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Sand Sediments in a Michigan Trout Stream
Part I.
In-Stream Sediment Basins: A Technique for Removing Sand Bedload from Streams

Edward A. Hansen
Gaylord R. Alexander
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SAND SEDIMENTS IN A MICHIGAN TROUT STREAM

PART I. IN-STREAM SEDIMENT BASINS: A TECHNIQUE FOR REMOVING SAND BEDLOAD FROM STREAMS[1]

Edward A. Hansen,[2] Gaylord R. Alexander and William H. Dunn[2]

Abstract

Erosion control techniques such as streambank stabilization and revegetation of eroding upland areas reduce only part of a stream's sediment load. This study demonstrated that an in-stream sediment basin can trap and remove almost all sand bedload sediments. Other advantages of sediment basins are that they can: 1) produce streambed downcutting to create deeper pools and improve streambed composition, and 2) keep critical spawning areas relatively free of sediment. Sediment basins should be used with caution in erodible bed streams that have no areas of erosion-resistant streambed to prevent possible excessive downcutting. Sediment basins can be added to the variety of techniques used to improve fish habitat, or they can be used alone to renovate sand-choked streams not amenable to the usual erosion control treatments.

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[2] Edward A. Hansen is a hydrologist at North Central Forest Experiment Station, Forestry Sciences Laboratory, Rhinelander, Wisconsin, and William H. Dunn is a Forestry Technician at Cadillac Ranger District, Cadillac, Michigan

Introduction

Trout streams in the Upper Midwest of the United States are typically low-gradient, slow to moderately flowing streams. These low-gradient streams contain natural streambed areas resistant to rapid downcutting composed of gravel, cobble, or boulders, glacial-deposited compacted clays, exposed bedrock or logs. Some of these streams have what is perceived to be excessive sand on the streambed. Other somewhat steeper gradient streams have less sand bed deposits but yet may have considerable sand in transport. Abnormally large amounts of man-induced sediments or sediments with associated catastrophic floods may be detrimental to trout habitat (Cordone and Kelley 1961). However, we do not know if low levels of moving sand bedload affect trout and trout habitat. In initiating this and other sediment-trout studies in Michigan, we speculated that low concentrations of sand bedload sediments in low-gradient streams may have measurable effects on trout or trout habitat.

The presence of sand sediment is deceiving in that it does not produce the turbidity commonly associated with severe stream sedimentation. Even substantial amounts of moving sand bedload are not readily apparent in steep-gradient streams. Only when the gradient is low enough for deposition does the sediment become evident by the presence of sand-filled reaches of the stream. Sampling with a hand-held DH-48 suspended sediment sampler (U.S. Interagency Committee on Water Resources 1963) over a natural streambed in low-gradient streams will miss much of the sand bedload sediment. This may lead inexperienced observers to erroneously conclude there is no significant sediment discharge when, in fact, there may be considerable sand moving in the unsampled zone adjacent to the streambed. A modified procedure of sampling with a DH-48 sampler over sills or weirs (Hansen 1974), or with a sampler designed specifically for sampling bedload (Helley and Smith 1971) will more realistically assess the presence of sand bedload.

Sand bedload may decrease food supplies of trout by scouring or burying desirable substrate, destroy cover by aggrading channels and filling pools, and reduce spawning success by covering or plugging gravels. The "finer" suspended sediments also negatively affect some of these same aspects of fish habitat. Consequently, reducing stream sediment load is often a major objective of fish habitat improvement programs.

Sediment reduction has most often been attempted with erosion control techniques such as fencing cattle from the stream, streambank stabilization, and revegetation of eroding upland areas. However, these techniques reduce only part of the sediment load. Often more than half of the load comes from untreatable nonpoint sediment sources such as gradual sheet erosion over large areas of the watershed (Parsons et al. 1963, Striffler 1964, Hansen 1971). If the stream bedload needs to be sharply reduced or if there are few treatable point sources of sediment, these common erosion control techniques will not be very effective. For such situations sediment basins are a potentially useful technique for removing sediments already in the stream (Hansen 1973). In-stream sediment basins can trap and remove almost all sand sediments and lesser amounts of silt and clay depending upon basin size and streamflow characteristics. Sediment basins, also referred to as sedimentation basins, debris basins, or sediment traps, have been used for many years in irrigation and hydroelectric projects (Brune 1953, Geiger 1963, Task Committee 1969). However, they have not been tested previously in fisheries "stream improvement" programs.

This paper reports on a field test of the effectiveness of a sediment basin in removing sand sediment from a typical Michigan trout stream and the effects on stream channel morphometry. We also discuss factors to consider when using sediment basins and the role of sediment basins in stream improvement programs.

Methods

This field study was conducted on a 2-mile section of Poplar Creek, a tributary of the Pine-Manistee River system in the lower peninsula of Michigan (Figure 1). Poplar Creek has a mean discharge of 18 cubic feet per second and a sediment load of 725 tons per year from a 12.4 square mile drainage area (Hansen 1971, 1974). Receiving a large influx of ground water but little over-land flow, the stream has a stable flow, typical of those in the sandy glacial outwash moraine areas of Michigan. For example, records for the Manistee River at Sherman show that the stream discharge that is exceeded 2% of the time in only 3.0 times greater than that exceeded 98% of the time (Velz and Gannon 1960). In the upper one and one-half miles of the study section, the sand bed stream meanders back and forth across a flat 150-foot wide plain bordered by 60-foot high bluffs on either side. The lower one-half mile of stream drops more rapidly through a narrow entrenched clay valley.

We measured the steam sediment load and stream morphometry 3 years before and 6 years after construction of a sediment basin. The sediment basin was excavated at the mid-point of the 2-mile section of stream (Figure 1). The basin was 160 feet long, 25 feet wide, and a maximum of 4 feet deep. Two of the 4 feet of depth was effective for trapping and holding sediment giving a storage volume of about 300 cubic yards. The sediment basin was initially excavated with a backhoe and then periodically cleaned with a dragline. The sediment basin was cleaned 14 times, an average of once every 5 months during the 6-year treatment period. After each cleanout the spoil was spread adjacent to the basin and sloped away from the stream with a bulldozer. The spoil was seeded twice with perennial rye to provide browse for wildlife, although it revegetated rapidly even without seeding. The basin was surveyed before and after each cleanout so that the volume of removed sediment could be calculated.

The survey consisted of transects spaced at 10-foot intervals along the length of the basin. At each transect a tape was stretched across the basin and depth readings were made at intervals along the tape with a level and survey rod.

Sediment sampling stations were located immediately above and below the sediment basin. A third sediment sampling station, along with a stream gauging station that continuously recorded streamflow, was located mid-way through the downstream treated section. Each sediment sampling station consisted of a submerged wooden sill across the streambed, placed a few inches above the original bed level (Hansen 1974). This permitted samples of sediment in transport to be collected throughout the entire vertical profile of stream flow thus sampling the total sediment load. Sediment samples were collected weekly with a DH-48 at all three stations; nearly 400 samples were collected at each station during the study. Sediment samples were collected at all sampling stations for 1 year before and 6 years after basin construction. At the stream gauging site, sediment samples were collected for 3 years before basin construction. All sediment samples were analyzed for total sediment concentration. In addition, about 20 percent of the samples were analyzed for the percent of sediment in stand sizes ($>$0.062 mm). A composite sample of the spoil from the last excavation, together with several stream water-sediment samples, was analyzed for nutrient content.

Permanent stream cross sections were established at 100-foot intervals along the entire study section to measure changes in stream morphometry. These cross sections were surveyed four times during the study: 1972, 1974 (the year the basin was constructed), 1977, and 1980. At each cross section a stake was permanently set on each bank. A steel measuring tape of known unit weight was then stretched at a measured tension between the two bank stakes. Distance from the tape to the streambed was measured at all major profile changes in a channel cross section with a survey rod. A third stake was buried on line in the streambed as a benchmark in case either bank stake moved after the initial survey. These survey data permitted calculating changes in stream width, channel scour or fill, and changes in the cross sectional area of water (cross sectional area multiplied by channel length gives the static water volume in the channel reach). These surveys were made during the same time of the year under conditions of stable low-flow. Maximum range in stream discharge at the gauging site over these four measurement periods was 13- to 15-cfs, except for a 17-cfs discharge 1 day during 1980. The water surface elevation data collected that day were adjusted based on the elevation change at the gauging station.

Results

Sediment Concentration

The average sediment concentration at all three sampling stations was about 52 ppm during the pre-treatment period (Table 1). During the 6-year period after construction of the sediment basin, the sediment concentration above the basin remained nearly the same at 55 ppm but the sediment concentration at the two sampling stations below the basin dropped 71% to about 15 ppm. Sediment data for wateryear 1975 are not included in the averages in Table 1 because that wateryear was a transition period for treatment effects. (A wateryear is the period of October 1 - September 30.)

Changes in total sediment concentration above and below the sediment basin throughout the study are illustrated in Figure 2. Each individually plotted data point is the average concentration of about 13 sediment samples collected over 3 months. The total sediment concentration sampled above and below the sediment basin was nearly equal until the basin was excavated. After excavation, the total sediment concentration below the basin dropped sharply compared to that above the basin. The effect of the sediment basin on the downstream sediment concentration is more apparent when the concentration data are expressed as ratios. Shown in Figure 3 are the ratios of sediment concentration below the basin versus immediately above the basin, and one-half mile below versus above the basin. Before basin construction the sediment concentration ratios fluctuated around a ratio of 1. After basin construction the ratio of sediment concentration below the basin versus immediately above the basin dropped very rapidly the first 3 months and then remained about 0.25 throughout the duration of the study. The ratio of sediment concentration one-half mile below the basin to that above the basin dropped more slowly and stabilized at the same level of 0.25 about 1 year after basin construction.

All this sediment reduction was in sand sizes; sand concentration dropped from 56 ppm above the basin to 8 ppm below the basin. In contrast, silt and clay concentration above and below the basin remained essentially the same averaging 7 ppm at all stations throughout the entire study section (Table 2).

Basin Excavation

Excavation of a sediment basin introduces some sediment to a stream. The magnitude of this induced sediment concentration was compared to the natural sediment concentration in the stream. The initial excavation of the basin on Poplar Creek produced a peak sediment concentration immediately below the excavation site of about twice that experienced during a flood peak that typically occurs several times a year, i.e., about 1,400 ppm (Figure 4a). In comparison, the average concentration measured during the year before basin construction was 52 ppm. Sediment entrained by the stream and leaving the site during excavation equalled 7.4 tons as compared to an average daily load of 2.5 tons. By the time the sediment pulse travelled one-half mile below the basin, the peak concentration was less than that they experienced during a typical size flood on Poplar Creek. During the initial excavation some of the excavated material was readily transportable clay and fines that had accumulated over the years. During succeeding sediment basin re-excavations most of the material removed was sand. Consequently, less sediment left the basin, and the downstream sediment concentrations were only about half that of the initial excavation (Figure 4b). The sediment leaving the basin site was 3.0 tons versus the average 2.5 tons per day. Attenuation of the sediment pulse was rapid after excavation stopped (note the sharp drop in sediment concentrations during the noon lunch periods).

Analysis of spoil from a basin cleaning showed levels of 16 ppm phophorous (P), 553 ppm calcium (Ca), and pH of 7. The effect of spoil removal on the stream's nutrient load was negligible because the nutrients removed in spoil represented only 0.11% of the P and 0.04% of the Ca that were carried in solution and suspension by the stream during the period of basin filling.

Sediment Volume Removed

The total sediment load upstream of the basin contained an average of 89% sand and 11% silt and clay. Of this, the sediment basin trapped 86% of the sand but less than 10% of the "fine" sediment for a combined 71% of the total sediment load. Almost all of the trapped sediment was sand.

The total measured volume of sediment trapped by the sediment basin in the 6-year period was 2,607 cubic yards. The total estimated sediment load calculated from 2 years of sediment sample data collected before basin construction in 1969 and 1970 was 725 tons per year. Converting this weight to volume and weighing it by the number of years the sediment basin was in operation and the proportion of the load trapped, results in an estimated 2,238 cubic yards of material trapped. (A bulk density of 98 lbs/ft^3

based on weight-volume measurements of water-lain sand deposits was used in weight-to-volume conversions.) This estimated volume compares favorably with the measured 2,607 cubic yards. The difference of the two values is well within the range of sampling error especially considering the year-to-year fluctuations in sediment concentration.

Stream Morphometry Changes

Changes in stream morphometry occurred in both control and treated sections and therefore the basin could not be positively identified as the causative factor. After basin excavation (in 1974) stream width decreased by 0.4 foot in the control section, and by 0.1 foot in the upper half of the treated section (Table 3). Streambed scour occurred over the entire study area, averaging 0.15 feet in the control, 0.15 feet in the upper treated, and 0.21 feet in the lower treated section during the period after basin construction.

Static water volume increased markedly below the basin as compared to above the basin, averaging only 3% in the control, 8% in the upper treated, and 7% in the lower treated clay bed area. In addition, in the first 700 feet of the upper treated section immediately below the sediment basin where the stream had an erodible bed, the static water volume increased 32%. Downstream from the first 700-foot section, the streambed was armored with gravel and there was much less change. Although these changes in water volume appear to be related to basin construction, the relations are not clear cut. Static water volume changes over the entire 1972-1980 measurement period were +11, +10, and +11% for the control, upper treated, and lower treated areas, respectively (Table 3). Also, a 700-foot section in the control had nearly a +32% increase in static water volume. Because stream discharge at the time of the various surveys was nearly the same, it was not a factor in the measured changes in stream width, streambed scour, or static volume.

Discussion

Effects on Sediment Discharge

An in-stream basin can cause a major reduction in sand bedload in a stream. The 71% reduction in stream sediment load removed by the basin is substantially greater than that measured or calculated for upland and streambank erosion control programs on other streams (Parsons et al. 1973, Striffler 1964, Hansen 1971). Because the basin trapped predominately sand-size sediment, it can be expected to have a positive impact on fish by reducing deposition on spawning beds, reducing the scouring of aquatic insects, decreasing areas of sand substrate, and increasing pool depth (Cordone and Kelley 1961). Also, the basin trapped little detritus other than water-logged wood particles, and the excavated spoil contained only a small portion of the stream's nutrient load, so the removed sediments should have little negative impact on food supply. Cleaning the basin did not produce unusually high suspended sediment concentrations (for this stream). Because these cleanouts lasted only about 8 hours and occurred only 2-3 times a year, we believe that the impact of these sediments on fisheries was insignificant. Finally and most important, measurements showed a significant increase in the trout population in the treated section after installation of the sediment basin (See Part II, this paper).

Effects on Stream Morphometry

A reduction in sand bedload would normally produce streambed scour and a generally deeper stream. In our study, however, accelerated downcutting downstream from the basin was limited by the high proportion of gravel on the streambed and by the resistant clay streambed. Consequently, there was little difference in scour above and below the basin. Maximum changes from basins would occur in streams with erodible beds.

The streambed scour was probably at least partially due to long-term geologic downcutting. Fish-cover devices constructed at water surface level in the claybed section of the study area in 1954 were exposed an average of 0.55 foot above the water surface 18 years later in 1972. This gives a stream downcutting rate of 0.24 feet in 8 years, which compares roughly with the 0.15- to 0.21-feet of scour measured in the various sections during the 8-year study (Table 3).

Although streambed scour could be attributed to geologic downcutting, the changes in static water volume can not. Increases in static water volume result from the combination of streambed scour without a commensurate drop in water surface elevation. This implies deeper pools and a slower moving stream, which are most reasonably attributed to a decrease in sediment load. The increase in static water volume downstream from the sediment basin after basin construction (particularly in the first 700 feet with an erodible bed) strongly suggests that it was the effect of the basin. However, comparable changes in the control section (although before basin construction) weaken this causal relation. It could be argued that the changes after sediment basin construction were not due to the basin, but were normal fluctuations in channel morphology. However, the timing and location of the increases in static water volume provide some evidence that the basin was at least a partial contributor.

The changes in morphometry that occurred in the untreated control section were obviously due to factors other than the sediment basin, and these factors may have also influenced channel changes in the treated section. One factor that might account for such changes is long-term fluctuations in the stream sediment load. For example, during the study new beaver dams were constructed upstream from the study area and other old ones failed, probably trapping and then releasing sediment in slugs. There is some evidence of periodic large "surges" of sediment in 1973-1974 and 1977-1979 (Figure 2). These time periods coincided with periods of frequent beaver dam washouts or removal. Another possible explanation for some of the changes in morphometry is the removal of some logs and brush throughout the study area at the beginning of the study to facilitate floating the electrofishing gear. Although such removal was intentionally kept to a minimum to avoid channel changes, it cannot be positively ruled out as a contributor to the observed changes.

Considerations When Using Sediment Basins

Sediment basins have several advantages and disadvantages (Hansen 1973). Their importance depends upon the manager's objectives and the characteristics of the stream under consideration.

Advantages

Sediment basins can: (1) remove most bedload in all streams including those with no treatable points of erosion; (2) produce streambed downcutting, creating deeper pools and possibly improved streambed composition; (3) be placed immediately upstream of critical areas such as zones of high spawning use (or potential use); and (4) increase habitat diversity on the alluvial plain by using the spoil to create wildlife openings. In our study the pH of 7 and substantial Ca and P in the spoil might make it useful for soil amelioration elsewhere.

Disadvantages

Basins (1) have little effect on reducing the "fines" in the sediment load; (2) need periodic cleaning; (3) produce aesthetically detracting spoil that may require revegetation or transfer to a disposal area; (4) could cause excessive streambed downcutting with accelerated bank erosion; (5) may produce abnormally high turbidities of short duration during cleanouts; and (6) may have to be clearly marked to avoid being a hazard to fishermen in otherwise wadable streams.

Several factors need to be considered when designing a sediment basin for fish habitat improvement objectives. Some of the more important factors are basin type, size, and location.

Basin Type

Sediment basins can be constructed by excavating a depression in the streambed or by creating an impoundment with a low-head dam. An excavated basin is usually more suitable than an impoundment on low-gradient streams, provided the streambed permits excavation. (Logs, boulders, bedrock, etc. would make initial excavation difficult.) Advantages of basins versus small dams are lower cost and less site disturbance.

Another advantage of an excavated basin is that it will trap sediment without causing coarser sediments to deposit upstream, as occurs with an impoundment (Eakin and Brown 1939, Gottschalk 1964, Borland 1971). Deposition upstream from impoundment leads to streambed aggradation and likely deterioration of fish habitat. Aggradation may extend upstream for many miles and will be greatest with high dams, low stream gradients, and coarse sediments. Thus, a dam will often create some of the same streambed conditions that it is designed to eliminate.

Basin Size

A sediment basin is designed to remove certain percentages of selected particle sizes from a stream. The larger the basin, the larger the percentage trapped and hence the greater the efficiency. Consequently, trap efficiency decreases as a basin fills. From a practical standpoint though, trap efficiency for sand sediment declines little until the basin is almost full. Trap efficiency can also be improved in all cases by minimizing turbulence. This can be accomplished through a gradual transition in channel width from the stream to the basin and by locating the basin in a straight stretch of stream to promote a uniform distribution of flow across the basin (Uppal 1966).

Sediment basins in trout streams should probably be small enough to trap mostly coarse sediments (usually sand) while the fine sediments pass through and out of the basin. This reduces the need for additional capacity to store fine sediment, and thereby decreases both the initial cost of the basin and future maintenance costs, without changing the benefits (Task Committee 1969).

Although fine sediment can be removed with a basin, it is not usually done because it would require a much larger basin than that needed for the removal of coarse sediments only (Churchill 1948, Brune 1953, Moore et al. 1960). In addition to its much higher cost, a large basin would tend to warm the water, which would more often harm than help trout. Also, it would trap the finer inorganic sediments and thus might affect downstream productivity.

Once it is decided what sediment sizes to remove from the stream, the basin size required to trap the smallest of these can be determined. (For the procedure for designing basin size, see Hansen 1973.)

Location

To maximize trap efficiency (percent of sediment load deposited), the basin should be located where the gradient is relatively flat (Brune 1953) with minimum turbulence. Because these two variables are closely related, the problem can be simplified by concentrating on stream gradient. The stream can be surveyed to determine the sections with lowest gradient. Or, in streams with a wide range in bed material (i.e., gravel, sand, and silt), the low-gradient sections can be identified as those zones with no gravel, particularly sandy areas containing wide bands of silt deposits. For streams with a continuous sand bed, other factors such as access or storage requirements for spoil may have priority over gradient in locating a basin.

To maximize the impact on fish habitat, the basin should be located immediately upstream from what is believed to be critical sediment-affected areas of the stream, e.g., sand-clogged spawning gravel or sand-filled pools.

Some Precautions

Sediment basins should not be used on all streams. On streams without natural controls (bedrock, clay, boulders, etc.) removal of bedload with basins could upset the stream-sediment equilibrium and create excessive stream downcutting. In extreme cases this could lead to a major upset in stream equilibrium with serious erosion propagating far downstream (Heede 1980). Streams most apt to produce this type of undesired consequence are steep-gradient streams with large quantities of bedload--streams most often found in mountainous areas. Low-gradient streams with frequent controls and small bedload (the type common to the Midwest) are not apt to produce serious consequences from basin construction. In some cases the rate of stream downcutting may even be reduced after construction of a sediment basin, e.g., we sepeculate that downcutting in the clay bed section of Poplar Creek may be reduced after the removal of the abrasive action of the moving sand bedload. Nevertheless, in streams without sufficient natural controls, artificial ones such as gravel or cobble riffles (required rock size depends upon stream gradient) may have to be constructed at intervals along the stream, thus adding to the cost of a sediment basin program. In extreme cases a basin site might have to be terminated.

Using Sediment Basins in a Stream Improvement Program

Stream improvement programs commonly include streambank stabilization and fencing for erosion control, stump revetments and log booms for fish cover devices, and occasionally deflectors and drop structures for pool digging. Cover devices and pool digging structures affect only the immediate vicinity of the structure, not the moving sediment load. Sediment basins, because of the major reduction in sediment load, will cause pool deepening over an extensive distance in erodible bed streams. And because the sediment load is reduced, other benefits to spawning and food supply may occur.

Sediment basins should not ordinarily be used as a substitute for such measures as streambank stabilization. Stabilizing eroding streambanks is a relatively permanent control of a sediment source, but removing trapped sediments from basins is an operation that must be continued as long as the stream improvement program exists. Sediment basins should be considered as an addition to the usual erosion control measures employed in stream improvement programs. Basins can greatly accelerate the time in which the stream can be "cleaned" of erodible sediment, and they will trap sand sediment origination from sources not readily stabilized. Basins add a new dimension to stream improvement programs because they can be used on sand bed streams with no treatable point sources of erosion, or they can be used to intercept and remove accidental sand "spills" from road crossings, development projects, etc. In addition, we speculate that basins can be used to trap some pollutants such as heavy metals or sludges either transported as bedload or adhering to the bedload.

The layout of a sediment basin network can be quite versatile to meet the needs of the manager. For example, if it were desirable to have only one basin cleanout a year on Poplar Creek, two or three basins could be added along the stream. Then each basin would eventually have to be cleaned only once a year and the volume of sediment at each basin would be only about one-third of that trapped at a single basin site. Also, stabilization of some obvious local sediment sources on Poplar Creek (campground-road crossing, housing development, abandoned beaver pond complex) would further reduce the basin capacity needed for an annual cleanout schedule.

Acknowledgment

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Table 1. Total sediment concentration (ppm) measured at three points along the stream before (1974) and after (1976-1980) construction of the sediment basin.

Sampling station	Pre-treatment	Treatment
Above basin	52	55
Below basin	52	16
One-half mile below basin	51	15

Table 2. Concentration (ppm) of sand, and silt and clay leaving the basin as compared to that in transport immediately above the basin.

Sampling station	Sand	Silt and Clay	Total[a]
Above basin	56	7	63
Below basin	8	7	15
One-half mile below basin	7	7	14

[a] Only a subset of all "treatment" samples were analyzed for particle size. Consequently the totals differ somewhat from the "treatment" concentration values in Table 1.

Table 3. Stream morphometry before, and 6 years after, excavating a sediment basin.

Stream section	Stream width 1972 (ft)	1974[a] (ft)	1980 (ft)	Streambed scour 1972-1974 (yd^3)	1975-1980 (yd^3)	(yd^3/mi)	(ft)
Control	19.3	19.0	18.6	288	591	591	0.15
Upper treated	18.4	18.2	18.1	106	270	540	0.15
Lower treated	13.6	13.0	13.6	115	287	574	0.21

Stream section	Static water volume 1972 (yd^3)	1974 (yd^3)	1980 (yd^3)	1972-1974 (% change)	1975-1980 (% change)
Control	3,053	3,303	3,403	+8	+3
Upper treated	1,524	1,557	1,681	+2	+8[b]
Lower treated	1,049	1,089	1,164	+4	+7

[a] The basin was constructed just after the 1974 stream survey.

[b] Static water volume increased 32% in the first 700 feet below the sediment basin.

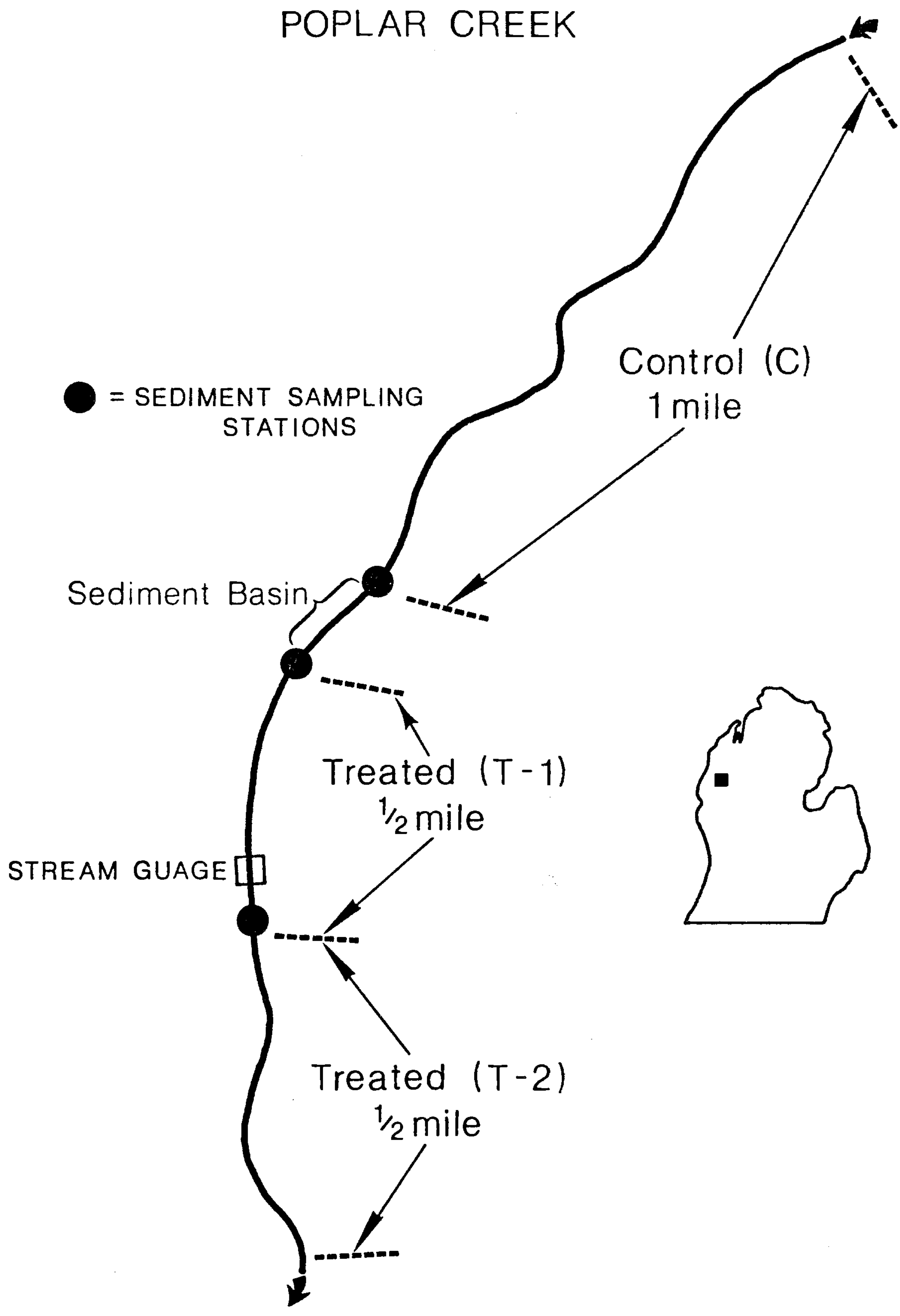

Figure 1. Poplar Creek study area.

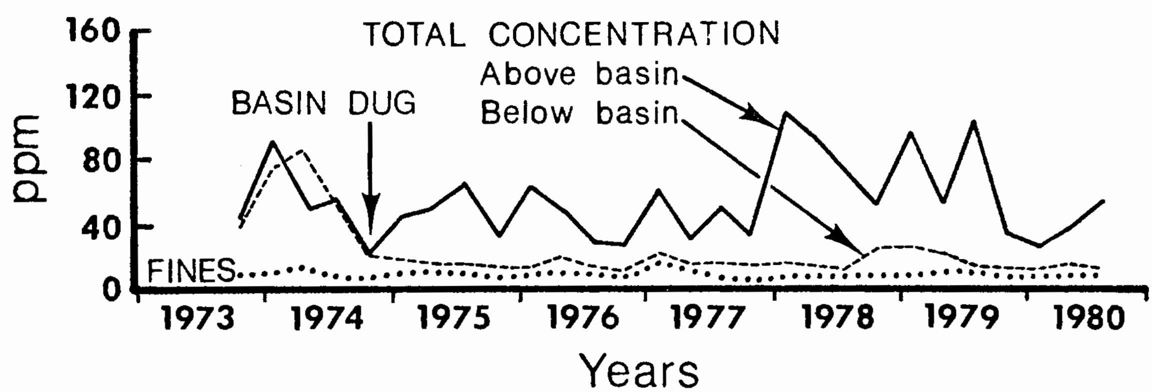

Figure 2. Sediment concentration above and below the sediment basin. Total concentration decreased sharply below the basin. "Fines" were the same in both places as shown by the single line.

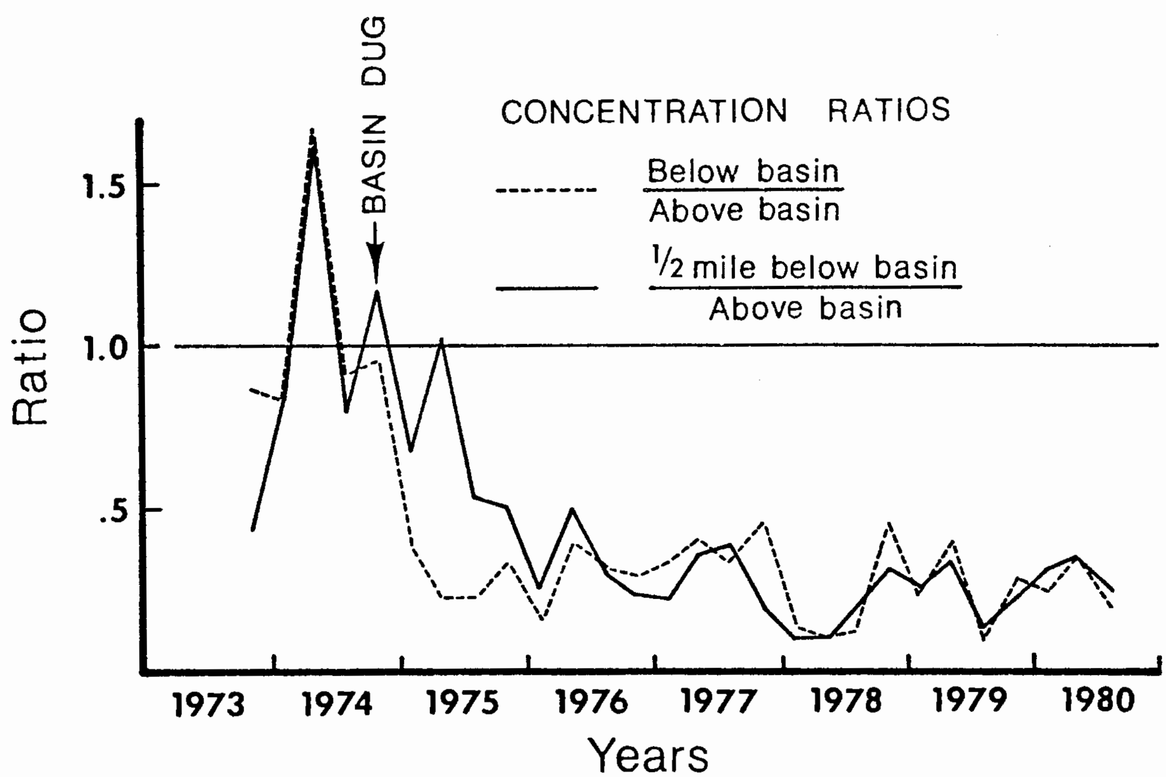

Figure 3. Ratio of sediment concentration above and below the sediment basin as affected by basin construction.

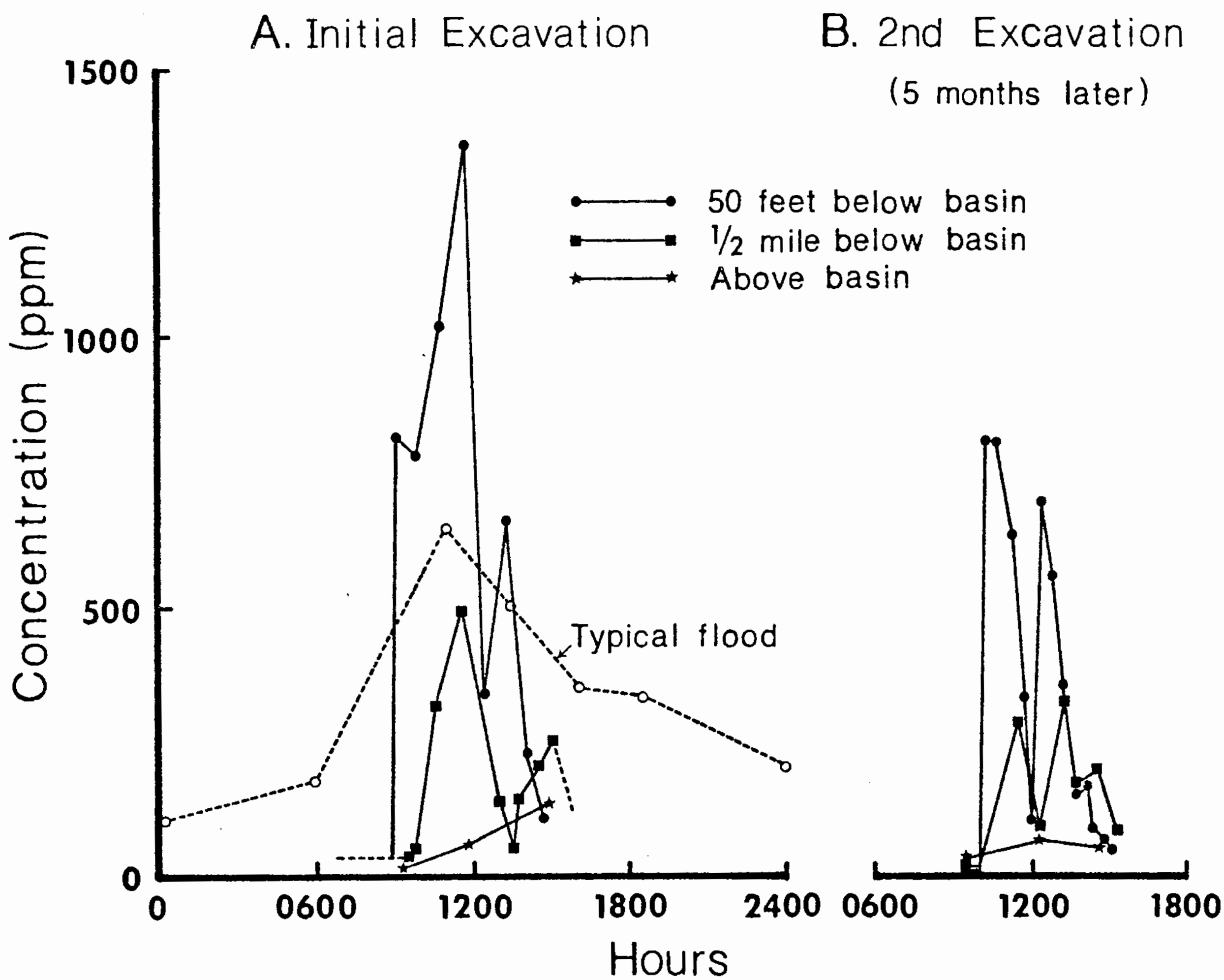

Figure 4. Stream sediment concentration due to (A) initial basin excavation and (B) second excavation.

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Report approved by W. C. Latta

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