was investigated in Colorado with the nested-net sampler. Samples from each of the three mesh sizes showed consistently higher night than day densities except at Snake River 4 (Fig. 2). Because drift retained by inner (larger mesh) net(s) was added to that of outer (smaller mesh) net(s) during analysis, density increased as mesh aperture decreased. However, for specific taxa in the drift assemblage, only the density of small individuals increased as mesh size decreased. Large individuals retained on the 425 μm or 209 μm nets did not increase in density as mesh size decreased. Nearly all individuals of some taxa passed through the 425 μm net, whereas less than 50 percent of other groups passed through (Slack, et al., in press). Lower percentages passed through the 209 μm net, but values for some insect families exceeded 50 percent. In Deer Creek, as an example, significantly more of the Stonefly nymphs, Nemouridae and Capniidae, passed through the 425 μm and 209 μm nets by day than by night, showing that for these groups, the average size of drift individuals was larger at night than during the day (Slack, et al., in press).

Detritus

In both study areas, the quantity of detritus in drift net samples differed between comparative sites and with time of day. In Idaho, the weight of sample detritus per 100 cubic meters of sampled water was significantly larger in the higher-gradient canyon reach than in the lower-gradient meadow reach and, at both sites, was significantly larger at night than during the day (Fig. 3 and 4). Evening and dawn samples had conspicuous unexplained high values in detritus abundance. Canyon detritus contained higher proportions of inorganic material (relatively lower ash-free dry weight) than did meadow detritus. In Colorado, the volume of detritus per 100 cubic meters of sampled water was largest in Deer Creek, smallest at Snake River 2, and increased downstream (Fig. 5). Higher values were found in night than in day samples. Single day and night detritus samples (09h and 21h MST) from three of the Colorado sites were dried and ashed after determination of their settled volumes. The same patterns of differences among sites and between day and night were observed for detritus weight as for volume for these samples.

The effect of net mesh size on detritus abundance was investigated in Colorado. The settled volume of detritus per volume of sampled water increased as mesh aperture decreased (Fig. 5), and the same pattern was observed for detritus weight. Furthermore, the day-night difference in detritus abundance was consistent for the three mesh sizes tested, i. e., for particles retained by the 425 μm net, passed through the 425 μm but retained by the 209 μm net, and passed through the 209 μm but retained by the 106 μm net.

DISCUSSION

Drift samples from Rocky Mountain streams exhibited spatial and temporal differences in density of suspended invertebrates and in efficiency of their catch by a net of given mesh size. Detritus from the invertebrate drift samples exhibited unexpected differences in quantities between day and night, and the differences were observed in both study areas. Factors that may have

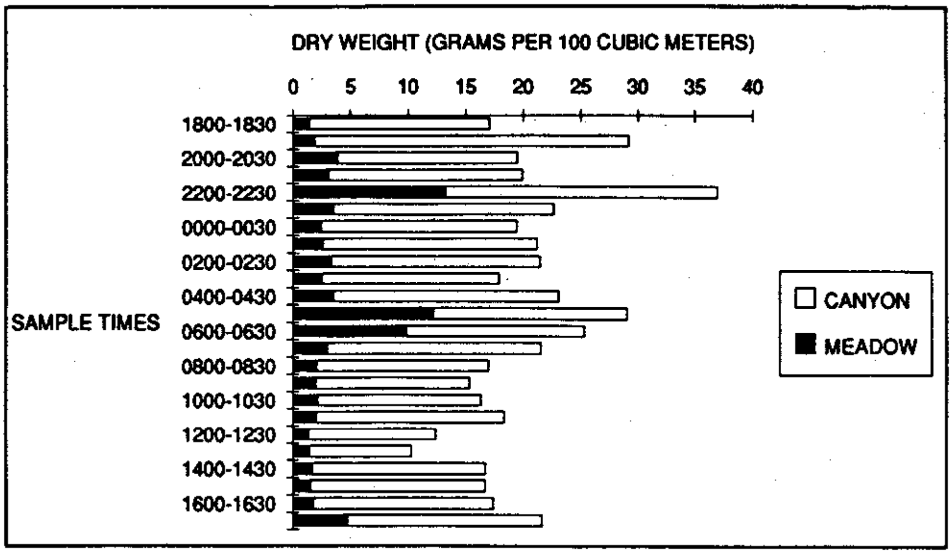


Fig. 3. Dry weight of drift-sample detritus over a diel cycle in simulaneous samples from two sites, Little Boulder Creek, Idaho.

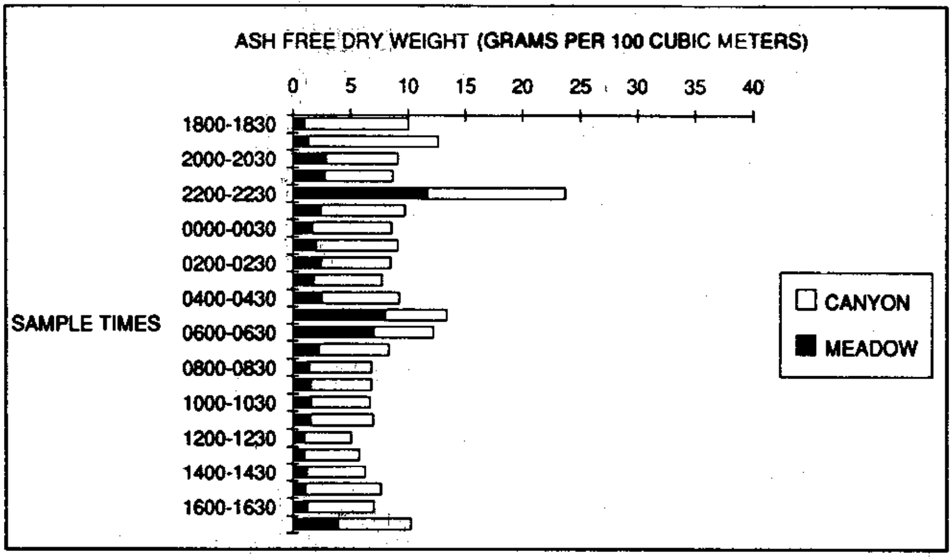


Fig. 4. Ash-free dry weight of drift-sample detritus over a diel cycle in simultaneous samples from two sites, Little Boulder Creek, Idaho.

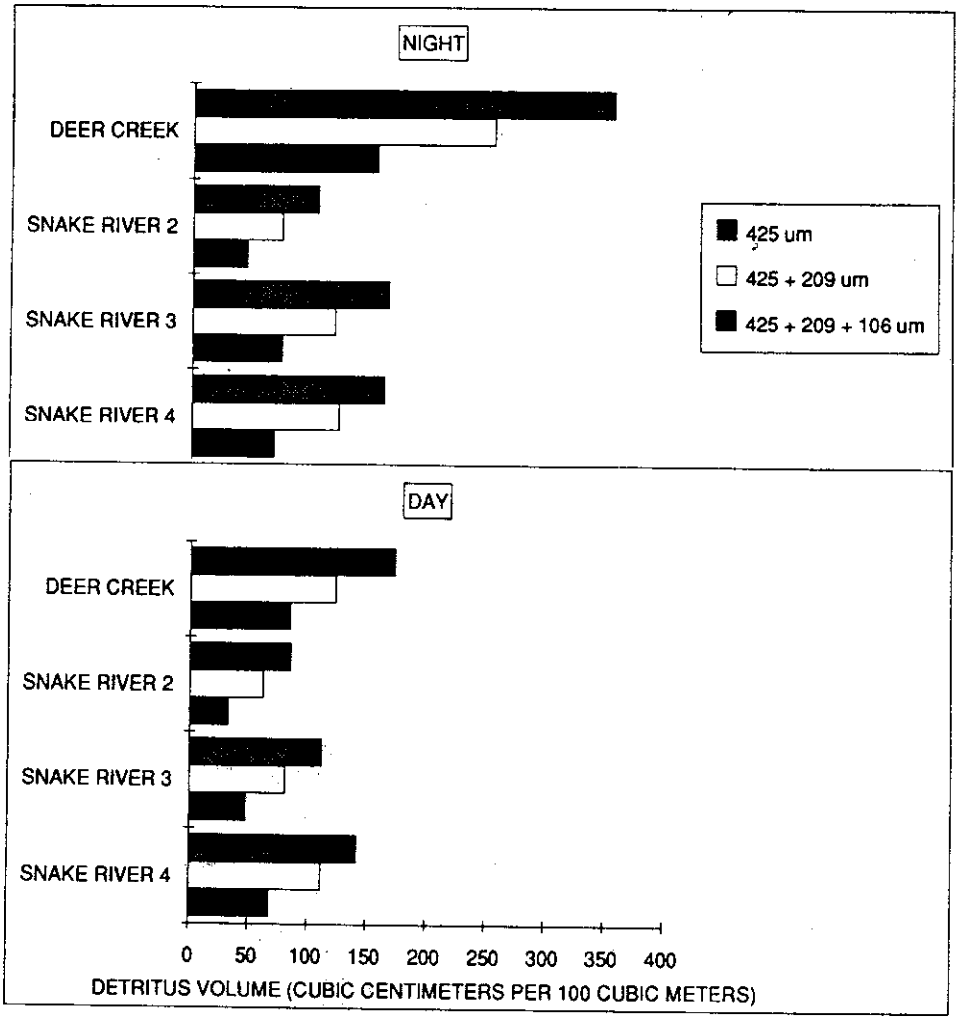


Fig. 5. Settled volume of drift-sample detritus in simultaneous day and night samples obtained with three mesh sizes of collecting nets at four sites, Deer Creek-Snake River, Colorado.

varied with a diel cycle during the study periods, e.g., stream discharge or the activity of animals in and around the stream, may have contributed to the day-night difference in detritus abundance. Although the underlying causal mechanisms for these diel patterns are unknown, the results do show that daytime suspended sediment sampling may not adequately represent either organic or inorganic detritus throughout a 24-hour period.

The results of the drift studies have application in developing sediment-sampling protocols. Transport studies may need to consider suspended organic as well as inorganic material because both are involved in the movement of substances of importance to water quality. Our data show diel, spatial and methodological effects on suspended sediment that apparently need to be considered in the design of sampling programs.

REFERENCES

Brittain, J. E., and Eikeland, T. J., 1988, Invertebrate drift - a review. Hydrobiol. 166, 77-93.

Cuffney, T. F., Wallace, J. B., and Lugthart, G. J., 1990, Experimental evidence quantifying the role of benthic invertebrates in organic matter dynamics of headwater streams. Freshwat. Biol. 23, 281-299.

Cummins, K. W., Wilzback, M. A., Gates, D. M., Perry, J. B., and Taliaferro, W. B., 1989, Shredders and riparian vegetation. BioSci. 39, 24-30.

Kuwabara, J. S., Chang, C. C. Y., Cloern, J. E., Fries, T. L., Davis, J. A., and Luoma, S. N., 1989. Trace metal associations in the water column of South San Francisco Bay, California. Estuar. Coast. Shelf Sci. 28:307-325.

McKnight, D. M., Behmel, P., Francko, D. A., Gjessing, E. T., Munster, U., Petersen, R. C., Jr., Skulberg, O. M., Steinberg, C. E. W., Tipping, E., Visser, S. A., Werner, P. W., and Wetzel, R. G., 1990. Group report. How do organic acids interact with solutes, surfaces, and organisms? In. Perdue, E. M. and Gjessing, E. T., eds., Organic acids in aquatic ecosystems., John Wiley & Sons, New York, p. 223-243.

Slack, K. V., Tilley, L. J., and Kennelly, S. S., in press, Mesh-size effects on drift sample composition as determined with a triple net sampler. Hydrobiol.

Tilley, L. J., 1989, Diel drift of Chironomidae larvae in a pristine Idaho mountain stream. Hydrobiol. 174, 133-149.

SEDIMENTATION ANALYSES TO EVALUATE AQUATIC IMPACTS

By Kathleen Sherman, Soil Conservationist, Federal Energy Regulatory Commission, Washington, D.C.1/

ABSTRACT

The Federal Energy Regulatory Commission (FERC) is evaluating the cumulative effects of constructing and operating multiple small hydropower projects proposed in the Nooksack (7 projects) and Skagit (8 projects) River Basins, Washington. The proposed projects are located on tributaries where anadromous (migrating) fish are present. Each project would consist of an intake structure to divert streamflows into a pipeline leading to a powerhouse where flows would be returned to the stream, causing a reach that would be partially dewatered during project operation.

Construction of the projects would generate fine sediments that may smother fish eggs and fill in spaces of the substrate used by small fish. Cumulative effects to aquatic habitat from sedimentation are related to the overlap of project impact zones where tributaries discharge into a common river reach. Operation of the proposed projects would also affect the movement of stream gravels; the diversion structure would interrupt the downstream recruitment of spawning gravels and alter gravel movement and distribution through the bypassed reach.

Evaluation of potential effects on sediment transport and deposition on aquatic habitat from constructing and operating the proposed projects, includes sediment modeling and field sampling of the stream channels. Sediment data will be used along with evaluations of watershed and project area stability, predicted increases in sediment yield, and location and abundance of potentially affected aquatic habitat to assess the relative risk of constructing the projects both individually and cumulatively.

Baseline conditions are defined for the subwatersheds through assessing the existing sediment yields, by considering natural sediment sources such as glaciers or areas of mass wasting, and man-made sources such as timber harvesting and roads. The hydrology of the subwatershed is also evaluated to consider undisturbed flows and alteration of the flow regime by project operation. Bedload transport models are used to evaluate the effects of project operation on movement of gravels used for spawning.

Potential increases in sediment yields from construction of the proposed projects are evaluated by considering the amount of disturbed area, erosion rates, and sediment delivery factors.

1/ The opinions and views in this paper are my own and do not necessarily represent the views of the Federal Energy Regulatory Commission.

Models to evaluate suspended sediment are used to identify areas where fine sediments would deposit and areas where sediments would be transported out of a given reach. Identified areas of sediment deposition will be compared to the locations of important anadromous fish habitat to assess the potential adverse effects to anadromous fish populations.

Baseline sediment conditions are also being assessed by making measurements in the stream channel using various techniques. This includes sampling transects using a series of core samples of the substrate, making embeddedness measurements, scour/fill measurements, and placing Whitlock-Vibert (W-V) boxes containing gravel at the surface of the streambed to be removed later to measure accumulation of fine sediments over time. Preliminary sediment data was collected during spring and summer of 1989 and consisted of particle size analysis of McNeil core samples; W-V boxes and rebar to measure scour/fill over time were also placed in the streambed when the core samples were collected.

INTRODUCTION

The FERC is responsible for licensing nonfederal hydropower projects. After an application for license is filed, FERC prepares a document (Environmental Assessment or Environmental Impact Statement) that evaluates the environmental impacts of constructing and operating the hydropower project, in compliance with the National Environmental Policy Act.

The Electric Consumers Protection Act of 1986 requires FERC to "give equal consideration to the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality".

Impacts to Aquatic Habitat

Evaluation of cumulative as well as project-specific impacts to fish spawning grounds and habitat is needed where multiple applications for license are filed for projects to be located in river basins that support runs of anadromous fish, such as the Skagit and Nooksack River Basins in Washington. Anadromous species in these basins include chinook, coho, pink, sockeye, and chum salmon, steelhead and sea-run cutthroat trout, and sea-run Dolly Varden.

An important component in evaluating impacts to anadromous fish spawning grounds and habitat is the potential for each project to generate fine sediments that could smother fish eggs, hinder fry emergence, fill in voids used by juveniles to overwinter, and fill in pools used for summer rearing. It is generally accepted that an inverse relationship exists between the amount of fine sediments in spawning or rearing areas and fish survival and abundance (Stowell et al., 1983). The detrimental effects of

excessive amounts of fine sediment on salmonid embryo survival are well documented in laboratory studies and field experiments (Iwamtoto et al., 1977).
The effects of project operation on the natural movement of gravels used for spawning must also be evaluated. Gravel bars that form riffles and intervening pools, constitute spawning and rearing habitat. If gravel bars are to be washed away or diminished in size due to the disruption of the gravel supply from a project's diversion structure, the spawning grounds and related habitat could be adversely affected.

Sedimentation analyses are used to predict the transport and deposition of both fine particles (< 6.4 mm) and spawning gravels (1/2 to 3 inches), as a component of a risk assessment to evaluate impacts to anadromous fish from construction and operation of the projects. In the Skagit and Nooksack Basins, cumulative impacts to aquatic habitat from sedimentation are considered by identifying and evaluating potential overlap zones where sediment would accumulate due to construction of projects on nearby tributaries that discharge into a common river reach.

Risk Assessment

Risk assessment considers: the likelihood of a project generating substantial quantities of fine sediments; existing sediment loads; the type and extent of the potentially affected aquatic habitat; and relative abundance of basin-wide populations of the various species of fish that could be affected.

The likelihood of a project generating substantial quantities of sediment depends on project area stability (soil types, geologic conditions, unstable areas) and site-specific erosion, sediment and slope stability control measures proposed for a project. Existing sediment loads are related to watershed stability--geologic characteristics such as mass wasting and slope instability, land use (primarily logging and roads), and presence of glaciers--as well as a stream's capability of transporting sediment.

The location and extent of spawning grounds and habitat used by anadromous fish within a project area or downstream of a project are identified, to give an indication of the quantity and quality of habitat that could be adversely affected by fine sediments generated as a result of project construction. The relative abundance of basin-wide populations of different species of anadromous fish is also considered in risk assessment. A smaller population of a scarce species is at a higher risk of being adversely affected by reduced spawning success than a larger population of a more abundant species.

Risk characterization establishes criteria for levels of risk. High risk is associated with large amounts of high quality habitat used by scarce species or an unstable project area; low risk is associated with small amounts of aquatic habitat "at risk" from sedimentation from construction of a project and a stable project area. Evaluation of cumulative impacts to basin-wide fish populations from sedimentation considers the level of risk associated with each project, the location and extent of overlap of project impact zones, effects of reduced spawning success on the abundance or scarcity of a species, and management plans of the fish and wildlife agencies.

Existing Sediment Load

The Skagit and Nooksack Rivers and their tributaries receive from their drainages a poorly-sorted sediment load that ranges in particle size from silt to boulders. Most of this sediment is carried by flows at or above bankfull stage, which in most years occurs for only a few days. The coarser fraction of the load, consisting mostly of gravels and cobbles, travels slowly and intermittently as bedload, and is deposited for various periods of time creating riffles and point bars along the channel.

Studies conducted in the nearby Snoqualmie River Basin, with similar watershed characteristics, indicate that most of the fine-textured suspendible load is from water erosion on unpaved road surfaces, while most of the coarse sand and gravel bedload originates from mass wasting, often associated with stream crossings by roads as well as natural landslides (Dunne, 1984).

The background sediment yield and composition of sediments for a river (or a tributary stream where a project is proposed), is evaluated by considering existing land use in the watershed (or subwatershed), geologic characteristics, composition of soils and mass wasting deposits, and composition of the stream substrate. Identification of current sources of sediment, their approximated annual contribution to the stream, and the grain-size distribution, involves mapping sediment sources on aerial photographs, field observations and measurements of landslide volumes, and sieve analysis to determine composition. Sediment yield rates for areas of various landtypes and uses, such as for glaciers and logged areas, are also used when predicting the existing sediment yield. Grain-size distribution of bed material is based on samples collected from the stream channel (Dunne, 1984; Westbrook, 1988).

Sediment Yield from Project Construction

The amount and type of sediments that may be generated from a project by land-disturbing construction activities is estimated by first quantifying the expected erosion. This is done by considering the amount of disturbed area and sampling of soils and unconsolidated deposits at the project site. Estimates of erosion are made by using the Universal Soil Loss Equation (American Society of Civil Engineers, 1975; Weichmeir et al., 1971). A sediment delivery ratio is used to predict the amount of eroded material expected to reach the stream based on proximity of land-disturbing activities to the stream (Darrach, 1978).

Estimates are also made by using rates of sediment yield developed for road construction in the Olympic National Forest (construction of project pipelines is assumed to be similar to road construction) (Reid, 1981). As neither model accounts for erosion from slope failure or mass movement, a "worst-case" evaluation of sediment input to a stream is based on actual site conditions, and considers size and composition of potentially unstable areas and their proximity to the stream.

The estimate of the amount of sediment expected to reach the stream from land-disturbing construction activities can then be compared to the existing sediment load in order to predict a magnitude of increase in sediment yield. This estimate gives a general indication of the potential severity of impacts to aquatic habitat from sediment generated from constructing a project.

Sediment Transport and Deposition

In order to assess sediment transport and deposition in a specific stream where a project would be located, the hydrology of the stream must be evaluated--both unregulated flow and any alteration of the flow regime caused by project operation. A range of flow conditions is examined, including low, mean annual, and flood flows. The representative hydrograph is used when assessing the transport and deposition of various particle sizes in specific stream reaches.

The small hydropower projects proposed in these basins typically use a small diversion structure with limited storage of water, so flows above an intake structure would basically be unaffected. The intake structure diverts streamflows into a pipeline leading to a powerhouse where flows are returned to the stream. This causes a bypassed reach that would be partially dewatered during project operation. At the intake, a variable amount of flow would be diverted from the stream to the powerhouse, depending on the flow in the stream at the time; below the powerhouse the stream would return to its natural flows. Minimum flow requirements established to protect fisheries habitat in the bypassed reach sets a lower limit on the amount of flow a project would divert.

The fate of sediments moving through a stream system is examined for various grain-size classes, from coarse gravel (16-90 mm) to silt (<0.07 mm). The stream system is broken up into channel reaches with roughly uniform hydraulic characteristics to determine if sediments would be predicted to be transported or deposited in a given reach under various flow conditions. This analysis accounts for variations in stream channel morphology (gradient and width) and substrate characteristics (channel roughness) of different stream reaches.

Various equations can be used to test whether a particle of a given size would remain in suspension given a specific flow condition in a given reach, based on the size of the particle and the shear velocity of the stream (Graff, 1971; Raudkivi, 1976; Vanoni, 1975). In order to compute the shear velocity, the flow depth at various discharges is determined using a form of Manning's equation (Dunne, 1984; Westbrook, 1987). The diameter of the largest mobile particle for a given discharge can be calculated by considering stream width, slope, channel roughness, and flow depth (Baker and Ritter, 1975).

The sediment that settles out of suspension does not necessarily become immobile; if there is sufficient shear stress, it becomes subject to bedload transport. The Meyer-Peter and Muller (1948) equation--a bedload transport equation for steep gravel-bedded rivers which has been calibrated on particles up to 29 mm--predicts the specific bedload flux of a specific grain-size per unit width of the river based on the specific water discharge, gradient of the water surface, and the diameter of the specific grain-size. Total bedload over the whole channel width and all grain sizes can then be derived.

The effects of a small impoundment created by a proposed diversion structure is evaluated by: (1) determining the reservoir trap efficiency by examining the residence time of water in the impoundment (depends on volume of the impoundment and discharge), and (2) determining flow velocity through the impoundment (depends on length of reservoir and residence time). Bed shear stress can be calculated from flow velocity through the impoundment, which can then be used to evaluate whether a given grain size would be mobilized at a specific discharge (Leopold, et al, 1964). The size of mobile particles can also be estimated directly from the calculated velocity (Fahnestock, 1963).

The results of these analyses are used to predict whether specific grain sizes would be either transported or deposited in various stream reaches under a range of flow conditions. Stream reaches where fine sediments generated by construction of a project would likely be deposited become the focus of an evaluation of potentially affected fishery habitat. Downstream gravel recruitment is assessed by examining the interruption of the movement of gravels by the diversion structure and by reduced flows in the bypassed reach, and the related effects on the size of gravel bars downstream used as spawning habitat.

Baseline Sediment Sampling

In order to evaluate the effect of increased sedimentation from construction of a proposed project, specific information on the locations of spawning grounds and habitat is developed for stream reaches that are predicted to have an increase in fine sediments. These specific areas within a given stream reach are then sampled for baseline conditions using McNeil core samples with wet-sieving and sampling suspended sediment to measure particle size distribution (Hamilton and Bergensen, 1984), measuring accumulated fines in W-V boxes (Wesche, 1989), and taking embeddedness measurements (Burns and Edwards, 1985); rebar is also pounded into the streambed to measure scour and fill over time. The W-V boxes, which are filled with gravel and placed at the surface of the streambed, are removed later to give a measure of fine sediment accumulation over time.

Percent fines in the streambed refers to that proportion of substrate composed of particles less than 6.4 mm. Embeddedness is a rating of the degree to which larger particles such as gravel or cobbles are covered with fine sediments--a zero rating means the larger particles are clear of fine sediments while a 100 percent rating indicates that the larger particles are completely covered with sediment.

Measurements of percent fines and embeddedness are compared to threshold levels where adverse impacts to hatching of eggs and emergence of fry is predicted to occur. While response of fish to changes in percent fines or embeddedness may be quite variable, in general as percent fines and embeddedness increases, the percent of fry successfully emerging decreases. The data indicates the presence of a threshold for fry emergence at about 20 percent fines; 34 percent embeddedness is regarded to be a biological threshold--streams with embeddedness values of more than 36 percent are indicative of severely impacted watersheds (Stowell et al., 1983).

Collecting McNeil samples is strenuous and time consuming, so W-V boxes were tried because it was reported that this method could allow for easier data collection (Wesche et al., 1986)--if the sediment data from the W-V boxes was comparable to the core samples, the boxes could be used in lieu of the McNeil sampler. The W-V boxes were expected to be sampled during spring and summer of 1990; however, about 95% of the W-V boxes were washed out during flood flows during the winter of 1989. While the W-V boxes appeared to be a good technique for sampling remote areas, the steep gradient and shifting substrate prevented the boxes from staying in place long enough to take meaningful long-term measurements.

Conclusion

Sedimentation analyses are useful tools for evaluating both project-specific and cumulative impacts to aquatic habitat from fine sediments generated by construction of hydropower projects and from altered gravel movement due to project operation.

REFERENCES

American Society of Civil Engineers, 1975, Sedimentation engineering. New York.

Baker, V.R., and D.F. Ritter, 1975, Competence of rivers to transport coarse bedload material. Geological Soc. of Amer. Bulletin, 86, 975-978.

Burns, D.C., and R.E. Edwards, 1985, Embeddedness of salmonid habitat of selected streams on the Payette National Forest. Unpublished report. Payette National Forest. McCall, Idaho. pp. 40.

Darrach, A.G., N.M. Curtis, and W.J. Sauerwein, 1978, Estimating sheet-rill erosion and sediment yield on rural and forest highways. U.S. Department of Agriculture Soil Conservation Service-West Tech. Ser. Ctr. Tech. Note-Woodland No. 12. Portland, Oregon. November 1978.

Dunne, Thomas, 1984, Effects of the Twin Falls and Weeks Falls projects on sedimentation along the Snoqualmie River system. Seattle, Washington. August 1984. pp. 55.

Fahnestock, R.K., 1963, Morphology and hydrology of a glacial stream - White River, Mount Rainier, Washington. U.S. Geological Survey Professional Paper 422-A. pp. 70.

Graff, W.H., 1971, Hydraulics of sediment transport. McGraw-Hill, New York.

Hamilton, K., and E.P. Bergersen, 1984, Methods to estimate aquatic habitat variables. Colorado Cooperative Fishery Research Unit, Colorado State University. Fort Collins, Colorado.

Iwamtoto, R.N., M.A. Madej, R.L. McComas and E.O. Salo, 1977, Sediment and water quality: a review of the literature including a suggested approach for a water quality criterion. Contract Report No. WY-6-99-0825-J. Environ. Prot. Agency Region X.

Leopold, L.B., M.G. Wolman, and J.P. Miller, 1964, Fluvial processes in geomorphology. W.H. Freeman Co. San Francisco, California. pp. 522.

Meyer-Peter, E., and R. Muller, 1948, Formulas for bedload transportation, Proc. Second Meeting Internat. Assoc. of Hydraulic Res., 39-64.

Raudkivi, A.J., 1976, Loose boundary hydraulics. Pergamon, Oxford. pp. 397.

Reid, L.M., 1981, Sediment production from gravel-surfaces forest roads, Clearwater Basin, Washington. Fisheries Res. Institute, Univer. of Washington. pp. 247.

Stowell, Rick, A. Espinoza, T.C. Bjornn, W.S. Platts, D.C. Burns, and J.S. Irving, 1983, Guide for predicting salmonid response to sediment yields for Idaho Batholith watersheds. U.S. Forest Ser. Intermountain Region. August 1983.

Vanoni, V.A., 1975, Sedimentation engineering, American Society of Civil Engineers manuals and reports on engineering practice. New York. pp. 745.

Weichmeir, W.H., C.B. Johnson, and B.V. Cross, 1971, A soil erodability nomograph for farmland and construction sites. J. Soil and Water Conservation 26, 189-192.

Wesche, T.A., D.W. Reiser, V.R. Hasfurther, W.A. Hubert, and Q.D. Skinner, 1989, New technique for measuring fine sediment in streams. N. Amer. J. of Fisheries Mgt. 9, 234-238.

Westbrook, Mark, 1987, Wells Creek hydroelectric project (FERC No. 4628): Erosion and sedimentation field study report. Western Power, Inc. Seattle, Washington. pp. 95.

CASE STUDY OF A SEDIMENT-LIMITED LAKE

by Charles M. Cooper, F. R. Schiebe, and J. C. Ritchie
Supvry. Ecologist, U. S. Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, Mississippi; Res. Hyr. Engr. and Director, ARS, Durant, OK; and Soil Scientist, ARS Hydrology Laboratory, Beltsville, MD.

ABSTRACT

Patterns of suspended sediments, biological productivity, and water quality were monitored routinely over a fourteen year period in Lake Chicot, Arkansas (1) to determine the effects of runoff from intensive agriculture and (2) to measure recovery after diversion of storm flows. Lake Chicot is one of the largest oxbow lakes (19.3 km^2) of the Mississippi River. Following extensive flooding and watershed enlargement in 1927, a dam which isolated the northern third of the lake basin was constructed across the lake above Connerly Bayou, the major point of inflow. The catchment area of the larger south basin was channelized and converted from hardwoods to rowcrop agriculture while catchment for the isolated north basin was cleared but not enlarged. Chlorophyll a concentrations showed that algal production density in the south basin was limited seasonally by suspended sediments. In comparison, algal density in the isolated north basin was significantly higher as a result of lower turbidity levels. In 1985, a pumping plant was completed on Connerly Bayou which allowed diversion of storm flows with large concentrations of suspended sediments into the Mississippi River. Without suspended sediment loading, water quality in the south basin rapidly improved and chlorophyll a concentrations increased. Significant differences in productivity between the two basins could not be detected as physical/chemical water quality parameters became more closely aligned.

INTRODUCTION

One of the most visible pollutants in fresh waters is suspended sediment. Instream suspended sediment and bedload materials are, by volume, the greatest polluting agents in the United States (Fowler and Heady, 1981). Accumulation of such eroded materials is a major problem in the management of lakes and reservoirs (Robinson, 1971; Cooper and McHenry, 1989). Since suspended materials can also play a major role in regulating physical, chemical, and biological processes (Schiebe, et.al., 1975; Cooper, 1988), productivity in lakes which are subjected to routine input of suspended sediment may be altered significantly.

Lake Chicot lies adjacent to the Mississippi River in the alluvial deposits that form much of the river corridor in the lower Mississippi valley. Since permanent settlement began in the 1830's, the percentage of Lake Chicot's watershed covered in bottomland hardwoods has declined while the size of the drainage net has increased, resulting in several decades of lake water quality deterioration from large quantities of agricultural runoff. A dam was constructed across the lake in 1948, isolating the northern fourth of the lake. This allowed basin differences to develop as sediment loading continued in the larger south basin. In 1985, a diversion system was completed which eliminated much of the annual suspended sediment load from entering Lake Chicot. Suspended sediments, biological productivity, and water quality were routinely measured in Lake Chicot for several years before and after diversion. The purposes of this paper are to evaluate (1) effects of runoff from intensive agriculture and (2) how they limited primary productivity and altered water quality and to discuss (3) lake recovery after diversion of storm flows.

STUDY AREA

Lake Chicot, Arkansas (19.3 km^2), an oxbow of the Mississippi River (Fig. 1) in east Chicot County, Arkansas, is 27 km long and averages 0.8 km in width. The primary land use in the catchment area which drains into the lake is intensive agriculture with the principal crops being cotton (Gossypium hirsutum), rice (Oryza sativa), and soybeans (Glycine max). Prior to a widespread Mississippi River flood in 1927, Lake Chicot was a single unit with limited inflow from Connerly Bayou and outflow via Ditch Bayou. Water quality, fisheries and recreational opportunities were excellent. Basin enlargement by the 1927 flood increased the contributing drainage area from approximately 100 km^2 to 930 km^2. This drainage flows through Connerly Bayou into the southern basin of the lake. The flood deposited large quantities of material across the lake immediately north of Connerly Bayou and formed a sizable sand spit. Simultaneously, the normal lake level was lowered as both Connerly and Ditch Bayous were deepened by scouring. In 1948, additional fill materials were added to the sand spit by the Arkansas Game and Fish Commission to form a dam that permanently divided the lake into two basins: an isolated northern basin (3.9 km^2) and a larger flow-through southern basin (15.4 km^2). While the southern basin had greatly increased flow from a 930 km^2 watershed through channelized drainage, the isolated northern basin had only ephemeral runoff from a predominantly agricultural watershed of < 100 km^2. At normal pool level, the south basin had a maximum depth of 9.2 m and a mean depth of 4.2 m while the north basin had maximum depth of 5.5 m and a mean depth of 3.4 m.

A thorough description of lake morphology is presented by Schiebe, et al. (1980) and sediment accumulation rates and patterns are described by Ritchie, et al., 1983).

METHODS

Water quality and sediment sampling began in June, 1976. Sampling routine, protocol, and methodology were established by January, 1977. Temperature, conductivity, dissolved oxygen, and pH were measured in-situ by electronic water quality meters. Total solids, suspended solids, dissolved solids, nutrients, chlorophyll, and coliforms were analyzed by standard methods (APHA, 1975; USEPA, 1974). Nine stations, including watershed channels, inflow, lake, and outflow were initially chosen for sampling purposes. That number was later reduced to six which were continued throughout the study. During the initial intensive phase of the study (1976-1979), samples were taken bi-weekly. Beginning in 1980, samples were taken monthly.

The data set used for analysis in this paper compared five years before diversion (1980 through 1984) and an equal period when major storms were diverted(1985 through 1989). Statistical analysis was obtained using the analysis of variance with least squares means procedures from Statistical Analysis Systems (SAS, 1985) to test for differences between the means. All differences reported as statistical or significant were statistically significant at the $P > 0.01$ level.

RESULTS

Pre-diversion Differences

During the 1970's and early 1980's, differences in watershed size and drainage characteristics produced highly significant ($P > 0.0001$) yearly differences in suspended sediment concentrations (Fig. 2) between the flow-through south basin and the isolated north basin of Lake Chicot. Mean suspended sediment concentration for the south basin for the five year period before the diversion (1980 to 1985) was 208 mg/L (Table 1), and only 47 mg/L for the north basin.

A comparison of the two basins showed that several other physical, chemical, and biological parameters differed greatly on a yearly or seasonal basis. Conductivity for the five year period before diversion was significantly higher in the south basin than it was in the north basin. PH and total chlorophyll, which reflected primary algal productivity, were significantly lower in the south basin. Conversely, filterable ortho-phosphorus (Table 1) was significantly higher in the north basin. There were no significant differences in measured nitrogen compounds between the two basins before diversion of storm flows began.

Annual cycles in the two basins portrayed complex ecological systems which responded to a combination of variables but more fully explained seasonal limiting factors. Annual temperature cycles (Fig. 2) for the two basins were virtually identical. Aquatic productivity was limited in winter as minimum water temperature generally ranged from 4 to 10 C but occasionally approached 0 C. Maximum summer surface temperature exceeded 35 C. Because of mixing conditions, periods of thermal stratification were brief in both water bodies. After fall turnover in September, the lake was usually homothermous until April.

While temperature was dependent upon broad-based seasonal and climatic conditions, suspended sediment cycles were directly dependent upon rainfall/runoff events. Seasonal suspended solids peaked every year with late winter and early spring storm events (Fig. 2). Highest concentrations of suspended sediment were measured in March or April each year. Weather patterns dictated that the majority of rainfall occurred during this time of year when there was minimum ground cover. Both basins reflected this pattern, but it was highly pronounced in the south basin. Suspended solids concentrations averaged 385 mg/L in the south basin each April before diversion; they averaged 69 mg/L in the north basin. Chlorophyll concentrations indicated a single major peak during September in the south basin (Fig. 3). Corresponding larger peaks were noted in the north basin in August, September, and October. In addition, chlorophyll peaks in the north basin coincided with spring and autumn turnover and also occurred in early winter when phytoplankton activity was stimulated by runoff events.

Post-diversion

The diversion of large storm flows from the south basin of Lake Chicot began in March, 1985. Suspended sediments immediately began to decline, and chlorophyll concentrations began to increase. From March to April, 1985, suspended solids in the south basin declined from 251 mg/L to 193 mg/L, which represents about half of the average pre-diversion suspended sediment concentration for April. Chlorophyll concentrations then increased steadily until they reached summer maxima.

Mean suspended sediment concentration for the five year period after completion of the storm flow diversion was 39 mg/L for the south basin and 30 mg/L for the north basin (Table 1). For the five years with storm diversion, suspended solids concentrations in the south basin were not significantly different from those measured in the north basin either before or after diversion. Conductivity and pH values were no longer significantly different in the two basins. Total chlorophyll concentrations in the south basin after diversion were significantly higher than they were prior to storm re-routing. They were not significantly different from chlorophyll values measured in the north basin before diversion. Because of lower nutrient input from the watershed and greater uptake by phytoplankton, phosphorus concentrations in the south basin declined significantly after storm diversion (Fig. 3). Cyclic growth phenomena and increased water level stability also caused increased phytoplankton production in the north basin after diversion; thus, it remained significantly higher in chlorophyll than the main body of the lake.

DISCUSSION

Before diversion, suspended material inflow and resulting suspended sediment concentrations represented the most noticeable difference between the two basins of Lake Chicot. While chlorophyll cycles represented the results of many variables, phytoplankton production was limited seasonally in the south basin by concentrations of suspended sediments. In a typical year during this period, light was limited by suspended sediments so that phytoplankton production was dampened inspite of excessive phosphorus. As sediments were removed from the water column in mid-June and early July, light penetration increased (Stefan, et al., 1983) and chlorophyll concentrations also began to increase. Chlorophyll peaked in September or October and then was dampened by reduced temperatures and inflowing suspended material from autumn storm events. In the north basin, chlorophyll peaks were generally associated with spring and fall turnover, summer maxima, and stimulation by storm events.

Storm flow diversion resulted in rapid changes in the south basin. When the spring flow of suspended solids was reduced, significant differences between the two basins in suspended solids and phosphorus disappeared. Mean annual chlorophyll concentrations in the south basin rapidly approached the project goal, i.e., concentrations similar to the historical values recorded from the north basin. Water clarity, an important aesthetic factor, greatly improved. Before the diversion began, there were significantly higher suspended sediments in the south basin from February through June over other months. There were no significant monthly differences in the north basin. After the diversion of storm flows began, the February through June period ceased being significantly different from other months.

As physical/chemical water quality conditions in the two basins became more closely aligned, differences in productivity cycles began to disappear. A comparison of two storms emphasizes the importance of this alignment. In a pre-diversion storm (12-83), suspended sediment concentrations in the south basin increased from 39 mg/L to 219 mg/L while total chlorophyll declined from 30 mg/m^3 to 2 mg/m^3. Suspended sediments in the isolated north basin increased from 29 mg/L to 159 mg/L. Unlike the south basin, phytoplankton growth was stimulated and total chlorophyll increased from 72 mg/m^3 to 127 mg/m^3. In a similar large storm (4-89) where high flows were diverted from the south basin, suspended sediments in that basin only increased from 4 to 13 mg/L and chlorophyll increased from 28 to 36 mg/m^3. Suspended sediments increased from 16 to 229 mg/L and chlorophyll temporarily decreased from 67 to 29 mg/m^3 in the north basin.

Sediment-laden runoff from intensive agriculture adversely affected the south basin of Lake Chicot, deteriorating water quality, water clarity, and primary productivity. As a result of diverting storm flows with an active/passive bypass system, suspended sediments were eliminated as a limiting factor. Thus, primary productivity increased and water quality/water clarity improved.

ACKNOWLEDGEMENTS

The authors wish to thank personnel from the Agricultural Research Service; The U. S. Army Corps of Engineers, Vicksburg District; The University of Mississippi Dept. of Biology; Soil-Plant Analysis Laboratory, Northeast Louisiana University; and the State of

Arkansas. They especially appreciate the assistance of Dr. Richard Price and Dr. Scott Knight. The project was jointly supported by the USDA and the U. S. Army Corps of Engineers, Vicksburg District.

REFERENCES

American Public Health Association, 1975, Standard Methods for the examination of water and wastewater; (14th ed.), Washington, D. C.

Cooper, C. M. and J. R. McHenry, 1989, Sediment accumulation and its effects on a Mississippi River oxbow lake. Environ. Geol. Water Sci. 13:33-37.

Cooper, C. M., 1988, The toxicity of suspended sediment on selected freshwater invertebrates. Vert. Internat. Verein. Limnol. 23:1619-1625.

Fowler, J. M. and E. O. Heady, 1981, Suspended sediment production potential on undisturbed forest land: J. Soil and Water Cons., 36:47-49.

Ritchie, J. C., C. M. Cooper, J. R. McHenry, and F. R. Schiebe, 1983, Resent sediment accumulation in Lake Chicot, Arkansas. Environmental Geology. 5:79-82.

Robinson, A. R., 1971, Sediment. J. Soil and Water Cons. 26:61-62.

SAS Institute, Inc., 1985, SAS/STAT Guide for personal Computers, Version 6 Edition, Cary, NC. SAS Inst. Inc., 378 pp.

Schiebe, F. R., J. C. Ritchie, and J. R. McHenry, 1975, Influence of suspended sediment on the temperature of surface waters of reservoirs. Vert. Internat. Verein. Limnol. 19:133-136.

Schiebe, F. R., J. C. Ritchie, and J. R. McHenry, 1980, Water quality improvement of Lake Chicot, Arkansas. Proceedings of the Symposium on Surface Water Impoundments. Minneapolis, MN, June 1980. pp. 686-693.

Stefan, H. G., J. J. Cardoni, F. R. Schiebe, and C. M. Cooper, 1983, Model of light penetration in a turbid lake. Water Resources Research 19:109-120.

U. S. Environmental Protection Agency, 1974, Methods for chemical analysis of water and wastewater. Methods Development and Quality Assurance Research Laboratory, Cincinnati, OH. EPA-6251 S-74-003. 298 pp.

Table 1. Means of selected water quality parameters measured from Lake Chicot, Arkansas, separated by basin and time.

	Suspended Solids	Dissolved Oxygen	Conduct.	pH	Total Chlor.	FOP[1]	Nitrates NO^3-N
	mg/L	mg/L	µmhos/cm	Units	mg/m^3	mg/L	mg/L
<u>BEFORE</u>							
North	47	10.1	174	8.3	45.3	0.04	0.29
South	208	9.6	198	7.8	18.1	0.08	0.48
<u>AFTER</u>							
North	30	10.8	224	8.0	84.2	0.02	0.06
South	39	9.8	282	7.9	41.7	0.04	0.43

[1] FOP - Filterable ortho-phosphorus

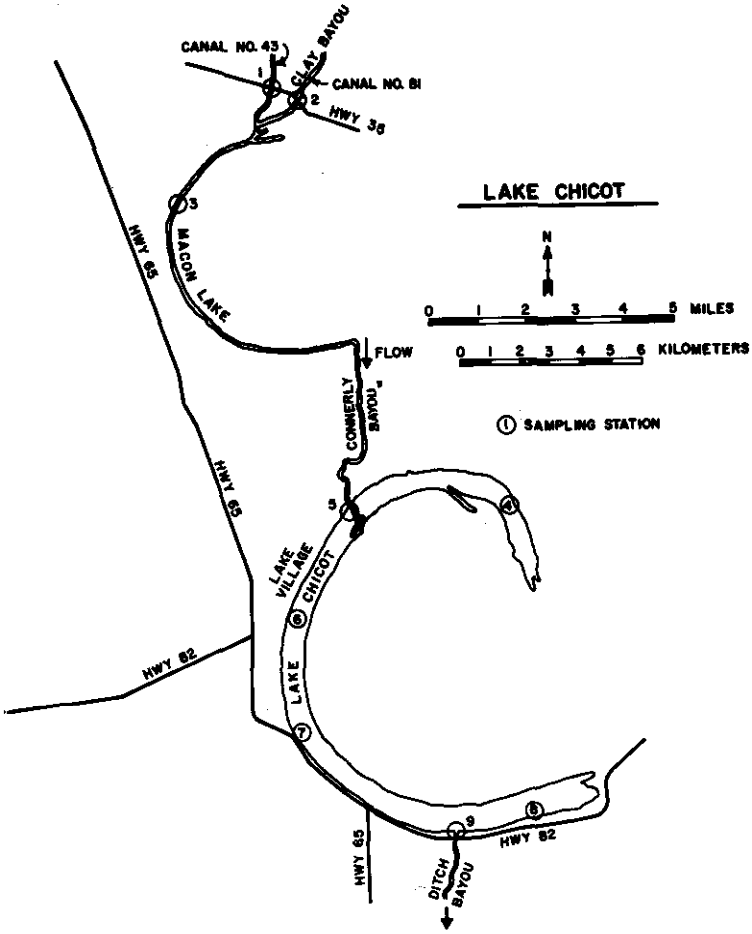


Fig.1. Map of Lake Chicot, Arkansas with sampling stations indicated.

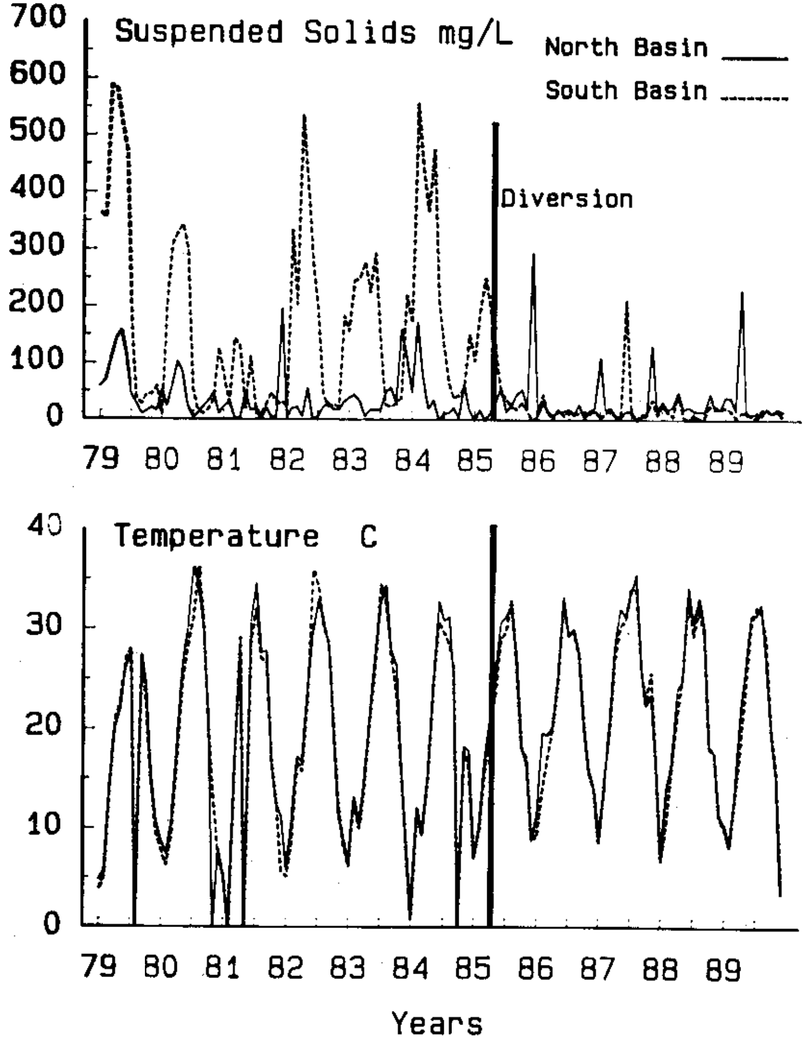


Fig.2. Surface suspended solids (mg/L) and temperature (C) values for the north and south basins of Lake Chicot, Arkansas before and after diversion.

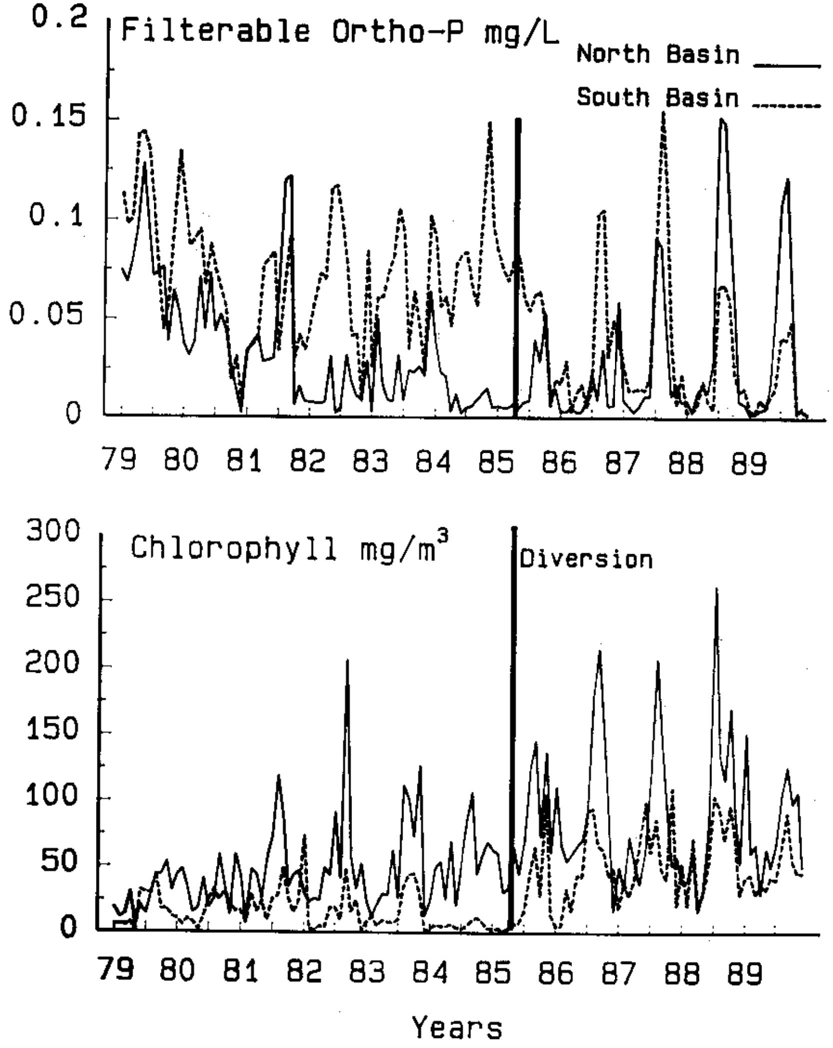


Fig.3. Surface filterable ortho-phosphorus (mg/L) and total chlorophyll (mg/m^3) for the north and south basins of Lake Chicot, Arkansas before and after diversion.

EFFECTS OF BANK PROTECTION ON STREAM FISHES

Scott S. Knight, Ecologist and Charles M. Cooper, Supvry. Ecologist. U. S. Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, MS

ABSTRACT

Streams of the bluff-line hills of northern Mississippi share a common characteristic of unstable beds of clay or shifting sand, with only the occasional fallen tree or log scouring a hole sufficiently deep to support larger game and non-game fishes. Bank protection measures that limit channel or shore line development logically adversely affect fish populations. However, those measures that promote the creation of scour holes provide refuge in a habitat limited environment and thus benefit fish. As a part of the Demonstration Erosion Control (DEC) Project in the Yazoo Basin, stream bank protection techniques were evaluated for their impact on catch per unit of effort, total catch, total numbers, and species diversity of fishes of Batupan Bogue Creek near Grenada, Mississippi. The 3 year study was designed to examine 3 protection measures and a control, each consisting of 3 replicates of old lateral dike sections, new lateral dike segments, transverse dike sections and natural bank reaches. Catch per unit of effort was higher along transverse dikes than along either type of lateral dike but was not different from the natural bank controls. Total catch in both numbers and weight was greater around the transverse dikes. No difference in species diversity was observed for any bank type. Poorest catches were associated with old lateral dikes with catch per unit of effort by number and weight being significantly lower along old lateral dikes than along all other bank types. Scour holes associated with transverse dikes probably do not effect fish production directly but provide additional areas capable of supporting both larger fish and greater numbers of fish. If not for these scour holes, larger fish would have to seek deeper water downstream, particularly during periods of low flow. Since costs for transverse dikes and lateral dikes are the same, transverse dikes provide an environmentally-sound, cost effective way to protect and stabilize stream banks.

INTRODUCTION

Typically streams of the bluff line hills of northern Mississippi seem to share one common characteristic in that they all have beds consisting of waves of shifting sand. Along natural sections of these streams, the occasional fallen tree or log will allow the current to scour a hole in the substrate thus providing the only suitable habitat for larger game and non-game fishes. Bank protection measures not contributing to hole scouring or that provide limited shore line development would logically adversely affect fish populations (Elser 1968, Peters and Alvord 1963, and Hjort et al., 1984). However, those measures that promote the creation of scour holes or other quality habitat should provide refuge in a relatively habitat-limited environment and, thus, benefit assemblages of fish (Bulkley et al. 1976., Hunt 1968, and Hunt and Graham 1972). Although a number of studies have investigated impacts of channel modifications on fish populations, either the various investigations have produced conflicting results or have been limited to larger river systems (Arner et al., 1976, Funk and Robinson 1974, Hjort et al., 1984, Pennington et al., 1985, and Thackston and Sneed 1982). It is likely that the possible benefits or detriments of stream bank protection depend to a great extent on the habitat homogeneity of the stream. The purpose of this study was to evaluate the impact on stream fishes of three bank protection techniques when compared with natural banks.

MATERIALS AND METHODS

Stream bank protection techniques were evaluated as to their impact on catch per unit of effort, total catch, total numbers, and species diversity of fishes of Batupan Bogue Creek near Grenada, Mississippi. The 3 year study was designed to examine 3 protection measures and a control, i.e., 3 replicates of old lateral dike sections, new lateral dike segments, transverse dike sections and natural bank reaches. Each dike section was located along 100 m portions of the creek channel as opposed to 100 m of shore line. Lateral dikes less than or equal to 5 years old were designated new lateral dikes and those in excess of 5 years were labeled old lateral dikes. Samples were taken semiannually as soon as water depth made sampling possible in the spring and in the fall between the first day in October and last day of September. Fish were collected by backpack-mounted electroshocker equipped with an automatic timer, and activated by the power switches in the electrode handles. Shocking times were recorded in order to calculate catch per unit of effort. Because of the tremendous variability in actual shocking time, it was felt that an index of stock abundance such as catch per unit of effort would provide a better means of evaluation the absolute weights or numbers.

Statistical analysis was obtained using the analysis of variance with least squares means procedures from SAS software (SAS Institute Inc. 1985) to test for differences between the means. All differences reported as statistical or significant were statistically significant at the $P > 0.05$ level.

RESULTS AND DISCUSSION

Electroshock sampling produced 3,514 fish, totaling 33.6 kg from the 12 collecting sites on Batupan Bogue Creek. Representatives of 52 species were collected during the three years of the study. Catostomids (suckers) were the dominant taxon by weight across all bank types with Centrarchids (sunfishes) being the most abundant.

Transverse dikes generally accounted for the greatest catches by weight; averaging 6.3 kg of fish per sample compared to 1.0 kg from old lateral dike, 1.6 for new lateral dikes and 5.0 kg for natural banks. Although catch by weight along transverse dikes was not significantly different along that from natural banks, it was statistically higher than catches from both old and new lateral dikes.

Transverse dikes produced more fish than did most of the other bank types, averaging 53 fish per collection compared to 23, 34 and 49 fish for old lateral dikes, new lateral dikes and natural bank, respectively. Again catch by number from transverse dikes, although not statistically different from natural bank, was significantly higher from both types of lateral bank protection.

Although useful, comparisons based on catch or numbers can be misleading unless differences in collecting effort can be taken into account. One method of accounting for differences in fishing effort is to report the catches on a per unit of effort basis, so that catch by weight is converted to catch per unit of effort and (CPUE) is expressed as kg of fish per hour. Similarly, count data may also be converted to numbers of fish per unit of effort (NPUE).

Average CPUE and NPUE for each bank type may be found in Table 1. CPUE for transverse dikes followed the same pattern as the raw catch data and indicated significantly higher CPUE for transverse dikes than for old or new lateral dikes. There was no statistical difference for CPUE between natural banks and transverse dikes, emphasizing the similarity between natural bank and transverse dikes from a fisheries point of view.

Table 1. Means and standard deviations of number, number weight catch per unit of effort (NPUE), and catch per unit of effort (CPUE) for each bank type.

Bank Type	Number of Species	NPUE (Number/h)	CPUE (Kg/h)
Transverse Dike	25.0 + 2.6	409.6 + 366.5 ††	46.1 + 50.8 ††
Natural Bank	24.6 + 1.1	356.7 + 281.3	31.5 + 47.3†
New Lateral Dike	19.3 + 0.6	380.0 + 314.2	13.7 + 26.5 ††
Old Lateral Dike	17.6 + 4.7	196.3 + 150.5 ††	8.0 + 13.3† ††

---

† Indicates a significant difference (P > 0.05) between natural bank and other bank types with same symbol.

†† Denotes significant differences (P > 0.05) between transverse dike and other bank types with same symbol.

Transverse dikes had significantly higher NPUE than old lateral dike. No other statistical differences were found for NPUE for any bank type.

When examined over time (Fig. 1), a steady decline in CPUE along lateral dikes was measured, while CPUE for transverse dikes, other than a decrease in 1987, greatly increased over the three year study. This decline in CPUE is not surprising since old lateral dikes generally had the lowest CPUE values and over time new lateral dikes aged to become old lateral dikes. From these data it appears that there is a lag period where fish previously associated with the natural bank gradually leave after a lateral stone dike is installed. This may be due to filling of small naturally occurring scour holes that existed prior to stone paving or the covering and or removal of woody debris typically associated with stream shoreline.

SUMMARY

Based on the results of this study, where some bank protection is deemed necessary, transverse dikes provide the most environmentally-sound alternative for bank protection than lateral paving, particularly in light of the fact that cost of transverse dikes per unit of bank protected is the same as cost of lateral dike per unit of bank protected. The least desirable protection measure for stream fish habitat appears to be old lateral dikes. Apparently, there is a lag period where fish first associated with the natural bank gradually leave after lateral stone paving has been placed. This is indicated by no statistical difference between natural bank and new lateral dike for CPUE but there is a significant difference between natural bank and old lateral dikes. There appears to be a steady decline in catch per unit of effort from natural banks to new lateral dikes and finally to old lateral dikes.

Scour holes behind transverse dikes probably do not effect fish production directly, but they do provide additional areas capable of supporting both large numbers of fish and larger fish that would have to seek deeper water downstream as water depth decreased during the dryer times of the year. Since downstream sites no longer have to support fish displaced from upstream areas, relief from density dependent pressures allows greater over all stream fish productivity.

ACKNOWLEDGEMENTS

This project was accomplished as part of the Demonstration Erosion Control Project in the Yazoo Basin, under the Watershed Processes Research Unit at the National Sedimentation Laboratory, United States Department of Agriculture, Agriculture Research Service. The authors wish to thank Robert Holley, Terry Welch, Steve Corbin, and Pat McCoy for their field assistance and Betty Hall for assistance in manuscript preparation.

REFERENCES

Arner, D. H., H. R. Robinette, J. E. Frasier, and M. H. Gray, 1976, Effects of channelization of the Luxapalila River on fish, aquatic invertebrates, water quality, and furbearers. FWS/OBS-76/08. U.S. Fish and Wildlife Service, Washington, D.C. 66 pp.

Bulkley, R. V., R. W. Bachmann, K. D. Carlander, H. L. Fierstine, L. R. King, B. W. Menzel, A. L. Witten and D. W. Zimmer, 1976, Warmwater stream alterations in Iowa. Extent, effects on habitat, fish, and fish food, and evaluation of stream improvement structures (Summary Report). FWS/OBS-76/16. U.S. Fish and Wildlife Service, Washington, D.C. 39 pp.

Elser, A. A., 1968, Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Am. Fish. Soc. 97(4):389-397.

Funk, J. L., and J. W. Robinson, 1974, Changes in the channel of the lower Mississippi River and effects on fish and wildlife. Aquatic Series No. 11 Missouri Dept. of Conservation, Jefferson City. 52 pp.

Hjort, R. C., P. L. Hulett, L. D. LaBolle, and H. W. Li, 1984, Fish and invertebrates of revetments and other habitats in the Willamette River, Oregon. Technical Report E-84-9, prepared by Oregon State University for the U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS. 117 pp.

Hunt, R. L., 1968, Effects of habitat alterations on production, standing crops, and yield of brook trout in Lawrence Creek, Wisconsin. Wisconsin Dept. of Nat. Resources, Div. of Conservation, Waupaca, WI. 32 pp.

Hunt, W. A., and R. J. Graham, 1972, Preliminary evaluation of channel changes designed to restore fish habitat. Dept. of Civil Engineering and Engineering Mechanics and Cooperative Fisheries Unit, Montana State Univ., Bozeman, MT. 78 pp.

Pennington, C. H., S. S. Knight, and M. P. Farrell, 1985, Response of fishes to revetment placement. Ark. Acad. Sci Proc. 39:95-97.

Peters, J. C. and W. Alvord, 1963, Man-made channel alterations in thirteen Montana streams and rivers. Montana Fish and Game Dept., Helena, MT. 10 pp.

Thackston, E. L. and R. B. Sneed, 1982, Review of environmental consequences of waterway design and construction practices as of 1979. Technical Report E-82-4, prepared by Vanderbilt University, for the U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS. 92 pp.

SAS Institute Inc., 1985, SAS/STAT Guide for Personal Computers, Version 6 Edition. Cary, NC, SAS Institute Inc., 378 pp.

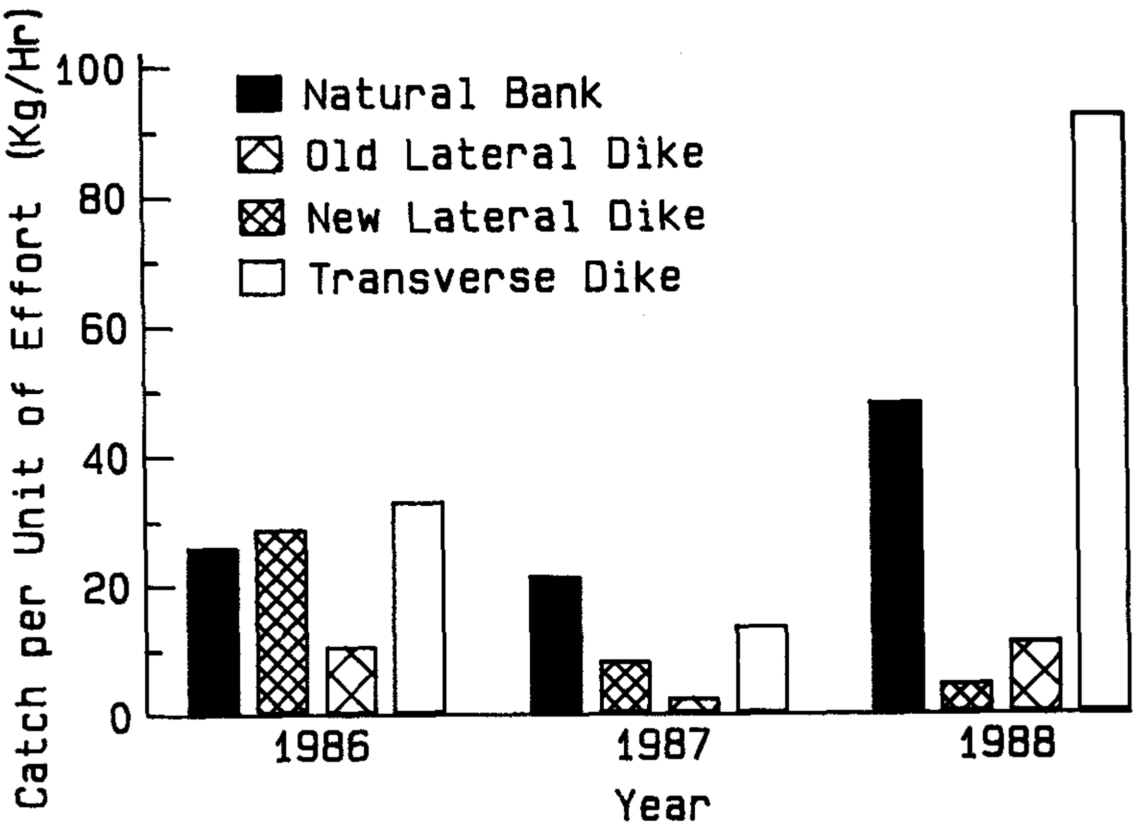


Fig. 1 Yearly catch per unit of effort for natural bank, old lateral dike, new lateral dike, and transverse dike.

A PROCESS TO EVALUATE WATERSHED CUMULATIVE EFFECTS

Meredith Webster, Ranger District Management Assistant
U.S. Forest Service, Siuslaw National Forest, Hebo Ranger District
Hebo, OR

Thomas Koler, Forest Resource Geologist
U.S. Forest Service, Olympic National Forest, Supervisor's Office
Olympia, WA

ABSTRACT

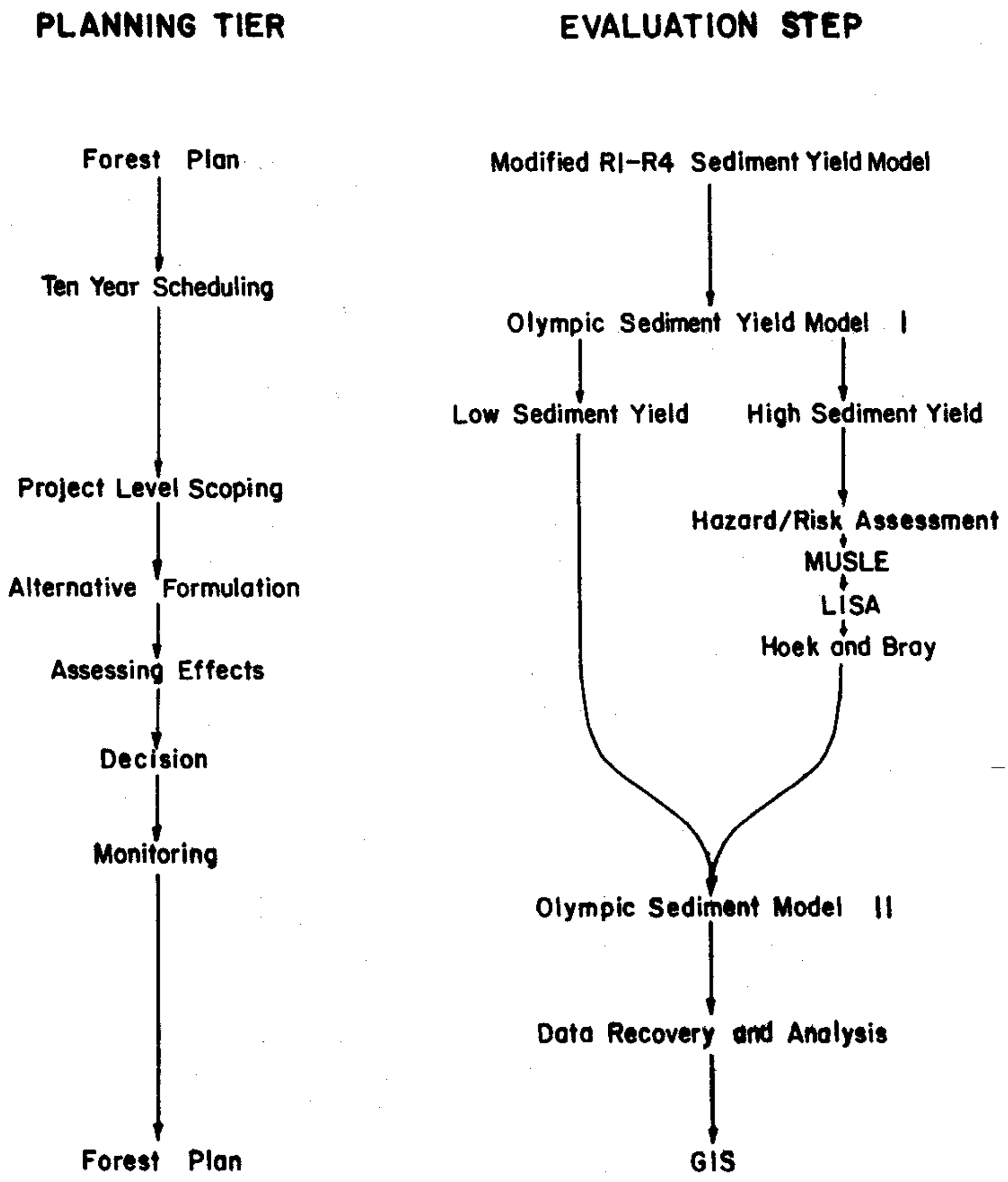
The National Environmental Policy Act (NEPA) of 1969, and the National Forest Management Act of 1976 require the U.S.D.A. Forest Service to assess and evaluate the cumulative effects of land management activities on resources of national forests. A cumulative effects process for soil, water, geology, and fisheries was developed for the Olympic National Forest in western Washington. Included within this process are a tiered set of analyses for forest planning (decade planning), ranger district planning (1-10 year planning, or 10 year scheduling), and timber sale or project planning (annual planning). The analysis used at the forest planning level is a modified version of the U.S. Forest Service R1-R4 Sediment Yield Model (Cline, et al, 1981). The analysis for the second and third levels are the Olympic Sediment Yield Models (OSYM) I and II (Webster, 1989). The OSYM I and II have been developed so that the planning process is linked from the first through the third planning levels. The result of the cumulative effects analyses is only one piece of information used in the planning process; other resources and concerns are also considered.

INTRODUCTION

This paper documents the Olympic National Forest cumulative effects analysis process for evaluating and assessing conditions of soil, water, geology and fisheries developed to be used in the 10 year schedule of activities, as well as in project level planning (see Figure 1). National forests are required to complete this type of work by the National Environmental Policy Act (NEPA) of 1969, and the National Forest Management Act of 1976. The process is linked to the cumulative effects analysis developed in the draft environmental impact statement for the Olympic National Forest Plan (1986). This forest plan level analysis is a modified version of the Regions 1 and 4 Sediment Yield Model (Cline, et al., 1981) adjusted for conditions found on the Olympic Peninsula (Stephens, 1984). The Olympic Sediment Yield Models I and II (OSYM I and II) have been developed to provide input to the process. The process is designed for use by resource specialists and employs a Geographic Information System (GIS) at map scales from 1:24,000 to 1:15,840. Data used in the models are stored in the Forest's GIS; in time, the models and the formulae will also be incorporated within the GIS.

DEVELOPMENT

Modified versions of the Regions 1 and 4 Sediment Yield Model (R1-R4 Model) are used for the Olympic cumulative effects process. The R1-R4 Model estimates the quantities of material eroded and models delivery to the stream system, routing the sediment through the system to a critical point or reach. Sediment yield estimates can then be used to predict impacts to fish habitat (e.g. water quality and fish spawning beds). In the planning process this model is scaler dependent at all levels. The mapping scales are 1:63,360 for forest planning (Modified R1-R4 Sediment Yield Model), 1:24,000 for ten-year scheduling (OSYM I), and 1:15,840 for project planning (OSYM II).



WATERSHED CUMULATIVE EFFECTS PROCESS

Figure I

An integral part of OSYM I and II is the identification of slope erosion classes within each analysis area. These slope erosion classes are based on sensitivity of soil mapping units, in the Olympic National Forest Soil Resource Inventory (SRI), to rockfall, debris flows, slope mass movements, and surface erosion (Jennings, 1983). Each soil mapping unit was given an overall erosion rating, and a map is generated depicting slope sensitivity to erosional processes. By overlaying this map with a riparian map, the slope erosion classes can be delineated. The slope erosion class maps are usually compiled in the GIS.

Parts of OSYM I and II also include a prediction routine for estimating the level of management activity that can occur to reach a predetermined sediment yield. The models also estimate recovery rates following a management activity.

In addition to OSYM I and II, an hazard/risk assessment of erosional processes is included in the cumulative effects analysis. This assessment includes determining soil surface erosion rates (using the Modified Universal Soil Loss Equation, Warrington, et al, 1980), soil slope stability analyses (Level I Stability Analysis after Hammond, 1989), and rock slope failures (methodology developed by Hoek and Bray, 1981). Results of these three evaluation tools are assimilated to create a hazard/risk map. Information is derived from the Olympic Geologic Resources and Conditions data base, and from specific data collected from field work for projects. The quantification of geologic conditions and geomorphologic processes are used to determine the probabilities in the hazard/risk assessment.

DESCRIPTION OF THE PROCESS

Land Management Planning (LMP)

Analyses of the natural and current conditions of each of 19 drainage basins on the Olympic Peninsula are included in the final environmental impact statement for the Olympic National Forest Plan. These analyses estimate the natural and management activity generated sediment yields for each basin in 1988. Calculations were done for National Forest and other ownerships within each complete basin. The Modified R1-R4 Sediment Yield Model is used at this planning level.

10 Year Activity Schedule

In creating a 10 year activity schedule, management activities are distributed among drainage basins. District managers need to know the condition of each basin in order to minimize adverse cumulative effects and to document the need for rehabilitation of highly affected areas. OSYM I is utilized at this planning level.

Project Level Planning

Scoping: At the scoping stage, an analysis area has been identified. The boundaries are specified, and the presence and condition of the resources in the analysis area are inventoried. This information can be used to define objectives for the analysis area. The cumulative effects analysis provides information on natural and current conditions, and a sensitivity analysis of the analysis area. This information, used in conjunction with other basin data, can be interpreted in order to make recommendations for the level of management activities in the area.

The Olympic Sediment Yield Model I is used to calculate an optimum level of management activity while not exceeding a sediment yield threshold. If the resource condition is favorable at all scales of analysis and the management objectives are expected to result in a desirable sediment yield, no further cumulative effects analysis is necessary.

Alternative Formulation: At this stage in the planning process, the information needs do not include cumulative-effects analysis results. The information needs are closely related to, and depend upon, the results of the cumulative-effects analysis process already completed. A hazard/risk analysis can be done for all or part of the analysis area, which can guide the planner to concentrate or avoid management activities on specific sites within the analysis area, thus being proactive to the predicted degree of impact. This should be done on lands with medium or high sensitivity, or where the sediment yields already indicate cause for concern. This step allows the manager to control the hazards which may put resources at risk as a result of the proposed activities.

Assessing Effects: Once alternatives are developed, predicted sediment yields can be calculated to compare them and the impacts on fish habitat can be estimated. In addition to providing a method for comparing alternatives, this analysis can guide the design of mitigation measures. The analysis displays geographic sources and the erosional processes generating the sediment, allowing mitigation measures to be designed to reduce sediment yield in the areas where it will be most beneficial. A cost/benefit analysis can be done. OSYM II is used from this point on in the NEPA process.

Decision: Once an alternative has been selected, a forecasting routine can be run to estimate the time at which the sediment levels will drop to the point that further activities in the analysis area can be planned.

Monitoring: Management activities seldom occur when planned. A two-year delay in timber harvest will result in a two-year delay in the sediment derived from that activity. The results of the forecasting routine for OSYM II will need to be updated as activities occur. Data are collected and analyzed for projects, especially those with predicted sediment yields approaching or exceeding the thresholds of concern. Another level of monitoring is the evaluation of sediment delivered at sample collection sites. This is a more intensive monitoring process which includes sediment collection during to peak flow events, and the position of sites down and upstream from an activity. Data collected from this level of monitoring can be used for calibrating the sediment yield models in highly sensitive basins. These and other resource data are updated in the GIS for later usage, including future forest plans.

CONCLUSION

This three level watershed cumulative effects process is multifunctional in that it identifies, evaluates, and predicts potential impacts to resources as a result of various management activities (e.g. logging, roading, burning, and log truck hauling). This process dovetails neatly into the NEPA process from scoping through monitoring. Management can use this process for highlighting the drainages which have the greatest need for rehabilitation, the level of harvest (with associated activities) appropriate for each drainage and which mitigation measures would be beneficial. The process does not place constraints on a manager; rather, it provides information to guide the resource decision.

REFERENCES

Cline, R., Cole, G., Megahan, W., Patten, R., Potyondy, J., 1981, Guide for predicting sediment yields from forested watersheds; Ogden UT: U.S. Department of Agriculture, Forest Service, Northern and Intermountain Region and Intermountain Forest and Range Experiment Station, 02 p.

Draft Environmental Impact Statement for the Land and Resource Management Plan, Olympic National Forest, 1986.

Hammond, C., Hall, D., Miller, S., Swetick, P., 1989, Level I Stability Analysis (LISA) User's Manual to Version 1.05; Moscow ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 256 p.

Hoek, E., and Bray, J., 1981, Rock Slope Engineering: The Institute of Mining and Metallurgy, London, UK, 309 p.

Jennings, J. W., 1983, Conversion of SRI mapping units on the Olympic National Forest to slope erosion class; Olympia WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, internal doc.

Stephens, R., 1984, Procedure to estimate sediment yields for watersheds on the Olympic National Forest; Olympia, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, internal doc., 15 p.

Warrington, G.E., Knapp, K.L., Klock, G.O., Foster, G.R., Beasley, R.S., 1980, Surface Erosion; in: Chapter 4 of An Approach to Water Resource Evaluation of Non-Point Silvicultural Sources (a procedural handbook); U.S. Environmental Protection Agency, Environmental Research Laboratory, Handbook EPA - 600, Athens, GA.

Webster, M., 1989, Cumulative Effects Analysis - A Practical Workbook Demonstrating the Cumulative Effects Analysis Process; Olympia, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, internal doc., 27 p.

United States Congress, 1969, National Environmental Policy Act: 42 U.S.C. 4321-4361.

______________________, 1976, National Forest Management Act: 16 U.S.C. 1600.

Permits to Regulate Urban Stormwater Discharges

BY: Thomas E. Davenport, Regional NPS Coordinator, USEPA, Chicago, Illinois; Mike Mitchell, Environmental Scientist, and Kevin Weiss, Environmental Engineer, USEPA, Washington,D.C.

ABSTRACT

Urban stormwater has been found to include significant quantities of pollutants, and in many areas adversely affects water quality and impairs achievement of designated water resource uses. To address urban stormwater problems, EPA and State pollution control agencies will be issuing discharge permits to the owner/operators of stormwater collection and conveyance systems and the related outfalls. These permits will require data collection and reporting, and the development and implementation of programs for reducing pollutant loadings to receiving waters. Programs in some cases will call for capital improvements, but in many instances the cost-effective approaches for solving the problems will be Best Management Practices (BMPs). These BMPs will reduce the introduction of pollutants to the storm sewer systems, by managing nonpoint sources (NPS) of pollution. Requiring NPS control components as part of stormwater permits will ensure: (1) that the permits will address all pollutants originating from NPSs; (2) that the BMPs required under the permits will economically control the pollutants identified; and (3) that the NPS control activities identified as being necessary will be fully implemented. Special conditions of a model stormwater permit will be presented, including examples of various types of BMPs utilized to prevent urban sediment problems.

INTRODUCTION

Stormwater runoff is rainwater or snowmelt which does not soak into the ground, but rather flows off lawns, streets and other paved areas, rooftops, and agricultural and undeveloped areas. As the stormwater flows across the ground it picks various substances, including such things as fertilizers, salt, heavy metals, oil and grease, and pesticides. These substances are then deposited in nearby wetlands, lakes and streams, as the stormwater follows natural and man-made drainage patterns and flows into these waterbodies. Through this process significant quantities of pollutants are discharged into the waters of the United States. Since these pollutants are from various areas and sources, and cannot be traced to a single, identifiable source, they are called NPS pollutants. (WDNR, 1987)

Stormwater is a major issue in many developed and developing areas, both in terms of the potential for flooding and in terms of the delivery of pollutants to nearby receiving waters. In developing areas, soils are frequently disturbed and erosion, and the subsequent discharge of sediments and fertilizers, can be a significant concern. Where development has occurred, many of the problems associated with stormwater stem from the fact that a large percentage of the land area is covered by buildings and pavement and other relatively impermeable surfaces. Stormwater cannot pass through these surfaces and seep into the earth;

to control pollutant loadings from urban stormwater. Section 405 of the Amendments outlined a permitting strategy to be used to regulate stormwater discharges. Section 319 outlines an overall approach for States to deal with NPS pollution.

Under Section 405; city storm sewers systems were divided into several categories, based on their size, each having different deadlines for meeting permitting requirements. In general, larger cities will have to apply for, obtain, and comply with permits for their storm sewer systems sooner than will small cities and towns. Storm sewer systems serving a population of less than 100,000 are generally not required to have permits until 1992. The deadlines in the 1987 Amendments are not applicable where discharges from the system are known to be causing water quality problems, or the system is a "significant contributor of pollutants." In these situations permits can be required by regulatory agencies sooner than the deadline dates. Permits will also be issued for stormwater discharges associated with industrial activity.

The control of stormwater through the permits program will generally follow this 3-step process: (1) describe or define the existing system, from both an engineering and an institutional perspective; (2) develop control or "management" program, including a proposed implementation schedule, for reducing pollutant loadings; and (3) implement the control program according to the approved schedule.

Issued permits will outline the water quality monitoring and reporting to be done by system owners, and the water quality objectives to be met. It will then be up to the regulated entity to develop a program for meeting this objective. The issued permits will include the control program necessary for reducing pollutant loadings. In some situations, the control program will include capital improvements, such as a treatment facilities. An example of a treatment facility that might be installed is an oil/grit separator. In many other cases the recommended program will outline Best Management Practices (BMPs) for soil erosion and sediment control. BMPs must be identified in the permit.

Proposed control programs will be reviewed by the regulatory agencies to assure BMPs are in place and water quality objectives are met. Specific milestones will be laid out to measure implementation of the program.

Upon approval of the control program, the owner/operators of a storm sewer system will be required to carry out the program according to the established schedule. Compliance with the terms of the permit will be tracked by EPA or the delegated State, and appropriate enforcement actions will be pursued where a program is not satisfactorily implemented. In this way the agencies charged with meeting the objectives of the Clean Water Act can ensure cost-effective measures for reducing urban NPS pollutant loadings are identified and then implemented, and that the requirements and objectives of the Federal statute are met.

Section 319 requires States to submit NPS Assessment Reports identifying navigable waters which, without additional control of NPS pollution, cannot be expected to attain or maintain designated uses. Section 319 also encourages States to submit State NPS Management Programs to address the NPS problems identified in the Assessment Reports. These Management Programs are expected to include implementation schedules and milestones for the first four years and the State Attorney General's certification that the state has adequate authority to instead it runs across these surfaces, rapidly accumulating in ditches, drains, and storm sewers.

Storm sewers are pipes laid underground, often below streets, used to convey runoff. Intakes located throughout an area capture the stormwater and direct it into the storm sewers. The storm sewers carry the runoff to streams and lakes where it is discharged. This type of drainage system can usually prevent localized flooding problems, but accumulates a relatively large volume of stormwater which is then released into the environment at fixed points. This can result in flooding problems downstream, problems associated not only with an increase in the volume of water delivered to receiving streams, but also the timing of the peak flows. Even though the storm sewers are not designed to capture and convey sanitary wastes, they do deliver NPS pollutants to waterways and can be significant contributors to urban water quality problems. Controls are needed to mitigate adverse impacts associated with urban stormwater.

URBAN NPS POLLUTANTS

That urban NPS pollution can be a significant concern has been confirmed by EPA as part of its National Urban Runoff Program (EPA, 1983). The State Section 319 Assessment Reports identified urban runoff and construction related impacts as a significant problem (Table 1). Among the pollutants identified thru NURP and Section 319 as being a problem were suspended solids, nutrients, metals, toxic organic chemicals, oxygen-demanding materials, and bacteria.

Table 1
Extent of urban* NPS pollution (EPA, 1990)

Waterbody type (units)	Extent	Percent	Rank
Estuary (mi^2)	651	11	2
Coastal acreages (acres)	84,673	17	2
Rivers (miles)	13,056	6	3
Lakes (acres)	345,943	8	2
Wetlands (acres)	2,914	6	2

* includes construction impacts

Most of the substances of concern in urban stormwater discharges come from industrial, commercial, and/or residential use. Areas with a great deal of construction are particularly susceptible to erosion, and thus can contribute a large share of pollutants. It is important to note that the volume of stormwater discharges and the concentration of pollutants in the stormwater affect the extent to which urban stormwater is harmful to receiving waters. Daniel (1978) found high concentrations of pollutants are associated generally with the following conditions: (1) densely populated and/or industrial areas; (2) intensive storms; (3) beginning stages of a storm; (4) prolonged dry periods prior to a runoff event; and (5) drainage areas with significant construction activity.

APPROACHES TO CONTROLLING STORMWATER

In the 1987 Amendments to the Clean Water Act (P.L.100-4), Congress established the approach to be used by EPA and delegated State pollution control agencies implement the proposed activities. These activities include BMP identification; regulatory and non-regulatory efforts to implement the program; and creation of a framework for implementing NPS abatement procedures.

ALTERNATIVES FOR MITIGATING URBAN NPS POLLUTION PROBLEMS

In addition to various types of capital projects, such as the construction of cement-lined retention basins or other treatment facilities, there are numerous other means of reducing urban stormwater pollutant loadings. In many situations these other alternatives may prove to be less costly for the regulated community, and it is likely that management practices will be part of most control programs that are developed.

In addition to a program for eliminating improper connections, there are other BMPS which can be employed to cost-effectively reduce pollution from stormwater.

A BMP is defined as a method that prevents pollutant detachment or reduces the amount of pollutants in runoff before it is discharged to a water body. Urban BMPs have the dual purpose of controlling nonpoint source pollution while providing effective stormwater management. To be effective BMPs must: control pollution, effectively utilize rainfall, minimize environmental impact and must be practically and economically sound. Most BMPs are designed to control either 1) detachment and transport, or 2) only transport of the pollutant it is designed to control.

There are four general categories of urban BMPs, based on the operating principle or the physical mechanism that reduces the amount of runoff pollutants discharged to surface waters (WCC, 1990).

1) Detention basins- Pollution control benefits result from a reduction in pollutant concentrations due to settling during the period runoff is detained.

2) Retention devices- Pollution control benefits result from permanently capturing urban runoff so that it never discharges directly to a surface water.

3) Vegetative controls- Pollution control benefits result from pollutant removal by reducing pollutant concentrations thru a combination of filtration, sedimentation and biological uptake and/or a reduction in loading due to infiltration or evapo-transpiration.

4) Source controls- Pollution control benefits result from a decreased availability of pollutants and thus lower total loadings.

It is important to note that some of these practices, especially those that mitigate surface water problems through increased infiltration, could potentially affect ground water in the area; this must be considered in the evaluation of stormwater control alternatives. Site-specific conditions determine which BMPs are appropriate. There are several key factors that influence the suitability of a particular BMP for a site. These include drainage area served, soil permeability, local acceptance, maintenance requirements and other restricting factors (WCC, 1990; Schueler, 1987; MPCA, 1989).

THE APPROACH RECOMMENDED FOR THE ROUGE BASIN

The Rouge Basin, which is located in Southeast Michigan in the Detroit metropolitan area, is an example of an area where stormwater discharges have contributed to the impairment of designated uses. The Rouge is a fan-shaped basin with four river branches which drains approximately 438 square miles (SEMCOG, 1988).

Included in the Basin are all or part of 48 municipalities, with a total population of more than 1.5 million people. Overall, more than 50% of the land in the Basin is used for residential, commercial, or industrial uses. The eastern portion of the basin has been developed for the longest time, and is the most intensely urbanized area. The northern and western portions of the watershed are mainly suburban and, to a limited extent, rural in nature (SEMCOG, 1988).

The City of Detroit and the older communities adjacent to the City have combined sewers. The newer suburbs to the north and west generally have separate systems. Most sanitary wastes in the area are treated at the Detroit wastewater treatment plant.

Extensive studies done by the Michigan Department of Natural Resources (MDNR) have shown that applicable water quality standards are not being met and the designated uses are not being attained. In fact, the Rouge, which flows into the Detroit River just upstream of Lake Erie, has been designated as an Area Of Concern by the International Joint Commission. Areas of Concern are those areas contributing the greatest pollutant loadings to the Great Lakes. The United States has been called upon to develop a Remedial Action Plan (RAP) aimed at controlling the discharge of pollutants to the Great Lakes ecosystem.

One of the most important steps in the preparation of the RAP was the identification of pollutant loadings and the sources of pollution in the Rouge Basin. A summary of the annual loadings into the Basin and the sources of nitrogen, biochemical oxygen demand (BOD^5), and total suspended solids, is shown below.

Table 2
Estimated Annual Pollutant Loadings to the Rouge Basin
(Data is expressed in pounds per year)

Source	BOD^5	Suspended Solids	Nitrogen
Point Source Discharges	1,890,000	7,120,000	No Estimate
CSOs	5,480,000	13,100,000	567,000
Stormwater	6,360,000	154,000,000	1,110,000

BOD^5, suspended solids, and nitrogen, in addition to numerous other substances, are causing the impairment of uses in the Rouge Basin. Clearly stormwater is a significant contributor to the water quality problems in the area. Pollutant loadings from stormwater must be controlled if beneficial uses are to be attained.

Inasmuch as stormwater is one of the key factors contributing to use impairment in the Rouge Basin, the RAP for the Rouge outlines several steps to be taken by either the State or local units of government to address this problem. These are summarized below.

(a) Programs to eliminate improper connections to storm drains should be implemented by the local health departments and drain commissioners in all sub basins where NPS pollutants are a concern.

(b) Local stormwater management programs should be evaluated in all Rouge Basin communities which are served by separate storm drains, and stormwater control programs should be developed.

(c) In accordance with the State's NPS Management Program, soil erosion and sediment control should be improved throughout the Basin, and chemical storage piles should be properly managed to reduce runoff of pollutants in wet weather.

(d) Permits should be issued by the MDNR to implement the requirements of the Rouge RAP and the Clean Water Act. These permits should include special conditions: on BMP implementation, operation, and maintenance. The permits should include provisions on erosion and sediment control, spill prevention, illicit connections, spill response, road & highway source control, service station, pesticide/fertilizer/herbicide application program, and an education program.

The RAP recommendations related to stormwater thus are consistent with the national stormwater and nonpoint source management programs mandated by Congress and slated for implementation by EPA and delegated State pollution control agencies.

CONCLUSION

Urban stormwater has been found to include significant quantities of pollutants, and to in many areas adversely affect water quality and impair achievement of designated uses. To address urban stormwater problems, EPA and State pollution control agencies will be issuing discharge permits which will require the development and implementation of programs for reducing pollutant loadings to nearby receiving waters. Programs in some cases will call for capital improvements, but in many instances the cost-effective approaches for solving the problems will be Best Management Practices. It is important to note that the regulatory agencies will generally not be determining how water quality objectives will be met. Rather, the pollution control authorities will generally prescribe the ends to be achieved, and leave it up to the owner/operators of systems to select the cost-effective approach(es) for achieving these ends. The control strategies will vary from area to area, depending on each system's (and each receiving water's) individual needs and conditions. Complete implementation of the stormwater permitting program will ensure that control programs address all pollutants of concern, that cost-effective means are identified for reducing pollutant loadings, and that the NPS control activities will be fully implemented so that the ultimate water quality benefits can be realized. Creativity and exchange of information will be vital, as attempts are made to utilize scarce public resources to capture the greatest possible water quality improvements.

DISCLAIMER; The contents of this paper do not necessarily reflect the views or policies of the United States Environmental Protection Agency.

REFERENCES

EPA, 1983, Results of the nationwide urban runoff program, volume 1, final report. USEPA, Washington, D.C.

EPA, 1990, FY 1989 section 319 report to congress-draft, USEPA, Washington, D.C.

MPCA, 1989, Protecting water quality in urban areas, Minnesota Pollution Control Agency, St. Paul, MN.

SEMCOG, 1988, Remedial action plan for the Rouge River. Southeast Michigan council of governments, Detroit, Michigan.

Schueler, T.R., 1987, Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments, Washington, D.C.

WCC (Woodward-Clyde Consultants), 1990, Urban targeting and BMP selection; an information and guidance manual for state nps program staff engineers and managers, USEPA, Chicago, Illinois.

WDNR, 1987. What is stormwater runoff? Wisconsin Department of Natural Resources, Madison, Wisconsin.

Soil Loss Limits and Water Quality

By Thomas E. Davenport, Regional NPS Coordinator, USEPA, Chicago, Illinois; Bruce Kirschner, NPS Specialist, IJC, Windsor, Ontario; James A. Meek, EPA Liaison for Water Quality, USDA, Washington, D.C. and Lyn T. Kirschner, Water Quality Specialist, CTIC, West Lafayette, Indiana

ABSTRACT

Water quality problems as a result of nonpoint source (NPS) pollution have been well documented. Agriculture has. been identified as the largest source of NPS pollution and sediment is the second greatest pollutant. Cropland soil erosion has been identified as the largest source of NPS sediment. Since erosion from cropland is an important source of sediment and related pollutants, and since measures to reduce cropland erosion typically will also reduce runoff, it is understandable that to date, NPS control efforts have centered around the reduction of cropland erosion. Unfortunately, as is well known, the sediment yield measured at a watershed outlet is not equal to upland erosion. More importantly, in regard to predicting water quality benefits derived from reductions in cropland erosion, a characteristic relationship of sediment yields to erosion alone does not exist. This paper will summarize some work that has been done in concentrating erosion control efforts in locations that have the greatest impacts in improving or protecting water quality.

INTRODUCTION

Erosion is defined as detachment and movement of soil or rock fragments by water, wind, ice or gravity. There are five principal types of water erosion: 1) gully; 2) natural; 3) rill; 4) sheet; and 5) splash erosion. Soil erosion has several major consequences: 1) the original sites of the eroded material are degraded, therefore potential productivity is lessened; 2) the sites of deposition of the soil particles are altered physically, chemically and hydrologically; and 3) the chemical and physical nature of the transporting water system is affected.

One of the long term effects of soil erosion is the entry of phosphorous and pesticides attached to eroded soil particles into waterways. Economic values related to the three major consequences are difficult to assess. Degradation of the productive capacity of agricultural land results in depletions of yield. However, the most serious problem with erosion is the deteriorating off-site effect it has on the aquatic environment. Runoff from agricultural land can carry soil particles, nutrients, pesticides, fertilizers, livestock wastes and other pollutants to receiving water. This runoff, carrying large amounts of suspended soil particles scours the stream channel, alters the character of the stream, and affects aquatic life by impairing functions such as photosynthesis, respirations, growth, and reproduction.

CONTROL OF SOIL EROSION

Soil erosion is not synonymous with soil loss, nor is soil loss equal to sediment yield (Dunne, 1978). The sediment producing process involves soil detachment, transport, and deposition. Physically and economically it is impractical to eliminate all sediment from surface waters.

Presently, the only feasible method of controlling this erosion and its impacts is by implementing various conservation practices which lower soil loss rates, thus improving water quality. Resource Management Systems (RMS) can be implemented by the individual land owner/operater that would reduce soil erosion to more tolerable losses. The basic principles of RMS's are to alter runoff, provide cover for soil or change the water absorption capacity of soil, rain splash energy, and soil structure. Most RMS's are designed to control either 1) detachment and transport, or 2) only transport of soil particles. RMS's can be divided into two classes. The first, cultural practices are nonstructural in nature. The second group consists of structural practices which usually require off-farm equipment for construction.

Erosion control is being used as a surrogate for sediment control because sediment control is less amenable to quantitative analysis. It is assumed that controlling erosion will also control sediment. However, many RMS's are least effective at controlling the movement of small particles (clay-organic complex) which are important due to their potential chemical interactions. Reductions in soil delivery does not always produce visible improvements in water quality since silt and clay particles are the hardest to control and yet contribute most to water quality. The idea of using erosion control as a surrogate for sediment control reflects the current lack of knowledge concerning origin, transport, deportation and control technology.

TARGETING EFFORTS

Many states are actively targeting agricultural NPS problem areas and then concentrating resources for treatment of identified problem areas. For example, Wisconsin Department of Natural Resources is targeting all lands within 1/8 mile from any intermittent or perennial water resources in priority watershed projects (WDNR, 1979). In Maryland, the Statewide Critical Areas for Potential Release of Agricultural NPS phosphorous and Nitrogen Report (MSSCC, 1984) has led to the targeting of priority watersheds for soil erosion and nutrient control. Larson (1989) determined that, that targeting involves explicitly searching for low cost approaches to protection for fisheries habitat in Great Lakes tributaries from agricultural pollutants.

The addition of filter strips to United States Department of Agriculture's Conservation Reserve Program (CRP) is a good example of targeting for increased water quality. CRP was designed to remove highly erodible cropland from production without regard to the water quality benefits. Even without targeting for water quality impacts, CRP is expected to result in a 200 million ton reduction in sediment, annually (USDA, 1988). The filter strip provision and the scour area provisions, on the other hand, are specifically designed to reduce sediment loadings to receiving waters.

NEW TECHNOLOGY

New technology is being developed to help resource planners determine the areas that can be teated effectively and have the greatest impact on water resources. This new technology can be an effective tool only if the planner makes the connection that water quality improvements or protection of existing water quality requires a greater understanding of the consequences of erosion, a greater awareness of the need for managing the availability of soil and a sense of location and transport routes.

In order to put in perspective the need for these new technologies, is useful to compare two watersheds: the Great Lakes' Lake Erie watershed and the Chesapeake Bay (Table 1). These watersheds have had considerable attention, and in the latter case, considerable funds. This comparison is particularly useful since it dispels the impression that adverse water quality impacts from the run off of sediment and chemicals from cropland come only from areas which are eroding at excessive rates. That is, effective resource protection is needed more than targeting on the basis of erosion rates.

The extremely high loading rates from Lake Erie drainage area results from very find textured soils and years of heavy fertilization resulting in very high soil phosphorous levels. However, erosion rates on these soils are fairly low and average slightly over "T" and sediment delivery rates low (<10) (Baker, 1985). If control efforts focus was maintenance of crop productivity, the Lake Erie Basin would not be a priority. Since it is desirable to look beyond controlling erosion to an extent that will merely sustain a high level of crop productivity and focus instead on controlling the most serious sources of suspended and dissolved contaminants it therefore is logical to target areas like the Lake Erie Basin which are yielding the greatest amount of suspended and dissolved contaminants.

Table 1
Lake Erie and Chesapeake Bay Basins Comparison
(adapted from Baker, 1988)

Parameter	Lake Erie	Chesapeake Bay
Land Area (Km^2)	56,980	165,000
River Sediment Loads		
metric tons/year	6,531,000	3,005,800
kg/ha/year	1,150	181
River Phosphorus Loads		
metric tons/year	8,400	4,659
kg/ha/year	1.47	0.28

TARGETING TECHNOLOGY

The above mentioned efforts to target eroding areas have all taken place during a period when the technology for the most part has consisted of methods that attempted to predict sediment delivery based on modifications to the Universal

Soil Loss Equation (USLE) (Reckhow, 1985). While it may seem that the recent advances in this technology have been evolving slowly, it should be remembered that the USLE is based on a 1940 equation and the USLE was first made available shortly after 1960. The next generation of commonly used techniques have involved computing the USLE soil loss and multiplying this by a sediment delivery ratio percentage to reflect the percent of total erosion delivery to the basin mouth. Both types of techniques lack the ability to estimate or quantify the amount nutrients or pesticide transported with the sediment.

A technique outlined in 1976 by McElroy and others overcomes this deficiency:

(1) Total Phosphorous (P) Load = (sediment yield) x (P content of sediment)

(2) P Content of sediment = (P content of soil) x (enrichment ratio)

(3) Sediment yield = (USLE output) x (sediment delivery ratio)

This technique was utilized by states to develop and track the implementation of their phosphorous loading reduction plan in response to the Great Lakes Water Quality Agreement.

In order to effectively target resources to the areas of greatest water quality concern, the potential pollutant index should be examined. The potential pollutant index is product of the enrichment ratio and sediment yield. The pollutant index is a measure of the amount and composition of the sediment yield from a particular site. The potential pollutant index can be utilized to establish relative priorities for land treatment and to determine the impact of proposed control strategies. Knisel (1980) and Davenport (1984) document the use of this technique.

Calculation of the potential pollutant index is dependent upon an accurate estimation of the sediment yield. In order to achieve more accurate estimates of sediment yield from small watersheds, Clarke (1983) and Clarke and Waldo (1986) developed a method which predicted sediment yield from slope weighted average of the site representative profiles. Results from limited testing of Clarke's method compared favorably to actual sediment delivery rates (Davenport, 1983; Braden, 1986). The utility of this type of sediment yield estimation technique has been enhanced by the development of a spreadsheet template by Jerry M. Bernard, sedimentation geologist with the USDA-Soil Conservation Service. The template and procedure are currently undergoing further testing and will serve as an interim method for estimating sediment yield from field sized area until the watershed and grid versions of the Water Erosion Prediction Project (WEPP) (USDA, 1987) are fully implemented.

USDA-Agricultural Service has two major ongoing efforts to enhance the technology available for targeting erosion control efforts for water quality purposes: 1) WEPP and 2) AgNPS (Young, 1989). AgNPS has been utilized to successfully identify eroding areas which impact water quality and to target cost-share funds to these areas (Ervin, 1988). In the Morrison Lake project, based on AgNPS predictions, land owners in areas that deliver the most phosphorus to the water course were slated to get a greater share of cost-share than farmers cultivating areas within lower phosphorus loading areas. WEPP is the replacement for the USLE and will predict erosion based on physical processes. WEPP will account for deposition in furrows, on concave slopes, at edges of land use changes, and in concentrated flow channels.

CONCLUSION

Accordingly, within the next few years, as WEPP products and more advanced, user-friendly versions of AgNPS are fully tested and widely implemented, the pollution index becomes more accepted, we should see great advances in our ability to determine the impact of erosion on receiving waters. WEPP products, for example, should be in widest use and will be used for estimating the impact of cropland, rangeland or forestland management on sediment delivery to receiving waters. AgNPS, in addition to calculating sediment delivery, estimates other pollutants.

In conclusion, it appears that we should prepare for the soon to be realized increase in our technical skills. By improving our handling of the vastly improved technical information, we will be in a position to obtain improvements in water quality while assisting landowners in the most cost-effective manner.

DISCLAIMER: The contents of this paper do not necessarily reflect the views or policy of the United States Department of Agriculture nor United States Environmental Protection Agency

REFERENCES

Baker, D.B., 1985, Regional water quality impacts of intensive row-crop agriculture: a Lake Erie basin case study, J. Soil and Water Conserv. 40, 125-132

Baker, D.B., 1988, Sediment, nutrient and pesticide transport in selected lower Great Lakes tributaries, USEPA, pp. 225.

Braden, J.B., Johnson, G.V., and Martin, D.G., 1986, Efficient control of agricultural sediment deposition in water courses. In: Options for reaching water quality goals. AWRA. pp. 69-76.

Clarke, C.D., 1983, Procedure for ranking sediment source areas, unpublished draft. USDA-SCS

Clarke, C.D., and Waldo, P.G., 1986, Sediment yield from small and medium watersheds. In: Proceeding of fourth Federal Interagency sediment conference. pp. 3-19 - 3-28.

Davenport, T.E., 1983, Soil erosion and sediment transport dynamics in the Blue Creek watershed, Pike County, Illinois,. IEPA/WPC/83-004. pp. 224.

Davenport, T.E., 1984, Field modelling in the Highland Silver Watershed. IEPA/WPC/84-026.

Dunne, T., and Leopold, L., 1978, Water in environmental planning, pp. 795.

Ervin, J.L., Kittleson, K.K. and Bill, B., 1988, AgNPS-use of the agricultural nonpoint source pollution model in Michigan. pp. 84.

Knisel, W.G., 1980, CREAMS: a field scale model for chemicals, runoff, and erosion from agricultural management systems. Conservation Report No. 26

Larson, R.S., Herricks, E.E., and Braden, J.B., 1989, Efficient protection of fisheries habitat in Great Lakes tributaries from agricultural pollutants, Illinois-Indiana
Sea Grant Program.

McElroy, A.D., Chin, S.Y., Nebgen, J.W., Aleti, A. and Bennet, F.W., 1976, Loading functions for assessment of water pollution from nonpoint sources. EPA 600/2-76-151.

MSSCC (Maryland State Soil Conservation Committee), 1984, Statewide critical areas for the potential release of agricultural non-point phosphorus and nitrogen.

Reckhow, K.H., Butcher, J.B., and Marin, C., 1985, Pollutant runoff models: selection and use in decision making. In; Nonpoint source pollution. AWRA, pp. 185-195.

USDA (United States Department of Agriculture), 1987, Water erosion prediction project, NSERL Report No. 1

USDA, 1988, A national program for soil and water conservation: the 1988-1997 update review draft. GPO.

WDNR (Wisconsin Department of Natural Resources), 1979, The Hay River priority watershed plan.

Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P., 1986, AgNPS-agricultural nonpoint source pollution model-a guide to model users. USDA-ARS.