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STATE OF THE ART OF STREAM MONITORING

by

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Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

The study was conducted in an effort to identify methods of stream monitoring for use by the Environmental Quality Division in improving its monitoring programs. A literature search was undertaken to determine the present knowledge of the effects of excess sediment on aquatic ecosystems and to investigate possible ways to monitor the impact of sediments on stream biota. Secondly, interviews were held with state and federal agencies involved with sediment pollution to determine the nature and extent of their programs, especially with regard to stream monitoring.

The results of the literature search and the agency interviews indicate that the Department could sample, process, and analyze stream bottom samples more efficiently and quantitatively than at present. Information obtained from the literature suggests that the analysis of stream bottom sediments could be used to assess sediment pollution. This method has several advantages over conventional techniques of chemical and biological monitoring.

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INTRODUCTION

It has long been recognized that the construction of highways exposes terrestrial environments to accelerated erosion. Sediment transported from the denuded areas often enters streams in the vicinity of the construction. During the past ten years, there has been increasing concern among environmentalists, legislators, and government agencies that sediment derived from highway construction sites can have detrimental effects on aquatic ecosystems. Recognition of this hazard has led to the development of a complex set of laws, programs, and procedures that directly or indirectly influence the design, location, construction, and maintenance of highways in Virginia and other states.

A variety of state and federal agencies now have some involvement in the prevention of sediment pollution. Several of these agencies review, comment upon, or take action on environmental aspects of highway construction projects proposed by the Department. The Environmental Quality Division must address itself to the questions, reservations, or objections raised by these agencies in order to obtain necessary construction permits. A program of stream monitoring, conducted by the Aquatic Ecology Section, has been developed as part of the response to this need.

Biological monitoring, including the sampling of both macroinvertebrates and fish, is the principal component of the program. Some chemical monitoring is also conducted. Biological monitoring has certain advantages over other types of stream monitoring, the foremost of which is its direct assessment of damage to an aquatic community caused by a pollutant; e.g., excess sediment. The major disadvantage of biological monitoring is the length of time required to sort the organisms from the debris in the samples and to identify them. The taxonomic work must be done meticulously by aquatic biologists with special training. Consequently, the results of quantitative biological monitoring may not be available for weeks or months after the sampling date. Therefore, this study was initiated to identify other types and methods of stream monitoring that would be rapid, quantitative, and efficient; that could be incorporated into the program of stream monitoring of the Environmental Quality Division; and that would be acceptable to the state and federal agencies involved with sediment pollution.

OBJECTIVES

The primary objective of this study was to identify rapid, quantitative techniques for sampling and assessing the state of stream environments. Toward that end, a two-part study was undertaken. First, a literature search was conducted to determine the present knowledge of the effects of excess sediment on aquatic ecosystems. A special effort was made to identify the mechanisms through which sediment imposes its detrimental effects, since this knowledge might suggest ways to monitor the impact of sediments on stream biota. Efforts were also made to evaluate the effects of sediment on various groups of organisms. Attempts to monitor the impacts of other pollutants — domestic sewage, for example — on aquatic organisms have often featured the designation, collection, and enumeration of "indicator taxa", which are said to react in characteristic ways to discrete levels or ranges of pollution. It was thought that the literature might permit similar designation of taxonomic groups indicative of sediment pollution. Finally, the sampling procedures used by the investigators were noted.

The second part of the study consisted of interviewing personnel from the agencies involved with sediment pollution. Information was sought concerning the nature and extent of their programs in this area, especially their programs of stream monitoring. Inquiries were also made about the interactions of the agencies with the Department, particularly with regard to the Environmental Quality Division and its program of stream monitoring.

Information obtained from the literature search and the agency interviews was evaluated and synthesized. Conclusions concerning the state of the art of stream monitoring and the implications for the Department are presented in the final section of this report.

LITERATURE REVIEW

Introduction

The scope of the literature search was limited in several respects. Sediment is often associated with other pollutants. For example, sediment washed from farmlands into an adjacent stream may contain toxic pesticides, excessive plant nutrients, or animal wastes, all of which can have deleterious effects on aquatic organisms. It is difficult or impossible to isolate the effects of several pollutants acting simultaneously, perhaps synergistically. Therefore, the literature search was restricted to cases where sediment was considered to be the only significant pollutant.

A second restriction involved the type of material used. There is an extensive body of ecological literature concerning sediment-organism interactions. While reference is made to some of this material, no attempt was made to review niche geometry, detritus food web dynamics, and other specialized topics with limited present applicability to the practical study of sediment pollution. Further, emphasis was placed on studies where attempts were made to obtain and assess direct evidence of the adverse effects of sediment on stream biota; speculative accounts of how sediment might affect organisms were given less attention.

Although studies of sediment pollution caused by highway construction were given primary consideration, it was necessary to include studies of other non-point sources in order to obtain sufficient information for review and synthesis. Accordingly, studies of the effects of hydraulic mining, gravel and sand washing, logging, and other streamside sources of sediments were reviewed. These inclusions widened the field of study sufficiently to require selection of sources; only the more significant papers are reviewed. Additional studies are cited in review papers organized by Cordone and Kelley (1961), Gammon (1970), Sorensen et al. (1977), Iwamoto et al. (1978), and Farnworth et al. (1979).

Primary emphasis is placed on the mechanisms by which excess sediments harm aquatic communities. Physical factors receive more attention than chemical effects, because it is not clear that the latter are substantial in cases where sediment alone is the pollutant. It is convenient to consider plants, macroinvertebrates, and fish separately, since these groups have often been studied in isolation in the field.

Effects of Sediment on Plants

It has been suggested that sediments may adversely affect aquatic plants by —

1. reducing photosynthesis,
2. mechanically abrading plant tissues,
3. burying plants, and
4. altering the community composition of aquatic flora by changing the physical environment.

Considerable evidence, much of it indirect, supports the suggestion that excess sediments reduce photosynthetic activity in plants. It has long been recognized that elevated levels of suspended solids reduce the penetration of sunlight into water. This reduction of sunlight presumably would impede or halt the processes of food production in microalgae, macroalgae, and vascular aquatic plants. Claffey (1955) found higher standing crops of phytoplankton in clear ponds and reservoirs in Oklahoma than in turbid ones. Buck (1956a and b) collected eight to twelve times as much plankton per unit area in clear ponds as in silted, turbid ponds. Sediment from a construction site was apparently responsible for a threefold reduction in algal productivity in a Virginia impoundment (Samsel 1973).

While the studies cited above clearly demonstrated depressed standing crops of algae in silted ponds, they did not conclusively show that the lowering of photosynthesis was the primary mechanism responsible for the observed reductions. Tilzer et al. (1976) recorded decreased photosynthesis in a sediment plume in Lake Tahoe. Despite the lack of other direct assessments of the effects of turbidity on plant productivity, Farnworth et al. (1979) concluded that suspended solids have a considerable impact on the primary production of aquatic ecosystems when they reduce light intensities. Standing waters would appear to be more susceptible to this effect than running waters, which support lower populations of phytoplankton and which are less likely to have elevated levels of suspended solids for prolonged periods. Reductions in photosynthesis caused by silt would also affect aquatic animals that depend on living plants, either directly or indirectly, for food, shelter, or breeding habitat. Organisms which derive most of their nutrition from organic detritus would not be affected as drastically in the short run.

The processes of abrasion and burial of aquatic plants by sediment cannot be separated in the field. Nuttall (1972) attributed the decline of aquatic flora downstream from a source of sediment pollution to the shifting of unstable sand deposits on the stream bottom, rather than to diminished photosynthesis. Gumtow (1955), Kobayasi (1961), and Tett et al. (1978) all concluded that the abundance of epilithic algae in streams is related to the size and stability of the bottom sediments. Algal populations associated with large rocks are generally rich and stable, while populations associated with sand are greatly reduced during periods of high flow, when sand can be transported as bedload. Excess sediment from non-point sources could blanket the bed of a stream with fine, unstable material that would not support the sustained growth of algae or aquatic macrophytes. The literature contains little direct evidence concerning this suggestion.

It is well known that different species of aquatic macrophytes and attached algae have different substrate preferences. Some require solid surfaces for colonization and growth; others grow in areas with fine-grained sediments (Minckley 1963; Hynes 1970a; Nuttall and Bielby 1973). Sediment derived from a highway construction project might change the community composition of the flora by altering the physical environment. Plants well adapted to silty areas would presumably replace those that require coarse sediments. Again, direct evidence is lacking.

Several conclusions can be drawn concerning the effects of sediment on plants. First, it is difficult to isolate the several effects posited above in a field investigation. Thus, an observed reduction in the standing crop of a plant community may not be due to diminished photosynthesis alone. It is possible, indeed likely, that the reduction of light, abrasion of living plants, and the alteration of the stream bottom occur simultaneously and synergistically to impose deleterious effects upon aquatic plants. The relative contributions of these factors probably differ among environments. As previously noted, a reduction of photosynthesis is probably more pronounced in ponds and lakes than in streams. Conditions of shifting, unstable sediments, on the other hand, would occur in streams more typically than in lakes and ponds.

Aside from questions of causal relationships, there is clear evidence that sediments can damage aquatic plants. Several studies in addition to those cited above warrant mention. Herbert et al. (1961) reported a virtual absence of benthic algae in Cornish streams receiving china clay wastes; Cordone and Pennoyer (1960) observed a marked reduction of attached algae downstream from a gravel mill that discharged sediment into Cold Creek and Truckee River, California; and King and Ball (1967) recorded a 68% decline in algal production in a Michigan stream polluted by sediment from a construction project.

The critical levels of sediment input that initiate damage to aquatic plants were not determined in any of the studies reviewed. The threshhold levels for such damage probably vary both between and within localities, and depend upon many factors, including the velocity of the current, temperature, water chemistry, flow regime, season of the year, and intrinsic biological variables. Consequently, the state of knowledge does not permit quantitative predictions of the effects of excess sediment on plants.

Effects of Sediment on Macroinvertebrates

Macroinvertebrates can be defined as animals without backbones that are large enough to be retained on a U. S. Standard No. 30 sieve (0.595 mm openings) (Greeson et al. 1977). Aquatic insects, which comprise a large portion of this heterogeneous group in most environments, have received much attention from aquatic ecologists. Other prominent groups include crustaceans, molluscs, gastropods, and annelid worms. These organisms play a central role in the food web of aquatic ecosystems by consuming algae and organic detritus, and thereby making the energy derived from those primary sources available to the fish and other large animals that feed upon macroinvertebrates. A strong case can be made for the use of macroinvertebrates as biological indicators of water quality, as later discussion will make apparent. Because of their ecological significance and their prominence in the literature of the effects of sediment on stream biota, the macroinvertebrates will be featured in this review.

Many studies have investigated the factors that govern the distributions of macroinvertebrates in natural waters. Reviews of these studies (Hynes 1970b; Brinkhurst 1974; Wetzel 1975; Merritt and Cummins 1978) have emphasized that the distributions and abundances of benthic invertebrates in streams are strongly related to the texture — i.e., the grain size distribution — of the sediment on the stream bottom.

Percival and Whitehead (1929) found that characteristic invertebrate taxa were associated with each of seven classes of substrates defined by the investigators. Comparable studies conducted by Hunt (1930), Ellis (1936), Moon (1939), and Pennak and Van Gerpen (1947) have provided additional evidence of the importance of the substrate as a factor influencing faunal distributions. A detailed ecological investigation made by Sprules (1947) disclosed that both the numbers of species and the numbers of individuals of aquatic insects in an Ontario stream were greatest in rocky riffle areas, lower in gravel and mud, and least in areas with sand bottoms. Recent and more sophisticated field studies (Leonard 1962; Ruggles 1966; Cairns 1967; MacKay and Kalff 1969; Reice 1974) have confirmed that the density, diversity, and standing crop of the invertebrate community generally decrease from rocks through gravel, mud, and sand.

The same sequence of substrate preferences has also been observed in laboratory and field experiments. Cummins and Lauff (1969) introduced various species of macroinvertebrates into a laboratory stream that contained trays filled with sediments of different grain sizes. Several of the species, especially those indigenous to riffles, preferred coarse substrates (8 to 16 mm particle size) to finer substrates. Rabeni and Minshall (1977) placed substrate-filled trays in a stream in Idaho. In both riffle and pool areas, colonization by invertebrates was least on trays filled with sand, greater on those filled with cobbles, and greatest on trays containing rocks more than 3.0 cm in diameter. These experiments have demonstrated that substrate texture is an important factor controlling the distributions of benthic organisms. Other environmental factors such as water temperature, current velocity, water depth, and aquatic chemistry also influence the occurrences of macroinvertebrates, and these factors probably interact inextricably with substrate variables.

The data reported above concerned substrate-organism relationships at the community level. It has been shown that substrate preferences vary among taxa of invertebrates. Many of the Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) are more abundant in gravel habitats with swift currents than in sandy areas with slow currents (Rees 1959; Gaufin 1962; Leonard 1962). Some of the aquatic Diptera, especially chironomid midge larvae, prefer sandy microhabitats to gravel and rock (Rees 1959). Substrate preferences may differ at the species level in some taxa, as indicated by a classic study of Diptera in a stream in Ohio (Paine and Gaufin 1956). These findings do not invalidate the observation that the production of macroinvertebrate communities typically decreases with decreasing sediment grain size.

The causal factors underlying invertebrate-sediment associations are not fully understood. Grain size is directly related to the surface area of particles available for colonization (Sprules 1947; Barber and Kevern 1973), the stability of the substrate (Chutter 1969; Hynes 1970b), the degree of compaction, and the volume of the intergranular voids (Hart and Brusven 1976). The texture of the sediment may indirectly affect macroinvertebrates by influencing the availability of periphyton (Tett et al. 1978) and organic detritus (Newell 1965; Egglishaw 1964, 1969; Pickral and Odum 1977) associated with the inorganic sediment particles. The nature of stream bottom sediments is governed by the flow regime, which affects organisms both directly and through its interaction with the substrate. Thus the microhabitat, food, and shelter available to benthic organisms are largely functions of the streambed sediment and the associated current regime.

If the aquatic substrate plays such an important role in governing invertebrate distributions, then it might be expected that alterations of the substrate caused by sediment pollution would have significant repercussions on the biota. Early studies documented the effects of siltation on macroinvertebrate populations downstream from hydraulic mining operations in the western United States. Taft and Shapavalov (1935) observed that numbers of benthic invertebrates were always lower in the vicinity of mining activities on the Klamath River, California, and its tributaries than in clear streams. Similar findings were reported by Sumner and Smith (1939), who collected bottom samples in tributaries of the Yuba and American rivers in California. Areas silted due to hydraulic mining were only 40% to 60% as productive as the unsilted areas upstream. Casey (1959) noted a 50% reduction of macroinvertebrates over a distance of one mile below a placer mining operation on Siegal Creek, Idaho. A one-quarter mile section immediately below the site was almost devoid of organisms. Ziebell (1957) reported a 85% reduction of bottom fauna caused by a gravel washing enterprise in Washington, and Ziebell and Knox (1957) found reductions ranging from 75% to 85% at a station located 1.7 miles downstream from a similar operation. Invertebrate decreases of 75% were demonstrated by Cordone and Pennoyer (1970) more than ten miles downstream from a gravel washing plant on the Truckee River, California. The findings of Bartsch and Schlipp (1953), Eustis and Hillen (1954), Wilson (1957), and other authors cited in Cordone and Kelley (1961) have provided additional evidence that sediment generated by hydraulic mining or gravel washing can have deleterious effects on macroinvertebrates.

Comparable studies have been conducted on streams receiving sediment from logging operations, including the construction of temporary logging roads. Bachmann (1958) noted significant reductions of bottom fauna in an Idaho trout stream that was silted during logging. Tebo's widely cited study (1955) involved extensive benthic sampling in a North Carolina creek that drained a logged watershed. During a period when silt accumulated in the creek, the numbers of invertebrates were reduced to 7.3 per square foot, compared to 25.5 a square foot at an unsilted control station. The macrobenthos recovered to normal levels shortly after a flood scoured the silt deposits from the bed of the creek. Burns (1972) also observed immediate detrimental effects of sediment following construction of logging roads in California, as did Brown and Krygier (1971) in Oregon, and Reed and Elliot (1972) in Alaska.

Several investigations have been undertaken to assess the impact of highway construction on aquatic biota (King and Ball 1964 and 1967; Peterson and Nyquist 1972; Barton et al. 1972; Porter et al. 1974; Barton 1977). Two recent studies deserve special attention with regard to the effects of sediment on macroinvertebrates. Reed (1977) obtained samples upstream and downstream from four highway construction sites in Virginia. Siltation caused by the construction reduced the numbers of invertebrate species by about 30% and reduced total numbers of individuals by 66% to 85%. The magnitude of these reductions was in the same range as that reported downstream from hydraulic mining, gravel washing, and logging, as noted above. As in Tebo's (1955) study, the macroinvertebrate communities in the Virginia streams examined by Reed recovered to normal levels soon after floods removed the accumulated silt from the respective stream bottoms. The diversity indices for the invertebrate communities did not reflect the unambiguous decreases in total numbers. In other words, all taxa apparently declined together during the period of siltation.

Chisholm and Downs (1978) conducted an investigation of similar scope at Turtle Creek, West Virginia. The creek, which was extensively altered during the construction of a four-lane highway, was compared to an undisturbed stream in the same area. Benthic invertebrates in Turtle Creek were reduced throughout construction, but the populations returned to levels comparable to those in the undisturbed stream within one year after completion of the project. The diversity of the benthos exhibited a decline followed by a recovery during the study. The greatest reductions in macroinvertebrates were observed in the headwaters of the creek, where the gradient was steep and there was little opportunity for recolonization of altered substrates by faunal drift (vide infra).

The collective evidence of the studies reviewed in the preceding paragraphs has conclusively demonstrated that excess sediment can reduce, or even decimate, populations of bottom dwelling invertebrates. Several authors have attempted to identify the causes of these reductions. Surber (1953) and Wallen (1951) suggested that sediment pollution has the primary effect of increasing the turbidity of the water and thereby decreasing the photosynthesis of aquatic plants. According to this view, the decline of benthic fauna is a secondary effect associated with the scarcity of plants as food. Most subsequent investigations, however, have emphasized habitat alteration as the major agent of faunal reductions. In fact, there appears to be an emerging consensus among aquatic ecologists that the adverse effects of sediment on invertebrates are attributable more to the deposition of sediment on the stream bottom than to the action of suspended sediment in the water column. The evidence for this perspective, which has significant implications for stream monitoring, warrants special attention.

Hamilton (1961) studied the flora and fauna downstream from a sand pit on a river in Scotland. Although the river was quite turbid much of the time, there was no apparent inhibition of algal growth. Likewise, macroinvertebrates were not affected adversely, unless there was visible deposition of sand and silt on the stream bottom. These observations led Hamilton to conclude that suspended solids, per se, are not harmful to benthic invertebrates. It is possible, of course, that suspended sediments with different characteristics might have direct detrimental effects on stream biota.

Field observations by other investigators have supported Hamilton's contentions. Nuttall and Bielby (1973) found that declines of invertebrates downstream from a source of china clay wastes in England were associated with the deposition of sediments on the bed of the stream, rather than with elevated concentrations of suspended solids. In a study conducted over a four-year period, Gammon (1970) observed the greatest reductions of invertebrates downstream from a gravel washing operation in Indiana at times when sediment settled out in the riffles. These reductions appeared to be unaffected by the levels of suspended solids. An ecological investigation of several South African rivers (Chutter 1969) produced evidence that moderate amounts of fine sediments deposited in rocky areas can cause considerable changes in faunal populations. These reductions did not require the complete burial of the original substrate.

The findings cited above have led to the formulation of an hypothesis concerning the mode of action of sediment pollution on benthic fauna. It was earlier stated that coarse substrates (rock, cobble, and gravel) generally support greater numbers of invertebrates than do fine substrates, especially sand. Coarse substrates provide optimal conditions of food and shelter for many species. The addition of excessive amounts of fine sediments into a stream may lead to the deposition of silt or sand on the creek bottom. Such deposition can gradually fill the interstices between large particles, and consequently remove microhabitat space for the normal fauna. Eventually, the continuing deposition of fine material may result in the complete burial of the original substrate. The entire process has been called "embedding" (Brusven and Prather 1974), and it represents a radical alteration of microhabitats in the stream bottom.

A few attempts have been made to quantify certain aspects of the embedding phenomenon. Cederholm and Lestelle (1973) found significantly fewer macroinvertebrates in gravels embedded with sand that had aggregate mean grain sizes less than 0.841 mm than in unembedded gravels with larger grain sizes. Similarly, Bjornn et al. (1974) recorded lower densities of insects in riffles containing large amounts of sediments finer than 1/4 inch compared to riffles that contained little fine material. Laboratory studies conducted by Cummins (1964) and Cummins and Lauff (1969) demonstrated that insect larvae indigenous to riffles prefer unsilted substrates to silted ones. Experiments conducted by Brusven and Prather (1974) have offered particularly impressive evidence of the detrimental effects of embedding. Aquatic insects were placed in an artificial stream with trays containing cobbles that were unembedded, partially embedded, or fully embedded with sand. Unembedded cobble was somewhat preferred over half-embedded cobble, and was greatly preferred over completely embedded cobble. Stream insects that inhabit interstices in the substrate were affected sooner than those that live on the substrate surface. Field observations made by the investigators confirmed their laboratory findings.

There is little evidence that macroinvertebrates are buried alive by the deposition of sediment. Rather, the animals "drift" from the impacted area before the substrate becomes fully embedded. Drift is a natural response to adverse conditions such as flooding. The insects detach themselves from the substrate, rise into the water column, and permit themselves to be transported by the current. Suitable areas downstream may be colonized by the drifting insects, and the area abandoned may later be recolonized by drifting organisms from upstream. Gammon (1970), Rosenberg and Wiens (1975), Reed (1977), and Chisholm and Downs (1978) have detected increased drift downstream from sources of sediment pollution. Invertebrate drift may be, in part, a response to increased concentrations of suspended solids as well as to increased deposition of fine solids. It should be noted, however, that the alteration of the substrate by embedding may prevent recolonization by subsequent drift, regardless of further changes in levels of suspended solids. The recovery of an embedded area of a streambed apparently depends on the removal of the excess fine sediment from the substrate. Scouring by floods probably removes the embedded sediment. Several investigators (Reed 1977; Chisholm and Downs 1978) reported essentially complete recoveries of stream fauna within one year after the termination of highway construction.

It has long been recognized that characteristic assemblages of invertebrates occur in different zones downstream from sewage outfalls. Numerous attempts have been made, especially under the aegis of the saprobic system (Bartsch and Ingram 1966), to designate specific groups of organisms as "indicator taxa" of water quality. Few studies have examined differential responses of the various macroinvertebrate taxa to sediment pollution. Not surprisingly, it appears that organisms which normally inhabit rocky substrates are more susceptible to sediment pollution. Thus, most families of stoneflies (Trichoptera) decline downstream from sediment sources (Reed 1977; Chisholm and Downs 1978). Invertebrates that prefer fine sediments under natural conditions and that have sometimes been shown to increase as embedding proceeds, include chironomid larvae, tubificid worms, and dragonfly nymphs (Hamilton 1961; Hynes 1966; Learner et al. 1971; Chutter 1969; Nuttall 1972). It cannot be said at present that any of these taxa will necessarily increase in areas on which silt and sand are being deposited, because an area that receives accelerated deposition of sediment generated by human activities may not be comparable to a natural, more stable area with fine sediments. Reductions of total numbers of invertebrates, rather than the responses of indicator taxa, provide the best current criterion for assessing sediment pollution.

Effects of Sediment on Fish

Much attention has been given to the possible effects of sediment pollution on fish, especially game fish. Cold water fisheries (e.g., salmon, trout) in the western United States have been intensively studied because of their commercial and recreational value, as well as their sensitivity to a variety of pollutants. It may be possible to extrapolate from the findings of these studies to communities of fishes indigenous to the warmer streams of the Piedmont and Coastal Plain of the eastern United States, which have been little studied with regard to sediment pollution.

It has been supposed that high concentrations of suspended solids may cause direct damage to the gills of fish. In fact, there is no convincing evidence for such an effect. In a widely quoted study, Wallen (1951) exposed 16 fish species to various concentrations of montmorillonite clay in aquaria. Clay suspensions did not damage fish gills at concentrations encountered in natural waters. Mortalities occurred only at exceedingly high concentrations of solids producing turbidities of about 200,000 JTU, and there was no evidence of damage to gills even at those levels. Comparable experiments conducted by Everhart and Duchrow (1970) and Neuman et al. (1975) produced results similar to Wallen's.

Field observations have also cast doubt on the supposition that high levels of suspended solids damage gill tissue and thereby increase fish mortality. Cordone and Pennoyer (1960) found no difference in numbers or the condition of fish above and below a gravel mill that discharged large quantities of suspended solids into a California stream. Similarly, Hamilton (1961) observed normal numbers of fish in the turbid region below a sand-washing operation in Scotland. Barton (1977) found no evidence of trout mortality due to suspended solids in a small Ontario stream receiving runoff from a highway construction project.

Other researchers, however, have stated that elevated levels of suspended solids do injure gills. Herbert and Merkens (1961) studied the condition of fish exposed to clay suspensions in aquaria. While the results of the study were highly variable, the authors concluded that suspended solids may reduce the survival of rainbow trout by causing changes in gill structure and thus making the fish more susceptible than usual to diseases. Additional findings by Herbert et al. (1961) strengthened his contention that suspended solids can indirectly contribute to fish mortality by causing sublethal changes in gill tissue.

In spite of these experimental data, there is little reason to extrapolate the findings to natural populations of fish. The studies involved exposing fish to extreme, unnatural conditions in small aquaria where they could not migrate to avoid hazardous conditions. Farnworth et al. (1979) and others have concluded that other factors associated with sediment pollution, such as habitat alteration, interference with normal reproduction, and destruction of food, are likely to have adverse effects on fish long before direct effects such as gill damage can occur. This conclusion is consistent with the observation that fish in unpolluted water are exposed to high concentrations of suspended solids during storms and periods of high flow. Native fish could not survive in our waters if they could not resist or evade high concentrations of suspended sediments for short periods of time.

Effects on Reproduction

Previous discussion of the adverse effects of sediments on macroinvertebrates emphasized the phenomenon of substrate embedding. Because the eggs and larvae (fry) of many species of fish are closely associated with bottom sediments, they are affected by the same factors that act upon benthic invertebrates. Numerous investigators have studied the relationships of salmonid fish to the substrate. Iwamoto et al. (1978) have written a detailed review of these studies, only the most pertinent of which will be mentioned here.

In an early investigation, Harrison (1923) observed that the mortality of salmon eggs and fry was higher in redds (i.e., spawning nests) constructed of small particles than in redds composed primarily of coarse gravel. Salmon fry live in the sheltered voids between particles in the redd, and emerge from the intragravel environment into the overlying water only after attaining a certain size. Harrison noted that many of the fry could not escape from fine gravel. Similar results were reported by Hobbs (1937). Shapovolov (1937), Gangmark and Broad (1955 and 1956), and Platts (1970) all reported high mortalities of salmon or trout eggs which could be attributed to the smothering effects of silt and sand. Shaw and Maga (1942) found that the addition of silt in the initial stages of the incubation of eggs was especially damaging.

The findings noted above came from laboratory studies. Other investigations have disclosed evidence that embedding affects natural populations of salmonids. McCrimmon (1954) found that the survival rate of Atlantic salmon fry was inversely related to the degree of embedding in riffle areas; survival was highest in unembedded riffles and lowest in fully embedded riffles. Embedding was judged to be the most important factor influencing the survival of juvenile fish. Neave (1947) and Johnson et al. (1952) obtained field data consistent with McCrimmon's conclusions.

More specific information about the processes and effects of embedding has been published. Shelton and Pollock (1966) monitored the survival of chinook salmon eggs in an incubation channel. The survival rate was significantly lower when 15% to 30% of the volume of the voids in the gravel was filled with sand and silt, compared to the survival rate in 100% gravel. A field study conducted by Phillips et al. (1966) demonstrated decreased survival of eggs and fry of coho salmon in gravels containing appreciable quantities of sediment less than 0.833 mm in diameter. Results obtained in another field study (McNeill and Ahnell 1964) led the authors to conclude that optimal redds should contain no more than 5% of material finer than 0.833 mm. Bjornn (1969) prepared various mixtures of sand and gravel into which he introduced eggs and fry of salmonids. The mortality of the embryos was 50% when sand accounted for 30% to 40% of the material in the redds. Experiments performed by Phillips et al. (1975) and Hall and Lantz (1969) produced comparable results.

Several instances of fish reductions caused by embedding due to sediment pollution have been identified. Burns (1972) studied the effects of logging on small streams in California. The proportion of fine sediments (less than 0.8 mm diameter) in the streambed increased by about 30% downstream from the logged areas. The biomass of both coho salmon and steelhead trout dropped by one-half during the same period. Burns attributed these sharp declines to the embedding of riffles with fine sediments derived from areas exposed to accelerated erosion after the removal of the vegetation. In a study of local interest, Branson and Batch (1972) recorded a high mortality of fish eggs in a warm-water Kentucky stream impacted by sediment from a strip mining operation. There was no evidence that changes in water chemistry were responsible for the egg mortalities. Bjornn et al. (1974) have offered particularly convincing data pertaining to the effects of embedding. The investigators deliberately polluted a section of stream with fine sediment and subsequently described the reductions in chinook salmon and steelhead trout as the spawning sites became embedded with the introduced sediment.

The mechanisms underlying the increased mortality of piscine eggs and larvae in embedded substrates are partially understood. It is known that the concentration of dissolved oxygen in the interstitial microenvironment is related to the rate of water flow through the sediment. The size of the gravel in a salmon redd influences the flow, and thus the dissolved oxygen content of the water (Phillips et al. 1966; Peters 1962). Cooper (1959) showed that sediments finer than 0.3 mm are especially effective in reducing flow and dissolved oxygen in coarse substrates. There is evidence that even short periods of low dissolved oxygen are lethal to salmonid eggs and fry (Alderice et al. 1958; Coble 1961). When oxygen is partially depleted but is not critically low, sublethal effects such as delayed development of larvae may occur (Brannon 1965). Reduced intragravel flows associated with embedding may also result in the accumulation of biogenic wastes toxic to eggs and fry, but few data are available regarding this possibility. Finally, the deposition of fine sediments in spawning areas physically occupies and removes microhabitats in the interstitial spaces, interferes with the normal feeding and movement of fry, and impedes the emergence of fry from the gravel bed into the water column. It should be noted that the factors outlined above probably influence macroinvertebrates and nongame fishes that lay their eggs in the sediment. Less research of this type has been done on these groups, because their importance to man is less obvious than that of game fishes.

Indirect Effects of Sediment on Adult Fish

The paucity of evidence that suspended solids cause direct damage to adult fish under field conditions does not support the conclusion that sediments are benign. On the contrary, sediment imposes indirect effects on adult fish and may influence their distribution in aquatic environments. McCrimmon (1954) found that juvenile salmon required streams with rocky areas that provide cover. Where fine sediment buried the rocks, the young fish were exposed to heavy predation. Stuehrenberg (1975) observed a similar decline in trout and chinook salmon due to "loss of refugia" from predators. Adult fish of many species spend much of their time in pools. Barton (1977) noted that fish migrated from an Ontario stream receiving sediments from highway construction only when sediment began to fill the pools. Bjornn et al. (1974) also observed a reduction in the numbers of fish after the investigators had dumped sediment into pools. A more elaborate experiment of the same type (Bjornn et al. 1977) yielded similar results. It appears that sediments first embed the substrate and then reduce the area and volume of pools. The former occurrence is deleterious primarily to eggs and fry; the latter affects adult fish.

Even when sediment itself does not harm fish populations, it may decrease the availability of their food. Elwood and Waters (1969) attributed an observed decrease in the growth rate of brown trout in a Minnesota stream to a reduction of macroinvertebrate populations. Lotrich (1973) noted that the fish species most severely affected by silt pollution in a Kentucky stream were those which fed primarily on benthic invertebrates. It will be recalled that invertebrate reductions of 75% or more have frequently been reported in areas downstream from sources of sediment pollution.

Excess sediment may also cause behavioral changes in adult fish. Vinyard and O'Brien (1976) found that the distance at which bluegill sunfish could detect their prey was reduced at high levels of turbidity. Bachmann (1958) stated that levels of suspended solids greater than 35 mg/l can interfere with the feeding activities of cutthroat trout. O'Brien (1977) studied the influence of turbidity on the bluegill sunfish, a visual feeder, and the gizzard shad, a nonvisual feeder. High turbidity reduced the ability of the bluegill to obtain food. Shad had a competitive advantage over bluegills under turbid conditions.

Other behavioral changes may be caused by excess sediments. Heimstra et al. (1969) studied green sunfish and largemouth bass in clean and in turbid water. In turbid water, both species exhibited less swimming, more frequent coughing and gill scraping, and abnornal patterns of social dominance compared to their behavior in clean water. Bachman's (1958) cutthroat trout discontinued feeding and sought shelter when the concentration of suspended solids reached 33 mg/l. Horkel and Pearson (1976) also observed reduced movement of fish at higher than normal levels of turbidity.

Perhaps the most common response of fish to sediment pollution is simple avoidance of the adverse conditions. Buck (1956) surveyed several ponds in Oklahoma and found that the distributions of the common fish species were limited by suspended solids. No largemouth bass were taken from waters with suspended solids in excess of 85 mg/l. Redear sunfish and bluegill were more tolerant of sediment, but neither species occurred in areas where concentrations of suspended solids were greater than about 175 mg/l. Buck further reported that fish production was 70% to 500% greater in clean ponds than in turbid ponds.

AGENCY INTERVIEWS

Introduction

A number of state and federal agencies are involved in one or more aspects of sediment pollution. The following agencies, which include several not listed in the working plan, were contacted:

1. State Water Control Board
2. U. S. Environmental Protection Agency
3. Virginia Marine Resources Commission
4. Soil Conservation Service (USDA)
5. Federal Highway Administration
6. Virginia Soil and Water Conservation Commission
7. U. S. Army Corps of Engineers
8. Virginia Institute of Marine Sciences
9. U. S. Fish and Wildlife Service
10. Virginia Commission of Game and Inland Fisheries
11. National Marine Fisheries Service (Dept. of Commerce)
12. U. S. Geological Survey

After initial contact was made by telephone, an interview was conducted at each agency. In most cases, several persons were interviewed, either simultaneously or sequentially. In other instances, persons employed by the same agency at different locations in the state were interviewed on separate occasions. For example, a first interview with the State Water Control Board (SWCB) was conducted at the Bridgewater Regional Office with administrators, aquatic biologist, and pollution control specialists; a second interview was held in the central laboratory of the agency in Richmond with persons engaged in stream monitoring; and a third interview (also in Richmond) involved personnel familiar with 401 certificates. Follow-up phone calls were sometimes made to obtain further information or to get clarification of statements made during the interviews.

This report represents a distillation of information obtained from the agency interviews. No attempt is made to summarize the interviews on an agency-by-agency basis, since much of this information would be irrelevant or redundant. Rather, processes or activities in which several agencies participate are identified and described. Since most of the agencies engage in several of these activities, their roles in various areas will be treated separately. Little will be said about the broad programs of the agencies in the area of water quality, except to note the components of those programs relevant to sediment pollution, stream monitoring, and the streamside construction projects of the Department.

Most of the interactions between the Department and the various agencies with regard to sediment pollution occur under the aegis of two major laws: The National Environmental Policy Act of 1969 (NEPA), and the 1972 Federal Water Pollution Control Act Amendments. The first of these acts has led to the current environmental impact statement and related documents, while the second has given rise to a system of permits that greatly affects the construction of highways in Virginia and in other states. Section 208 of the 1972 legislation defines a third program that is distinguishable from both the environmental impact statement process and the permitting procedures. All of these programs are outlined below, with emphasis on the permitting process.

Environmental Impact Statements

The NEPA requires that an environmental assessment be made for any proposed project that will receive any federal funding. The Federal Highway Administration (FHWA) is the administering agency for the assessment of highway construction projects. Three types of documents are prepared by the Environmental Quality Division of the Department, which coordinates with the FHWA.

1. Simple statements ("categorical exclusion") — routinely prepared for small projects where there will be no environmental impact.
2. Environmental assessment — prepared in cases where limited impacts will occur and little environmental controversy will arise.
3. Environmental impact statement (EIS) — required for all projects that will be complex or controversial.

Subsequent comments will concern the EIS process, unless otherwise specified. Among the factors that must be considered in an EIS are air quality, noise, historical and archaeological sites, wildlife, prime farmland, esthetic impacts, and others. A water quality assessment must be made for any water crossing, even for small, categorical exclusion projects. This assessment is usually performed by the Aquatic Ecology Section of the Environmental Quality Division. While a visual survey may be sufficient for a stream with low discharge (less than 5 cfs), biological sampling is conducted on larger streams. Macroinvertebrates are caught with a dip net and identified (often in the field) to the "order" level. In other cases, fish are caught by electroshocking and identified. A summary of findings and an assessment of the probable impacts of the construction on water quality are contained in both the draft and final copies of the EIS. The raw data developed during the stream survey are provided in a technical report that interested parties may obtain from the Department upon request. Consultants are sometimes hired to do the field sampling and the taxonomic work on large, sensitive projects. Aquatic insects may be identified to the "family" level in such cases.

A number of state, federal, and local agencies are given the opportunity to comment on a project prior to the drafting of a document by the Department. Further, a public hearing must be held before the final EIS, including all comments from the reviewing agencies and private parties, is written. There is rarely any significant response to the water quality assessments.

Occasionally, parties commenting on an EIS do raise objections to a highway construction project on grounds related to water quality. The proposed construction of Interstate 64 in Allegheny County several years ago concerned members of Trout Unlimited, a conservation group, and others who feared that trout populations in Simpson Creek would be adversely affected. The conservation group threatened to take legal action to block the construction, but later withdrew its opposition when the Environmental Quality Division offered to conduct monitoring in Simpson Creek before, during, and after construction, and to report the data to Trout Unlimited.

In another case, the Secretary of Transportation imposed stream monitoring on the Department in connection with the review of the EIS for the controversial construction of a new section of Interstate 66 in Northern Virginia. The details of this type of monitoring, which is considerably more elaborate than the biological sampling performed for a routine EIS, will be examined later. It is sufficient at present to state that formal, quantitative stream monitoring is undertaken in the context of the EIS process only in rare instances in response to outside pressure or directives, or in connection with field studies conducted by the Research Council.

The 208 Program

Section 208 of the 1972 Federal Water Pollution Control Act Amendments provides a mechanism for planning, implementing, and coordinating efforts for the control of point and non-point sources of water pollution. The U. S. Environmental Protection Agency (EPA) administers the program on the national level, and the SWCB is the administering agency in Virginia for 208 planning.

Originally intended as a planning exercise for municipalities, the 208 program was greatly expanded when a federal judge ruled that 208 plans were required for all areas in the nation.

Virginia has developed a nonregulatory program to meet the needs of the Act in the area of non-point source pollution. The SWCB has coordinated the development and distribution of handbooks of "Best Management Practices" (BMP's) in agriculture, forestry, surface mining, and several other areas. The BMP concept has been borrowed from agriculture, where practices such as contour plowing, strip cropping, and the use of grass waterways have long been encouraged by the Soil Conservation Service and other agencies to reduce soil erosion from farmlands. Analagous practices have been identified and described in the BMP handbooks for nonagricultural activities.

BMP's relating to construction activities are contained in the <u>Virginia Erosion and Sediment Control Handbook</u>. The lead agency for new construction is the Soil and Water Conservation Commission (S&WCC), which administers the State Erosion and Sediment Control Law and which reports to the SWCB. According to personnel from the S&WCC, their program meets the requirements of the national 208 program and would have been implemented without 208. While the S&WCC has full enforcement powers over local construction activities, it does not exercise a direct enforcement function under law with respect to the Department's construction projects. Rather, the agency performs a watchdog function by annually approving Departmental standards and guidelines for erosion and sediment control, by responding to complaints concerning construction projects, and by conducting spot inspections at construction sites. The agency recognizes that the Virginia Department of Highways and Transportation has its own expertise in erosion control.

The role of stream monitoring in the 208 program can be stated succinctly. Neither the EPA nor the SWCB nor the S&WCC routinely monitors streams receiving sediment from non-point sources. The SWCB occasionally determines the levels of suspended solids downstream from a construction site, but only in response to a specific complaint. While the Board has the authority to require stream monitoring by the Department at construction sites, it seldom imposes such requirements at present.

The S&WCC does not have the capability for monitoring streams; it defers to the SWCB in matters pertaining to water quality. In short, the current emphasis in the 208 program is on BMP's, which are on-the-site practices and control measures such as straw bales, silt fences, etc., used to minimize pollution at the source. Impacts of non-point source pollution on water quality receive less attention.

The 208 program for non-point source pollution is rudimentary in comparison with the extensive programs for point sources administered by the EPA and the SWCB. Sewage treatment plants and various industrial polluters must obtain permits which set limits on the amounts of specific pollutants that may be legally discharged into streams. Clients of the SWCB must regularly submit samples of their effluents for chemical or bacteriological testing. In addition, the agency periodically conducts formal surveys of major clients to assure their continuing compliance with the terms of their respective permits.

It cannot be determined whether the present nonregulatory 208 program for non-point source pollution will evolve into a regulatory program in the foreseeable future. Some of the persons interviewed expressed the opinion that a regulatory program would not be feasible for pollutants such as sediment which have numerous sources (e.g., farms) over wide areas. Other interviewees noted that the EPA already is applying pressure to localities to adopt BMP's. Further, the EPA will review Virginia's efforts to control non-point source pollution, and the federal agency may impose a regulatory program complete with permits and reports. Requirements for stream monitoring might be included in such a program, but there are no clear indications of this at present. "Best Management Practices" remains the catch phrase. The meaning of the word "best" is indeterminate in the context of the 208 program.

The Permit Process

Although the Department has little routine interaction with state and federal agencies under the auspices of the 208 program, it has regular contacts with several agencies which either issue or comment on permits required for highway construction projects. Three major permits may be required on a project: the 404 permit from the U. S. Army Corps of Engineers, the 401 certificate from the SWCB, and the Subaqueous Bed Permit from the Virginia Commission of Marine Resources. The three permits are interrelated, and a single joint application for permits can now be filed with the Marine Resources Commission, which distributes appropriate information to the other permitting agencies.

Many features of the several permits can be understood with reference to the 404 program. This program, which regulates the discharge of dredged or fill material into the nation's waters, was established by Section 404 of the 1972 Federal Water Pollution Control Act Amendments and by Section 404 of the 1977 Clean Water Act, and updated version of the 1972 legislation. It is not readily apparent how a program that might be expected to belong to the province of the EPA came instead to be administered by the Corps of Engineers, an agency whose reputation has been for construction rather than for regulation in aquatic environments. The 1972 law required that a 404 permit be obtained from the Corps whenever navigable waters might be impacted by the proposed construction project. Originally, the word "navigable" was defined in the conventional sense; later, the term was applied to all creeks with names, including some first order and second order streams in the Piedmont and in the mountains. The full permit process can now be avoided if the stream has a mean discharge less than 5 cfs. "Nationwide Permits" are routinely issued in such cases, or if other criteria are met (e.g., less than 200 cubic yards of access fill will be used on a project). Major projects adjacent to streams always require a 404 permit.

Several related procedures comprise the 404 permit process. First, the SWCB must issue a 401 certificate in accordance with the 1972 federal law mandating the 404 program. A 401 certificate states that water quality standards will not be violated during the proposed construction. The issuance of a 401 certificate is always a necessary precondition for obtaining a 404 permit, and the certificate becomes a part of the permit. Many 401's are processed routinely and rapidly by the SWCB for highway construction projects, especially if the Department will not operate equipment in streams contiguous to the project. In other cases, the SWCB scrutinizes proposed projects over a longer period of time. While the SWCB has never denied a 401 certificate to the Department, it may join with other agencies in suggesting or requiring modifications in the location, design, or methods of construction, as described below.

The Corps of Engineers is required by law to coordinate with three federal advisory agencies in all elevations for 404 permits. The agencies are the EPA, the U. S. Fish and Wildlife Service (F&WS), and the National Marine Fisheries Service (NMFS). These advisory agencies to the Corps comment on environmental aspects of proposed highway construction. Other agencies that are sometimes invited by the Corps to participate in the review process include the Virginia Commission of Game and Inland Fisheries and the Virginia Marine Resources Commission. The latter agency may be required to issue a Subaqueous Bed Permit if state-owned stream bottoms will be disturbed during construction. Little will be said about this type of permit, which is often required for tidal waters, because it is rarely, if ever, denied on environmental grounds.

An application for a 404 permit is acted upon by the district engineer of the Corps. He must consider many variables, in addition to environmental impacts, in arriving at his decision. However, he cannot issue a permit over the unrelenting objections of any of the three federal advisory agencies. If objections are made, the district engineer can give the dissenting agency 20 working days to notify the division engineer of the Corps, whose office is in New York, of the grounds for its objections. High ranking officials of the Corps and the agency that has objected to the issuance of the 404 permit may meet and attempt to resolve the impasse. Theoretically, a continuing conflict could lead to a final decision by the secretary of the army, whose ruling could be vetoed by the administrator of the EPA. In practice, decisions on 404 permits are almost always made at the district level of the Corps.

In the past, the Department often applied for 404 permits after highway alignments had been selected and rights-of-way had been purchased. Under those circumstances, the permit applications became locked into the review process, and the Department was reluctant to make changes in projects that had already reached the final stages of design. The result was a growing backlog of projects mired in the 404 permit process. In response to this situation, Melvin Thomas of the Environmental Quality Division initiated in 1976 a process of interagency early coordination. Representatives of the agencies that will later review permit applications (i.e., the Corps, SWCB, F&WS, NMFS, and EPA) attend monthly meetings in Richmond sponsored by the Environmental Quality Division. Other agencies frequently represented include the Commission of Game and Inland Fisheries, the Marine Resources Commission, and the Commission of Outdoor Recreation. Highway construction projects in the early planning stages are presented to the agency personnel. Several alternative alignments are typically offered for consideration. Road maps and topographic maps of the sites are provided. Members of the staff of the Aquatic Ecology Section show slides of possible stream crossings or encroachments on wetlands, and give verbal descriptions of the various sites. The representatives of the agencies are invited to comment on the project and the possible alignments. They may also comment on design features, erosion control measures, and types of mitigation (e.g., creation of new wetland areas to replace acreage that will be destroyed during construction) which may facilitate obtaining the required permits. Field inspections are conducted at proposed construction sites where potential environmental impacts may be of particular concern to the reviewing agencies.

While the coordinating agencies share some broad areas of environmental concern, their specific interests differ somewhat. The NMFS is especially concerned with the potential impact of sediments on anadromous fishes such as striped bass and several species of shad. The Game Commission focuses its attention on trout streams. There was a consensus among the interviewees that the F&WS has a broad and deep commitment to the total environment. Thus, the agency may adopt a preservationist stance toward aquatic ecosystems which have little obvious economic or recreational value. The EPA also has broad interests, which include air quality and noise impacts of the proposed highway, as well as water quality considerations. All of the agencies may devote careful attention to certain stream crossings, encroachments on wetlands, and stream channelization projects, especially if trout, smallmouth bass, or endangered aquatic species may be affected.

The comments made by the agencies during the early coordination sessions are later considered by the Department before the alignment is chosen and the project enters the design stage. Further coordination with the agencies takes place after the preferred alignment has been selected. Additional information about the site is presented to the agency representatives, who offer more specific comments about mitigation and erosion control measures that may help to secure favorable responses from these agencies when they later formally review the permit application.

By all accounts, the early coordination process has been very successful. Daugherty (1979) has estimated that 90% of all projects that have been presented and discussed in early coordination meetings have been granted 404 permits by the Corps without modifications in design. Another 9% of these projects have been granted permits after some design modifications were made. Only 1% have been denied 404 permits, and most of those projects were designed before environmental considerations had assumed their present importance in highway construction. All of the persons interviewed agreed that early coordination expedites the permit process.

Stream monitoring plays two roles in the permit process. During early coordination, personnel from the Aquatic Ecology Section sample macroinvertebrates or fish in streams which may be crossed during highway construction. This cursory, qualitative sampling is the same type utilized to obtain water quality data for environmental impact statements. Chemical parameters such as pH and dissolved oxygen may also be determined in the field by rapid methods. The agency personnel who participate in the 404 process stated that the Department's program of cursory sampling provides useful information about the aquatic communities that may later be affected by sediment runoff from the construction site. For example, biological sampling can be used to determine whether or not a stream contains trout. This determination can have substantial consequences, since greater efforts are generally made to avoid or protect trout streams than other upland streams. While the Commission of Game and Inland Fisheries or the SWCB can sometimes provide reliable information about the presence or absence of game fish in a stream, it may be useful to obtain more detailed, up-to-date information in other cases.

None of the aforementioned agencies routinely monitors streams adjacent to highway construction projects. Personnel from the SWCB stated that cursory monitoring might be initiated in response to a complaint from the public. Most of the interviewees noted that their agencies have insufficient manpower to engage in programs of stream monitoring. One agency had planned to commission a research project to study the effects of sediment derived from highway construction sites on stream biota, but the project was abandoned when funding could not be obtained.

Semiquantitative biological monitoring is conducted by the Division on certain projects under the aegis of the 404 program. Such monitoring typically involves environmentally "sensitive" projects where feasible alternative alignments are not available. Trout streams and streams containing endangered species (e.g., freshwood mussels) are examples of sensitive areas. The techniques and methods used in these monitoring projects are selected by the Environmental Quality Division, not by the state and federal agencies. Some of this monitoring is cursory and qualitative; on other projects, more thorough, quantitative monitoring is accomplished, as described in a subsequent section.

On-site enforcement of the erosion control measures specified in 404 permits is limited. The Corps of Engineers has primary responsibility in this area, since it is the issuing agency for the permits. Personnel from the Norfolk District Office of the Corps make spot checks, rather than routine, systematic inspections of construction sites. If violations are noted, they may be reported to the Environmental Quality Division for possible remedial action. Persons from other agencies which participate in the 404 program sometimes make independent spot checks.

Most of the agency representatives expressed the opinion that the Department's Erosion and Sediment Control Manual is excellent. They also stated that erosion control devices are frequently installed and maintained improperly in the field, with the result that the effectiveness of the control measures is greatly reduced.

STREAM MONITORING

Introduction

It was the purpose of this study to identify rapid, quantitative methods that could be used by the Environmental Quality Division in its program of stream monitoring. Findings from the literature search and the agency interviews can now be combined toward that objective. The following discussion is selective and summary. Emphasis is placed on types and techniques of stream monitoring that are judged to be most appropriate for assessing sediment pollution, and that are consistent with the programs and criteria of the agencies that interact with the Department in this area. Three broad classes of monitoring will be considered: chemical, physical, and biological.

Chemical Monitoring

Chemical monitoring has long been used to assess the amounts of inorganic and organic substances entering natural waters from sewage treatment plants and from a wide variety of industries. Specific chemical assays have been developed and standardized for dozens of elements and compounds considered to be water pollutants, including toxic metals, oxygen-depleting wastes, certain organic compounds (e.g., phenols), pesticides, phosphates and nitrates, cyanides, and oil and grease. Detailed methods for the analysis of these pollutants are presented in the Standard Methods for the Examination of Water and Wastewater, 14th Edition prepared by the American Public Health Association et al. (1976), EPA manual Methods for Chemical Analysis of Water and Wastes (1979), and the American Society for Testing and Materials Annual Book of ASTM Standards - Part 31 (1978). Modern laboratories use a variety of spectrophotometers, chromatographic methods, and selective ion probes in addition to the traditional "wet" techniques to perform chemical tests.

Chemical monitoring is more widely used than biological and other kinds of monitoring in this country. The EPA has required and promoted chemical monitoring, as have the water quality agencies of the states. Virginia's SWCB administers a large program of chemical surveillance. Sewage treatment plants of all sizes and a diverse array of industries are required to collect samples of their effluents at regular intervals, to submit the samples to an approved laboratory for chemical testing as specified in their respective permits, and to report the results to the SWCB. The SWCB also conducts periodic chemical surveys of its major clients to monitor their compliance with effluent limits. Further, the agency conducts monthly sampling at 307 stream stations throughout the state. Suspended solids, biochemical oxygen demand, chemical oxygen demand, total organic carbon, chlorine, pH, and fecal coliform levels are determined routinely for each station, and other tests may be performed.

Chemical methods offer advantages over other types of stream monitoring in some, but not all, situations. These methods have been refined and standardized over a period of years. Chemical techniques are often very accurate and precise, and automated procedures have been developed for the analysis of some pollutants.

Several disadvantages and limitations are associated with chemical monitoring. While this type of monitoring is appropriate for the direct assessment of substances in effluents or in aquatic environments, it may be much less appropriate for assessing the effects of the pollution on aquatic ecosystems. If, for example, a factory is discharging a toxic substance into a stream, chemical monitoring can provide data about the concentration of the substance in the effluent and at stations located at various distances downstream from the factory. These data may be very important, especially when the downstream water is used by man for drinking or swimming, and when it is known that certain concentrations of the substance are dangerous to humans. In cases where pollutants affect aquatic biota without threatening human health, it may be more relevant to estimate the adverse impacts of the pollutants than to know their concentrations in the water at various locations and times. It is often difficult, if not impossible, to relate concentrations of pollutants to reductions of aquatic biota in even a semiquantitative manner. Synergistic interactions among several pollutants may cause damage to stream fauna greater than the additive effects of the individual pollutants. Chemical pollution often varies in time, both diurnally and over longer periods. This temporal variability confounds attempts to predict the effects of pollutants on aquatic organisms.

Chemical surveillance would appear to be less suitable for sediment pollution than for industrial effluents. Particulate sediment is not a chemical pollutant in the usual sense, although it may induce changes in the chemistry of natural waters. Investigators have monitored pH, alkalinity, hardness, acidity, and dissolved solids upstream and downstream from sources of sediment pollution. While the results have been somewhat variable, it cannot be concluded at the present time that any of the aforementioned parameters can provide a reliable index of sediment pollution. Nor does the literature contain evidence that changes in aquatic chemistry associated with sediment pollution play a major role in reducing aquatic communities. Rather, the preponderance of evidence indicates that sediment itself is responsible for these reductions.

The Environmental Quality Division conducts a limited amount of chemical testing as part of its overall program of stream monitoring. Simple tests (pH, dissolved oxygen, temperature, etc.) are often performed in conjunction with cursory biological sampling to provide data for environmental impact statements and the permit process. More detailed chemical testing may be done by other laboratories when quantitative monitoring is undertaken by the Environmental Quality Division. In light of the considerations noted above, there is little reason to recommend that additional emphasis be given to chemical monitoring. This conclusion is strengthened by the fact that none of the agencies which were interviewed indicated that they considered this type of monitoring to be particularly useful for assessing sediment pollution.

Biological Monitoring

General Considerations

Unlike chemical surveillance, biological monitoring involves the direct assessment of damages inflicted on aquatic communities by pollutants. This type of monitoring can be considered appropriate for evaluating sediment pollution, since aquatic ecologists and governmental agencies recognize the reduction of stream biota as a primary effect of sedimentation. Several of the agencies interviewed conduct some kind of biological monitoring, either in relation to sediment or, more commonly, to other pollutants.

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There are no universally accepted standard methods of biological monitoring. Rather, diverse approaches, methods, and analytical procedures are used. Among the taxonomic groups that have been used as indicators of water quality are bacteria, phytoplankton, zooplankton, periphyton, vascular plants, benthic invertebrates, and fish (James and Evison 1979; Greeson et al. 1977). While any of these groups might have advantages as indicators in certain situations, benthic invertebrates have been used more frequently than other groups. Several considerations have favored the selection of these organisms in programs of biological monitoring. Because benthic macroinvertebrates are widely distributed in aquatic environments, they can be readily collected in appreciable numbers. Their large size relative to unicellular organisms facilitates the identification of macroinvertebrates, and their limited mobility restricts them to a particular environment. Thus, their response to pollution can be monitored over time at fixed stations. Fish, on the other hand, can leave and enter an impacted area in an unpredictable manner that may confound efforts to detect and estimate population changes caused by pollution. Many macroinvertebrates live for months or even several years. Consequently, it is possible to study their integrated response to conditions which have prevailed for some time. Since invertebrates have specific habitat preferences, changes in the composition of a benthic community may indicate the influence of sediment or other pollutants that cause habitat alterations. Hynes (1970a, b), Warren (1971), Cairns and Dickson (1973), Hellawell (1972), and Hart and Fuller (1974) have discussed the interpretation of benthic data with regard to water quality.

Because of the prominence of macroinvertebrates in the literature of biological monitoring, and because these organisms have been featured in the monitoring program of the Environmental Quality Division, the following discussion will concern methods for the collection, sorting, and identification of benthic invertebrates. These topics will be treated selectively, with emphasis on methods which seem most appropriate for use by the Division. More detailed information about specific methods of collection is available in the literature (Welch 1948; Macan 1958; Barnes 1959; Cummins 1962; Needham and Needham 1962; Southwood 1966; Schwoerbel 1970; Holme and McIntyre 1971; Edmondson and Winberg 1971; American Public Health Association et al. 1976; Merritt and Cummins 1978). Methods for the analysis of macroinvertebrate data have been presented by Cummins (1962), Southwood (1966), Sokal and Rohlf (1969), Elliot (1971), Weber (1973), Keefe and Bergersen (1975), Dickson et al. (1978), and Smith (1979).

Qualitative Sampling

It is convenient to distinguish three broad classes of sampling for benthic invertebrates (Greeson et al. 1977). The first is the faunal survey, which is a qualitative approach. This type of sampling is done to determine which taxa are present at a sampling station and to estimate the relative abundances of the various taxa. The investigator attempts to sample as many habitats as possible within the station to obtain representatives of as many taxonomic groups as possible. Nearly any sampling method or combination of methods may be used, including hands, dip nets, dredges, grabs or any of the methods employed in more quantitative sampling procedures, as described below. No attempt need be made to sample in a standard manner within or between habitats, since quantitative results are not sought.

Invertebrates that have been collected by qualitative methods are sometimes preserved in a solution of formaldehyde, 70% ethyl alcohol, or 40% isopropyl alcohol and then transported to the laboratory for sorting and identification. Sorting of the preserved specimens from associated sediment and organic detritus in the samples, which may require many hours when quantitative sampling is undertaken, can be greatly expedited for qualitative sampling. In fact, the sample may be examined in the field, and the frequencies of the various taxa can be characterized by convenient but imprecise terms such as "common", "scarce", or "absent".

The SWCB uses a type of qualitative biological sampling, which they refer to as cursory monitoring, to determine the nature of the biota downstream from sewage treatment plants and from sources of industrial pollutants. Aquatic biologists at the U. S. F&WS use qualitative sampling to assess invertebrate populations in trout streams. The biological sampling conducted by the Environmental Quality Division to obtain data for environmental impact statements is similar to that conducted by the SWCB. A D-frame dip net is used to collect specimens that are identified to the order level in the field. The interpretation of the data considers both the numbers of taxa present and the relative abundances of certain orders within the sample. It is assumed that the composition of the sample reflects the water quality at that station. For example, large numbers of ephemeroptera (mayflies) and stoneflies (Plecoptera) are said to be indicative of clean water, while a predominance of chironomid larva or rat-tailed maggots indicates badly polluted water. While general associations between the composition of invertebrate communities and water quality have been established with limited success for oxygen demanding wastes (e.g., domestic sewage), it has not been demonstrated that these communities respond in the same manner to sediment and other pollutants.

Despite this reservation, it may be concluded that the qualitative sampling performed by the Environmental Quality Division is entirely adequate for its intended purposes: to provide very general, descriptive information for the EIS and related documents; to obtain data for consideration in the 404 program, including early coordination; and to accomplish quick monitoring in response to situations that may arise during or after the construction phase of a project. This cursory sampling is judged to be at least as effective as that practiced by agencies involved with water resources. There is little reason at present to change the procedures now used by the Aquatic Ecology Section for the qualitative sampling of macroinvertebrates. However, certain rapid methods of physical monitoring, later described, could be used to supplement the biological methods.

Quantitative and Semiquantitative Sampling

Quantitative and semiquantitative sampling can provide considerably more information about the status of benthic populations than can qualitative sampling. All of the devices used for quantitative sampling permit, in theory, the collection of macroinvertebrates from a defined area of a stream bottom. After the specimens have been sorted, identified, and counted, the frequency of each taxon can be expressed as the number of individuals per unit area, e.g., per square foot or per square meter. Standardized data of this type can be compared both within and between sampling stations and among sampling dates.

Several classes of apparatus are used for quantitative sampling of the benthos. The various grab samplers all have some sort of spring-loaded, metal jaws. A grab sampler is lowered by a cable from a boat to the bottom of the water column. As the sampler touches the bottom, the jaws trip and bite into the sediment, thereby collecting invertebrates and sediment from a certain area. The Eckman, Ponar, and Van Veen grabs have frequently been used in quantitative surveys in coastal and estuarine waters. None of these samplers can be used with confidence in upland streams, where gravel and rocks in the sediment prevent the jaws of the grab from closing completely, and part or most of the sample may be lost while the apparatus is being pulled up to the boat.

The Surber sampler has been used more frequently than any other collecting device in quantitative stream surveys. It consists of two conjoined parts: a simple metal quadrat that is manually pushed into the stream bottom to encompass a known area, and a mesh bag that is mounted on a second metal frame at a right angle to the sampling quadrat. The area of the stream bottom enclosed by the quadrat is thoroughly agitated to dislodge the invertebrates, which are transported by the current into the mesh bag.

Hess samplers are similar to Surber samplers. The major differences between the two are that the Hess sampler encloses a circular area of the sediment rather than a square area, and that the space above this sampling area is completely surrounded by a cylinder of nylon mesh. The latter feature prevents invertebrates from bypassing the collection bag after they have been dislodged from the sediment.

The Wilding stovepipe sampler and the Lium sampler, among other devices, are essentially similar to the Surber and Hess samplers, both of which are available in several modified versions. Because all of these samplers are operated by hand, their use is restricted to water less than 1.0 to 1.5 meters deep. Since these devices displace water while moving in a stream, they can cause scouring at the site to be sampled unless care is taken by the person operating the sampler.

Coring tubes, which have been widely used to collect quantitative samples of sediments and microfauna, are less suitable for sampling macroinvertebrates. Since corers take small samples, it is necessary to obtain many of them in order to accomplish representative sampling of an invertebtate community. Moreover, corers cannot be used to sample rocky substrates. Hydraulic devices such as the Pickral-Odum (1977) detritus sampler, a benthic vacuum cleaner powered by a 3.5 HP pump, are effective only in areas with fine-grained sediments.

Semiquantitative sampling, which is less rigorous than qualitative sampling, includes several methods in addition to those noted above. A dip net may be used to sample in a standardized manner or for a specified period of time. This procedure, which is used by the Environmental Quality Division for occasional projects that require stream monitoring on a continuing basis, has several drawbacks. It is difficult to ensure that all stations are sampled in the same manner. This difficulty is particularly severe when the sampling does not conform to a stratified design, v.i. It is widely recognized that invertebrate communities of pools and riffles differ significantly in taxa and in total numbers, biomass, and productivity. If dip netting is carried out for 20 minutes at each of several stations, and if the ratios of pool to riffle area sampled differ between the stations — e.g., 40% of the sample at one station was obtained from riffles, while only 20% of a second sample represented riffles — then the results will indicate a difference between the stations, even if there are no real differences in invertebrate communities among comparable habitats at the stations. Standard dip netting is even more difficult to accomplish when two or more persons participate in the sampling process, because of differences in site selection, technique, and effort among investigators. Further, the data obtained by sampling with a dip net for a specified period of time are merely relative. For example, it can be stated that more mayfly larvae, etc., were collected at one station than at another; but little can be said about the numbers of mayflies per square meter of stream bottom at the respective stations. Thus, it is difficult to compare data among sampling sites and dates, or data reported by different investigators. It would be possible to conduct stratified sampling of discrete habitats with a dip net and to sample measured areas of the stream bottom instead of sampling for some interval of time.

Artificial substrates have sometimes been used in semiquantitative studies of macroinvertebrates. Among these devices are the Hester-Dendy multiple plate sampler, the barbecue basket sampler, and the collapsible basket sampler. The use of artificial substrates must be considered inappropriate for assessing the impact of sediment pollution on stream biota. Evidence disclosed in the preceding literature review demonstrated that the occurrence and density of benthic invertebrates are related to the texture of the natural substrate, and that sediment pollution affects these organisms primarily by the addition of fine-grained material to the natural substrate. Artificial substrates are essentially large, solid objects suitable for colonization by invertebrates. In an area where fine-sediment is being deposited, such an object provides a haven for benthic invertebrates that would otherwise evacuate the area because of the increasingly unfavorable conditions in the natural substrate. Thomas (1975) found that artificial substrates situated downstream from construction projects were sometimes colonized more heavily by organisms than were artificial substrates placed upstream from the sites, despite conspicuous reductions of biota in the downstream sediments.

Several general designs have been used to sample benthic invertebrates. The major types are random sampling, stratified random sampling, and systematic sampling. Elliot (1971) has provided an excellent account of statistical principles of sampling as applied to macroinvertebrates. Only a few selected remarks will be made here. First, it is clear that these organisms are not distributed uniformly throughout a stream. Communities vary considerably between pool and riffle habitats, and variations exist among microhabitats within these habitats. Quantitative sampling must take account of the heterogeneity of invertebrate distributions. Stratified random sampling or systematic transect sampling has been strongly recommended by Cummins (1962), Elliot (1971), and others. Comparisons among different stations along a stream should be made among like habitats; upstream riffles should be compared with downstream riffles and upstream pools with downstream pools. Secondly, it is recommended that multiple (i.e., replicate) samples be taken at each station in order to assess population variances and to permit statistical comparisons to be made among the stations. The quantitative monitoring currently performed by the Environmental Quality Division is deficient in this regard. One huge sample is collected at each station, and some of the results cannot be adequately evaluated by objective methods.

The above observations suggest that the quantitative biological monitoring conducted by the Environmental Quality Division could be made more quantitative in several respects. Most of the investigators whose studies were reviewed earlier used Surber samplers, modified Hess samplers, or some similar quantitative device to collect benthic material for faunal analysis. Aquatic biologists who were interviewed at the SWCB, the EPA, the Army Corps of Engineers, the F&WS, and the Soil Conservation Service also recommended the Surber or the modified Hess sampler for quantitative assessments of the effects of pollutants. They acknowledged, however, that less quantitative devices such as the dip net may permit somewhat more rapid sampling. Results from both the literature search and the agency interviews indicate that replicate sampling is a desideratum of modern, quantitative aquatic sampling. The collection of three to six samples at each station would probably be adequate for statistical comparisons.

Processing of Biological Samples

Samples collected by any of the methods described above, with the exception of artificial substrates, contain large quantities of sediment and organic detritus. In a quantitative study, efforts are made to remove every preserved specimen from the accompanying debris. This process can be extremely tedious and time consuming. Various methods have been developed to expedite the sorting of invertebrates in the laboratory. It may be possible to discard fine portions of the sediment by washing the sample on appropriate sieves (Jonasson 1958). In many cases, organisms can be segregated from the debris by agitation and decantation, since they are less dense than sediment grains. Pickral and Odum (1977) have used the same principle to partition organisms from debris in a settling tube. Benthic samples can be immersed in a sucrose solution of 1.12 specific gravity (Anderson 1959; Lackey and May 1971). Most of the invertebrates will float on the solution, while the sediment and detritus will sink. Elutriation techniques have also been used in faunal analysis (Cummins 1962). Finally, stains such as Rose Bengal have been used to effect the differential staining of organisms and thus facilitate their detection and removal from the sample. Williams and Williams (1974) have described a counterstaining technique that can expedite the sorting of invertebrates from detritus.

At present, the Environmental Quality Division sorts samples by the reliable, but very slow, process of visual examination and handpicking. Far more time is spent in the sorting of samples than in field work. There is little doubt that some of the techniques noted above could, if adapted for use by the Division, reduce the time required to process benthic samples. Indeed, it may be possible to achieve large reductions in processing time if appropriate combinations of methods can be identified and implemented. By increasing the efficiency of laboratory processing of samples, the Aquatic Ecology Section could perhaps allocate the modest amount of additional time that might be required by the replacement of semiquantitative methods of field sampling with fully quantitative methods. In summary, the results of the literature search and the agency interviews suggest that the Environmental Quality Division could obtain more accurate benthic data with less overall effort than expended at present.

Physical Monitoring

Temperature and Suspended Solids

Certain physical aspects of the aquatic environment can be monitored to assess the impacts of some pollutants. Water temperature is often measured in stream surveys, because temperature is an important variable that affects the rates of chemical reactions, the solubility of dissolved gases, and the types and numbers of organisms in streams. Thermal plumes originating from both nuclear and conventional power plants have been monitored to ensure that receiving waters do not attain temperatures lethal to fish or other organisms.

While it has been suggested that elevated levels of suspended solids may interact with solar radiation to cause thermal changes in streams, the literature contains no significant examples of this hypothesized phenomenon in natural environments. Consequently, water temperature, per se, cannot serve as an adequate indicator of sediment pollution. It is possible that the effects of sediment on stream biota are more severe at certain ranges of temperature than at others. The literature contains insufficient data to permit the evaluation of this possibility.

Suspended solids, another physical variable, are commonly assessed, together with chemical or biological variables, in programs of stream monitoring. The relationship between suspended solids and alterations of stream communities is complex and poorly understood. It is difficult to discriminate the effects of suspended particles moving in the water column from the effects of the deposition and movement of sediment on the bed of the stream. Considerable evidence, previously outlined, indicates the importance of the processes of deposition, embedding, and bedload transport in causing reductions of benthic populations. While the evidence for the adverse effects of suspended solids on stream biota is less conclusive, it has been suggested that high levels of particulate matter can impede the photosynthesis of aquatic plants, decrease the visual range of fish and other consumers, impair the filtering efficiency of gill tissue in fish, abrade plants and sessile invertebrates, and otherwise disrupt the growth, behavior, and reproduction of aquatic organisms.

Suspended solids in a stream can be monitored with reasonable accuracy and precision by well established methods. Grab samples can be taken at discrete depths in the water column, or depth-integrated samples can be obtained with standard devices. Automated samplers have increasingly been used in recent years. A study in progress at the Research Council (Wyant, progress report in preparation) entails the monitoring of suspended solids upstream and downstream from highway construction sites to evaluate the efficiency of the erosion control practices of the Department. The suspended solids data from this kind of investigation could be compared with invertebrate data generated by quantitative sampling methods to determine the degree of association between increases in solids and reductions of benthic communities. It might be possible to identify tolerance limits for suspended solids beyond which macroinvertebrate numbers or biomass decline significantly. Suspended solids may afford a convenient indicator of sediment pollution, even if particulate matter in the water column is not the primary factor responsible for faunal declines. That is, concentrations of solids in the water may correlate highly with the rates of deposition and embedding on the creek bottom, which directly determine the adverse impact on the benthos.

Monitoring Stream Bottom Sediments

Sediment pollution might be monitored by measuring changes in the depth and texture of material on the stream bottom downstream from the source of sediment. Several considerations commend this type of monitoring. As previous discussion has made apparent, there is much evidence that the deposition of sediment on the bed of the stream, rather than the action of suspended solids, is primarily responsible for the observed reductions in numbers of invertebrates and fish eggs in areas affected by sediment pollution. By monitoring changes in bottom sediments, one could directly assess the major factor that causes faunal declines in impacted streams. Information obtained from the literature search strongly suggests that such declines are directly proportional, within limits, to the degree of embedding of the aquatic substrate. Consequently, it should be possible to collect samples of bottom sediments periodically at fixed stations downstream from a construction site or some other non-point source of sediment pollution, sieve and analyze the sediment samples by standard methods, detect changes in the percentage of fine fractions in the samples (due to embedding), and determine the degree of embedding at which benthic organisms begin to exhibit adverse effects from sediment pollution. After critical levels of embedding have been determined, standards could be set for stream bottom sediments and standard practices for sediment monitoring could be specified.

The type of monitoring proposed above has not been investigated to any appreciable extent. Sediment monitoring would not be appropriate for most of the water pollutants that are of concern to the various federal and state environmental agencies; classical chemical or biological monitoring is usually preferred for soluble substances. Sediment, however, is not readily soluble and typically does not give rise to chemical changes that can easily be monitored. While the monitoring of stream bottom sediments has limited applicability to most pollution problems, it may be the method of choice for the surveillance of non-point sources of sediment pollution.

Although the regulatory agencies have not explored the possibility of such monitoring, the results of the interviews conducted during this study indicate that many of the aquatic scientists employed by the various agencies are favorably disposed toward the concept of monitoring sediment changes in the vicinity of highway construction projects. Because practices of stream monitoring have not yet been highly developed for non-point sources by the agencies, research conducted by the Council and the Department could help to define methods and criteria that would meet present or future requirements in this area.

Aside from theoretical considerations and the probable support of the agencies, sediment monitoring has several favorable characteristics. First, sediment analysis can be accomplished rapidly and efficiently. It would require significantly less time than quantitative biological monitoring. Secondly, it could be performed by personnel with limited training, while biological monitoring must be performed by aquatic biologists with special training. Thus, sediment monitoring could be undertaken by Departmental personnel outside of the Environmental Quality Division when biologists from that office could not be available to monitor a project. Thirdly, proven methods now exist for the analysis of fluvial sediments. Finally, some types of stream monitoring (e.g., analysis of suspended solids) require that either personnel or operative automatic samplers collect samples during storms or at other specific times. This requirement would be less strict for sediment monitoring, since embedding typically occurs over extended periods of time. Even if the deposition of sediment on a stream bottom occurred during the span of a single storm, the physical alteration of the substrate should be apparent for weeks or months after the event.

In summary, the literature review, the agency interviews, and consideration of the practical aspects of stream monitoring all suggest that changes in the texture of fluvial sediments downstream from a construction site might be monitored by reliable, convenient, efficient methods to evaluate the extent of the damage inflicted on an aquatic ecosystem by runoff from the project. A study has recently been initiated by the Research Council (Pickral, in progress) to evaluate the feasibility of including sediment analysis in the Department's program of stream monitoring.

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