Silt, Turbidity and Suspended Sediments in the Aquatic Environment:

An Annotated Bibliography and Literature Review

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The impacts of siltation and suspended sediments on water quality and resident aquatic organisms is one of the most common problems facing resource managers today. Most construction activities in or near a watercourse have the potential to result in decreased shoreline stability and/or an increase in siltation, suspended sediments and turbidity.

This annotated bibliography was prepared in response to requests from several Ontario Ministry of Natural Resources biologists and technicians in the Southern Region. I have attempted to assemble and summarize reference material on various aspects of this topic including sources of suspended solids, physical/chemical processes, impacts to water quality and aquatic life, and remediation. Obviously the topic is very broad and this bibliography certainly does not represent an exhaustive listing of all reference material on the subject. Rather, it is intended to provide a consolidation and synthesis of information which is readily available for day-to-day use by field staff.

Almost 1200 references are cited. Citations were extracted from the primary literature as well as a bibliography prepared in 1993 (Kerr, 1993) as part of a provincial aquatic habitat training initiative. Information was extracted from a variety of sources. Many references were obtained from the Science and Technology Transfer Unit collection in Kemptville and Brockville. Margaret Wells conducted a literature search from the Ministry of Natural Resources libraries in North York and Maple. Additional reference material was also provided by Neil MacLean, Cheryl Lewis, Norm Smith, Neville Ward, Cindy Rusak, David McLeish and Henk Rietveld. Norm Smith and Rob Tavares also provided useful editorial comments. I am especially indebted to Chuck Newcombe, British Columbia Ministry of the Environment, Lands and Parks, for his extensive contribution of data and reference material as well as his editorial review of an earlier draft.

Abstracts, summaries or extracts of each paper are included whenever possible. In some cases e.g., Ward (1992), the entire text has been included while in other instances e.g., Committee for Water Quality Criteria (1972), an extract from the original text has been selected. Numerous papers, for which abstracts could not be obtained, have also been included as potential reference sources. For additional references on this topic the reader is directed to Newcombe (1994a) and Golder Associates Ltd. (1995).

It is hoped that this bibliography will provide a useful general reference for field staff in their ongoing activities to protect aquatic habitat in Ontario.
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Synthesis of Selected Literature

This section will attempt to provide a general synthesis and overview of the information which is subsequently cited under five general categories:

O Sources of Suspended Solids
O Physical/Chemical Processes
O Impacts of Silt and Suspended Sediments
O Techniques to Reduce Suspended Solids
O Turbidity/Suspended Sediment Water Quality Standards

(A) Sources of Suspended Solids

There are numerous potential sources of soil and other material which may become suspended or settleable upon reaching a waterway. Examples of some of the most noteworthy include:

(i) Agriculture
   - cropping too close to ditches, drains and watercourses can accelerate bank erosion;
   - access to watercourses by cattle and other livestock can lead to the loss of riparian vegetation and deterioration of shoreline leading to sediment pollution.

(ii) Dams and Reservoirs
    - act as settling basins for silt and other suspended materials;
    - recreation and aesthetics impaired;
    - aquatic habitat lost.

(iii) Dredging
    - destabilizes substrate and the associated benthic macroinvertebrate community;
    - alteration of water circulation patterns and submarine mudflows;
    - uncontrolled redistribution of sediments at disposal site sometimes smothering benthic organisms;
    - localized changes in water chemistry including reduced dissolved oxygen levels, the release of toxic compounds and increased turbidity.

(iv) Erosion
    - primary source of suspended solids in coastal zones;
    - greatly accelerated by many human activities which remove vegetative cover and expose soil.

(v) Flooding
    - extremely high concentrations of suspended solids may persist in rivers in flood for relatively long periods.
(vi) **Forest Fires**
- run-off from burned catchments increased substantially due to accelerated overland flow rates (from reduced infiltration capacity) and mass soil movement.

(vii) **Logging Activities**
- greatly accelerated surface erosion and sedimentation which continues after logging activity ceases;
- severity of impact depends on topography, climate, soil types and amount of soil disturbance.

(viii) **Mining**
- run-off from mine spoils and coal washing/granite crushing facilities, etc. can dramatically elevate suspended sediment concentrations and cover spawning substrates.

(ix) **Recreational Boating and Navigation**
- resuspend sediments thereby increasing turbidity;
- wave wash erodes material from riverbanks and lake shorelines;
- displace male Centrachids guarding nests thereby increasing egg predation and reducing nesting success.

(x) **Roads**
- road construction and associated culvert installation result in dramatic short term increases in suspended sediment;
- massive soil erosion and sediment production from logging roads (dependent on whether road has paved or gravel surface);
- disruption and/or removal of riparian vegetation;
- significant increases in turbidity and suspended solids;
- destabilized shoreline and sediment from backfill associated with bridge construction and stream crossings.

(xi) **Urban Development**
- increased soil exposure and sediment loads from topsoil removal during early phases of construction;
- sediments and other compounds (i.e., heavy metals and oil) from storm sewers and street run-off.

(xii) **Wind/Wave/Current Action**
- resuspension and transport of substrate sediments.

(xiii) **Ice Breakup and Movement**
- ice scouring increases shoreline erosion
- release of sediments from melting ice and snow
- increased sediment transport capabilities.
(B) Physical/Chemical Processes

A detailed summary of sediment transport mechanisms and physical processes is provided by Everest et al. (1987). Generally, sediments are classified according to their grain size (Table 1). It is usually the smaller (i.e., < 74 microns) particles which cause turbidity (Newcombe 1994b). Sediment size also is a major determinant of transport rate and settling characteristics (Table 1).

<table>
<thead>
<tr>
<th>Particle Size Millimeter Microns</th>
<th>Size Class of Particle</th>
<th>Velocity of Settling Particle (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-4000</td>
<td>Boulders: very large</td>
<td>-</td>
</tr>
<tr>
<td>1000-2000</td>
<td>large</td>
<td>-</td>
</tr>
<tr>
<td>500-1000</td>
<td>medium</td>
<td>-</td>
</tr>
<tr>
<td>250-500</td>
<td>small</td>
<td>-</td>
</tr>
<tr>
<td>130-250</td>
<td>Cobble: large</td>
<td>-</td>
</tr>
<tr>
<td>64-130</td>
<td>small</td>
<td>-</td>
</tr>
<tr>
<td>32-64</td>
<td>Gravel: very coarse</td>
<td>-</td>
</tr>
<tr>
<td>16-32</td>
<td>coarse</td>
<td>-</td>
</tr>
<tr>
<td>8-16</td>
<td>medium</td>
<td>-</td>
</tr>
<tr>
<td>4-8</td>
<td>fine</td>
<td>-</td>
</tr>
<tr>
<td>2-4</td>
<td>very fine</td>
<td>-</td>
</tr>
<tr>
<td>1-2</td>
<td>1000-2000</td>
<td>Sand: very coarse</td>
</tr>
<tr>
<td>0.5-1</td>
<td>500-1000</td>
<td>coarse</td>
</tr>
<tr>
<td>250-500</td>
<td>medium</td>
<td>26-53</td>
</tr>
<tr>
<td>125-250</td>
<td>fine</td>
<td>11-26</td>
</tr>
<tr>
<td>62-125</td>
<td>very fine</td>
<td>2.6-11</td>
</tr>
<tr>
<td>31-62</td>
<td>Silt: coarse</td>
<td>0.66-2.6</td>
</tr>
<tr>
<td>16-31</td>
<td>medium</td>
<td>0.18-0.66</td>
</tr>
<tr>
<td>8-16</td>
<td>fine</td>
<td>0.044-0.18</td>
</tr>
<tr>
<td>4-8</td>
<td>very fine</td>
<td>0.011-0.044</td>
</tr>
<tr>
<td>2-4</td>
<td>Clay: coarse</td>
<td>&lt; 0.011</td>
</tr>
<tr>
<td>1-2</td>
<td>medium</td>
<td>-</td>
</tr>
<tr>
<td>0.5-1</td>
<td>fine</td>
<td>-</td>
</tr>
<tr>
<td>024-0.5</td>
<td>very fine</td>
<td>-</td>
</tr>
</tbody>
</table>

Sources

(i) Grade Scale - Particle grade scale developed by the Subcommittee on Sediment Terminology, American Geophysical Union.


The process of sedimentation occurs in three stages: (1) detachment and entrainment of particles by flowing water; (2) transport; and (3) deposition.

**Basically, there are two major types of sediment transport mechanisms:**

1. **Suspended sediment transport** - usually silt-clay sized particles which are transported downstream and deposited in the floodplain or stream/lake bed.

2. **Bedload transport** - involves larger particles moving along the bottom. Their movement is greatly affected by the roughness of the bottom. Fine bedload material is more subject to differential transport (i.e., by storm events) than coarse material.
In flowing waters, the deposition of suspended sediments onto the substrate usually occurs when velocity decreases to the point that sediments can no longer be transported. The intrusion of fine sediments into a gravel streambed is determined by discharge, water depth, velocity, rates of sediment transport and the initial concentration of suspended sediment (Beschta and Jackson 1979; Paustian and Beschta 1979). At very low flows (< 0.2 cms) round gravels tend to accumulate more fine sediment than angular gravels (Meehan and Swanson 1977). This trend tends to reverse when flows exceed 0.4 cms. Generally, sediment if flushed from small streams at increased discharges (Bilby 1985).

In standing waters (i.e., lakes), the settling of finely divided particles, having densities near that of water, is greatly affected by temperature variations and thermal stratification (Great Lakes Basin Commission 1976a). This can create a separation of suspended materials in the water column above and below the thermocline. Under poor flushing conditions, this density gradient has resulted in turbidity induced meromixis (Larson 1979).

In addition to various impacts on aquatic organisms, suspended materials in the water column have other physical and chemical effects. Suspended solids adsorb and concentrate trace metals and other contaminants and can transfer them from terrestrial to aquatic environments thereby increasing their bioavailability to aquatic life (Murty 1986; Persaud and Jaagumagi 1995). Turbidity causes light to be scattered and absorbed rather than transmitted in a straight line. Thus, light penetration is reduced. Turbid water also absorbs heat so an increase in suspended sediment can cause water temperatures to increase (Marcus et al. 1990). The re-aeration of surface waters has been found to decrease as the average suspended sediment concentration increased (Alonso, McHenry and Hong 1973).

(C) Impacts of Silt and Suspended Sediments

There are numerous direct and indirect impacts of silt, suspended sediments and associated turbidity (see Appleby and Scarratt 1989; European Inland Fisheries Advisory Commission 1965). These include changes to water quality, reduced light penetration diminished recreational values and aesthetics as well as direct and indirect impacts to fish, invertebrates, aquatic plants.

Changes in Water Quality

Suspended sediments can alter taste, odor, temperature and abrasiveness of water (Oschwald 1972) and reduce levels of dissolved oxygen particularly in deeper, thermally stratified lakes (Appleby and Scarratt 1989; Cramer 1974). Increases in sediment inputs have also been noted to decrease pH at the substrate-water interface of streams (Lemly 1982). A decrease in water clarity is another obvious change resulting from an increase of suspended solids.

Reduced Light Penetration

Increased turbidity, associated with suspended solids, reduces the penetration of sunlight. This in turn reduces photosynthetic activity (Marzolf and Arruda 1980; McCubbin et al. 1990; Meyer and Heritage 1941; Persaud and Jaagumagi 1995) and limits primary production (Gliwicz 1986; McCubbin et al. 1990; Munavar et al. 1991; Murphy et al. 1981; Wilson 1957).
Impacts on Aquatic Plants

Impacts to aquatic macrophytes vary from none (Edwards 1969) to the decrease of loss of various species (Moss 1977; Robel 1961). Documented effects include physical damage to leaves (Lewis 1973), reduction in photosynthetic activity (Chandler 1942; Chapman 1962; Ward 1992; Warren 1971), slower growth rate (Lewis 1973), and a reduction in the maximum depth of colonization (Canfield et al. 1985; Garrard and Hey, 1988).

Impacts on Invertebrates

Tolerance of various aquatic invertebrates varies according to the species however a wide range of impacts have been documented:

Reduced Feeding Activity - Filter feeding invertebrates are generally less tolerant of turbid conditions than other aquatic species. Increases in suspended sediment concentration (to 50-100 mg/l) decreased ingestion rates to potential starvation levels (Arruda, Marzolf and Faulk 1983). Suspended clay was found to reduce Daphnia feeding rates (Kirk 1991 b; McCabe and O'Brien 1983). Under highly turbid conditions, mussels and clams usually close their shells. Either the mussel cannot feed or silt laden food is rejected as pseudofaeces and the animal starves (Ellis 1936). Turbid conditions may also result in a reduction of food quality (i.e., leaf litter) for benthic macroinvertebrates (Forbes, Magnusson and Harrell 1981).

Toxicity and Direct Mortality - Suspended sediments have been found to be acutely toxic to amphipods (Forbes, Magnusson and Harrell 1987). Silt layers, 1/4 - 1 inch in thickness, can produce a high mortality in some freshwater mussels (Ellis 1936). "Red mud" was found to increase mortality rates of a planktonic copepod (Paffenhofer 1972). Koenings et al. (1990) demonstrated that turbidity reduced Daphnia survival.

Impede/Alter Movements - Sediment additions in a Northwest Territories river increased the numbers of different macrobenthos drifting downstream (Rosenberg and Wiens 1978). Similar observations on movements and colonization were also reported on Emerald Creek, Idaho (Leudtke and Brusven 1976).

Altered Species Composition and Abundance - There is considerable evidence to indicate that changes in the abundance and composition of invertebrate communities are associated with increases in suspended solids and turbidity. Gammon (1970) found that suspended loads between 40-120 mg/l resulted in a 25% reduction in macroinvertebrate density; at a sediment load of more than 120 mg/l, macroinvertebrate density decreased by 60%. Standing stocks of Daphnoid zooplankton have been reduced at elevated turbidities in Lake LeRoux, South Africa, and in an Amazonian floodplain lake (Carhalho 1984). Insect densities (drift and benthos) were found to be smaller in stream riffles with large amounts of sediment (Bjorn et al. 1974). Densities of Chironomids decreased in abundance by 90% after a release of suspended solids downstream from Guernsey Reservoir, Wyoming (Gray and Ward 1982). Erman et al. (1977) reported that invertebrate diversity in sediment California stream were greatly reduced for a period of at least ten years following logging activities. Stream invertebrate densities have been reduced in areas sedimented from upstream construction activities (Bowlby et al. 1987; Tebo 1955). Productivity of aquatic insects declined by 85% due to increased suspended solids in a stream below a gravel
Changes in species composition have also been documented (Lenat et al. 1981). Lemly (1982) noted that species richness and diversity of filter feeding benthic insects were significantly reduced in areas polluted by elevated sediment inputs. Chuter (1969) concluded that there could be considerable changes in the invertebrate fauna in flowing waters associated with levels of silt and sediment which did not completely smother them. The abundance and distribution of mayflies, clams and bryozoans are some species which have been documented to respond negatively to turbid waters (Cooper 1987). Cuker (1987) noted a species shift in algal communities associated with increased turbidity.

(v) **Physiological Changes** - The most harmful effect of suspended solids on invertebrates is the clogging of their filter feeding apparatus and digestive organs. Other physiological impacts associated with increased suspended sediments include reduced fecundity and brood size (Kirk 1992), retarded development of eggs and larvae (Appleby and Scarratt 1989; McKee and Wolf 1963) and increased water pumping rates (Appleby and Scarratt 1989).

(vi) **Decreased Primary Productivity** - Increased levels of suspended sediment coupled with high flows can remove algae from substrates resulting in a reduction in biomass (Alabaster and Lloyd 1980). Lloyd (1985) concluded that an increase in turbidity of 25 NTU (Nephelometric Turbidity Units) in shallow, clear-water systems may potentially reduce stream productivity by 13-50% or more and be associated with an increase in suspended sediment concentration of approximately 25-100 mg/l. A 5 NTU increase in turbidity in clear-water systems may reduce the primary productivity by 3-13% or more and be associated with an increase in suspended sediment concentration of approximately 5-25 mg/l. In Lake Erie, turbidity was found to influence composition, size, duration and time of occurrence of phytoplankton pulses and vertical distribution of microcrustacea (Chandler 1942). Turbid water can also limit the production of zooplankton (Committee Restoration of Aquatic Ecosystems 1992; Hart 1987).

(vii) **Growth Rates** - Probably as a result of reduced feeding activity as well as diminished food value, growth rates are often delayed or reduced in many organisms (Appleby and Scarratt 1989; Kirk 1992; Paffenhofer 1972).

**Impacts on Fish**

Probably the most research on the impacts of silt and suspended sediment sediments on aquatic organisms has involved fish. Some of the most comprehensive work has been done by C. P. Newcombe (1986a, 1986b, 1994a, 1994b) and this material is highly recommended for more detailed information.

Generally, tolerance varies considerably between different fish species, the various particle sizes and types, and water quality parameters (including temperature). For example, larger particles having greater angularity have generally been found to be more lethal than smaller and smoother particles (Appleby and Scarratt 1989; Newcombe 1994b). Smaller particles lack the mass to cause mechanical damage to gill tissue but are capable of stimulating mucous production in the gill epithelium (C. P. Newcombe, British
The effects of suspended sediments on fish is also influenced by water temperatures with more severe impacts occurring at higher water temperatures. This phenomena is probably a function of reduced activity (and metabolic rate) at cooler temperatures as well as the fact that saturation concentration of dissolved oxygen is an inverse function of water temperature.

Impacts are based on intensity which Newcombe (1986a) defines as the product of concentration of suspended sediment multiplied by the duration (hours) of exposure of the organism. On this basis, he developed a Stress Index. The Stress Index is based on the natural logarithm of the product of suspended solid concentration (mg/1) and duration of exposure (hours). The resulting value is expressed in terms of mg.hr/1. Newcombe also identified three basic categories of effect: behavioral (transient), sublethal and lethal. The index can then be used to rank anticipated effects (Table 2). It is important to realize that average severity of effects differ among fish species as well as life history stage. In addition, the onset of ill effects is often abrupt and can occur at relatively low concentrations and brief duration of exposure.

Younger life stages of fish are usually the most vulnerable and more severely impacted (Alexander and Hansen 1986; Appleby and Scarratt 1989; Newcombe 1994b). Generally, the larval stage appears to be the more sensitive than the egg or juvenile stages (Appleby and Scarratt 1989). Newcombe (1994b) also concluded that exposed fish eggs are generally more sensitive (and vulnerable) than eggs buried in the substrate.

Table 2: Ranking of effects of suspended sediments on fish and aquatic life.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Category of Effect</th>
<th>Description of Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Increased coughing rate</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Alarm reaction; avoidance reaction</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Behavioral Effects</td>
<td>Avoidance response; abandonment of cover</td>
</tr>
<tr>
<td>4</td>
<td>Reduction in feeding rates</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Impaired homing</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Poor condition of organism</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Moderate habitat degradation</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Physiological stress and histological changes</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sublethal Effects</td>
<td>Reduction in growth rates</td>
</tr>
<tr>
<td>10</td>
<td>0-20% mortality</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>&gt; 20-40% mortality</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>&gt; 40-60% mortality; severe habitat degradation</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>&gt; 60-80% mortality</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Lethal Effects</td>
<td>&gt; 80-100% mortality</td>
</tr>
</tbody>
</table>

Source: Newcombe and MacDonald (1991)

There have been some benefits observed from increased suspended sediments in aquatic ecosystems. These include increased protection to prey fish from predators (Bruton 1985; Doan 1941; Godin and Gregory undated) as well as the predators themselves (Gregory and Northcote 1993), increased
production for some species such as channel catfish (Homer 1956), enhanced fishing success for species including eels (Deelder 1970), assisted feeding.

Impacts to fish will be summarized under the following categories: movements and avoidance, feeding impairment, physiological changes, sedimentation of spawning beds, growth rates and production/abundance.

(i) **Movements and Avoidance** - Although not all fish avoid turbid waters, elevated turbidity or levels of suspended solids often induce avoidance reactions and may modify natural movements and migrations of many fish species. McLeay et al. (1984) found that Arctic grayling were displaced at suspended sediment concentrations of 300 mg/1 or greater. Juvenile salmonids have been known to leave channels containing sedimented substrate which did not provide interstitial spaces for winter refuge (Bjornn et al. 1974; Hillman, Griffith and Platts 1987; Marcus et al. 1990; Sigler, Bjornn and Everest 1984 ). In fact, the abundance of juvenile salmon in pools of small streams declines in direct proportion to the amount of habitat lost to sedimentation (Bjornn et al. 1977). Gammon (1970) reported that fish vacated stream pools after deposits of sediment accumulated but returned after winter floods had removed sediment deposits. Erman and Lignon (1988) found that three spine stickleback and prickly sculpin numbers were significantly reduced in areas exposed to a frequent flow of water laden with fine sediments. Paramagian (1991) concluded that sediment was a major habitat factor limiting the viability of smallmouth bass populations in Iowa.

Other behavioral changes have been observed. In some species, the tendency to migrate has been noted to decrease with increasing water turbidity (Appleby and Scarratt 1989). Berg and Northcote (1985) reported that, at high turbidities, dominance hierarchies broke down and territories were not defended. Under turbid conditions Heimstra et al. (1969) noted that social hierarchies in green sunfish were disturbed. In Lake Texoma (Oklahoma-Texas), behaviour of larval shad and freshwater run were altered by an inflow of turbid water. Larval shad became concentrated near the surface while larval drum were distributed throughout the water column in contrast to their normal concentration near the bottom (Matthews 1984). Similarly, vertical migrations of herring, which are related to light intensity, have been disrupted (Appleby and Scarratt 1989).

(ii) **Feeding Impairment** - Reduced light penetration affects sight feeding fish by reducing efficiency of prey location (Berg and Northcote 1985; Godin and Gregory undated; Vinyard and O'Brien 1976; Zettler and Carter 1986). Turbidity can reduced the feeding of predatory fish even under abundant food conditions (Gregory 1991; Vinyard and O'Brien 1976). Miller and Menzel (1986) reported a negative relationship between water transparency and muskellunge feeding activity. Turbidity from suspended clay particles significantly reduced the feeding rate of bluegills on Daphnia (Gardner 1981). The feeding rate of Arctic grayling has been impaired at increased sediment concentrations (McLeay et al. 1987). Larval striped bass consumed 40% fewer prey in water having suspended solids concentrations of 200-500 mg/1(Breitburg 1988). A reduction in feeding activity of juvenile coho salmon was noted at suspended sediment concentrations of 300 mg/1(Gregory and Northcote 1993). Redding et al. (1987) reported that feeding rates of yearling coho salmon and steelhead was reduced at high (2-3 gm/1) of suspended solids. After two hours of exposure to turbidity of 3 5 ppm, cutthroat trout in an Idaho river stopped feeding (European Inland Fisheries Advisory Council 1965). As suspended sediment
concentrations increased, Johnson and Wildish (1982) noted a depression in the feeding rate of larval herring.

For Pacific herring, Boehlert and Morgan (1985) found that the incidence and intensity of maximum feeding occurred at levels (500-1000 mg/l) of suspended solids significantly greater than controls (0 mg/l). At higher levels of suspended solids feeding decreased. They hypothesized that suspensoids may have acted to improve visual contrast thereby increasing feeding efficiency.

Physiological Changes - Several species of fish have been found to be relatively tolerant of high suspended sediment concentrations (Petticord 1976). Fish can tolerate short episodes of extremely high levels of suspended sediment by exuding a protective mucus on the skin and gills. This mucus traps and continually removes trapped particles but comes at a metabolic cost which places the fish under stress (Committee Restoration Aquatic Ecosystems 1992; Persaud and Jaagumagi 1995). For a direct effect or mortality to occur the levels of suspended solids must be very high and dissolved oxygen relatively low. Excessive levels of silt clog opercular cavities and irritate gills leading to respiratory difficulties and poor health (Phillips 1971). At very high turbidities, sediment-clogged gills cease to function as oxygen exchange sites and the fish dies from a combination of anoxemia and carbon dioxide retention (Ritchie 1972). In a study with green sunfish, Hokel and Pearson (1976) found that ventilation rates increased under highly turbid conditions to compensate for reduced respiratory efficiency while maintaining a constant oxygen uptake.

In most cases, elevated suspended sediments have sublethal effects. These may include increased fin rot and body abrasion (Herbert and Merkens 1961; Ritchie 1972), paler coloration (McLeay et al. 1984), delayed maturation (Reynolds et al. 1988), elevated cough frequency (Servizi and Martens 1992), elevated microhematocrit (packed red blood cell volume), hemoglobin concentration and red blood cell counts (Appleby and Scarratt, 1989; Redding et al. 1987) and decreased tolerance rates and time to death when exposed to other environmental stressors (Appleby and Scarratt 1989; McLeay et al. 1984; Redding et al. 1987).

Sedimentation of Spawning Beds - Perhaps one of the most well known impacts is the sedimentation of fish spawning grounds. Generally, silt which settles on/into spawning substrate prevents successful incubation and hatching of fish eggs requiring a clean surface. Sediment clogs the interstitial spaces in gravel reducing water flow and, hence, oxygen availability to eggs which ultimately causes them to suffocate (Doudoroff 1957; McQuinn et al. 1983; Peters 1965; Ventling-Schwank and Livinstone 1994). Other impacts include a reduction in spawning activity (Saunders and Smith 1965), reduced adhesiveness in sauger eggs (Doan 1941), accumulated toxic metabolites around incubation eggs (McCubbin et al. 1990; Phillips 1971), delayed and/or reduced emergence (Hausle and Coble 1976; Sheppard et al. 1984) and blocked fry emergence (McCubbin et al. 1990; Phillips 1971; Shaw and Maga 1943).

There has been considerable study to quantify these impacts. In an experiment involving white perch and striped bass, Morgan et al. (1983) found increased levels of sediment (> 0.8 mm) slowed egg development and eventually resulted in mortality. Silt deposition of 1 mm per day in two South Dakota lakes was associated with a 97% mortality of pike embryos (Hassler 1970). Increased turbidity and sedimentation has also been found to reduce spawning and incubation success of yellow perch (European Inland Fisheries Advisory Council 1965; Thorpe 1977), pikeperch (European Inland Fisheries Advisory Council 1965) and lake whitefish (Fudge and
Survival to emergence of salmonid eggs relates negatively to the percentage of small fines in redds (Chapman 1988; Phillips 1971; Reiser and White 1988; Shaw and Maga 1943; Shelton and Pollock 1966; Tappel and Bjornn 1983). Bjornn et al. (1977) suggested that when the percentage of fine sediment exceeds 20-30% in spawning riffles, survival and emergence of salmonid embryos begins to decline. Erman and Lignon (1988) recorded that incubating rainbow trout eggs had significantly lower survival rates (30.7% and 41.8% respectively) at sites exposed to silted water than those (61.4%) in clean water. In a South Wales river, 98-100% rainbow trout egg mortality was attributed to heavy siltation. In Bluewater Creek, Montana, Peters (1967) reported that the best (97%) survival of trout eggs occurred where stream discharges were stable and sediment concentrations were low. Langer (1980) reported a reduction in survival of chum salmon eggs at suspended sediment concentrations of 97 mg/l.

Altered Growth Rates - Generally, an increase in suspended solids results in reduced growth rates. This has been documented for Arctic grayling (McLeay et al. 1987), crappies (Buck 1956), coho salmon (Sigler, Bjornn and Everest 1984; Smith and Sykora 1976), rainbow trout (Sigler, Bjornn and Everest 1984), brook trout (Sykora, Smith and Synak 1972), and largemouth bass (Buck 1956).

Concentrations at which reduced growth rates have been documented range from 50 mg/l (Herbert and Richards 1963) to 130 mg/l (Buck 1956).

Production/Abundance - Increasing sedimentation and turbidity suppress fish production. The standing crop of fish in a small southern Ontario stream was reduced from 24 to 10 kg/ha as a result of increased suspended solids associated with highway construction (Barton 1977). In a study of 23 streams in England, there was an average of 2-5 fish/1000 feet of sediment polluted stream compared with 16-27 fish/1000 feet of unpolluted stream (Ritchie 1972). Homer (1956) found that the average weight of fish from clear-water farm ponds was 1.7 times greater than ponds having intermediate turbidity and 5.5 times greater than muddy ponds. In rivers with suspended solid concentrations of 1000-6000 ppm china-clay wastes, brown trout densities were approximately 1/7 of populations in clean (60 ppm) streams (Herbert, Alabaster and Lloyd 1961). A reduction in sand bedload resulted in a 28% increase in brown trout and rainbow trout production (Alexander and Hansen 1983). Alexander and Hansen (1986) also reported that a 4-5 fold increase in sand sediment into Hunt Creek, Michigan, resulted in a significant reduction in brook trout abundance. Reduced standing crops of brook trout have also been associated with siltation in Ellerslie Brook (Saunders and Smith 1965).

Buck (1956) documented the changes in centrarchid production associated with varying turbidities:

- < 25 mg/l (clear) - centrarchid yield 161.5 lb./acre
- 25-100 mg/l - centrarchid yield 94.0 lb./acre
- > 100 mg/l (muddy) - centrarchid yield 29.3 lb./acre

In addition to an actual decrease in productivity, the diversity of fish stocks is also reduced with increasing suspended sediment concentration (European Inland Fisheries Advisory Council 1965; Garrard and Hey 1988). Marcuson (1968) documented changes in the trout:coarse fish ratios in Bluewater Creek, Montana, with decreases in suspended sediment. These shifts result from an alteration in the composition and diversity of the aquatic community to those more tolerant of increased turbidity (often "less desirable" species).
Several effective guidelines and techniques have been developed to reduce or prevent increases in suspended sediments in lakes, rivers and streams. These include vegetated buffers, sediment traps, silt barriers, use of chemicals, flushing and erosion control.

Vegetative Buffers

Vegetative buffers are intended to intercept overland soil run-off before it enters a waterbody as well as stabilize streambanks and shorelines to prevent erosion. The effectiveness of vegetated buffers depends on their width as well as the types of vegetation, soils, slopes and surrounding activities. A range of buffer widths from 3-200 meters has been found to be effective (Castell, Johnson and Conolly 1994). Recommended widths of buffer strips generally range from 15 to 30 meters however (Plamondon 1982; Erman, Newbold and Roby 1977).

Sediment Traps

Sediment traps are usually in the form of man-made ponds or natural wetlands although other structures, such as brush-mulch, has proven to be effective. They have been proven to be very efficient at sediment removal. Mielke (1985) reported that sediment traps were 97% efficient for agricultural run-off. The overall efficiency of a 2.7 acre reservoir was estimated to be 77% (Dendy and Cooper 1984). In Chicago, a small lake was found to be 91-95% efficient in removing suspended sediment from urban run-off. In other situations, wetlands have been demonstrated to serve as extremely efficient sediment traps (McIntyre and Naney 1991).

Instream sediment traps can create deeper pools by increased downcutting, keep spawning areas sediment free and trap/remove almost all sand bedload sediments. In a Michigan trout stream, sediment traps reduced sand bedload sediment by 86% (Alexander and Hansen 1983). The dimensions, especially height:mouth opening, is important in determining particle retention (Hargrave and Burns 1979).

Silt Barriers

Silt barriers or curtains are gaining more popularity as they are relatively inexpensive, durable and easily placed. The Ontario Ministry of Transportation and Communications (1981) reported that a flexible curtain used in their construction projects was 95% effective.

Synthetic Chemicals

Synthetic polymers have been used to reduce turbidity of fish culture station water supplies (Olson et al. 1973).
flushing

flushing by natural or artificial means, can also be successful at removing sediments which have become embedded in the substrate. Above average discharges (more than normal snow melt runoff) is often necessary to dislodge and transport sediment deposited within stream riffles (bjornn et al. 1977; coats et al. 1985). it is important to consider the flows required to remove (flush) material without adversely modifying the size of the existing substrate material (milhous 1982). mechanical cleansing of spawning beds has limited value where sediment pollution is a recurrent problem (carling 1994). scheduled water releases from a reservoir (at a recommended rate of 365 cfs) was successful in sediment removal in the colorado river (eustis and hillen 1954). other mechanical means of removing sediment from the substrate include high pressure fire hoses and mechanical units which suck-up sediments lodged in the substrate and spray removed silt onto the streambank (mih and bailey 1979; meehan 1971).

erosion control

since erosion is undoubtedly one of the single largest sources of sediment inputs to aquatic ecosystems, erosion control techniques should be a priority in all undertakings. there are numerous techniques and best management practices for various activities in this regard. some of these include:

<table>
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<th>activity</th>
<th>erosion control measures</th>
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<tr>
<td>agriculture</td>
<td>o conservation tillage and cropping</td>
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<td>o proper drain maintenance techniques</td>
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<td>o grassed waterways</td>
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<td>o retire fragile lands</td>
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<td>o contour farming practices</td>
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<td>o streambank fencing to restrict livestock access to waterbodies</td>
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<td>o water/sediment control basins</td>
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<td></td>
<td>o grassed/vegetated filter strips</td>
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<td></td>
<td>o use of trees and hedgerows as windbreaks</td>
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<td>o cover crops</td>
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<td>dredging</td>
<td>o timing restriction to avoid sensitive periods</td>
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<td>o use of protective barriers to control suspended materials</td>
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<td>o use of diked or confined disposal areas</td>
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<td></td>
<td>o inland transport or dredge spoils for landfill</td>
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<td></td>
<td>o construction of marshes and spoil islands</td>
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<td>logging activities</td>
<td>o stratify land according to erosion hazard</td>
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<td>o avoid repeated use of same skid trail</td>
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<td></td>
<td>o keep slash and logging debris out of water</td>
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<td>o fell trees away from shoreline (not into water)</td>
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<td>o straw mulch and seed exposed mineral soil</td>
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<td>o plant riparian vegetation</td>
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<td>o restrict log skidding and driving through streams</td>
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<td></td>
<td>o grade slopes to stable angles</td>
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<td>o brush mulch and water bars as sediment traps</td>
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<tr>
<td>Activity</td>
<td>Erosion Control Measures</td>
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| Pipeline stream crossings      | O complete work in shortest time possible  
                               | O construction during the season/time of least disturbance to aquatic biota  
                               | O limit in-stream activities  
                               | O immediately implement post-construction stabilization measures                                                                                                                                 |
| Resuspension of sediments      | O develop/maintain stands of submersed aquatic macrophytes  
                               | O control abundance of some fish species (i.e., carp)  
                               | O control speed and frequency of recreational boating activities                                                                                                                                 |
| Roads and bridges              | O temporary runoff controls such as check dams, flow spreaders, water bars, etc.  
                               | O grading slopes to stable angles (within 100 m of waterbody)  
                               | O vegetate exposed mineral soil  
                               | O remove bridges and culverts after use  
                               | O ongoing road maintenance and repair  
                               | O avoid damaging shoreline banks  
                               | O minimize construction times and activities in/around water  
                               | O redesign/relocate bridges and roads away from sensitive areas  
                               | O sediment barriers such as silt fences, straw bales, brush barriers, etc.                                                                                                                                               |
| Shoreline alterations          | O maintain existing shoreline and aquatic vegetation  
                               | O use clean materials heavy enough to prevent movement by waves  
                               | O avoid disturbing beach, bank and shoreline adjacent to the top of the bank  
                               | O utilize clean washed stone or pea gravel below the high water mark  
                               | O beach construction with sand should only be permitted above the high water mark  
                               | O preferred building materials should be natural or inert substances                                                                                                                                               |
| Stormwater runoff              | O prevent erosion during all phases of contraction and post construction  
                               | O source controls (i.e., street cleaning, etc.) should be employed to minimize sediments in Stormwater  
                               | O use of vegetated buffers  
                               | O control of suspended sediments being discharged  
                               | O maximize on-lot controls to reduce off-lot movement of Stormwater                                                                                                                                               |
| Urban construction             | O limit construction activities in and adjacent to watercourses  
                               | O schedule construction during dry weather periods if possible  
                               | O revegetate denuded areas and bare sites  
                               | O restrict filling activities along shorelands  
                               | O create or retain vegetated buffers and riparian zones  
                               | O align roads and access routes parallel to contours  
                               | ensure all sediment control methods in place before vegetation removal and on-site grading commence  
                               | O maximize on-site filtration  
                               | O divert runoff from denuded areas  
                               | O retain existing vegetation as much as possible and/or establish temporary groundcover  
                               | O time activities to avoid sensitive periods and minimize erosion potential  
                               | O incorporate specialized measures on steep slopes or highly erodible soils                                                                                                                                              |
Activity | **Erosion Control Measures**
---|---
Urban construction (cont'd) | O construct and utilize sediment traps on-site  
O situate soil stockpiles as far away from watercourses as possible  
O all construction vehicles should leave the sites at 1-2 designated points

(E) **Turbidity/Suspended Sediment Water Quality Standards**

Establishing fixed standards or guidelines for turbidity and suspended solids are difficult for several reasons:

(i) there are substantial daily and seasonal variations in suspended solids in most flowing waters;  
(ii) acute effects on aquatic organisms are often difficult to demonstrate;  
(iii) tolerance varies according to the species and life stage of various aquatic biota;  
(iv) impacts to aquatic biota depend, not only on the concentration of suspended materials but also on the duration of exposure and size of materials in suspension;  
(v) impacts differ depending on whether solids remain in suspension or settle to the substrate (standing vs. flowing waters);  
(vi) impacts on fish habitat are strongly influenced by sediment availability and transport dynamics through the system.

Several recommended standards for turbidity and suspended solids have been published:

**European Inland Fisheries Advisory Commission (1965)**

- < 25 mg/l  
  no harmful effects  
- 25-80 mg/l  
  sustain moderate-good fisheries  
  slightly reduced yields  
- 80-400 mg/l  
  unlikely to support good fisheries  
- > 400 mg/l  
  support only poor fisheries

**Ontario Ministry of Environment (1984)**

Suspended matter should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10%.

**Canadian Council Ministers Environment (1994)**

Suspended solids should not exceed 10 mg/l when background suspended solids concentrations are equal to or less than 100 mg/l. Suspended solids should not exceed 10% of background concentrations when background concentrations are greater than 100 mg/l.
25 mg/l - high level of protection required
80 mg/l - moderate level of protection
400 mg/l - required low level of protection
> 400 mg/l - required very low level of protection

The combined effect of color and turbidity should not change the compensation point more than 10% from its seasonally established established norm; nor should such a change place more than 10% of the biomass of photosynthetic organisms below the compensation point.

*Lloyd (1987)*

A water quality standard that permitted an increase of 25 nephelometric turbidity units (NTU) above ambient will provide moderate protection for clear, coldwater streams in Alaska.

**British Columbia Ministry of Environment (Singleton 1985)**

Induced nonfilterable residues should not exceed 10 mg/l when background nonfilterable residue is less than or equal to 100 mg/l, nor should induced nonfilterable residue be more than 10% of background when background is greater than 100 mg/l.

**Manitoba Department of Environment (Williamson 1983)**

Water should be free from materials that produce turbidity in such a degree as to be objectionable or to impair any beneficial use. The maximum acceptable concentration for nonfilterable residue is 25 mg/l.
Annotated Bibliography of Selected Literature


Abstract - In Iowa, the character of the streams has gone through a series of changes, beginning with the first clearing of the hillsides for pasture and the breaking of the prairie sod for corn. Today, the state presents a topography of denuded hillsides, heavily silted valleys, crumbling river banks and shifting channels. The gradual change in the stream environment caused by erosion has brought about a corresponding change in the fish fauna. Where once abounded those types of fish that preferred cold, clear water, today are found forms that are able to live in warm, turbid and often times polluted streams.

Erosion control will improve for fishing a large portion of the state which has little or no fishing territory at this time. Good farming practices are directly correlated with fish management. If soil is saved by mechanical means and crop conserving methods, fisheries will be improved. The wise management and conservation of Iowa soil will be a long step toward bringing about the return of the species of fish which originally flourished in the streams of Iowa.


Abstract - The effect of suspended solids on freshwater fish is illustrated from field and laboratory studies on china clay wastes together with work on the effects of other chemically inert material, wood fibre, ferric hydroxide and oxidizable organic solids and mention is made of work in the marine environment. Tentative
Water quality criteria formulated by the European Inland Fisheries Advisory Commission for inert suspended solids and inland fisheries are outlined and compared with conditions prevailing in rivers in the United Kingdom. Reference is made to current work by the Water Pollution Research Laboratory on the role of organic suspended matter in the presence of soluble poisons and on the effect of hydraulic conditions on the settlement and oxidizability of suspended solids from sewage effluent.


Abstract - Water quality criteria for suspended solids are needed by those who have to manage inland fisheries and must sometimes decide, for example, how much matter could enter a river or lake without undue risk to a fishery or whether it is worth attempting to develop a commercial or recreational fishery in water already containing a known concentration of such materials. There are at least five ways in which an excessive concentration of finely divided solid matter might be harmful to a fishery in a river or lake. These are: (a) by acting directly on the fish swimming in the water in which solids are suspended and either killing them or reducing their growth rate, resistance to disease, etc. (b) by preventing the successful development of fish eggs and larvae, (c) by modifying natural movements and migrations of fish (d) by reducing the abundance of food available to the fish, (e) by affecting the efficiency of methods for catching fish. Some or all of these factors could operate together to harm a fishery.

There is evidence that not all species are equally susceptible to suspended solids and that not all kinds of solids are equally harmful. Unfortunately there is very little information on these and many other aspects of the problem and much of the evidence which does exist is less firmly established than is desirable. It has therefore been concluded that definite water quality criteria which distinguish between the many different kinds of finely divided solids to which different sorts of inland fisheries may be subjected cannot yet be proposed. Nevertheless, when the evidence is considered as a whole, certain general conclusions can be drawn.

There is probably no sharply defined concentration of solid above which fisheries are damaged and below which they are quite unharmed. It appears that any increase in the normally prevailing concentration of suspended matter above quite a low level may cause some decline in the status and value of freshwater fishery and that the risk of damage increases with the concentration. Although there is not enough evidence to allow the relation between solids concentration and risk of damage to be defined at all precisely, the degree of risk to fisheries may be divided into four arbitrarily defined categories and that rough estimates may be made of the ranges of concentration to which they would generally correspond. From the approach to the problem the following tentative criteria are presented. With respect to chemically inert solids and to waters which are otherwise satisfactory for the maintenance of freshwater fisheries:

(a) There is no evidence that concentrations of suspended solids less than 25 mg/l have any harmful effects on fisheries.

(b) It should usually be possible to maintain good or moderate fisheries in waters which normally contain 25-80 mg/l suspended solids. Other factors being equal, however, the yield of fish from such waters might be somewhat lower than from those in category (a).

(c) Waters normally containing from 80-400 mg/l suspended solids are unlikely to support good freshwater fisheries although fisheries may sometimes be found at the lower concentrations within this range.

(d) At the best, only poor fisheries are likely to be found in waters which normally contain more than 400 mg/l suspended solids.
In addition, although concentrations of several thousand mg/l solids may not kill fish during several hours or days exposure, such temporary high concentrations should be prevented in rivers where good fisheries are to be maintained. The spawning grounds of salmon and trout require special consideration and should be kept as free as possible from finely divided solids.


Abstract - A review of the effects of sedimentation on aquatic biota is presented. The detrimental effects of increased suspended and settled sediments on fish, bottom invertebrates and primary productivity are documented. It is shown that the upper tolerance level for suspended sediment is between 80-100 mg/l for fish and as low as 10-15 mg/l for bottom invertebrates. Recovery of the aquatic biota from increased sedimentation is dependent on the severity of sediment additions and the discharge level of the rivers or streams. Recovery from short term additions of sediment is usually complete within one year.


Abstract - This is the second of a two part sedimentation study. A sediment basin excavated in a Michigan trout stream reduced the sandy bedload sediment by 86% (from 56 ppm down to 8 ppm). Following the reduction in bedload, trout number increased significantly during the next 6 years. Small or young trout increased about 40% throughout the treated area. Larger and older trout increased in that part of the treated area that had an erodible sand bed. Although trout production increased 28%, growth rate of the trout changed but little. Both brown trout, Salmo trutta, and rainbow trout, Salmo gairdneri, populations responded similarly to the bedload reduction. However, statistical tests were more conclusive for brown trout than for rainbow trout because of the lower year to year variation of the brown trout populations. The results suggested that in-stream sediment basins are an effective means for removing sand bedload and that even small amounts of moving sand bedload sediments can have a major impact on a trout population.

Abstract - An experimental introduction of sand sediment into Hunt Creek in the northern Lower Peninsula of Michigan that increased the bed load 4-5 times resulted in a significant reduction of brook trout, Salvelinus fontinalis, numbers and habitat. The brook trout population declined to less than half its normal abundance. The growth rate of individual fish was not affected. Population adjustment to the poorer habitat was via a decrease in brook trout survival rates, particularly in the egg to fry and/or fry to fall fingerling stages of their life cycle. Habitat for brook trout and their food organisms became much poorer as judged by the drastic reductions of both. Stream morphology changed considerably, the channel becoming wider and shallower. Furthermore, sand deposition aggraded the streambed and eliminated most pools. The channel became a continuous run rather than a series of pools and riffles. Water velocities increased as did summer water temperatures. Relatively small sand bed load concentrations of only 80 ppm had a profound effect on brook trout and their habitat.


Abstract - An experimental introduction of sand sediment into Hunt Creek in the northern Lower Peninsula of Michigan that increased the bed load four to five times resulted in a significant reduction of brook trout, Salvelinus fontinalis, numbers and loss of habitat. The brook trout population declined to less than half its normal abundance. After the experimental treatment was stopped the stream was allowed to cleanse itself of sand naturally for a 5 year period, followed by another 5 year period when sediment basins were constructed to accelerate sand clean out. The gross channel morphometry, bed type, water velocities and trout cover recovered in about 6 years. However, to date, some sand is still in deposition along the stream edge and within gravel riffles and still adversely effects trout spawning, nursery habitat and production of invertebrate trout foods. Little improvement in the numbers of young-of-the-year brook trout has occurred 10 years after experimental sand additions were discontinued. In spite of this reduced recruitment the population of older brook trout has nearly completely recovered. This has come about through increased survival of age 1 and older trout presumably because the habitat has been restored for these larger fish. The growth rate of individual trout showed little change over the course of the study. The decline in habitat quality induced by increased sand bed load caused a decrease in brook trout survival rates which reduced trout numbers. When there was less food, there were fewer fish. thus, daily ration and growth did not change substantially. When sand bed load was reduced and habitat improved there were increases in trout survival, trout numbers and food abundance but little change in trout growth. This study has demonstrated that a relatively small sand bed load concentration of only 80 ppm had a profound negative effect on brook trout and their habitat. Moreover, it demonstrates that reduction of bed load can improve trout populations and trout habitat considerably. However, full recovery from the effects of elevated sand bed load levels will take a long time in low gradient streams with relatively stable flow regimes.


Abstract - A runoff and sedimentation research program was initiated in 1957 in the Northern Great Plains. Established at Newell, South Dakota, the project involves 16 grassland watershed ranging in size from 30 to 13,000 acres. Data collected during a 3.5 year period show more than three times as much runoff from the fine-textured soils as from the medium-textured soils of the rangeland. Also, dissipation of stored water by evaporation, percolation and seepage from reservoirs may be quite significant.

The data on water and sediment yield that are being obtained are applicable in western South Dakota, southwestern North Dakota, northeastern Wyoming and central and eastern Montana. this part of the Northern Great Plains comprises about 104 million acres.


Abstract - The surface reaeration of uniform streams, with and without sediments in suspension, has been studied in the laboratory.

Based on the premise that the reaeration rate is controlled by an effective vertical diffusivity at the free surface and by turbulent mixing beneath it, an equation was developed to predict the reaeration rate of uniform clear water flows. The laboratory data gave support to the developed equation.

This equation was then modified in order to account for the effect of suspended sediments on the surface reaeration of uniform sediment laden streams. The new equation was substantiated by the experimental results, which indicate that the reaeration rate decreases as the average sediment concentration increases. The decrease was attributed to the dynamic influence of the suspended particles on the turbulent flow field.


Abstract - Forest management activities in a second order drainage stream increased suspended sediment yields 7.7 fold in the first year following road construction and two-fold following logging in the next year. Sediment supply limitation resulted in poor correlation between sediment concentrations with discharge. Sediment transport was strongly hysteretic with the highest sediment concentrations occurring on the rising limbs of snowmelt hydrographs and individual peaks. In addition to discharge, hydrograph characteristics such as limb, dQ/dt, and the product of dQ/dt and limb aided in assigning variability of observed sediment concentrations. Sediment-turbidity relationships were strongly discharge dependent, reflecting the changing composition of the suspended load with stream power and sediment supplies.


Abstract - Timber harvesting and its associated roads can, have, and still do cause serious erosion and sedimentation. The amount of damage on site in local streams and downstream varies widely with topography, climate, soils and the amount of soil disturbance which depends on such things as care in logging, intensity of cut and the equipment used. In some steep fragile areas conventional logging may not be possible without intolerable damage. For many of these reasons, the effect of timber harvesting on erosion, including its effect on water quality, is generally a greater problem in much of the west than it is in the east.


Abstract - Structures made in the late 1930s helped boat access for sport fishing. Shoreline erosion continues on Crean and Waskesiu lakes and a loss of sand beaches has been noted due to high water levels. Spawning habitat for lake trout has been impaired by siltation related to dams and water level regulation.


ANONYMOUS. 1979. Impacts of sediment and nutrients on biota in surface waters of the United States. Technical Publication PB80-129588, Environmental Research Laboratory, Georgia University, Athens, Georgia.


Abstract - Changes in or adjustments of a stream channel without protection of the stream geometry can affect fish life. Stream channels are in delicate balance with their sediment loads and water discharges. Construction activities, including stream improvement, within a watershed, particularly those which encroach directly on a stream channel, must be based on a knowledge of stream behavior and sedimentation in unanticipated, detrimental changes in the shape and location of the channel are to be avoided. Valuable guidance regarding the effect of stream improvement designs may be derived from studying existing installations and correlating the circumstances involved with those is situations under consideration.

Abstract - Literature concerning the lethal and sublethal effects of suspended solids on marine and estuarine fish and shellfish is reviewed with reference to ocean and coastal zone dredging and dumping where applicable.

Experiments indicate that many species of adult fish and shellfish survive in concentrations of suspended solids far greater than those commonly observed in nature. Eggs and larvae are less tolerant to suspended solids than are adults and larvae are more sensitive than eggs. Tolerance varies between species and between particle type. Particles in the larger size range or having the greater angularity have been shown to be more lethal than smaller or smoother particles.

Histological and hematological evidence of suspended sediment damage to fish and shellfish is explored and some mechanisms by which such effects are realized are outlined. Observations pertaining to behavior, feeding, growth, fishing success and habitat alteration are included. Several conclusions regarding current ocean dumping and dredging practices are presented.


Abstract - Reservoirs built on rivers draining agricultural watersheds are often turbid with suspended sediments. Filter-feeding zooplankton i.e., members of the genus Daphnia, seem to be as abundant in such reservoirs as in natural lakes. Using controlled laboratory conditions, we have investigated the potential role of suspended sediments in the nutrition of Daphnia from a turbid reservoir. In three sets of experimental procedures we measured: (1) the physical effect of sediments on the ingestion and incorporation rates of algae by daphnids, (2) the ingestion rates of two sizes of clay mineral sediment particles by daphnids, and (3) the growth and survival of daphnids fed yeast and sediments with and without organic matter adsorbed onto the particle surfaces.

Increases in suspended sediment concentration from 0.0 to 2451 mg/l decreased ingestion rates of C14 labeled Chlorella vulgaris by Daphnia parvula and D. pulex by approximately 95% and decreased incorporation rates by 99%. Sediment concentrations of 50-100 mg/l reduced the algal carbon ingested by daphnids to potential starvation levels. Zn65 labeled fine and coarse (1.88 and 4.65 um mean diameter) clay mineral sediment particles were fed to D. parvula, D. pulex and D. similis. Ingestion rates of sediments by daphnids were limited at particle concentrations of 5.0 x 106 particles/ml and were dependent on particle size, daphnid species and body size. Fine particles were ingested at greater rates by D. pulex and D. parvula than were coarse particles, while D. similis ingested coarse and fine particles at similar rates. In addition, D. pulex had higher ingestion rates in each particle size suspension than did D. parvula or D. similis. The differential ability to ingest these particles suggests a mechanism of regulating daphnid species composition if the organic matter adsorbed to these sediment particles is useful as food. To evaluate this mechanism, we adsorbed dissolved organic protein to sediment particles. When D. pulex were fed the
amended sediment suspension, they grew larger than when fed control sediments, but not as large as when fed yeast. D. parvula grew equally well when fed either yeast or amended sediments. Thus, dissolved organic matter can be made available for daphnid growth by the mechanism of adsorption.


Abstract - Present knowledge regarding associations between sediment and riverine habitats is summarized. Physical processes govern aquatic habitat quality and development. Within limits, engineering approaches can be used to evaluate and predict aquatic habitat conditions. Stream reaches and the habitats they provide may be categorized by dominant bed material type: boulder-cobble, cobble-gravel, sand or fine bed. As the grain size distribution of the bed load approaches that of the bed material, the number of benthic species declines. Sediments provide cover and spawning sites for fish and habitat for fish food organisms. Sediment also serves as an indirect indicator of fish habitat quality when it provides a temporal integration of depth and velocity. Major environmental issues associated with sediment transport in rivers include transport of organic sediments, sediment-water quality interactions, deposition of sediments finer than gravel on and within coarser deposits and filling of low velocity areas contiguous to major river channels. Most stream organisms can withstand short term exposure to elevated levels of suspended sediment but chronic exposure is more detrimental.

AULD, A. H. AND J. R. SCHUBEL. 1974. Effects of suspended sediment on fish eggs and larvae. Special Report 40, Reference 74-12, Chesapeake Bay Institute, Johns Hopkins University, Baltimore, Maryland.


Abstract - Eggs and larvae of six species of anadromous and estuarine fish indigenous to the Chesapeake Bay were exposed to concentrations of suspended sediment ranging from a few mg/l to 1000 mg/l to determine the effects of different concentrations on hatching success and short term survival. The egg experiments indicated that concentrations of up to 1000 mg/l did not significantly affect the hatching success of yellow perch, blueback herring, alewife or American shad eggs. Concentrations of 1000 mg/l significantly reduced (P < 0.05) the hatching success of white perch and striped bass but lower concentrations did not.

Experiments with larvae indicated that concentrations of > 500 mg/l significantly reduced (P < 0.05) the survival of striped bass and yellow perch larvae exposed for 48-96 hours. American shad larvae appeared to be less tolerant than the other two species tested. Concentrations > 100 mg/l significantly reduced the survival of shad larvae continuously exposed for 96 hours.

The significance of these results are discussed relative to natural and man-induced changes in sediment loading of estuaries.


Abstract - Two pairs of comparable turbid ponds were selected to test the practicability of algal-clay coagulation as a means of clarifying turbid ponds. One pond of each pair was fertilized with nitrogen and phosphorus; the other was left as an unfertilized control. Algal growth was induced in both fertilized ponds, leading to a significant reduction of turbidity. The sedimentation of the algal-clay clusters removed clay, algae and nutrients from the water column. The addition of fertilizer seems to be an efficient and economical means to clarify turbid ponds.


BACHMANN, R. W. 1980. The role of agricultural sediments and chemicals in eutrophication. J. Water Pollution Control Federation, 52: 2425-2432.


Abstract - Buffer zones have been gaining popularity as a method of protecting the stream ecosystem from the increased sediment deposition (due to accelerated soil erosion) which frequently follows forest
harvest operations. The development of criteria for buffer zone designs is traced in the relevant forestry literature and current recommendations are found to originate from a surprisingly small database that developed in the 1950s and 1960s.

The recommendations and criteria for buffer zones appearing in the silvicultural water quality management plans of eight southern states and the U.S. Forest Service are reviewed. Guidelines range from vague references in some plans to explicit criteria pertaining to buffer zone prescriptions in others.

The effectiveness of three different buffer zone configurations in precluding sediment delivery to forest streams was tested utilizing four first order drainage basins located on the Hill Demonstration Forest, Durham County, North Carolina. No differences in buffer zone effectiveness were detected.

Pretreatment data were insufficient due to poor sampling techniques. Variations in the sediment concentrations of the treatment watershed can best be explained by pool logging practices, the inherent variability of small forested watershed and the accelerated decomposition of the forest floor immediately adjacent to stream banks.


Abstract - A buffer strip can perform a multitude of functions and these include channel stability, a filter for sediment and nutrients, water purification (i.e., bacteria and pathogens), a nondisturbance area and the provision of terrestrial and stream habitat. These functions are reviewed with specific application to Australian conditions and methods for modeling their performance are outlined. The primary focus is on the use of buffer strips to minimize waterway pollution from diffuse sources since their use is often justified on this basis. Particular attention is given to the conditions under which a buffer strip will act as an effective filter and the conditions under which it will fail. Buffer strips are most effective when the flow is shallow (non-submerged), slow and enters the buffer strip uniformly along its length. Their sediment trapping performance decreases as the sediment particle size decreases. Nutrients are often preferentially attached to fine sediment. As a result, buffer strips should only be considered as a secondary conservation practice after controlling the generation of pollutants at their source and, to be effective, buffer strips should always be carefully designed, installed and maintained.


Abstract - A limnological investigation was carried out to document the effects of constructing a modern highway across a small stream in southern Ontario. During construction, suspended solids increased to as high as 1390 mg/l but later returned to pre-construction levels of < 5 mg/l. Similarly,
increased ten-fold to 0.61 gm dry weight/square cm/day directly below the construction site during stream rechannelization after completion of the culvert. Decreased proportion of organic matter in sediments indicated that they came from the construction site. Sediments were readily removed by spates and apparently settled out in downstream ponds. There was no change in water chemistry. Standing crop of fish was reduced from 24 to 10 kg/ha immediately below the site. This decrease did not occur further downstream and fish populations at the affected site returned to original levels after construction. No change in numbers of riffle macroinvertebrates was observed during or after construction. However, there was a noticeable shift in species composition. Invertebrates present during construction activities may have remained in sheltered areas avoiding sedimentation effects. Evidence from invertebrate sampling in denuded areas around the site strongly suggests that organisms which may have been removed during construction were replaced quickly by drift.


Abstract - The relationships between riparian land use and environmental parameters that define the suitability of southern Ontario streams for trout were examined for 40 sites on 38 streams. Weekly observations of maximum and minimum temperature, coarse and fine suspended matter and discharge were made during June, July and August, 1980. Land use was determined from aerial photographs of each stream. Fish were surveyed at each site during August by electrofishing and seining.

The only environmental variable which clearly distinguished between trout and non-trout streams was weekly maximum water temperature: streams with trimean weekly maxima less than 22°C had trout; warmer streams had, at best, only marginal trout populations. Trout streams tended to have low concentrations of fine suspended solids and a more stable discharge but so did many of the other streams. Water temperature, concentration of fine particulate matter and variability of discharge were inversely related to the fraction of the upstream banks covered by forest. Fifty-six percent of the observed variation in weekly maximum water temperature could be explained by the fraction of bank forested within 2.5 kilometers upstream of a site. Other land uses were not clearly related to stream variables except that high concentrations of fine suspended solids were most often observed in reaches used as pasture.

Analysis of data from sites located within buffer strips yielded a regression relating maximum weekly temperatures to buffer strip length and width. The regression accounted for 90% of the observed variation in water temperature for these sites. The model was verified further by comparisons with observed temperatures at a second set of sites located downstream from buffer strips.


Abstract - This paper reviews sedimentation and downstream effects of dams and impoundments. Biological aspects such as changes in benthos, plankton and fish are discussed.


Abstract - The comparative effects of mechanical and chemical site preparation on water yields and sediment losses following clearcutting were evaluated over a 4 year period in the Athens Plateau area of southwestern Arkansas. After one year of pretreatment measurements, three forested watersheds were clearcut and the residual vegetation and debris were sheared and windrowed but not burned. Three watersheds were clearcut in a similar manner but received chemical site preparation. Residual trees on two watersheds were injected with 2,4-D amine; the third watershed was aerially sprayed with a mixture of Tordon (active ingredient picloram) and Garlon (active ingredient triclopyr). Three additional watersheds were left undisturbed for controls. Mean annual sediment losses on the mechanically site prepared watersheds during the first post treatment year were significantly higher than those from either the chemically site prepared watersheds on controls. Chemical site preparation did not significantly increase sediment losses. Although second year losses for the mechanical site preparation and control treatments doubled over first year levels, no significant treatment effect was detected for either site preparation treatment. Third year losses decreased below first year losses for all treatments but not to pretreatment year levels. The relatively sharp declines in sediment losses during the third post-treatment year were attributed to rapid regrowth of natural vegetation on the sites.


Abstract - The transport of stream bedload sediment was monitored continuously in small stream from 1975 to 1982 following forest fires in 1974 and 1980. The stream is located in the east subcatchment (170 ha) of Lake 239 it the Experimental Lakes Area, northwestern Ontario. Precipitation, stream discharge, bedload transport and concentration of suspended materials were measured quantitatively and organic debris was observed and collected. Bedload transport increased 20-fold following the first fire and threefold after the second. Particle sizes tended to increase during the period of study. Bedload data suggest a recovery period of 5-6 years following the first fire and a shorter one following the second. A mass budget of material load transported in a single year following recovery indicated a dominance of dissolved load (87%) followed by suspended load (10%) and bedload (3%).


Abstract - Lack of research data on potential sedimentation has hindered watershed development. Sedimentation threatens the designed lifetime of watershed reservoirs. The magnitude of this threat is emphasized in this article.


Abstract - The respiratory movements are an important aid in the diagnosis of fish disease and in differentiating the reaction of fish to a toxic environment. Pathologic changes in respiratory activity may be produced by disease or by changes in the environment which tend to render existence impossible. The environment affects respiratory movements by a reduction in the dissolved oxygen and by the presence of toxic substances. Impurities of a technical nature, such as sand, clay, fine gravel, cellulose, fibers and other waste material, have no appreciable effect although fish may avoid such waters. Indirectly, fish are affected by the destruction of their spawning and feeding grounds. The mere presence of large quantities of sediment does not interfere with respiration unless some active chemical stimulant produces an excessive secretion of mucus from the cells of the gill filaments. In this manner, a chemical insufficient to affect fish directly may, in the presence of mechanical pollution, cause clogging of the gills and ultimately death of the fish.


Abstract - More than 200 sediment trap samples have been collected throughout Lake Michigan during the period of 1978 through 1983. These traps passively collect the particulate matter settling out of the water column. In this report we present a summary of our results to date, including (1) four years of mass flux data at a station 35 km off Grand Haven, Michigan which indicates the year-to-year variation in fluxes are small, (2) comparison of mass fluxes during the period of stratification and the isothermal period which show large amounts of winter resuspension and (3) the large spatial variations in mass flux throughout the lake.


Abstract - Many aspects of the transport of sediment by rivers have been elucidated in the past few decades and the subject is still under active research. Nearly all of this work relates to open water conditions. Once the bed shear stress exceeds a threshold value, the bed load is the amount of bed material being transported per unit time in close proximity to the bed. It is strongly dependent on the bed shear stress as well as on sediment and fluid properties. The suspended load is material that is transported mostly in suspension with only infrequent contact with the bed. Vertical diffusivity and flow velocity are important factors in determining the suspended load in addition to bed shear and sediment/fluid properties.
For the same discharge, the presence of an ice cover generally reduces the sediment "driving" parameters (shear stress, velocity, diffusivity), so the sediment transporting capacity should be significantly reduced. More experimental data are needed, however, both in the laboratory and in the field to define fully the effect of an ice cover.

The preceding considerations apply to relatively coarse sediments that are not subject to formation of cohesive bonds and consequent flocculation. Relatively little is known about the behavior of fine cohesive sediments (< 62 μm) in open water flow. A major environmental effect of fine sediments is their strong adsorptive tendency so that the fate of many aquatic contaminants is governed by the transport, erosion and deposition of fine particles.

Sediment can also become entrained into an ice cover. This results from frazil entrapment of individual sand and gravel particles, from anchor ice releasing off the substrate and carrying material into the surface ice cover, or from the ice cover freezing into the bed with subsequent dislodgement of ice and bed material by river-stage rises.

The disruptive effects that moving river ice may have on in situ sediment structure have not been addressed. Such ice shove could reduce sediment strength, which could lead to unstable sediments and slumping or to bank sediments with greater susceptibility to subsequent erosion by other processes.


Abstract - For three decades, state efforts focused solely on sediment problems in rural areas. Then, in the fourth decade, a new culprit on the Maryland sediment control scene - urban development - resulted in the Attorney General's office declaring sediment a pollutant on July 31, 1961. That ruling stated that silt discharged into the water of the state resulting from stormwater runoff over land area exposed from land clearing or development operations was legally subject to regulatory control by state agency.

During the 1970s, Maryland's sediment control activities consisted of three general phases: an orientation phase, a shakedown phase, and an operational phase. Not until 1981, however, did sediment control receive any real emphasis.

Three deficiencies appeared to be at the root of most inadequate programs: lack of administrative commitment to the program, inadequate field inspection and an inadequate enforcement process. Many local jurisdictions failed to commit themselves to developing an effective erosion and sediment control program for several reasons.


Abstract - The territorial, gill-flaring and feeding behavior of juvenile coho salmon, Oncorhynchus kisutch, in a laboratory stream was disrupted by short term exposure to suspended sediment pulses. At the higher turbidities tested (30 and 60 nephelometric turbidity units (NTU)), dominance hierarchies broke down, territories were not defended and gill flaring occurred more frequently. Only after return to lower turbidities (0-20 NTU) was social organization re-established. The reaction distance of the fish to adult brine shrimp decreased significantly in turbid water (30 and 60 NTU) as did capture success per strike and the percentage of prey ingested. Implications of these behavioral modifications suggest that the fitness of salmonid populations exposed to short term pulses of suspended sediment may be impaired.


Abstract - The effect of siltation on stream fish in northeast Missouri was evaluated using community structural measurements and a functional approach that emphasized feeding and reproductive guilds. As the percentage of fine substrate increased, the distinction among riffle, run and pool communities decreased, primarily because the number of individuals of typical riffle species decreased. Within the riffle communities the abundance of fish of two feeding guilds - benthic insectivores and herbivores - was reduced as the percent of fine substrate increased. The abundance of fish in other feeding guilds was not affected. The only reproductive guild to be similarly affected was the simple and lithophilous, whose members require a clean gravel substrate for spawning. Species within each guild affected by siltation had significantly similar trends in abundance. The guild analysis indicated that species with similar ecological requirements had a common response to habitat degradation by siltation.


Abstract - Suspended sediment production after road construction, logging and slash disposal was significantly increased (p=0.95) on two watersheds in Oregon's Coast Range. A 25% patch cut watershed showed increases during 3 of 8 post-treatment years. These increases were caused primarily by mass soil erosion from roads. Monthly sediment concentrations before the occurrence of the annual peak flow were increased more than those following the annual peak. Surface erosion from a severe slash burn was the primary cause of increased sediment yields for post-treatment years on a watershed that was 82% clearcut.
Monthly sediment concentrations were generally increased throughout the winter runoff period on this watershed. The flushing of suspended sediment in Oregon Coast Range watersheds is apparent from seasonal changes of suspended sediment rating curves.


Abstract - A rectangular flume was used to study variables affecting the intrusion of fine sands into a stable gravel streambed. The amount of intrusion by sand (median particle diameter 0.5 mm) was determined under varied conditions of discharge, depth, velocity, flume slope and rates of sediment transport. During all experimental tests, sand particles were trapped in voids within the upper 10 cm of an initially clean gravel bed (median particle diameter 15 mm), forming a barrier to further intrusion. An analysis of flow variables showed that flow conditions, as indexed by Froude number, significantly (90% confidence level) affected intrusion amounts, possibly by influencing the rate and depth of formation of the sand seal. Intrusion amounts, expressed as a percent of total volume, varied from 2 to 8%. Two replications used a finer grade sand (median particle diameter 0.2 mm) that intruded more and, in one case, completely filled the gravel pore space (25% by volume) further indicating that particle size, and not hydraulic variables, may have a more important influence on the total amount of intrusion.


Abstract - Erosion and sedimentation are natural processes that cannot be stopped or eliminated entirely. Both processes have been accelerated by human intervention such as lateration of stream courses, construction of dams, changes in flow regime, constriction on and alterations of floodplains and drastic changes in land use patterns. Consequently, erosion and sedimentation have a significant impact on the Illinois River, including its backwater and bottomland lakes. According to the Illinois State Water Plan Task Force report published in 1984, erosion and sedimentation is the major critical issue in water resources facing the State of Illinois. The Illinois River basin, which drains about 44% of the State obviously contributes significantly to this water resources problem.

Recent research on erosion and sedimentation in the Illinois River has shown that about 13.8 million tons of sediment is delivered to the Illinois River valley annually. Our of this total sediment, 8.2 million tons are trapped in the valley and the remainder is delivered to the Mississippi River. Most backwater lakes along the Illinois River have lost about 72% of their original capacity and sediment has already filled in some of these lakes. This excessive rate of sedimentation had reduced the ecological and recreational value of most lakes along the river making sedimentation the most difficult and still unmanaged problem facing the Illinois River valley. Research recently conducted by the Illinois State Water Survey has also shown that the Peoria and LaGrange Pools are the two major pools in which most of the sediments are produced and deposited. These are also the major areas in which most of the backwater lakes are located. The river changes significantly to a flatter gradient within Peoria and LaGrange Pools, forcing the deposition of sediments at a much higher rate. By 1985, Peoria Lake had lost about 68% of its original capacity. The U.S. Corps of Engineers has been dredging the Illinois River at several locations to maintain adequate navigation depth with the Alton Pool requiring the most dredging.

The management of soil erosion and sedimentation in the Illinois River basin will be one of the major environmental issues in Illinois for years to come. Consequently, a comprehensive management plan needs to include two major components: erosion control and sediment management. The erosion control component includes developing programs to control watershed erosion, streambank erosion and bluff erosion. The sediment management component will have to deal with four major issues: backwater sedimentation, main channel sedimentation, sediment removal at selected reaches and sediment quality.


Abstract - A study was conducted on Bluewater Creek during April, May and June 1962 to determine the effects of various amounts of suspended sediment on egg survival of rainbow trout and cutthroat trout. Water temperature, stream discharge and suspended sediment data were collected. A particle size analysis of the original material placed in the redds was compared with materials removed after the egg incubation periods. The apparent velocity and dissolved oxygen concentration of the ground water within the redds were determined by means of a Mark VI groundwater standpipe. When sediment settled into a redd the permeability of the gravel and consequently the apparent velocity of the groundwater was decreased. A total of 60 or more tons of suspended sediment passed the redds before apparent velocity showed a perceptible decrease. Apparent velocity decreased as the total suspended sediment load increased beyond this level. Redds exposed to 290 or more tons of suspended sediment had the highest egg mortality. Redds with the lowest suspended sediment load, highest apparent velocity and highest dissolved oxygen concentration had the highest egg survival. Multiple regression analysis of the results whose apparent velocity, dissolved oxygen, suspended sediment load and stream discharge were the important factors determining rainbow and cutthroat trout egg survival.

**Abstract** - This study examined the input of sediment from a gravel-surfaced road to a small western Washington stream to determine to what extent this material deposited on the streambed or intruded into the gravels used by salmonids for spawning. Sediment deposition occurred only during periods of low flow and was flushed from the system with even modest increases in stream discharge. There was no significant difference in the level of fine sediment (< 2 mm) in gravels above and below the input point. The predominant reason for the lack of deposition or intrusion of this material was the small size of the road sediment, 80 percent, by weight, being finer than 0.004 mm. Less than 10 percent of the fine sediment in the streambed was finer than 0.063 mm. The size of the material delivered to the stream was likely limited by the gentle gradient of and vegetation in the roadside ditches.


**Abstract** - Some water quality standards established by the states permit only minor increases in suspended sediment when background turbidity is low, allow greater absolute increases as background levels rise and do not consider acclimation of stream biota to high turbidity. Juvenile coho salmon, *Oncorhynchus kisutch*, were subjected to experimentally elevated concentrations of suspended sediment and did not avoid moderate turbidity increases when background levels were low, but exhibited avoidance when turbidity exceeded a threshold that was relatively high (> 70 NTU) and was varied according to previous suspended sediment exposure.


**Abstract** - A team of investigators from the disciplines of engineering, entomology and fisheries cooperated in a study to assess the temporal and spatial impact of decomposed granite bedload sediment on insect and fish populations and on the capability of mountain streams in the Idaho batholith to transport this sediment. This investigation was designed to provide information for resource managers who formulate watershed management guidelines for streams of the Idaho batholith and other areas with granitic baserock.

Three approaches were used in the study:

1. **Correlation surveys** - We surveyed natural streams in the Idaho batholith to correlate the amount of sediment in the substrate with sediment movement, standing crop of insects, numbers of drifting insects and the distribution and abundance of juvenile chinook salmon, *Oncorhynchus tshawytscha*, and steelhead trout, *Salmo gairdneri*.

2. **Experimental channels** - We constructed artificial channels and controlled variables to test experimentally the effects of various levels of riffle sedimentation on the distribution and abundance of insect and fish populations.
Addition of sediment to natural streams - We added sediment to both riffles and pools in a study stream during the summer low flow to assess the effects of large amounts of sediment on fish and insects in a stream with small amounts of naturally occurring sediment already present. We assessed physical characteristics of the stream and monitored changes in the fish and insect populations before, immediately after and three weeks subsequent to the sediment additions. Both test and control sections were studied.

Data collected from stream surveys, channel experiments and sediment addition to a natural stream indicated that juvenile chinook salmon and steelhead trout were not adversely affected during the summer when there was a large amount of sediment in the riffles. Insect densities (drift and benthos) were smaller in riffles of natural streams with large amounts of sediment, but decreased densities of insects were not reflected in population densities or size of the fish.

Reduction of pool area or volume with sediment in small streams will likely result in reduction in summer capacity of a stream for fish proportional to the percentage of pool area or volume lost.

In our tests with fully sedimented riffles during the winter, fewer age-0 steelhead trout and chinook salmon remained in the channels with sediment than in the ones without sediment because these fish normally entered the crevices in the substrate during the winter and were not able to do so in sedimented riffles. Larger juveniles resided in pools during the winter and were not affected by sediment in the riffles.

Insect abundance was not decreased by adding sediment to riffles in the test channels or by adding sediment to a short section of a natural stream. Insect species diversity decreased temporarily in both test channels and the natural stream after sedimentation of riffles but there was no measurable effect on the density of benthic or drifting insects one or more days after sedimentation.

Based on the physical characteristics of the streams we studied and a review of bedload discharge formulas, we concluded that the Meyer-Peter-Muller formula appears most applicable to estimate sediment transport capabilities of streams which flow through broad mountain valleys in the Idaho batholith. Additional data is needed, however, to thoroughly test this conclusion. Sediment transport was negligible in the streams we studied during the summer low flow period.

These studies are being continued to verify some of the findings and include more streams in our studies.


Abstract - in the experimental portions of our studies we found that excessive amounts of coarse sand and smaller sediments can (1) affect the aquatic insect populations when deposited in riffles; (2) reduce the summer rearing capacity of streams when deposited in pools; and (3) reduce the winter fish capacity of streams when deposited in the larger interstitial spaces of stream substrate. In earlier studies it has been demonstrated that survival and emergence of salmon and steelhead trout embryos were reduced by excessive amounts of fine sediment in spawning riffles. We were unable to consistently correlate insect abundance to riffle sedimentation or fish abundance to either of the above variables in the natural streams, but less than full seeding of the rearing areas with salmon fry may have been a reason for the lack of consistent results.

Survival and emergence of salmon and trout embryos in spawning riffles may not limit the abundance of these fish in batholith streams, except in years with small spawning escapements. Summer rearing or
winter holding habitat in the stream may be more important than embryo survival in regulating fish abundance in most years.

If we come back to the question "How much sediment (coarse sand and smaller) is too much?" we find that when the percentage of fine sediment exceeds 20 to 30 percent in spawning riffles, survival and emergence of salmonid embryos begins to decline. When riffles are fully imbedded with fine sediment, insect species composition, if not abundance, changes. The abundance of juvenile salmon in pools of small rearing streams declines in almost direct proportion to the amount of pool area or volume lost to fine sediment deposited in the pool. The number of juvenile salmon and trout a stream can support in winter is much reduced when the interstices in the stream substrate are filled with fine sediment.

To avoid seriously reducing the salmonid production capacity of a batholith stream, fine sediment should not be allowed to fill in the pools or to fully imbed the larger substrate rocks. In years with small spawning escapements, spawning riffles should not have large amounts of fine sediment or the rearing areas will not be fully seeded with fry.

Since it is not practical to determine the sediment budget (input minus deposition + pickup = output) for each stream, we advocate using the percentage of fine sediment in selected riffle areas as the primary index for monitoring the deposition of fine sediment in streams and for determining when too much deposition is occurring in Idaho batholith streams. Monitoring the percentage of fine sediment in riffles is, admittedly, an after the fact measurement as far as the riffles are concerned, but may give advance warning of excessive fine sediment inputs that will fill pools and substrate interstices. At the least, if sample sites are properly located, the riffle sedimentation index can be used to help locate sources of excessive amounts of fine sediment.

Our rationale for using the percentage of fine sediment in selected riffles as the primary index for monitoring the "sediment health" of a stream is based on several considerations. The determination of a sediment budget for most streams would not be practical. The measurement of bedload sediment transport during peak discharge is difficult in most streams. Annual accurate measurement of sediment transported throughout the year would be costly. Turbidity of the stream has been used as an index of total sediment transport in some streams but is indirectly and perhaps poorly related to the deposition of coarse sand and smaller sediments in Idaho batholith streams. Core sampling of riffle sediments in Idaho batholith streams can be done during the low flow periods of summer. Relatively precise estimates of riffle sediment can be obtained if annual sampling sites are restricted to spawning riffles most of which have gravels of a size which can be handled by core sampling techniques.

The percentage of fine sediment in riffles not only provides a measure of the suitability of the riffles for embryo survival, but also should be an index of the amount of fine sediment being deposited in pools or substrate interstices. If the riffles contain small amounts of fine sediment, then it is not likely that significant amounts of sediment are being deposited in pools or between the boulders of the stream substrate.

Sediment transport and deposition in relation to discharge for given sections of the batholith streams we studied can be generalized. For a given section of stream there are critical discharges which will transport the coarse sand and smaller sediment across riffles, out of pools, out of riffles after dislodging the armor layer, and out of the substrate after moving the large boulders. In the batholith streams we studied, the snow melt runoff was rarely sufficient to transport sediment out of the pools. An above average snow melt runoff would be needed to dislodge the armor layer on the riffles so that sediment trapped within the riffles could be removed. The amount of coarse sand and smaller sediment that can be transported through a given section of stream is a function of discharge.
In a year of above average runoff with discharge capable of moving the armor layer on the riffles, the fine sediment within the riffles becomes available for transport down the stream. If the stream were to run out of sediment to transport while the discharge is still large enough to move the armor layer on the riffles, the amount of sediment redeposited within the riffles would be minimal. If the stream is still transporting fine sediment after the discharge has declined below the quantity which dislodges the armor layer on riffles, then the riffles would be refilled with fine sediment. If the stream is still transporting fine sediment after discharge has fallen below the level which removes fine sediment from pools, then the pools would be refilled.

Some of the streams we studied, such as Elk Creek, contained large amounts of fine sediment. We believe there is little prospect that such streams can remove excess amounts of fine sediment. Because of their low banks and the broad valley in which they are situated, the depth in the streams during snow melt runoff seldom reaches the critical level required to completely cleanse the pools, much less remove the armor layer from the riffles so that the riffles can be cleansed of fine sediment. Streams such as Elk Creek may have always contained larger amounts of fine sediment than other streams; it is difficult to determine whether cattle grazing and limited road encroachment have increased the amount of fine sediment in Elk Creek.


**Abstract** - Fishes inhabiting estuaries, rivers and embayments are subject to turbid conditions. Larvae of many fishes utilize estuaries as nursery areas. For visual plankton feeders, such as larval fishes, turbidity may reduce search and reaction distances resulting in lowered feeding abilities. In this study feeding Pacific herring larvae, *Clupea harengus pallasi*, were exposed to suspensions of estuarine sediment and Mount St. Helens volcanic ash at concentrations ranging from 0 mg/1 to 8,000 mg/1. In all experiments, maximum feeding incidence and intensity occurred at levels of suspension of either 500 mg/1 or 1,000 mg/1 with values significantly greater than controls (0 mg/1). Feeding decreased at greater concentrations. The suspensions may enhance feeding by providing visual contrast of prey items on the small perceptive scale used by the larvae. Larval residence in turbid environments such as estuaries may serve to reduce predation from larger, visual planktivores, while searching ability in the small larval perceptive field is not decreased.

Abstract - As part of the Commonwealth of Massachusetts research into the environmental effects of offshore sand and gravel mining, acute bioassays were performed on several commercially valuable marine fish and shellfish utilizing various levels of suspended, fine-grain, marine sediment. The species tested displayed a remarkable tolerance for short term exposures to the levels of suspended sediments which they might encounter in the dredge plume of an offshore sand and gravel mining operation.


Abstract - To predict the fate and transport of any aquatic pollutants it is essential to describe the dynamics of aquatic particulate material. Therefore, particle characteristics, such as size, surface area and concentration must be quantified. To assess particle characteristics for the optimization of water treatment plant design we have used power law distribution (PLD) analysis to characterize particulate material entering Lake Erie; however it was not applicable for the characterization of algal populations. In order to develop a generally applicable size distribution parameterization, three additional probability density functions were fit to a variety of aquatic suspensions - tributary sediments, nonflocculating and flocculating algal suspensions. Four functions were tested against the observed distribution generated by these various particle types. Only the four parameter beta distribution (FPBD) satisfactorily describes all cases. By comparing the FPBD coefficients, R and T, with known particle distribution characteristics, we will show that these coefficients have physical significance in terms of size dynamics, types of flocculation and thus types of particles transport regimes.


Abstract - Streambank erosion is very costly and a major problem throughout the United States. If left unchecked, this erosion can become acute and result in astronomical losses of land and other physical
property. Studies were done on stream channels in northern Mississippi to determine the feasibility of using vegetation to stabilize eroding streambanks. This use of vegetative materials was developed from the concept that vegetation, properly established and managed, will provide satisfactory and economical protection and help to supplement and reduce the use of expensive structural materials. Studies were conducted on 1,536 m (5,040 linear ft) of formed channel banks with 29 treatment areas 15.2-182.9 m (50-600 ft) long. The treatment areas were composed of 19 species of vegetative plantings with various combinations of six different structural materials. The studies were continued for 10 growing seasons to allow proper evaluation of the plant materials. To be effective in protecting streambanks, plant materials must survive the cycles of extreme meteorological conditions of a given area. Results showed that vegetative materials can be successfully used in a streambank protection program and should be considered an integral part of the engineering design.


Abstract - To determine any long-term impacts related to the construction of the Hanlon Expressway at a tributary of Mill Creek, Ontario, we collected data on fish and invertebrate populations, water quality and bedload during the summer of 1985 and compared them with original data collected by Mathers (1978) from 1972 to 1976 (before, during and after the construction). Bed load remained elevated immediately downstream from the construction site. A continuing source of the bed load material is marl beds that were exposed during relocation of the west branch of Mill Creek. Material from the relocation channel has covered the stream bed for 250 meters downstream from this channel. This material is moving downstream at the rate of about 25 meters per year and is expected to reach mainstream Mill Creek by the year 2010. Invertebrate density was lower in the stream area overlaid by bed load marl. Biomass of brook trout, Salvelinus fontinalis, remained about one-half pre-construction levels. Although brook trout density remained constant at this location, the average size of trout is now smaller and these impacts appear to be caused by the material from the west relocation channel that has reduced the quality of habitat for fish and invertebrates. Farther downstream, fish biomass has increased to pre-construction levels, but brown trout, Salmo trutta, have replaced some brook trout. Sodium and chloride levels have increased two to three fold at all stations; part of this increase appears to be related to the use of de-icing salt in the vicinity of the highway construction. Nutrients, heavy metals and other water quality variables showed no changes related to highway construction.


Abstract - Striped bass, Morone saxatilis, breed in waters often affected by human activities that increase turbidity. Laboratory experiments were conducted to examine the effect of turbidity on the numbers and sizes of prey consumed by striped bass larvae during 25 minute feeding trials. Larvae feeding on natural prey assemblages, primarily composed of copepods, consumed approximately 40% fewer prey in suspended solids concentrations of 200 and 500 mg/l than in 0 or 75 mg/l. In contrast, larvae feeding on Daphnia pulex captured the same average number of prey at all suspended solids concentrations tested. Turbidity also had no effect on the size of copepods or D. pulex eaten.


Abstract - The suspended solids load of an estuarine system consists of either living or non-living organic material and of inorganic suspensoids. Studies by the author and others indicated that except for periods of extremely high freshwater discharges the inorganic suspended solids load is higher in the transition zone between fresh and salt water than in either the upstream or downstream zones.

The quantity of suspended solids in water has a definite effect on water's esthetic quality and its value for recreational purposes. The biological effects of inorganic suspended solids are complex and extremely difficult to quantify. The role of siltation in the destruction of recreational beaches and aquatic habitats is well documented.

Turbidity and the subsequent siltation reduce the quality of estuarine waters for the intended uses and degrade the system as a biological habitat. They are pollutants and the rate at which they are introduced into estuarine systems has been grossly accelerated by man's terrestrial activities.


Abstract - Although erosion and sediment controls share a similar purpose, they function differently. Erosion control measures, such as straw mulching and seeding vegetation to exposed soil, are undertaken to prevent soil from eroding. Sediment control measures, such as silt fences, sediment basins and diking, are sued to prevent eroded soils from leaving construction sites.

Golf course construction frequently involves clearing vegetation from the soil surface. If precautions are not taken, substantial quantities of sediment - detrimental to aquatic environments and trout habitat - may by lost through erosion. The potential for increased sedimentation resulting from erosion is normally only threatening during the construction phase. After construction, golf courses are seeded to grasses and sediment losses from turf via runoff are very low.

Sedimentation during construction was suggested as having the most visible and possibly the most devastating impact on mountain trout habitat. Sediment during golf course construction was acknowledged as the primary cause of the elimination of wild trout reproduction and reduction of the standing crops of brown, brook and rainbow trout in the impacted streams. Mountain development, which included a golf course as the single greatest land disturbing activity, resulted in the
North Carolina's best wild trout water; subsequently, the affected water was reclassified as general trout water and stocking became necessary to sustain the fishery.

The creation of the Kananaskis Country Golf Course by the Alberta provincial government in the late 1970s had a significant effect on the fishery in Evan-Thomas Creek. Inadequate sediment controls coupled with the failure to retain stream buffers along the lower Evan-Thomas Creek where it flows through the golf course, resulted in extensive siltation of the stream that was still noticeable in 1992.

While no references were located to indicate the frequency that golf course construction has caused excessive siltation of aquatic environments, golf course developers who have caused excessive siltation during construction that was damaging to trout habitat have been convicted in Canada and the United States.

Regardless of whether golf course or residential developments are involved, sediment yields from construction sites are inherently variable and site dependent. Yorke and Davis (1972) determined direct relationships exist between the sediment yield of a basin and the area under construction, the season when construction occurred, the slope of land under construction and the proximity of construction to streams. Investigations involving comparisons between construction site watersheds and agricultural watershed revealed sediment yields from construction sites are considerably larger (19.2 versus < 1 tonne/ha/year).

Accumulated silts deposited over stream substrates can have widespread and permanent effects on trout, salmon and other clear, coldwater fish species. Populations frequently suffer indirect effects through reduced survival of fish eggs and alevins, reduced populations of aquatic insects and bottom dwelling organisms, damage to the aquatic plant community and destruction of fish habitat.

Practices that may minimize aquatic environmental degradation resulting from inadequate sediment and erosion controls during golf course construction include:

(1) Designing courses that minimize the need for mass grading.
(2) Minimizing the duration that soils are exposed especially during seasonal high risk periods.
(3) Avoiding development on steep slopes (> 20%) or highly erodible soils.
(4) Enforcement of erosion and sediment control programs.

General sediment and erosion controls, not specifically designed with golf course developments in mind, are also a useful source of information concerning potential preventative measures.


Abstract - Secchi disk transparency in lakes is a function not only of the turbidity caused primarily by plankton, but also of the organic color level in the water. Multiple regression analysis of data from 55 Florida lakes yielded a close fitting equation of the type SD + a (color) + b (turbidity) + c. The statistical relationships between inverse transparency and chlorophyll a and between log transparency and log chlorophyll a exhibited greater scatter. Experiments in which concentrated solutions of humic substances were added to a large plastic "limno-bag" verified the linear relationship between SD and color content but yielded a different slope than that obtained by regression analysis. The maximum possible transparency (assuming zero turbidity) was similar for both the experimental and regression relationships at color levels above 50 platinum (Pt) units, but increasingly divergent results were predicted by the two approaches at lower color levels. At a color of 100 Pt units, the maximum Secchi disk transparency is about 2.4-2.8 m. Because of the crudeness of transparency measurements, use of the above regression equation to compute
transparencies from measured turbidities appears to be more reliable than use of the experimentally derived equation.


Abstract - The impact of road construction, two patterns of clear-cut logging and controlled slash burning on the suspended sediment yield and concentration from three small watersheds in the Oregon Coast Range was studied for 11 years. Sediment production was doubled after road construction but before logging in one watershed and was tripled after burning and clear-cutting of another watershed. Felling and yarding did not produce statistically significant changes in sediment concentration. Variation in the relation between sediment concentration and water discharge on small undisturbed streams was large. Conclusions about the significance of all but very large changes in sediment concentration are limited because of annual variation for a given watershed, variation between watersheds and variation with stage at a given point.


Abstract - Studies conducted in laboratory streams showed that torrent sculpins, Cottus rhotheus, congregated in regions of limited cover when exposed to a sand substrate. When cobbles were added their distribution was more uniform. Various combinations of sand, pebbles and cobbles significantly influenced sculpin predation on the stonefly Hesperoperla pacifica, the mayfly Ephemera grandis and the caddisfly Rhyacophila vaccua. During 24 hour tests, each species experienced 95-100% predation when tested on sand substrates. When different combinations of cobbles and pebbles were added, predation was appreciably reduced. Sculpin predation on H. pacifica, Hydropsyche spp., and Heptagenia solitaria was influenced more by substrate than suspended sediments when substrate and suspended sediment (0-1250 mg/l) were tested interactively. Predator avoidance tactics differed among prey species as changes were made in the physical characteristics of the environment.


Abstract - High suspensoid loads are a common feature of many Southern Hemisphere inland waters. Case studies on a natural lake (Chilwa), a man-made lake (LeRoux) and southwest Indian Ocean estuaries reveal that the effects of turbidity on fish in these systems differ widely. In Lake Le Roux, high suspensoid loads influence fish by causing a reduced growth rate, a decrease in size at first maturity and maximum size and a movement inshore by large fishes to feed on phytobenthos. High turbidities in lake Chilwa sharply reduced food availability in benthic offshore zones and restrict fishes to pelagic and inshore food resources. The resuspension of sediments by wind action may cause fish mortalities through deoxygenation of the water column. Moderate turbidity levels appear to be beneficial to fish in estuaries by affording protection from predators in shallow, food-rich areas. Turbidity gradients may also provide a navigational aid to fish entering estuaries.

While ecological studies on Southern Hemisphere inland waters are fairly advanced, experimental work is restricted. Such research in the Northern Hemisphere has revealed that high suspensoid loads may influence breeding success, egg and larval survival, population structure and size, as well as food availability and feeding efficiency. The effect of suspensoids on the breeding success and feeding efficiency of Southern Hemisphere fish need further investigation.

Moderate suspensoid loads are a natural feature of many inland waters, but sustained high levels reduce the photic zone, blanket the benthos and interfere with the feeding efficiency of fish. The curtailment of soil erosion should therefore be regarded as a priority in the management of inland fisheries, especially in Third World countries where poor land use practices have resulted in a marked deterioration of water quality. The need to study and manage river catchments holistically is emphasized.


Abstract - At the end of two growing seasons, the average total weight of fish in clear farm ponds was approximately 1.7 times greater than in ponds of intermediate turbidity and approximately 5.5 times greater than in muddy ponds. Differences were due to faster growths by all species and to greater reproduction in clear ponds particularly by bluegills and reedear sunfish. Of the three species used in farm ponds, largemouth bass were most affected by turbidity in both growth and reproduction. Redear sunfish appeared less retarded in growth than did bluegills during the first year but the two sunfishes appeared equally restricted in both growth and reproduction during the second year.

Average volume of net plankton in surface waters of clear ponds during the 1954 growing season was 8 times greater than in ponds having intermediate turbidities; 12.8 times greater than in the most turbid ponds.

In hatchery ponds, high turbidities reduced growth and total yield of bass and bluegills but increased channel catfish production. Individual catfish grew faster in clear ponds, but muddy ponds yielded much greater weights of channel catfish than either clear or intermediate ponds. This was due to a higher rate of survival. The presence of carp caused reduced growth of bass and bluegills but ponds with carp produced greater yields of channel catfish and young bluegills than ponds without carp. Sodium silicate proved effective in sustaining hatchery pond turbidities when introduced in suspension with finely divided clay.

Growth of largemouth bass, white crappies and channel catfish were much slower in turbid Heyburn than in clear Upper Spavinaw reservoir as well as in all other Oklahoma reservoirs of similar age and size. Growth of flathead catfish was the most favorable of any Heyburn species studied and it is apparently well adapted to the turbid environment. The number of species, as well as individuals, was low in turbid Heyburn reservoir apparently due to a lack of successful reproduction in the turbid waters and also to competition from the better adapted catfishes. Extreme scarcity of forage species, particularly gizzard shad, limited growth and development of bass, crappies and other carnivorous species at Heyburn. Heyburn largemouth bass and white crappie populations exhibited unusual dominance by older individuals. This seemed to be due to successively smaller year classes as a result of increasing turbidities.

In 1954, the average volume of plankton in surface waters was 13.8 times greater in Upper Spavinaw than in Heyburn and average volume from the 60 foot depth at the clear reservoir was greater than the combined total from surface, 15 foot depth and 30 foot depth in the muddy reservoir. This contrast was less marked in 1955 possibly due to somewhat lower average turbidities at Heyburn.

The clear reservoir attracted more anglers, yielded greater returns per unit of fishing effort, as well as more desirable species and was immeasurably more appealing in the aesthetic sense.


Abstract - Since 1923, the Dorr Company has been making sedimentation studies of the waters of some of the turbid rivers of the middle west. This paper presents the summarized results of these studies with a comparison of the settling behaviour of the different river waters.
The advantages of pre-sedimentation in the treatment of highly turbid waters may be summarized as follows:

1. The reduction of turbidity results in a substantial saving in chemicals required for coagulation.
2. Pre-sedimentation furnishes water uniformly low in turbidity for secondary coagulation, resulting in smoother plant operation.
3. Pre-sedimentation removes the bulk of the suspended solids, thereby greatly reducing the accumulation of solids in the coagulating basins with a resulting saving in the cost of cleaning these basins.
4. The water discharged with the solids from the pre-sedimentation basins has not been chemically treated. The cost of water wasted in the sludge is therefore less in the case of pre-sedimentation than when the raw water is directly treated with coagulants.
5. Where the water is to be subsequently softened, preliminary tests indicate that pre-sedimentation will effect a considerable saving in lime.


Abstract - Determination of the incidence and pattern of lake shoreline spawning by sockeye salmon represents a new application of radio-telemetry. Although the extremely turbid nature of Tustumena Lake (> 50 NTU) negated our efforts to locate redds, a few hundred yolk-sac fry were found during our shoreline surveys after lake levels had dropped. This finding and the annual use of shorelines by spawning adults suggest that shoreline spawning occurs in Tustumena Lake. We know of no previous descriptions of shoreline spawning by sockeye salmon in a glacially turbid lake.


Abstract - Changes in the size composition of spawning bed materials in six coastal streams were monitored for 3 years to determine the effects of logging on the habitat of silver salmon, Oncorhynchus kisutch, and trout, Salmo gairdneri and S. clarkii. Four test streams in unlogged watersheds and the undisturbed upstream section of one test stream served as controls. A variety of stream types in second-growth and old-growth forests was selected for observations.

Spawning bed composition in the four test streams changed after logging, roughly in proportion to the amount of streambank disturbance. The heaviest sedimentation occurred when bulldozers operated in narrow stream channels having pebble bottoms. In a larger stream with a cobble and boulder bottom, bulldozer operations in the channel did not increase sedimentation greatly. Sustained logging and road construction kept sediment levels high in one stream for several years. Sedimentation was greatest during periods of road construction near streams and removal of debris from streams, confirming the need for special measures to minimize erosion during such operations. Control streams changed little in spawning bed composition during the 3 years.

Abstract - The effects of logging and associated road construction on four California trout and salmon streams were investigated from 1966 through 1969. This study included measurements of streambed sedimentation, water quality, fish food abundance and stream nursery capacity. Logging was found to be compatible with anadromous fish production when adequate attention was given to stream protection and channel clearance. The carrying capacities for juvenile salmonids of some stream sections were increased when high temperatures, low dissolved oxygen concentrations and adverse sedimentation did not accompany the logging. Extensive use of bulldozers on steep slopes for road building and in stream channels during debris removal prolonged adverse conditions in one stream and delayed stream recovery. Other aspects of logging on anadromous fish production on the Pacific Coast are discussed.


Abstract - A 20 month study of some effects of highway construction on water quality was conducted during construction of Interstate 10 at Tallahassee, Florida. Highway construction resulted in significant increases in turbidity, suspended solids, total phosphorus, and dissolved silicon in downstream waters despite use of recommended procedures for erosion control. Highway construction did not result in significant increases in dissolved phosphorus or nitrogen.


Abstract - For the three study streams, suspended sediment concentration could not be analyzed with precision using discharge data only. The suspended sediment rating curves (daily suspended sediment concentration versus discharge) for Emerald Brook, North Brook and Smelt Creek had correlation.
coefficients of 0.30, 0.36 and 0.26 respectively, rendering our model inconclusive. Partitioning the data annually did improve the correlation coefficient up to 60% for some years while for others the correlation coefficient was as low as 0.007. However, care should be taken when data are partitioned annually because a high correlation coefficient is sometimes due to the limited number of observations (as in this case). In terms of confidence intervals, a high correlation coefficient based on only a few observations is no better than many observations with a low coefficient.

For future studies relating the suspended sediment to other hydrological parameters, daily precipitation or mean antecedent precipitation could be investigated as the independent variable. Another possible model is the bivariate regression analysis using both the daily discharge and a second variable involving precipitation. Different activities on the drainage basins could also affect the suspended sediment concentration at different times of the year. These activities, such as agricultural and roadway practices, make the analysis more complex and less economical because of the increased number of variables involved.

Joint monitoring programs of both suspended sediment concentration and fish population dynamics are needed to enable us to better understand the two phenomena and their interactions. This could be possible using Environment Canada's sediment survey program in the Gulf Region. Salmonid populations could be measured near one of these stations in order to establish databases on both sediment loads and salmonid populations. Some attempt might be made to relate the occurrence and duration of high levels of suspended sediment to fish spawning success, benthic production and changes in habitat availability.


Abstract - A Helley-Smith pressure differential bedload sampler was used to measure bedload transport at consecutive riffle sections of a riffle-pool-riffle sequence on Bambi Creek, a small (154 ha), second order stream on Chichagof Island, Alaska, during four storms over a 2-year period. Maximum bedload transport rate measured was 4920 kg/h at a streamflow of 2.35 cubic meters/sec corresponding to a storm having a 5-year return interval. Transport of larger sediment (0.8 mm) varied systematically with streamflow at the two sampling locations. At flows up to approximately bankfull, transport of large sediment was greatest at the upstream site; at flows above bankfull, transport of large sediment was greatest at the downstream site. The net import of large sediment to the pool during moderate stormflows and net export of large sediment from the pool during flows above bankfull may be related to a "convergence" or "reversal" of competence between the upstream riffle and subsequent pool at flows approximating bankfull stage. Cross-sections monitored within the study reach indicate that stormflows resulted in net filling of the riffle sections and net scour of the pool; periods of low streamflow resulted in net scour of the riffles and net filling of the pool.


Abstract - In a review of the effects of suspended solids on freshwater biota for the U.S. EPA, Sorenson et al. (1977) pointed out that acute effects on specific organisms were difficult to demonstrate; succession and/or adaptation can allow communities to be maintained even though specific organisms differ. They concluded, however, that suspended solids may have significant effects on succession because of shading, abrasive action, habitat alteration and sedimentation. Suspended solids have a significant effect on community dynamics when they interfere with light transmission. The role of sediments as a reservoir of toxic chemicals has been demonstrated. Relatively high concentrations of suspended solids are needed to cause behavioral reactions or death in a short time in fish. Recovery is fairly rapid when fish are returned to clear water.

Most flowing waters have considerable variation in suspended solids from day to day. Because this natural variation is so great it is not desirable to establish fixed rigid guidelines.

Lloyd (1985) concluded that an increase in turbidity of 25 NTU (Nephelometric Turbidity Units) in shallow, clearwater systems may potentially reduced stream primary productivity by 13-50% or more, and be associated with an increase in suspended sediment concentration of approximately 25-100 mg/1. A 5 NTU increase in turbidity in clear water systems may reduce the primary productivity by 3-13% or more and be associated with an increase in suspended sediment concentration of approximately 5-25 mg/1.

McLeay et al. (1984) completed a comprehensive study of the direct effects on salmonids using Arctic grayling, Thymallus arcticus, and placer mine sediments from the Yukon Territory. At suspended sediment concentrations of 100 mg/l or greater, fish growth was depressed and feeding responses were slower. At concentrations of 300 mg/l or greater, fish were displaced downstream, oxygen uptake rates were increased and fish tolerance to a toxicant was reduced. Langer (1980) found that a marked reduction in survival of chum salmon, Oncorhynchus keta, eggs occurred at a suspended sediment concentration of 97 mg/l. A reduction in the feeding of juvenile coho salmon, Oncorhynchus kisutch, occurred at 300 mg/l.

As a guideline, suspended solids should not exceed 10 mg/1 when background suspended solids concentrations are equal to or less than 100 mg/1. Suspended solids should not exceed 10% of background concentrations when background concentrations are greater than 100 mg/1.
sediment quality guidelines for the protection of aquatic life. Introductory guidance is also provided on how these guidelines are intended to be used in conjunction with other types of information.


Abstract - Several techniques are recommended to reduce erosion and siltation of watercourses during forest management activities. These include:

- Sedimentation basins should be constructed at the end of each ditch. Sedimentation basins will slow down the flow of water and collect suspended particles which are deposited on the basin floor. Therefore, water quality of natural watercourses is not affected by the residue in water from the ditch network.

- Limit the amount of traffic over watercourses. Areas where vehicles cross should be well indicated. Choose spots where the bed is rocky. Cross the watercourse at a right angle and always cross at the same spot.

- Try to control water-induced erosion of the wood roads by placing them along the contours of the terrain (perpendicular to the slope).

- Use culverts when the road crosses an intermittent or perennial watercourse. The culvert should be wide enough to allow for the maximum water flow. If the diameter is too small, the culvert will not be able to drain all the water and some of it will run onto the road surface and cause erosion. No matter what type of culvert is used, it should always be placed along the axis of the watercourse. Any change caused in the direction of the watercourse could lead to the erosion of embankments.


Abstract - Using data from lakes located in Finland, Florida and Wisconsin, we demonstrate that there is a significant positive relationship (r = 0.70; P < 0.01) between water transparency as measured by the use of a Secchi disc (SD) and the maximum depth of colonization (MDC) by aquatic macrophytes. This relationship was used to develop and test an empirical model to predict MDC values from SD values. The best fit logarithmic model was log(MDC) = 0.61 log(SD) + 0.26 where MDC and SD values are expressed in meters. The model, however, has a 95% confidence interval of 46-236 percent of the calculated MDC value. Separate regression equations were subsequently developed for each geographic region. It is hypothesized that differences in the light compensation points of different species of aquatic macrophytes may account for a large portion of the variability in the MDC-Secchi relationships. Influence of light availability and lake morphometry on potential aquatic weed problems in lakes is discussed.


Abstract - The siltation of an experimental gravel bed, with three grades of sands moving in suspension and as bedload, was examined in a flume. For low suspended sediment concentrations (< 300 mg/l) the mean deposition rate was 1.34% of the initial gravel volume filled per hour. Deposition rates for sands 0.15-1.4 mm in diameter with suspended sediment concentrations of 38-9100 mg/l and Froude numbers in the range 0.008-1.21 were constant with respect to Froude number. For all concentrations the deposition rate was strongly linearly correlated with the suspended sediment concentration. The downstream decrease in siltation rate from a point source was a negative exponential function of distance from that source.
Turbulent resuspension of sediment prevented deposition in a surface layer of gravel of thickness approximately equal to the mean grain size of the gravel. Mean flow data, especially where derived from velocity profile data measured in the outer boundary layer, have limited value for siltation investigations concerned with processes occurring very close to the bed. Practically, results indicate that open work gravels will rapidly become silted in flows with low concentrations of suspended solids. Consequently, mechanical cleansing of spawning beds has limited value where sediment pollution is likely to be a recurrent problem. A simple equation describing the downstream extent of silting from a point pollution sources is presented that requires verification in natural streams.


Abstract - We measured levels of inorganic suspended solids in Little Wall Lake, Iowa, and concluded that sediment resuspension occurred when wind velocities exceeded critical velocities as calculated from wave theory. The percentages of the lake bed subject to resuspension for winds of given velocities were calculated, as were the percentages of time that winds of such velocities could be expected. We concluded that only a small percentage of the lake bed is subject to resuspension most of the time. The techniques to calculate wind effects and to summarize the data on frequency of wind mixing used in this study should be generally applicable to problems of sediment resuspension in other shallow lakes.


Abstract - The management of stormwater runoff water quality will become increasingly important into the 21st century as more natural lands succumb to development. Wetlands are a valuable resource for they are natural water quality filters and enhance groundwater recharge. Utilizing certain natural wetlands for stormwater treatment was approved by the Florida legislature in 1984. Despite legislative approval, the ability of natural wetlands to treat stormwater as well as the extent to which the wetlands themselves are effected have been questioned. Two objectives of the study were: (1) to assess the effectiveness of a natural wetland to treat stormwater runoff and (2) to document the effect of stormwater treatment on wetland vegetation. Flow-weighted water quality samples were taken at each inflow and outflow as well as rainfall and pollutant load removal efficiencies were calculated. Two detailed vegetation analyses were conducted during the study and results were reported as percent cover.

During the two and one half year study, eighty-three storm events were sampled for water quality. Dry season pollutant removal was better than the wet season. Pollutant removal during the 1992-1993 period (wet and dry seasons) was better than 1991-1992. Negative Fe (-15%) and Mn (-44%) mean removal
efficiencies were detected during the wet seasons. Negative TKN (-5%), TON (-12%) and Fe (-8%) mean removal efficiencies were detected during the 1991-1992 period. A total of 34 and 40 plant species were observed during the 1992 and 1993 detailed vegetation analyses respectively. Dominant species (including cover types) were Panicum hemitomon, open water, Pontederia cordata, litter and Nymphaea odorata. Physical alteration to the south edge of the wetland and construction of a sediment basin facilitated establishment of Typha latifolia, Typha domingensis, Ludwigia peruviana and Mikania scandens (nuisance plant species). None of these nuisance species were observed at the natural north edge.


Abstract - The population behavior of Daphnia gessneri in a floodplain lake (Lago Grance) of the lower Rio Solimões was investigated between April 1979 and March 1980 with regard to (1) predation by the fish called tambaqui (Colossoma macropomum), (2) water level fluctuation and (3) water transparency. Zooplankton density samples were collected at two sites near mid-lake where water depth and Secchi disc transparency were measured. In addition, qualitative samples of zooplankton and fish collections were taken at several sites in the adjacent floodplain areas. The author concludes that fluctuations in Daphnia gessneri populations correlate most with intense predation by fish and water turbidity.


Abstract - Upland vegetated buffers are widely regarded as being necessary to protect wetlands, streams and other aquatic resources. Buffer size requirements, however, have typically been established by political acceptability, not scientific merit. This often leads to insufficiently buffered aquatic resources. In order to assist public agencies in formulating appropriate buffer standards, we conducted a literature search for the scientific functions of buffers. The literature search reconfirmed the need for buffers and emphasized the importance of considering specific buffer functions. A range of buffer widths from 3 m to 200 m was found to be effective depending on site specific conditions; a buffer of at least 15 m was found to be necessary to protect wetlands and streams under most conditions.


**Abstract** - Penetration of daylight into the water of western Lake Erie was measured with a Weston photronic ceel several times each month from September, 1939 to November, 1940. The depths to which one percent of surface light penetrated varied from a maximum depth of 9.7 meters when turbidity was 5 ppm to a minimum of 0.8 meters when turbidity was 115 ppm. The greatest percent of surface light reaching a depth of one meter was 10.8 times greater than the least; the greatest percent reaching a depth of two meters was 86.6 times greater than the least. Difference between the greatest and the least values for each of these two depths was due to the difference in turbidity and not to the nature of the light reaching the surface of the water. Greatest loss of light in the first meter of water occurred within the first 10 cm. This loss varied from 13 to 49 percent of the surface light. Turbidity, which varied from 5 to 230 ppm, was due primarily to materials derived from bottom sediments; the inorganic component of this material is present in larger quantities than the organic component. Fluctuation of turbidity values are not limited to season but they often occur weekly due to changes in meteorological conditions. Transmission of light by these waters was highest during winter, spring and early summer and it was lowest during late summer and autumn. Light transmissions is most uniform vertically when stormy conditions prevail and it is least uniform when relatively calm conditions follow stormy periods. In western Lake Erie, an ice cover 40 cm in thickness obstructed light penetration to no greater degree than 40 cm of water having a turbidity of 20 ppm or greater. Biologically, turbidity and its variations in western Lake Erie may influence: (1) composition, size, duration and time of occurrence of phytoplankton pulses; (2) rate of photosynthesis at various depths; (3) position of the compensation point of higher aquatic plants and phytoplankters; (4) vertical distribution of microcrustacea; and (5) magnitude of the commercial catch of saugers, *Stizostedion canadense*. 

Abstract - Chemical quality of surface waters can be expected to change following timber harvest, especially where slash burning has occurred. Increases in total dissolved solids, nitrates and phosphates are some of the changes to be expected. Suspended sediment and sediment bed loads can be expected to increase after timber harvest, the extent of increase depending on the land treatment. Current knowledge indicates that logging roads are greater sources of sediment in logging than is the clearcut or harvesting operation itself. The effect of sedimentation upon fish reproduction has received more attention than any other phase of the logging-fish problem. The available data overwhelmingly show that sedimentation reduces the survival of salmonid embryos. There is some indication that severe concentrations of suspended sediment may have another effect on salmonid reproduction by preventing or decreasing spawning when high turbidity occurs during spawning season. Increases in stream turbidity reduce light penetration and can cause reduction in photosynthesis activity of green plants. This may seriously disrupt one basic supply of fixed plant energy and ultimately affect the entire ecosystem if turbidity is extensive in duration. Increases in sediment discharge cause increases in the proportion of fines present in the substrate and, if sufficiently severe, tend to fill the apertures and spaces around the gravel, rubble and other bottom irregularities, reducing protective cover for young fish and decreasing bottom productivity.


Abstract - Laboratory studies have not duplicated the structure and composition of egg pocket centrum in redds of large salmonids and thus have not accurately modeled survival of embryos and alevins in natural egg pockets. Field studies of capped natural redds have related survival to conditions in the redds or surrounding areas but not demonstrably in egg pockets. These data probably do not accurately reflect conditions faced by embryos or emerging alevins. The few data on egg pocket characteristics indicate that geometric mean particle diameter, fredle index and permeability are higher in gravel surrounding the embryos than elsewhere. Survival to alevin emergence usually regresses positively on each of these factors separately and on dissolved oxygen in intragavel water. Survival to emergence usually relates negatively to percentages of small fines. Quantitative predictors depend upon careful definition of egg pocket structure through field surveying of egg pocket centrum locations and on intensive study of pocket conditions. Laboratory duplication of egg pocket structure and physical variables will permit more accurate modeling of effects of fines on survival to emergence. Redd capping in natural redds can provide estimates of survival to emergence, which one may relate to average egg pocket conditions and to variates in the redd. After appropriate modeling, it may become possible to relate conditions outside of the egg pocket to the environment within it and to survival to emergence.


Abstract - Sidecast dredging has been employed annually in the New England region for the past four years. Operation of the dredge is restricted to inlet channels and ocean sand shoals. Physical and chemical analysis of sediment samples from eighteen navigation projects confirm that the dredged material consists primarily of clean fine to coarse sands. Some channels, however, are characterized by eelgrass patches with subsequent higher percentages of fine grain sediment. Preliminary studies by the New England
Division Army Corps of Engineers has concentrated on evaluation of dredging effects on turbidity, dissolved oxygen and mobilization of trace metal constituents. Four projects have been selected for comparison of pre and post dredging impacts on benthic communities.

From the general information presently available, the following conclusions and recommendations are offered:

1. Local conditions characterizing individual harbor channel environs produced differences in the dilution rate and areal extent of the turbidity plume.
2. Aerial photographs and transmissometer recordings show that the discharge plume may be discernible over a distance of some 750 to 1,000 meters from the dredge.
3. A correlation between turbidity and sea state was shown during monitoring. In some instances wind-generated waves increased turbidity to levels approaching those caused by the dredge.
4. There were no oxygen reductions detected during dredge-disposal operations.
5. Preliminary water sample analysis for trace metals which might become suspended as a result of dredging revealed elevated concentrations over ambient for mercury, nickel, copper and arsenic. Further sampling is required to better define the relationship of mechanical erosion imposed by wave action and tidal currents to fluctuations in metal concentrations.
6. The occurrence of live macrobenthos following dredging indicates that this dredge method does not adversely affect these populations beyond the actual work period.
7. The recovery rate of benthic populations will vary depending on the substrate and according to the diversity and species numbers found at a particular project. Recolonization and attainment of "climax" populations will be slowest in those areas where eelgrass habitats are eliminated or severely altered.
8. Since shellfish beds are located outside the established dredge areas, the effects associated with direct removal and smothering are avoided.
9. Future improvement of the efficiency in the sidecast maintenance dredging program will benefit from increased knowledge of littoral transport rates and current dynamics.
10. Some operational safeguards that can be implemented to mitigate ecological impacts include: (a) dredging only on ebbing tides; (b) casting in the direction of prevailing littoral drift; (c) scheduling dredging action to circumvent peak periods of fish migration and (d) limiting areas of operation to outer bars or shoals and inlets.


Abstract - Stream water must be clear enough to permit the sunlight to reach the stream bottom and the algal community where most of the primary production of a stream occurs. Elimination of such production may severely reduce the invertebrate fauna of a stream. Salmonids feed by sight and can have difficulty finding food items in highly turbid water. High concentrations of suspended solids may also directly damage invertebrates and fish, primarily their fragile gill structures. Additional impacts can occur if suspended sediments settle onto stream bottoms and suffocate salmonid eggs and alevins and destroy benthic invertebrate populations.

This document contains numerous mitigative guidelines pertaining to erosion control and the prevention sediment inputs to running waters.


Abstract - The non-filterable residue method and the method for total concentration of suspended sediments are commonly considered to be equivalent. An examination of data collected on the Stikine River in northwestern British Columbia and Alaska showed a large difference between the two techniques. Comparisons between a peristaltic pump and USP63 sampler did not support the hypothesis that different sampling methods were responsible for this discrepancy. The two analytical methods were compared using water from rivers with varying concentrations of suspended sediment. The non-filterable residue method, in which an aliquot is used, underestimated the suspended sediment content by 46-89% when compared with the total concentration method, in which the whole sample is used. This difference was attributed to the difficulty in obtaining an accurate subsample from water samples containing a high proportion of sediments in the coarse size fraction. It was concluded that the whole water sample should be used for the measurement of non-filterable residue, which would then give an accurate estimate of total suspended sediments.
sediment concentration. This same problem will potentially bias the results of chemical tests such as the total metals measurement in which a subsample is used for analysis.


Abstract - Most of the literature concerned with the effects of silt and sand on the invertebrate fauna of streams and rivers has described changes taking place when biotopes are completely smothered by silt and sand. In few of these studies were the kinds of animals found recorded. There have been few studies of the effect of silt and sand on individual species. The invertebrate fauna of two biotopes in the streams and rivers of the Vaal River system, South Africa, changed with the amount of silt and sand in the watercourses. Where there were large amounts of silt and sand the variety of animals recorded from the stones in current biotopes was reduced but the density of the fauna as a whole did not change. However, the density of many groups of animals was affected. Some of the animals adversely affected by silt and sand appeared in larger numbers below impoundments in which silt and sand would settle. In the sediment biotopes the summer density of the fauna was lowest where there was a lot of silt and sand. Large amounts of silt and sand were associated with large summer declines in the surface dwelling animals as a proportion of the whole sediment fauna. Differences between the summer proportions of surface dwelling forms in fine and coarse sediments were due to faunal differences. Sediments were not studied below impoundments.

It is concluded that there may be considerable changes in the composition of the current fauna due to silt and sand without the biotope being smothered and that increases in the amount of silt and sand in river beds lead to increased instability of the sediments which adversely affects their fauna.


Abstract - A study on sediment transport and channel change was conducted on Zayante Creek and the lower San Lorenzo River in Santa Cruz County, California. A rainstorm with a recurrence interval locally in excess of 150 years occurred during the study year, 1982. Stream surveys indicated that significant aggradation occurred during and after the peak flood. Upper study reaches were substantially recovered after high flows of early April, but the lower study reaches still had significant filling of pools and burial of riffles by sand. Increases in width-depth ratio were minor and localized in upper reaches but were significant in lower reaches. Large inputs of sand, primarily from landsliding, altered the sediment transport regime. A higher proportion of the bedload is now transported by lower flows than before the January event. Roads at sand quarries contributed significantly to sediment input to the stream. A
proposed dam may alter the sediment transport regime of Zayante Creek. Mitigating the effects of this dam on downstream fish habitat may require occasional bankfull discharges.


Abstract - Walleye tolerate a wide range of dissolved solids up to 15,000 mg/l. The optimum range is about 40-80 mg/l. Walleye are generally intolerant of industrial effluents creating sedimentation on the substrate.


Abstract - The surface of particulate matter may act as a substratum for microbial species, although the particle itself may or may not contribute to their nutrition. When the presence of particle matter enables the environment to support substantial increased populations of aquatic microorganisms, the dissolved oxygen concentration, pH and other characteristics of the water are frequently altered.

There are several ways in which an excessive concentration of finely divided solid matter might be harmful to a fishery in a river or a lake. These include:

- acting directly on fish swimming in water in which solids are suspended, either killing them or reducing their growth rate and resistance to disease;
- preventing the successful development of fish eggs and larvae;
- modifying natural movements and migrations of fish;
- reducing the food available to fish;
- affecting efficiency in catching the fish.

With respect to chemically inert suspended solids and to waters that are otherwise satisfactory for the maintenance of freshwater fisheries, the European Inland Fisheries Advisory Commission (1965) reported:

- there is no evidence that concentrations of suspended solids less than 25 mg/l have any harmful effects on fisheries;
- it should usually be possible to maintain good or moderate fisheries in waters that normally contain 25 to 80 mg/l suspended solids; other factors being equal however, the yield of fish from such waters might be somewhat lower than from those in the preceding category;
waters normally containing from 80 to 400 mg/l suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations within this range;

only poor fisheries are likely to be found in waters that normally contain more than 400 mg/l suspended solids.

In addition, although several thousand parts per million suspended solids may not kill fish during several hours or days exposure, temporary high concentrations should be prevented in rivers where good fisheries are to be maintained. The spawning ground of most fish should be kept as free as possible from finely divided solids.

While the low turbidities reported above reflected values that should protect the ecosystem, Wallen (1951) reported that fish can tolerate higher concentrations. Behavioral reactions were not observed until concentrations of turbidity neared 20,000 mg/l and in one species reactions did no appear until turbidities reached 100,000 mg/l. Most species tested endured exposures of more than 100,000 mg/l turbidity for a week or longer, but these same fishes finally died at turbidities of 175,000 to 225,000 mg/l. Lethal turbidities caused the death of fishes within 15 minutes to two hours exposure, Fishes that succumbed had opercular cavities and gill filaments clogged with silty clay particles from the water.

In a study of fish and macroinvertebrate populations over a four year period in a stream receiving sediment from a crushed limestone quarry, Gammon (1970) found that inputs that increased the suspended solids load more than 40 mg/l (normal suspended solids was 38 to 41 mg/l and volatile suspended solids 16 to 30 mg/l) resulted in a 25 percent reduction in macroinvertebrate density in the stream below the quarry. A heavy silt input caused increases of more than 120 mg/l including some decomposition of sediment and resulted in a 60 percent reduction in density of macroinvertebrates. Population diversity indices were unaffected because most species responded to the same degree. The standing crop of fish decreased dramatically when heavy sediment occurred in the spring; but fish remained in pools during the summer when the input was heavy and vacated the pools only after deposits of sediment accumulated. After winter floods removed sediment deposits, fish returned to the pools and achieved levels of 50 percent of the normal standing crop by early June.

Not all particulate matter affects organisms in the same way. For example, Smith et al (1965) found that the lethal action of pulp mill fiber on walleye fingerlings, Stizostedion vitreum vitreum, and fathead minnows, Pimephales promelas, was influenced by the type of fiber. In 96 hour bioassays, mortality of the minnows in 2,000 ppm suspension was 78 percent in the conifer groundwood, 34 percent in conifer kraft and 4 percent in the aspen groundwood. High temperatures and reduced oxygen concentrations increased the lethal action of fiber.

Buck (1956) studied the growth of fish in 39 farm ponds having a wide range of turbidities. The ponds were cleared of fish and then restocked with largemouth black bass, Micropterus salmoides, bluegill, Lepomis macrochirus, and redear sunfish, Lepomis megalotis. After two growing seasons the yields of fish were:

- clear ponds (< 25 mg/l suspended solids) - 161.5 lb/acre
- intermediate ponds (25-100 mg/l suspended solids) - 94.0 lb/acre
- muddy ponds (> 100 mg/l suspended solids) - 29.3 lb/acre

The rate of reproduction was also reduced by turbidity, and the critical concentration for all three species appeared to be about 75-100 mg/l. In the same paper, Buck reported that largemouth black bass, crappies (Pomoxis) and channel catfish, Ictalurus punctatus, grew more slowly in a reservoir where the water had an average turbidity of 130 mg/l than in another reservoir where the water was always clear.
Floating materials, including large objects as well as very fine substances, can adversely affect the activities of aquatic life. Floating logs shut out sunlight and interfere particularly with surface feeding fish. Logs may also leach various types of organic acids due to the action of water. If they have been sprayed with pesticides or treated chemically, these substances may also leach into the water. As the logs float downstream their bark often disengages and falls to the bed of the stream, disturbing benthic habitats. Aquatic life is also affected by fine substances, such as sawdust, peelings, hair from tanneries, wood fibers, containers, scum, oil, garbage and materials from municipal and industrial wastes, tars and greases and precipitated chemicals.

Overall, two recommendations are offered:

1. The combined effect of color and turbidity should not change the compensation point more than 10 percent from its seasonally established norm, nor should such a change place more than 10 percent of the biomass of photosynthetic organisms below the compensation point.

2. Aquatic communities should be protected if the following maximum concentrations of suspended solids exist:
   - High level of protection - 25 mg/l
   - Moderate level of protection - 80 mg/l
   - Low level of protection - 400 mg/l
   - Very low level of protection - > 400 mg/l


Abstract - Sediments constitute 47% of the materials introduced from nonpoint sources. Particle size ranges from rocks, gravel and sand to very fine silt. Large particles usually settle to the bottom fairly rapidly but the fine silt remains suspended for long periods of time, producing turbidity. Because turbidity causes light to be scattered and absorbed rather than transmitted in a straight line, light penetration is reduced in turn diminishing or even eliminating plant growth.

When plant beds are eliminated turbidity problems may worsen. Plant roots anchor the bottom against wave action and disturbance by bottom feeding fish such as carp. The stems and leaves of floating and emergent plants dampen waves. Wind has little effect on the turbidity of backwater lakes along the Illinois River when plants were present but that there was a marked effect when vegetation was absent. The loss of aquatic macrophytes leads to the loss of associated "weed fauna" (i.e., the snails and aquatic insects that graze on the plants and in turn provide food for young fish). Smith (1971) indicates that populations of bigeye shiner, Notropis boops, bigeye chub, Hybopsis ambloplites, and pugnose minnow, Notropis emiliae, have been decimated in Illinois streams because of the disappearance of aquatic vegetation. Predatory fish do not depend directly on plants for their livelihood but they do depend on good visibility for finding food. Although fish are able to find food using alternate senses, such as the lateral line system, Vinyard and O'Brien (1976) found that turbidity can reduce the feeding of game fish even if there is an abundance of food in the water. However, in many cases food is not abundant because turbid waters also limit the production of zooplankton on which forage fish such as gizzard shad live. Buck (1956) found that the ratio of forage fish to predaceous bass and crappie was approximately 1 to 1 in muddy water and 13 to 1 in clear water. He found that when so little food was available there was only a small population of older, slow growing bass with very low rates of reproduction. In clear water, he found large bass populations that were reproducing successfully. In addition to sight feeding, many species of game fish exhibit complex
reproductive and social behaviors that depend on visual cues. A reduction in visibility interferes with these visual cues and thereby reduces reproduction.

Fish can tolerate short episodes of high levels of suspended sediment and some species in laboratory bioassays have survived mixtures that can be characterized as slurries of suspended clay particles (Wallen, 1951). Fish exude a protective mucus on their skin and gills that traps and continually flushes particles away. However, this protective mechanism requires metabolic energy and constitutes a stress on the fish at the same time as its ability to find food is reduced.

Other organisms also have similar protective mechanisms. Mussels have a protective mucus on their gills and can close their shells, but these are only temporary measures and the defenses of mussels against excessive sediment are eventually overwhelmed by long periods of exposure. Because mussels are nonselective filter feeders, the food available to them in silt laden waters is diluted by the presence of inorganic silt which is rejected as pseudofeces. Laboratory experiments with freshwater mussels kept in water having continuous very high loads of suspended sediment showed that silt interfered with their feedings because the mussels stayed closed 75-95% of the time. Mussels dying in these experiments always contained deposits of silt in the mantle cavity and frequently in the gill chambers (Ellis, 1936). The yellow sand-shell, *Lampsilis anondontoides*, a sand inhabiting species was most readily killed by silt deposits in Ellis's experiments and has also disappeared from the Illinois River probably due to increased silt loads (Starrett, 1971). Recent studies have focused on the impact of intermittent exposure to high silt levels such as might be found in navigable rivers. Payne et al. (1987) found that when freshwater mussels were exposed to intermittent high levels of suspended solids, feeding was disrupted and they shifted to catabolism of endogenous nonproteinaceous energy reserves.

Therefore, although some adult organisms can withstand enormous amounts of sediment in water for several days or weeks, a population may eventually die out due to starvation, reproductive failure or cumulative stress (Illinois EPA, 1979). Thus, the long term effect of chronic suspended sediment is to change the species composition of a body of water by changing the habitat and the food supply and by bringing about differential rates of reproduction in different species.


**Abstract** - Available data on the suspended sediment concentration in streams used by Pacific salmon shows that these streams normally carry relatively small amounts of suspended sediment during the spawning and incubation period of salmon. Methods of determining size of bedload materials that may be expected on a given portion of stream bed are presented. Reference is made to earlier work which shows how such layers of bed material can reduce the survival of salmon eggs by reducing flow of water through the gravel. The flow of water through a gravel bed is determined by the characteristics of the gravel and the imposed hydraulic gradient. The permeability of gravel is expressed in terms of particle size grading, porosity and particle shape, and a formula is developed relating permeability and flow. It is shown that fine sediment has a large influence on the permeability of gravel.

The effect of a flow of silty water over a gravel bed is measured and it is shown that deposition of silt occurs within the gravel even though velocities are too high to permit deposition on the gravel surface. This deposition reduced the permeability of the gravel. Formulae are developed which relate time and silt size and concentration to the effect on a given gravel. The results show that the least damaging effect on salmon eggs would occur with a very coarse gravel and the most severe effect would occur with fine gravel.
such as found in typical spawning beds. The prevention of deposition of sediment upon or within a spawning bed is shown to be essential to high survival rate of salmon eggs to emergent fry. The effect of suspended sediment on an upwelling type of artificial spawning or egg incubation bed is also examined. It is shown that permeability of these beds can be reduced by sediments in the water. This may be prevented by providing settling basins to clarify the incoming water. These basins should be capable of removing all sediments which could settle in the distribution system and also all sediment with a settling velocity less that the apparent upwelling velocity.


Abstract - The macroinvertebrate fauna of Bear Creek, a 83 kilometer stream which flows through six oxbow lakes, and two off-stream lakes in the same watershed was studied for two years. Bear Creek, a tributary of the Yazoo River in the Delta region of Mississippi, drains 330 square kilometers of intensively cultivated agricultural land and carries a continuing sediment concentration during the rainy season of up to 1300 mg/l. Benthic organisms were collected monthly from August, 1976 through August, 1978 at six stream stations and at 14 lake stations, across a variety of substrates, and at depths ranging from 0.5 to 6.5 meters. In most lake and stream sections of the creek, Chaoborus (one species), Chironomidae (nineteen genera) and Oligochaeta (three species) dominated the benthos. Thirteen other genera of insects were represented as were Bryozoa (four genera), Mollusca (nine genera), Hirudinea (five genera) and Crustacea (three genera). There was continuous stress from high rates of sedimentation (up to seven cm/year) as indicated by low taxa richness and diversity at a majority of stations sampled. Most creek stations were subject not only to annual sedimentation and flushing but also to fluctuations in water level and drying. Secondary productivity varied greatly (1 to 31 gm dry weight/sq. meter/year) and was almost totally dependent on three taxa of pollution tolerant organisms except in unstressed stream reaches. Low productivity in riverine lakes, when compared to stream sections was partially due to differences in species distribution in lotic and lentic habitats. The mayfly, Hexagenia bilineata, the clam, Sphaerium rhomboideum, and the bryozoan, Pectinatella magnifica, responded negatively to environmental stresses induced by seasonally high concentrations of suspended sediments.


Abstract - Instream suspended sediments and bedload are, by volume, the largest category of pollutants in the United States. The Mississippi River carries 331 million tons of topsoil to the Gulf of Mexico annually. Yearly discharge from agricultural land to waterways in the United States is estimated at 1,079 million tons of sediments and 477 million tons of total dissolved solids. This sediment load also represents the loss of topsoil that may only be replenished at a rate of less than one inch in 200 years. Sediments
carried in runoff degrade downstream water quality and carry nutrients and pesticides that adversely influence aquatic life. Sediment accumulations fill drainageways, culverts and stream and lake beds, resulting in restricted flow, habitat degradation, navigational difficulties and reduced productive life of reservoirs.

In lakes, suspended sediments limit aquatic primary productivity, especially where suspension persists seasonally and limits light penetration. For example, in a multiyear study of Lake Chicot, Arkansas, algal biomass was significantly less in the turbid main south basin, which drained a channelized 360 square mile agricultural watershed, than in the isolated, less turbid north basin with a watershed of less than 40 square miles. From 1980 to 1984, sediment concentrations each April averaged 69 parts per million in the north basin and 385 parts per million in the main body of the lake. A stormflow diversion completed in 1985 significantly decreased suspended sediments in the south basin. Mean suspended sediment concentrations for the five year period after the diversion was completed were similar - 39 parts per million in the south basin versus 30 parts per million in the north basin. As the suspended sediment load decreased, water quality of the south basin improved rapidly. Significant differences in algal density between the two basins disappeared as physical and chemical water quality parameters became more closely aligned.

Slow flowing streams in the Mississippi River delta have many characteristics in common with natural oxbow lakes in the region. Suspended sediments are slow to deposit and they degrade water quality conditions for longer periods than in upland streams. In two upland streams within the loess hills region of Mississippi, suspended sediment loads generally exceeded 80 to 100 parts per million - the maximum for optimal fish growth - only during and immediately following storm events.

Sediment accumulation in streams and lakes must be viewed as part of total water quality deterioration because it directly degrades fish habitat by burial. In natural lakes along Bear Creek, a drainage system in the flat alluvium of the Mississippi River, where 75% of the land is in cultivation, Ritchie and his associates (1979; 1986) found that one to three inches of fine sediments has covered the bottoms of many lakes and stream sections with fine silt.

Bottom sediment accumulations also are sinks for persistent pesticide residues and metals. Sinks add to long term contamination because they permit low level re-entry of pollutants over long periods. In a recent study of Moon Lake, situated in the delta region of Mississippi, DDT, arsenic and mercury were detected in accumulated sediments of all 65 lake and wetland sediment cores examined.

Erodible cropland contributes the most sediment when soil tillage and minimum cover conditions coincide with seasonal heavy rainfalls. The most critical period on cultivated fields is during seedbed preparation and planting. An Alabama study showed that as much as 85% of total sediment loss may occur during the critical period from soil tillage until crop canopy and root development.

The first principle of sediment reduction from agricultural land centers on sound land use policy and management. Land should be used only within the capability to support crop production without excessive erosion. Highly erodible land should not be cultivated without protective soil and water conservation practices. The primary method of preventing sediment related pollution involves such practices as conservation tillage, cover crops, grassed waterways, terraces, filter strips, water and sediment control basins and contour farming. Comparing sediment and nutrient losses from conventional and no-till soybean systems in northern Mississippi, McDowell and McGregor (1980) found that no-till systems reduced annual soil loss to only 1% of that measured from conventional tillage. In an evaluation of winter cover crops for sediment and runoff reductions in northern Mississippi, Mutchler and McDowell (1990) found that even when cover crops were established after cotton harvest in a conventional tillage system measured runoff fell from 48% to 26% of total rainfall and soil loss decreased from 33 tons to 9 tons per acre.
Farm ponds and water/sediment retention structures also are effective measures for removing sediments from runoff. In a five year study, Dendy and Cooper (1984) found that a 3.5 acres farm pond removed 77% of the annual sediment inflow from a mixed pasture, row crop watershed. The new concept of using slotted board outlets to pond runoff and trap sediment can be excavated periodically and easily returned to farm fields. Field outlet or overfall pipes also eliminate lateral stream headcuts, another source of sediment. By slowing and reducing runoff, soil and water conservation practices also reduce crest levels for large storms which trigger major sediment contributions from stream banks and beds.


Abstract - This paper summarizes American experience of the effects of urbanization on streams and compares it with British and Australian experiences. Guidelines outlining matters needing special consideration and some measures to combat the more common problems are suggested. Urbanization causes flood peaks for return periods of one to five years to be increased by up to three times and for longer return periods by up to two times. Runoff volumes also increase dramatically especially for smaller storms. During construction of urban developments, sediment production is commonly increased by a factor of 50 or more. The quality or urban runoff is usually no better than secondary sewage treatment effluent and is often much worse.


Abstract - Almost all of the investigations we have reviewed on the effects of sediment on the aquatic life of flowing waters have been done on streams inhabited by trout and salmon. Only historical changes and the work of Ellis (1931) are available to evaluate the warm waters.

There is abundant evidence that sediment is detrimental to aquatic life in salmon and trout streams. The adult fishes themselves can apparently stand normal high concentrations without harm but deposition of sediments on the bottom of the stream will reduce the survival of eggs and alevins, reduce aquatic insect fauna and destroy needed shelter. There can scarcely be any doubt that prolonged turbidity of any great degree is also harmful. The question is "how much sediment is harmful?" has not yet been answered since most workers have failed to measure the amounts of sediment. The Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Commission (1956) reviewed the problem and reached the following conclusion: "... only a small amount of sand or silt shifting in and around the gravel of the bottom eliminates much of the area suitable for the attachment or hiding of the aquatic insects and drastically
reduces the total production of these forms. Small amounts of sand, not discernible by casual inspection but evident only on close examination of the bottom materials, can bring about significant changes. To the best of our knowledge, adequate data are not available on the amounts of inorganic materials which can be added to a stream without significant harm to its productive capacity." This certainly agrees with our own observations. Field investigations with electric sampling gear in the Sierra Nevada over the past years have led us to develop the maxim "Clean stream bottoms mean good trout populations." By "clean" we mean lacking much sand.

Many of the sediment problems reported in the literature are the result of large scale discharges of sediment from gravel washing or mining operations. These are often spectacular but probably less important than the gradual deposition being caused by erosion. The increasing activity of man on our mountain watershed in California is resulting in obviously increased erosion and sediment deposition. Our failure to recognize that even small amounts of sediment may be harmful may well result in gradual destruction of the majority of our streams, while we work feverishly to solve more obvious and spectacular problems.

We have been impressed by two facts. First, there has been sufficient work done to establish the fact that sediment is harmful to trout and salmon streams; the only references found to the contrary (Ward, 1938) have been adequately criticized. Second, our experience in the Sierra Nevada indicates that the bulk of the damage there is unnecessary. It can be prevented with known land use methods often with little or no additional expense. Much of it is the result of carelessness. More than anything else we need to develop a philosophy of land husbandry that will avoid the creation of untreated and running sores on the earth's surface. Man must acquire a responsibility to future generations that matches the power he has gained through the development of heavy machinery. Our observations in the field and our review of the existing literature leads us to the unshakable conclusion that unless this can be done many of our trout streams will be destroyed by the deposition of sediment.


Abstract - Establishment of water quality standards for suspended sediment has been delayed partially by lack of information on sediment persistence in channels. In streams with dominantly suspended sediment loads, suspended sediment concentrations can be studied by correlating these concentrations with turbidity. In the stream I studied, both discharge and sediment concentration increase downstream during floods because of the confluence of sediment-laden tributaries. Duration of suspended sediment concentrations in channels is reduced by higher rates of preceding flows, increased volumes of groundwater, and through-flow contributions to flood hydrographs, multi-peaked hydrographs and sediment concentration peaks preceding water discharge peaks.


Abstract - We planted a sandy dredge spoil with panic grass, sea oats, and American beachgrass supertidally and needlerush, cordgrass and saltgrass intertidally in a North Florida estuary. Supertidal plants were fertilized at rates of 0, 100, and 200 pounds per acre with 10-10-10 fertilizer twice during the
growing season. Fertilization increased total biomass of panic grass and height of sea oats. The 200 pound rate increased growth of beachgrass roots and rhizomes. Fertilization also increased the nitrogen, phosphorus and potassium concentrations in some plants. Survival was poor among plants in the intertidal zone, probably because of the stress caused by current and waves.


Abstract - An examination of 37 lakes in the central region of Canada revealed that the summer condition of northern pike, Esox lucius, was correlated with Secchi depth but there was no such correlation for walleye, Stizostedion vitreum. A study of the diets of the two predatory fish coexisting in a prairie lake showed overlap in the food items selected in July. Food density did not appear to be limited. Walleye food consumption rose from about 1% body weight in the spring to 2% in late summer and was less than 1% in the late autumn and early winter. Pike food consumption was similar except it rose to over 3% in the early winter when the lake froze over and the water cleared. High turbidity in the prairie lake during the open water period may have reduced the ability of pike to feed.


Abstract - Accumulation of residue in stream channels occurs naturally in large amounts, particularly in old-growth forests. Residue volumes may triple in streams after timber is felled without buffer strips or other special measures designed to minimize accumulations. Although most of the large residue may be yarded out of the stream, fine residue may remain at levels higher than before logging. Fine residues affect fish habitat by reducing dissolved oxygen levels in surface water and by interfering with the circulation of surface and intergravel water. Large residues affect fish habitat by influencing stream hydraulics, the stability of the bed and banks during "flush-outs", and by blocking fish migration. Residue removal from streams must be done with care in order to minimize damage to fish habitat. Vegetation immediately adjacent to the stream is important to the aquatic habitat, influencing both water temperature and food supply for the fish. Protecting this streamside vegetation during logging and residue treatment is essential on valuable fish streams. The greatest single research need in the area of logging residue and fish habitat is the integration of studies concerned with logging method or residue treatment and those concerned with aquatic biology over a wide range of forest-stream-logging situations. Key areas of research are the impact of various logging methods on residue accumulation and on fish populations and the impact of residue accumulation on debris avalanches or "flush-outs".


Abstract - Juvenile coho salmon, Oncorhynchus kisutch, production (tissue elaboration) was monitored in 12 laboratory streams under six replicate treatment levels of fine sedimentation. Increasing sedimentation suppressed fish production. Our data confirm that habitats of salmonid juveniles, as well as spawning areas, should be protected against fine sediments. Substrate score, a visual technique for evaluating stream substrate quality, correlated closely with both the geometric mean particle size of the substrate and fish production, and can be easily applied in the field.

Abstract - A regional approach to estimating sediment damages in lakes and reservoirs indicated that 0.22% of the nation's water storage capacity is lost annually. Of this, an average of 24% is due to soil erosion on cropland. The greatest water storage capacity losses from deposited sediment originating on cropland occurred in the central United States. Annual national damages to storage capacity ranged from $597 million to $819 million, with cropland's contribution being $144 million to $197 million.


Abstract - Laboratory experiments were performed in clear and turbid water to determine the effects of prey size, orientation and movement on the reactive distance of largemouth bass, Micropterus salmoides, when feeding on crayfish, Procambarus acutus. In clear water, the reactive distance increased linearly with an increase in prey size and prey movement resulted in a significant increase in the reactive distance. Prey orientation (head-on versus perpendicular) did not change the reactive distances. In moderately turbid water, the reactive distance did not increase with increased prey size, and prey movement did not result in any changes in the reactive distance. The absence of any effects of prey orientation in clear water or prey movement in turbid water is inconsistent with results from studies using different species (primarily planktivorous fish). I propose that largemouth bass change their foraging tactics as prey visibility changes. When prey are highly visible (low turbidity), predators attack (react) only after prey recognition, which is based on multiple cues such as prey size (length and width) and movement. When prey are less visible (high turbidity), predators attack immediately upon initial prey sighting which does not depend on prey size or movement.


Abstract - Independent and interactive effects of phosphorus and clay loading on pelagic community organization and productivity were tested in a small piedmont lake in North Carolina. Twelve limnocorals (2 m diameter and 3 m deep) were used for field manipulations. Treatments (in triplicate) were unaltered controls, P loading of 3.3 mg/m²/day, kaolinite clay loading of 100 g/m²/day and combined clay and P loading. Fertilization with P significantly increased rates of turbidity reduction in comparison to controls (Secchi depth increasing at 7.2 vs. 5.8 cm/day) and also significantly lowered sustained turbidity in treatments under clay loading. Clay loading reduced net community productivity (NCP), Chlorophyll a concentrations and algal cell numbers. Suspended clay also caused a shift in algal community composition; Trachelomonas superba and other flagellates replaced the otherwise dominant blue-green Spirulina major. Fertilization with P increased NCP and algal densities and favored development of the N2 fixing blue-green algae Anabaena spiroides and Anabaena circinalis. Combined P and clay loading produced intermediate values of turbidity, NCP and Chlorophyll a. Simultaneous clay loading eliminated the influence of P fertilization on algal community structure, yielding an assemblage dominated by flagellates. Clay turbidity also caused a shallowing in the daytime distribution of zooplankton.


Abstract - The effects on zooplankton community structure of P loading and two different kinds of suspended sediments were tested in a small lake. Limnocorrals were used in a complete, triplicated, six-treatment-block design. Treatments were loading with P, kaolinitic clay (K), K=P, montmorillontic clay (M), and M=P plus a control without additions. P fertilization caused blooms of blue-green bacteria and resulted in reductions of the dominant copepod (Diaptomus mississippiensis) and cladocerans (Diaphanosoma brachyurum, Bosmina longirostris and Ceriodaphnia reticulata), while causing a 5-fold increase in rotifers (mostly Keratella cochlearis). Zooplankton in the K and K=P treatments were similar to the control, but cladoceran species other than Diaphanosoma were reduced. M was more detrimental to zooplankton than K, causing a 10-fold decrease for all crustaceans. We attribute this in part to lower algal densities in the M treatment. Simultaneous P loading mitigated the effects of M on Diaphanosoma, rotifers and copepods and may involve a transfer loop in which dissolved organic C adsorbed on clay becomes available to filter-feeding zooplankton. The effects of mineral turbidity apparently cascaded up the food chain, with both kinds of clays reducing densities of Chaoborus larvae.


Abstract - A two year study in Breathitt County, Kentucky, indicated that terraces can effectively control runoff and erosion on surface mine benches. In an area where the spoil was predominantly shale, peak flows on a terraced plot averaged 65 percent less than on the control plot, sediment yield averaged 52 percent less and total runoff averaged 42 percent less. Comparable figures on a set of plots having substantial amounts of sandstone were 65, 70 and 6 percent, respectively. Average storm runoff duration was 1 percent higher on the terraced plot of each pair.


Abstract - EPA and a number of states have placed emphasis on controlling sediment laden runoff from erosion at construction sites. Here's how annual soil losses compare: Well established areas, such as cities, lose about 0.5 tons per acre. Farmed areas shed an average of about 4 tons per acre. Disturbed urban land erodes at an average 69 tons per acre. Any unprotected graded land may lose up to 180 tons per acre. Contractors, land owners and the public are now paying for the effects of soil erosion and they will continue to pay more. Why? Because it clogs waterways, plugs culverts and silts other properties.


Abstract - Gravel-filled traps were buried in the beds of streams draining steep logged and unlogged catchments of the Dazzler Range in northern Tasmania, Australia, and removed after storm events to assess infiltration of fine (less than 1 mm) material into the bed. All stream catchments were geomorphically similar, over similar altitude ranges and had moderately erodible sandy-clay soils on 25-35 degree slopes. Study catchments were selected to control for aspect, logging treatment and coupe age. Fine sediment infiltration into the stream bed was assessed for 15 tributary ephemeral streams in logged areas and 11 streams in unlogged areas. The logged catchments had been clearfelled in three time periods - 1990-1991; 1988-1989; and 1986-1987 - all by skyline cable logging. Trap yield was also assessed in riffles of the perennial valley floor streams upstream and downstream of the junction of six logged and six unlogged tributaries and upstream and downstream of four old but actively used road crossings. Trap yield was significantly higher in logged than in unlogged ephemeral streams for size fractions ranging from less than 125 to 500 ,um by factors ranging from two to three, but not for sediment between 0.5 and 1.0 mm. Trap
yield of organic sediment of less than 125 μm declined with time after logging and burning whereas inorganic sediment yield showed no clear trend with coupe age. Trap yield of 0.5-1.0 mm organic sediment was also significantly enhanced by logging and by burning. Sediment yield of streams logged in 1986-1987 was not significantly higher than for control streams, whereas inorganic sediment and 0.5-1.0 mm organic sediment yields were highest for recently burnt coves. A significantly greater number of increases in trap yield occurred between riffle pairs of valley floor streams adjacent to junctions of logged tributaries when compared with control riffle pairs. Logged tributary junctions were associated with an increase in the organic content of sediment. Road crossings were associated with large increases in infiltration in adjacent riffle pairs, 30-50 years after construction. Current forest practices do not protect ephemeral headwater streams from enhanced sediment inputs, the long-term significance of which is unknown. Recovery of sediment fluxes in these streams to background levels appears to take 5 years or longer.


Abstract - Age determination and pollen analysis were used to obtain data on erosion rates and land use history from sediment cores taken from Frains Lake near Ann Arbor, Michigan. When forest is removed from a watershed the increase in sediment yield may be between 10 and 100 fold. In many cases, erosion has been greatest in recent years when suburban housing was built. It is suggested that a comparison of different parts of the country and worked would yield useful information on the susceptibility of different kinds of landscape and soils to erosion following disturbance by humans.


Abstract - Ogoki River diversion had minimal effect on Lake Nipigon fisheries where whitefish, pike and lake trout fisheries were declining. Winter drawdowns in the lake increased minimally but not enough to affect egg incubation. Some siltation problems were noted in the northern part of the lakes where diverted water enters. Problems were recorded higher up the diversion route where walleye were adversely affected by increased turbidity.


Abstract - This paper reviews the types and causes of fluctuations in abundance on lake whitefish as well as summarizing information on reproduction, development and early life history. Among the environmental factors affecting abundance were water level fluctuations, turbidity and siltation (especially in relation to spawning sites).

DEELDER, C. L. 1970. Synopsis of biological information on the eel, Anguilla anguilla. FAO Fisheries Synopsis 80, Rome, Italy.

Abstract - Fishermen reported that discoloration of the Bann River (Northern Ireland) i.e., by peat bog drainage, made eel fishing better than under the same conditions without turbidity.


Abstract - While sedimentation rates are generally within design requirements in most of the nation's reservoirs, many small reservoirs, particularly those in watersheds where land in intensively used, are losing their storage capacity much faster than originally anticipated.


Abstract - The sediment trap efficiency of a 2.7 acre reservoir was measured during a 2-year period. While the overall trap efficiency was about 77%, monthly trap efficiencies ranged from 9% to 100%. Trap efficiency was generally much higher for storms accompanied by high sediment loads and high sediment concentrations. Trap efficiency was generally low for storms producing low sediment concentrations. Highly variable flow detention times may explain part of the variation in storm trap efficiencies.


**Abstract** - High levels of suspended sediments and increased sedimentation of spawning and foraging grounds can significantly reduce habitat suitability. Increased suspended sediment loading can result in a variety of negative impacts including:

(i) **Abrasion** - causing damage to eyes, scales and gill tissue increasing the fish's vulnerability to infection and disease and reducing their ability to absorb oxygen;

(ii) **Turbidity** - feeding efficiency of visual feeders will be reduced. Primary productivity of waterbodies will also be reduced because of limited light penetration;

(iii) **Aggradation** - settling of suspended sediment particles may cover spawning and foraging grounds, reducing spawning success and stream productivity; and

(iv) **Isolation** - suspended sediment absorbs radiant energy which increases the stream temperature. Altered temperature regimes may result in conditions favoring a change in species abundance and/or diversity.

As a general guideline it is recommended that, for waters having background levels of total suspended solids less than 100 mg/l, values not increase by more than 10 mg/l. For waters where suspended solids exceed 100 mg/l, increases should not exceed 10% of the background levels.

Increased suspended sediment concentrations and inflow can be associated with most development activities in a watershed including forestry, agriculture, stream crossings, mining, hydrotechnical projects and urban development.

Erosion is also a natural process which contributes suspended sediment to waterways. The principal factors influencing the existence or extent of soil erosion are precipitation, soil characteristics, topography and vegetation. Erosion control measures must address one or more of these factors to be effective. Principles of erosion and sediment control include:

- Fit the project to the terrain
- Minimize the duration of soil exposure
- Retain existing vegetation wherever possible
- Grade the disturbed soil to a stable slope
- Encourage re-vegetation
- Divert runoff away from exposed soil
- Keep runoff velocities low
- Trap sediment before it can cause damage

The technology for erosion and sediment control is well developed. A number of techniques and their application include riprap, slope modification, re-vegetation, check dams, sediment traps, brush barriers, silt fences and forest floor filters. The implementation of economical control measures, when and where required, can reduce the environmental damage caused by erosion and sedimentation. The effectiveness of the mitigation techniques described may be increased by combining more than one method.

**DEPARTMENT OF FISHERIES AND OCEANS AND BRITISH COLUMBIA MINISTRY OF ENVIRONMENT, LANDS AND PARKS. UNDATED. Stream stewardship: A guide for planners and developers. Victoria, British Columbia. 50 p.**

**Abstract** - Land development frequently creates increased soil erosion. Soil exposed during clearing, grading and material stockpiling operations can be easily transported into streams destroying their
as fish habitat. The objective of erosion and sediment control measures is to stabilize disturbed soils and manage surface runoff to intercept sediments before they leave the site.

During the construction process, it is necessary to plan and implement sediment control measures to ensure that any aquatic habitat, which may be affected onsite of downstream from development activities, is protected from sediment contamination. Where site conditions make it difficult to control erosion completely and where sediment will affect sensitive fish habitat, it will be necessary to construct and maintain sediment control structures. Such structures should be considered as a last line of defense and consideration should be given to ensure that these facilities are well maintained and functioning properly at all times.


Abstract - All aspects of timber harvest, from felling and skidding to road construction, have major impacts on the quality and productivity of aquatic ecosystems. Timber removal affects water yield, water quality, water temperature, habitat structure and bank and shoreline stability. Any activity that results in the delivery of sediment to aquatic systems adversely affects the quality of fish habitat. Roads are the most significant source of sediment. Poor road location, inadequate drainage, unstable cuts and fills, and improper stream crossings contribute to erosion. Guidelines are available for designing access roads and water crossings. Road design standards should adequately meet the fishery management objectives. The location and construction of road systems must be specified, monitored and controlled to ensure resource protection of aquatic resources. Road locations near and in areas of concern are most critical. Stream crossings should be planned and designed properly. The location of roads by logging operators from the seat of a crawler tractor is no longer an acceptable method of conduct.

Proper road maintenance must be provided during the life of the road. Road maintenance is required to minimize sedimentation of waterways. Erosion control throughout road construction, use and abandonment is an ongoing process. Restrict the use of roads during rainy periods and during spring break-up to minimize damage to road surfaces, drainage structures and road profiles.

When a road is physically abandoned, appropriate measures should be taken to prevent erosion and sedimentation of waterbodies. This may include removal of culverts and bridges, grading slopes to stable angles, installing water bars, and revegetating exposed mineral soil. Active and abandoned roads should be inspected annually and necessary repairs planned. Good road management practices apply to all road types. Low-standard tertiary roads have the potential for causing significant adverse impacts on aquatic resources.

In general, roads and landings are not permitted in areas of concern involving critical fish habitat, especially those that include coldwater fisheries. Here, harvesting is restricted entirely or is limited to selection methods. Timber production is not the driving factor in these areas. All efforts should be made to avoid...
damaging banks and shorelines, to keep debris out of waterways and to minimize sedimentation. Harvest restrictions are less demanding for coolwater and warmwater streams and lakes. Trees should be directionally felled away from streams and lake shorelines. Winches should be used to remove timber and keep equipment away from banks and shorelines. For fish habitat protection, buffer strips of undisturbed vegetation should be 30 m wide (from each bank) where sideslopes are less than 15% and up to 90 m wide for sideslopes greater than 40%. These widths may need to be larger to ensure the wind-firmness of the stand.

Foresters and fisheries biologists need to coordinate the collection of resource inventory information during the forest planning process. This data is necessary in evaluating the impacts of management alternatives. Timber management guidelines are provided for protecting fish habitat and can be used in planning harvest activities in or near riparian areas. These guidelines should be used in developing timber management plans and stand prescriptions. Operations in these "areas of concern" should be evaluated by an interdisciplinary team of resource managers. Mitigative measures and the conduct of logging should be specified in management plans, stand prescriptions, timber sales contracts, harvest approval documents and license agreements.


Abstract - Of the factors, other than intensity of fishing, relating to the abundance of certain fishes in western Lake Erie, turbidity of the water is important. A highly significant degree of correlation (r = 0.79) has existed for the past 10 years between the mean April-May turbidities as measured at Cleveland and the total Ohio sauger catch three years later. There is considerable evidence that the lake turbidities during these months bear a significant relationship (r = 0.60) to the mean precipitation in the same months at several points along the southwestern shore of the lake. It is suggested that higher turbidities may act to prevent stickiness in sauger eggs, may give young fry protection from predators and may facilitate the young saugers feeding by concentrating plankton organisms near the surface.


Abstract - Many freshwater fishes occur in very turbid waters. Some species may avoid such waters and fishes may not thrive in them because of various indirectly harmful effects on their environments of the turbidity and of the deposition of solids. Developing eggs of fish, as well as fish food organisms, may be smothered by deposits of silt. However, direct injury to fully developed fish by nontoxic suspended matter apparently has been demonstrated convincingly only in tests with concentrations which are most uncommon in both natural and polluted waters.
Wallen (1951) reported results of numerous experiments designed to determine the direct effect of montmorillonite clay turbidity on warmwater fishes of 16 species. He cites many other references. Usually he observed no behavioral reactions of the experimental fish until the turbidity values neared 20,000 ppm (as SiO2) and some species reacted only to much higher turbidities. With the exception of only a few cases other than turbidity, the fish died only when the turbidity values were well above 50,000 ppm. According to Wallen, most of the experimental fishes "enduring exposure to more than 100,000 ppm of turbidity for a week or longer, but these same fishes finally died at turbidities of 175,000 to 225,000 ppm. Lethal turbidities caused the death of fish within 15 minutes to 2 hours after the onset of exposure. Fishes that succumbed to turbidity had opercular cavities and gill filaments clogged with silty clay particles from the water".

Clogging or blanketing of the gills of fish with matter suspended in water, such as soil particles, fibers and precipitates, is not unusual when fish are exposed to various toxic solutions containing the suspended material. Injury to the gills by harmful dissolved substances probably results in the inability of the fish to keep their gills clean. The clogging of the gills may possibly contribute sometimes to the injurious action of the toxic media, without being the primary cause of injury, which it may seem to be. Interference with gill functions ascribable to chemically inert suspended matter as the primary cause or factor apparently can occur only when the concentrations of suspended matter are exceedingly high so that it is of little practical importance.


Abstract - A quick and reliable method of measurement is necessary to set standard limits on the amount of suspended sediment to be tolerated in streams near land use operations. Turbidity measurements may be useful if a major portion of the total turbidity is contributed by settleable solids, if a relationship exists between turbidity reading and weight per unit of volume of suspended sediment and if a reliable meter is available. Water with turbidity readings greater than one JTU (Jackson Turbidity Unit) is generally composed mostly of settleable solids unless distorted by color. Non-filterable and total dissolved solids contribute variable amounts of light penetration reduction. Percentage contribution to turbidity of settleable solids is highly variable from sample to sample and from station to station.

A high correlation exists between turbidity readings and weight for individual sediment types of suspension, but a poor relationship exists when sediment type is varied. Experiments conducted on the Hach model 2100, the Hellige and the Jackson Candle turbidimeters resulted in a highly significant difference (P < 0.01) between readings on the same sample of suspended sediment. Turbidity is a questionable measure of suspended solids in water. A more accurate index would be suspended solids measured gravimetrically.


Abstract - A programmable calculator connected to an interface circuit can control automatic samplers and record streamflow data. The circuit converts a voltage representing water stage to a digital signal. The sampling program logs streamflow data when there is a predefined deviation from a linear trend in the water elevation. The calculator estimates suspended sediment discharge from rating coefficients for the gauging site. When a threshold value of accumulated suspended sediment discharge is reached, the calculator sends a signal to the interface circuit that activates a pumping sampler. The sampling program is easily updated and data are transferred to a computer by using a digital cassette recorder. This system increases sampling flexibility and efficiency.


Abstract - Correlation curves were developed relating nephelometric turbidity units (NTU) with total suspended solids (TSS) for diked upland dredged material placement site effluents of three U.S. Army Corps of Engineers (COE) maintenance dredging projects in the Chesapeake Bay, Maryland. The procedure was developed in an effort to ensure compliance with Maryland's 400 milligrams per liter (mg/l) TSS standard for COE dredging projects. Samples of the sediments to be dredged were collected and analyzed, correlating turbidity readings with TSS determined by standard gravimetric techniques. The correlation curves were provided to the COE inspectors to measure the effluent with a turbidity meter and to extract a TSS concentration from the correlation curve. Samples collected and analyzed after initiation of the dredging indicated that the correlation curves were an overestimate of the actual TSS concentrations of the effluent discharges. The procedure, endorsed by the State of Maryland, provided immediate on-site TSS analysis eliminating the previously encountered delays in obtaining gravimetric analysis of effluent discharges and potential contract management problems.


Abstract - Analysis of gravel samples is reported for five streams in southeast Alaska. A 10 cm diameter cylinder sampler was used, with sieve analysis presented as percent fines, by weight. No consistency was apparent in the levels of fines, which was less than 0.833 mm, from stream to stream. The monitoring standard of percent of fines less than 0.833 mm detected wide variations in fines, and demonstrated long term trends in the Kadaschian River. The highest percentage of fines was approximately 13 percent for three streams.

Increased escapement goals are advocated for streams suspected of having increased amounts of fines.


Abstract - Despite the high silt loads of its rivers through the recently accelerated erosion of soils in South Africa, there appears to have been no intensive and direct work upon the effects of this siltation upon the aquatic macrophyte vegetation. Available data indicate a general decline in the aquatic vegetation as a result of the changed aquatic environments. The need for research on the aquatic and fringing vegetation is emphasized, and the need for conservation of the fringing vegetation along natural drainage lines.


Abstract - Soil erosion measurements on small upland watersheds totaling 229 watershed-years show that most of the total erosion occurring over a long term period of record comes from a few large storms. Nine 1-ha (2.5 acre) watershed containing residual soils with silt loam surfaces on B and C slopes were farmed under a corn-wheat-meadow-meadow rotation with moldboard plowing, disking and harrowing in April of the corn years for seedbed preparation and cultivation for weed control. After corn harvest, stalks were disked prior to winter wheat seeding. There was no tillage in the wheat or meadow years. Erosion from the contoured watersheds averaged 30% of that from the straight-row treatment. With more than 4,000 rainfall events during the study period, the five biggest erosion-producing events on each watershed accounted for 66% of the total erosion over 28 years. On one watershed, one storm caused more than half of the long term measured erosion.

Abstract - Samples of suspended microscopic particles were collected from a small stream (Shelligan Burn) over a distance of 3.6 kilometers in conditions of low and high flow and from a longer stream (River Almond) over a distance of 27 kilometers during average flow.

In the low flow conditions in the Shelligan Burn the commonest material was non-cellular detritus with living diatoms all originating from the bed of the stream as the only relatively abundant component. The concentration of some species of diatoms varied considerably in the course of the stream, others were more evenly distributed. Zoospores of Chlorophyceae were in much higher concentration in one short stretch of the stream whereas filaments of the same group were fairly evenly distributed. Backwaters contained lower concentrations of certain components presumably due to local sedimentation in the decreasing rate of flow. No clear differences were found between samples from pool stations and those from nearby riffles. A sample from the mouth of a small tributary contained more of certain materials originating from its denser bankside vegetation and less moss because of its sparseness on the unstable bed. Its diatom flora was different from that of the main stream having fewer of the epilithic and epiphytic species but more of the mud-surface ones. As there was no significant downstream increase in the volume of flow the absolute abundance of particles was relative to their concentration.

In one flood condition in the same stream there was a downstream increase in the concentration of suspended monocotyledonous tissue and non-cellular detritus. The absolute abundance of detritus at the most downstream station was at least forty-five times greater than it was in the low-flow conditions.

In the River Almond the commonest materials in suspension were again non-cellular detritus and diatom cells. There was a distinct downstream increase in the concentration of the diatoms and also of Chlorophyceae. The volume of flow increased downstream so that between the most upstream and downstream stations the absolute abundance of diatoms increased 100 times and Chlorophyceae increased 1000 times.


Abstract - Erosion silt alters aquatic environments, chiefly by screening out light, by changing heat radiation, by blanketing the stream bottom and by retaining organic material and other substances which create unfavorable conditions at the bottom. The present erosion silt loads of our inland streams have reduced the millionth intensity depth for light penetration from 15,000 mm to 34,000 mm or more to 1,000 mm or less, the summer average for the Mississippi River (1934) above Alton, Illinois, being less than 500 mm. Erosion silt in river water acts chiefly as an opaque screen to all wave lengths of visible light, but in very muddy waters a small differential was found favoring the transmission of scarlet-orange light.
Erosion silt alters the rate of temperature change in river waters. This is particularly significant in deep river lakes where thermal stratification of the water produces a stratification of the silt load, a warm muddy river, the hyperlimnorrheum flowing over a clear, cold lake, the hypolimnion, during the summer months.

Excepting the very quiet portions, erosion silt is quite uniformly distributed throughout the waters of rivers even in very deep holes and in those river lakes in which there is no thermal stratification. The amount of organic material carried to bottom with erosion silt ranged from 8 to 12 percent of the dry weight of the mud on the bottom of Lake Pepin and Lake Keokuk. Erosion silt does not materially alter the salt complex or the amount of electrolytes in river waters.

Experimental studies demonstrated that layers of fine silt from one fourth of an inch to one inch thick produced a very high mortality among freshwater mussels living in gravel or sand beds and in water which was otherwise favorable.


Abstract - In a review of the effects of suspended solids on freshwater biota for the U.S., Sorenson et al. (1977) pointed out that acute effects on specific organisms were difficult to demonstrate for suspended solids; succession and/or adaptation can allow communities to be maintained even though specific organisms differ. Suspended solids have a significant effect on community dynamics when they interfere with light transmission. The role of sediments as a reservoir of toxic chemicals has been demonstrated. Relatively high concentrations of suspended solids are needed to cause behavioral reactions or death in a short time in fish. Recovery is fairly rapid when fish are returned to clear water. Lloyd (1985) concluded that an increase in turbidity of 25 NTU in shallow, clear-water systems may potentially reduce stream primary productivity by 13-50% or more and be associated with an increase in suspended sediment concentration of approximately 25-100 mg/l. A 5 NTU increase in turbidity in clear-water systems may reduce the primary productivity volume of lakes by approximately 75%, reduce stream productivity by 3-35% or more and be associated with an increase in suspended sediment concentration of approximately 5-25 mg/l. Most flowing waters have considerable variation in suspended solids from day to day. Because this natural variation is so great it is not desirable to establish fixed rigid guidelines. Suspended solids should not exceed 10 mg/l when background suspended solids concentrations are equal to or less than 100 mg/l. Suspended solids should not exceed 10% of background concentrations when background concentrations are greater than 100 mg/l.


Abstract - A small coastal stream in the San Francisco Bay area of California, USA, received the discharges from a drinking water filtration plant. Two types of discharges were present. Discharges from filter backwashing were 3-4 times base stream flow, occurred 10-60 times per day, contained fine sediments and each lasted about 10 minutes. The other discharge was a large steady flow of relatively sediment free water from occasional overflow of the delivery aqueduct which generally lasted several hours a day.

Samples of invertebrates from natural substrates had significantly fewer taxa and lower density at the two stations below the backwash than at the two above. However, when stable artificial substrates were used, there were no significant differences among all four stations. The aqueduct apparently had no effect because the invertebrate community at the station upstream of the backwash but downstream of the aqueduct was statistically similar to the station above the aqueduct. To test for acute toxicity, we exposed additional artificial substrates to short term simulated backwash conditions. These exposures had no effect on invertebrate density or drift. Three spine stickleback, *Gasterosteus aculeatus*, populations were also significantly reduced at the two downstream stations and were made up mostly of larger, adult fish. Prickly sculpins, *Cottus asper*, restricted to the most downstream station, were emaciated and had poor growth, probably as a result of scarce benthic food organisms. Artificial redds with eggs of rainbow trout, *Salmo gairdneri*, had significantly lower survival at two stations below the plant backwash (30.7% and 41.8%) than at the one above it (61.4%). Hatchery rainbow trout held in cages below the treatment plant from 7 to 37 days survived and continued to feed.

Thus, the major effect of the water treatment plant on fish and invertebrates probably was not from acute toxicity in the discharges or the occasionally large discharge of clean water from the aqueduct but was from the fluctuating backwash flows containing fine sediment that displaced small fish downstream and created unstable substrates for invertebrates.

The filter plant that we studied is a direct feed type (that is no sedimentation before filtration). These generally require greater frequencies of backwashing than do conventional plants and may therefore have greater biological impacts. Direct feed plants are becoming increasingly popular throughout the world for the most part because they are cheaper to build and operate. But if the associated biological problems are mitigated, than the cost savings of direct feed compared to conventional plants may be lost.


Abstract - Sixty-two streams in northern California were studied to evaluate the impact of logging with and without streamside buffer strips; the buffer strips were evaluated to test their effectiveness with specific reference to macroinvertebrate communities.

Changes in logged streams were similar to some of the changes caused by development, such as sewage effluents and thermal discharge and from runoff from agricultural activity. Changes that occur involve increased water temperature, discharge with higher peaks and lower base flows, increased suspended and deposited sediments, and increased nutrient concentrations. These changes are more subtle types of water quality degradation than sewage effluents and toxic wastes. The study found that logging without buffer strips causes a substantial change in the benthic invertebrate population compared to unlogged streams, while streams with buffer strips at least a total of 30 meters wide or 15 meters per side have invertebrate populations and physical characteristics indistinguishable from unlogged streams. Streams with less than 30 meter buffers generally show the same impacts as unprotected streams. Streams without protective measures have invertebrate diversities significantly lower than unlogged streams for at least 10 years following the cessation of logging activities. In this study, lowered diversity of invertebrates, together
with increased total population and dominance of a few taxa, are used as indicators of detrimental impacts. Sedimentation, nutrient loss and fish populations were not measured but it was assumed that changes in these areas occurred in the streams studied based on findings in other studies.

Buffer strips of at least 30 meters in width effectively protect streams from the detrimental effects of logging, preserving both the diverse riparian habitats and the aesthetic value.


Abstract - During 1980-81, transport of bedload sediment and channel morphology were determined at Trap Bay Creek, a third order stream that drains a 13.5 square kilometer watershed on Chichagof Island in southeast Alaska. Bedload sediment was sampled for 10 storms: peak flows ranged from 0.6 to 19.0 cubic meters per second and transport rates ranged from 4 to 4400 kilograms per hour. Peak transport rates typically occurred during peak streamflow. Transport of bedload sediment at a riffle over 1600 meters upstream from the mouth of the watershed was greater for most storm events than that measured at another riffle 22 meters downstream. Transport was greatest at the downstream riffle, however, during the most severe storm of the season and during another storm one week later. Both magnitude of storm and availability of sediment appeared to determine the transport of bedload sediment in Trap Bay Creek. Regression relationships were developed between streamflow (independent variable), several transport variables and particles sizes in two diameter classes. Analysis revealed that total bedload discharge was positively correlated with streamflow; transport of either diameter class, however, had no consistent relationship with streamflow from one storm to the next. Relationships between particulate organic matter and streamflow were also highly variable from storm to storm. Observations indicated that large organic debris, especially fallen trees, played a major role in determining channel morphology; tidal action was an important factor affecting channel characteristics in the lower 1300 meters of the channel.


Abstract - This is the first of a series of reports on water quality criteria for European freshwater fish prepared for and approved by the European Inland Fisheries Advisory Commission. The background of the project is described and reasons for establishing water quality criteria for fish explained. This is followed by a literature survey of the direct effects of solids in suspension on death or survival of fish, their growth and resistance to disease; suspended solids and reproduction; effects on behaviour; effect on food supply; and total effect of suspended solids on freshwater fisheries. Finally, tentative water quality criteria are suggested.


Abstract - Grandy Dam, is located on the Colorado River about six miles northeast of Granby, Colorado. Prior to the closure of Granby Dam in September, 1949, and to a smaller degree thereafter, a large quantity of sediment was introduced into the Colorado River. It was agreed that removal of the sediment was necessary to preserve the productivity of the stream. A scheduled water release to flush away deposited
sediment was developed. The operation was intended to coincide with the breakup of ice in the river so that scouring action of the floating ice would aid in dislodging sediment from the rocks. Maximum flows were limited to 365 cubic feet per second (cfs). Curtailment or cessation of operations was to take place in the event of the formation of ice jams. The operation would also be terminated if it failed to accomplish further removal of sediment.

It is considered that the flushing operation achieved a substantial degree of success in restoring habitat conditions that are favorable to organisms which serve as food for trout. The removal of sediment from riffles was of particular significance as riffle areas are normally the most important segments of a stream with regard to the production of food organisms. Sediment deposited at the edge of the stream channel during the flushing operation constitutes a threat to future production of trout food as this sediment, if washed into the stream, would cause a recurrence of unfavorable habitat conditions. Releases at the rate of 365 cfs would probably have been more effective in removing sediment from pools and might also have permitted less to settle along the sides of the stream channel.


Abstract - The term "sediment", as commonly used by fishery biologists, means fine sediment and excludes up to 90% of sedimentary material in streams. In mountainous terrain, hill-slope erosion (primarily mass soil movements) provides periodic inputs of sediment into stream systems, often during periods of high flow when two major sediment transport mechanisms are active: (1) suspended sediment transport and (2) bedload transport. Suspended sediment consists primarily of silt and clay sized particles that may be rapidly transported downstream and locally deposited on floodplains and over bank storage locations or that may infiltrate into gravel interstices of the bed. Bedload transport, consisting primarily of coarse sands or larger particles, is complex and sporadic, and has major implications regarding channel morphology and the quality of spawning gravels. It is greatly affected by large roughness elements (logs, boulders, bedrock outcrops, etc.). Hence, the impacts of sediment on fish habitat are influenced by both sediment availability and the subsequent routing of these materials through the channel system.

The effects of fine sediment on aquatic life have been studied intensively for more than three decades, both in situ and in the laboratory. Laboratory studies have demonstrated potential negative effects of fine sediment on macroinvertebrates, on survival and emergence of salmonid embryos and alevins, and on growth of salmonid fry. But there are significant difficulties extrapolating these findings to the field. Nearly all laboratory survival studies have used simplified unnatural gravel mixtures to test incubation and emergence of salmonid fry. Also, mitigating factors in streams, such as structural roughness elements and spawning behaviour of female salmonids, complicate direct field application of laboratory studies. The relatively few studies dealing with the effects of sediment from forest management in natural environments have been less conclusive. Some negative effects observed in the laboratory also occur from acute of chronic sedimentation in the field. The problem with interpreting the results of field studies is that increased fine sediment from forest management is almost always accompanied by other environmental effects.
Also, field studies have shown both increases and decreases, in salmonid populations associated with forest management. The studies have generally failed to isolate the effects of fine sediment from other habitat changes.

A more holistic view of the role of sediment in stream ecosystems is needed. Undisturbed streams in the forest have sorted abundant sediments in their channels and maintained an equilibrium between sediment input and sediment routing. An abundance of large organic debris and other roughness elements played an important role in the storage and routing of sediments. Forest management has broadly changed sediment storage and equilibrium in streams throughout much of the western United States. The general result has been a concurrent loss of roughness elements and accelerated routing of sediment through fluvial systems. There is evidence that stable channels containing stored sediment and large organic debris are more devoid of sediment or channels that are aggregated and unstable. Thus there seems to be a broad middle ground between too much and too little sediment in salmonid habitats.

Forest practice rules designed to minimize introduction of fine sediment in streams are justified, but in themselves do not ensure protection of salmonid habitats. These rules might result in improved water quality and a reduction in fine sediment in gravels, but they do not ensure protection of the physical structure of salmonid habitats. In fact, large losses of productive habitat have occurred while these rules were in force. The long term emphasis of forest practice rules on control of water quality and fine sediment must be expanded to a more holistic view of salmonid habitat. Protection of streamside vegetation and physical structure of rearing habitat for juvenile salmonids must be given equal emphasis.


Abstract - Three experimental stream ecosystems were used to determine the effects of sediment and contaminated sediment: one stream received 1.7 gm/1 uncontaminated sediment for 2 hours each week for 6 weeks; one stream received 1.7 gm/1 contaminated sediment (50 to 1600 ppm triphenyl phosphate applied in increasing doses each week) for 2 hours each week for 6 weeks; and the third stream was maintained as a control. Each stream was monitored for changes in nutrient dynamics, leaf decomposition, primary production and invertebrate dynamics. Both sediment and sediment/triphenyl phosphate altered the drift dynamics of benthic invertebrates. Invertebrates in the sediment treatment exhibited delayed nocturnal drift while those in the sediment/triphenyl phosphate treatment drifted immediately once a threshold of toxicity was reached. Both sediment and sediment/triphenyl phosphate decreased the percent similarity of benthic invertebrates, reduced the drift of filamentous algae, increased the production of rooted flora and increased net nutrient retention. However, neither treatment altered leaf decomposition rates nor affected benthic invertebrate dynamics (total number, number of species or diversity) or insect emergence.

Abstract - With the growing concern of nonpoint pollution sources and sediment loadings of streams, the actual practices employed by designers should be closely evaluated. Research needs for boundary erosion remediation techniques such as the sedimentation basin also need to be aimed at realistic goals for urban and construction sites. Advancements have been made toward improving basin trapping efficiencies in the mining industry where permanent pools are typically employed; however, these advancements have, for the most part, not been adopted for use in urban and construction areas where the basins are typically dry until a runoff event occurs. Researchers should evaluated current recommended guidelines realizing that errors in design and construction techniques will occur but that some methods may be found to have a higher tolerance for errors than others. If this issue is not addressed, we may eventually have to control effluent limits in one form or another even for areas currently too small to require regulation.

Erosion and sedimentation control in regional and site planning. J. Soil and Water Conservation, 36(4): 199-204.

Abstract - Planning erosion and sedimentation control methods is but one aspect of physical planning. Planners are equally concerned about stormwater impacts, socioeconomic impacts, aesthetics and a host of other objectives. The planner seeks to make all site components work together to accomplish the goals of the owner and the public and to use the land in a way that is safe, stable and protective of natural and cultural resources.

I have tried to bring together the known erosion and sedimentation control methods available to planners. There are more methods than most planners realize and this review identifies alternatives that planners can build into their plans.

Erosion and sedimentation control methods are deeply embedded in the location, type and arrangement of land use. They cannot be added to or subtracted from any given plan without affecting other aspects of the plan. And other aspects cannot be modified without affecting erosion and sedimentation control methods.

These methods are at the heart of physical planning. To be implemented effectively, they must be identified and considered in the early planning stages, which confirms that physical planners are as important to the solution or erosion and sedimentation problems as has been suspected.


Abstract - Rivers transport large quantities of sediment during ice breakup. This transport causes physical, chemical and biological changes to occur in the water or on the river floodplains, banks and bed. There are several breakup processes that initiate sediment motion or enhance transport. In this paper we quantify the bedload and suspended sediment transport capacities of an ice-covered river with the shear stress on the bed and a composite shear stress, respectively, obtained from a model that considers coupled flow and ice motion. The abrupt motion of a river ice cover decreases the resistance to the flow, causing surges to develop that significantly increase the shear stresses and the sediment transport capacities. A case study of breakup on the Connecticut River is generalized by varying model input parameters that may be
uncertain, including the relative roughness of the ice and the bed, the ice velocity and acceleration through time, the flow velocity prior to ice motion and the energy gradient of the flow. The results presented include the surging flow velocities, dimensionless ice/flow velocity ratios, and dimensionless shear stresses for the ice zone, bed zone and composite channel. In each case we quantify the relative increases in the shear stresses through time that are a direct result of the ice motion and parameter variation.


Abstract - In 1975, a study was initiated in the nearshore waters of Lake Erie to evaluate the impact of open-lake dredged spoil disposal on natural benthic macroinvertebrate communities. Disposal of two types (sandy-silt and coarse sand) of dredged sediments were investigated. The results indicated that certain species were able to take advantage of the disturbed surface sediments and thrive after disposal. This dominance of opportunistic species coupled with general population density variability within each of the more abundant species indicated an unstable community structure at the disposal sites which continued throughout most of the study. The site receiving river spoils (coarser sand) appeared to readjust to predisposal conditions much faster than the other.


Abstract - Coal ash effluent from the settling basins of an electric generating station on a Wisconsin River floodplain, Columbia County, Wisconsin, modified stream habitats adjacent to the site. Both water and substrate quality were affected. conductivity, turbidity and some dissolved elements increased downstream of the effluent and alkalinity and pH decreased. Acidification of the effluent before its discharge to streams resulted in precipitation of elements (i.e., chromium, barium, aluminum) into a "floc" that coated the stream bottoms. The purpose of this paper is to summarize studies of the impact of those habitat modifications.
on stream macroinvertebrates during one pre-operational year (1974) and five post-operational years (1975-1979).

Numbers and taxa of macroinvertebrates that colonized artificial substrates were fewer downstream than upstream of the effluent and after than before operation of the generating station. Acute toxicity of young-of-the-year amphipods, *Gammarus pseudolimnaeus* occurred when the effluent was concentrated. Sublethal effects on caged crayfish, *Orconectes propinquus*, were observed as reduced metabolic rates and increased tissue levels of five elements (chromium, barium, zinc, selenium and iron). Decomposition and microbial colonization of leaves were inhibited downstream of effluent, indicating reduced macroinvertebrate food quality.

Using conductivity of the effluent as an indication of its concentration, thresholds that elicited macroinvertebrate responses occurred between conductivities of 800 and 1,000 pmhos/cm at 25°C. Habitat loss occurred where thresholds were exceeded year-round in the 5 kilometer ash pit drain. Thresholds were occasionally exceeded downstream in Rocky Run Creek where macroinvertebrate responses were variable.


**Abstract** - One externality of soil loss from cropland is sedimentation of drainage ditches. Such sediment deposits in six Ohio counties related significantly to gross soil erosion estimates calculated with the universal soil loss equation. Removal of the sediment costs an average of 45 cents per cropland acre served by the drainage ditches. This cost could be reduced nearly 25 percent with the use of common soil conservation practices.


**Abstract** - The construction of a dam on a free flowing stream changes the basic hydrological characteristics of the watercourse. The velocity of the stream is reduced and subsequent changes occur in temperature, turbidity and the quality of water. Fish are affected directly and indirectly to varying degrees, depending upon the species, by these modifications.

Because water impounded by a reservoir is necessarily held longer than water flowing in a stream, modifications of its quality are likely. The period of storage will, to some degree, modify temperature, dissolved gases and suspended solids in the water.

With the reduction of adequate spawning areas, caused by inundation of the best gravels, more and more fish are forced to spawn in the marginal areas of the spawning ground. In these marginal areas, the eggs, even though successfully deposited, may be more subject to such unfavorable influence as freezing and/or drying, siltation and scouring with changing water levels or poor circulation of water.


Abstract - The 614 million acres of undisturbed forest land in the contiguous United States contribute more than 100 million tons of suspended sediment to the nation's public waterways each year. The rates of suspended sediment production on undisturbed forest land serve as benchmarks against which the effects of intensified silvicultural activity on annual rates of suspended sediment production can be assessed. Nonpoint pollution from undisturbed forest land varies widely, ranging from .001 -.009 tons per acre per year in scattered producing areas to as much as 3.3 tons per acre per year on isolated forests in southern and Pacific coast areas. Coupling forested acres with the rate of sediment production per acre indicates that the Northwest and Southeast have the heaviest suspended sediment rates in the contiguous United States.


Abstract - Sediment loading manifests itself in several ways:

- burial of existing substrates which renders rock and gravel substrates unsuitable for fish spawning and alters the distribution of macrophytes and benthic fauna;
- increased turbidity resulting in decreases in primary productivity and the effectiveness of visual predators;
- contamination of the sediments;
- resuspension of sediments by storms, boating activity and construction increases turbidity and re-exposes contaminated sediment to the water column.

Rehabilitative methods include:

- reducing the input of inorganic particles through soil conservation practices, runoff control, reforestation and shoreline stabilization, control of forest fires and logging activities and treatment of waste discharges.
- reducing the resuspension of sediments by sealing fine sediments with sand cover and restricting dredging activities in areas susceptible to resuspension.


Abstract - Recent investigations on the Saskatchewan River indicate that DDT associated with suspended solids gave outstanding results in the control of black flies. Black fly larvae have been practically eliminated from other streams and rivers by the application of DDT at rates as low as 0.1 ppm but the maximum distance of effectiveness was approximately nine miles and some of the treatments were destructive to other aquatic life as well as black fly larvae. In contrast with these results, during 1948-51 larvae of Simulium arcticum were largely eradicated from sections of the Saskatchewan River for as long as 98 miles by single applications of DDT. The DDT was applied at rates as low as 0.09 ppm for 16 minutes as a 10% solution in methylated naphthalene and kerosene.
Outstanding characteristics of the Saskatchewan River include its large rate of discharge (up to 120,000 cfs), its freedom from aquatic vegetation and the turbidity of the water during certain seasons of the year. During the tests, the suspended solids content of the water ranged as high as 551 ppm and samples obtained by sedimentation from river water collected so far as 68 miles downstream from the point of application contained 0.24-2.26 ugm of DDT per gram of solids. This material consisted mainly of clay and fine silt and laboratory experiments showed that it would adsorb DDT from suspensions or 0.1 ppm of DDT in distilled water.

A study of the feeding habits of the larvae of S. arcticum showed that suspended particles in the river water, including much inorganic material, were consumed. It was also noted during the larvicide tests that the treatments produced much greater mortality of black fly larvae than of other aquatic insects which normally do not feed on small particles suspended in the water. Quantitative samples of aquatic organisms collected before and after single applications of DDT indicated that, whereas black fly larvae were almost eliminated for distances ranging from 40 to 98 miles, populations of other aquatic insects were reduced by an average of 50% in two tests and were unchanged in two others.

The results suggest that other fast-flowing rivers in which the water is turbid at the time of treatment might be treated similarly and perhaps in certain clear water streams and rivers, finely divided organic material with marked DDT adsorptive properties could be added along with the larvicide and kept in suspension.


Abstract- Although this report is limited to one set of three watersheds and a relatively short period of time, it clearly provides an estimate of sedimentation that can and does occur in the western Cascades. Where topography in this province is steep (valley sideslopes and drainage headwalls greater than 60 %) and where soils are naturally unstable (derived predominantly from tuff and breccia parent material), landslides are the major source of stream sedimentation. Their occurrence is more frequent where logging roads intersect stream channels. Slide-producing storms occur in this province at 3 to 4 year intervals and must be considered in harvesting plans.

This study suggests that we can expect a minimal deterioration in water quality arising from sedimentation where disturbance from road construction is minimized by reduction of midslope road mileage through the use of specially designed yarding systems. Where midslope roads must be constructed across steep sideslope or headwall areas, all knowledge available to the engineer should be used to stabilize roads. In the logging operation, every effort should be made to minimize disturbance to the streambed by keeping slash and debris out of the streams.


Abstract - Flooding of Southern Indian Lake for hydroelectric power development has resulted in extensive wave erosion of glacio-lacustrine clay shore material and greatly increased suspended sediment levels. Winter sedimentation on spawning grounds of lake whitefish, *Coregonus clupeaformis*, ranged from 0.03 to 0.14 g dry weight sediment per square cm. This deposited a layer 1-4 mm in depth. The sediment, low in organic content, was categorized as silty clay. The effect of this winter sedimentation on survival of whitefish eggs was tested at four sites over a range of winter sedimentation rates. Three of the sites were whitefish spawning areas. Egg survival was significantly higher for eggs incubated in cages designed to minimize exposure to sedimentation compared with survival in cages allowing full exposure to sedimentation. Winter sedimentation rates and whitefish egg survival were negatively correlated for cages designed to minimize exposure to sedimentation, while egg survival in the exposed cages was uniformly low.


Abstract - A novel device for the collection of sedimenting matter in lakes consists of a Van Dorn water sampler divided in half by a horizontal septum. During exposure, one compartment, directed upward, serves as a sampling compartment; the other, directed downward, serves as a reference compartment containing only hypolimnetic water and attached growth. The device is reliable and easy to handle. Its application in Canadarago Lake, New York, during the 1969 growth season shows that incoming phosphorus in this lake is recycled about 10 times during the growing season.


Abstract - Turbidity, caused by suspended clay particles, significantly reduced feeding rates but not size selectivity of bluegills, *Lepomis macrochirus*, preying on two size classes of *Daphnia pulex*. Bluegill feeding rates in a 3 minute period declined from approximately 14 prey per minute in clear water to 11, 10, and 7 per minute in pools of 60, 120 and 190 NTU (nephelometric turbidity units) respectively. Size
selectivity was independent of turbidity level; the proportion of large daphnia consumed was approximately 0.70 in all treatments and the control. These turbidity levels covered the range of turbidities found in North Carolina lakes.


Abstract - The flow dynamics and particle trapping characteristics of several designs of sediment traps were investigated using dye, sea-water, and deep-sea lutite in a recirculating flume and fish tank at velocities of 0, 4, and 9 cm/sec. Particles are collected through a process of fluid exchange rather than falling freely into a trap. the efficiency of a trap is therefore a function of the residence time and circulation pattern of fluid within the trap, processes which are controlled primarily by trap geometry and secondarily by current velocity. Cylinders trap particles in close agreement with the sediment deposition rate in the flume. Funnels generally undertrap, but their efficiency may be improved by constructing a baffle at the top of the funnel. Containers with narrow mouths and wide bodies consistently overtrap at an unpredictable rate of many times the actual vertical flux of particles.


Abstract - Sediment traps whose particle collection abilities had been calibrated in a laboratory flume at velocities of 0, 4, and 9 cm/sec were deployed in natural bodies of water for intercalibrate larger traps under current conditions ranging from tranquil to over 20 cm/sec. for cylinders, the height to width ration is the controlling factor of the mass of sediment collected. Traps can be scaled up in size and maintain a similar (though not necessarily correct) collection rate. Increasing current velocity will alter the collection rate of a trap in a manner which depends on the trap geometry. The size distribution of particles collected in traps is biased by trap geometry with over-efficient traps collecting more fine particles (< 63 um).


Abstract - Increasing levels of turbidity reported for parts of the Norfolk Broads over the last century have been attributed to algal growth. This paper demonstrates how the resuspension of bed sediments by a single moving boat is possible and how the diurnal variation of boat traffic movement has distinct effects on patterns of suspended sediment concentration and hence turbidity. Control of boat speed and frequency thus has important implications for the management of turbidity levels in Broadland.


Abstract - Levels of turbidity in the Norfolk Broads increased during the last century. Macrophytes subsequently declined from increased shading and thereby reduced the protection of river banks from erosion, particularly from boat wash. The diversity of fish stocks also declined with diminishing food resources. The turbidity is largely ascribed to algal blooms and secondarily to motorized boat traffic. The daily patterns of boat traffic are responsible for large diurnal variations in suspended sediment concentration and hence turbidity. Much of the boat-induced sediment remains in suspension until the next day, but the effect of boat traffic on turbidity is seasonal. control of boat speed and frequency has important implications for the control of turbidity levels in Broadland and thus for the ecological and physical management of these waterways.

Abstract - Winter in cold climates is a season when some of the well documented processes that contribute to riverbank erosion have either slowed or are inactive. For example, river hydraulic forces are often minimal and usually affect only the upper portion of the riverbed, not the riverbank directly, because river stage and discharge are frequently at an annual low and rivers are often completely or partially ice-covered. Precipitation usually falls as snow, which minimizes overland flow down the bank face during precipitation events as well. However, numerous field observations show that bank erosion does not cease during the winter. Freeze-thaw cycling and the formation of ground ice in riverbanks disrupt bank soil structure, thereby reducing soil strength, which often results in in situ bank sediment being dislodged and moved down slope via gravity. Sublimation of ground ice at the bank face during the winter also releases ice-bonded sediments and when ground ice melts in the spring a saturated zone of bank face sediment remains that is unstable and susceptible to slides. River ice can abrade and transport in situ bank soils and any sediments that have accumulated along the bank face and toe as river stage rises in the spring. If the freezing and thawing ground ice processes and river ice actions do not directly remove bank soils, they can individually or collectively disturb the soils sufficiently to make them more susceptible to erosion by processes that are active during other seasons. Thus, year-round measurements are needed to determine the seasonal extent of erosion, including the quantitative effects of winter factors. Only from such studies will we improve our current inadequate capability to predict riverbank recession.


Abstract - Rotenone, antimycin, permethrin, pydrin and Salicylanilide I were tested for their toxicities against fathead minnows, Pimephales promelas, in the presence of Canadian waterweed, Elodea
canadensis, or suspended clay. The plants had little effect on the activity of rotenone and antimycin but substantially reduced the activity of permethrin and pydrin (synthetic pyrethroids). Bentonite severely inhibited the activity of all chemicals tested. Salicylanilide I was affected least and pydrin most (27 times as much pydrin was required when 1 gm/1 of bentonite was present in 96 hour tests). The efficacy of the registered fish toxicants rotenone and antimycin is probably not significantly affected by vegetation under field conditions but is greatly reduced by suspended bentonite clay.


GIPPEL, C. J. 1989. The use of turbidity instruments to measure stream water suspended sediment concentration. Monograph Series No. 4, Department of Geography and Oceanography, University College, Australian Defence Force Academy, Canberra, Australia.


Abstract - Clay suspended in lake water may be an important factor in limiting primary production by decreasing availability of light and of nutrients. Seasonal changes in the concentration of suspended clay in a lake or reservoir are usually attributed to the periodicity in hydrological events such as flooding, stratification and mixing. From data presented here, it is evident that filter feeding plankton are also important in determining the seasonality of clay abundance. I show that monthly, predator-induced periodicities in the density of zooplankton are synchronized with the periodicities in the rate of decrease in the clay-induced turbidity of the surface waters of a tropical reservoir.


GODIN, T. I. AND R. S. GREGORY. UNDATED. Reaction times of chinook salmon fry, Oncorhynchus tshawytscha, to prey in turbid water. Draft paper to be submitted for publication, Vancouver, British Columbia.

Abstract - Suspended sediment lowers the visibility of prey to foraging fish by scattering light signals in the foreground. Turbidity can also act to increase the visibility of prey. Particulates in the water column may also scatter light in a manner which creates uniform background illumination increasing prey contrast. A multi-chambered experimental arena allowing independent manipulation of background and foreground turbidities (0-400 mg/1) was used to determine the reaction times of chinook salmon, Oncorhynchus tshawytscha, fry to variously contrasted Artemia prey over a fixed distance. Six conditioned subjects were used in the experiments. Reaction times were 20-40% faster with darkened prey as compared with light prey and 25-37% faster for prey against turbid as compared to non-turbid backgrounds. With uniform foreground and background suspended sediment levels, no significant differences in reaction times were found among conditions ranging from clear to moderately turbid (100 mg/1). Given the reduced visual range in turbid waters, the latter observation suggests the possibility of faster reaction times within the reduced visual field.


*Abstract* - Depending upon the timing, location and type of equipment used, dredging can have a significant impact on the aquatic environment if not adequately planned and monitored. The aquatic habitats of the lower Fraser River support valuable fisheries and wildlife populations. As many as 650 million juvenile salmon pass through the lower Fraser River during downstream migration so it important that dredging operations be managed in a way which avoids or minimizes adverse impacts on the environment. The Fraser River dredging guidelines provide the major rules for the protection of fisheries.
The environmental impacts of dredging can be direct or indirect associated with both the physical and chemical aspects of disturbing river sediment and waters. These effects include:

- Entrainment of juvenile fish and invertebrates in suction dredges;
- Increased turbidity or resuspension of sediments in the water column;
- Smothering of benthic organisms which provide food sources for fish populations;
- Alteration of flows, reducing spawning and rearing habitat area and productivity;
- Destruction of migrating and spawning eulachons.

Increased concentrations of suspended material, or turbidity, occurs at the dredge site and, usually more extensively at the dump site. This turbidity decreases light transparency in the water column, affecting photosynthesis. Phytoplankton are apparently little affected but filter feeding zooplankton may be affected. Clogging of gills can also occur but fish are generally mobile enough to avoid such areas. Pelagic populations may also be displaced by entrainment in sinking dredge material.

Covering or smothering of benthic organisms may occur when resuspended sediment settles surrounding the dredge site or at the dump site. This can result in a reduction in abundance, biomass and species diversity. Individual species vary in their reaction to dumping. Nearshore algae such as kelp beds are particularly vulnerable. Some burrowing invertebrates can re-establish contact with the sediment-water interface if not buried too deeply. The thickness of material which will cause permanent burial depends on the size and behaviour of species as well as physical and chemical factors involved in the deposition of dredge material. Recovery or recolonization usually occurs if dumped material is not contaminated and if dumping is infrequent. The recolonization period varies from a few months to a couple of years. The structure of colonies using disposal areas may also differ from that formerly present.

Sediments are effective traps for many organic and inorganic materials because of sorption and ionic processes, although the dredged sand fraction is less prone to contamination. Other materials such as wood debris, sinks to the bottom and is covered by sediment and decays anaerobically. When these sediments are disturbed through dredging, dissolved oxygen levels, especially in wood contaminated sediments, and reintroduction to the water column of metal and organic toxics which become available for biological uptake, nutrient increases from sediments with high detritus content, and hydrogen sulfide release where sediments are characterized by high levels of bacterial decomposition of organic matter.

Most of the negative impacts on fisheries can be avoided through consideration of the mechanical manipulation of the dredge and the timing of migration of different fish species, avoidance of sensitive shallow areas during downstream migration and avoidance of productive habitat areas.


Abstract - The influence of red-clay turbidity on behavior and distribution of brook trout, Salvelinus fontinalis, and creek chubs, Semotilus atromaculatus, was measured in the laboratory. Creek chubs preferred highly turbid water (56.6 formazin turbidity units - FTU) over moderately turbid water (5.8 FTU) but brook trout did not show a preference. In moderately turbid water, both species were more active and used overhead cover less than in clear water. The results indicate turbidity may represent an important isolating mechanism that promotes production of creek chubs.


Abstract - The relation of turbidity to suspended matter in the Enoree River follows a definite pattern. Similar patterns may or may not exist in other rivers, but detailed investigation of the relation of turbidity to suspended matter appears to be warranted where the establishment of such relations would be of value in estimating suspended load.

Old turbidity measurements must be used with extreme caution for estimating past transportation of suspended sediment. To use past records the following points must be established:

1. The original turbidity standard used must have been constant and must either be available for use in conjunction with current investigations or be capable of accurate reproduction. Measurements based on comparison with standard suspensions are especially susceptible to error.

2. The turbidity records must be supplemented by discharge records.

3. There must be no reason for suspecting that the average coefficient of fineness has not remained reasonably constant at the point of measurement. Changes in average coefficient may be anticipated if conditions in the drainage area have changed radically with respect to land use or to pollution of the stream by municipal or industrial sewage. Great changes in the quantity of transported sediment, as indicated by major changes in turbidities, may have been accompanied by change of coefficient.

4. Turbidity measurements correlated against gravimetric determinations of suspended matter over a sufficiently long period must show a reasonably definite average relation of turbidity to suspended matter.

In future suspended load investigations, turbidity measurements supplemented by a few gravimetric determinations may cut laboratory costs considerably with little or no reduction in accuracy. The reliability of this method, however, should be verified for the particular conditions encountered by sufficient comparisons of turbidity and suspended matter concentration. Such comparisons may indicate an average relationship which could be used to obtain sufficiently accurate results in a long terms suspended load measuring program without supplementary gravimetric analyses. Because of the great variation of the fitness coefficient, especially during flood stages when transportation is greatest, suspensions of river silt should not be used as turbidity standards unless their reliability is checked over a sufficient period.


Abstract - Effects of sediment release from Guernsey Reservoir on macroinvertebrates of the North Platte River, Wyoming, were investigated during the summer of 1981. Suspended solids concentrations during sediment release increased from < 20 mg/l to > 300 mg/l. Because fine particulates remained in suspension, mean particle size of substrates was unaltered. Densities of chironomids decreased 90% + during sediment release but recovered to initial levels in 3 weeks after the release ended. Densities of mayflies and
oligochaetes increased. Changes in benthic populations were highly correlated with increases in suspended solids.


Abstract - Suspended materials, inorganic or organic, have a considerable effect on light penetration. The more turbid the water, the less the light penetrates. Thus natural light penetration may be limited to a thin zone at the water surface under extremely turbid conditions. Finely divided particles of clay, silt, organic material and plankton produce most of the light attenuation, especially in nearshore areas and shallow portions of the lakes. Larger particles especially those which have a higher density than the water, settle rapidly and are little affected by water temperature variations. The settling of finely divided particles with densities approaching that of water is greatly affected by temperature variations and stratification. This creates a natural separation based on size and composition. Organic material especially tends to concentrate above the thermocline as settling is impeded by the underlying water of greater density and viscosity. Below the thermocline settling rate is more uniform because the hypolimnion is structurally more stable than the epilimnion. Suspended material may concentrate near the bottom. These materials may be colloidal or they may be due to transport or resuspension of materials.

Transparency of the Great Lakes is not uniform nor is it stable. Fluctuations may be short term, catastrophic, seasonal or annual and are both areal and vertical. The physiography of a lake basin, depth and depth variations, bottom types, character and extent of influx, exposure to wind fields and thermal structure all cause variations in transparency. Natural changes adhere to a basic annual cycle with short term effects superimposed. The effects of all the controlling variables are more or less predictable in time and space. Investigations that are limited in duration and area studied or that consider effects without analyzing causes may appear to be random or may lead to erroneous management recommendations. Definitions of the annual cycles in a lake are necessary adjuncts to shorter term programs because they form a baseline on which to superimpose the segments. Factors that control physical properties should be better defined and the proper time and space perspectives of problem areas should be determined before development of any reasonable comprehensive management plan.


Abstract - I investigated the effect of turbidity on the foraging behaviour of juvenile chinook salmon, Oncorhynchus tshawytscha, in the laboratory. Specifically, I examined a behavioral "tradeoff" between visual ability and "perceived" risk.
I assessed visual ability by measuring the reaction distance of juvenile chinook to planktonic Artemia prey. I found chinook exhibited a log-linear decline in reaction distance with increasing turbidity.

To determine the effects of turbidity and microhabitat on foraging rate, I conducted separate experiments for surface (Drosophila), planktonic (Artemia), and benthic (Tubifex) prey across a range of turbidity levels (0, 25, 50, 100, 200, 400, 800 mg/l). Foraging rates were reduced at higher turbidity conditions for all three prey. However, for surface and benthic prey, foraging rates were also low in clear water; highest rates were attained at intermediate turbidity levels (50-200 mg/l). The degree to which intermediate turbidities were associated with higher foraging rates was size-dependent. Smaller individuals (50-57 mm fork length) exhibited relatively higher foraging rates in clear conditions than did larger individuals. However, planktonic foraging rates by juveniles were consistently high in clear water regardless of fish size.

In experiments manipulating light level independent of turbidity, I allowed salmon to forage under conditions which were either turbid or clear but with light intensity correspondingly reduced. Foraging rates were similar between the two treatments for planktonic prey, but differed for benthic and surface prey. Generally, foraging rates exhibited by juvenile chinook salmon could not be explained on the basis of visual ability alone. I suggest that young salmon also exhibited foraging behaviour consistent with their perception of risk to predation.

In arena experiments, juvenile chinook distributed themselves randomly in turbid conditions; in clear conditions they associated with the bottom. When bird and fish predator models were introduced the fish altered their spatial distribution, occupying deeper regions regardless or turbidity. However, their response in turbid conditions was less marked and lasted for a shorter time. Turbidity apparently mitigated the perceived risk of predation in juvenile chinook.

I developed a conceptual tradeoff model that predicted the general effect of turbidity on foraging behaviour. Assuming differences in either prey quality or perceived risk of predation in three microhabitats (surface, water column, bottom), the model resolved the apparent dissimilarities between planktonic and other foraging behaviors. Perceived risk of chinook to predation was significantly different between surface and water column microhabitats. When exposed to a non-visual "fixed risk" stimulus (sound), salmon apparently perceived less risk as turbidity increased.

I conclude that in turbid waters juvenile salmon exhibit foraging behaviour in a manner consistent with a tradeoff between their visual ability and perceived risk.


Abstract - The effect of turbidity on the predator avoidance behaviour of juvenile chinook salmon, Oncorhynchus tshawytscha, was determined in controlled laboratory experiments. Bird and fish models were used to simulate predator risk. In the absence of risk, juvenile chinook were distributed randomly within an experimental arena in turbid conditions (23 NTU) but in clear conditions (< 1 NTU) they associated with the bottom. When introduced to bird and fish predator models, the chinook altered their distribution and occupied deeper parts of the arena regardless of turbidity level. However, their responses in turbid conditions were less marked and of shorter duration. Turbidity apparently reduced the perceived risk of predation in juvenile chinook.

**Abstract** - We investigated the effect of turbidity on the foraging behavior of juvenile chinook salmon, *Oncorhynchus tshawytscha*, in the laboratory. We assessed visual ability by measuring the reaction distance of juvenile chinook to planktonic adult *Artemia* prey. Chinook exhibited a log-linear decline in reaction distance with increasing turbidity. These results were similar to those obtained by workers for other species. We also determined the effect of turbidity on the foraging rate of juvenile chinook for surface (*Drosophila*), planktonic (*Artemia*) and benthic (*Tubifex*) prey across a range of turbidity levels (< 1, 18, 35, 70, 150, 370, 810 NTU). Foraging rates were reduced at higher turbidities for all three prey. However, for surface and benthic prey, foraging rates were also low in clear water while highest rates were attained at intermediate turbidity levels (35-150 NTU). We suggest that increased feeding rate in turbid conditions reflects a reduced potential risk to predators.


**Abstract** - This paper describes experiments with cutthroat trout fingerlings which were designed to obtain information on the direct effect of large amounts of soil sediment in water on fish inhabiting such water. Fish from sediment laden water (2,300 - 3,500 parts per million) were compared with fish held in control (clear) water under the same other conditions. Among the observations were behavioral differences. Other observations are also outlined.


**Abstract** - Winter habitat utilized by age-0 spring chinook salmon was assessed in Red River, a tributary of the South Fork Clearwater River, heavily embedded by fine sediment. Eight percent of the chinook salmon emigrated from the study sites when stream temperatures were 4-8°C (October), apparently because suitable winter habitat was not available. Those that remained selected submerged sedges and grasses overhanging undercut banks as cover where water velocities were less than 12 cm/sec. After cobble substrate was added to the streambed under banks and mid-channel in a glide and riffle, eight times more chinook salmon used the cobble substrate in November as compared with the November density of the previous year.

In the Henry's Fork of the Snake River, we observed and enumerated juvenile rainbow trout by snorkeling at night and in the day in areas impacted by heavy grazing and in those that were not grazed. Water temperatures ranged from 0.3 to 7.0°C and the areas were free of anchor and surface ice. During the day, no fish were observed as all were concealed in the substrate. Trout emerged from the substrate at night. Dusk emergence began 25 to 35 minutes after sunset at light intensities near 0.4 x 10⁻² watts/sq. meter. At night, no juveniles were observed in or near large macrophyte beds in non-bank areas. A total of 96%
of the 1,531 fish observed during the night at the Last Chance site were near boulder clusters along the bank. This habitat represented only 35% of the bank habitat surveyed. We observed juvenile rainbow trout densities of 5 to 100 fish /100 sq. meters in the ungrazed bank habitat which consisted of boulder clusters and undercut banks. Only deep and well developed undercut banks continued to provide concealment cover at lower flows. These banks were only found in areas where not grazing occurred, such as on islands and within fenced areas.


Abstract - Estimates of specific annual suspended sediment yields, some of which rank among the highest reported in the world, are presented for 33 basins of South Island, New Zealand. Yield from each basin was determined by combining a suspended sediment concentration rating with the complete flow record of each sediment yields and climatic, hydrologic and physiographic parameters of each basin demonstrates that most of the variance in yields is explained by catchment mean rainfall. Geology apparently has little influence on sediment yield as suspended sediment concentration ratings, from rivers draining catchments of differing lithology, and regolith, are indistinguishable. Specific suspended sediment yield prediction equations are given for four defined regions covering in area almost all South Island; and except for one area, feature rainfall as the principle independent variable. Differences between regions may be due to variations in intensity, frequency and duration patterns of storms. It is proposed that a simple power law relationship between yield and rainfall provides a useful suspended sediment yield estimates in mountainous regions of temperate maritime climate, provided catchments have not been modified extensively by man.


Abstract - Many of the freshwater areas in the world are turbid, due to suspended inorganic particles. The euphotic depth of the shallow turbid impoundment, Wuras Dam, varies between 0.3-1.3 meters. This results in a compressed production profile where accurate measurements become difficult. Tubes of various lengths have been used and usually render higher rates when compared to discrete bottle incubations. A tube the depth of the euphotic zone confines the phytoplankton in the light and the rates measured represent the maximal possible under the prevailing conditions. Longer tubes include an aphotic portion and give an idea of the magnitude of respiration losses. The depth of the mixing layer appears to be especially important in turbid systems as the time spent in the dark, relative to the light is of great importance and may be the most important regulating factor in such waters.


Abstract - The author was a member of the Trans-African Hovercraft expedition of 1969-70. He took the opportunity to measure the conductivity, pH and bicarbonate content of the water at a number of points along the course of the Senegal, Niger, Genue and Shari rivers. Samples of water were treated to preserve them and sent to England for further analysis. The results are presented here together with the results of other analyses that have been made from time to time in the past. An attempt is made to estimate the seasonal and annual transport of dissolved and solid load by these rivers. Precipitation over the catchments and dust falling on the lakes and rivers are evidently sources of dissolved load difficult to quantify.


Abstract - Our estimates of the off-site sediment damage costs for selected agricultural watershed in Illinois indicate that these costs typically are 10 to 15 percent of private net income and can be much higher under contemporary farming techniques. In addition, off-site damage costs appear to be many times larger than on-site sediment damage costs (production effects). This suggests that soil conservation efforts should be refocused to include considerations of the social costs caused by off-site sediment damages.


Abstract - The hydrologic regime and zonation of riparian vegetation influenced the quantity and quality of coarse particulate organic matter (CPOM; > 1mm) stored in the channel and upper bank of a prairie stream. In a 5.4 kilometer intermittent reach of the South Branch of Kings Creek on Konza Prairie, Kansas, total annual import was lowest in headwater reaches and increased downstream. Total storage of benthic
CPOM in the dry channel and on the bank before the flow period was highest in the fourth and fifth order gallery forest zone (999 gm ash-free dry mass/sq. meter) and less in upstream reaches (320-341 gm/sq. meter). These longitudinal patterns of CPOM annual import and storage (before the flow period) were opposite those predicted by the river continuum concept for streams draining forested regions. Following flow, headwater channels had more CPOM (291 gm/sq. meter) than downstream reaches. On the bank, storage was always highest in downstream reaches. Composition of CPOM both in the channel and on the bank varied with changes in riparian vegetation; grass tissues dominated in headwater channels, while wood and leaves of trees and shrubs were more abundant downstream. During the flow period storage of CPOM increased only in headwater channels where retention was high despite the lack of woody debris. In this intermittent prairie stream, benthic CPOM may not contribute consistently to the terrestrial/aquatic linkages that are suggested in the river continuum concept because of (1) a paucity of large CPOM sources (i.e., trees, shrubs) in the upper reaches and (2) a hydrologic regime that reduces the amount as well as the predictability of stored CPOM. The biota of prairie streams must have opportunistic food gathering and reproductive strategies to take advantage of variable food resources in a flow environment that is itself very unpredictable.


Abstract - For the second time in this century the American public is concerned about man-induced soil erosion. The current concern focuses on the effects of water-borne and deposited sediment on aquatic environments, often many miles below the point of origin of the eroded earth.

Organic sediment - not necessarily soil derived - often does more harm to aquatic environments than inorganic sediment. Sources of sediment can be both natural and man-made. Though the natural variability of stream sediment movement may be large, it is logical that the natural regime of streams increasingly is being altered by various changes in channel conditions and by changes in sediment contribution from man's activities. The implications of the sediment problem and its environmental effects are most pronounced in construction areas.

Environmental effects of sedimentation include a reduction of dissolved oxygen in waterbodies, diminished aesthetics and recreational values, reduced storm sewer and drainage channel capacities, increased harbor and channel shoaling, reduced crop yields and agricultural efficiency, inhibited aquatic life, increased damage to flood inundated structures, reduced infiltration of rain into the ground and reduced life of reservoirs.

Once sediment enters a stream system it is usually thought of as a public problem. Thus, responsibility is easily avoided. The sediment problem, like that concerning water and water quality is a "people problem".


Abstract - The purpose of this work is to establish an erosion-transportation-accumulation diagram for fine recent deposits on lake bottoms and to show empirically that an understanding of the bottom dynamic processes is of vital importance for proper interpretation of sediment data.

The potential maximum effective fetch (PF_{eff}) has been used to indicate the available water energy and the water depth has been used to indicate the effectiveness of the PF_{eff} on the bottom. The 50% water content of surficial sediments, 0-1 cm has been utilized as a physical sediment parameter to distinguish erosion from transportation and the 75% water content to separate transportation from accumulation.

Relationships between water content, bulk density and grain size are discussed. The distribution pattern of different elements (Be, B, V, Ni, Cu, Zn, Mo, Ag, Cd, Sn, Hg, Pb, Bi, P and N) in the sediments of Lake Vanern is interpreted in the light of the bottom dynamic processes.


Abstract - Selected samples of raw water from the upper Niagara River were analyzed using Aqueous Phase Liquid Extraction (APLE) coupled with full scan. GC/MS analysis in El and NCI mode, as well as analysis for standard organochlorine residues and PCBs specific analysis for polychlorinated dioxins and dibenzofurans (PCDDs/PDFCs). In addition specific analyses were made from grab water samples, acid soluble compounds, chlorphenols using derivatization and volatile aromatics. Comparison of this
analytical approach was made to USEPA standard method 625 for volatile and extractable organics. Similar comprehensive analyses were carried out on suspended sediment material removed prior to the use of the aqueous phase liquid extraction technique and on standard raw water grab samples. Recoveries of detectable organics were significantly different using the two basic analytical approaches. The APLE sampler allowed detection limits of 5 parts per quadrillion (ppq) for most residues found in water.


Abstract - A large area of the Lake States is covered by a deep mantle of sandy glacial drift. Streams in this area generally have lower sediment concentrations than other areas of the United States. Even so, stream sediments are slowly filling harbors and reservoirs and possibly damaging fish habitat. This paper gives the results of a study designed to determine the sediment sources, the size and quantity of bank sediments, the timing of delivery, and the method of transport. The change in sediment load and streambed composition, and some possible effects of streambank stabilization are also presented for a section of stream with many eroding banks.


Abstract - Sedimentation basins, also referred to as debris basins or sediment traps, have been used for many years in irrigation and hydroelectric works. Basins trap most of the sand and lesser amounts of silt and clay depending upon basin design and stream characteristics. This paper explores the potential of sedimentation basins for reducing sediment loads in trout streams.

There is considerable evidence that abnormal amounts of man-induced sediments, particularly the moving coarse grain sediments, are detrimental to trout habitat. Consequently, reduction of instream sediment has been one major objective of most trout habitat improvement programs. This has been traditionally attempted by using erosion control techniques such as fencing cattle from the stream, streambank stabilization and revegetation of eroding upland areas. However these techniques may not be very effective in reducing the sediment load, since often more than half the load comes from very gradual (essentially untreatable) sheet erosion over large areas of the watershed.

If the stream sediment load needs to be drastically reduced, sedimentation basins are required. Sedimentation basins can be used as a substitute for, or as a complement to, traditional erosion control measures, depending on the objectives. Basins would be particularly applicable for reducing abnormally high loads of coarse grain sediments.

Abstract - Easily installed wooden sills permit collection of bed load sediment normally missed in the unsampled zone. Sills also (1) provide a rigid unchanging control at which to sample, (2) reduce the chance of sample bias from sediment stirred up by the wader, and (3) permit control of the sampling interval because the sample points can be marked directly on the sill. Field data indicated that the sill samples probably provided better measurements of total sediment discharge than traditional stream samples do. Nonuniformity of bed load discharge in cross sections of the sampled streams complicated the problem of getting unbiased samples. Lateral nonuniformity of sand bed load discharges was greater in coarse (gravel and cobble) bedded channels having small sand loads. Sampling modifications are proposed to compensate for the nonuniformity.


Abstract - Techniques for erosion control such as bank stabilization and revegetation of eroding upland areas reduce only part of a stream's sediment load. This study on Poplar Creek in Michigan (one of two papers) demonstrated that an instream sediment basin can trap and remove almost all sand bedload sediments. Other advantages of sediment basins are that they can (1) produce downcutting to create deeper pools and improve streambed composition and (2) keep critical fisheries spawning areas relatively free of sediment. Sediment basins should be used with caution in streams with erodible beds that have no areas of erosion-resistant streambed to prevent possible excessive downcutting. Sediment basins can be used with other techniques to improve fish habitat or they can be used alone to renovate sand choked streams not amenable to the usual erosion control treatments.


Abstract - Experiences of numerous state and local governments reveal the promises and pitfalls of a mandatory approach to erosion and sediment controls. Our recommended design criteria are general, presenting basic guidelines and major issues to consider. We made no attempt to reach specific conclusions about penalties for noncompliance, necessary funding and staff required. These evaluations can only be made by individual states. But the general criteria, when tailored to meet specific situations, should provide a basis for development of comprehensive, flexible erosion control programs.


Abstract - Theoretical considerations of the effects of turbulence around and within sedimentation traps show that the aspect ratio (height:mouth opening) of the traps is important in determining particle retention. Collection efficiency and comparative measures of deposition per unit area in traps of various design were
independent of this ratio in calm water, but an asymptotic relation of increased collection efficiency with higher aspect ratio existed under nonstagnant conditions. Turbulent mixing in a water column could be assessed by comparisons of deposition in collectors exposed simultaneously but having different aspect ratios.


Abstract - This review addresses three of the possible mechanisms by which trace metals can be concentrated by sediments and suspended particulate matter. These are physico-chemical adsorption from the water column, biological uptake particularly by bacteria and algae, and the sedimentation and physical entrapment of enriched particulate matter. The relative importance of these three mechanisms will be different, depending upon the aqueous system but there have been insufficient studies to allow the establishment of even "rule of thumb" guidelines as yet about their quantitative importance under different conditions.

The importance of natural organic matter in the cycling of trace metals in aquatic systems has been stressed. This organic matter may complex with the trace metals and keep them in solution or it may enhance the association of the trace metals with particulate matter by becoming adsorbed to the particulate surface and then complexing with the trace metals in the solution phase. Enhanced metal-particulate associations may also arise if the metal-organic complexes are able to adsorb to the surface.

The behaviour of natural organic matter may be the single most important influence on trace metal cycling in aquatic systems and should receive considerably more attention in the future.


Abstract - The abundance and composition of entomostracan zooplankton were studied between 1977 and 1984 in relation to abiotic and biotic conditions in Lake le Roux (LLR), a large silt-laden reservoir on the Orange River formed in 1976. The community consisted of Metadiaptomus meridianus, Lovenula excellens, Daphnia gibba, D. barbata, D. longispina and Moina brachiata, and various Cyclopoida. Zooplankton biomass varied seasonally from winter lows below 50 mg/sq.m at 21 - 23°C. It correlated strongly and positively with prevailing water temperature and transparency but only weakly with chlorophyll concentration. Mean annual zooplankton biomass, which varied four-fold (97 - 408 mg/sq.m) in 7 years, increased with annual mean transparency (23 - 75 cm Secchi depth) and especially with summer heat content (33 - 230 degree days above 20°C) which was itself positively correlated with transparency. Daphnid species showed most annual variation in abundance. Large forms (D. gibba and D. barbata) were scarce or absent in two years of very low transparency and low planktivore abundance. The smaller D. longispina developed once during clearer conditions when more fish were present. Copepod biomass
also varied inversely with turbidity, but was not as severely reduced at high turbidities. Smallmouth yellowfish, *Barbus aeneus*, is the principal planktivore and candidate fishery species in LLR. It feeds selectively on *Lovenula* and large daphnids. Catches and growth rates of yellowfish varied directly with the abundance of zooplankton, particularly large food forms, and with water transparency. High turbidity and associated food limitation seems to reduce standing stocks especially of the daphnid zooplankton more than the effects of fish predation. Spawning of yellowfish depends upon the release of water from an upstream reservoir which concurrently reduces transparency and thus zooplankton availability in LLR. Transparency values above 30 - 35 cm SD appear necessary for the development of sufficient and suitable zooplankton to benefit the fishery.


Abstract - The temporal dynamics and demography of *Metadiaptomus meridianus*, *Lovenula excellens*, *Daphnia gibba*, *D. barbata* and *Moina brachiata* were studied for two years in a small bay of Lake le Roux (Orange River, South Africa). Total zooplankton biomass and population density were 1.4-3 times higher during the less turbid conditions of 1982-83 (Secchi depth transparency around 35 cm) than they were at around 25 cm Secchi depth during 1981-82 when *D. barbata* was absent.

On average, instantaneous birth rates, rates of population change and death rates varied only slightly between years. Birth and death rates were considerably higher above 15°C than below 15°C. These rates correlated with one another and with zooplankton abundance both inter- and intraspecifically suggesting that competitive interactions were important in population regulation. Mortality rates varied more strongly and consistently in a density dependent direction than did birth rates. In addition to depressed fecundity, the inferred survival of young was poor and population growth low, possibly because food shortage caused high post-natal mortality.

Estimates of annual production derived from finite birth rate values varied consistently with annual differences in biomass and amounted to between 6 and 10 gm/m²/year dry weight. Annual P/B ratio virtually doubled from 45 to 75 following reductions in turbidity, annual differences in PB ratio were slight.


Abstract - Changes in zooplankton composition and abundance in Lake le Roux, a turbid subtropical reservoir on the Orange River in South Africa, were correlated with changes in water transparency (related to suspended sediment levels) during a 7 year field study. Results of radio-tracer studies of the effect of mineral turbidity on zooplankton feeding rates which potentially influence competitive ability, and thus community structure, are reported here.

Feeding rates of five zooplankters were very variable but consistently declined with rising turbidity; rates of decline differed between species. A regression estimate of the critical turbidity threshold at which food intake matched the estimated respiratory need was derived for each species. This yielded the following "turbidity tolerance" ranking: *Moina brachiata* > *Metadiaptomus meridianus* > *Daphnia gibba* > *D. barbata* > *D. longispina*. The consistency between this ranking and one based upon
abundance-transparency relationships in the field study suggests that community structure is related to differential feeding capabilities, although other influences are not excluded.

Tests on *D. gibba* and *M. meridianus* failed to reveal any detectable feeding range saturation (incipient limiting food level) below 1.2 mg/l C. The relative reduction in feeding rates at elevated turbidity was nearly 3 times greater for the daphnid than the copepod over a range of food concentrations and considerably reduces the competitive ability of this (and other) daphnids. The turbidity tolerance disparity between *Moina* and the daphnids demonstrates amore complex situation than a simple copepod/-cladoceran dichotomy. These findings and their implications are discussed in relation to wider features of zooplankton ecology.


**Abstract** - The transparency of Lake Erie water has apparently not changed significantly since the 1920's. Characteristically, transparency in the western basin in kept extremely low during the entire ice-free period by silt brought in from farmlands in the Maumee River drainage and from the continual resuspension of sediments by strong winds. In the central and eastern basins there is a 50% increase in suspended material from summer to early winter which is attributed to the movement of water from the western part of the lake, seasonal increase in organic material, turbulent storm effect and vertical circulation of the entire water column as the thermocline lowers and disappears.


**Abstract** - I examined the impact of small suction dredges (hose diameter < 16 cm) on fish and invertebrates in two California streams (North Fork of the American River and Butte Creek) in a two year study. I studied both the effect of one dredge (1980) and the effects of an average of six dredges in a two kilometers section of stream (1981). Ten replicate Surber samples per station were taken monthly to compare macroinvertebrate abundances at control and dredged stations before, during and after dredging in both years. Dredging significantly affected some insect taxa when substrate was altered. A recolonization experiment showed that numerical recovery of insects at dredged sites was rapid. Mask-and-snorkel censuses and observations of tagged fish indicated that major changes in available habitat caused local decreases in fish density. Dredging affected riffle sculpins, *Cottus gulosus*, more severely than rainbow trout, *Salmo gairdneri*, probably because of differences in microhabitat requirements. Local turbidity increases below active dredging probably did not affect invertebrates and fish.


**Abstract** - Survival of artificially fertilized ova and larvae of northern pike, *Esox lucius*, was estimated from embryos held in natural spawning areas in Lake Oahe and Lake Sharpe, two main stem Missouri River reservoirs. Mortalities approaching 100% during early embryonic development were associated with sudden drops in water temperature below 10°C or prolonged temperatures near 5°C. Silt deposition of
1.0 mm per day was associated with mortality of 97% or above. Following hatching, available food appeared to be a more important factor in survival than temperature change or silt deposition.

Estimates of year class strength of northern pike in the two reservoirs suggest that large year classes were associated with stable to rising water level and temperature, flooded vegetation and calm weather during the spawning season. Small year classes have been associated with abrupt water temperature fluctuations, dropping water levels and high silt deposits.


Abstract - The amount of erosion and sediment occurring below logging roads on steeply sloping granitic soils in ponderosa pine lands of southwestern Idaho was studied intensively. Seven road and slope characteristics amenable to quantitative evaluation were investigated to determine their relationship to the distance that sediment moved downslope from a road embankment. Four of these characteristics - the slope obstruction index, cross ditch interval squared, embankment slope length and the product of the cross ditch interval and road gradient - were found to influence sediment flow distance significantly. These characteristics were incorporated into an equation that promises to be valuable in determining the safe width of buffer strips necessary to protect lower roads or stream channels from sediment damage emanating from road construction activities.


Abstract - From the inception of a study of cutting ponderosa pine on 16 small watersheds in the Boise Basin Experimental Forest, sedimentation was checked reasonably well because of careful advance planning, close supervision of logging and application of intensive measures for controlling erosion promptly after harvest. Sediment that reached the stream channels originated primarily on haul roads. Proximity of a road to a stream affected the frequency with which sediment flows reached that stream. Sediment reached channel bottoms through undisturbed buffer strips averaging 8 feet wide, but did not reach them if the strips were more than 30 feet wide. After 3 years, movement of sediment "en route" had almost halted.


Abstract - Alevins of brook trout, Salvelinus fontinalis, were buried in laboratory troughs in spawning gravel containing 0 to 25% sand. Sand slowed emergence and reduced the number of fry emerging. Weight of fry was not related to proportion of sand in the gravel but was related to time; the fry were heaviest near the time of peak emergence and lighter before and after the peak. Survival was estimated to be 84% from egg deposition to hatching for brook trout in Lawrence Creek, Wisconsin, and 70% from hatching to emergence, providing a total estimate from egg deposition to emergence of 59%.


Abstract - We compared the fish communities of two shallow lakes in the lower Waikato river basin, North Island, New Zealand, to determine the effects of elevated suspended solids (SS) and collapse of submerged macrophytes. Lake Waahi was turbid (20-40 grams per cubic meter SS) and devoid of submerged macrophytes whereas Lake Whangape was clearer (5 grams per cubic meter SS) and dominated by submerged macrophytes. The lakes had similar fish species richness and had nine major species in common; representing eight families including Anguillidae, Retropinnidae, Galaxiidae, Eleotridae, Mugilidae, Ictaluridae, Poeciliidae and Cyprinidae (two species). The only major fish that was absent from Lake Waahi was a lacustrine form of the common smelt, Retropinna retropinna, which disappeared after the lake became turbid in the late 1970s. CPUE, condition and size of most species in Lake Waahi were similar to, or greater than, those in Lake Whangape. Lake Whangape clearly exceeded Lake Waahi only for CPUE of two species. Within Lake Whangape two species displayed significantly greater condition and one species greater size, in a turbid arm of the lake than in the main basin. Apart from lacustrine Retropinna retropinna, the fish in these lakes appear well adapted to cope with or to avoid the direct toxic effects of suspended and settleable solids on sensitive early developmental stages. In Lake Waahi loss of cover and food provided by submerged macrophytes appears to have been compensated for by increased turbidity and an associated increase in the biomass of the mysid, Tenagomysis chiltoni (a major prey item).


Abstract - Silt suspended in the water column is probably the most prevalent of the suspended solids. It generally results from runoff where land has been disturbed by plowing or excavation. Ground up wood fibers can also be a significant form of suspended solid pollution.

When investigating the effects of pollution on fish (or other organisms) it is useful to keep in mind the following spectrum (the expression "levels of complexity is often used to designate this topic):
Starting at the top, foreign chemicals or conditions of low environmental oxygen or elevated temperature exert their primary effects at the enzyme level, or they may alter some other cell function such as permeability of membranes. These changes affect cell integrity, ultramicroscopic structure and grosser functions such as energy expenditure or secretion rate of a hormone.

Moving further down the levels of integration spectrum, chronic exposure to a pollutant may depress growth, although not always. Reproduction is one of the processes of fish that is most sensitive to pollution, particularly the larval stages. Anything that affects the nervous system will alter behavior and many substances directly cause alterations in the functions of the nervous system. They may affect behavior indirectly, as well, by affecting other organ functions such as osmoregulation and metabolism of sex hormones. Finally, changes in the function of a group of organisms in an ecosystem cause effects on other organisms whether they be predators or prey. In the levels of integration spectrum, it is important to realize that no level is more important than another.

The qualitative and quantitative physiological impact of a substance depends both on the level of dose and the duration of exposure. For doses below the sublethal level of response, a wide variety of reversible and irreversible processes takes place.

Prolonged exposure within the upper end of the sublethal zone may cause death through a general weakening of the animal so it becomes more susceptible to disease and/or predation. The lethal dose (LD50) is usually defined as that dose which causes death to half of the test animals within a specified period of time.


Abstract - We used the Iowa State University national programming model to evaluate the economic impacts of controlling nonpoint pollution from agriculture and to assess whether environmental improvement goals could be met in conjunction with high agricultural exports. Alternatives analyzed included a base solution, high exports, land and water conservation and environmental enhancement. High exports could be attained simultaneously under the land and water conservation alternative. Exports must be reduced, however, under the environmental enhancement alternative. To meet exports under the land and water conservation alternative, 10 million acres of wetland would need to be converted to cropland. Returns to land would increase considerably under all alternatives other than the base solution. There
would be wide variations among regions, however. In general, a relative redistribution of income from irrigated to dryland and from erosive to nonerosive farming regions would occur.


Abstract - Shoreline erosion added an annual average of 4,000,000 tons of mineral sediment per year to Southern Indian Lake (postimpoundment area 2391 square kilometers) during the first three years of impoundment. This erosion increased sedimentary input to the lake by a factor of 20. The lake retained 90% of this eroded material within its basin and 80-90% of the retained material was deposited nearshore. Despite the production of extremely fine constituent particle sizes, eroding shoreline generated predominantly large clay aggregates, initially transported offshore as bedload. During bedload transport, abrasion of clay aggregates produced fine particles that became suspended. Over 80% of the suspended load is lost to outflows from the lake because the suspended load is primarily fine silt and clay-sized particles, most of which do not settle even under winter ice cover. The extensive nearshore clay aggregate deposits are temporary and net deposition in these areas will change to net erosion when input of sediment from eroding shorelines ceases. The effects of shoreline erosion on the lake's sediment regime will persist for decades.


Abstract - The impoundment of Southern Indian Lake (SIL) and diversion from the lake of the Churchill River in northern Manitoba, Canada, were the subjects of two independent environmental impact statements. Subsequently, a case study measured change in the limnological and biological characteristics of the lake after development. Comparison of pre and post impoundment observations allows an assessment of the predictive capability that was applied to the lake by the preimpact statements. Predictions related to the physical environment i.e., increased shoreline erosion, littoral sedimentation, higher turbidity and decreased light penetration and visibility were qualitatively correct; however, an unpredicted decrease in water temperature also occurred. Increased phosphorus availability and light limitation of primary production were also correctly forecasted in a qualitative manner. These aspects will be quantitatively predictable in future reservoirs because of studies at SIL and elsewhere. Biological responses above the primary trophic level were mostly not predicted or predicted incorrectly. Unpredicted changes that were especially significant to the fishery were rapid declines in the quantity and quality of whitefish, Coregonus clupeaformis, catch, increases in mercury concentrations in fish, and the need for extensive compensation programs to keep the fishery economically viable. Testable hypotheses to explain all unpredicted events have been formulated but require experimental verification. The paradigm of reservoir ecosystem development that is present in the literature requires reformulation if future environmental impact analyses of reservoirs are to be improved.


Abstract - Timber was harvested for the first time in a mixed conifer forest of the Arizona White Mountains in 1978-1979. Trees were harvested by patch cuts and group selection. Logs were yarded by crawler tractors. After harvest, 19 small subdrainages were equipped with runoff and sediment collectors. The forest floors in the subdrainages were classed as undisturbed, moderately disturbed or severely disturbed. Severe disturbance, caused by logging and monitoring activities, was associated with a pre-existing erosion pavement that had developed for unknown reasons.

Although overland flow and sediment delivery differed significantly between the severely disturbed and undisturbed groups during the 5 year postharvest period, all quantities were practically insignificant. The group severely disturbed by logging had an average of only 0.006 mm/yr annual soil loss. Overland flows ranged between 0.7 and 15.4 mm/yr and sediment between 5.67 and 268.78 kg/ha/yr.

Summer yields of overland flow and sediment delivery were significantly higher than those in winter. Precipitation amounts were about equal for both seasons, but summer precipitation is of monsoon origin. Flow and sediment yields were not significantly different between moderately disturbed and undisturbed forest floor. Recovery from disturbance could not be detected.


Abstract - Young largemouth bass tend to prefer a higher illumination that adult bass but adult bass also display positive phototaxis. Direct lethal effect of turbidity caused gill filament clogging at an average concentration of 101,000 mg/l. Angling with a light is not as effective in turbid water as it is in clear water.


Abstract - Behaviour of juvenile largemouth bass and green sunfish in aquariums was measured under conditions of clear water, 4-6 JTU, and 14-16 JTU for 30 days. The activity of bass was significantly reduced by turbidity; sunfish activity was reduced but not significantly. Feeding and attack behaviour was not influenced. Scraping behaviour of both species was higher under turbid conditions. There was evidence that turbidity disturbed normal social hierarchies in green sunfish.


Abstract - Runoff was measured from a 564 ha catchment located on the Entiat Experimental Forest for nine years before a severe wildfire in 1970 destroyed the mixed conifer vegetation. Runoff records from the Chelan River (2393 sq. km) were used as control data for determining changes in water yield during the seven years following the fire. The first post-fire year was a period of transition in which the soil profile retained more water than in previous years and measured runoff was 8.9 cm greater than the predicted value based on pre-fire conditions. Runoff from the burned catchment during subsequent years was much greater than measured values before the fire. Measured minus predicted runoff, based on the pre-fire calibration equation, varied from 10.7 cm during the dry year of 1977 to 47.2 cm during the abnormally wet year of 1972. Flow duration curves indicated that runoff at each percent value after the fire was at least double the comparable pre-fire value. Sediment production increased dramatically after the fire because of increased flow rates, increased overland flow caused by reduced infiltration capacity, and mass soil movement. Sediment yield is beginning to decrease as stream channels become stabilized and vegetation on upper slopes improves infiltration capacity.


Abstract - It seems to be generally accepted that for suspended solids to have a direct effect on fish, the concentration must be very high. There is no doubt that many species of freshwater fish can withstand extremely high concentrations of suspended solids for short periods but this does not mean that much lower concentrations are harmless to fish which remain in contact with them for a very long time. The possibility that concentrations of suspended solids lower than 1000 ppm may exert some directly harmful effect on fish has received relatively little attention, however, and this aspect of the problem is the subject of the investigation described in this paper.


Abstract - In some Cornish rivers suspended matter from china-clay workings is the only important polluting material, and such streams provide good sites for investigating the effect of chemically inert suspended solids on fisheries, since there are other unpolluted streams of similar size and character nearby. This paper describes a survey made during May 1960 to determine the status of the brown trout, Salmo trutta, in both clean and polluted parts of the rivers Par, Fal and Camel, and also in two unpolluted streams, the Luxulyan, which is a tributary of the Par, and the Tresillian. The concentrations of suspended matter, the numbers, size and age of the trout, and the amount of food available to them in these streams were investigated.


Abstract - Although data from polluted streams and from laboratory studies show that a fishery is likely to be seriously harmed if the average concentration of suspended matter in the water is greater than about 600 ppm, it is doubtful what effect average concentrations in the approximate range of 90 and 300 ppm are likely to have. In laboratory experiments, 200 ppm wood fibre and 270 ppm kaolin and diatomaceous earth have killed substantial proportions of the trout kept in them for long periods and 90-100 ppm have been harmful to a lesser degree but the data from the questionnaire indicate that there are some rivers which support reasonable fish populations even though the suspended solids concentration is often about 200 ppm and sometimes higher while the present study has shown that trout can be kept in good health for nine months in 200 ppm coal washery waste solids. Whether or not concentrations within this range
will be harmful may depend on the nature of the solid material itself or on whether or not other features of the environment favor survival.

However, none of the laboratory experiments in 30 ppm kaolin and diatomaceous earth and in 50 ppm wood fibre and coal washery solids have provided any evidence that such concentrations make well grown trout more susceptible to disease or reduce their chances of survival and the data from polluted rivers show that there are many streams containing up to 60-70 ppm of a variety of industrial waste solids which support reasonable populations of fish. The only evidence for any adverse effect of such concentrations is that 50 ppm wood fibre and coal washery solids reduced the growth of rainbow trout in the laboratory. However, these trout grew quite well, more than trebling their weight in 8 months and the lengths and weights of brown trout from a stretch of the river Camel containing 60 ppm suspended solids differed very little from those in unpolluted Cornish streams. The effect of 150-60 ppm solids on growth thus seems rather unlikely to be serious in practice.


Abstract - Summer and winter habitat utilized by age-0 spring chinook salmon, Oncorhynchus tshawytscha, was assessed in the Red River, an Idaho stream heavily embedded with fine sediment. During the summer of 1985, chinook salmon used habitats with water velocities less than 20 cm/sec, depths of 20-80 cm, and close associations with cover (undercut banks). Densities were greater than 60 fish/110 sq. meters. As the fish became larger they selected faster, deeper water. Eighty percent of the chinook salmon emigrated from the study sites in October when stream temperatures were 4-8°C, apparently because suitable winter habitat was not available. Those fish that remained in the study sites selected areas where submerged sedges and grasses overhanging undercut banks provided cover and where water velocities were less than 12 cm/sec. After cobble substrate was added to the streambed (September, 1985) beneath undercut banks and in midchannel in a glide and a riffle habitat, eight times more chinook salmon used the cobble substrate in November 1985 as compared with November 1984. Significantly more chinook salmon utilized cobble placed under banks than any other area. By March 1986, cobble piles were embedded with silt and sand and chinook salmon densities were not significantly different from those found in March 1985.

Abstract - Measurements of water turbidity and of boat movements were made on a shallow Broadland river, the River Ant, above and below Barton Broad. A model was used to predict water turbidities from typical boat movement patterns. This demonstrated that long-term build-up of boat-induced turbidity through the holiday season was unlikely and that most of the turbidity in and below Barton Broad on the river Ant was due to algae, not to boating activity.


Abstract - An investigation of sediment toxicity in the western basin of Lake Erie was conducted during 1987 in view of concerns over effects of open-lake disposal of dredged sediments of existing fisheries. Study objectives were to characterize sediment toxicity in frequently dredged areas and an open lake disposal site using Microtox and Pimephales promelas larval survival and growth assays. Field collected sediments were used to prepare the sediment elutriates used as the toxicant in all assays. Microtox assay results indicated sediment elutriates from several locations were toxic to the test organism, Photobacterium phosphoreum, with EC50 values as percent elutriate ranging from 20 to > 100. Results of P. promelas larval survival and growth tests were less conclusive with the majority of the sediment elutriates having little or no effect on either survival or growth of the larvae. The Microtox assay is an effective means for conducting screening tests of large numbers of samples prior to definitive assays. Based on this study, the sediment elutriates tested exhibited few adverse effects on P. promelas larvae, however, extrapolation of these results to effects on existing fisheries in western Lake Erie must consider differential species sensitivity and the limited number of sediments assayed in the present study.


**Abstract** - Ventilation and oxygen consumption rates of green sunfish exposed to bentonite clay suspensions were measured at 5, 15, 25 and 35°C. Ventilation rates were not affected by bentonite clay suspensions below 2,125 FTU (Formazin Turbidity Units) at 5°C, 1012 FTU at 15°C and 898 FTU at 25°C. At turbidity levels exceeding 1012 FTU at 15°C and 898 FTU at 25°C ventilation rates increased 50-70%. Tests were inconclusive at 35°C due to high mortality. Oxygen consumption rates were not affected by turbid suspension of up to 3,500 FTU at any of the four temperatures. Evidence suggests that increased ventilation rates under highly turbid conditions are a means of compensating for reduced respiratory efficiency and a strategy for maintaining a constant oxygen uptake. The costs of increased ventilation rates were probably met by a reduction in activity.


**Abstract** - Small forest areas in steep terrain can be clearcut without serious erosion and damage to water quality if the logging operation is carefully planned and conducted.


**Abstract** - The influence of different forestry practices on streamflow has been investigated since 1951 on 5 forested watersheds, 38 to 96 acres in area, on the Fernow Experimental Forest in the mountains of West Virginia. The effects of cutting and logging practices on water quality are reported in this article.

Practices ranged from a commercial clearcutting without regard to water values or the future value of the property, to an intensive selection cutting with careful planning and careful logging. The experiment demonstrated that excessive damage to water quality can be avoided even when logging on steep terrain. Measured maximum turbidities of streams were 56,000 ppm on the commercial clearcut area and only 25 ppm on the most intensive selection cut watershed. Most of the damage to water quality occurred during and immediately after logging.

Recommended forestry practices discussed include: planning of the logging operation; proper location, drainage and grade of skid roads; and timely completion of the operation in any specific area. In most respects, practices recommended for watershed protection also contribute to the overall efficiency of the logging operation.

Abstract - Whatever "turbidity" really is, it was recently blamed for three incidences of fish kills immediately downstream of bottom-only release reservoirs in California and Nevada. Two successful criminal cases were brought against the reservoir operators and regulatory agencies suggested high reservoir minimum pools as a solution to future problems. Since fixed, and high, minimum pools constrain reservoir operational flexibility and lose more water by evaporation, they are not necessarily welcomed by system operators. There is much uncertainty in determining when turbidity would rise at given pool sizes using conventional current-particle size resuspension diagrams or shear stress assumptions at low water levels in stratified and unstratified water. Consequently we developed empirical low pool solutions and made chemical investigations into the source or resuspended matter in eutrophic reservoirs. Very low minimum pools (2.5% of maximum volume) were maintained without resuspending large amounts of bottom sediments in one case, holding turbidity increases to below those harmful to adult brown trout (< 40 NTU). In larger reservoir fluctuations between 1 and 10 NTU seemed to be endemic and may be due to lake whiting or phytoplankton derived from broken zooplankton fecal pellets, rather than resuspension of bottom sediments even with a low minimum pool (25% of maximum volume).


Abstract - Research was performed in laboratory streams to evaluate periphytic biomass accrual, export, and community composition over a range of limiting nutrient (phosphorus) concentrations with variable velocity, and suspended sediment addition, in comparison to constant velocity and no suspended sediment. In fixed-velocity treatments, velocity increase to 60 cm/sec significantly enhanced biomass accrual, but further increase resulted in substantial biomass reduction. Average biomass loss rates did not change significantly over a velocity range of 10 - 80 cm/sec. Diatoms were favored at relatively high velocities and low phosphorus concentrations, whereas the blue-green Phormidium tended to dominate at higher SRP concentrations and the green seemed to prefer lower velocities.

Sudden increases in velocity raised instantaneous loss rates by an order of magnitude or more, but these high rates persisted only briefly. As a result, marked biomass reductions were not apparent a day after the velocity change. Dominance change from filamentous green or blue-green to diatoms immediately after the increase was reversed within 2 days. Loss rate increases due to solids addition were much smaller than those accompanying velocity increase, but simultaneous velocity elevation and solids addition produced instantaneous loss rates approximately double those with velocity increase alone.

The experiments demonstrated that an elevation in velocity, above that to which algae were accustomed, led to increased loss rates and temporarily reduced biomass. However, recolonization and growth after biomass reduction were apparently rapid. Substantial export of periphyton following solids addition required erosion of the protective boundary layer accompanied by a velocity increase. These results are applicable to understanding the response of lotic periphytic algae to elevated, turbid storm discharges and similar runoff or high-flow events.

Areal uptake rates of P by algae growing in the laboratory streams increased with soluble reactive phosphorus (SRP) concentration, up to approximately 15 pgm/1 in overlying water. They also increased above 35 cm/sec. Overall, uptake rates seemed to vary inversely with biomass. The ration of areal uptake rate/biomass was significantly less where mean biomass was 411 +/- 6 mg chlorophyll a/sq. m compared to 223 +/- 8 chlorophyll a/sq. m. The results suggested that although nutrient uptake is primarily a surface phenomenon, diffusion to interior cells can also determine the responses of attached communities. Both diffusion and uptake rate were stimulated by increasing nutrient concentration and velocity up to certain levels, but became limited by biofilm thickness and scouring.


Abstract - Agriculture has had severe effects on aquatic habitats. Water quality and aquatic habitat is inversely proportionate to the level of agricultural intensity.

Buffer strips are one of many measures available to improve the problem. From the standpoint of bank stability, relatively narrow buffer strips (3 meters) are effective and can have both environmental and agricultural benefits. Wider buffer strips, for the purpose of filtering sediment and contaminants, can be either unreasonably large or require frequent maintenance to the point of being intolerable to agriculture. In consideration of the numerous most effective measures available to remediate off-site impacts at the source, buffer strips are not generally considered cost effective. Therefore, use of buffer strips for silt control should be limited to very special circumstances such as coldwater fisheries and then in conjunction with upland at-source controls.

The minimum buffer strip standards are those required for channel stability and include a width of 3 meters on each side; grass/legume vegetation; shrub/tree plantings on the south and east sides of the watercourse; and special measures where concentrated flows enter the channel. In most cases, the channels associated with agriculture will be municipal drains constructed under the Ontario Drainage Act.


Abstract - Unaltered streams are usually clear, and running water animals and plants have in general become adapted to silt-free situations. Most of their specializations relate to the substratum which provides them with shelter, attachment sites and food. Our knowledge of the effects of turbidity and siltation by inert solids on plants, benthic animals, fishes and their eggs is reviewed. It is concluded that the upper tolerable level of turbidity is probably less than 80 mg/1 of inert silt, and that any considerable amount of deposition is bound to have biological consequences.


Abstract - Results of recent laboratory experiments concerned with the flocculation, entrainment and deposition of fine-grained sediments in lakes will be reported. Flocculation experiments were conducted using a modified viscometer while the entrainment and deposition experiments were done in an annular flume. The flocculation experiments show the dependence of flocculation rates on sediment concentration and fluid shear. Starting with disaggregated particles, an equilibrium particle size distribution is reached
in times of 2 to 24 hours for concentrations of 100 to 500 mg/l and shear stresses of 2 to 5 dyes/cm², values which are typical of the Great Lakes. The effects of flocculation and particle size variation on entrainment and deposition are significant and will be discussed.


Abstract - This paper is concerned with sedimentation and the causes and effects of resuspension of these sediment particles at Lake Chautauqua, a lateral reservoir lake along the Illinois River. Between 1953 and 1957, 346 turbidity determinations were made with a Jackson turbidimeter and 156 water transparency readings were taken with a Secchi disk. Turbidity of the lake ranged from less than 25 ppm to 800 ppm. The resuspension of sediment particles, which were originally carried and deposited in the lake by flood waters of the Illinois River, caused the high turbidities at Lake Chautauqua. The disturbance of the lake bottom by fish and/or water motion produced by wind caused sediment particles to become resuspended. Wind velocity had little or no effect upon turbidity when vegetation or ice cover was present in the lake or in areas where depth of the water exceeded about 5.8 feet. When depths of the lake were less than 4.8 feet and vegetation or ice cover was absent, turbidity tended to vary with wind velocity. During periods when wind had little or no effect upon turbidity, fish activity and, to a lesser extent, phytoplankton usually prevented the lake from becoming clear. Over an eight year period, the removal of 2,022,965 pounds of fish from the lake by commercial fishermen had no apparent effect upon vegetation growth or turbidity. During moderately high river stages, turbidity was affected only in areas where the river water was overflowing into the lake. Important duck food plants that were formerly abundant were adversely affected by sedimentation and fluctuating water levels. Changes had also occurred in the species composition of the fishes. The shallowness of Lake Chautauqua through much of the growing season assured that most of the lake was within the euphotic zone and this was considered to be an important factor in the high productivity of this turbid, fertile lake.


Abstract - A flume study was conducted to examine (1) changes in the particle-size distribution of sediments in riffles due to the proportion of sand in transport and the total rate of bedload transport at the time the riffle is deposited and (2) the effect of high sand transport rates on the stability of gravel riffles. The median particle size of sediment deposited in the riffle was larger than that of the sediment in transport. Small but significant decreases in the median particle size of riffle sediments resulted as the sand-to-gravel ratio of sediment in transport varied from 1:1 to 5:1. Gravel deposition efficiency decreased linearly as a function of the sand-to-gravel ratio. Increased concentrations of sand in transport caused previously stable gravel riffles to undergo scour. These results, in combination with information from other studies, suggest that an alluvial channel with poor-riffle sequences and with sand and gravel beds may respond to increased delivery of sand by reducing form roughness. Form roughness can be reduced by degrading riffles and filling pools. Subsequent responses may be increases in width-to-depth ratio and slope.


Abstract - Sediment resuspension dynamics and discharge of sediment downstream in Marsh Lake (Minnesota) were examined during 1991 and 1992 under a variety of wind conditions. Based on a theoretical wave model, nearly the entire sediment surface area (81-100%) can be disturbed by wave activity at wind velocities as low as 15 km/hour blowing from any direction. As an apparent result of dense submersed macrophyte beds that in 1991 covered nearly the entire lake, measured sediment resuspension was much less frequent than expected from wave theory in 1991 than 1992. Critical thresholds of wind velocity required to resuspend sediment were much higher in 1991(20 km/hour) than in 1992 (12 km/hour) resulting in a lower frequency of resuspension events in 1991 (5%) than in 1992 (32%). Discharge of resuspended sediment to downstream Lac Qui Parle Reservoir was much less in 1991 when submersed macrophytes were abundant than in 1992 when macrophytes were absent. These results suggest that the development and maintenance of stands of submersed aquatic macrophytes may be an effective management tool for limiting wind-driven sediment resuspension and sediment discharge in shallow impoundments and lakes.


Abstract - Survival of naturally spawned walleye, *Stizostedion vitreum vitreum*, eggs to pre-hatching stage was determined on five bottom areas of Lake Winnibigoshish, Minnesota, and connecting waters over 4 years. These bottom types included soft muck, sand, gravel, rubble and boulders. Egg sampling was done at intervals throughout the incubation period and estimates of egg abundance made shortly after the completion of spawning and at or near the eyed egg stage. Initial fertility of walleye eggs was high (96-100 percent), but the percentage of live eggs declined steadily during incubation. During the eyed-egg stage, however, there was an apparent increase in the percentage survival because of disappearance of dead eggs. Egg survival was best on gravel-rubble both as percentage survival and numbers of eggs surviving the eyed stage. Survival of eggs on improved gravel-rubble bottom was as high as 35.7% but on muck bottom was as low as 0.6%. Survival on better bottoms of gravel and rubble averaged 25%. Abundance of eggs on sand bottom to which gravel and rubble had been added was more than 10 times that observed previously, and survival of eggs on the improved bottom increased five-fold. Length of incubation period, which was determined by water temperature, was a factor in egg survival. Walleyes selected gravel bottom for spawning when it was available and most eggs were deposited in water from 12 to 30 inches deep. Low water levels in the spring of 1958 made much former spawning area unavailable and may have been a factor in a weak 1958 year class.


Abstract - Information on sediment and phosphorus loads through time and space, coupled with descriptions of trends in water quality and fish communities, provide useful reference points and goals for water management. These are needed in Lake Simcoe where the coldwater fish community and water quality have deteriorated. The sedimentation basin and thickness of post-glacial beds in Lake Simcoe were defined by sonar and together with data on total phosphorus (P) and bulk density used to estimate the pre-1800 sediment load of 27,300 tons/year and P load of 28.2 tons/year. The recent sediment load of 63,900 tons/year and P load of 74.6 tons/year were obtained by scaling up pre-1800 rates using ratios of recent to pre-1800 mass sedimentation rates and P loads at 20 core stations. Time variable mass sedimentation rates and P concentration profiles facilitated the division of P load into three components - natural load, anthropogenic non-point source load and anthropogenic point-source load. Analysis of temporal trends indicated that non-point-source P inputs peaked approximately 85-95 years before present (BP), declined to about 30 years BP and increased again since then in the main basin. The dominant peak in Cook Bay occurred 35-45 years BP after marshes at the head of the bay were drained and the lower Holland River was channelized for agricultural purposes. Point-source P was detected in cores beginning
about 50-75 years BP and increased toward the sediment-water interface. Spatial distribution of P load changed after settlement when altered limnological conditions and loss of marshes changed the P-retention coefficients (R) in bays.


Abstract - The purpose of this study was a preliminary attempt to determine if increase levels of suspended sediment occurring, for example, after dredging and dumping activity and resultant decreases in light intensity, reduce prey visibility for larval herring to such an extent that the feeding rate is affected. The effect of suspended sediment on larvae of different life stages was also investigated.

As suspended sediment concentrations were increased, prey visibility decreased and larvae moved into the better illuminated surface layers to feed. We believe the depression of the feeding rate by herring larvae is a function of larval age/size with smaller larvae being more affected by increased levels of suspended sediment than are larger larvae. Our results also demonstrate an effect of light intensity on feeding rate, although they cannot be compared with other studies since our light measurements were made at the water surface.


Abstract - Sediment deposited in a flood control structure was measured after record floods in southwestern Wisconsin on June 17 and June 30-July 1, 1978. The structure is in Driftless Area, where high relief, erodible soils and land use contribute to high soil losses. The two floods deposited 4.1 acre feet of sediment in the structure. This translates into a sediment yield of 3,200 tons per square mile from the 2.3 square mile drainage basin. Comparison of this yield to the average annual sediment yield of 13 tons per square mile between 1968 and 1974 illustrates the importance of isolated hydrologic events in determining sediment yields in the Driftless Area.


Abstract - An old conservation practice has the potential to be a valuable tool in our arsenal of erosion control technology - using sediment, build bioterraces, diffuse concentrated flows of runoff water, and protect downwind soils and crops from wind erosion.

The general concept of this technology is that narrow rows of stiff, erect, densely tillered grass are planted in parallel lines across the dominant slope of the field. As these rows mature into continuous hedges, they inhibit the flow of water through them during runoff events. Where runoff concentrates in rills and ephemeral gullies, these hedges pond water causing a large part of the sediment load to deposit thus filling the depression and creating a series of benched terraces. These broad grass-backed bench terraces diffuse and spread the flow so that it trickles through the grassed backslopes with little or no further erosion. Grass hedges are more narrow than traditional buffer strips, beginning at only a few inches in width and growing to needed widths as terrace berms increase in height.


Abstract - Soil erosion is a critical problem on the dry, steep sloped wheat lands in the Pacific Northwest where snow on frozen soil is often melted rapidly by warm winds and rain from the Pacific Coast.
Reviewed in this article are the erosion control practices that research and farmer experience have proved effective in controlling soil loss.


Abstract - Forest planners, by selecting a particular harvest level, can read the cost of avoiding sediment directly from a graph generated by a computer model. The Integrated Resource Planning Model combines harvest and road building activities. For variables corresponding to traffic flow and choice of investment on road links, the coefficients are cost and sedimentation rate. For each given level of harvest, the model solved for the best combination of harvest options, road-link standards and distribution of traffic over the network. The steps can be arranged in a time sequence by selecting a permissible maximum total sedimentation rate.


Abstract - In mainland Australia and in southern Africa, the aridity of the climate and sparse vegetative cover increase the susceptibility of the soils to erosion and as a consequence surface waters are usually turbid. The inanimate suspensoids in such waters, the "tripton" fraction of the limnologist, are responsible for virtually all the light scattering and also, by virtue of the yellow-brown humic materials adsorbed on their surface, for a substantial part of the light absorption. Spectral absorption data for suspensoids in terms of their in situ absorption coefficient values and the contribution of suspensoids to absorption of photosynthetically available radiation (PAR) are given for certain Australian waterbodies.
To understand the effect of suspensoids on attenuation of the solar flux with depth, the scattering coefficient must also be known, and this can be determined from the nephelometric turbidity or from upand down-welling irradiance measurements. The effect of particle size on scattering efficiency is discussed.

An equation expressing the vertical attenuation coefficient for downward irradiance as a function of absorption coefficient, scattering coefficient and solar altitude is presented and is used to explore the effects of absorption due to dissolved color and suspensoids and the effects of scattering by suspensoids on the penetration of PAR.

Suspensoids, by increasing the rate of attenuation of the solar flux with depth, can greatly diminish the euphotic depth of a waterbody with a consequent decrease in the ration of the euphotic to the mixed depth: thus turbidity can reduce productivity of a waterbody substantially below that which might be expected on the basis of nutrient availability. Shallow turbid waters of low intrinsic color can, however, be highly productive. By diminishing the depth of the layer within which solar energy is dissipated as heat, suspensoids can greatly modify the hydrodynamic behaviour of waterbodies and this also has far-reaching ecological consequences.

Suspensoids drastically impair the visual clarity of water, a fact of major significance for the aquatic fauna as well of aesthetic significance for humanity. The reciprocal of the Secchi depth is more correctly thought of as a guide to the vertical contrast attenuation coefficient rather than to the vertical attenuation coefficient for irradiance. The reflectivity of a waterbody, being at any wavelength proportional to the backscattering coefficient divided by the absorption coefficient, is highly dependent on the concentration and optical character of the suspensoids present. This has implications not only for the appearance (color, muddiness) of the water to an observer, but also for the remote sensing of water composition by air or satellite borne radiometric sensors.


Abstract - Suspended sediments (clay and silt particles) differentially inhibit cladoceran populations, but not rotifer populations, and can change the outcome of competition between rotifers and cladocerans in favor of rotifers (Kirk and Gilbert, 1990). This paper provides a mechanistic explanation for the population and community effects of suspended clay. Feeding experiments with radioactively labeled phytoplankton cells (Cryptomonas) showed that the presence of suspended clay (< 2 gm particle size) significantly decreased the phytoplankton ingestion rates of five cladoceran species (Ceriodaphnia dubia, Daphnia ambigua, D galeata mendotae, D. magna, and D. pulex) by 13 - 83% but not those of three rotifer species (Keratella cochlearis, K. crassa and Synchaeta pectinata). When radioactively labeled phytoplankton cells and clay particles were offered simultaneously, cladocerans were less selective for phytoplankton over clay than were rotifers. Thus, cladocerans ingested more suspended clay particles than did rotifers, and this caused the reductions in phytoplankton ingestion rates. Smaller cladocerans were less selective for phytoplankton over clay than were larger cladocerans, and their phytoplankton ingestion rates were thus reduced more by clay. Rotifers fed more selectively than either large or small cladocerans, were able
to avoid ingesting clay particles, and therefore were not inhibited by suspended clay. Thus, differences in the feeding modes and selectivities of rotifers and cladocerans form the mechanistic basis for the change in competitive outcome in favor of rotifers observed in the presence of suspended clay. This mechanism may form the basis for changes in the relative abundance of rotifers and cladocerans in turbid lakes and reservoirs.


Abstract - Suspended sediments often reduce cladoceran abundance in the field and reduce the algal feeding rates of cladocerans in the laboratory. This paper explores the behavioral mechanisms by which suspended clay reduces Daphnia feeding rates. Feeding experiments using radiolabelled Cryptomonas cells showed that 50-200 mg/l coarse suspended clay (particle size < 2 um) reduced the algal ingestion rate of Daphnia ambigua by 29-87% but fine suspended clay (< 1 um) had no effect. Suspended clay decreased feeding rate by 60-70% at low algal concentrations (< 5 x 10^3 cells/ml) but by only 27% at high algal concentrations (20 x 10^3 cells/ml). Thus, the inhibitory effects of suspended clay are greater at low algal concentrations. The sudden addition (or removal) of suspended clay caused immediate reductions (or increases) in algal ingestion rate.

Observations of the feeding behaviour of tethered D. pulex showed that the frequency of postabdominal rejections increased greatly in the presence of suspended clay. The rejected boluses contained both algae and clay. Thoracic feeding appendage beat frequency decreased in the presence of suspended clay decreasing the volume of water searched for food particles.

These behavioral responses indicate that clay reduces cladoceran feeding rate by mechanically interfering with both the collection and ingestion of algal cells. Both inhibitory effects are caused because cladocerans collect and ingest suspended clay particles. The behavioral mechanisms by which cladocerans regulate their feeding rate in very high concentrations of algal cells (rejection of excess food and reduction in thoracic limb pumping movements) are the same mechanisms responsible for the inhibition of algal ingestion rate in the presence of high concentrations of suspended clay particles.


Abstract - Suspended sediments often reduce the abundance, fitness and feeding rates of planktonic cladocerans. This paper examines the effect of suspended clay particles on the body growth and life history parameters of Daphnia ambigua. Cohorts were exposed to zero or 50 mg/l suspended clay (particles size < 2 um). Individuals exposed to clay had significantly lower body lengths at a given age than individuals in the control cohort. Parameters for the von Bertalanffy body growth equation were calculated for each individual; the asymptotic maximum body length (L max) was reduced, but the growth rate constant (k) was unaffected by the presence of suspended clay. Body length at reproductive maturity was lower in the presence of suspended clay; this may be an adaptive response and is similar to the response of cladocerans to limiting food concentrations.

Age specific survivorship and fecundity were both reduced and the ages of maturity and first reproduction were both increased in the presence of suspended clay. The overall effect of these demographic changes was a 70% decline in the net reproductive rate (Ro), a measure of fitness.

Suspended clay affected the relationship between body length and fecundity. Animals of a given length produced fewer eggs in the presence of suspended clay. In addition, there was a significant interaction in the effects of bodylength and clay on brood size: the slope of the regression line of brood size as a function of body length was lower in the presence of clay. This interaction has also been observed in limiting food
concentrations and may be caused by reductions in body length at maturity in low food or high clay environments.

The similarity between the effects of limiting food concentrations and suspended clay on *Daphnia* body growth, survivorship, fecundity and brood size makes sense given previous observations showing that suspended clay reduces the feeding rate of *D. ambigua* by up to 70% due to mechanical interference with feeding behaviors.


Abstract - The direct and indirect effects of suspended clay on the population dynamics of several species of planktonic rotifers and cladocerans were investigated using long-term laboratory experiments. Life table and population growth experiments showed that high but naturally occurring, concentration (50-100 mg/1) of coarse, suspended clay (< 2 um particle size) caused large reductions in the population growth rates (rm) of four cladoceran species (*Bosmina longirostris*, *Ceriodaphnia dubia*, *Daphnia ambigua* and *D. pulex*). Juveniles were more susceptible than adults to suspended clay. Low concentrations (10 mg/1) of coarse clay and high concentrations of fine clay (< 1 um) did not decrease and sometimes increased cladoceran population growth rates. Both the inhibitory effects of high concentration of coarse clay and the stimulatory effects of low concentrations of clay were greater at limiting food (*Cryptomonas*) concentrations. The population growth rates of four rotifer species (*Brachionus calyciflorus*, *Keratella cochlearis*, *Polyarthra vulgaris*, and *Synchaeta pectinata*) were not affected by high concentrations of coarse or fine clay, even at very low food levels. The population growth rate of the rotifer *K. crassa* was decreased by coarse clay.

The threshold food concentration (the food concentration measured as dry mass at which populations growth rate equals zero) of the cladoceran *D. ambigua* was increased from 0.15 to 0.40 pgm/ml in the presence of 50 mg/1 coarse clay, indicating a reduced ability to compete in exploitative contests. The threshold food concentration of the rotifer *K. cochlearis* (0.05 pgm/ml) was unaffected by suspended clay. Suspended clay reversed the outcome of two rotifer-cladoceran competition experiments, between *K. cochlearis* and *C. dubia*. In the absence of clay, the cladocerans dominated; in the presence of clay, the rotifer dominated. The presence of suspended sediments in natural ecosystems, such as turbid lakes and reservoirs, should favor rotifers over cladocerans and thus influence the structure of zooplankton communities.


KOCHENDERFER, J. N. AND J. D. HELVEY. UNDATED. Forest access roads. Central Hardwood Notes, Northcentral Forest Experiment Station, Forest Service, U. S. Department of Agriculture. 4 p.

Abstract - The bare soil exposed by road building is the major source of stream sediment from logging operations. Roads normally expose soil on about 10% of logged areas.

Some measures which will reduced erosion from forest access roads include:
O plan road locations to avoid wet areas including streams, lakes and wetlands;
O keep forest access roads within acceptable grade limits;
O decide on the appropriate number and size of culverts;
O build truck roads and skid roads in dry weather if practical;
O avoid skidding and hauling logs during rainy periods or when surfaces are freezing or thawing;
O seed roads and landing after logging to provide additional protection against erosion.


Abstract - Glacial lakes, turbid (> 5 nephelometric turbidity units) with suspended particles (1-30 um) have both lower May-November levels of chlorophyll a and temperatures compared to nonglacial systems. Macro-zooplankton densities are also lower and dominated by Cyclops and Diaptomus. Extensive surveys showed that, regardless of the presence or absence of planktivorous fish, filter-feeding cladocerans (i.e., Bosmina, Daphnia and Holopedium) were only absent from the limnetic zooplankton community of the glacial lakes. Both laboratory and in situ biochamber experiments demonstrated that turbidity reduced Daphnia survival and recruitment. Nondiscriminating filter feeders ingest glacial silt (average diameter of 11 um) because the size range overlaps that of the phytoplankton. We speculate that such an inefficient foraging strategy, especially when silt levels are high and algal numbers low, lowers energy extractable from ingested food below maintenance levels. Thus, the limnetic macro-zooplankton community of most Alaskan glacial lakes is restricted to either the selective herbivore Diaptomus and the raptorial feeding Cyclops, or to just Cyclops.


Abstract - Brown and rainbow trout (Salmo trutta and S. gairdneri) eggs were held in continuous low suspensions of 0, 60, 125, and 250 ppm conifer groundwood fiber 6 to 8 days before hatching. Resulting alevins were held in the same fiber concentrations until swimup (14-16 days), then removed and maintained in clean water for up to 91 days. Suspended fiber had no effects upon egg survival, respiration rate of embryos or growth rates of alevins and juveniles from eggs incubated in fiber but hatched and grown in clean water. When alevins were held in wood fiber suspensions, survival was reduced from 98 to 100% in controls to 0 to 72% in 250 ppm fiber; respiration rate from 336.6 mm³/gm per hour in controls to 146.3 in 125 ppm fiber; breathing rate from 1.39 to 1.92 respiratory movements per second in controls to 0.52 to 0.97 in 250 ppm fiber; heart rate from 1.50 to 1.60 beats per second in controls to 0.67 to 1.33 in 250 ppm fiber; and instantaneous growth rate (g) from 0.213 to 0.345 in controls to .0061 to .0062 in 250 ppm fiber. Growth rate of rainbow trout juveniles in clean water after exposure to fiber during the alevin stage was significantly reduced only in the 250 ppm fiber group. Concurrent tests indicated that observed effects were due to the fiber and not to residues of a mercuric slimeicide added to the fiber at the paper mill.


Abstract - Turbidity and suspended sediment analyses were made on stream samples collected in the Sleepers River watershed of northeastern Vermont. Results showed that turbidimeter readings could be used to estimate suspended sediment concentrations in the 16 to 6,366 milligrams/liter range observed by using the prediction equation Y = AXᵇ. The equation was similar for the three watersheds studied, where soils, topography and other factors were essentially the same. Samples were collected during two years of storm and snowmelt runoff on catchments draining from 16.2 to 43.5 square kilometers. Discharges ranged from 140 to 18,000 liters per second. The sediment particles were mostly of stream bank origin and were primarily silt or very fine sand.


Abstract - Average annual soil loss from four tile outlet terrace systems in Iowa was less than 750 pounds per acre and less than 5 percent of soil erosion between terraces. Sediment concentrations averaged
between 800 and 3850 parts per million. Most soil lost consisted of particles and aggregates with diameters less than 0.016 millimeter.


Abstract - Flood flows into a river impoundment early in its history are believed to have produced a deepwater layer of highly turbid water that persisted owing to the slow settling of suspended material and poor reservoir flushing ability. Subsequent inflows of considerably cleaner water, superimposed on the turbid layer created a pronounced middepth density gradient. Possibly, circulation of water between the two layers was restricted for several years and a condition regarded as a meromictic may have been established.


Abstract - Conservation districts, long at the forefront of efforts in Wisconsin to control soil erosion on agricultural lands are now focusing more of the technical resources on erosion problems in areas undergoing residential, commercial and industrial development.

Conservation of erosion control plans are an integral part of preliminary subdivision proposals. The following represent a variety of concerns often considered:

- soil suitability
- drainage
- critical area treatment
- grading and revegetation
- road ditches
- protection of adjacent property
- related resource concerns

In the future, urban districts should carry our informational and educational erosion control programs for the public. Another likelihood in the future will be the regulation of all forms of land disturbance activity in urban areas.


Abstract - Behavioral responses of whitefish, Coregonus clupeaformis, and rainbow trout, Salmo gairdneri, to drilling mud (1 to 1000 ul/l) and its supernatant fraction (55 to 10,000 ul/l) were tested in laboratory experiments. Experiments were run under infrared as well as under visible light, to separate photically from chemically elicited responses.

Four response parameters were recorded and analysed: (1) percent test time spent in pure compared to contaminated water; (2) effect of contact with contaminant on swimming speed, turning rate and frequency of movements across the centerline of the test chamber (boundary between pure and contaminated water); (3) extent of penetration by fish into pure vs. contaminated water; (4) time spent at the end walls of the pure vs. contaminated water side.

Conclusions on preference or avoidance are derived from these behavioral elements. The results are discussed with regard to LC50 values of drilling fluids.

Abstract - Soil losses and sediment yields due to silvicultural activities generally occur when the protective litter layer is disturbed. Water from undisturbed forest lands is high quality because the canopy and litter layer protect the soil surface and enhance soil biological activity. With the litter intact, water infiltrates the porous upper soil layers rapidly and rarely flows over the surface. Without this protective layer, however, raindrops detach soil particles and start eroding, transporting and depositing sediments. Dislodged soil particles wash into soil pores, decrease soil porosity and overland flow starts. Soil porosity is also reduced by compaction from heavy equipment used in forest operations especially when soils are wet.

Changes in stand density or the forest canopy will change the water regime. Clearcutting may significantly increase streamflow from the harvest area because the amount of water lost to interception and used by vegetation in the evapotranspiration process is reduced. Streamflow will last longer in the spring and begin sooner in the fall.

Several recommendations are offered to reduce soil disturbance and minimize the effects of timber harvesting and site preparation:

O during harvests, skid uphill or away from stream channels to haul roads located on contours or ridge tops. Avoid skidding practices that channel water into streams;
O log only when soils are relatively dry. Wet weather logging compacts soils and increases erosion;
O after logging operations are completed, high erosion hazard areas such as landings, skid trails and temporary access roads should be disked or ripped, seeded and fertilized based on local or regional recommendations;
O prevent water from collecting in landings and flowing down roads and skid trails. Water bars, outsloped roads and revegetation immediately after logging will generally prevent excessive erosion. For minor soil disturbances, use cull logs and brush to disperse water until natural vegetation forms a protective cover.


Abstract - This paper summarizes the available data on environmental impacts associated with timber harvesting and proposes a preliminary model for predicting an index of on-site erosion and downstream sediment yield. Sediment yield studies in mountain watersheds have shown that most of the erosion impact occurs within a few years after disturbance. This should be considered in land use planning in terms of protection and long term effects on hydrologic parameters such as water quality. By describing the disturbed area in terms of watershed slope and engineering design patterns, the land use planner has some flexibility in evaluating the potential impacts of various road systems. The model described is based on data obtained from a carefully constructed road system and a high standard of follow-up maintenance. Any application of the model should presume similar standards of construction and maintenance.

Abstract - A series of entrainment and deposition experiments was performed with the general purpose of increasing our understanding of the parameters on which entrainment and deposition depend and the specific purpose of obtaining entrainment rates for a variety of sediments from the western basin of Lake Erie. The experiments were performed in an annular flume. A rotating top produced a turbulent flow which in turn exerted a turbulent shear stress on the sediments deposited on the bottom of the flume. Four different sediments from the western basin of Lake Erie were analyzed. Large variations in entrainment and deposition rates occurred and are shown to be dependent on the shear stress, water content (time after deposition), the type of sediment (grain size and mineralogy), and the manner of deposition. In the interpretation of the experiments, it is necessary to consider the frequency distribution of sediment properties as well as the average properties.


Abstract - Threespine sticklebacks, Gasterosteus aculeatus, and coho salmon, Oncorhynchus kisutch, fry were challenged in static 96 hour bioassays with suspensions of sediment from the Duwamish Waterway, Seattle, Washington. Doses of up to 5% wet weight (28.8 g/liter dry weight basis) were used. No observable effect on the fish of contaminants released from the sediment was elicited although high levels of these contaminants, such as volatile solids, COD, organic nitrogen, oil and grease, zinc and lead were present.


Abstract - Responses of the benthic insect community of a southern Appalachian trout stream to inorganic sedimentation and nutrient enrichment were monitored over a period of eight months. Entry of pollutants from point sources established differentially polluted zones, allowing an assessment of impacts due to sedimentation alone and in association with elevated nutrient levels. Input of sediment resulted in a significant increase in bed load and decrease of pH at the substrate-water interface (P < 0.05). The zone receiving nutrient runoff from livestock pasture exhibited elevated levels of nitrate and phosphate but available data indicated such concentrations to be quite low. Species richness, diversity and total biomass
of filter feeding Trichoptera and Diptera, predaceous Plecoptera and certain Ephemeroptera were significantly reduced in the polluted zones. Inorganic sedimentation, operating indirectly through disruption of feeding and filling of interstitial spaces, was considered to be the primary factor affecting filter feeding taxa. Decomposition of compounds associated with materials in the bed load may depress pH and eliminate acid sensitive species of Plecoptera and Ephemeroptera. Such processes of acidification may be particularly important to Appalachian streams since the pH of regional surface waters is characteristically acidic prior to sedimentation. Accumulation of particles on body surfaces and respiratory structures, perhaps as a function of wax and mucous secretion of surface electrical properties, appears to be the major direct effect of inorganic sedimentation on stream insects. Growth of the filamentous bacterium Sphaerotilus natans were also frequently associated with silted individuals in the zone receiving nutrient addition. Distribution of the bacterium suggested that silted substrates, perhaps as related to the presence of iron compounds, are required for colonization in dilute nutrient solutions. The primary effect of Sphaerotilus colonies appears to be augmentation of particle accumulation through net formation by bacterial filaments. Data indicated that inorganic sedimentation and nutrient addition operate synergistically, eliminating a significantly greater number of taxa than exposure to one pollutant alone.


**Abstract** - Two upper Piedmont streams were studied to determine the effects of road construction, especially sediment inputs. Benthic macroinvertebrate data suggest that the stream community responded to sediment additions in two different ways. Under high flow conditions the benthic fauna occurs mainly on rocky substrates. As sediment is added to a stream the area of available rock habitat decreases, with a corresponding decrease in benthic density. There is, however, little change in community structure. Under low flow conditions, stable sand areas may support high densities of certain taxa. Density of the benthic macroinvertebrates in these areas may be much greater than the density recorded in control areas, and there are distinct changes in community structure.


**Abstract** - Finely suspended materials, having dimensions at and near the overlap in size ranges for the particles colloid continuum, were sampled from four Ontario lakes during periods of calm. The lakes chosen were two large lakes of public concern (Ontario and Erie) and two small lakes undergoing intensive scientific investigation (Jack and St. George). The finest of the aggregated particles, as arbitrarily defined by observations from optical and scanning electron microscopy, were examined in detail at the high resolution level provided by transmission electron microscopy applied to ultrathin sections of chemically stabilized specimens. Four general features of the finest particles and of mixed aggregates of colloids (approximately 0.1 um to 10 gm) are revealed clearly at high resolution scanning electron microscopy and optical microscopy. However, these four general features, revealed only at high resolution, are important to an understanding of natural sedimentation and flocculation phenomena. They are: a great
inter-penetration of particle surface and aquatic milieu; high internal porosity; the presence of surface extensions permitting physical bonding to other particles; the presence of fibrils as internal bridging structures. All features are not necessarily present in the same particle but all are commonly encountered in most samples, and all tend to be ignored in standard analysis of lake particles.


Abstract - Driftnets, basket samplers and artificial streams were used to investigate the influence of heavy sand accumulations on insect drift, colonization and upstream movements in Emerald Creek, northern Idaho. Most riffle insects successfully passed through low velocity, sandy reaches 80 m long. Upstream movements on sand were impeded by flows as low as 12 cm/s, except for the heavily cased caddisfly, Dicosmoecus spp.


Abstract - Gametophyte material of the aquatic moss Eurhynchium riparioides was placed into suspensions of coal dust ranging from 100 to 5000 mg/l in concentration. After one week, concentrations above 500 mg/l were causing severe abrasive damage to the leaves however this effect was observed at 100 mg/l after three weeks. The higher concentrations of coal dust were affecting growth by limiting the increase in length which was observed in the control flasks. Also, after a period of three weeks the production of side branches decreased with increase in coal dust concentration and at 500 mg/l lateral shoots were almost absent. The production of chlorophyll a was also limited by the presence of coal dust but even at the high concentration of 5000 mg/l chlorophyll a production was not prevented entirely. A possible mechanisms for the action of coal dust is postulated.


Abstract - Jackfish Lake water levels are higher since a dam was constructed in 1966. Cottage development around the lake and agricultural practices in the watershed have resulted in increased silt loadings and slight increases in total dissolved solids. The standing crop of benthos has increased threefold. Murray Lake is less affected by cottages and agriculture.

Whitefish, walleye and cisco declined in Jackfish lake after 1955 while pike have increased. In Murray Lake all fish have increased except whitefish. Commercial whitefish fisheries operate on both lakes and current quotas exceed sustainable levels.


**Abstract** - The resuspension and transport of fine-grained sediments in Lake Erie has been calculated for a variety of wind conditions. The emphasis was on the effects of major storms. Calculations were made for different constant wind speeds and wind directions and also for the November 1940 storm, one of the largest in the last century. The results indicated that major storms, despite their infrequent occurrence, are responsible for most of the resuspension and transport of fine-grained sediments in Lake Erie. The results of the calculations are also used to more quantitatively interpret geochronological data from Lake Erie.


**Abstract** - The resuspension properties of sediments from the Fox, Saginaw and Buffalo rivers were investigated by means of laboratory experiments and field measurements. In this work, an annular flume and a portable resuspension device (Shaker) were used. The advantages, disadvantages and limitations of these dives are discussed. By a combination of laboratory and field tests, these resuspension properties of undisturbed sediments in each of these three rivers were approximately determined as a function of shear stress and time after deposition. The results show distinct and quantifiable differences in resuspension properties between sediments in each of the rivers and between muddy and sandy sediments within a river. For each type of sediment in a particular river, the resuspension data can be approximated by a simple equation.


**Abstract** - Influences of physical and chemical characteristics of sediments and of groundwater inputs on the distribution and biomass of Erasian milfoil, Myriophyllum spicatum, were studied in Devil's Lake, Wisconsin. Sediment cores from inside and outside M. spicatum beds were analyzed for density, particle size composition and moisture, organic, elemental and nutrient contents. Groundwater direction, volume and nutrient concentration were determined using seepage meters. Whereas sediment composition appears to be inadequate to support dense growth of macrophytes, localized groundwater inputs may be important in regulating the distribution and biomass of M. spicatum in Devil's Lake.


**Abstract** - Eighteen late summer runoff events were monitored in 1981 on three small watersheds in the Price River basin, Utah. Average concentrations of total solids from a single storm ranged from 2783 mg/l on Coal Creek to 267 680 mg/l on Wattis Branch. The largest discharge of total dissolved solids, 47 mg, was on Wattis Branch. Average single storm concentrations of total dissolved solids ranged from 181 mg/l on Coal Creek to 7680 mg/l on Wattis Branch. Particularly high concentrations of total solids and total dissolved solids occurred in runoff on all three watersheds during the first monitored storm following a long, dry period, suggesting a flushing of accumulated sediments and salts. Average storm total solids and
total dissolved solids concentrations corresponded to surface soil loss potential as indexed by universal soil loss equation parameters.


Abstract - Data from four reservoirs representative of different trophic states and with different apparent optical properties were analyzed to determine the relationship of Secchi depth to algal biomass as measured by chlorophyll a. In the eutrophic reservoir Secchi depth was determined partially by the chlorophyll a content ($r^2=0.31$) but only when chlorophyll a data from "bloom" conditions are included. In the two mesotrophic reservoirs, Secchi depth was entirely determined by non-algal turbidity. In the oligotrophic reservoir, Secchi depth was determined neither by chlorophyll a nor non-algal turbidity and was probably determined by dissolved color. When data from the four reservoirs were pooled (N=205), 53% of the variation in Secchi depth was explained by: $SD = 2.55 - 0.52$ (turbidity) + 0.005 (chlorophyll a). It is apparent that attempts to estimate algal biomass for trophic state classification or other management practices from Secchi depth data are inappropriate even where even moderate amounts of non-algal turbidity are present.


Abstract - Incubating salmonid eggs in streambeds are often threatened by deposition of fine sediment within the gravel. To relate sedimentation of spawning gravel beds to sediment transport, infiltration of fine sediment (< 2 mm in diameter) into clean gravel beds, bed material size distributions, scour-fill depths, and sediment transport during 10 year storm flow events were measured in three streams of north coastal California. Although suspended sediment comprised most (75-94%) of the classic load during storm flows, bed load material (0.25-2 mm) accounted for most (70-98%) of the fine sediment accumulated in experimental gravel implanted in the streambeds. Sand trapped in the interstices of the top several centimeters formed a seal that impeded deeper deposition of very fine sand and finer material. The seal was responsible at least in part for a decrease in the rate of fine sediment accumulation with increasing cumulative bed load transport. Areas of the streambeds commonly scoured or filled 0.1 m or more during storm flows, and thus scour and fill commonly created a sandy layer at least as thick as the seal formed by sediment infiltration. Scour could erode eggs laid in the bed and expose deeper levels of the bed to infiltration by fine sediment, but at the same time could allow fine sediment to be winnowed away. Great temporal and spatial variation in sedimentation in these streams suggests that individual storms of moderate size pose a threat to eggs in many but not all areas selected by fish for spawning.


Abstract - Evaluating the effects of sediment transport on spawning habitat requires the measurement of changes in bed material that result from both infiltration of fine sediment and scour and fill. To adequately document changes from both processes one must survey, instrument or sample the bed before a period of sediment transport and repeat measurements or recover sampling devices afterward. Scour chains can be used to record maximum depth of scour that occurred during a flood. Documenting changes in bed material size requires that adequately large samples be taken and that the process of deposition of fine sediment in the gravel framework not be disturbed by the sampling device. Infiltration bags fulfill these requirements.

Abstract - A model is presented that simulates the effects of streamflow and sediment transport on survival of salmonid embryos incubating in spawning gravels in a natural channel. Components of the model include a 6 year streamflow record, an empirical bedload-transport function, a relation between transport and filtration of sandy bedload into a gravel bed, effects of fine sediment infiltration on gravel properties and functions relating embryo survival to gravel properties. High flow events drive temporal variations in survival; cross-channel variations in bedload transport cause spatial variations. Expected survival, as a result, varies widely from year to year and between spawning runs in a single year. Alternative functions from previous research that relate survival to fine sediment concentration in spawning gravel and to intergravel rates of flow yield categorically different results. The relative uncertainty of the components of this model indicates that the greatest research needs are to understand how sediment transport affects the intergravel environment and how these changes affect embryo development and survival.


Abstract - Evidence both of trophic level changes induced by reduction in light penetration and or more direct effects of sediment and turbidity on aquatic life indicated that turbidity constitutes a valid and useful water quality standard than can be used to protect aquatic habitats from sediment pollution. A review of studies conducted in Alaska and elsewhere indicated that water quality standards allowing increases of 25 or 5 nephelometric turbidity units above ambient turbidity in clear coldwater habitats provide moderate and relatively high protection, respectively, for salmonid fish resources in Alaska. Even stricter limits may be warranted to protect extremely clear waters but such stringent limits apparently are not necessary to protect naturally turbid systems.


Abstract - Turbidity results from the scattering of light in water by organic and inorganic particles; however high turbidities usually are caused by suspended inorganic particles particularly sediment. For several Alaskan lakes, we found that the depth to which 1% of subsurface light penetrated had a strong inverse correlation with sediment induced turbidity. We also developed a model that describes the decrease in primary production in shallow interior Alaskan streams caused by sediment induced turbidity. Euphotic volume in lakes correlated strongly with production of juvenile sockeye salmon, Oncorhynchus nerka. We also observed reduced abundance of zooplankton, macroinvertebrates and Arctic grayling, Thymallus arcticus, in naturally and artificially turbid aquatic systems. Turbidity measurements correlated less consistently with measures of suspended sediment concentration (total nonfilterable residue), but provided an adequate estimator for use as a water quality standard to protect aquatic habitats.


Abstract - We monitored the effluent from three small drainage systems, 7 to 10 acres, in central Ohio during the periods from April through July in 1972 and March through August in 1973. Two of the
drainages, the Dellinger and Durban farm sites, were cropped to corn and received nominal amounts of chemical fertilizer. The third drainage, the Wedding site, was in continuous alfalfa and previously received applications of dairy manure. Average nitrogen losses were 37, 19 and 0.6 pounds per acre per year for the Dellinger, Durban and Wedding sites, respectively. Nitrogen concentrations tended to decrease with time during each growing season. A preplant application of 200 pounds of nitrogen per acre apparently resulted in increased nitrogen concentrations on the Dellinger site in 1973. Tile effluent from the alfalfa site had consistently low nitrogen concentrations. Most of the nitrogen lost was in the nitrate form. Phosphorus losses were 0.3, 0.3 and 0.1 pound per acre per year for the sites. Potassium losses were 1.6, 3.1 and 1.1 pounds per acre per year while sediment losses averaged 335, 47 and 148 pounds per acre per year. 1989. Nutrient and sediment removal by vegetated filter strips.


Abstract - Although riparian wetlands in different environments feature some differing characteristics, they all share common functional traits. Riparian ecosystems in Coastal Plain environments may have more potential for controlling water quality because of land use and hydrologic characteristics, but all streamside ecosystems exert significant effects on nonpoint source pollution. Management or preservation of riparian ecosystems must occur on a watershed by watershed basis and either management or preservation should take into account the potential use of the ecosystems to enhance water quality. Many areas of riparian habitat, especially on perennial streams in the west, are lost to impoundments or overwhelmed by invasion of exotic species. Future management policies for riparian ecosystems should recognize inherent and man-made regional differences. In the west and midwest, restoration of riparian ecosystems may be a cost effective means of controlling nonpoint source pollution. In the east, especially in the Piedmont and Coastal Plain, management of existing riparian ecosystems to improve both their productivity and their pollution control capacity is in order. Projects that link riparian ecosystem management with upland conservation practices should be considered in watershed management programs.

Abstract - Sediment deposition from 1880 to 1979 was estimated for the riparian zone of a coastal plain agricultural watershed. Two approaches were used: (1) deposition estimates based on changes in depth to the argillic horizon along transects from fields to streams and (2) calculations of mass of deposition derived from estimated 100-year upland erosion based on the universal soil loss equation and a sediment delivery ratio. Estimates of changes in depth to the argillic horizon along nine transects yielded a mean of 52 Mg/ha/year with a range of 7.6 to 92 Mg/ha/year. The estimated average annual rate of gross erosion minus sediment transport from the watershed was 35 Mg/ha/year. Thus, the average annual rate of sediment deposition on this watershed during the 1880-1979 period was 35 to 52 Mg/ha/year. These data suggest that riparian ecosystems are important sinks for sediments.


Abstract - Driftnets, basket samplers and artificial streams were used to investigate the influence of heavy sand accumulations on insect drift, colonization and upstream movements in Emerald Creek, northern Idaho. Most riffle insects successfully passed through low-velocity, sandy reaches 80 m long. Upstream movements on sand were impeded by flows as low as 12 cm/sec except for the heavily cased caddisfly, Discomoecus spp.


Abstract - The Pennsylvania Department of Environmental Resources, Bureau of Forestry, developed a set of best management practices (BMPs) to limit and/or control nonpoint source pollution from silvicultural activities. Nonpoint source pollution in a forested watershed is characterized by changes in stream temperature, turbidity/sediment levels and nutrient concentrations and export. A watershed study conducted on the Leading Ridge Experimental Watershed in central Pennsylvania suggested that the BMPs were effective in controlling nonpoint source pollution from a 44.5 hectare commercial clearcut. Slight increases in stream temperature, turbidity and nitrate and potassium concentrations were observed, but these increases did not exceed drinking water standards.


Abstract - Sublethal levels of suspended conifer groundwood impaired oxygen uptake and swimming ability of fathead minnows, Pimephales promelas. In fiber-free water active metabolism at 15, 18 and
21°C was 11.7, 13.0, and 14.9 mg O2/kg of fish per minute, respectively, when oxygen was not limiting. Fiber suspensions of 100 to 800 ppm were tested and at 21°C for each doubling in fiber concentration, active metabolism was reduced by about 1.3 mg/kg per minute and the decrease was about the same at all dissolved oxygen (DO) levels. At 15°C, for each doubling in fiber concentration, active metabolism was reduced by 1.0 mg/kg per minute at low DO levels (2.5 ppm) and by 0.2 mg/kg per minute at high DO levels (9.0 ppm). Swimming endurance was reduced by suspended fiber with the effect being greatest at low DO levels. Hematocrit rose by approximately 2 for each doubling in concentration of suspended fiber and rose by 1.4 for each 1 ppm decrease in DO. Gill cleaning reflexes increased markedly with increase in fiber concentration and this activity was considered to raise the energy requirements for maintenance. Lowered active metabolism and lessened swimming endurance are considered to indicated stress conditions and to decrease survival and production of fish in natural habitats.


Abstract - A field study utilizing simulated rainfall and bare plots 5.5 m wide by 22 m long was conducted to study the effectiveness of vegetated filter strips 4.6 and 9.2 m long in removing nutrients and sediments from agricultural runoff. Losses of N and P from plots with filters were highly variable as compared to losses from plots with no filters. Generally, nutrient removals appeared to be greater with the longer filters, but decreased as the number of runoff events increased. Mass losses of TSS, TN and TP in surface runoff were reduced by 66%, 0% and 27% respectively by 4.6 m (15 ft) long filters. TSS, TN and TP reductions by 9.2 m (30 ft) long filter strips of the lengths utilized in this study were effective in removing sediment from runoff but should not be relied upon as the primary means to reduce nutrient losses from agricultural areas.


Abstract - An index of sediments less than 0.3 mm stored in the top layer of small streams was estimated by disturbing a fixed area for 2 minutes and catching the resultant sediment drift in downstream traps. The method was used in 24 small northern California streams and was tested by releasing known amounts and sizes of sediments in controlled trials. Field use showed general agreement with an exponential model of decrease in sediment trapped vs. distance. Sites in disturbed reaches (watershed logged with no streamside buffers of with buffers less than 30 m) had higher indices of stored sediment than control sites. Estimates from controlled trials averaged 7.5% higher than actual losses for composite size classes < 0.3 mm, 19.7% higher than actual losses for just the < 0.125 mm class, and 15.2% for all 14 trials. The method is relatively simple and suitable for remote locations, particularly in studies comparing many small streams.


MANITOBA DEPARTMENT OF NATURAL RESOURCES. 1990. Recommended buffer zones for protecting fish resources in lakes and streams in forest cutting areas. Winnipeg, Manitoba.


Abstract - Though researchers do not agree on the exact size of fine sediment, it is generally less than 6.3 mm in diameter. Sediment transport in streams is a very complex relationship involving at least 30 variables. But, in general, transport of fine sediment may be via saltation along the stream bottom or suspension in the water column, with discharge and channel slope proportional to the quantity and size of transported sediment. Typically, transport of sediment is greater on the ascending limbs of storm hydrographs, but this is due more to the supply of sediment rather than the hydraulics of the flows.

Everest et al. (1987) suggested that some fine sediment may be beneficial to salmonids by contributing to increased invertebrate productivity and that the adverse consequences of fine sediment introduction to trout streams have been overstated. Nonetheless, the transport and deposition of fine sediment frequently are assumed to deleteriously affect survival throughout the life history of salmonids.

Turbidity is a measure of the scattering and absorption of light by dissolved and particulate matter in water. Usually, turbidity and suspended sediment concentration are highly correlated; thus turbidity can provide an index of suspended sediment concentrations (SSC). Because murky water absorbs more heat than clear waters, increased suspended sediment loads can cause water temperatures to increase. Water with a temperature of 5°C is able to carry 2 to 3 times more sediment than 27°C waters.

SSC may directly or indirectly influence the survival of salmonids. SSC can affect fish directly by clogging and damaging respiratory organs; laboratory and field studies have shown that the extent of this impact depends highly on the size and composition of the suspended material and on the individual species of fish. It has been found that high SSC elevated several physiological measures of stress in juvenile coho salmon and steelhead. Over 50% of juvenile coho and chinook salmon died after a 96 hour exposure to water containing about 500 mg/l of SSC. SSC above 100 mg/l have reduced the survival of juvenile rainbow trout. Reductions in growth or feeding of salmonids were associated with turbidity over 25 nephelometric turbidity units (NTU). Since salmonids are considered to be sight feeders, the reduction in light transmission caused by high turbidity may result in less feeding and decreased growth. In response to turbidity, salmonids may change their use of cover or reduce territoriality. When given the opportunity, juvenile coho salmon avoided turbid water. Despite these impacts, salmonids often successfully inhabit streams with seasonally high turbidities perhaps due to behavioral modifications and to limited exposure to concentrated suspended sediments.

Deposition of fine sediment can acutely affect survival of salmonids (1) during intragravel incubation of eggs and alevins; (2) as fingerlings; and (3) throughout winter. Timing, source and quantity of deposited sediment can affect survival. Winter peak flows and thus sediment transport and deposition correspond with the incubation of eggs and alevins of salmon and steelhead in the Pacific Northwest. But cutthroat and rainbow trout in the central Rockies spawn after the spring peak flows and redd substrates may change very little throughout incubation.

The percentage of fine sediment in twelve southwestern Washington streams was more closely related to the percentage of the watershed composed of sedimentary rock than to the percentage of watershed area in roads. A stream draining a heavily roaded watershed composed of soils derived entirely from volcanic
rock had a lower proportion of fine sediment in the stream channel compared with channels in watersheds largely composed of sandstones and siltstones.

Increasing proportions of fine sediment in substrates have been associated with reduced intragravel survival of embryonic brook trout, brown trout, cutthroat trout, rainbow trout, steelhead and various species of Pacific salmon. But increases of fine sediment can directly limit survival to emergence only by entrapping alevins; the potentially greater influence on survival by increased sediment deposition is the decrease in dissolved oxygen concentration coupled with reduced intragravel water flow. For example, no correlation between the amount of fine sediment in redds and the survival to emergence of rainbow trout but they did report that reduced survival in redds was significantly correlated with both reductions in intragravel flows and in dissolved oxygen concentrations. Furthermore, most studies evaluating the impacts of fine sediment on embryonic survival have been conducted in the laboratory; few or no field studies have satisfactorily quantified actual impacts.

Fingerling density has often been associated with low concentrations of fine sediment deposited between and on the surface of larger substrate particles. This is defined as embeddedness. It has been found that the production of coho salmon increased as embeddedness decreased. After the installation of a sediment trap, the abundance of juvenile brown and rainbow trout in a Michigan stream increased by 40%. Following the experimental addition of fine sediment to a Michigan stream, brook trout densities declined by more than 50%. It is thought that fine sediment filled in pools and interstices between cobble thus reducing the amount of habitat available to fingerling and adult salmonids. Nonetheless, it has been reported that the relation between the rearing densities of salmonids and fine sediment was equivocal with several studies demonstrating no or a positive relation between fingerling abundance and embeddedness. This suggests that changes in stream morphology caused by fine sediment may outweigh the effects of embeddedness on fingerling survival.

Declining water temperatures winter may cause salmonids to seek refuge within the interstitial spaces of the substrate. Juvenile steelhead trout left experimental channels containing large amounts of fine sediment compared to those containing little or no fine sediment. Deposition of fine sediment could also restrict winter cover for adult fish by filling in low velocity habitats. Very little additional research has been conducted to quantify the effects of fine sediment on winter habitat in the western United States.

The European Inland Fisheries Advisory Commission concluded that suspended sediment can affect aquatic organisms by killing them directly, by reducing growth rates and resistance to disease, by preventing successful development of eggs and larvae, by modifying natural movement or migration patterns, or by reducing the natural availabilities of food. A review completed by the National Academy of Science suggested that a limit of 25 mg/l of suspended sediment would provide high, 80 mg/l moderate, 400 mg/l low and over 400 mg/l very low levels of protection for aquatic organisms. The present water quality criterion established by the Environmental Protection Agency for fish and other aquatic life is based on the depth in the water column at which planktonic photosynthesis equals respiration; hence it does not apply to most salmonid habitats in the central Rocky Mountains. Based on a review of turbidity studies in Alaska, a water quality standard that permitted an increase of 25 NTU's above ambient would provide moderate protection for clear, coldwater stream habitats.


Abstract - Mean monthly water temperatures on Bluewater Creek varied from a high of 73°F at station 4 to a low of 36°F at station 5. Mean monthly discharge ranged from a high of 81 cfs at station 5 to a low of 3 cfs at station 4. Mean monthly sediment concentrations and loads were lowest at station 1 and
progressively increased downstream. Two streambank improvement projects were completed during the report period. Data collected after completion of these projects indicated a marked reduction in suspended sediment at two station immediately downstream from the improvements. The brown trout population declined progressively from 100% of the fish population at station 1 to less than 1% at station 5. Brown trout comprised 79% of the fish captured at station 3 during the 1966 report period, 12% in 1963 and 20% in 1961.


Abstract - This report describes findings gathered during the report period and compares current data with data collected before completion of three stream habitat improvement projects on Bluewater Creek. Maximum and minimum water temperatures, mean monthly sediment discharge and mean sediment data are tabulated and discussed for the report period. Mean monthly sediment concentrations and loads were lowest at station 1 and progressively increased downstream. Average suspended sediment load has been reduced by 1.9 tons/day or 32% at station 2, 14.0 tons/day or 52% at station 3 and 10.5 tons/day or 44% at station 4 following the three stream bank improvement projects located near station 2. Trout composition at all stations on Bluewater Creek represented 37% of the fish sampled in 1968 compared to 13% in 1963 prior to habitat improvement. Trout:rough fish ratios were not appreciably altered following a 32% reduction in sediment load at station 2. Corresponding with a 52% reduction in sediment load at station 3, there has been a change in weight ratios of trout:rough fish from 39:61 in 1963 to 63:37 in 1967 to 78:22 in 1969. At station 4 the trout:rough fish weight ratio had changed from 12:88 in 1963 to 34:66 in 1967 to 51:49 in 1968.


Abstract - Erosion, sedimentation and turbidity can be controlled during and after logging in New England forests by conscientiously following regulations and guidelines known as Best Management Practices (BMPs). This is demonstrated by comparing sediment yields and stream turbidities from cut and uncut watersheds at the Hubbard Brook Experimental Forest in central New Hampshire. Sediment yields from uncut forests average about 40 kg/ha/year but are highly variable from year to year and from watershed to watershed. Disturbances due to cutting and logging can increase sediment yields. For example, in the first year after a whole tree clearcut at Hubbard Brook, sediment yields increased 10 to 30 fold over uncut watersheds. However, total yields after cutting and skidding were still small and did not greatly affect stream turbidity.


Abstract - The differences between natural lakes and reservoirs are variously significant to the regulation of limnetic processes. Large suspended sediment loads 0.1 to 0.5 grams per liter are common in rivers of agricultural landscapes of the Great Plains of the United States. This material often reduces light penetration to the extent that photosynthetic production is inhibited despite high nutrient loads that are
also common in the Central Plains states. Such bodies of water do not fit most phosphorous-chlorophyll regression models: they are "low and to the right". Nevertheless, zooplankton populations do not seem to be reduced under such conditions. They are able to filter small particles and clays and use the bacteria and/or the dissolved organic matter associated with them. This implies that the river and its drainage basin continue to be the driving variable for the secondary production in a reservoir in a fashion distinctly separate from natural lakes where zooplankton phenomena have been investigated more fully.


Abstract - Relationship between streamflow and/or water quality and densities of smallmouth bass, *Micropterus dolomieui*, were determined for four streams in southwestern Wisconsin. Streamflow conditions during the bass nesting period have been an important determinant of year class strength with best year classes generally produced when streamflow was below normal. Extreme drought conditions prevailed in southwestern Wisconsin through most of 1988 and the first half of 1989 and the 1988 year class was strong in all four streams. In one system, smallmouth bass densities were reduced from 186/km to 16/km after a runoff event during which the dissolved oxygen concentration was reduced to near 0 mg/1. The cause of the dissolved oxygen reductions during runoff events has not been determined by appears to be related to recent changes in watershed land use. Another factor affecting smallmouth bass densities may be inorganic and organic chemicals found in storm runoff. Suspended solids concentrations and associated turbidity in ranges found during runoff events may have been detrimental to smallmouth bass populations.


Abstract - Concern for the natural environment has focused attention on sources of sediment, including unprotected roadbanks. Results of a statewide survey to determine the extent of soil erosion on publicly owned or leased right-of-way on all Wisconsin roadways were reported in 1968. The 1968 study produced the following recommendations:

- purchase and use specialized seeding and mulching equipment;
- control all erosion sites reported in this survey that can be a major source of sediment for Wisconsin’s surface waters within five years;
- consider the use of incentive funds to reduce active erosion along town and country roads;
- build sediment retention structures as part of all new construction and maintain them until permanent structures and vegetation achieve adequate control;
- establish vegetation on all new road cuts and fills, particularly along town roads;
- secure wider right-of-way where needed

All erosion problems are associated with construction or maintenance. There is an increasing awareness of proper construction techniques and erosion control practices following construction. Erosion control now is a consideration in determining side-slope steepness.

Erosion must still be controlled better during construction, particularly don town roads near surface waters where the impact of sedimentation may be great. Applying such programs significantly reduced the number of erosion sites along county roads showing that the results are worth the effort.
Abstract - Tucker-trawl collections showed that behavior of larval shad, Dorosoma spp., and freshwater drum, Aplodinotus grunniens, was altered by inflow of turbid water into Lake Texoma (Oklahoma-Texas) in two different years. During periods of increased turbidity, larval shad were concentrated in a reduced volume of water near the surface and larval freshwater drum were distributed throughout the water column in contrast to their normal concentration near the bottom. In 1981 and 1982, greatest decline in abundance of larval shad came after zooplankton density fell below 100 per liter and during or immediately following an extended period of high turbidity. Nutritional stress resulting from decline in zooplankton abundance and changes in larval fish behavior during turbid conditions could be one important factor in population dynamics of shad in reservoirs.

Abstract - To compare vulnerability to predation by northern pike, Esox lucius, several species of fish in various combinations were held with pike in plastic swimming pools with and without cover and in small ponds. The most vulnerable species in order were gizzard shad, Dorosoma cepedianum, carp, Cyprinus carpio, bigmouth buffalo, Ictiobus cyprinellus, fathead minnow, Pimelphales promelas, and smallmouth bass, Micropterus dolomieui. White sucker, Catostomus commersoni, green sunfish, Lepomis cyanellus, largemouth bass, Micropterus salmoides, golden shiner, Notemigonus crysoleucas, and yellow perch, Perca flavescens, showed intermediate vulnerability. Channel catfish, Ictalurus punctatus, northern pike, bluegill, Lepomis macrochirus, and black bullhead, Ictalurus melas, were least vulnerable. In two experiments in which fish were put in cages in turbid water, relative vulnerability was the same as in clear water. Pike could not be conditioned to eat golden shiner or bluegill. There was a tendency for certain sizes of pike to select the smaller carp, fathead minnow and the bluegill within the size ranges tested.

Abstract - Increased logging activity in the suburban forest heightens the risk of scarring the landscape and silting of streams and it increases the need for specialized management to stabilize the soil with vegetation after harvest. Appropriate management requires evaluation of soil and seedbed characteristics and site conditions of slope and shade. This study evaluated the effects of site, fertilizer and mulch on initial density of planted species and subsequent invasion of volunteers from surrounding seed sources. The results can be used by foresters and loggers to develop more effective treatments to stabilize disturbed areas with vegetation.

**Abstract** - This paper reports the effect of suspended silt on the feeding and reproduction of *Daphnia pulex* and the impacts of suspended silt and clay on freshwater zooplankton community structure. The effects of suspended silt and clay on the filtering and assimilation rates of *Daphnia pulex* were determined using a C14 radio-tracer method. Both filtering and assimilation rates are severely depressed at even low concentrations of suspended silt and clay. Life table studies also showed population growth rate of zooplankton was significantly diminished by suspended silts and clays. The relative abundance of zooplankton varied markedly between two lakes of differing turbidity levels, the more turbid lake having a higher relative abundance of large zooplankton species. Suspended silt and clay reduced zooplankton feeding and production but probably influenced zooplankton community structure by impairing the ability of visually feeding planktivorous fish to locate their prey.


**Abstract** - Sediment is the number one pollutant to waterbodies worldwide and the cause of a variety of problems in lakes and ponds. Sediments create turbidity and fill up pond and lake basins, thus reducing their recreational use. Algae causing nutrients and heavy metals can piggyback on sediments getting a free ride to the lake or pond. Excessive heavy metals can make lake sediments toxic, preventing rooted plant growth and decreasing the number of aquatic organisms living in the sediments.

The soundest approach to curtail sediment pollution is to prevent sediments from getting into a stream, lake, pond or reservoir in the first place. However if excessive sediment do erode from the landscape the next line of defense is to remove these sediments from the lake or pond. Another important action is to protect streambanks and lake shorelines from eroding. Streambanks and shorelines contribute sediments directly to a lake or stream and the best erosion control programs on upland areas can be undermined if erosion is not checked on streambanks and lake shorelines. The first half of this chapter describes
techniques and projects for keeping soils and sediments from getting into streams and lakes. The last half addresses various ways to remove excessive sediments (on a small scale) from lakes and ponds.


Abstract - Sediment is defined as inorganic, undissolved matter ranging in size from fine colloidal clays (particles less than 0.004 mm in diameter) to larger particles most commonly referred to as fine pebbles (particles 2-4 mm in diameter). This class of particles is commonly referred to as "fines" by fisheries biologists. Silt, which makes up a large component of our soils, is midway in size between sand and clay particles.

The deposition of these suspended sediments on the stream substrate usually occurs when stream flow velocities decrease to a point where the stream flow can no longer transport these sediments in suspension.

The construction of resource roads can introduce sediments into aquatic habitats originating from any activity that disturbs the soil. Severe soil disturbance and subsequent erosion can result from the removal of vegetation along the proposed route. Flowing water in roadside ditches can carry large amounts of sediment into aquatic habitats such as streams and ponds unless such ditches are first diverted into vegetated areas or settling ponds.

Other potential sources of sediments entering streams or ponds result from the careless installation of culverts and bridges, grubbing of riparian lands, runoff from the road surface or infilling of roadbase materials directly into aquatic habitats. Such sediments can be transported great distances and thus can affect aquatic habitats far removed from the original source.

The biological effects that sediments can have on aquatic life can be divided into those which have direct effects and those which have indirect effects. Direct effects of sediment on fish can include mortalities by suffocation due to silt clogging gill surfaces (at exposures in excess of 20,000 mg/l) or from stress caused by hyperventilation.

Sediment particles abrade the body surface and the gill tissue of fish. The sediment has its greatest effect on the sensitive gill tissues because the sediment passes over the gills as the fish breathes. The gill tissue responds to the abrasions by secreting a mucous covering for protection. If the sediment levels are high, the sediment particle will adhere to the mucous in such large quantities that the gill cannot adequately pick up enough dissolved oxygen resulting in the suffocation of the fish. Sediments can also directly affect fish eggs and alevin survival as well as block fry emergence from the gravel.

The factor that most often causes the greatest mortality of salmonid fishes is the destruction of their eggs by sedimentation of the spawning grounds. Trout and salmon require clean gravel deposits with which to build their nests or redds. The eggs are buried 15-35 cm into the gravel by the female fish where they remain for up to five months until they hatch into young larval fish called alevins. The alevins remain in the gravel until they have developed into fry. To successfully develop from egg to fry, salmon and trout are totally depended on physical and chemical characteristics in their subgravel environment. Sedimentation can alter these parameters to such an extent that viable salmonid populations cannot survive.

In sediment-free streambed gravel deposits there is a good flow of water below the streambed through the substrate. Sediments tend to clog interstitial spaces in gravel, reducing water flow and hence oxygen availability to the eggs causing them to suffocate. This reduced flushing rate also permits the accumulation of toxic metabolic wastes around the eggs which, in high enough concentrations, can be fatal. Heavy
sedimentation can also blanket the stream substrate physically blocking fry emergence from the gravel. Even if the sedimentation occurs at a time when salmonid eggs, alevins or fry are not in the gravel, a blanketing of the stream bottom can render often limited spawning habitats useless for future spawning potential, thereby potentially decreasing the productivity of a stream or pond. Even when the discharge of sediment stops, its effect on fish populations will continue until it is flushed from the stream substrate. Unfortunately, this can take a considerable amount of time ranging from months to years.

The indirect effects of sedimentation on aquatic life are often more subtle and not usually as easily recognizable. These include the decrease in food availability to salmonid fish, either by killing aquatic insects on which fish feed or by increasing the turbidity of a stream or pond to a point where fish can no longer locate their food. It should be remembered that salmonid fishes rely primarily on sight to locate their prey.

Sediment also can decrease the productivity of aquatic environments by scouring or smothering the encrusting growth of green algae (periphyton), which is the basis of the conversion of sunlight to usable energy within the stream. Sustained periods of high turbidity within a pond will eventually reduce light penetration thereby reducing or eliminating photosynthesis by plant life. This can cause a chain reaction affecting the ecology of a pond that would be harmful for all aquatic life in the pond.


Abstract - In this investigation, an evaluation was made of the lethality of a suspended clay mineral texturally representative of the sediment-size fraction with which contaminants are most commonly associated. The study involved a phylogenetically diverse selection of marine and estuarine macrofauna. The time-concentration mortality response of 16 species of fish and invertebrates indicated widely differing sensitivities to high concentrations of clay suspended in the water. Organisms restricted to muddy bottoms were found to be very insensitive to high suspended clay concentrations. However, some open water fish, fouling organisms, and sandy bottom epifauna were found to be relatively sensitive. Tolerant species were also identified from these groups.


Abstract - Sediment yield measured from 1 and 2 acre agricultural watershed largely was a function of rainfall energy, rainfall intensity and crop cover characteristics. Suspended sediment yield from a 6 000 square mile watershed primarily was a function of the transport capacity of streamflow. The temporal patterns of sediment yield and suspended sediment yield are distinctly different on the different sized areas. The energy intensity parameter devised by Wischmeier from plot data seems valid for calculating the sediment yield from small watersheds.


Abstract - Long term land use and reservoir sedimentation were quantified and linked in a small agricultural reservoir watershed system without having historical data. Land use was determined from a time sequence of aerial photographs and reservoir sedimentation was determined from cores with $^{137}$Cs dating techniques. They were linked by relating sediment deposition to potential sediment production which was determined by the Universal Soil Loss Equation and by SCS estimates for gullied land. Sediment cores were collected from Tecumseh Lake, a 55 ha reservoir with a 1189 ha agricultural watershed, constructed in 1934 in central Oklahoma. Reservoir sediment deposition decreased from an average of 5933 Mg/year from 1934 to 1954, to 3179 MG/year from 1954 to 1962 and finally to 1017 Mg/year from 1962 to 1987. Potential sediment production decreased from an average of 29 892 to 11 122 and then to 3589 Mg/year for the same time periods as above, respectively. Reductions in deposition and sediment production corresponded to reduction in cultivated and abandoned cropland which became perennial pasture. Together, cultivated and abandoned cropland accounted for 59 percent of the watershed in 1937, 24 percent in 1954 and 10 in 1962. Roadway erosion, stream bank erosion, stored stream channel sediment and long term precipitation were considered but none seemed to play a significant role in changing sediment deposition rates. Instead, the dominant factor was the conversion of fields to perennial pastures. The effect of conservation measures on reservoir sedimentation can now be quantified for may reservoirs where historical data is not available.


Abstract - Recent sediment deposition rates were investigated using cesium-137 dating techniques in a 95 ha (2350 acre) area of Grassy Island wetland. The wetland is on the eastern shore of Reelfoot Lake in northwestern Tennessee. The forested wetland traps sediment transported by Reelfoot Creek from 31 000 ha (76 600 acres) of easily eroded loess bluff hills and uplands, of which 16 000 ha (39 500 acres) were cropland. Sediment deposition in the study area amounted to 3 million Mg (3.3 million tons) in the 21 year period from 1964 to 1985. Average sediment deposition rates were high, with 2.6 cm/year (1.0 inch/year) in the area where silt sediment was accumulating and 1.3 cm/year (0.5 inch/year) in the remaining study area. Deposition rates coincided with estimated high erosion rates from cropland on the watershed, but only about 21% of the erosion from cropland was accounted for in sediment deposition. The capacity of the wetland to trap sediment though considerable was limited in comparison to soil erosion from steep cropland where no conservation measures were used.


Abstract - By the term "silt" is meant loose sedimentary material, rock particles, mud or clay that settle readily and may be transported by bedload movement. Silt results from erosion, logging, mining, dredging or irrigation operations, etc. Fine silt may stay in suspension and be classified as "suspended solids" while the larger particles settle to the bottom of the water course. In natural waters, suspended solids consists normally of erosion silt, organic detritus and plankton. Like other suspended solids in streams, silt may have far reaching effects on the nature and biota of the stream by reducing the amount of light transmitted
by the water, by altering the rate of temperature change in water strata, by absorbing organic material and other substances that create unfavorable conditions on the bottom and by blanketing the stream bottom. Although a moderate amount of silt may have a beneficial effect on aquatic life by increasing the amount of mineral nutrients available, excessive quantities have been reported to affect deleteriously all of the desirable uses of water.

Suspended solids and siltation hinder fish production, smother food organisms, destroy spawning grounds, fill pools, trap bacteria and decomposing wastes on the bottom which depletes oxygen. Smith (1940) has reported that silting has reduced the bottom fauna of the Rogue River by 25-50%. According to Ellis (1944), hard particles cause abrasive injuries to the delicate external organs such as gills, spiracles and fins of miscellaneous aquatic animals and fine particles tend to coat and destroy eggs. He recommended that suspensoids of a hardness of one or more should be so finely divided as to pass through a 1000 mesh screen and that the stream bottom should not be blanketed to more than one-quarter of an inch. It has been pointed out that healthy fish may swim through heavy suspensions of solids without significant injury; yet in the presence of even low concentrations of toxic substances, fish may be so weakened that the abrasive and clogging actions of suspended solids become more effective and dangerous and even lethal.

Salmon and trout can withstand a heavy load of silt for several weeks; nevertheless by limiting successful reproduction and the food supply, silting is harmful to fish. Ward (1938) agrees that silt deposits may smother spawning beds and nests but believes that natural and mining silts are not always inimical to fish life; they may possibly be beneficial because of the food organisms and particles they carry and because muddy waters afford protection to fish against predatory animals and anglers. Ward cites experiments in which young salmon were maintained for 3-4 weeks without harm in circulating water containing a suspension of mud in a concentration above 1000 mg/l. Griffin (1938) has reported experiments of 3-4 weeks duration in which trout and salmon fingerlings fed and grew apparently well in muddy water carrying a constant silt load of 300-750 mg/l and, for short intervals, daily during stirring, a load as high as 2300-6500 mg/l. Tests on the survival of rainbow trout in suspensions of inert solids (kaolin and diatomaceous earth) showed that concentrations of 30 mg/l had no observable effect, a few fish died at 90 mg/l, while at 270 mg/l more than half of the fish died in 2-12 weeks. No difference could be detected between the lethal effects of kaolin and diatomaceous earth although the particle size of the former lay mostly in the range of 0.13-5.0 microns. In concurrent field tests in England, it was found that a stream containing 60 mg/l of suspended solids had just as many trout and invertebrates as a clear control stream; but in the river Fal, with 1000 mg/l of suspended matter, trout were only one-seventh and invertebrates only one-third of the densities in control streams. In the polluted River Par, with about 6000 mg/l of suspended solids, trout were one seventh and invertebrates one nineteenth of the densities in the control streams.

Ziebell (1960) and Wagner (1959) measured the productivity in terms of aquatic insect populations upstream and downstream from a gravel dragline operation. They found a productivity decline of 85% as a result of the gravel operations. Turbidities were increased from zero to 91 mg/l and suspended solids from 2 mg/l upstream to 103 mg/l downstream. Tarzwell (1957) cites an instance where bottom samples from a silted area averaged only 36 organisms per square foot whereas in a clean stream bottom the average was 249 organisms per square foot.

According to Robinson (1959) concentrations of some suspended materials as high as 1458 mg/l were filtered and passed through the gut of Daphnia magna with no apparent harm; but charcoal and montmorillonite were toxic at 100 mg/l, ground glass at 98 mg/l, chlorite at 120 mg/l and illite at 264 mg/l. In concentrations of suspended matter and silt higher than 750 mg/l, the development of eggs and larvae of the venus clam was decreased.


Abstract - Measurements of accumulated sediment in interbank basins of unreclaimed strip mines determined the average annual soil loss from unvegetated, 18 year old spoil banks. Assuming the universal soil loss equation (USLE) can be used to estimated sediment yield from strip mine slopes, the topographic factor in the USLE was determined in two ways, and values for erodibility (K) were calculated. The technique is applicable to unreclaimed mines where interbank basins trap all slope derived sediments.


Abstract - The effects on underyearling Arctic grayling, Thymallus arcticus, of a 6 week exposure to differing strengths of suspended placer mining sediment was examined under controlled laboratory conditions during the summer of 1983. Groups of sixty grayling captured from a Yukon River tributary stream were transferred to eight test streams and acclimated to laboratory feed and water quality conditions. Thereafter, sediment collected from the downstream end of a Yukon placer mine settling pond was introduced continuously to six streams at a controlled rate in order to expose fish to suspended sediment concentrations of 100, 300 or 1000 mg/1 (two streams per treatment). Two control streams continued to receive clear (nonfilterable residue < 5 mg/1) freshwater. Fish in each stream were fed a measured ration (7% weight/day) of Biodiet, 4-5 times daily, together with supplemental feeding of live zooplankton, Daphnia pulex. Water quality conditions for each stream, including temperature, pH, conductivity, dissolved oxygen, nonfilterable residue and turbidity, were monitored daily.

The survival of fish in each stream throughout the 6 week test period was high (87-95%) and unaffected by the sediment suspensions. Fish growth, as monitored by weekly weighing of individual fish, was decreased slightly (6-10% relative to control fish) but significantly by 100 and 300 mg/1 and more markedly impaired (33% relative to controls) by 1000 mg/1. The linear distribution of grayling in each stream was unaffected by the lowest (100 mg/1) suspended sediment strength examined; however, the majority of fish held in each stream containing 300 or 1000 mg/1 sediment were displaced downstream throughout the test period.

Feeding response trials were conducted in each stream using live surface drift (adult fruit flies, Drosophila melanogaster), sub-surface drift (brine shrimp, Artemia salina), and benthic invertebrates (tubificid worms). Times to detect and consume surface drift for naive fish (previously unexposed to sediment) or those held in test streams for 5 weeks increased progressively with increasing sediment strengths. All suspended sediment strengths examined increased the response times relative to those for control fish. For each respective concentration, naive fish were slower to respond to surface drift. The majority of naive fish held in 1000 mg/1 sediment failed to accept the surface or sub-surface food types offered. Feeding
trials conducted with grayling offered brine shrimp or tubifex worms in each test stream after 5 or 6 weeks' sediment exposure indicated that the feeding activity of fish in 1000 mg/l suspended sediment was impaired, whereas those reared in 100 or 300 mg/l sediment responded to these sub-surface food types as quickly as control fish in clear water.

The coloration of fish exposed to 300 or 1000 mg/l suspended sediment was paler than that of controls or those held in 100 mg/l sediment for 6 weeks. Otherwise, the appearance of all sediment exposed fish (including gross observations of fish gills) was indistinguishable from that of controls. Biological characteristics determined for fish groups sampled from each stream after 6 weeks' sediment exposure, including condition factor, body moisture content (%), blood hematocrit (%), blood leucocrit (%), and plasma glucose (mg%), were unchanged from control values for all sediment strengths examined.

The performance of fish groups sampled from each laboratory stream upon completion of the 6 week exposure was examined using standardized acute lethal tolerance tests with the reference toxicant pentachlorophenol, sealed jar bioassays (tolerance to hypoxia), and tests for upper lethal temperature tolerance. Both groups of fish chronically exposed to the two higher suspended sediment strengths examined (300 or 1000 mg/l) showed a decreased tolerance to this reference toxicant, and decreased times to death (increased oxygen uptake rates) in sealed jar bioassays. The ability of fish to withstand hypoxia or upper lethal temperature extremes was unaffected by the prolonged sediment exposures.

It was concluded that, whereas chronic exposure of Arctic grayling to suspended sediment concentrations < 1000 mg/l may not cause direct mortalities of fish or impair their respiratory capabilities, suspended sediment strengths above 100 mg/l causes a number of serious sublethal effects including impaired feeding ability, reduced growth rates, downstream displacement, color changes and decreased resistance to other environmental stressors. The environmental relevance of these findings is discussed.


Abstract - Underyearling Arctic grayling, Thymallus arcticus, from the Yukon River system were exposed for 4 days to suspensions of fine inorganic (< 250 g/l) and organic (< 50 g/l) organic sediment and for 6 weeks to inorganic sediment (< 1000 mg/l) under laboratory conditions. The test sediments were collected from an active placer mining area near Mayo, Yukon Territory. The exposures evoked sublethal responses but did not cause gill damage. Mortalities (10 and 20%) occurred only in experiments at 5°C with inorganic sediment concentrations > 20 g/l. Six weeks of exposure to sediment concentrations > 100 mg/l impaired feeding activity, reduced growth rates, caused downstream displacement, color changes and decreased resistance to the reference toxicant pentachlorophenol but did not impair respiratory capabilities. Stress responses (elevated and/or more varied blood sugar levels, depressed leucocrit values) were recorded after short exposure (1-4 days) to organic sediment concentrations as low as 50 mg/l. Inorganic sediment strengths > 10 g/l caused fish to surface. The lethal and sublethal responses of Arctic grayling to pentachlorophenol were similar to those determined for other healthy salmonid fishes.


Abstract - Numerous references in the literature indicate that the specified timber management operations result in the addition of sediment to streams, but the magnitude of the effect is not well documented. The amount of erosion resulting from non road operations depends significantly on the slope, the soil type and the particular logging practices used. Most references relate to studies in mountainous areas of North America. One study in the Experimental Lakes Area of northwestern Ontario indicated little erosion and sedimentation were measured one and two years after clearcutting. Bedload sediment was not measured in this study.

A few studies have reported the amount of sediment yield resulting from deforestation. Barman et al. (1974) indicated that deforestation at Hubbard Brook increased sediment yield from 2.5 tonnes/sq. km/year to a maximum of 38 tonnes/sq. km/yr in the first three years after cutting. In this case herbicides were used to suppress revegetation. Lull and Sopper (1969) reported that careless clearcutting in West Virginia increased sediment yields by 100 fold.

Most authors indicate that the amount of sediment export from most timber management operations is considerably less than from roads. It has been reported that non road operations produced from 8-20% of the sediment eroded from roads.

Of all timber management operations, road construction is the main source of sediment inputs to streams. No studies of the effect of forest road construction on sediment yields have been done in Ontario although Mattice (1977) documented the occurrence of appreciable erosion from roads in some areas. Studies of erosion and sedimentation resulting from highway construction in southern Ontario indicated that bedload sediment levels increased fivefold downstream of a stream crossing.

Numerous studies, primarily on the west coast of North America, indicated that increased sediment input resulting from timber management operations increase the proportion of fine sediments in spawning gravel. In areas of Washington State containing 4-7% road areas, the proportion of fines in gravels was 15-23% compared to 10% in “natural” gravels. Other studies also report increased fines on stream bottoms as a result of logging operations. There appear to be no studies of this effect as a result of logging in Ontario.

Increased flushing of gravels under elevated flows may remove fines but higher flows are required to do this than to move bedload sediment downstream. Sufficient flows may not occur every year and fine sediment may therefore remain in spawning gravel for several years.

The magnitude and duration of increased sedimentation as a result of timber management activities in Ontario are uncertain, as are the effects on spawning areas and fry production. Guidelines to control sedimentation from roads are being developed while guidelines exist to protect against sedimentation from most other timber management activities. The effects of these activities without guidelines are judged to be significant but the effectiveness of the guidelines are uncertain. Guidelines to control sedimentation resulting from prescribed burning do not exist. The significance of this effect in Ontario is presently uncertain.


Abstract - Suspended sediment yields were determined for 36 basins and dissolved sediment yields for 21 intermediate-sized stream basins in southern Alberta, Canada. Calculation of long term mean sediment loads was based upon the establishment of sediment rating-curves for gauging stations at the basin outlets and the construction of a sediment duration curve from sediment rating and flow duration curves.

Mean yearly suspended sediment export ranged from 12.55 tons/sq. mile to 576.9 tons/sq. mile with 58% of the basins yielding less than 200 tons/sq. mile. These rates are in close agreement with values reported by others for western Canada. Dissolved sediment yields ranged from 0.89 to 286.6 tons/sq. mile per year with 50% of the catchments contributing less than 50 tons/sq. mile per year.

Relationships between sediment yields and geomorphic and hydrologic variables were subjected to regression analysis. Highly significant relationships were established between sediment yields, unit mean discharge, mean annual discharge, local relief, elevation and mean land slope. Mean land slope and unit mean discharge were the variables which gave the highest correlation coefficients. Predictive equations were developed which allow sediment yields to be determined for ungauged catchments.


Abstract - Atlantic herring, Clupea harengus harengus, eggs from the Isle Verte (Quebec) stock were incubated in the laboratory at six combinations of temperature-salinity levels and in tidal pools subjected to a wide variation in physico-chemical conditions. Data were obtained on rates of embryonic and larval development and growth, percent embryonic survival and percent total hatch and compared to data from Pacific (Clupea harengus pallasi), Atlantic and Baltic (Clupea harengus membras) herring populations to examine the extent of divergence between these groups. Early development patterns of Isle Verte herring corresponded closest to those of other cold water populations in the North Atlantic. The field experiment showed a negligible effect of individually fluctuating physico-chemical parameters on percent egg survival in tidal pools. However, low oxygen concentrations combined with silt accumulation resulted in massive mortalities.


Abstract - Excessive sediment in the spawning gravels of salmon streams is believed to be one of the factors limiting salmon production. Natural as well as man caused sedimentation is of concern. With the goal of improving the salmon spawning habitat in the streams of Alaska's National Forests, the Forest Service has been instrumental in the development of a machine for "cleaning" streambed gravels. The riffle sifter, as it is called, is a self powered amphibious vehicle that stirs up the fine materials and sprays them out onto the streambanks.

The objective of this study was to evaluated some of the effects of the riffle sifter on populations of bottom fauna is some typical salmon streams in southeastern Alaska.

Results may be summarized as follows:

- in the gravel cleaned sections of all three streams, noticeable decreases in bottom fauna occurred immediately after the cleaning. Decreases occurring immediately after the cleaning operation were also observed in the untreated section although these decreases were not as great as those in the treated sections;
O a decrease of about 30% in materials measuring less than 0.4 mm was found after the cleaning in Slocum Creek;
O a 65% decrease in materials measuring less than 0.4 mm was found after the cleaning in Lover's Cove Creek;
O the sampling of bottom fauna also indicated that Lover's Cove Creek was given the most thorough cleaning although in all three streams the great variation among samples made only gross observations realistic;
O in the Lover's Cove Creek channels, recruitment of bottom organisms to pre-treatment levels appeared to be occurring 3 months after treatment and recruitment appeared to be complete in terms of biomass one year after treatment;
O if present, differences in the composition of invertebrate species in all streams as a result of cleaning were masked by natural variation.

To summarize, the cleaning of gravel in three streams initially reduced the bottom fauna populations in each of these streams, but within one year these populations apparently returned to the pre-treatment levels in each of the streams.


Abstract - Pristine habitats are increasingly difficult to find. Serious consideration should be given to locating and preserving such stream habitats to serve as study areas and to furnish baseline data on the condition and productivity potential of streams in the western United States.

Once natural conditions are established and the effects of grazing various stream and riparian habitats are known, then researchers will be able to provide resource managers with guidelines for predicting the effects of alternate grazing strategies on the condition and productivity of stream and riparian systems. This information then, will enable resource managers to make decisions more effectively on the use of rangelands with maximum consideration of aquatic resources.

Further research is needed on both the physical/chemical and biological aspects of livestock grazing and aquatic habitat inter-relationships. The resource manager needs this type of quantitative information to make sound land use planning decisions. Physical and chemical considerations include the effects of livestock grazing in valley bottoms on water quality, stream channel morphology, streambed condition and the riparian zone. Biological information must concern livestock impacts on standing crop and species diversity of fish and benthic invertebrate populations, bacteriological aspects of water quality and recreational and esthetic values involved in use of the fishery and aquatic and riparian habitats.

Modern grazing systems seek to improve livestock production while protecting range. Resource managers need to know how these grazing systems influence other resources including anadromous and resident coldwater fish populations.

Before the impacts of such land uses as livestock grazing on fish habitats can be evaluated, researchers need to know what the natural or pristine conditions of streams are or were prior to their uses.

Abstract - The results of this study suggest that, in the absence of storm flows, gravel shape can have an appreciable effect on short term sediment accumulation in spawning gravels. This is particularly evident for flow rates < 0.8 cubic meters per second (rates within our experimental range).

At very low flows (< 0.2 cubic meters per second) round gravels tend to accumulate more fine sediment than angular gravels. This relationship is reversed as flow rates increase above approximately 0.4 cubic meters per second and angular gravels tend to accumulate more sediment.

When fertilized salmonid eggs are "planted" in artificial containers, survival appears to be potentially greater if they are placed in a structure in which streamflow can be controlled than when they are placed in a natural streambed subject to storm flows and consequent gravel disturbance.

Survival of salmonid embryos, at least in the early stages of development, may be somewhat greater in angular gravels than in other gravel types. Since the amount of fine sediment which accumulates during a range of water flow conditions is somewhat greater in angular gravels than in other gravel types, embryo survival may at times be highest in those gravels containing the most fine sediment; this situation is probably due to other factors such as amount of intragravel void space, water velocity, etc.


Abstract - This paper provides a look at natural processes and several regional studies to suggest principles for reducing the impact of logging on erosion and sedimentation. These general principles include:

- timber harvesting, including cutting, skidding and road construction, to tend to accelerate erosion and sedimentation;
- accelerated erosion and sedimentation may cause either onsite or offsite (downstream) damage, or both. They are usually - but not necessarily - cause and effect phenomena;
- erosion hazards vary greatly with location, even within small areas;
- roads create a disproportionate share of the problems, probably greater than 90% in most areas;
- under certain conditions, mass erosion problems can occur from timber removal alone but are much more likely to occur on roads over a considerably broader scale of site conditions;
- accelerated erosion and sedimentation can and often does continue after the logging operation ends;
- some general guidelines for minimizing erosion and sedimentation problems include stratifying land according to erosion hazard, minimizing road impacts, and use proper procedures and techniques to assure erosion control.


Abstract - Erosion plots and sediment dams were used to evaluate the effects of jammer and skyline logging systems on erosion and sedimentation in steep, ephemeral drainages in the Idaho Batholith of central Idaho. Five year plot data indicated that no difference in erosion resulted from the two skidding systems as applied in the study. Sediment dam data obtained concurrently showed that the logging operations alone (excluding roads) increased sediment production by a factor of about 0.6 over the natural sedimentation rate. Roads associated with the jammer logging systems increased sediment production an average of about 750 times over the natural rate for the six year period following construction.


Abstract - In North America, two groups of freshwater mulluscns are most threatened by human activities and require ecosystems approaches to their sustainability. Prosobranch snails in the family Hydrobidae are restricted to small spring systems and are limited by their relative immobility, dependence on highly oxygenated waters and use of gills. Many are narrow endemics of localized springs, which are altered by groundwater depletion and surface water diversion and by changes in water quality such as nutrification and chemical pollution from non-point sources. Spring alteration can result in direct species extirpation. Conservation through threat assessment and abatement is recommended. Most rare and declining native mussels are Unionidae in riverine ecosystems. Their relative immobility, long lifespan, filter-feeding habits and parasitic larval stage make them highly vulnerable to habitat disturbance. The major cause of their declines has been the fragmentation of river ecosystems through impoundments, channelization and other activities such as timber harvesting, which alter flow and sedimentation patterns. Fragmentation acts to increase the distance between mussel subpopulations and may have major consequences on the metapopulation structure of species, particularly rare species and those with narrow host fish requirements. As some populations are eliminated and dispersal distances are increased, demographic and genetic constraints will diminish the ability of local populations to respond to natural environmental disturbance as well as human-induced changes. Sustainable ecosystem management in river systems will require devising strategies to conserve mussel metapopulations.


Abstract - On clear summer days the rate of apparent photosynthesis in the submerged aquatic plant, Ceratophyllum demersum, decreases progressively with depth of submergence. No indications were
found, even in relatively clear water, that the rate of photosynthesis was ever less in plants just under the surface than in plants at greater depths. When Lake Erie water attains approximately its maximum turbidity the rate of photosynthesis in this species is markedly reduced, even at depths of one meter and less. With the water at approximately the minimum turbidity attained during the summers of 1937 and 1938, the compensation point was at a depth of between eight and ten meters; when the water was at approximately the maximum turbidity attained during these two summers the compensation point was at a depth of between one and two meters.


Abstract - We estimated rates of erosion from a number of nonvegetated roadsides by determining roadcut geometry and substituting for parameters in the universal soil loss equation. The average rate of erosion from 104 separate sites was 354 tons of soil per acre per year. We verified the estimate by measuring sediment yields from plots established on selected roadsides. Differences in erodibility between surface soils and subsoils, variations associated with the length of the sampling period and variations in rainfall patterns accounted for the differences between measured and predicted erosion rates.


Abstract - Mulches of crushed stone, gravel and woodchips showed great potential for erosion control on construction slopes. Soils covered with 1 inch of stone mulch were much less erodible than those with more than 2 tons per acre of straw. Heavier rates of stone of 1 1/2 inches of woodchips were even more effective. Good to excellent stands of grass were obtained on many of the stone and woodchip treatments following erosion tests. The study was conducted on a 20 percent borrow pit sideslope with slope lengths up to 150 feet.


Abstract - Water and sediment control basins formed with discontinuous, parallel terraces using riser inlets and underground pipe outlets were evaluated for soil erosion and sediment control on a loess derived association of Usthothents and Haplustolls in northeastern Nebraska. The structures, parallel to existing field boundaries, provided straight rows as well as erosion protection on severely dissected landscapes that were too undulating to farm using conventional terrace systems. With clean cultivated corn, sediment trapping efficiency exceeded 97% and the basins retained sediment near its point of origin. The small quantity of sediment discharged from the outlet contained 12% silt and 88% clay after about 2 hours of runoff. Based on sediment trapped in the basins, an 86 mm storm transported about 40 tons/ha into the basins. A smaller storm (50 mm) deposited about 17 tons/ha. Sediment discharged during the initial runoff from a storm was high in silt and low in clay particles.

Abstract - A machine developed to remove silt and sediments from spawning gravels utilizes high velocity hydraulic jets, a suction system and separation system. The unit travels in the streams during the cleaning operation and sprays the removed silt on the stream banks above the high water level.


Abstract - Northern river breakups are the most significant annual hydrological event not only because of their extreme potential for morphological changes but also because they provide the environmental set point for the coming year. River beds and banks are scoured by rapidly moving ice, which in combination with maximum stage, ice jams and increased stream velocities, result in maximum sediment yield to river systems. It is known that most metal transport is associated with suspended solids; however, there are virtually no data on suspended solids and metal concentrations in northern rivers during actual breakup to determine natural fluxes.

The purpose of this study was to determine sediment and metal fluxes just before, during and immediately after river ice breakup. An intensive sampling program was carried out on the Liard River and Mackenzie River at Fort Simpson during April and May, 1993. Initial observations reveal strong correlations between suspended sediment and metal concentrations and break-up conditions. Recommendations for sampling refinements and further study are presented.


Abstract - This paper reviews the ecological implications of river regulation and training in gravel bed rivers. In the introduction the importance of fines in the ecological system of a gravel bed river is emphasized. The following three sections describe the sediment transport processes in a gravel bed river with special regard to the fate of fines and considers their effect on ecological habitats. The final section describes the ecological effects of the operation of a large reservoir on a river where the armour layer controls the nature of the gravel bed.

Identification of the principles which govern habitat response to stream regulation enable the ecological effect of changes in water and land management to be predicted. In using these principles, particular attention must be given to the effect of changes in peak flows and the load of sand and fine material.

Of particular concern is the need to be able to manage a water resource system in order to maximize the benefits derived from the system. In order to do this we must allocate water to the maintenance of suitable habitat conditions within the stream bed as well as within the stream channel. In the case of gravel bed rivers, consideration must be given to the flows required to "flush" the fines through the system without adversely modifying the size of the material.


Abstract - For a sight feeding predator such as muskellunge, environmental factors that affect the field of vision influence foraging behaviour. Typical elements in nature include light intensity, water transparency, and obstructions within the visual field. Decreases in the former two factors tend to lower the predator's reactive distance to prey and thus reduce its frequency of attack. This relationship is predicted by theoretical models of feeding strategies and has been demonstrated for a number of sight feeding fishes.

Relative to muskellunge, Oehmcke et al. (1958) stated that feeding was hampered by turbid water but provided no documentation. In our study, the strong direct association between water transparency and fish activity might be interpreted as presumptive evidence for this relationship. A turbid ity-reduced visual field might also dampen reactions to congeners, other larger predators and human disturbances. Manteifel et al. (1978) suggested that reduced water transparency can suppress diel and, especially, crepuscular behavior patterns. Alternatively, changes in transparency might affect prey behavior and, thus, muskellunge reactions to prey activity. It seems plausible, therefore, that the seasonal change in Okoboji muskellunge diel behavior is at least partly a function of transparency changes. The significant inverse association of water transparency and water temperature confounds this interpretation however.


Abstract - Predation on juvenile brown shrimp, *Penaeus aztecus*, by three species of estuarine fishes was examined in a series of laboratory experiments to determine the effect of turbid water and the presence of a suitable substratum for burrowing. Regardless of the type of substratum, turbid water increased predation by southern flounder, *Paralichthys lethostigma*, and decreased predation by Atlantic croaker,
*Micropogonias undulatus*. In both clear and turbid water, the presence of sand, which allowed shrimp to burrow, decreased predation by southern flounder but had no significant effect on feeding rates of Atlantic croaker. There was a significant interaction between the effects of turbidity and substratum on predation by pinfish, *Lagodon rhomhoides*. Turbid water decreased predation in tanks with hard substrata but had no significant effect in tanks with sand. The presence of sand reduced predation only in clear water tanks. Burrowing by brown shrimp was reduced in turbid water which may explain this interaction. Overall, the data indicate that both turbid water and a suitable substratum for burrowing may reduce predation on brown shrimp, but the value of these refugia is highly dependent upon the species of predator.


**Abstract** - In turbid reservoirs, vegetation is usually sparse; as such, the vegetated littoral typically available as refuge to small bluegill in clear-water system, is nonexistent. To determine how small bluegill persist with their predators in turbid reservoirs, we designed experiments to quantify (1) reactive distance of bluegill to largemouth bass, (2) habitat choice by small bluegill, and (3) bluegill predation by largemouth bass as a function of turbidity. Reactive distance declined exponentially with increasing turbidity for small bluegill (35-40 mm, TL) exposed to largemouth bass (250 mm, TL). However, bluegill had a greater reactive distance than largemouth bass across all turbidities (0-50 nephelometric turbidity units, NTU, at 330 lux). Using inclined (15°) pools with water depths 0-50 cm, bluegill used open-water habitat (20-50 cm deep) when turbidity exceeded 5 NTU but remained inshore at lower turbidities. In 24 hour predation experiments, bluegill mortality increased with increasing turbidity i.e., as bluegill moved offshore their vulnerability to a predator increased. Turbidity may reduce bluegill encounters with predators, causing them to reside in habitats that increase their risk of predatory mortality. This phenomenon may influence bass/bluegill population dynamics in turbid reservoirs.


Abstract - Eggs and larva of white perch, Morone americana, and striped bass, Morone saxatilis, were exposed to a range of suspended sediment concentrations. Percent hatch of white perch eggs was not significantly affected by 50-5,250 mg/liter of suspended sediment but developmental rates were significantly lower at sediment concentrations above 1,500 mg/liter. Hatch of striped bass eggs was not significantly affected by 20-2,300 mg/liter suspended but development was slowed significantly at concentrations above 1,300 mg/liter. Four concentrations of suspended sediment in the range of 1,626 to 5,380 mg/liter resulted in 15-19% mortality of white perch larvae during 1 day exposures. Four suspended sediment concentrations in the range of 1,557 to 5,210 mg/liter caused 20-31% mortality of striped bass larvae during 1 day exposures and 25-57% mortality during 2 day exposures. Covering the white perch eggs with a sediment layer greater than 2 mm thick (to about 1.2 mm above the top of the egg) resulted in 100% mortality; layers less than 0.45 mm thick did not influence hatchability. Rate of egg development was significantly lowered when sediments were over 0.8 mm thick. Eggs and larvae of both species were resistant to high sediment concentrations.


Abstract - This paper presents a comprehensive review of the literature on the physical, chemical and biological effects of dredging and spoil disposal and identifies alternative spoil disposal methods. Important physical effects of dredging and open-water spoil disposal are the alteration of circulation patterns and the uncontrolled redistribution of sediments eroded from the spoil mound at the disposal site. Changes in the chemistry of the sediments at the dredging and disposal sites and of the water overlying these areas are likely to result from dredging and dumping, especially if the dredged sediments have a high organic content or are contaminated. Although direct burial of organisms and destruction of the habitat are the two most obvious biological effects of dredging and dumping, the effects can be reduced by careful timing of dredging and placement of the spoil. A critical problem requiring further study is the uptake and concentration of contaminants associated with polluted dredge spoils by marsh vegetation, phytoplankton, zooplankton, benthos and fish. Possible alternatives to present methods include the use of diked or confined disposal areas, construction of marshes and spoil islands, and treatment and inland transport of dredge spoils for landfills.


Abstract - Synoptic surveys of turbidity were carried out in the navigable waterways of Broadland in the summer and winter of 1973, and of phytoplankton in the summer of 1973. The differential distribution of phytoplankton is discussed in terms of nutrient loadings on and flushing coefficients of, the waterway. Highly significant correlations were obtained between phytoplankton numbers and turbidity in the system as a whole and in Broads and rivers considered separately. A very weak correlation between boat activity and turbidity was shown to be non-causative; however boats do stir up sediment and erode material from river banks. It is concluded that increase in turbidity is a function of increased nutrient loading from human activities in the catchment area and that boat disturbance does not contribute significantly to the sustained turbidity. Increases in turbidity of the water have been associated with the loss of macrophytes.


Abstract - An underwater camera system was designed to record the behavior of male nest-guarding longear sunfish during periods of boating activity. Boats traveling at slow speeds near nests usually drove males from their nests, increasing the likelihood of egg predation. Boats moving at higher speeds or further from nests caused little or no displacement of males, but increased turbidity and possible success of predators. Location of a nest near cover increased the male's ability to protect his nest during repeated surface disturbances. Once predation occurred, predators were more persistent, making the nest increasingly vulnerable to future attacks.


Abstract - The effect of navigationally induced suspended sediments from the Upper Great lakes connecting channels on the size-fractionated primary productivity was evaluated by the Carbon-14 technique. The method was on-site, rapid, sensitive and inexpensive and provided dynamic toxicological information essential for hazard assessment. Enhancement and inhibition of the primary productivity was observed in various parts of the Upper Great lakes connecting channels. These responses seem to depend on the type of natural plankton and their exposure to various contaminant/nutrient complexes generated by the disturbance of the bottom sediments during the passage of ships. Traditionally, only the inhibition of primary productivity was monitored to toxicity but it is important also to evaluate the implications of enhancement because they may increase eutrophication and the propagation of nuisance blooms and change intricate food-web interactions. The procedure, adopted in this study for the first time, seems to provide simple and rapid screening of environmental perturbations from navigational activities.


Abstract - Mixing depth and turbidity negatively affect the productivity of an aquatic environment through the control they exert on the effective energy available for photosynthesis. A feedback equation is
developed that defines the interaction of these two quantities with the production by phytoplankton. The equation permits calculation of the relative productivity of any body of water provided nutrients are assumed adequate and provided depth of mixing and turbidity are known. Calculated relative production corresponded very well with observed production for a series of 33 small shallow ponds. The possibility is advanced that the same principles apply to reservoirs when thermocline depth can be regarded as mixing depth, and further, it is suggested that the productivity of reservoirs might be increased by reducing the depth of the mixed layer by withdrawing from the surface. In addition, this practice might further enhance the production by mixing deeper water, richer in nutrients, into the euphotic zone during the productive season.


Abstract - Small streams differing in sediment composition were compared in logged and forested reaches to determine effects of accumulated fine sediment on stream communities under different trophic conditions. Three stages of forest community succession were studied in the Cascade Mountains: recently clear-cut areas without forest canopy (5-10 year after logging); second growth forest with deciduous canopy (30-40 years after logging); and old growth coniferous forest (> 450 years old). One stream with mostly coarse sediment (56-76% cobble) and one with more fine sediment (5-14% sand and 23-53% gravel) were contrasted for each successional stage. In general, streams traversing open clear cuts had greater rates of microbial respiration and greater densities or biomasses of aufwuchs, benthos, drift, salamanders and trout than did the shaded forested sites regardless of sediment composition. We conclude that for these small Cascade Range streams, changes in trophic status and increased primary productivity resulting from shade removal may mask or override effects of sedimentation.


Abstract - Suspended particles, both living and nonliving, alter the toxicity of a compound by influencing the extent of bioavailability of a compound. An application of DDT as a rate of 0.09 mg/l for 16 minutes in the Saskatchewan River eliminated the blackfly larvae over a stretch of 98 miles. A similar treatment in other areas eliminated the insect larvae in only a stretch of 9 miles. The difference was attributed to the high turbidity in the former case, with suspended particle load of 551 mg/l. It was explained that in the presence of suspended particles, most of the DDT was adsorbed to the particulate matter, and because of the greater consumption of suspended particles by Simulium larvae, a better control ensued in areas of high turbidity.

To examine the influence of suspended particles on the toxicity of xenobiotic chemicals, Brungs and Bailey (1966) suspended 50 mg/l on montmorillonite clay, Brookston silty clay loam or activated carbon (particle size of clay or carbon, 1 to 2 um) and added endrin to the system. The LC 50 values calculated with the clays were similar to those of the controls but in the presence of activated carbon, the LC 50 value was approximately 50 times that of the controls. In the latter, too, the LC50 was comparable to that of the
controls. However, the endrin concentration in true solution alone, and not that adsorbed to the carbon particles, was taken into consideration. The presence of suspended particles reduced the mortality of mosquito larvae caused by parathion or parathion and atrazine together. Presence of clay particles in the test tanks greatly reduced the toxicity of lindane to a number of test fish.

Although Brungs and Bailey (1966) suggested that chemicals adsorbed to suspended particles were not bioavailable, the work of several others showed that chemicals adsorbed to sediments and suspended particles leach into water and as such are absorbed by the aquatic organisms. Such a desorption is a function of the water solubility of the compound and the levels of organic matter. Lower chlorinated biphenyls partitioned into water to a greater extent than the poorly water soluble, higher chlorinated biphenyls. In eutrophic lakes, in the presence of greater amount of organic material, less of the adsorbed DDT was available for absorption, whereas in oligotrophic lakes the presence of more suspended matter meant availability of more dieldrin for absorption.

The influence of suspended matter on the acute toxicity of pesticides to fish has not been investigated to a great extent. This problem deserves a closer inspection, especially with hydrophobic compounds that have tested near or above their saturation limits in water. When a compound is employed above its limit of water solubility, the amount in excess of the saturation limits will be present in precipitation or adsorbed to the walls of the test containers. The suspended particles also adsorb the amount that is in excess of the water solubility. Traditionally, the LC50 values have been calculated on the basis of the quantity of the compound that had been introduced into the test tanks, or in a few instances, on the total amount present in the system that could be extracted from water and quantified. In either case the LC50 values of the hydrophobic compounds reported earlier exceeded the water saturation concentration of those compounds.


Abstract - Estimates of the amount of material moving annually from terrestrial ecosystems to the ocean are largely based on an incomplete understanding of events occurring throughout the hydrologic year, and only a vague comprehension of in-stream processes controlling that export. Discharge, suspended sediment, particulate organic matter (POM; > 0.5 um), dissolved organic carbon (DOC; < 0.5 um diameter) and the percentage of organic matter were measured from 1979 to 1981 in five pristine Quebec streams: First Choice Creek (1st order; watershed area 204 sq. km), Beaver Creek (2nd order; 1.83 sq. km), Muskrat River (5th order; 204 sq. km), Matamek River (6th order; 673 sq. km) and the Moisie River (9th order; 19871 sq. km). All streams, with the exception of First Choice Creek, have a strong spring freshet when 43-55% of the annual discharge occurs. By describing sediment and organic carbon export throughout the annual hydrologic cycle, I showed that during the 2 month spring freshet 71-92% of the annual sediment load is exported but only 59-65% of the annual POM load and only 47-51% of the annual DOC load. Sediment yield is relatively constant between watersheds (1.5-7.5 gm/sq. m/year) as is POM export (1.0-6.7 gm ash-free dry weight [AFDW]/sq. m/year); however export DOC varies from 3.1 gm C/sq. m/year in First Choice Creek to 48.4 gm C/sq. m/year in Beaver Creek. There appears to be rapid loading of carbon between 1st and 2nd order streams in boreal forests, followed by biological and physical processing as watershed area increases. Thus, for the Moisie River watershed, export of total organic carbon (TOC) is reduced to only 4.7 gm C/sq. m/year. Export of coarse particulate organic matter (> 1 mm) is negligible (normally < 0.1 mg/l) as is oxidation of the suspended load (< 0.5%/day). Effects of summer storms, natural diel variations and depth of sample from the water column are shown to have a minimal influence on concentrations. Rating curves (kg/day vs. discharge) are developed to estimate the annual yield of sediment, POM and DOC and to evaluate long term variations. From the results, I suggest that in-stream processing and retention devices exert considerable control over the quantity and nature of
suspended organic material. Physical processes such as the discharge regime and stream power are relatively less important in determining organic concentrations but more important in determining sediment concentrations.


Abstract - Field and laboratory studies were conducted to characterize concentrations, factors determining concentrations, particle size composition and presumed food quality of particulate organic matter (POM) transported by streams of four different orders in Oregon's Cascade Mountains. Devils Club Creek (first order) and Mack Creek (third order) as high gradient, heavily shaded headwater streams receive large amounts of forest debris. Lookout Creek (fifth order) and the McKenzie River (seventh order) have lower gradients and more organic inputs from in situ aquatic primary producers and organic matter drifting from upstream areas than from the adjacent forest. Concentration of particulate organic matter is low during periods of nonstorm discharge and not significantly related to stream power or type of organic input. All streams transport a mean POM particle size < 12 um. Over 70% of all particulate matter transported is very fine particulate organic matter (VPOM: 0.45-53 um). Except for spring, the ratio of coarse (> 1 mm) to fine (0.45 um - 1 mm) organic matter (CPOM:FPOM) is near zero, but remains elevated for the McKenzie River during all seasons. As determined by the amount of chlorophyll, carbon to nitrogen (C:N) ration, percentage or organic matter and respiration rate, the presumed food quality of drifting organic matter is potentially better in downstream reaches.


Abstract - Respiration rates of Opsanus tau in suspensions of Fuller's earth (2.20 gm/l) and in resuspended Patuxent River sediment (1.58 gm/l) did not differ significantly from rates of fish in filtered water. Oxygen consumption rates of fish exposed to Patuxent River sediments (3.36 gm/l) after 72 hour exposure to 11.09 gm/l of the same material exhibited significantly greater (P < 0.05) variance than control fish. Respiration rates of fish tested in filtered water after 72 hour exposure to 10.37 gm/l of Patuxent River sediment were not different from those of control fish. Respiration variances differed between males and females only in Patuxent River sediment suspensions. Fish held in Patuxent River sediment suspensions of 14.6 gm/l for 72 hours exhibited no significant changes in erythrocyte count, hemoglobin concentration, microhematocrit or blood osmolal concentration compared with control fish. Toadfish appear to be largely unaffected by highly turbid conditions.


Abstract - A survey of world literature pertaining to the effect of inert sediments on fisheries provides generalizations regarding the severity of impact at specified intensities of pollution. These generalizations are of use primarily to environmental managers who need to know the potential consequences of pollution rates that exceed the levels established by regulatory agencies. In general, severity of impact is a function of the intensity of pollution where intensity is defined as the concentration of inert sediment in water (mg/l) times the duration of an organism's exposure to them (hr). Intensity of pollution, thus, has the units: mg hr/l.

When the natural logarithm of the product of these two variables is used as an Index of Stress, the literature identifies three broad categories of effect: behavioral (-0.1147 to 5.8556 mg hr/l), sublethal (6.309 to 11.1797 mg hr/l) and lethal (11.3572 to 13.1347 mg hr/l). A statistical comparison of the severity of impact as a function of the intensity of pollution indicates that the three categories are not significantly different from each other at the xx% level.
A fourth category contains anomalies involving the lack of lethal effect at pollution intensities that were, on average, greater than those known to cause serious problems (13.0005 to 14.4431 mg hr/1). Invariably, these anomalous results pertain to 1) hardy species, including marine invertebrates, adapted to turbid water; 2) long exposures at very low concentrations or very short exposures at very high concentrations; 3) tests conducted in very cold water; or 4) a combination of these.

Based on these findings, and notwithstanding the importance of variables excluded from this survey, these natural logarithms provide a convenient Index of Stress. This Index can be used as a quick, reliable guide to the severity of environmental impact when there is neither the time nor the resources to conduct and environmental impact study.


Abstract - Meta-analytical review of nearly 140 articles on suspended sediment pollution in aquatic ecosystems has generated statistically significant correlations, based on nearly 1200 data points for severity of effect as a function of dose, where dose is defined as the product of concentration of suspended sediment and duration of exposure. Documentation of the rationale for each of these data points is provided.

Two mutually exclusive sub-sets of meta-data show similar patterns: (i) meta-data for juvenile salmon show severity of effect \( SE = 0.866 \log_e [\text{mg/hr/l}] - 0.73 \) \( (r^2 = 0.85; N = 19; P < 0.01) \); and (ii) pooled meta-data (including various life history phases of fish, phytoplankton, zooplankton, algae and damage to aquatic habitats) show severity of effect \( SE = 0.738 \log_e [\text{mg/hr/l}] + 2.179 \) \( (r^2 = 0.638; N = 120; P < 0.01) \).

Impacts as a function of Stress Index (where Stress Index is defined as the natural logarithm of dose) can be displayed in a 3 x 3 matrix. Key findings are (i) harmless transient effects are generally associated with a Stress Index less than 6; (ii) sublethal effects and other effects such as reduced survival of egg incubation are generally associated with a Stress Index less than or equal to 12; and (iii) lethal effects and habitat damage predominate when the Stress Index is greater than 12.

Other potential correlations exist in the data but have not been confirmed statistically: (i) severity of effect is an inverse function of particle size (large particles are more harmful than small ones); (ii) severity of effect is a function of particle roughness and angularity (angular particles are more harmful than smooth particles); (iii) severity of effect is a function of water temperature (ill effects are generally least severe in cold water except for latent ill effects on incubation of eggs and survival of alevins; (iv) among salmon and trout and other species of coldwater fish post-larval forms (adults and juveniles) are relatively more hardy than eggs and alevins.

These findings are helpful for managers of coldwater fisheries who must assess the probable severity of pollution episodes, thereby to allocate resources for remediation and to apportion penalties.

Abstract - Data gleaned by meta-analysis of published literature on the ill effects of suspended sediment pollution are used here to document average severity-of-effect as a function of dose (where dose = concentration x duration, and has the units of mg/1 hr) in fish. Dose-response patterns are based on average severity-of-effect scores, superimposed on a Stress Index matrix (13 x 10 cells) that defines the observed range of concentration (in mg/1 < 13) and duration of exposure (in hr < 10).

Five dose response patterns were developed based on 302 severity-of-effect scores (906 data triplets). These patterns are uniquely different among the groups of fishes studied and vary as a function of life history phase, species and natural history: larvae and fry are the most vulnerable stages in the life history of any fish species included in the study and eggs are nearly as sensitive to harm as larvae and fry. Among members of the family Salmonidae (salmon, trout and grayling) juvenile and adult life history phases are the least vulnerable. Estuarine fishes are generally more vulnerable than salmon, trout and grayling. And, ill effect as a function of reproductive strategy (buried eggs vs. exposed eggs) showed similar patterns. Analysis of variance and mathematical description of the dose-response curves generated by the meta-data should be calculated in future to allow quantitative differences among fishes to be described objectively.


Abstract - Resource managers need to predict effects of pollution episodes on aquatic biota and suspended sediment is an important variable in considerations of freshwater quality. Despite considerable research there is little agreement on environmental effects of suspended sediment as a function of concentration and duration of exposure. More than 70 papers on the effects of inorganic suspended sediments on freshwater and marine organisms were reviewed to compile a data base on such effects. Regression analysis indicates that concentration alone is a relatively poor indicator of suspended sediment effects. The product of sediment concentration (mg/1) and duration of exposure (h) is a better indicator of effects. An index of pollution intensity (stress index) is calculated by taking the natural logarithm of the product of concentration and duration. The stress index provides a convenient tool for predicting effects for a pollution episode of know intensity. Aquatic biota respond to both the concentration of suspended sediments and duration of exposure, much as they do for other environmental contaminants. Researchers should, therefore, not only report concentration of suspended sediment but also duration of exposure of aquatic biota to suspended sediments.


Abstract - Juvenile rainbow trout, Oncorhynchus mykiss, (< 6 cm fork length) died when exposed to suspended sand particles (100-170 microns in diameter) in an intermittent pollution episode in Bellevue Creek (in the Mission area of Kelowna, British Columbia, Canada). Sand-laden water was pumped from a trench into the stream intermittently for about 57 hours during an eight day period. During one pumping episode (October 1994), concentrations of suspended sediment (silt and sand) ranged from 2929 mg/1 at the outlet of the discharge pipe to 5710 mg/1 approximately 20 m downstream. The average concentration of these two sampling points is 4315 mg coarse SS/1. For the purposes of this précis, and in the absence
of other data on concentration of suspended sediment, this is accepted as the average concentration of suspended sediment during the 57 hours of active pollution.

Upstream from the pollution site, at the Gordon Road bridge crossing, concentration of suspended sediment was < 4 mg/l. Water temperature was 10°C and the stream discharge was very small (estimated to be less than 70 l per minute). In the wetted reaches immediately upstream from the bridge, algal growth was evident and rainbow trout sub-yearlings were abundant. There were several try in each pool and an estimated 50-100 individuals in the reach at Gordon Road bridge.

Downstream from the sediment discharge point, the stream bed within the wetted perimeter was heavily covered with silt. All crevices between the rocks were filled with the fine sediment originating from the discharge point. Algal growth normally visible on the rocks was covered by a layer of sediment. Dead fish were found in various parts of the stream. It is believed that most of the fish normally present in this part of the stream died. Only a few fish were observed in any of the wetted areas for a considerable distance downstream. The wetted width of the stream varied from 0.3 m to 3.0 m. Average wetted width was 1 m to 2 m. Bank width was about 10 m throughout this reach.

Six dead juvenile rainbow trout were collected from the stream. These specimens were frozen to be used in court as evidence of the harmful effect of the pollution episode. One of the dead fish was autopsied for indications of the cause of death. Food items in the gut were undigested. Undigested food in the fish's foragut suggests that the fish died suddenly. There was no sand in the buccal cavity, esophagus, gut or intestine. Gill tissues were pink and showed no signs of hemorrhage however they lacked the coating of mucus normally found on a healthy gill. All the mucus, except for the sand-laden remnant on the distal surface of the gill, had been removed apparently washed away by repeated or prolonged exposure to suspended sediment in the water. There was no other evidence of sand or silt in or on the gill tissue. Abrasion of gill tissue would be manifest initially at the cellular level and would be invisible under a dissecting microscope. Gill damage leading to suffocation, is the most probably cause of death.


Abstract - Sedimentation occurs when particles (silt, algae, animal feces and dead organisms) sink through the lake column onto the lake bottom. Sedimentation is a very important process that affects phytoplankton biomass levels, phytoplankton community succession and transfers of organic matters, nutrients and particles associated contaminants from the lake's upper layers to the bottom sediments. One reason for the dominance of blue-green algae in some lakes is their ability to regulate their buoyancy and, therefore, to counter sedimentation. Sedimentation of particulate organic matter from the water column to the lake bottom provides a critical linkage between planktonic primary production and the growth of bottom dwelling organisms (such as aquatic insect larvae, clams and crayfish) that eat this detrital organic matter and, in turn, are eaten by larger predatory organisms such as fish and turtles.

Settling plankton, zooplankton feces and other organic detritus particles are degraded in the water column and in the bottom sediments through oxygen consuming decomposition processes. Organic matter decomposition, a collective term for the net conversion of organic material back to inorganic compounds, occurs through the respiratory activities of all organisms, including bacteria, fungi and other microbes.

In the hypolimnion of productive lakes, the sedimentation of organic matter from the surface waters is extensive. And because algae and other suspended particles are abundant, light penetration through the water column to the hypolimnion is limited or absent and photosynthesis cannot occur. Under these conditions the oxygen consumed in the hypolimnion and bottom sediments during the decomposition (respiration) of this organic matter greatly exceeds the oxygen produced. Also, as described earlier, the hypolimnion is isolated from the atmosphere by a temperature or water density barrier to mixing known as the metalimnion. The result, in productive thermally stratified lakes, is the depletion and sometimes a complete absence of dissolved oxygen in the hypolimnion. A similar result can occur, though more slowly, in shallow productive lakes with a prolonged snow and ice cover.

The chemical and physical changes associated with oxygen depletion are marked. They include increased nutrient release from the bottom sediments, destruction of oxygenated habitats for aquatic animals and incomplete decomposition of sedimented organic matter.


Abstract - A forest fire burned 4811 ha of the lower Beaver Creek drainage and was followed by an intense conventional rainstorm causing extensive soil erosion. Runoff from the event caused physical and
biological degradation of the stream. This study evaluated recovery of trout and aquatic macroinvertebrates, use of the stream by spawning alluvial rainbow trout, emigration of young-of-the-year rainbow trout to the Missouri River, and changes in substrate composition. Two months after the fire and flood, trout populations in the impacted portion of the stream were nearly eliminated; within 2 years numbers of age-0 to age-III rainbow trout had increased to 5878/ha (68.68 kg/ha) compared to an abundance of 3841/ha (49.34 kg/ha) before the event. The resident brown trout stock did not recover during the period of study. Numbers of adfluvial rainbow trout spawners using Beaver Creek did not differ significantly from pre-event years, however, there was a large increase in recruitment of young-of-the-year rainbow trout to the Missouri River. Fine sediments (< 0.85 mm) increased significantly in riffle areas following the event; fine sediments decreased 7.7% in riffle areas in 2 years. Adult rainbow trout selected spawning sites containing significantly less fine sediments than were measured in randomly sampled riffles. The benthic community was assumed to have been severely reduced by scouring of the substrates during the flood. The benthic community had recovered by the fall of 1986, however, percent occurrence of several taxa was lower in the impacted area due to greater embeddedness of cobble substrates.


Abstract - Solutions to the problem of delivery of pollutants from nonpoint pollution sources and their enrichment during the conveyance of sediment are crucial if water quality improvement objectives are to be considered in nonpoint pollution abatement programs. Without knowledge of delivery mechanisms, abatement measures would be based on soil losses (source strength) rather than on a water quality impact.

We believe the following conclusions can be drawn that should lead to further research:

The sediment delivery process and its components are known only qualitatively. Breaking down the process into its components - overland flow, vegetative filtration, channel processes - and developing quantitative models and descriptions for each component are the most feasible approaches.

Studying the components of the delivery process requires the coordinated effort of several groups of scientists especially watershed morphologists, soil scientists and hydraulic and hydrologic engineers.

The spatially and temporally lumped estimates of delivery ratios are not suitable for water quality studies involving nonpoint pollution. The delivery process and the values of parameters to which the magnitude of delivery ratios are related represent a hydrologic stochastic process that should be treated as such. Estimates of delivery ratio are needed that reflect the dynamic and stochastic nature of the processes.

Development of spatially distributed or sequentially lumped approaches to the description of the delivery process are important because it appears that large scale, lumped approaches are inadequate. In contrast to the disturbed parameter concept, in which a basin is divided into a large number of more or less uniform or small scale, lumped pseudouniform elements, the sequential approach is more lumped. Yet it preserves the identity of each individual delivery process. Basically, the sequential approach follows the sediment particle in a Lagrangian scheme (rather than fixed in a space - Eulerian scheme used for distributed parameter models) and applies the appropriate delivery factors based on the process applicable to each sequential modeling subunit. For example, the process begins with detachment, followed by overland
flow, vegetational filtering and channel and flood plain flow. Subdivision into smaller subunits may be needed to preserve the uniformity of the computational segments.

The statistical characteristics of delivery ratios should be established to provide information on the reliability of the various lumped forms that are or could be used by practitioners. If delivery ratios or, by the same reasoning, enrichment ratios are highly variable and have a strong random component, use of the large scale lumped approaches may not be feasible.

The relationship between delivery ratio, pollutant distribution in soil and sediment, and enrichment ratio should be established otherwise large errors may be associated with estimates of pollutant loads from nonpoint sources. It appears that the use of "potency factors" is inappropriate. Developing a relationship between pollutant content of soil and runoff characteristics using adsorption isotherm concepts could provide a means of better understanding the enrichment "quality" aspects of the pollutant delivery process. Adsorption characteristics of pollutants in soils and in runoff should be established.

Models are needed that are capable of representing sediment storage in its intermittent form and include particulate pollutant transport. This is especially important when investigating nonconservative pollutants, such as ammonium and soil organic compounds.

NUTTAL, P. M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall. Freshwater Biology, 2: 181-186.

Abstract - Using an F.B.: A net, a total of fifty-four samples were taken from the River Camel, Cornwall, during the summer of 1970 and the winter of 1971. Erosion from a tributary of the river Camel was found to deposit an estimated 10,000 m$^3$ of sand in the main river over a period of two years. The poor incidence of plants and macroinvertebrates from the river was associated with the unstable shifting nature of the sand deposits, rather than turbidity or abrasion caused by particles in suspension. Sand deposition accounted for the low diversity of invertebrate species below the tributary and resulted in the elimination of several species which were frequent upstream. *Baetis rhodani, Rhithrogena semicolorata* and *Tubificidae* were abundant where sand deposition had occurred.


Abstract - A survey of the macroinvertebrate fauna of rivers receiving china clay wastes was carried out during 1971-72. Rivers polluted by clay waste supported a sparse population of few species. Rooted vegetation was absent, although clean headstreams and unpolluted reaches supported a rich community of aquatic plants. Control streams supported thirty-six times the density of animals found at clay polluted stations. The composition of species was greater in unpolluted rivers, moorland headstreams and at station downstream of sewage outfalls compared with clay polluted reaches. *Baetis rhodanii, Perlodes microcephala* and the burrowing forms *Tubificidae, Naididae* and *Chironomidae* were in greater abundance in clay polluted reaches. China clay pollution either eliminated or reduced the abundance of several species frequent in control streams. The poor incidence of plants and macroinvertebrates from rivers receiving china clay waste was associated with the deposition of fine inert solids derived from the clay extraction process rather than turbidity or abrasion caused by particles in suspension.


Abstract - It has been demonstrated through a pilot treatment systems that synthetic polymers worked effectively in reducing turbidity of the hatchery water supply. Two years of monitoring the water and recording turbidity levels of treated and untreated flows were completed. Growth differences between test fish were measured as well as histological changes in gill structure. No adverse effects were noted in fish reared within treated water while those reared in untreated water of high turbidity lost weight and appeared quite inactive throughout the study. A full scale treatment plant using synthetic polymers to reduce turbidity has been designed for use on the main water supply. A change in water quality as a result of less turbidity would allow the hatchery to operate on a daily feeding schedule without interruption and provide a more efficient operation in terms of production, manpower utilization and total costs.


Abstract - A study was carried out to provide some background data on river bottom materials, operating characteristics of dredging equipment and spoil disposal practices. Active dredging projects were visited; bottom samples were taken for chemical and physical characterization and to measure the effects of dredging on water quality. Conflicts in land use and competition for land is making the availability of acceptable sites for land disposal of spoil more and more difficult. More effort needs to be put into the development of long term plans for such disposal. The effects of different dredging methods are discussed; the main detrimental results can include reduced oxygen levels, smothering of bottom organisms, release of toxic compounds in localized areas, turbidity plumes and submarine mudflows. The dredging and disposal of material in a partially confined area behind a dike or breakwater can be an effective method of restricting or retaining the movement of turbid water and insuring the retention of spoil material within a specified area. The design and operation of diked areas for the land disposal of dredge spoil often provides an inadequate detention time for settling of the waste water prior to its discharge into the receiving water.


Abstract - Provincial guidelines for turbidity recommend that suspended matter should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10 percent.


Abstract - Short and long-term effects of sedimentation may involve the alteration of the light, temperature and water chemistry regimes of the watercourse. As contaminated sediment may be released into the water column during trench excavation, bed disturbances shall be restricted to as small an area as possible.

Input from construction related sediment loads may result in adverse impacts on the ecosystem and watercourse uses. Every effort shall be made to reduce the extent and duration of turbid conditions and the quantity of sediment loads.
Nineteen recommendations for minimizing adverse environmental impacts of watercourse crossings are detailed in Procedure B-6-1: "Evaluating Construction Activities Impacting on Water Resources." The reduction of in-stream work time is a fundamental principle of the recommendations.

The method of stream crossing selected shall be based on a site specific evaluation. Adverse or undesirable water quality and water use impacts associated with watercourse crossings by transmission pipelines shall be minimized by applying the following criteria:

- the shortest possible construction time;
- construction during the season of least disturbance to aquatic biota and watercourse users; limited in-stream disturbance;
- immediate implementation of post-construction stabilization measures.


Abstract - Excessive aquatic plant growth and algal blooms are largely caused by human activity around a lake. One specific cause of excessive aquatic plant growth is sediment input - too many sediments are washing out of the watershed and into the lake, giving plants a foundation in which to take root.

Sediment input occurs when people clear their lots of natural vegetation, sometimes right down to the shoreline. "Improving" the natural shoreline (for example, by filling, dredging or building docks and boathouses) can also cause sediment input problems.

There's a very simple way to avoid this problem: Don't change the natural shoreline. Don't clear away natural vegetation on your property - leave it there to control erosion. In fact, you should consider planting more vegetation on your land.

Building on, or altering your shoreline can also cause sedimentation problems. That's why you can't build anything on or near the water without a permit. There are ways to build a dock, create a beach and make a channel for your boat that have very little impact on the environment.


Abstract - The principles of erosion and sediment control design are based on simple common sense. Erosion control is done to prevent or minimize the erosion of soil. Sediment control is the trapping of suspended soil particles being transported downstream in flowing water to prevent their discharge into the aquatic environment of a stream. Erosion control is obviously the only effective long term solution whereas sediment control is a short term remedy to minimize the impact of unavoidable erosion that does occur during the construction period.

The eight principles of erosion and sediment control are:

1. Fit the road to the terrain
2. Minimize the duration of soil exposure.
3. Retain existing vegetation where feasible.
4. Grade disturbed soil to a stable slope.
5. Encourage re-vegetation.
6. Divert runoff away from exposed soil.
8. Trap sediment before it can cause damage.


Abstract - Four categories of development activities are of particular concern with respect to increased sedimentation and turbidity: site preparation; stormwater management; dredging and filling; and water crossings, diversions and channelizations.

Sediment is soil that has been eroded and has entered a waterbody. The term sedimentation refers to sediment particles which fall out of the water column and settle to the bottom of waterbodies where they cover the existing substrate (this is also known as bedload or lakebed sediment). It is difficult to predict where sediment will be deposited in a particular watercourse because of the number of factors which influence transport i.e., stream velocity, sediment grain size, etc. However, there is ample evidence of the effects of bedload or lakebed sediment on fish habitat. Sediment can smother bottom dwelling organisms, such as invertebrates and plants, thus reducing food supplies for fish and can eliminate key spawning and rearing areas; this can affect the habitat of a broad range of species.
Turbidity refers to sediment particles which are suspended in the water column itself. Suspended sediment can disrupt spawning and feeding behaviour and lead to damage i.e., to the gills, or death of fish where they are unable to avoid high sediment loads. The type of sediment is a critical factor in the assessment and mitigation of impact. Fine sediments, such as silt and clay, tend to stay in suspension longer than coarse sediments such as sand. Impacts increase with increased sediment concentrations and duration of exposure, and can range from temporary behavioral changes to sublethal physical damage to mortality. Phillips (1971) reported fish mortality after exposure to sediment levels of 200-300 mg/l for a number of days.

Due to water movement patterns, sedimentation and turbidity impacts often occur at some distance from the actual development site. Factors which influence sedimentation and turbidity impacts to fish habitat include the proximity of the development site to a lake or stream and/or the presence of a storm sewer which empties into a waterbody, land slope gradients, slope length and soil types.

During site preparation, the removal of vegetation and the disturbance of the soil mantle can lead to unstable soil conditions whereby sediment is washed into nearby lakes or streams. Studies have shown that erosion rates for construction sites with no erosion control measures are 200-400 times higher than natural erosion rates. It is estimated that, in the absence of erosion control measures, new construction areas could produce approximately 4 tonnes of sediment for every new resident.

Stormwater runoff from development sites is typically of greater velocity and magnitude than that prior to the development. This alone frequently leads to increased sedimentation and turbidity in adjacent waterbodies; in addition, the increased magnitude of runoff can accelerate the erosive forces in receiving watercourses, thus generating additional sediment loads.

The most common fish habitat impact associated with dredging and filling is an increase in suspended solids (turbidity). Generally, the impact from dredging is short-term and occurs during and shortly after the dredging takes place. Fill material, however, can contribute to increased suspended solids over much longer periods of time if the materials deposited are not stabilized. Wind and/or currents have a major influence on near-shore environments and play a large part in the erosion and deposition of sediments. In many instances, wind and/or currents in combination with dredge and fill activities have resulted in significant off-site impacts through the transport of fill or dredged materials i.e., downstream or along the shoreline from the development site.

Water crossings, diversions and newly channelized areas can lead to increased sedimentation and turbidity from the disturbance of streambeds and inundation of water onto unstable soils. With the exception of washouts, ditch and fill slopes are the main sources of increased sediment levels resulting from water crossings; these soils can be unstable and are inundated with water during storm events. In a natural channel, meanders act to dissipate the energy of the current. Channels constructed without regard to natural morphology and function can become unstable and are susceptible to increased rates of erosion, sedimentation and turbidity.


Abstract - Willows are an ideal native plant for restoring degraded shoreline to a more natural state. Restoration of our waterfront is important because natural shorelines protect water quality, prevent erosion and provide habitat for wildlife.

This Extension Note provides information on how to plant willows along shorelines. Some of the basic guidelines include:
the best sites for willow have a slope less than 2:1. Grading may be necessary to achieve the right slope.

willows should be planted in the spring, in rows parallel to the waterway and 0.75 - 1.0 meter apart.

cautions should be used when planting in natural ditches or waterways as they may eventually stop or divert the flow of water.

in the fall, after one growing season, the plants can be pruned back to five centimeters above the surface.

native grasses, clover, shrubs and other vegetation should also be considered to provide additional shoreline stabilization and add vegetative diversity.


Abstract - The potential for controversy associated with aquatic sand and gravel extraction is frequently linked to the turbidity created by the operation and how it may affect other uses of the water in the vicinity. Local conditions will govern the extent of any harmful effect.

Impairment of property values, potential threat to local aquaculture operations and municipal water supplies; aesthetic impairment within the waterway at the extraction site, or on route to the landing have to be considered. Ministry of Environment approval of dredging operations is often conditional on monitoring requirements including turbidity around the dredge as it is working. This in turn requires knowledge of pre-operafon turbidity or suspended solids prevailing at the site. Some jurisdictions have gone to great lengths to investigate the effects of turbidity depending on the nature of the operation, whether screening takes place on-water and time of exposure depending on the duration of dredging within each day. Gijssen (1988) examines the effects of suspended sediment at some length and provides available comparison of potential environmental impacts on wild fisheries and aquaculture fisheries. None of the Ontario operations dredge for 24 hours a day. In fact, much of the working day is spent by a loaded barge/ship traveling to and from the landing site. Thus, the turbidity plumes within the water column and on the surface at the sites will have time to settle out depending on size of fine particles, depth, water temperatures and currents.

The effect of turbidity is not restricted to spawning bed siltation but may also be detrimental to benthic (bottom dwelling) organisms slowing down the rate of recolonization. In the absence of studies in Ontario waters, and in view of the mixed results in other jurisdictions, it appears that future authorizations should attempt to control turbidity as much as possible by directing the mode and pattern of extraction, including on-water screening (as determined by wind, current, etc.) requiring mitigation measures and monitoring the results.


Abstract - During the construction phase of any urban development, eroded sediment during runoff events may increase by one thousand times or more compared to pre-development conditions. These guidelines have been developed to enable a developer or municipality and/or their consultants to evaluate the site erosion potential based on the following basic information: slope gradient, slope length and soil type.

If sediment laden storm drainage could flow off the site, then the sensitivity of the overland flow route(s) and receiving waterbody must be determined. Environmentally sensitive streams with fish habitats would require extensive control measures, regardless of the erosion potential of the site. On the other hand, waterbodies with low environmental sensitivity would not require such stringent controls especially if the site had low erosion potential.

All urban construction sites should consider some minimum control measures to address the environmental pollution caused by mud tracking onto municipal streets, windblown dust and water borne sediments entering the municipal sewer system. Throughout the guidelines, the approach has been to encourage prevention rather than to effect cure; emphasis has therefore been placed on protection of exposed surfaces and the control of runoff. Sediment control is to be practiced to prevent off-site sedimentation damage.

We believe that a site evaluation process using more than three classes (i.e., high, medium, low) implies a level of precision that is not matched by control methods in the field. To gain the support of practitioners, evaluation schemes should not be too complex and some discretion in choice of methods to meet their goals must be given. Two of the main factors to consider when determining erosion and sedimentation controls are the sensitivity of the downstream environment and the availability of on-site retention facilities.


Abstract - Ecological functions of wetlands include:

- Maintaining and improving water quality, aiding in flood control and protecting shorelines from erosion;
- Trapping sediments which would otherwise fill watercourses;
- Assisting in maintaining water quality in adjacent lakes and streams that support fish populations;
- Immobilizing some contaminants and nutrients;
- Providing important habitat for a wide variety of plant and animal species such as breeding, spawning, migrating, etc.


Abstract - The Ontario Ministry of Transportation and Communications (MTC) has recently employed a unique marine protection system to isolate construction-caused sediment in the immediate work site. Silt barriers were developed to minimize sediment contamination of sensitive downstream sites. A silt barrier is a vertical plastic curtain suspended on floats and secured to the bottom to form a giant settlement basin around the construction site.

Although silt barriers have been used in Ontario since 1972, they have not yet found widespread acceptance throughout the Province. The type of silt barrier used by MTC (a flexible curtain) works well being 95% effective. They are relatively inexpensive, easy to place and durable. Success with the initial application of flexible silt barriers, with only minor problems has warranted further use on other projects. This report outlines the MTC application of silt barriers with consideration of other current practices.


Abstract - Impacts on waterbodies caused by highway construction occur mainly as physical pollution in the form of sediment from the land disturbing activities associated with construction of the highway.

Sedimentation of the aquatic ecosystem is probably the greatest and most easily understood of all the water quality problems caused by highway construction. This occurs due to the erosion of freshly exposed and disturbed land surface with subsequent moving towards the stream by overland flow and downstream sediment transport to the point where the final impact is felt. The greatest opportunity for physical impact occurs during construction when soil is freshly disturbed and before a protective cover can be established.

In channelization projects, where the length of the channel may be shortened, the gradient is also altered. This causes the stream to seek a new equilibrium and upstream scour occurs until equilibrium is re-established. The erosion products are deposited in the downstream reaches. Urban channelization projects rarely disrupt natural ecosystems but have a potential to disrupt downstream ecosystems by increasing peak runoff of low quality urban drainage.

Siltation, although traditionally treated as an aspect of water quality, is closely interrelated with both water quantity and stream alterations. Silt may enter systems from a wide variety of sources; the most common sources are:

- runoff from disturbed land during and after construction;
- instream work with heavy equipment;
- storm sewers;
- sand blasting and painting.

The effects of silt on fish and fish foods are well documented in the scientific literature. The impact is directly related to the amount of sediment, the nature of the sediment which enters the stream, the flow in a stream, the time of year and the duration of sediment load. The amount of sediment in the water may be reported as:

*Total suspended solids* - determined by filtering a known volume of water and measuring the dry weight of the material on the filter paper.
(ii) **Turbidity** - the optical property resulting from impurities in the water (including silt) which cause light to be scattered or absorbed rather than transmitted in a straight line.

(iii) **Bedload** - the amount of sediment moving along the bed of a stream. This would be a more meaningful measurement but is rarely taken since it requires more sophisticated equipment than the above.

Increased sediment in streams may affect fish both directly and indirectly. Direct mortality by suffocation due to silt clogging gill surfaces or from extreme stress caused by hyperventilation is a rare problem and will occur only under the most severe circumstances.

Indirect effects of sediment on fish resulting from loss of habitat and food supply are much more common than suffocation. Most of these indirect effects are caused by sustained high turbidity and sediment leaving suspension resulting in its deposition on the substrate. If high turbidity is sustained for several days (more than 4 or 5) during the spawning season, it may severely disrupt spawning activities of species that depend exclusively upon visual stimuli for successful reproduction. During other seasons of the year, sustained high turbidity will impair the feeding efficiency of fish and, in the long term, adversely affect growth and survival. Suspended sediments can also damage the breathing organs of aquatic invertebrates or clog their feeding apparatus resulting in a loss of these organisms and ultimately a reduction in the food supply of fish. Settled on the stream bottom, sediments fill in rearing pools, reduce intra-gravel flow in spawning areas and suffocate the eggs of both fish and aquatic invertebrates.

The deposition of suspended sediments on stream bottoms normally occurs when water velocity decreases to a point where it can no longer transport the sediment in suspension. Most of the siltation or sedimentation problems arise from particles in the size range of fine sand to silt (0.25 - 0.005 mm). Finer materials, including clays, are very slow to leave suspension (up to 200 days) and normally cause minimal short term effects on stream fishes; however, they may cause a considerable decrease in water clarity. If a large plume of clay is discharged into a lake or pond, it will decrease the light penetration and production of food organisms for resident fish. Reduced visibility may also affect the feeding success of fish, especially if sustained inflows of fine materials maintain a high turbidity for an extended period.

Sediment deposition will lead to an adverse effect on the aquatic environment. If the sediment is acidic or basic, a change in pH of the water may occur.

Water has a large solvent capacity. Because of this, some of the solid material that washes into it dissolves. This increase in dissolved solids can make the water unsuitable for aquatic life. Sediment serves as a transport mechanism for pesticides, heavy metals, algal nutrients, organic matter, bacteria and viruses. Organic matter or carbon compounds and oxidizable chemicals can create an oxygen demand in the water. This oxygen demand can deplete the dissolved oxygen (DO) in the water, which is vital to the life of fish and other aquatic animals. Excessive quantities of algal nutrients, such as phosphorus, nitrogen and potassium, can clog waterways, deplete the dissolved oxygen supply, block out sunlight and advance the rate of eutrophication. There are many other effects from specific pollutants such as toxic effects of pesticides.


**Abstract** - Sediment originating from soil erosion has physical, chemical and biological effects on water resource use. Sediment particles pollute water to the extent that their presence reduces water quality for a particular use.

The physical presence of sediment produces turbidity. Turbid water has impaired water quality for most uses. Reduction in light penetration due to suspended sediment may alter oxygen relationships in surface water. Production of fish and other aquatic life is reduced by excess turbidity. Taste and odor, temperature and abrasiveness of water may be altered by the physical presence of sediment.

Sediment in water provides a surface for the sorption and desorption of potential pollutants. The sediment particles may scavenge or remove substances such as nutrients, pesticides, heavy metals and radioactive isotopes from water. The sorbed substances may be fixed so that they no longer are available as pollutants. They may be contacted by aquatic organisms and concentrated in the aquatic food chain. Deposits of sediments with their absorbed constituents may be buried by later deposition. The buried deposits may be re-exported or transported to new locations. The effects of sorption and desorption may be different in short term and long term periods.

Sediment influences eutrophication through deposition of sediments and through nutrients released from the sediments. The deposition effects are more obvious and may have a greater effect on eutrophication than the nutrients in the sediments.


**Abstract** - The effect of "red mud" at a dilution of 1:10^5 to 1:10^6 on growth, body weight and mortality of juvenile stages of the planktonic copepod *Calanus helgolandicus* were investigated. In the presence of phytoplankton *C. helgolandicus* ingested large amounts of "red mud". In comparison to control copepods growth of "red mud" animals was delayed. Mortality of "red mud" animals was 5 to 8 times higher than that of control animals. The dry body weight of CIII, CV, and adults raised from NV/NVI in "red mud" was far lower than the dry weight of the control animals. All results show that "red mud" at the above mentioned dilutions affects negatively juvenile stages and adults of *Calanus helgolandicus*.


**Abstract** - In streams of eastern and central Iowa, the densities and standing stocks of smallmouth bass, *Micropterus dolomieui*, were determined at 37 sites and compared to habitat quality measurements.

Abstract - Armored stream segments may affect the suspended sediment regime of small mountain streams in western Oregon by the release of fine sediments stored in the bed gravels. Sieve analysis of bed materials indicated that at least 30 percent of the suspended sediment yield for the 1975-76 winter had been stored in the streambed. Suspended sediment concentrations during storm generated runoff were influenced by stream discharge and hydrograph characteristics. Sediment-discharge relations for individual storms were characterized by hysteresis loops. A seasonal flushing of fines was shown by a progressive decrease in the ratio of suspended sediment to stream discharge during the winter runoff period.


Abstract - Sediments introduce nutrients, salts, pesticides and other persistent organic compounds sorbed to soil particles into the aquatic environment. The finer sediment particles, by virtue of their greater surface area to volume ratio, adsorb relatively greater quantities compared to larger sediment particles. Sediments lower the recreational and aesthetic value of the watercourse due to turbidity and associated contaminants. Sediments may impair water quality for agricultural use, water treatment plants and industries. Other potential effects of increased sediment on the physical/chemical components of the aquatic environment include: organic enrichment, effects on water uses, accumulation of sediment at river mouths and harbors and co-accumulation of contaminants.

The sedimentation effects of construction can result in adverse impacts on aquatic biota by affecting primary productivity, benthic organisms and fish.

The photosynthetic production of organic matter by green plants, such as plankton and algae (autotrophs), is referred to as primary productivity. The increased turbidity which results from the introduction of suspended sediment into the water column attenuates the penetration of light and curtails photosynthesis, thereby adversely affecting one of the basic food sources of the aquatic environment. In those cases where in-channel vegetation is affected, a loss of protective cover may also results. In order to prevent unnecessary adverse impacts upon primary productivity, every effort should be made to reduce the extent and duration of turbid conditions. This is best achieved by limiting construction in and adjacent to watercourses to the absolute minimum. In addition, sediment control measures that reduce the loss of sediment to watercourses should be used whenever possible.
Smallmouth bass were found at 22 of the 37 sites in densities ranging from < 1 to 669 fish/ha; standing stocks ranged from 0.1 to 53 kg/ha. Bass abundance was higher (P > 0.05) in stream reaches with small drainage areas and were significantly higher (P < 0.05) in reaches downstream of dams (compared to areas above the dams). All bass captured were from stream reaches classified as having good or fair habitat using the habitat ranking system developed during earlier segments of this study. Population densities in good habitat areas were two times greater than those in only fair habitat areas, but no bass were found in silt-laden reaches of poor habitat. Sediment is a major habitat factor in the viability of smallmouth bass populations. Although modeling indicated bass populations are improved with a 305 mm minimum length regulation, restoration of habitat alone could make even greater gains in densities and standing stocks.


Abstract - Through the years, forest owners and managers have been warned about the soil and water erosion caused by grazing. Indeed, such damage occurs but careful observation usually shows that active erosion is localized, commonly in places where too many animals have bee restricted for too long on too small an area.

Reduced water quality is unavoidable where animals have free access to forest streams. Deposit of body wastes directly into or close to water courses is an obvious source of pollution. Trampling stream banks and wading in channels increases the sediment load in streams. Fencing stream channels and immediate environs is an obvious way to maintain high water quality. Fencing not only protects the highly sensitive channels but establishes a filter strip to intercept sediment originating from upslope grazing.


Abstract - Statistical analyses were made on 812 forest soil erosion measurements and estimates of sediment yield in five forest streams. More than 100 of those reports showed that streams draining forested land along the Pacific Coast yield far more sediment per unit area of watershed than do streams of forested regions elsewhere in the nation. In the other 700 reports, no significant differences (P = 0.05) were found among sediment yields in streams draining predominantly forested land of the eastern United States and of western regions other than the pacific Coast. About one-third of these eastern and western observations denoted sediment yields not exceeding 0.02 tons per acre per year, and three-fourths of the total did not exceed 0.25 tons. About one-fourth fell between .25 and 1.00 tons and a few exceeded 1.00 tons per acre annually. Nonforest land use within some of the larger watersheds may account for many of the higher sediment yields. These nationwide results are consistent with regional compilations. A long term average of not more than 0.25 tons per acre per year in streams of the eastern and western United States (but not of the Pacific Coast) can provide a first approximation of sediment yield from predominantly forested land. Amounts derived by prediction equations should be questioned if they greatly exceed 0.25 tons per acre per year.

The survival of benthic organisms depends upon the preservation of the watercourse substrate as suitable habitat. The most severe impact of sediment on the benthic community is the blanketing of the channel bed as a result of rapid sediment deposition. This either destroys the organisms or causes them to drift downstream. These bottom dwellers form a vital link in the aquatic food chain and elimination of these organisms can result in an overall reduction in productivity as dependent predators are forced to abandon regions thus affected. Most sediment problems related to construction are relatively short term and can be overcome. Short term impacts can often be tolerated by benthic organisms. Re-colonization of areas can occur relatively rapidly once the source has been stopped though in some cases the original benthic community structure may be altered.

Increased turbidity adversely affects those species of fish which rely on sight for feeding and escaping from predators. Excessive sediment levels may also affect the respiratory mechanism of fish through clogging or abrasion of the gills, although many species of adult fish are able to withstand high levels of suspended sediment for extended periods of time by exuding a protective mucous on their skin and gills. However, this does not assure survival since the production of this mucous depletes metabolic reserves at a time when feeding is inhibited by turbid conditions. Sediment can also clog the interstices of the substrate in fish spawning areas thereby interfering with the normal exchange of water which replenishes the oxygen supply and removes accumulated waste products. This impact can be lethal to emerging young. The loss of reproductive capacity through physiological stress, loss of spawning beds and destruction of eggs or fry may result in a more significant negative impact on fish species than the direct short-term abrasion and clogging effects on adult fish. Although the damaged habitat may recover eventually, recolonization may be by less desirable species.


Abstract - Contaminated sediment has been singled out as a major environmental problem. The concern is that persistent toxic substances - poisonous substances that take a long time to break down - in the sediment will accumulate in carp, catfish and other bottom dwelling fish as well as in the bottom dwelling organisms such as worms and midges that live in the sediments. These contaminants may be transferred to fish either because they have fed on the organisms or come into contact with the sediments. These chemicals may be transferred again to wildlife, birds and people who eat the fish. This process, by which organisms can accumulate levels of persistent chemicals higher than in sediments or water, is called biomagnification.

The primary source of contaminants in sediments is toxic chemicals from industrial and municipal discharges of waste water. The runoff from cities, towns and agricultural areas may also contribute to the problem. Other sources include:

- lakefilling or the practice of creating more land by building up the shoreline with rubble, bricks, stones, concrete and loose earth may also add to the problem unless the fill is free of contaminants.

- chemicals in factory emissions which, attaching themselves to particles of dust or droplets of water, fall back to the earth in the form of dust, rain, hail or snow.

The ministry has several programs in place which, either directly or indirectly, tackle the problem of contaminated sediment:
The Municipal Industrial Strategy for Abatement (MISA) - The aim of the program is to reduce drastically the discharges of toxic chemicals from industry and municipalities either by improving treatment plants or by changing industrial processes so that toxic chemicals are no longer needed.

The Remedial Action Plan (RAP) Program - The aim of the program is to help clean up the 17 Areas of Concern in Ontario identified by the International Joint Commission as being badly contaminated. The RAP teams have identified contaminated sediment as one of the factors contributing to poor water quality and living conditions for the sediment dwelling organisms also known as the benthic community.

Operations Lifelines and the Beaches Improvement Program - The aim of these programs is to help municipalities improve stormwater management and reduce the amount of runoff from cities and towns.

Fill Quality guidelines for Lakefilling in Ontario - The aim of the guidelines is to protect the quality of the aquatic habitat. The guidelines regulate the quality of fill used, based on the Provincial Sediment Quality Guidelines and the Provincial Water Quality Objectives/Guidelines.

The purpose of the Sediment Quality Guidelines is to protect the aquatic environment by setting safe levels for metals, nutrients (substances which promote the growth of algae) and organic compounds. The guidelines replace the Ministry's 1976 Open Water Disposal Guidelines. Those guidelines originally were developed to determine whether or not dredged material was suitable for disposal in open water. Over time their use was expanded to include all aspects of sediment assessment. The guidelines are designed to help environmental managers - Ministry officials and environmental consultants - make decisions on a whole range of issues that affect the quality of sediment. For example, the guidelines will be used by RAP teams to determine which sediments are contaminated and how to manage the problem most effectively.

The guidelines establish three levels of effect - No Effect Level, Lowest Effect Level and Severe Effect Level. The Lowest Effect Level and Severe Effect Level are based on the long term effects which the contaminants may have on the sediment dwelling organisms. The No Effect Level is based on levels of chemicals which are so low that no contaminants are passed through the food chain. The levels of effect are designed to help environmental managers determine:

- when sediment may be considered clean;
- what levels of contamination are acceptable for short periods of time while the source of the contamination is being controlled and cleanup plans are being developed;
- what levels of contamination are considered severe enough to consider the possibility of either removing the sediment or covering it with a layer or two of cleaner sediment. This is called capping.

The three levels of effect are:

The No Effect Level - This is the level at which the chemicals in the sediment do not affect fish or the sediment-dwelling organisms. At this level no transfer of chemicals through the food chain and no effect on water quality is expected. Sediment that has a No Effect Level rating is considered clean and no management decisions are required. Furthermore, it may be placed in rivers and lakes provided it does not physically affect the fish habitat or existing water uses - for example a water intake pipe.

The Lowest Effect Level - This indicates a level of contamination which has no effect on the majority of the sediment dwelling organisms. The sediment is clean to marginally polluted. Dredged sediments containing concentrations of organic contaminants - PCB's or pesticides for example - that fall between the No Effect Level and the Lowest Effect Level may not be disposed of in an area where the sediment at the proposed disposal site has been rated at the No Effect Level or better. Contamination in sediment that exceeds the Lowest Effect Level may require further testing and a management plan.
The Severe Effect Level - At this level, the sediment is considered heavily polluted and likely to affect the health of sediment dwelling organisms. If the level of contamination exceeds the Severe Effect Level than testing is required to determine whether or not the sediment is acutely toxic.


Abstract - This report of an investigation of Bluewater Creek, Montana, a stream greatly influenced by agricultural practices, considers the relationship between stream discharge and sediment concentrations and their subsequent effects on the intragravel apparent velocity (seepage rate) and intragravel oxygen supply to the developing trout embryos. There was progressive downstream increase in sediment concentrations at the five sampling areas in the stream. Man-made redds filled with gravel chips were placed in the vicinity of each sediment sampling station. The intra-gravel dissolved oxygen concentration rate and apparent velocity decreased progressively downstream in relation to the progressive downstream increase in sediment concentration. Accompanying this was a progressive increase in trout embryo mortality. These findings illustrate how agricultural practices such as overgrazing, brush and tree removal on floodplains and river banks, snag removal and channel realignment, row crop production on steep sloping land, and surface irrigation return water can introduce detrimental quantities of sediment into streams.


Abstract - The effects of sedimentation rates, stream discharge and water temperature were studied in Bluewater Creek, Montana. Trout of all ages were abundant where sediment concentrations or loads were low (range in daily load 0.2-11 tons) and stream discharge stable (range in mean daily discharge 10.012.0 cfs). Few trout were found where sediment concentrations or loads were high (range in daily load 2-1,800 tons) and discharge erratic (range in mean daily discharge 4-485 cfs). Water temperatures were higher than desirable for trout (above 80F for more than 3 hours on summer days) in areas of the stream influenced by irrigation surface return flow. The best survival of trout eggs (97% survival) was found where stream discharge was stable and sediment concentrations were low.


Abstract - A series of laboratory experiments have been conducted to determine the impact of suspended sediment on marine and estuarine invertebrates and fish. The experimental facility provided controlled and stable levels of suspended solids, temperature, salinity and dissolved oxygen in large aquaria with an open, once through flow of water.

Initial experiments screened a variety of species for sensitivity to suspensions of uncontaminated solids. Then the influence of temperature, dissolved oxygen and the interaction of these variables on the lethality of suspended solids to the more sensitive species was determined. These experiments, which established a basic knowledge of responses to suspensions of uncontaminated particles were followed by tests using suspensions of uncontaminated natural sediments. Current experiments with the same species are being conducted with contaminated natural sediment.

Results indicate many species are relatively insensitive to inert suspended solids. Sensitive species are more easily killed at water temperatures or if dissolved oxygen is reduced. The combination of summer temperature and lowered dissolved oxygen is particularly stressful. However, under most conditions
suspended particles themselves are lethal only at concentrations higher than normally created by
dredging operations, with important possible exceptions. The effects of suspensions of
uncontaminated natural sediments do not seem to differ significantly from those of inert clay
minerals. Experiments with contaminated natural sediments indicate a much greater potential for
adverse impact than would be associated with uncontaminated sediment.

25) In R. A. Baker [ed.], Contaminants and Sediments, Volume 1: Fate and Transport, Case Studies,
Ann Arbor Science, Ann Arbor, Michigan.

Abstract - This chapter deals with the direct effects of suspension of relatively uncontaminated and
relatively contaminated sediments on marine macroinvertebrates. Mortality and tissue accumulation
of contaminants were the primary topics of investigation. The exposure times and suspended
sediment concentrations producing mortality or tissue accumulation of contaminants are discussed in
relation to conditions created by typical dredging operations.

These experimental results, assessed in light of the literature reviewed for this study, lead to the
following conclusions:

1. Ecological degradation due to the direct or indirect effects of typical suspended sediment conditions
created in the water column by most dredging or disposal operations is unlikely. Water column
suspended sediment levels created by most such operations are lower than lethal levels and exist for
times far shorter than lethal exposure times for most adults and larvae. Coral reef communities may
be an exception to this generalization.

2. Fluid muds have the potential for producing conditions of high suspended sediment concentration and
low dissolved oxygen for periods sufficient to cause mortality of a variety of organisms. This
potential exists in uncontaminated fluid muds and is increased in contaminated fluid muds. Whether,
and to what extent, this potential is actually realized at a particular site will depend on the occurrence
and areal distribution of the fluid mud; its suspended sediment and dissolved oxygen concentrations;
contamination status; persistence; and whether it covers susceptible species. Fluid mud can have
substantial acute impacts of finite duration on relatively immobile benthic infauna and epifauna.
Fluid mud may be created on the bottom by pipeline disposal (and perhaps by hopper disposal) of
hydraulically dredged, fine grained sediment and is unlikely under other conditions.

3. Tissue accumulation of contaminants even from contaminated sediments was the exception rather
than the rule in the present study. That uptake that did occur was seen only after days of exposure to
suspended sediment concentrations in the tissues to levels only a few times higher than in the
sediment.

4. Suspensions of contaminated sediment are potentially more harmful than uncontaminated sediments,
but even so, lethal conditions are unlikely to be created in the water column by most typical dredging
or disposal operations. Contaminated fluid muds are of more concern than either uncontaminated
fluid mud or water column suspension of contaminated sediment as discussed above.

solids on San Francisco Bay organisms. Appendix G In Dredge Disposal Study, U. S. Army
Engineer District, San Francisco, California. 158 p.


Abstract - This investigation was to study the interaction of environmental contaminants (defined as substances not formed biologically or naturally, and which are not normally indigenous to the water) on the microbial portion of the ecosystem. Particulate suspended materials (minerals and detritus) were examined on a physical and biological basis and characterized using differential and gradient centrifugation in conjunction with electron microscopy. Several characteristic fractions of suspended particulate material were examined for ability to influence biological reactions. The particulate fraction of water is important to microbial relationships in the area of interfaces and biological activity. It is known that particles and molecules in solution accumulate at interfaces (this includes chemicals which can either act favorably (nutrients) to organisms or unfavorably (pesticides) to organisms), and that enzymatic reactions are concentrated at membranous surfaces. Therefore, it is of significant importance to study the capabilities of non-biologicals that commonly end up in the waters on such colloidal or molecular interfacial systems.


Abstract - Research in the field is summarized. Sediment influences fish in several ways. In suspension, (1) it blocks the transmission of light reducing algae production, and (2) it damages the gill membranes causing death where concentrations are high and exposure is prolonged. When sediment settles on the gravel beds, it is harmful in the following ways: (1) it fills the interstices reducing interchange between surface waters and waters within the gravel bed. This reduces the supply of dissolved oxygen to the egg and interferes with the removal of metabolites (carbon dioxide and ammonia). (2) Sediment also forms a barrier to fry emergence by blocking the route of egress. (3) Low dissolved oxygen and the physical barrier effect of sediment appear to be additive in reducing survival. (4) Survival after fry emergence is impaired because of a loss of escape cover and a reduction of aquatic organisms that are food for fish. Examples are cited showing that pink and chum salmon survival is inversely related to the amount of sediment in gravel beds.


Abstract - Eight mixtures of sand and gravel were tested in experimental troughs, to simulate hatching conditions in coho salmon, Oncorhynchus kisutch, and steelhead trout, Salmo gairdneri, redds. Fry were released into perforated, open ended chambers below the gravel surface. An inverse relationship was found between the quantity of fines and emergent survival. Mean emergent survival for coho salmon ranged from 96% in the control mixture to 8% in 70% sand (less than 3.3 mm diameter). Mean emergent survival for steelhead ranged from 94% to 18% respectively. Premature emergence of coho fry was related to higher concentrations of fines. These premature fry were smaller and retained more yolk than fry emerging at normal times.


Abstract - The concentration of inorganic and organic suspended sediments is analyzed in seven streams subject to different cutting procedures. Skidding the logs across the streams maintains the concentration of the inorganic and organic fractions above 1000 and 500 mg/l respectively with maxima reaching 197 000 and 65 000 mg/l. The concentrations generally remain under 35 mg/l when the stream is protected by a buffer zone. This zone may be a strip of standing trees or a width of soil untouched by the skidders. Disturbances of small tributaries frequently increases the concentration levels in the main stream above 100 mg/l with maxima reaching 960 and 2030 mg/l for the inorganic and organic factions, respectively. The supplementary input of particulate matter becomes negligible one year after logging, except in Liniere stream. There is no direct relation between the width of the green strip and the input of suspended sediments. The best protective measure is the conservation of a buffer zone along all the watercourses. This strip of unperturbed soil should be about 10 to 15 m wide.


Levels of surface and subsurface fine sediment (< 4.75 mm in diameter) were measured annually from 1965 to 1985 in spawning and rearing areas for chinook salmon, Oncorhynchus tschawytscha, and steelhead, O. mykiss (formerly Salmo gairdneri) in the South Fork Salmon River, Idaho. Between 1950 and 1965, logging and road construction, in combination with large storm events of 1964 and 1965, resulted in the delivery of increased amounts of fine sediments to the South Fork Salmon River. Surface and subsurface fine sediment levels peaked at 46% of the surface area in 1966 and 48% of the volume in 1969 respectively. A logging moratorium initiated in 1965, coupled with natural recovery and watershed rehabilitation, led to significant decreased in the amounts of fine sediments delivered to and stored in the South Fork Salmon River; this reduction led to a limited resumption of logging operations within the watershed in 1978. By 1985, surface and subsurface sediment levels in chinook salmon spawning areas averaged 19.7% of the surface area and 25.4% of the volume, respectively. However, additional recovery to prelogging fine sediment levels is probably contingent on both further watershed recovery and the occurrence of flood flows capable of transporting material downstream. An equilibrium between incoming sediment from the watershed and outgoing sediment from the river appears to have been reached under flow regimes that have occurred since 1975.


Sedimentation of C, N and P from the water column was assessed during the ice-free seasons of 1986-91 in three northern Wisconsin lakes. Seasonal trends in mass sedimentation were different among lakes but consistent from year to year within each lake. High rates of nutrient sedimentation were associated with spring and fall blooms of large siliceous algae. Nutrient recycling, calculated as the difference between uptake during photosynthesis and loss to sedimentation, showed seasonal trends that were related to sedimentation. Recycling within the water column was the most important source of nutrients to primary producers, accounting for 85-90% of P demand during the summer stratified period.


A large portion of the four billion tons of soil eroded from our land annually is scoured from the beds and banks of natural channels that are dry much of the time. How are old channels to be improved and new ones built so that storm water can be accommodated without causing excessive erosion:

(i) Lining with grass
(ii) Drop structures
(iii) Lining with asphalt or concrete
(iv) Rock linings
(v) Use of reverse filters


Abstract - Total dissolved solids (TDS) and chlorophyll a were not related in 25 lakes which were all off the Precambrian Shield. Both on-shield and off-shield lakes were included in the previous report which showed a significant relationship between TDS and productivity. When data from on-shield and off-shield lakes were analyzed separately there was no significant positive relationship between TDS and lake biomass or productivity. It was also shown that mean depth was as good a predictor of fish production as the TDS: mean depth ratio, the morphoedaphic index.


Abstract - Yearling coho salmon, Oncorhynchus kisutch, and steelhead, Salmo gairdneri, were exposed to high (2-3 g/l) or low (0.4-0.6 g/l) concentrations of three kinds of suspended solids (topsoil, kaolin clay and volcanic ash) as long as 7-8 days. Such exposure did not cause mortality but plasma cortisol concentrations were temporarily elevated in both species after exposure to 2-3 g/l of suspended topsoil, indicating that such exposure may have been stressful to the fish. Feeding rates of both species were reduced at high exposure concentrations. Exposure of yearling steelhead for 2 days to high or low concentrations of suspended topsoil, kaolin clay or volcanic ash, induced similar elevations of plasma cortisol levels and, in groups exposed to high concentrations, blood hematocrits were increased. Osmoregulatory performance if fresh water and after transfer to 26% seawater was unaffected and gill tissue appeared normal, after exposure to suspended solids. Exposure of yearling steelhead to high concentrations of suspended topsoil reduced the fishes tolerance of subsequent infection by the bacterial pathogen, Vibrio anguillarum. These results suggest that coho salmon and steelhead can survive exposure to high concentrations of suspended solids, but may undergo sublethal physiological stress that reduces their performance capacity.


Abstract - This paper consists of an evaluation of methods to be used to measure suspended sediments or solids especially for monitoring programs. The author discusses how to deal with variation by comparing measured levels to background values. He also discusses what would be considered adequate sampling frequency, methods for determining particle size and effects of particle size on recovery of sediment in samples. He also analyzes methodology to determine suitable locations for sampling for suspended solids and suggests that further study is required to determine the relative effectiveness of various types of waste water sampling methods.


Abstract - Erosion on roads is an important source of fine-grained sediment in streams draining logged basins of the Pacific Northwest. Runoff rates and sediment concentrations from 10 road segments subject to a variety of traffic levels were monitored to produce sediment rating curves and unit hydrographs for different use levels and types of surfaces. Those relationships are combined with a continuous rainfall record to calculate mean annual sediment yields from road segments of each use level. A heavily used road segment in the field area contributes 130 times as much sediment as an abandoned road. A paved road segment, along which cut slopes and ditches are the only sources of sediment, yields less than 1% as much sediment as a heavily used road with a gravel surface.


Abstract - The regulation of streamflows can alter the natural regime of a system by removing peak flows and reducing the stream sediment transport competency. The net effect can be that sediment which is inputted to the system tends to accumulate rather than being periodically removed (flushed) as during spring runoff. The deposition and aggradation of sediments ultimately becomes a problem which it affects the biotic community. In this case, a release flow (flushing flow) which simulates high runoff events may be periodically needed to remove fine sediments from the stream.

The purpose of this study was to review and summarize existing information on flushing flows and to provide a better understanding of the physical and hydraulic parameters which respond to changes in flow and how they influence the aquatic biota. The actual need for a flushing flow should be based on the results of sediment monitoring studies (where possible) using appropriate field techniques. Once the need for a flushing flow has been established, it is important to determine the best time for its implementation. Important considerations include: (1) species of fish present in the system; (2) life history functions of important species; (3) historical runoff period; (4) project flow availability; and (5) water temperature.

Ideally, the most effective time for implementing a flushing flow is that which provides the greatest benefits to the biotic communities. Detailed species-life history charts should be developed and consulted to assist in the determination. The determination of the magnitude of flows is the most important and most difficult aspect of formulating a flushing flow recommendation. No single, standard approach has been developed for this purpose. Until methods are developed, evaluations today will need to utilize an approach tailored to the specific needs and characteristics of each stream and project. This may entail the use of several different office techniques to derive an initial flow estimate, followed by detailed field studies to refine and finalize the recommendation.

The most reliable method for establishing required flushing flow rates is to observe various test flow releases. Field observations such as the sampling and tagging of bed material, should be made before and after each release to determine the actual effectiveness. Flow releases may not be feasible on all streams.
However, where feasible, they provide the best results of all methods. Where test flow releases cannot be made, the use of methods based on sediment transport mechanics may be the most reliable approach for determining flushing flow rates.

An evaluation of the effectiveness of a recommended discharge for removing sediments should be a logical part of every flushing flow study. Through this process, actual, versus desired results can be compared and refinements made. This study reviewed 24 different techniques which could be used for assessing the effectiveness of the flows.

This study resulted in the development of the following guidelines for conducting flushing flow studies: (1) flushing flow studies should utilize an interdisciplinary team approach; team members should include at a minimum a hydrologic engineer and a fisheries biologist; (2) an initial determination of the actual need for the flushing flow should precede detailed assessments; (3) the assessment approach should be tailored to the specific needs and characteristics of each stream and project; office and field techniques both may be required; (4) for comparative purposes more than one method should be used for deriving flow recommendations; (5) flushing flow recommendations should be stated in terms of magnitude, timing and duration; (6) follow-up studies should be conducted to evaluate the effectiveness of the flow and allow for adjustments.


Abstract - We compared, in the laboratory, egg survival and alevin and fry size of steelhead, Oncorhynchus mykiss (formerly Salmo gairdneri) and chinook salmon, O. tshawytscha, after incubations in 16 mixtures of two distinct size classes of sediment. Fine sediments were less than 0.84 mm in diameter and coarse sediments were 0.84-4.6 mm in diameter. We incubated recently fertilized and eyed steelhead and chinook salmon eggs in Whitlock-Vibert boxes placed in controlled flow channels. Egg survival in both sediment types was inversely related to the percentage of sediments within the incubation gravel; the poorest survival occurred in fine sediments. Percentage egg survival was positively related to intragravel water velocities, which ranged from 36 to 1,550 cm/hour. No definitive relationship was found between sediment size and concentration and alevin and fry quality. Overall, our results indicated that different sizes and mixtures of sediment can affect egg survival differently. The results confirmed that it is the smaller sediments (< 0.84 mm) that are the most detrimental to incubating eggs.


Abstract - The construction of linear facilities increases the sediment load of streams in the area. This effect becomes acute in the case of stream crossings. Fish are directly and adversely affected by the increase in undissolved solids. Under laboratory conditions the onset of direct mortality has been observed at concentrations as low as 90 ppm while 50% of the specimens of one species (coho salmon) failed to survive 36 hours at concentrations of 1250 mg/1. It has been demonstrated that fish exposed to levels of suspended solids, below those found to be lethal, have reduced oxygen uptake and impaired swimming ability. Furthermore increased sensitivity of fish to suspended solids under conditions of oxygen deprivation and susceptibility to predation while under stress have been reported. Increased sediment yields result primarily from the destruction of vegetation thereby increasing surface wash and gullying activity. In
permafrost regions thermokarst activity is an additional problem. Increased sediment yield may also result from physical damage to the ground surface in the form of, for example, increased surface soil compaction and increased surface run-off, or the churning and dislocation of soils by vehicles leading to increased erodibility or the oversteepening of slopes leading to increased probabilities of mass movements and river bank slumping. No quantitative studies dealing specifically with the geomorphic effects of such activities at stream crossings were found in the literature. However, studies of the effects of construction activities in temperate regions suggest that slope sediment production may increase by as much as two orders of magnitude in disturbed areas. Various control measures will undoubtedly reduce the total amount of sediment entering the stream at the site of the crossing but the effectiveness of these measures does not appear to have been examined systematically.


Abstract - During the summers of 1982, 1983 and 1985, we assessed the effects of placer mining sedimentation on Arctic grayling, Thymallus arcticus, in the headwaters of Birch Creek, northeast of Fairbanks, Alaska. We compared differences between two streams (one that was undisturbed and one with mining activity upstream) near the confluence. Studies of caged fish demonstrated that, if grayling could not escape from streams carrying mining sediments, they would either die at high rates (sac fry) or suffer gill damage, starvation and slowed maturation (age-0 fingerlings and age-2 juveniles). Indirect effects of sedimentation, through loss of summer habitat for feeding and reproduction, may more severely affect grayling populations than the direct effects of sedimentation on the health and survival of individual fish.


Abstract - All reservoirs are destined to be filled with sediment. As deposition depletes the storage space, the benefits that a reservoir is able to provide are reduced. The rate at which the total storage space is depleted is only a portion of the problem. Since different elevations are allocated for different purposes (flood control, power production, irrigation, navigation, etc.), it is important for those charged with the responsibility of planning and regulating reservoirs to know how the trapped sediment will be distributed over the planned economic life. In the past, several methods, both theoretically and empirically derived, have been developed to predict this distribution. Their general application as a predictive tool is extremely limited.

In order to develop a methodology which has widespread applicability for predicting the distribution of sediment, the physical processes responsible for the patterns of deposition are used as the common denominator. These processes, to include reservoir operation, particle settling as related to size fraction, erosion in dewatered areas, consolidation, etc., affect sedimentation in relatively the same manner in all
reservoirs. The processes are delineated and the complex interactions of the dominant processes are simulated using a computer model. Given the reservoir geometry (topographic survey), the water inflow versus outflow (reservoir operating rules) and expected sediment inflow, the model will provide a reasonable approximation for both the amount of sediment entrapped and the location of the sediment within the reservoir for the period.


Abstract - Vertical distribution of sediment (particle diameter < 3.33 mm) and organic debris was studied in coho salmon, *Oncorhynchus kisutch*, redds in three Oregon coastal streams subjected to different degrees of logging. Gravel composition in frozen cores varied significantly among redds in both logged streams. Sediment content in redds appeared to decrease with depth in the logged streams but differences in gravel composition among streams obscured differences among depths. Sediment layers of variable thickness were visible in several core samples. In one logged stream, redds contained an average of 25% less sediment than redds used one year earlier. Organic content of the gravel represented < 2.8% of the core samples by weight and was directly related to the quantity of sediment in the streambed. The pattern of vertical distribution of organic debris in the clearcut stream (most abundant near the surface) differed significantly from that in the other two streams. Patterns of distribution and variability in gravel composition were consistent with post-logging changes in gravel permeability and survival to emergence of coho salmon.


Abstract - Quantitatively, sediment is the greatest single pollutant in the nation's water. Its affects on aquatic ecosystems are many and varied. For example, sediment may affect fish or shellfish either by damaging the organisms physically or biologically or by damaging the habitat in which the organisms live.

Wallen (1951) found that fish could tolerate turbidities up to 100 000 parts per million for a week or longer but the same fish died in turbidities above 175 000. Ellis (1937) studying fish and freshwater mollusks in turbid waters, observed the same phenomenon. In both cases, sediment clogged gills ceased to function as oxygen exchange sites; with decreased aeration of the blood the fish died from a combination of anoxemia and carbon dioxide retention. Pautzke (1937), studying the effect of coal washings on trout, found that within 2.5 hours all fish in the washings died while a control group of fish in water from the same mine remained alive. Heavy secretions of mucus covered the gills and bodies of the dead fish. The gills were faded in color and blood vessels in the liver and heart "stood out, giving a hemorrhagic appearance in both organs." Kemp (1949) noted gill damage from turbidity and considered 3,000 ppm dangerous. He also attributed a large fish kill and damage to oyster beds on the Potomac River after a flood in 1936 to turbid waters.

Herbert and Merkens (1961) noted little effect of turbidity on trout at 0, 30, and 90 ppm but more than half of the fish died when turbidity reached 270 and 810 ppm. Histological examination showed lesions and thickening of gill tissue in most of the fish. After 148 days, the two scientists removed half the fish remaining in the water with 270 ppm turbidity and put them in water with 1 000 ppm turbidity for 9 months. They concluded that no definite relation exists between the period of survival of fish and their exposure
to high concentrations of suspended material. They did note, however, that more fin rot developed at higher turbidities and Paul (1952) noted mechanical abrasion to fish due to turbidity. These abrasions caused the fish to be more susceptible to micro-organism infections. Direct physiological damage to fish as a result of turbidity under natural conditions is limited since fish can withstand high turbidity for short periods and can move to areas of lower turbidity. However, turbidity creates an added physiological stress which makes the fish susceptible to infection by disease-causing micro-organisms.

Sediment and/or turbidity damage aquatic ecosystems in a number of ways:

1. Reduction of light penetration by sediment is marked. This light reduction can inhibit photosynthesis leading to a decline in food in the aquatic ecosystem and thereby limiting its carrying capacity.
2. A reduction in oxygen in water directly due to turbidity has not been exhibited experimentally or with field data but decomposition of organic matter frequently deposited with sediment used dissolved oxygen thereby effectively reducing the oxygen content in water.
3. Sediment reduces the survival rates of eggs and alevins dramatically. Hassler (1970) reported 97% mortality among northern pike eggs covered with 1 millimeter of silt. Sediment reduces percolation, thereby reducing the oxygen supply around the eggs. Emergence of fry from streambed redds also is restricted by sediment.
4. A reduction in the number and kind of bottom organisms due to sediment is most noticeable among shellfish. Ellis (1936) reported a freshwater mussel population was eliminated by sediment covering the beds. Mansueti (1961) estimated that sedimentation had destroyed one-half of the fish and oyster spawning grounds in the upper estuary of Chesapeake Bay. Oysters, hard clams and blue crabs need to attach to firm bottoms, free from heavy mud. Reductions in the insect fauna of stream bottoms and of bottom-growing plants have been related to sediment and also to fish population reductions.
5. Turbidity reduces the ability of fish to find food but it may also allow young fish to escape predators.
6. Reduction of depth and duration of streamflow due to erosion and sedimentation reduces the number of habitats for fish and reduces the amount of shelter in trout streams thereby effectively limiting trout populations.

Sediment may also affect other ecological parameters such as temperature and water quality. All combine to exert stress on fish populations which can reduce or change these populations. A few examples of these changes include:

1. A study of 13 sediment polluted streams and 10 unpolluted streams (clear) in England showed an average of 2-5 fish per 1,000 feet in the polluted stream and 16-27 fish per 1,000 feet in the unpolluted stream.
2. In Lake Erie, the fish population has changed from discos, whitefish and yellow perch to sauger, sheepshead, catfish and carp partly because of the increase in sediment.
3. Change from game fish to "less desirable types" in the fish fauna of the Midwest has been attributed to sediment.
4. The Forest Service estimates that a clean stream with spawning gravel in Alaska is worth about $131,000 per acre for salmon production while a sediment polluted stream is worth $26,000 per acre.
Sediment does affect the fish and shellfish fauna of aquatic ecosystems. Under most conditions the ecological effect of sediment on aquatic ecosystems is probably greater than the physiological effect of sediment on fish. But the combination of ecological and physiological effects creates an additional stress on fish populations which tends to change these populations either in number of in dominant fish species thereby altering original aquatic ecosystems.


Abstract - Effective sediment ponds can be built in depressions or on shallow soil areas at minimum cost to a farmer if he uses his own equipment during slack work periods. The sediment can be used to improve the land's topography and value. Despite these benefits however trapping sediment in man made ponds must be considered a short term or emergency measure. Solution of the sediment problem over the long term depends on effective conservation treatment at the sediment source.


Abstract - To better understand the complex ecological relationships within waterfowl marshes, a vegetation production study was initiated in the Bear River marshes during the summer of 1959. Vegetation and water samples were collected from 42 sampling sites. Strong correlations were found between vegetation production and water depth, water depth and turbidity, and turbidity and vegetation production. Deeper waters were observed to support larger crops of aquatic vegetation. These deeper waters also contained less suspended matter. Water depth at the delta of the Bear River is a significant factor to be considered in the management of the local marshes for the production of the greatest amount of aquatic waterfowl food.


Abstract - Sediment, as a pollutant, has a two fold effect on the environment. It depletes the land resource from which it comes and impairs the quality of the water resource in which it is entrained and deposited. Sediment may also act as a scavenger, sorbing other pollutants, such as agricultural fertilizers and
pesticides, from solution and depositing them in stream channels or reservoirs. In some cases this may be beneficial; in others it may concentrate pollutants with harmful repercussions.

With improved technology sediment yields can be reduced but it is virtually impossible to reduce erosion to the extent that sediment in streams, lakes, reservoirs and valleys would no longer be a problem. Unless a stream flows in a nonerodible channel, the stream will attempt to transport sediment up to its energy ability, and it may erode its bed or banks to obtain this material. Man's challenge is to reduce erosion; control the energy of streamflow; and create, where possible, nonerodible stream boundaries.


Abstract - Two channels built into the Harris River, Northwest Territories, were used to study responses of invertebrates to sediment addition. Sediment was added to one channel continuously for approximately 5 h. The other channel was used as a control. In August, 28.27 kg of sediment or 1.38 kg/m² of channel bottom were added. Values for September were 35.88 kg or 1.53 kg/m².

As a result of sediment additions, numbers of macrobenthos drifting from the sediment addition channel (S) increased significantly over those drifting in the control (C) in August (= summer) and September (= fall). Total drift from S was > 3 times higher in August and > 2 times higher in September than from C. Significantly higher numbers of macrobenthos drifted in fall than summer. Numbers of macrobenthos drifting during sediment addition were significantly related to time in September but not in August, indicating a seasonal difference in temporal response to sediment addition. Two explanations are proposed for the response of the September community, as indicated by shape of a polynomial regression curve, to sediment addition. No significant difference existed in standing crops of macrobenthos in the substrate in C and S after sediment addition.
Sediment addition caused (1) higher numbers of Oligochaeta and Simuliidae to drift in August and September; (2) higher numbers of Plecoptera and Ephemeroptera to drift in September but not in August; and (3) higher numbers of Hydracarina and Chironomidae to drift in August but not in September.

We suggest that future work try to relate amounts of settled rather than suspended sediments to quantitative responses of stream macrobenthos. We recommend that highway and pipeline construction undertaken in watersheds of Mackenzie Valley streams during the open water period, resulting in sediment addition to these streams, should be done during summer rather than spring or fall, providing river discharge is adequate to transport the added sediment.


Abstract - The effectiveness of a "brush mulch" to control erosion and sediment at road-stream crossings was evaluated by measurement and comparison of upstream and downstream suspended sediment. The brush mulch consisted of logging debris, such as branches, tree tops and logs 2-15 cm in diameter laid on the ground to intercept and to slow overland flow and to trap sediment. Two treatments were defined and tested. Treatment number 1 was a brush mulch and grass-fertilizer mixture applied by hydroseeding to three bare soil road-stream crossings. Treatment number 2 was a grass-fertilizer mixture applied by hydroseeding to another three road-stream crossings.

Total seasonal and storm sediment production for mulched and unmulched crossings averaged 31 and 37, and 566 and 2297 kg/day/ha, respectively. Tests showed significant differences between treatments for both seasonal and storm sediment production. The levels of significance were low because of high variability in sediment production among treatments and road crossings. Frequent on-site inspections during storm and nonstorm conditions, however, identified sources of variability and supported a final conclusion that the brush mulch was effective for erosion and sediment control at road-stream crossings.


Abstract - The uniform settling velocity attained sooner or later by a falling particle depends upon the resistance offered by the settling medium. For small particles this resistance in turn depends chiefly upon the viscosity of the fluid but for large particles it appears to be controlled almost entirely by impact. Small rounded quartz grains (very fine sand and silt) fall through water with the velocities given by Stokes' law of viscous resistance but coarse sand, pebbles and boulders follow a totally different law.

Granting certain assumptions about the deflection of water, the impact of a rising current required to support a pebble can be deduced theoretically. Published data on settling velocities seem to confirm this deduction and they also suggest the approximate equivalence of these settling velocities to the velocities required to transport pebbles along the bed of a stream (of either water or air).
Stokes' law and the impact formula may be combined very simply into a general equation for the settling velocities of large and small grains. This general equation, which contains no empirical constants, accords very closely with published data on quartz grains but not so closely with data on fragments of galena.


Abstract - Literature pertaining to sediment in stream ecosystems is reviewed. Suspended sediment can alter the water chemistry and cause temperature decreases and turbidity increases. Deposition of sediment may change the character of the substrate, block interstices and reduce interstitial volume. Turbidity levels as low as 5 NTU can decrease primary productivity by 3-13%. An increase of suspended sediment levels increases the drift fauna and may reduce benthic densities as well as alter community structure. Fish are not so obviously affected, although death resulting from clogging of the gills may occur in sensitive species. Suspended and deposited sediment may alter fish community composition, both by interference with run-riffle-pool sequences and by favoring olfactory feeders over visual feeders. In many situations aesthetic reactions to suspended sediment may be of more concern than biological ones. In already turbid water, a 20-50% reduction in clarity may not be detectable whereas in normally clear water a clarity reduction of 10-15% is distinguishable. Recovery from the effects of suspended sediment and sediment deposition is usually rapid, once the source of contamination is removed and as long as the stream is prone to regular spates; the aesthetic recovery may only take days whereas biological recovery may take months.


Abstract - All facts when ordered and synthesized with previously published information suggest that light is the principal abiotic controlling variable of the environment that determines temporal and spatial dimensions of feeding and reproduction in the walleye, Stizostedion vitreum vitreum. Underwater observations during the day revealed that adult walleyes were active in turbid regions of a lake but rested in contact with the substrate in clear water regions. In the latter instance physical shelter served to shield the eyes of the walleyes from the ambient light. An inverse relation was noted between numbers of walleyes sighted per hour of transect swum and transparency levels of the water. In experimental angling during the open water season, the total number of walleyes captured and the catch per unit of effort were positively related to illuminance levels. Winter angling through the ice showed a similar relationship, though at percentage light transmission levels one order of magnitude lower. Percentages of walleyes captured per 1/2 hour increment during open-water at dusk were positively related to percentage decrease in illuminance for the same time intervals and inversely related to absolute levels of illuminance. Other authors have determined the nuptial activity also, and hence reproduction, is governed by variations in the ambient light regime.


Abstract - Rivers and lakes have many physical, chemical and ecological features that may be readily compared or contrasted. Rivers integrate erosional and depositional habitats, the former typically occurring in sections where rapid flow prevails, often in the narrow, upper reaches, while deposition of silt and detritus occurs in regions of slow current. Material input and transport capacity must be in dynamic equilibrium if the stream bed is neither to erode nor to accumulate debris or silt. Overall, lakes are more stable physically and, in general, their shorelines are eroded more slowly than are the banks of rivers.
While the causative factors in natural river bank erosion are primarily water current and changing water levels, shoreline erosion of lake shores is largely due to wind-induced waves.

The lotic environment is typically more turbid than the lentic environment. Turbidity levels vary from headwaters to mouth, from river to river, and temporally within any stream. The muddy-bottomed, downstream areas where the mean particle size of the substrate decreases are generally the most turbid except for glacial streams. Turbidity at high levels may represent an environmental stress. Improper land use management, resulting in increased rates of erosion, is often the culprit. The consequences or excessive turbidity are as follows: (1) reduced light penetration and therefore reduced photosynthesis; (2) altered water chemistry; (3) altered physical habitat; (4) injuries to biota; (5) reduction in standing stocks of benthos; and (6) hindered reaeration. Turbidity is likely to be more critical in rivers than in lake because of the vulnerability of the former habitat to rapid changes in water levels and bank undercutting. The most successful river biota, however, have responded over time by physiological adaptation, or by the development of special structures that enhance sight,


Abstract - Investigations were initiated to evaluate the effects of sedimentation on the algal composition, primary productivity rates and chemical nutrient concentrations of a 17 acre recreational impoundment in central Virginia. Comparisons during the winter seasons of 1972-1973 indicated that as a result of sedimentation, from lake front home construction, the total numbers of algal genera in the lake decreased from 24 to 16, productivity as measured by 14C02 and total extractable chlorophyll decreased two fold and several important nutrients increased significantly.


Abstract - Use of bark as a mulch on seeded areas offers an outlet for large amounts of this timber mill residue. Experiments at five locations in southern West Virginia showed that bark compares favorably with straw and wood fiber mulches for stabilizing soils on disturbed sites. Based on findings from the five experiments, bark applications of 30 and 50 cubic yards per acre are recommended. Slopes steeper than 2:1 and those facing south and west need the heavier application, as do sites exposed over winter. The experiments also demonstrated that improved equipment is needed to apply bark mulch efficiently.


Abstract - Low standing crops of brook trout, Salvelinus fontinalis, were closely associated with siltation in Ellerslie Brook, Prince Edward Island, and appeared to result from the destruction of hiding places. Spawning was also curtailed by silting. Following scouring, trout stocks soon increased. The remarkable adaptability of trout to silting, in a habitat with favorable flow and water temperature was illustrated.

Abstract - Proposals to extend commercial shipping in the St. Marys River (connecting Lakes Superior and Huron) to include winter months have raised concerns regarding its effect on lake herring, Coregonus artedi. Because lake herring spawn in the fall and their eggs overwinter in the river and hatch in spring, their hatching success could be impacted by early opening of the locks in spring. Our laboratory studies showed that, under the range of turbidities expected in the river due to vessel traffic, lake herring eggs hatched and larvae fed adequately. Field incubation studies produced about 75% survival and 70% hatching success of lake herring eggs at two of three study sites. Collections in the river throughout the month following ice-out showed that sufficient plankton of appropriate size were available to ensure growth and survival of larval lake herring. We did not detect any negative impacts on the early life stages of lake herring as a result of sedimentation in the laboratory or field. However, detailing the spawning sites of lake herring and defining the normal survival to hatch in these areas are necessary before making accurate predictions of the effects of early season vessel traffic on lake herring hatching success.


Abstract - A slot mulch method of tillage and residue management is being developed to control runoff and erosion on land where infiltration is restricted due to frost or soil characteristics. Soil slots, installed approximately on the contour, are filled with crop residues to prevent freezing, surface sealing and lateral flow. Field trials, infiltration tests and theoretical analyses all show the method has potential for increasing infiltration and reducing erosion.


Abstract - The effect of placer mining effluents on Arctic grayling fingerling and egg survival was tested in mined and unmined streams in interior Alaska. Also the influence of turbidity on Arctic grayling reactive distance and avoidance behavior was tested in a laboratory choice chamber. Arctic grayling fingerlings suffered less than 1% mortality during a 96 hour toxicity test in both clear (mean NTU = 1.4) and mined (mean NTU = 445) streams. Arctic grayling eggs did not show significantly (P > 0.1) higher mortality in mined streams than in unmined streams. In a laboratory choice chamber test, Arctic grayling avoided water with a turbidity above 20 NTU. Arctic grayling reactive distance diminished proportional to the natural logarithm of turbidity.


SCHUBEL, J. R. 1968a. Suspended sediment of the northern Chesapeake Bay. Technical Report 35, Chesapeake Bay Institute, Johns Hopkins University, Baltimore, Maryland.


**Abstract** - Yellow perch and striped bass eggs were incubated in suspensions of different concentrations of natural, fine-grained sediments. The results showed that in the laboratory concentrations of up to 500 mg/l did not significantly affect the hatching success of yellow perch or striped bass eggs, but that concentrations of 1000 mg/l did significantly affect their hatching success.


**Abstract** - The objectives of the studies at Carnation Creek were to assess the effects of current forest harvesting practices on the composition and quality of spawning gravel and their influence on the survival or condition of emerging fry. Fines increased in the deeper layers of the streambed below the area of intense streamside logging. The larger the fine particles and the deeper their penetration, the slower their rate of cleaning. Egg to fry mortality increased as accumulating pea gravel and sand reduced the mean particle size of materials in the streambed. Sources of sediment included landslides, road surfaces and eroding streambanks. When the length of sediment impacts increase, the probability of natural regulators occurring also increase.


Abstract - A model consisting of a farm enterprise budget generator, a hydrologic model, and a matrix generator was used to address several questions in a specific watershed: How much subsidy would be required to induce farmers to adopt conservation tillage crop production systems? How large a tax on conventional crop production systems would be required to render those systems less profitable than systems that conserve more soil or create less stream pollution? How would adoption of conservation tillage practices offset stream sedimentation? What effects would restricting stream sedimentation from farming operations have on income? What are the potential tradeoffs between stream pollution and farm income? Results indicate that subsidies, taxes and the imposition of sediment restriction all could reduce stream pollution. There would be large differences, however, among these approaches in costs, stream pollution, soil loss and farm incomes.


Abstract - Ammonia and suspended sediments occur together in many aquatic environments but there is no published information on their combined toxicity. The purpose of the work reported herein was to examine the acute lethal toxicities of mixtures of Fraser River sediments and ammonia to juvenile chinook salmon, Oncorhynchus tshawytscha.

The 96 h LC50 for juvenile chinook salmon exposed to ammonia at 7.0°C was 0.45 mg/l un-ionized NH3 with 95% confidence limits of 0.43 to 0.47 mg/l. Juvenile chinook salmon appeared less tolerant to ammonia than rainbow trout or coho salmon but this observation may have been associated with the lower bioassay temperature.
The 96 h LC50 for juvenile chinook salmon exposed to suspended sediment was 31 g/l at 7.0C with 95% confidence limits from 29 to 33 g/l. Juvenile chinook salmon tolerated nearly twice as much suspended sediment as sockeye salmon.

The possibility that acute toxicities were additive was examined. Our results indicate that the combined toxicity of ammonia and suspended sediment is less than additive.


**Abstract** - Tolerance of underyearling coho salmon, *Oncorhynchus kisutch*, to Fraser River suspended sediments (SS) at 7C was independent of season of the year. However, coho of 0.52 g (4.0 cm) possessed only 35% of the tolerance of larger specimens. Tolerance to SS was temperature dependent with 96 h LC50 at 1 C and 18C being 47 and 33% respectively of the value at 7C. Tolerance was further reduced among underyearling coho which were later found to have a viral kidney infection. Cough reflex, oxygen transfer, oxygen saturation levels, metabolic rates and capacity to do work all probably affect the relationship between SS tolerance and temperature.


**Abstract** - Underyearling coho salmon, *Oncorhynchus kisutch*, were exposed to sublethal concentrations of Fraser River suspended sediments (SS) in the laboratory. Comparisons with other rivers indicated that Fraser river sediments caused the lowest turbidity for a given SS value. Blood sugar levels (y) were elevated and directly proportional to SS exposure (x) according to $y = 5.79 + 4.23(x)$. Published blood sugar data for adult sockeye salmon (*O. nerka*) exposed to Fraser River SS were in agreement with the linear relationship for underyearling coho. Cough frequency was elevated approximately eightfold over control levels at 0.24 g SS/L. No increase in cough frequency was observed at 0.02 g SS/L. Avoidance was defined by movement to the surface to escape higher SS at depth. Mean avoidance (y) was related to SS by $y = 0.077 + 4.457(x) - 1.547(x^2) + 0.202(x^3)$. Mean avoidance was less than 5% up to the inflection point at 2.55 g SS/L but rose to approximately 25% at 7.0 g SS/L. Laboratory results indicated that sublethal responses could be expected at naturally occurring SS levels in the Fraser River.


Abstract - Sediment was artificially added to a small southeastern Alaskan salmon stream. Observations in sedimented and control riffles indicate that the amount of sediment settling to the stream bottom decreases exponentially with distance downstream. The dissolved oxygen content of intragravel stream water remained high in sedimented riffles. The added sediment was removed from streambed gravels by fall freshets and floods.


Abstract - Salmon eggs hatched in the usual manner by placing a basket of eggs in the flowing water of a hatchery trough produced a yield of 79.9% fry with 733 temperature units. Salmon eggs placed in prepared gravel beds constructed in a hatchery trough and receiving only normal hatchery water produced a maximum yield of 25.4% and an average yield of 16.2% fry. Occasional silting of the water supply due to storms may have lowered the yield. To first emergence from the gravel 992 temperature units were required. Salmon eggs in prepared gravel beds that received mining silt for intervals of 2 to 72 days beginning with the initial stages of incubation produced a maximum yield of 2.4% and an average yield of only 1.16% fry. A total of 1385 temperature units were required to first emergence from the gravel. Many of the undeveloped eggs remaining in the gravel were preserved with a coating of silt. Fry that died or failed to emerge outnumbered those that worked through the gravel. Salmon eggs in prepared gravel beds that only received mining silt during the emergence period produced a yield of 13.4% fry but earlier silt additions extending back into the incubation period produced progressively lower yields which reached zero with silting at the beginning of the incubation period. In this series, the number of undeveloped eggs that were coated and preserved with silt increased steadily with earlier and longer periods of silt addition. Very few fish that hatched failed to emerge but many fry apparently worked forward through a screen rather than upward through the gravel and deposited silt.

From the data presented in this paper it is evident that the yield of fry from eggs hatched in gravel beds supplied with normal hatchery water is far below that attained by the usual procedure of basket hatching in flowing water. The experiments further show that mine silt deposited on gravel spawning beds during either the early or later stages of incubation results in negligible yields of fry and is therefore a serious menace to natural propagation.

From a practical standpoint this damage to spawning beds would occur when mining silt enters a stream at times other than storm periods when the water velocity is insufficient to carry the sediment in suspension. It is a well known fact that the velocities necessary to dislodge deposited particles are far greater than the velocities required to carry the same particles in suspension. For this reason natural stream turbidity is largely limited to those periods when storm water causes erosion. During these periods stream flows in areas suitable for steelhead, trout or salmon spawning are sufficient to prevent bottom deposits of natural erosion silt and damage to eggs in the gravel is minimized. Thus, while mining silt may be natural material, its presence in waterways during non-erosion periods results in bottom deposition which is unnatural and damaging.
From the data presented, it is apparent that adequate control to prevent the discharge of mining silt where spawning grounds may be affected is essential to the preservation of normal fish populations and legislation to secure the necessary protection is therefore recommended. This recommendation applies only to protection of spawning grounds as the studies did not include the effect of suspended silt on fry after emergence above the gravel. However, irrespective of whether fry and adult fish are injured by silt in suspension, the damage to domestic, agricultural, industrial and recreational water uses from high turbidity is sufficient to justify a reasonable but adequate control. To secure such control, not only on mining but on pollution from varied sources, the authors suggest that a state agency with authority to act with respect to all water values and uses above mentioned would be desirable. In this way the public could be assured of proper action on complaints and violations rather than being referred from agency to agency having different jurisdictions as now happens.


Abstract - This bibliography summarizes the physical, chemical and biological effects of roads on aquatic ecosystems. Although major emphasis is placed on the aquatic environment, impacts on the terrestrial environment are also listed. Road have the greatest effect on the aquatic environment through suspended sediments and sediment deposition. Both direct physical damage to biota and indirect effects such as habitat changes are considered. Since the effects of sedimentation from mining, dredging, channelization and logging have been most exclusively studied, many of the papers selected have been drawn from these areas.


Abstract - We collected samples of runoff water from four Tennessee watersheds subjected to various cropping, tillage fertilization and/or waste disposal practices over a three year period. Among the quality constituents we examined were nitrates, phosphates, chlorides, dissolved solids, sediment, suspended matter, turbidity, biochemical oxygen demand, dissolved oxygen, fecal coliform and 13 selected metals. Concentrations of most of the constituents in runoff water were generally low. Highest concentrations were usually associated with high antecedent rainfall and the absence of vegetative cover.


Abstract - Fall chinook salmon eggs in an Abernathy incubation channel suffered as much as 85% mortality when 15 to 30% of the voids in the gravel beds were filled with sediment. With one 70 foot section of the channel used as a silt settling basin, the mortality was reduced to 10% or less. We believe that a siltation control system consisting of a flushable sand trap and settling basin constitute the most economical means of reducing the amount of sediment entering this and similar channels.


Abstract - The time dependent flow and dispersion of suspended sediments in the western basin of Lake Erie are being studied by means of numerical models utilizing data from remote sensing studies and flume experiments. Mechanisms of sediment dispersion included in the models are convection and turbulent diffusion, river loading, gravitational settling and physical resuspension and deposition at the sediment-water interface. The time dependent currents are computed by means of a free surface
hydrodynamic model. A wave hindcasting model is used to compute the wave parameters needed for estimation of shear stress generated at the sediment-water interface under given wind conditions. The rate of sediment resuspension as a function of bottom shear stress and sediment properties is based on data from flume experiments using lake sediments. A series of numerical calculations with the models were performed on a two-dimensional lake with a variable bottom representing a transverse cross section of Lake Erie. It was found that wind direction and fetch length can significantly affect the sediment dispersion patterns. The two dimensional and three dimensional models were both used to simulate realistic short-term events in Lake Erie and the model outputs compare favorably with the synoptic surface sediment dispersion patterns deduced from the multispectral scanner data.


Abstract - Streambed samples from known bull trout spawning areas in four tributaries to the North Fork of the Flathead River, Montana, demonstrated that spawning areas in one of the tributaries (Coal Creek) contained significantly higher percentages of fine sediment than the other three tributaries. Bull trout embryo survival and subsequent fry emergence success was highly correlated ($r^2 = 0.87$) to the percentage of material less than 6.4 mm within the streambed of Coal Creek. A significant correlation ($r^2 = 0.40, P < 0.001$) was found between substrate score and densities of juvenile bull trout (fish longer than 75 mm) in 26 Swan River tributary reaches. Increase in estimated sediment loads attributed to road development (expressed as percentage over natural) was significantly correlated ($P < 0.001$) with three different expressions of substrate composition (substrate score, percentage of material less than 6.4 mm, and percentage of material less than 2.0 mm) for 46 Swan River tributary reaches.


Abstract - Composition of gravel was measured in selected pink salmon spawning riffles in several streams in southeast Alaska, one stream in Yakutat, and one stream in Prince William Sound, during the period 1963-1971. Over 2,000 streambed samples were analyzed for fine particulate matter. The point measurement, percent < 0.83 mm in diameter, was used throughout. There was good agreement between percent < 0.83 and the "Fredle Index" and between results of analyzing gravel samples by the volumetric (wet) method and gravimetric (dry) method.

The mean percent particle size < 0.83 mm for 18 streams was 8.9. Separation of streams in logged watershed from those in unlogged watersheds resulted in means of 9.1 percent for stream in logged drainages and 7.1 percent for streams in unlogged watersheds, but tests with a nested analysis of variance showed no significant difference in percent fines < 0.83 between six streams in logged watersheds and six streams in unlogged watersheds. Tests for differences between sediment levels sampled during different seasons showed significant differences in some cases, and none in others.
Abstract - Bedload transport in a small gravel bedded stream on Chichagof Island, Alaska, was measured for 33 autumn storm flows during 1980 through 1985 to determine temporal and spatial trends within a riffle-pool-riffle sequence. The transport of fine sediment was more frequent than coarse sediment. Scouring of coarse material in the reach appeared to be triggered only by high flows with T > 5 years. Within a given storm season, both antecedent storm history and cumulative flow (above the threshold for bedload transport, 0.25 m³/s) influenced bedload transport; however, the effects of these seasonal factors changed from year to year, presumably in response to storage and release of sediment around large organic debris upstream. Hysteresis loops existed in bedload transport versus flow plots for many storms. Fine bedload material was more subject to such differential transport over the storm hydrograph than was coarse material. During the 6-year period, both riffles scoured along most of the channel width while the middle portion of the pool filled.

Abstract - Suspended sediment data from a 154 ha watershed on northeast Chichagof Island, Alaska, were collected over three fall storm seasons from 1980 to 1982. Sediment rating curves for nine pooled storms explained less than 34 percent of the variation in total suspended solids (TSS). Significantly higher concentrations of suspended sediment occurred during the rising limb of storm hydrographs than for similar flows on the falling limb, accounting for hysteresis loops in TSS versus streamflow plots for individual storms. These hysteresis loops were wider during early season storms, indicating that easily transportable fine sediment may have been flushed from the upper portion of channel banks and from large organic debris during early season peak flows. Regression relationships (TSS vs Q) developed for the highest stormflows (> 1 m$^3$/s) had steeper slopes than the lower stormflows (< 1 m$^3$/s). Turbidity correlated well (r = 0.94) with TSS for all stormflow data combined. Organic matter constituted an average of 35 percent (by weight) of TSS for all water quality samples.


Abstract - Chronic turbidity in streams during emergence and rearing of young anadromous salmonids could affect the numbers and quality of fish produced. We conducted laboratory tests to determine the effect of chronic turbidity on feeding of 30-65 mm long steelheads, Salmo gairdneri, and coho salmon, Oncorhynchus kisutch, in straight and oval channels. Fish subjected to continuous clay turbidities grew less well than those living in clear water and more of them emigrated from channels during the experiments.


Abstract - During the summers of 1982 and 1983, the author assessed the effects of placer mining sedimentation on Arctic grayling in the headwaters of the Birch Creek and Chatanika River drainages, northeast of Fairbanks, Alaska. In each drainage 1 compared the differences between two streams near their confluence, one that was undisturbed and one with mining activity upstream. Although many age-0 and adult grayling used unmined streams for summer habitat, no grayling were found in mined streams except during periods of migration. Apparently, grayling consistently chose clearwater streams for summer residence. Caged fish studies demonstrated that if grayling could not escape from streams carrying mining sediments, they would suffer direct, chronic effects, including gill damage, dietary deficiencies and slowed maturation. The indirect effects of sedimentation on grayling populations, through loss of summer habitat for feeding and reproduction are more severe than the direct ones.


Abstract - Addressed are the effects of navigation on the magnitude, duration and transport of resuspended sediments in a navigation pool in the Upper Mississippi River. Examined were 50 commercial and 16 recreational vessel passages at five different main channel and adjacent side channel locations and in one channel in the backwaters. Flow patterns create an active interchange of water and sediment between the main channel and backwater areas. This interchange is essential to the ecological stability of the backwaters. However, backwater areas at many locations are currently oversupplied with sediments; consequently rates of sedimentation increased. Evaluation of factors that are thought to increase the rates of sediment transport to backwater areas is critical because of potentially significant alteration of vast areas of productive aquatic habitat. One important factor contributing to sedimentation is commercial and recreational navigation. Initial studies indicated that navigation can increase sediment transport rates in the main channel of the river.


Abstract - Renewed activity in the placer gold mining country of the Pacific Coast states has raised the question of how much harm silt does to salmon and trout. The effect silt may have on migrating adult fish on the selection of spawning places and on the survival of fish food is discussed. The conclusion is drawn that silt, whether from placer mining or natural erosion, is harmful to salmon and trout if it is heavy enough to form a layer on the stream bottom or if it persists during periods between floods.


Abstract - A study of the effect of lime-neutralized iron hydroxide suspensions on eggs and alevins of brook trout, Salvelinus fontinalis, and coho salmon, Oncorhynchus kisutch, was conducted with a modified proportional diluter. Effects were interpreted from data on hatchability, survival and growth in five test concentrations and control. Growth of 90 day old coho salmon alevins was reduced in water containing 1.27 mg Fe/liter of lime neutralized suspended iron whereas hatchability was unaffected in the highest concentration tested, 10.5 mg Fe/liter. However, 10.5 mg Fe/liter water had no measurable effect on hatchability, survival and growth of brook trout alevins. The safe upper limit of lime neutralized suspended iron for hatchability, survival and growth of coho salmon alevins may lie between 0.97 and 1.27 mg Fe/liter.


Abstract - The accelerating erosion and degradation of Ontario's soil resource base is a threat to the security of agriculture and to the quality of our water resources. But just as importantly, it robs future generations of a soil resource legacy upon which their survival depends.

While the evidence is far from complete, several facts are indisputably clear. Soil erosion and degradation are occurring at unprecedented levels; most is occurring on croplands devoted to the row crop, cash crop syndrome; crop yields are beginning to drop on many otherwise productive soils and waters are being polluted by sediment and sediment borne chemicals. A recent study has reported that cropland erosion losses resulting from yield reduction, nutrient and pesticide losses alone approximate $68 million annually.

Responses to date by government and the agricultural community have been out of scale with the magnitude and severity of a problem which only threatens to worsen before it gets better. The need is urgent for a major, well organized and adequately funded response to soil erosion and soil degradation.
This is a call for action by all those who care about the future of Ontario's foodland resource base and the welfare of future generations.


Abstract - Research on watershed runoff losses from cotton cropping systems in limestone soil regions is limited. Runoff of water, sediment, total N and particulate P were measured from a 3.8 ha (9.4 acre) watershed during three years of conservation tillage (CvT) followed by three years of conservation tillage (CsT). The study was conducted from 1984 through 1989 in the Limestone Valley region of northern Alabama on slopes of 1-6 percent and Decatur and Emory soils. Although CsT resulted in a higher proportion of annual rainfall as runoff than CvT, about twice as much sediment was discharged from the watershed with CvT than with CsT (average of 2979 vs. 1311 kg/ha/year). A few intense storms during late winter through early spring, before full cotton canopy, contributed to most of the erosion losses in CvT. Annual mean concentrations of N in runoff were equally low for both tillage systems, ranging from 1.3 to 2.2 mg/l during the six years. Winter rye was very effective in diminishing N concentrations in runoff from January to spring fertilization. A temporary period of elevated N and P concentrations occurred in runoff sampled shortly after surface application of NP fertilizer in April, especially with CsT. In our study, most of the runoff P loss was associated with the solution rather than the particulate phase and more P runoff occurred with CsT than with CvT. In balance, however, CsT is more environmentally acceptable than CvT for cotton production, assuming prudent NP fertilizer management.


Abstract - Fish habitat models for streams were developed to help explain the decline and possible replacement of smallmouth bass, Micropterus dolomieu, by largemouth bass, Micropterus salmoides, in the Ozark border region of Missouri. Largemouth bass were more successful than smallmouth bass in situations that were relatively warmer, with a greater percentage of total area as pool. The high siltation levels of pools may favor the reproductive capabilities of largemouth bass. Smallmouth bass favor clean rock or gravel substrate for spawning whereas largemouth bass will spawn on a variety of substrates.

The strongest associations witnessed in this study suggest that efforts geared toward reduction of thermal and fine sediment inputs and proper pool-riffle morphometry will lead to maintenance or enhancement of smallmouth bass populations in the Ozark Border region. An obvious focal point is management of the riparian corridor on a large spatial scale - preferably the basin level.


Abstract - A small lake in the Chicago Metropolitan Area was from 91 to 95 percent efficient in removing suspended sediment and from 76 to 94 percent efficient in removing copper, iron, lead and zinc from urban runoff. Sediments accumulated in the lake in the form of an organic rich mud at an average rate of 20 mm per year; this reduced lake storage and covered potential habitat for aquatic organisms. Copper, lead and zinc concentrations were closely associated with suspended sediment concentrations and with silt and clay sized fractions of lake sediment. Although concentrations of mercury and cadmium were near detection limits in runoff, measurable concentrations of these metals accumulated in the lake sediments.


**Abstract** - Influence of red clay turbidity on survival, growth and distribution of larval lake herring, *Coregonus artedii*, was measured by holding larvae for 62 days at nine levels of suspended solids varying from 0 to 48 FTU (1 to 29 ppm). Test concentrations included the normal turbidity range of the red clay area in western Lake Superior. The bioassay was conducted in a continuous flow system using chambers designed to elicit normal behavioral responses to turbidity and light.

Growth and survival were not influenced at the range of concentrations studied. Larvae in the higher suspensions were distributed to the surface of the test chambers, a condition which may indirectly influence survival in Lake Superior.


**Abstract** - The experimental dosing apparatus was a modified proportional diluter equipped with a neutralization device and with a series of detention and oxygenation tanks. Ferric hydroxide was obtained by neutralization of ferrous sulfate using calcium hydroxide. After neutralization, oxygenation and detention, suspended iron was released automatically at regular intervals into the test aquaria. Four concentrations of iron were maintained, each containing 10 young brook trout (3 months old). The data on length of brook trout revealed a definite trend toward smaller size with increasing concentration of suspended ferric hydroxide, with the largest trout in 6 mg Fe/1 and in the control. The average weight of brook trout was much lower in high iron concentrations than in the control and 6 mg Fe/l. The final mean weight of fish in 50 mg Fe/1 represented only 16 percent of the control, with gradually increasing percentage proportions occurring in lower iron concentrations. The final mean weights of the fish in 6 mg Fe/l and in the control were almost identical. The average growth rate computed for five different size groups of fish revealed a sudden decline in growth of brook trout exposed to 12, 25, and 50 mg Fe/l. The growth rate of brook trout in 6 ml Fe/1 and in the control shows only a leveling trend as of the thirty-fifth week. It is assumed that impaired visibility due to high turbidity prevented the fish from feeding which, in turn, resulted in slow growth in high iron concentrations - 12, 25 and 50 mg Fe/l.


**Abstract** - A new method for describing the size composition of salmonid spawning gravel was developed. For gravel samples from Idaho and Washington streams, cumulative distributions of particles sizes for gravel smaller than 25.4 mm were consistently plotted as straight lines on log-probability paper. Because of the log normal distribution of the particle sizes in this range, the size composition of the spawning gravel size were the percentage of the substrate smaller than 9.50 mm and the percentage smaller than 0.85 mm.

Salmonid embryo survival was related to these two groups of particle size in laboratory tests. In these tests, 90-93% of the variability in embryo survival was correlated with changes in substrate size.
composition. Equations were developed to describe the effect of spawning gravel size composition on chinook salmon, *Oncorhynchus tshawytscha*, and steelhead, *Salmo gairdneri*, survival to emergence in a wide range of spawning gravel mixtures.

Gravel mixtures containing high percentages of fine sediment produced slightly smaller steelhead fry than gravels containing low percentages of fine sediment, but the difference was not significant (P=0.05). There was no relationship between changes in gravel size composition and the size of chinook salmon emergence. In gravels containing large amounts of fine sediment, many of the steelhead and chinook salmon fry emerged before yolk sac absorption was complete.


Abstract - Siltation, resulting from improper land use practices, is regarded as one of the most important factors contributing to a reduction in the acreage of desirable fishing waters in the United States. The purpose of this report is to present data regarding the effects of siltation on the bottom organisms of Shope Creek, a small trout stream which receives the drainage from a 212 acre logged watershed.

During storm periods, the turbidity of Shope Creek was appreciably increased by the highly turbid waters from the logged area. Roads and skid trails proved to be the major source of turbidity. From April, 1951 to March, 1953 an average of 5.34 cubic feet of soil per lineal foot of road surface was eroded from the logging road.

From October, 1952 through January, 1953, the period of maximum accumulation of sediment in the affected section of Shope Creek, there was a significantly lower standing crop of bottom organisms at the station below the mouth of the logged watershed.

A flood on February 21, 1953 removed the accumulation of sand and silt in Shope Creek below the mouth of the logged watershed and reduced the bottom fauna at the lower station to 7.3 organisms per square foot, as compared with 25.5 organisms per square foot at the upper station which had not been subject to siltation from the logged watershed. The February flood exposed an excellent bottom of rubble and gravel at the lower station; from February through May spring rains and high streamflow prevented the re-accumulation of sand and silt at the lower Station on Shope Creek. During this period there was no significant difference in the standing crop of bottom fauna at the control and treated stations. During June, when silt had begun to re-accumulate, the control section again produced a larger standing crop of bottom organisms. The difference was not statistically significant.


Abstract - We conducted three exploratory experiments of factorial design on the effects of mineral turbidity in 18 large (70001) fiberglass tanks containing plankton communities derived from Lake Texoma (Oklahoma-Texas), a large reservoir often subject to turbid inflows. Replicate plankton communities developed for 30-45 days in response to 4-9 treatments of planktivorous fish, dead fish, nutrient additions and artificial removal of zooplankton with plankton netting (or combinations of these manipulations). In one experiment we then added three concentrations of kaolin and in the other two experiments we added bentonite or powdered silica to the replicate tank communities. We measured the responses of the diverse plankton communities to the addition of mineral turbidity for an additional period of 30-45 days.

Effects of introduced minerals (quality or concentration effects) and food web treatments after mineral addition (fish, nutrients, etc.) were determined by analysis of covariance after observations were adjusted for the value of each response variable at the time of mineral addition. Covariance analysis resulted in a statistical model explaining > 80% of the variance for most response variables. The values of response variables at the time of mineral addition were often the most important source of variation, suggesting the importance of biotic community resiliency to the effects of mineral turbidity. There were few effects of mineral particles on physical or chemical (temperature, conductivity, oxygen, pH), nutrient (nitrate, phosphate, alkalinity) or biotic (algal or zooplankton populations) components of the tank communities. Mineral effects were found for several measures of water clarity (Secchi depth, turbidity, and the concentration of small sestonic particles).


Abstract - Suspended sediment loads decreased in the South Atlantic, Gulf of Mexico and in California coastal waters and increased in the North Atlantic coastal waters. Suspended sediment yields decreased slightly between 1980 and 1989 in all coastal regions except the Great Lakes and the South Atlantic-Gulf of Mexico regions; these were the result of increased soil conservation efforts (i.e., conservation tillage and other best management practices) which reduced erosion 13% between 1982 and 1987. Suspended sediment loads were particularly high in California streams in areas where timber harvesting exposed soil to erosion.


Abstract - This report describes the administrative and technical problems that define what to measure and how to measure suspended sediment in small mountain streams. It examines the factors that govern the data collected in a monitoring program, with particular attention to use of automatic pumping samplers.


Abstract - The "Selection at List Time" (SALT) scheme controls sampling of concentration for estimating total suspended sediment yield. The probability of taking a sample is proportional to its estimated contribution to total suspended sediment discharge. This procedure gives unbiased estimates of total suspended sediment yield and the variance of the estimate while automatically emphasizing sampling at higher flows. When applied to real data with known yield, the SALT method underestimated total suspended sediment yield by less than 1% whereas estimates by the flow duration sediment rating curve method averaged about 51% underestimation. Implementing the SALT scheme requires obtaining samples with a pumping sampler, stage sensing device, and small battery powered computer.


Abstract - Increased turbidity reduced spawning success among Severn River, Maryland, perch but the effects of turbidity and increased salinity were not distinguished. Numbers of perch decrease as turbidity increase which is consistent with a mode of life dependent primarily, although not wholly, on sight.


Abstract - The sustainability of aquatic and riparian ecological systems is strongly tied to the dynamics of the streamflow regime. Timber harvest can influence the flow regime by increasing total flow, altering peak discharge rate, and changing the duration of flows of differing frequency of occurrence. These changes in the energy and sediment transporting capability of the fluvial systems can cause an alteration in both channel morphology and aquatic habitat. Depending on practices used, timber harvest can increase the rate of sediment introduction to the channel system, thus further confounding the energy/transport relationship.

Diversion and augmentation also alter the natural flow regime and disrupt the energy distribution in the system. Diversion decreases the energy regime available to transport the sediment load and may cause aggradation and vegetation encroachment. Elevated flow regimes from augmentation may result in extensive scour, loss of aquatic habitat and, ultimately, a change in the relationship between the aquatic and terrestrial components.

This paper addresses the flow parameters which influence sediment transport and the implications of changing flow dynamics, whether from flow or forest management, and the effect it has on the transport process.


Abstract - Siltation, the leading cause of nonpoint source impacts, is especially harmful to fish and aquatic ecosystems. Sediment harm fish by reducing dissolved oxygen levels, which puts them under chronic stress, and by smothering eggs and newly hatched fry. Resultant high turbidity reduces sight feeding and growth by salmonids and interferes with migration. Sediment deposits also can eliminate aquatic plants that provide cover for fish and invertebrates they consume. The flow of sediment often carries with it nutrients and pesticides that degrade water quality and diminish biological productivity.

States with waters containing crucial salmonid (trout and salmon) habitat are among the hardest hit by agriculture-related nonpoint source pollution. Siltation is the predominant cause of degradation in up to 25 percent of the impaired rivers and streams in California, Nevada, Washington and Pennsylvania, up to 50 percent in New York, Montana and Colorado, and up to 75 percent in Wyoming.


**Abstract** - The natural recovery of trout, Salmo *trutta*, populations in an industrial river, the Ebb Faver, South Wales, has been depressed by problems of natural recruitment. Rainbow trout, Salmo *gairdneri*, eggs were planted in river gravels to assess the effects of siltation on salmonid spawning success. In reaches where siltation due to the coal industry has occurred, 98-100% of eggs died during incubation in the gravels. Experiments using standpipe techniques measured gravel permeabilities and rates of dissolved oxygen (DO) supply to artificially planted eggs, the results showed a strong dependence of hatching success and alevin size on these two parameters. The median lethal DO supply rate was about 50 ugm/cm²/h.


**Abstract** - Laboratory avoidance studies indicated that coho salmon, raised in clean water, have shown a definite response to lime-neutralized iron hydroxide suspensions at the range of 4.25-6.45 mg Fe/l. The same species of fish, exposed for several months to different concentrations of the pollutant, has shown almost identical response as the fish raised in the control water.


U. S. ARMY CORPS OF ENGINEERS. 1962. Practical guidelines for controlling erosion at culvert outlets. Waterways Experiment Station, Vicksburg, Mississippi.


Abstract - Waters entering a lake generally carry suspended particles, including organic matter, clays and silt washed from the watershed and carried downstream to the lake in rivers and streams. These particles settle once they reach the relatively quiescent lake environment; as a result, lakes are extremely efficient sediment traps. Although filling with sediments is a part of a lake's natural aging process, poor land management practices can speed this process significantly. Watersheds that have soils with a high clay content, more erodible soils and more exposed soil and disturbance contribute greater quantities of suspended sediments. In addition, sediments can carry substantial quantities of adsorbed nutrients and chemical contaminants. Thus, lakes receiving high sediment loads frequently also receive excessive inputs of nutrients and toxic contaminants.

Much of the sediment load entering a lake, together with the particulate matter produced internally (primarily dead organic particles from plants and animals living within the lake) eventually settles to the bottom. The rate of sedimentation and the types of materials deposited determine the physical characteristics of the bottom substrate which, in turn, influence oxygen levels in and near the bottom sediments and the types and productivity or organisms that live there. Many fish species deposit their eggs in these bottom sediments; different fish species prefer or require different substrate types. For example, lake trout require well oxygenated, gravel substrate with little silt or clay. High sedimentation rates, resulting from large inputs of suspended sediments to the lake may smother and kill eggs deposited on the bottom.

In lakes with a high concentration of suspended particulates, most of the incoming light is absorbed or backscattered in the first few feet of water. Deeper waters receive little heat input and have inadequate levels of light for plant growth. Low light may, in such waters, be a major factor limiting plant growth and lake productivity.
channels, lakes, wetlands and reservoirs and increases the potential for flooding downstream. Sediment may fill in water supply reservoirs, eventually requiring costly dredging or new water sources.

These suspended solids make the water appear muddy, decreasing its value for fishing and recreation. As sediment settles to the bottom, phytoplankton, fish and invertebrates have difficulty feeding and reproducing. Other aquatic life may be smothered or deprived of essential sunlight. Sediment can also carry other materials - such as nutrients, pesticides and trace metals - that can harm both aquatic life and human health.

Sediment and erosion are at their peak when the soil is disturbed along with the vegetation that stabilizes it. And once sediment enters a stream, it can take many years to travel through the waterway. As silt, clay and sand move downstream, they erode the streambank, affecting fish and wildlife habitat along the way.


Abstract - We conducted laboratory experiments to determine relationships between water turbidity, piscivory, fork length and development of the retina in juvenile walleyes, *Stizostedion vitreum*. Walleyes, 85 mm and longer, ate a greater weight and number of fathead minnows, *Pimephales promelas*, in turbid water than in clear water. Feedings were inhibited at the highest turbidities (100 and 161 nephelometric turbidity units, NTU) in one hour feeding trials but not at the highest turbidity (121 NTU) in four hour trials. In contrast, walleye in the shorter length group (< 75 mm) fed at approximately the same rate in clear and turbid trials, but consumption was inhibited at the two highest turbidities (100 and 161 NTU) used in one hour trials. The tapetum lucidum was present in the retina of walleyes used in all the experiments. Aggregation of photoreceptor cells in the retina into groups of 20 to 30 (to form macrorceptors) begins when walleyes are approximately 60 mm long. Macrorceptors are believed to increase acuity in dim light. In our experiments, the development of macrorceptors was related to increased feeding efficiency in turbid water. The development of scotopic vision early in life permits walleyes to exploit dimly lit environments not used by other predators.


Abstract - Fish live and thrive in water with turbidities that range above 400 ppm and average 200 ppm. The waters of the Great Lakes usually are clear except in Lake Erie where the turbidities of the inshore areas averaged 37 ppm; the turbidities of the offshore waters averaged less. Lake Erie waters were no clearer 50 years ago than they are now. In fact, the turbidity values are less now than they were in the earlier years; the annual average of the inshore waters dropped from 44 ppm before 1930 to 32 ppm in 1930 and later, and the April-May values decreased from 72 ppm to 46 ppm. Any general decline in the Lake Erie fishes cannot be attributed to increased turbidities. Furthermore, these turbidities averaged well below 100 ppm and, therefore, were too low to affect fishes adversely.

Turbidity in the open waters of Lake Erie is primarily the result of wave action induced by winds. River discharge is a minor factor even in the western end of the lake. Other probable factors are plankton, the eastward movement of the water mass, currents, seiches and possibly bacteria. Wave action is undoubtedly the dominant agency in soil erosion along the shores of all of the Great Lakes.

No evidence exists that fluctuations in the abundance of zooplankton, the basic food of fishes, and of the fishes themselves are positively correlated in Lake Erie, or that the plankton crop in this lake is ever in short supply. On the contrary, all available evidence shows that Lake Erie is comparatively rich in plankton and that the western end in spite of its turbidity is richer than the eastern. Some factor other than turbidity dominates the basic productivity of western Lake Erie.

With respect to turbidity, Lake Erie has not become less suitable for fishes. This conclusion also receives support from the study of the fishes themselves. It was demonstrated that the growth of the western Lake Erie fishes compared very favorably with that of fishes in the other Great Lakes or similar waters. It was shown further that the known occurrence of relatively strong year classes in this lake was not consistently associated with low turbidities and conversely that the known low turbidities of the Lake Erie waters were not always accompanied by large year classes. Also, contrary to the "turbidity theory" certain clear water varieties, such as the walleye, have increased tremendously in recent years in Lake Erie whereas the supposedly turbid water forms, such as the sauger, have decreased in abundance. Reference was made to Doan's work, wherein he attempted to show correlation between turbidity and abundance for several species of Lake Erie fish but failed to do so except for the sauger where he reported a positive correlation. With respect to the productivity of fishes Lake Erie ranks first among the Great Lakes and the western end in spite of its greater turbidity surpasses the eastern. As judged by certain accepted standards of water suitability, Lake Erie ranks high and the western end again surpasses the eastern. Finally, it was pointed out that the fishes which inhabit the clear waters of the Great Lakes declined as well as those which live in the more turbid waters and that turbidity, therefore, cannot be a factor in the depletion of all Great Lakes fishes. Furthermore, the reduction in abundance repeatedly has been associated with increased fishing intensity.

All of the evidence indicates, then, that soil erosion on farms and the turbidity of the water were not major factors, if operative at all, in the decline of Great Lakes fishes and that they did not make Lake Erie unsuitable for fish life.


Abstract - Sediment supplies and stream discharge together determine the patterns over time of suspended sediment loads in small streams. Most of the uncertainty in empirical stream flow-sediment relationships can be attributed to changing supplies. Our transport model utilizes a power function of the form $C = aQ^b$ where $C$ and $Q$ are sediment concentration and stream discharge, respectively. This expression was augmented with a variable $S$ representing sediment storage in the channel system. The resulting supply based model was calibrated to concentration and streamflow time series data from four storm events in a small forested watershed in coastal Oregon. We also calibrated the model to data from a controlled reservoir release in Utah, during which streamflow was held constant for an extended period. In all cases the supply based model followed observed concentration time series more accurately than did a transport model based on $Q$ alone. We further enhanced performance of the supply based model by distributing sediment supplies $S$ among several compartment which were assessed at different levels of stream discharge. Both the single compartment and distributed models demonstrate the a knowledge of sediment supplies can improve predictions of suspended sediment concentrations during storm runoff.


Abstract - We have shown that macrophytes in Lake Whangape can tolerate periods of substantial natural shading largely because the lake is flushed unusually rapidly. At periods of slower flushing, however, it is important to ensure that the lakewaters are not muddied by point source discharges. New insights such as this, gained from studying the requirements for macrophyte success in an unusual lake, should assist with management of macrophyte communities both here and in other lakes.


Abstract - Predictions based on the Shields diagram and confirmed by experiments conducted in eutrophic Lake Sempach imply that bottom currents associated with winter storm events are responsible for the simultaneous transport of coregonid eggs and fine silt and clay (grain size < 10 um) from the spawning grounds into deeper lake regions. The critical shear stress required to initiate egg transport is estimated to lie in the range of 0.02 - 0.04 N/m$^2$, corresponding to mean current speeds of 10 - 15 cm/sec at a reference height of 0.5 m above the sediment surface. On settling out, egg burial is likely. This will increase egg mortality not only by physically hindering oxygen transport to the egg, but also in POC rich eutrophic sediment, by relocating the egg in a zone of steep oxygen gradients and low mean oxygen concentrations. Microelectrode measurements and computation of the thickness of the oxygen diffusive boundary layer over the sediment reveal that even eggs that escape interment are likely to be subjected to ambient oxygen concentrations insufficient for development to hatching. It is suggested that transport and burial may in general be important factors determining coregonid egg mortality in eutrophic lakes.


**Abstract** - Changes in the reactive distance of bluegill, *Lepomis macrochirus*, to various sizes of *Daphnia pulex* were measured at light intensities ranging from 0.70 to 215.3 lx (0.065-20.0 ft-c) and at turbidities ranging from 1-30 Jackson Turbidity Units (JTU). Both reduced illumination and increased turbidity caused substantial reduction in the reactive distance of bluegill for all prey sizes and particularly for large prey. This result should be considered in efforts to determine fish feeding rates in lakes, and may be particularly relevant to vertically migrating zooplankton or those inhabiting more turbid waters.


**Abstract** - To determine the effect of placer mining on benthic macroinvertebrates, we determined selected water quality characteristics and sampled benthic invertebrates in nine hydrologically similar and proximally located streams, ranging from unmined to heavily mined streams. Placer mining caused increased turbidity and increased amounts of settleable solids and suspended sediment (nonfilterable residues). Sediment from placer mining was associated with decreased density and biomass of invertebrates. In a stream where mining began in mid-August, Orthocladiini (*Diptera: Chironomidae*) and Chloroperlid stoneflies decreased in abundance while they were not decreased in a nearby unmined stream. Water mites seemed to be the organisms most affected by placer mining.


**Abstract** - During the last three and one-half years the U.S. Army Engineer District, San Francisco, has been involved in a series of research investigations to define the environmental ramifications of dredging and disposal activities in San Francisco Bay. The investigations included elements examining the impact operations generated on water quality, sediment heavy metal release and benthic and pelagic organisms both in terms of physical and chemical effects. In the upper water column neither dredging nor disposal operations cause significant changes in water quality. Plumes were observed but these were generally of short duration and seldom contain suspended solids concentrations. At the disposal site, sediment releases can cause dissolved oxygen reduction of 6 parts per million for durations of 3 minutes. Suspended solids concentrations can increase to 22 gm/1. The relevance of these suspended solids concentrations was evaluated by a series of turbidity bioassays. The physical impact of various particle concentrations with changes in temperature and dissolved oxygen was investigated using several San Francisco Bay benthic and pelagic species. In general, the results showed that the levels observed in the field would not cause adverse effects on adult benthic species at saturated oxygen and winter temperatures (10°C). Effects were more pronounced at higher temperatures and lower dissolved concentrations. Pelagic species could be negatively impacted by the solids concentrations found at disposal sites with increasing effects as temperature and dissolved oxygen conditions became more adverse. Investigations of desorption phenomena showed that cadmium, lead, zinc and copper can be emitted from resuspended San Francisco
Bay sediments under oxygen rich conditions. Biological investigations showed that dissolved heavy metal ions can be accumulated during low salinity periods and desorbed as the salinity increases. Heavy metals may be taken up and accumulated by organisms following dredging and disposal activities via chemical reactions in the water column causing increased ambient concentrations or by ingesting and breaking down organic matter containing metals.


Abstract - Sediment rating curves are often used to estimate suspended sediment loads where the sampling program is insufficient to define the continuous record of sediment concentration. Use of this technique will involve errors in the values of sediment load produced and comparison with measured daily values has been employed by several workers to assess the magnitude of these errors. Comparisons are more difficult for small- and medium-sized catchments because of the general lack of direct measurements of loads. Recording turbidity meters could be employed to provide a continuous record of sediment concentration which can be used to calculate sediment loads. Results are presented for the river Creedy in which the values of sediment load calculated from the continuous concentration record have been compared with estimates derived from rating curves. The rating curve data have been grouped according to season and stage tendency to provide various rating relationships. Values of annual sediment load estimated by using a rating curve could involve errors of up to +280%, whereas the errors for monthly loads could range between +900% and -90%. Careful consideration should be given to possible error terms before rating curve estimates of sediment load are used in statistical and other analyses.


Abstract - A laboratory experiment was conducted to test the effects of population density, sediment type and flow rate on the drift of a stonefly. Three types of sediment patches were placed in artificial stream channels. Acroneuria abnormis individuals were introduced on these sediments in a range of population densities. Drift from the patches was greatest from gravel, intermediate from cobbles, and least from stones. From all the substrates drift increased with increasing benthic density. Current velocity differentially affected drift only from gravel. Analysis of variance showed that all main effects and interactions were highly significant. Drift was judged density independent from gravel and density dependent from cobbles and stones. The data suggest that interference competition led to the density dependent drift. The implications for proposed active versus passive mechanisms for drift are discussed. Passive mechanical removal seems to be an inadequate explanation for our findings.


Abstract - Erosion is a natural process. However man's activities such as road building, can greatly increase the amount and rate of soil erosion. Erosion and the resultant input of soil particles (sedimentation) to lakes and streams is of particular concern to fish managers. Soils that are high in silt and fine sand and low in clay and organic material are generally the most erodible. Well drained, sandy and rocky soils are the least erodible.

Sediment is classified by particle size; the three major classes being sand, silt and clay. The size of the particle and the water velocity determine how the particle is transported. Coarse particles, like sand and gravel, usually move by rolling along the stream bottom as part of the bedload. Thus their concentrations are low in the water column. In comparison, silt and clay are usually transported in suspension and their concentrations are generally uniformly distributed throughout the water column.

Once fine silt or clay particles are deposited in fast flowing water, they will travel great distances as suspended sediment before settling. This suspended sediment is often measured as total suspended solids (TSS) in milligrams per liter (mg/l) or the equivalent parts per million (ppm) and sometimes referred to as turbidity.

Increased turbidity levels limit photosynthesis by algae and rooted aquatic plants by reducing sunlight penetration into the water. This limits production of food for aquatic life. As well, turbidity can cause
changes in fish feeding behaviour, since prey is less visible. Suspended sediment can harm incubating fish eggs and fry and reduce the abundance of insect larvae, a food source for fish, by filling up the larvae's guts or nets with indigestible material. High levels of suspended sediment, exceeding 200-300 mg/l, can cause fish mortality if lasting for many days.

The damage done to aquatic organisms by increased suspended sediment levels is a function of the concentration of the sediment in water (mg/l) times the duration of the organisms exposure to them in hours. Total suspended solids less than 25 mg/1 shouldn't harm fish or fish habitat. However, even these low levels of suspended sediments shouldn't last longer than several weeks, since rubble/gravel areas will rapidly become silted even in flows with low concentrations of suspended solids. Thus, it's important to correct any chronic erosion problems immediately.

Where there are spawning areas downstream, there should be restrictions on instream construction activities during fish spawning and egg incubation times. This is to prevent the addition of any suspended sediment from attaching to the adhesive surface of fish eggs. This adhesive surface, for example, enables walleye eggs to attach to rocks in strong currents, and pike eggs to attach to emergent vegetation away from oxygen poor bottom sediments. A South Dakota study found that a deposit of 1 millimeter of silt per day during pike egg incubation caused egg mortalities of 97% or more (Hassler, 1970). For northwestern Ontario, timing restrictions are used to protect fish spawning and egg incubation areas from instream construction activities.

If the water velocity is less than the soil particle velocity, then the particle becomes bedload sediment as it slides, rolls or bounces along the bottom. Bedload sediment may fill in the interstitial spaces or crevices between rock, rubble/gravel spawning areas, suffocating any eggs or fry if they are present. A declining percentage of fry emerge as the percent of fine sediment increases in the spawning bed. This is another reason for restricting instream construction activity during fish spawning and incubation periods.

Interstitial spaces must be free of sediment for successful egg incubation, so that water currents can freely mix with the eggs to deliver oxygen and remove waste products such as carbon dioxide and ammonia. For walleye, egg survival to the fry stage is best on gravel/rubble substrate. When eggs were deposited on sand, egg survival declined by two-thirds. When laid on a silt or muck/detritus bottom, survival was one-tenth that of a clean gravel/rubble area. The interstitial spaces of rocks or gravel also hide eggs from predators such as other fish. If the interstitial spaces are filled with sediment, the eggs from broadcast spawners, like walleye and whitefish, lie on top of the sediment and are more accessible to predators.

Bedload sediment also adversely affects invertebrates by filling up their crevice homes, muddying over their attachment surfaces and eliminating interstitial spaces which act as a storehouse for organic silt on which many other invertebrates feed. While it is true that some benthic organisms are encouraged by inorganic silt (sediment), they are quite different in life form i.e., worms or midge larvae replace mayflies and caddisflies, so that the newcomers are not as readily available as food for the original species of fish.

Spring floods may not have enough velocity to remove sediment from these interstitial spaces. These "flushing flows" need to remove sediment from between the rocks, not just from the surface of the spawning bed. In some cases where sediment has been inadvertently deposited for example because of a culvert washout, the use of a "mud pump" may be required to remove the sediment from between the rocks. As well, the Ontario Ministry of Environment's Spill Action Centre should be notified of any culvert washouts. Washouts deposit sediment in the stream which could be considered a "contaminant" as defined in Section 14 of the Environmental Protection Act.

Problems of having sediment deposited in water can be minimized if the contractor uses construction practices outlined in the 'Environmental Guidelines for Access Roads and Watercrossings.' For water
crossing sites that could affect critical fish habitat, it is advisable that sediment control plans be developed. Combining the knowledge in the "Environmental Guidelines" with more effective planning, will help to ensure that water crossing construction will still maintain the productivity of the aquatic environment.


Abstract - Solid materials finding their ways into natural waters may have some undesirable effects while carried in suspension and can have other undesirable effects after finally settling to the bottom. The kinds and sources of such materials are many. Silt, eroded from land disturbed by cultivation, logging or road building, often has pollutional effects. Mining, gravel and other industrial operations may increase the load of finely divided, chemically inert materials carried by waters. The dredging of harbors and channels has deleterious effects on estuarine environments to which bottom materials are carried in suspension. Damage to valuable uses of affected waters makes this an important kind of pollution.

While in suspension, such solids cause waters to be turbid; reduced light penetration may restrict the photosynthetic activity of plants and the vision of animals. These finely divided materials at high concentrations are known to interfere with the feeding of animals that obtain their food organisms by filtration and they may be abrasive to sensitive structure such as the gills of fish.

On settling to the bottom, solid materials often harm this important aquatic habitat. Oyster lands made soft with silt may no longer be able to support the weight of their product. Rocky bottoms previously providing homes for many animals may be buried. Stream gravels where salmon deposit their eggs may lose their porosity, thus reducing the movement of water carrying oxygen to the developing embryos. These are very real kinds of pollution.

Dissolved solids too may bring about undesirable changes in aquatic environments and be considered pollutants. When separately dissolved in pure water, some of the salts present in sea water are toxic to marine and freshwater animals at concentrations lower than their concentrations in the sea. Even sodium chloride is in this group. The toxicity of such solutions is due to the metal cations. When various salts are present in suitable proportions, the different cations counteract each other and the solution is considered to be physiologically balanced. Sea water is such a balanced solution. Its harmful effects on freshwater organisms are caused by high osmotic pressure not toxicity of its individual components.

Dissolved salts in natural waters are increased by many of man's activities: irrigation of land; discharge of oil field and other brines; diversion of streams and deepening of ship channels permitting the intrusion of sea water into former freshwater areas. Water in these ways sometimes becomes no longer suitable for domestic, agroci--; or industrial uses. But here we are concerned with animals that must continue to survive, reproduce, grow and move in changing waters, if they are to be successful and useful to man.

Freshwater organisms are adapted to living in waters of low salt concentration. Their mechanisms for maintaining water and salt balance with their environment cannot usually cope with great increases in dissolved solid concentration. So, either directly or indirectly, increases in osmotic pressure of aquatic environments may affect some stage in the life history of freshwater animals in ways decreasing their distribution, abundance and value to man. Marine animals face similar problems of salt and water balance when unusual amounts of freshwater enter marine environments. Man's activities may cause either kind of pollution: an increase or a decrease in osmotic pressure that is deleterious to aquatic life.


Abstract - There are approximately 180 miles of coal haul roads in three eastern Kentucky counties. The amount of erosion from these roads will be great unless protective measures are taken immediately following abandonment. If the roads are not going to be used after abandonment, all culverts should be removed and cross channels provided. A grass cover should be established immediately and trees planted. Where the road is to be used, arrangements should be made for maintenance. Application of these measures in the total restoration program would control or reduce erosion from roads no longer used to transport coal from opencut mines in rough terrain.


Abstract - Techniques commonly used to measure fine sediment accumulation in streambed gravels can be labor and equipment intensive. We evaluated the sediment trapping capabilities of modified Whitlock-Vibert boxes under both laboratory and field conditions and compared the accumulated fine sediment to that contained in adjacent gravels as indicated by McNeil core samples. Our results suggest the boxes can be used as an alternative to core sampling for monitoring intergravel fine sediment levels. Advantages include ease of transport to remote field sites, small sample volumes and reduced analysis time. Problems encountered were displacement of boxes by flood and ice flows and inundation by large sediment spills.


Abstract - Adult male chinook salmon, Oncorhynchus tshawytscha, were tested for behavioral responses to suspended volcanic ash from Mount St. Helens, Washington. Chinook salmon exhibited a strong baseline preference for clean (ash free) home water over a clean non-natal water source. The addition of ash to the home water significantly reduced preference for home water, apparently because of an avoidance response to ash, not an inability to identify home water. The ash also reduced upstream movement in the testing apparatus. The homing performance of displaced chinook salmon was assessed after a 7 day
exposure to an ash suspension of approximately 650 mg/liter. The ash did not affect the proportion of fish that homed.


Abstract - This publication consists of a review of the ecological and biological effects of turbidity in aquatic ecosystems. It includes a review of the means of measuring turbidity, the dynamics of suspended particles, effects of turbidity in estuaries, a review of studies examining turbidity and its effects worldwide and means for mitigation.


Abstract - The purpose of this work was to test the hypothesis that smelt, Osmerus mordax, are capable of avoiding suspended sediments and hence may avoid fixed nets in the estuary where high levels of suspended sediment are present as a result of dredging and dumping. There appeared to be a threshold effect between 18.8 and 21.8 mg/1 suspended sediment. The apparent threshold of approximately 20 mg of suspended sediment/1 for the smelt avoidance response is higher than that found for herring (approximately 10 mg/1). These experiments do provide indirect evidence that smelt could avoid areas high in suspended solids. The results indicate the need for field studies of smelt behavior where other behavioral drives such as migration and escape movements may override the avoidance movements observed in our laboratory tests.


Abstract - Large organic debris in old growth forests provides important sediment storage elements on hill slopes. As the old growth trees fall or blow down across the slope, they form a series of cross-slope obstructions. Sediments and small organic debris from upslope mass movements are deposited behind these obstructions forming a series of terraces which temporarily delay the delivery of sediments to stream channels. Documentation of this storage role of large organic debris is provided from an old growth Sitka spruce-western hemlock forest site in the Queen Charlotte Islands of British Columbia.

Abstract - While sediment in surface waters may be one of our more serious water quality problems, the sources of this sediment are not well defined. Sediment control programs for water quality are presently concentrating on the application of best management practices (BMP's) across the watershed with little regard to location. The authors have studied sediment movement patterns in a midwestern watershed using fallout cesium-137 techniques and have concluded these programs may be largely ineffective. The implications from this work are that cropped floodplains are the most severely eroded lands in the watershed, followed by cropped lands bordering the floodplains. Most of the eroded sediment either originates on or is delivered directly to the active floodplain and hence to the stream. The authors conclude that the majority of cropped uplands may not be nearly as important in determining sediment levels in streams as is generally thought.


Abstract - A field experiment showed that benthic invertebrates in running water exhibit preferences for different substrate particle sizes. Maximum numbers and biomass occurred on medium gravel (24.2 mm mean diameter) whereas diversity was greatest on large gravel (40.8 mm). Individual species fell into four groups: upper, medium and lower size preference and no preference. The addition of a limited quantity of sand to medium gravel affected only a few species.


Abstract - The CREAMS (Chemical, Runoff and Erosion from Agricultural Management Systems) field scale model is used to evaluate the effectiveness of grass filter strips for erosion control. Simulations are presented for filter strips of several widths (3-15 m), slopes (2.4-10%), and grass stand qualities (Manning's n, 0.023-0.46) on a 1.6 ha wheatland watershed in the Reddish Prairie land resource area. Filter strip effectiveness is dependent upon strip width, Manning's n, slope and slope configuration and storm intensity. For 2.4% slopes with a concave-convex, concave or uniform configuration, a filter strip 15 m (50 feet) wide with a good grass stand (Manning's n of 0.46) reduced soil loss 29%, 26% and 33% respectively. A 2.4% convex slope presented the worst general condition for filter strip use, although a 15 m wide filter strip with a good grass stand could reduce soil loss as much as 46%. Results indicated that CREAMS can be a useful tool for evaluating filter strip effectiveness in reducing sediment yield.


Abstract - This paper reviews some of the literature on the effects of inert inorganic materials on aquatic life. Some of the results reported from such pollution are poor phytoplankton productivity resulting from increased turbidity, losses of trout and trout spawn near placer mining operations, decrease and deterioration of sports fish due to poor agricultural practices and smothering of benthic and invertebrate organisms. By measuring sedimentation rates downstream from a gold dredge, several conclusions were made. Although the screening of the light was a significant factor in lowered biological productivity, the abrasive or molar action of the larger particles of sediment and the smothering of fish food organisms and fish spawning beds are considered to be of greater importance. As a guiding principle in establishment of water quality criteria for permissible concentrations of silt and turbidity in streams, certain percentage increases above levels at normal flow in waters is suggested.


Abstract - Eroded streambanks are common in agricultural areas where farm animals have ready access to streams. Deposition of eroded streambank soil onto the streambed during storm events may reduce fish density and recruitment, and affect macroinvertebrate community density and diversity. The main objective of this study was to determine if there is a relation between the amount of sediment being eroded from agricultural areas and the densities and diversities of fish and aquatic macroinvertebrates. Cedar Run and Slab Cabin Run, two of three major tributaries in the Spring Creek watershed, Centre County Pennsylvania, transport elevated levels of suspended sediment in proportion to the length of eroded stream banks adjacent to grazed areas along each stream. The main stem of Spring Creek receives the runoff from these two agricultural streams. The headwaters of Spring Creek proper have little agricultural sediment loading and served as a reference for comparing sediment loading to the other two streams. Sediment loading, substrate composition, water temperatures, fish and aquatic macroinvertebrates were assessed at nine sites. Sediment yield was estimated to be 0.234, 0.698 and 1.221 tonnes per square kilometre of watershed area per million cubic meters of discharge per year in Spring Creek, Cedar Run and Slab Cabin Run respectively. Spring Creek had significantly higher quality trout spawning substrate and habitat than the other two streams. Water temperatures below 5°C were found most often in the Slab Cabin Run, sometimes in Cedar Run and never in Spring Creek. Aquatic macroinvertebrate densities were also significantly different among streams with Spring Creek at 15,293/sq. metre, Cedar Run at 7,241/sq. metre and Slab Cabin Run at 5,000/sq. metre. Aquatic macroinvertebrate diversities were not significantly different due to substitution of pollution tolerant taxa in place of pollution intolerant taxa. Adult and age-0 brown trout, Salmo trutta, populations were also significantly different among streams. Spring Creek has 1,000/km and 1,967/km, Cedar Run had 214/km and 173/km, and Slab Cabin had 15/km and 20/km adult and age-0 brown trout respectively. Temperature and flow variation play a role in brown trout population dynamics. Although these two variables were more closely linked to ground water entry into the stream than to the loss of riparian vegetation in grazed area, sediment loads were also inversely related to age-0
brown trout and aquatic macroinvertebrate densities. The data suggest that while the degree of sediment deposition and the status of aquatic communities are a function of the degree of disturbance in the riparian zone, the amount of ground water entering the stream may also significantly influence aquatic community structure.


WOLMAN, M. G. 1964. Problems posed by sediment derived from construction activities in Maryland. Report to the Maryland Water Pollution Control Commission, Annapolis, Maryland. 125 p.


WONG, W. L. AND R. H. McCUEN. 1982. The design of vegetative buffer strips for runoff and sediment control. Technical Paper, Maryland Coastal Zone Management Program, Civil Engineering Department, University of Maryland, College Park, Maryland.


Abstract - The importance of eggs pockets to survival to emergence for the eggs and alevins of all large salmonids was extrapolated from data on the substrate composition of 16 egg pockets and the permeability of 15 egg pockets. We suggest that researchers collect numerous samples throughout incubation from the redds of several species of large salmonids from many different streams to elucidate the structure and function of egg pockets. Because of the sources of variation and error associated with egg viability and
deposition in the field, we question the utility of capping redds to accurately estimate survival to emergence.

We concur that information on the structure of egg pockets should be incorporated in laboratory experiments conducted to evaluate the relation between survival to emergence and intragravel conditions. We suspect that much of the current information on survival to emergence derived from laboratory studies could be applied to the field but only when embryonic survival characteristics and intragravel conditions in laboratory tests match those in the field. The investigations of egg pockets we have suggested should resolve this problem.

Fisheries researchers should be aware of statistical problems that can cause misleading results. Realism in simulating intragravel conditions must be matched with rigorous analyses of the data from experiments involving survival to emergence.


Abstract - Recreational motorboats with engines of 28-165 hp were operated at three selected lakes in central Florida. A pair of isolation chambers representing aquatic habitats was placed in each lake for control and mixing studies of sediments and the overlying water. Mixing in isolation chambers was performed by small electric motors connected to two blade propellers. Agitation of the water column in the mixing stations and inside the isolation chambers increased water turbidities and phosphorus concentrations. The increase in turbidity and phosphorus content occurred at a much higher rate than the turbidity decline after cessation of mixing. The increase in phosphorus content could result in an increase in lake productivity as noticed from the increase of chlorophyll a concentrations in mixing stations. The data from this study indicate a substantial increase in turbidity and phosphorus concentration are possible due to recreational boating on shallow lakes. These effects are significant and should be addressed in water resource studies. Whether control of boat size or horsepower is required on these types of lakes is not determined. However, the study provides a base for regulatory control to prevent degradation of water quality from propeller-induced mixing and for consideration in waste-load allocation modeling.


Abstract - Lake Temiskaming, a long narrow lake between Ontario and Quebec, contains a permanent turbidity gradient although seasonal turbidity values continually change throughout. Polar ordination indicated that the crustacean plankton community structure was closely related to the first (turbidity) axis. Mean body size was also positively related to turbidity suggesting that reduced transparency in turbid waters might protect large zooplankters from visually seeking fish predators. *Mysis refcta* and *Leptodora kindii*, the two largest species, were most abundant at the lake's turbid (northern) end with declining numbers toward the clear (southern) end. Many smaller copepods and cladocerans showed reduced numbers at the northern stations during the turbidity maximum in early June, possibly because of impaired feeding ability after which they progressively increased through the season relative to numbers in the south. *Daphnia galeata mendotae* failed to show this seasonal increase at the turbid end possibly because of selective cropping by *Mysis* and *Leptodora*. Many species displayed somewhat higher midday vertical distributions in turbid than in clear waters.


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Boehmer, Westneat and Cook (1975)
Burger et al. (1995)
Campbell (1954)
Chevalier, Carson and Miller (1984)
Colby, McNicol and Ryder (1979)
Cooper, Knight and Herring (1982)
Cyrus and Blaber (1987a; 1987b)
Deelder (1970)
Doan (1941)
Everest et al. (1987)
Gamblin, Griffiths and Platts (1987)
Griffin and Van Oosten (1945)
Griffin (1938)
Guebitz (1966)
Harvey (1986)
Herbert et al. (1961)
Koski (1972)
Levinski (1986)
Marcuson (1966; 1968)
Martin et al. (1984)
Mason, Graczyk and Kerr (1991)
McGreer and Munday (1982)
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Murty (1986)
Newcomb and Flagg (1983)
Newcombe (1986b; 1994a; 1994b)
Newcombe and Jensen (1995)
O’Connor, Neumann and Sherk (1976; 1977)
4.3.2 Movements and Avoidance

Behavoir Bisson and Bilby (1982)
Bjornn et al. (1974)
Brannon, Whitman and Quinn (1981)
Crouse et al. (1981)
Cyrus (1983)
Dadswell, Melvin and Williams (1983)
Griffith, Contor and Hillman (1989)
Heimstra, Damkot and Benson (1969)
Hillman, Griffith and Platts (1987)
Lawrence and Scherer (1974)
Matthews (1984)
Miner and Stein (1988a; 1988b)
Noggle (1978)
Ryder (1977)
Servizi and Martens (1992)
Stuehrenberg (1975)
Swenson and Matson (1976)
Whitman, Quinn and Brannon (1982)
Wildish and Power (1985)
Wildish, Wilson and Akagi (1977)

4.3.3 Feeding

Berg and Northcote (1985)
Berkmann and Rabini (1987)
Boehlert and Morgan (1985)
Bolton (1985)
Breitburg (1988)
Brusven and Rose (1981)
Bruton (1985)
Burns (1972)
Crowl (1984; 1989)
Eccles (1986)
Foster (1978)
Gardner (1981)
Godin and Gregory (undated)
Gregory (1991; 1993)
Gregory and Northcote (1993)
Hayes and Rutledge (1991)
Hayes et al. (1992)
Howick (1986)
Johnston and Wildish (1982)
Jorgenson (1966)
Kelley (1959)
Matthews (1984)
Mauck and Coble (1971)
McLeay et al. (1987)
Miller and Menzel (1986)
Minello, Zimmerman and Martinez (1987)
Miner (1990)
O'Brien (1977)
Redding, Schreck and Everest (1987)
Sigler (1981)
Sigler, Bjornn and Everest (1984)
Sloane-Richey, Perkins and Malueg (1981)
Sykora, Smith and Synak (1972)
Vandenbyllaardt et al. (1991)
Vinyard and O'Brien (1976)

4.3.4 Physiology

Appleby and Scarratt (1989)
Auld and Schubel (1974; 1978)
Belding (1929)
Boehlert (1984)
Carlson (1984)
Doudoroff (1957)
Goldes (1983)
Heath (1987)
Heidinger (1976)
Horkel and Pearson (1976)
4.3.5 Sedimentation of Spawning

Sites Burns (1970; 1972)
Chapman (1988)
Colby, McNicol and Ryder (1979)
Dean (1976)
Diplas and Parker (1985)
Doudoroff (1957)
Francis et al. (1979)
Hall (1984a)
Hassler (1970)
Hausle and Coble (1976)
Johnson (1961)
Lisle (1989)
Lisle and Lewis (1992)
McNeil and Ahnell (1964)
Meehan and Swanston (1977)
Morgan, Rasin and Noe (1973; 1983)
Muncy et al. (1979)
Peters (1965)
Phillips (1971)
Phillips et al. (1975)
Platts and Megahan (1975)
Platts et al. (1989)
Reiser and White (1988)
Ringler and Hall (1988)
Savino et al. (1994)
Schubel, Auld and Schmidt (1973)
Schubel and Wang (1973)
Scrivener (1988)
Shaw and Maga (1943)
Shelton and Pollock (1966)
Shepard et al. (1984)
4.3.6 Growth

Alexander and Hansen (1983; 1988)
Bruton (1985)
Buck (1956)
Crouse et al. (1981)
Herbert and Richards (1963)
Sigler (1981)
Swenson and Matson (1976)
Sykora, Smith and Synak (1972)

4.3.6 Survival and Mortality

Bruton (1985)
Canadian Council of Ministers of the Environment (1994)
Chapman (1988)
Committee on Water Quality Criteria (1972)
Hassler (1970)
Hoke et al. (1988)
McQuinn et al. (1983)
Morgan, Rasin and Noe (1983)
Newcombe, Shepherd and Hoyer (1995)

4.3.8 Abundance and Production

Baines and Pace (1994)
Bjornn et al. (1977)
Buck (1956)
Erman and Lignon (1988)
Francis et al. (1979)
Gradall and Swenson (1982)
Gunter (1957)
Klamt (1976)
Konopacky (1984)
Muncy et al. (1979)
Paragamian (1991)
Saunders and Smith (1965)
Sigler, Bjornn and Everest (1984)
Stuehrenberg (1975)
4.4 Invertebrates

Aldridge, Payne and Miller (1987)
Arruda (1980)
Arruda and Marzolf (1984)
Arruda, Marzolf and Faulk (1983)
Bjornn et al. (1977)
Brusven (1970)
Brusven and Hornia (1984)
Brusven and Prather (1974)
Buch et al. (1980)
Carvalho (1984)
Chiba and Oshima (1957)
Chutter (1969)
Cooper (1987; 1988)
Cooper and Bacon (1980)
Cuker (1987)
Cuker, Gama and Burkholder (1990)
Cuker and Hudson (1992)
Culp, Wrona and Davies (1986)
Cummins and Lauff (1969)
Doeg and Milledge (1991)
Erman and Erman (1984)
Edmundson and Koenings (1985)
Ellis and Heim (1985)
Erman and Lignon (1988)
Flint (1979)
Forbes, Magnuson and Harrell (1981)
Gannon and Beeton (1969)
Geddes (1984)
Gliwicz (1986)
Gray and Ward (1982)
Grobelaar (1985)
Hall, Haley and Glason (1984)
Hanks (1976)
Hart (1986a; 1986b; 1988)
Harvey (1986)
Havens (1991)
Herdendorf et al. (1977)
Homer et al. (1990)
Johnson (1971)
Kirk and Gilbert (1990)
Koenings, Burkett and Edmundson (1990)
Larson (1972)
Lemly (1982)
Lenat, Penrose and Eagleson (1981)
Luedtke, Brusven and Watts (1976)
Luedtke and Watts (1976)
Marzolf and Arruda (1980)
McCabe and O'Brien (1983)
McClelland (1972)
McClelland and Brusven (1980)
Mehlhop and Vaughn (1994)
Nuttal (1972)
Nuttal and Bielby (1973)
Paffenhofer (1972)
Rae (1987)
Richardson (1985)
Robertson (1957)
Rosenberg and Wiens (1975; 1978)
Sherk, O'Connor and Neumann (1976)
Threlkeld and Soballe (1988)
Tilzer et al. (1976)
Van Der Lingen (1984)
Von Guerard (1991)
Wagener and LaPierre (1985)
Wallace and O'Hop (1979)
Walton, Reice and Andrews (1977)
White and Gammon (1977)
Williams and Mundie (1978)
Zettler and Carter (1986)
Zurek (1980; 1982)

4.4 Molluscs and Crustaceans

Cobb (1972)
Cooper (1987)
Davis (1960)
Davis and Hidu (1969)
Harrison and Farina (1965)
Hart (1987)
Loosanoff (1961)
Loosanoff and Tommers (1948)
McKinney and Case (1973)
4.6 Water Quality Deterioration

Bartsch (1960)
Basta and Bower (1976)
Brehmer (1965)
Cooper and McHenry (1989)
Cordone and Pennoyer (1960)
Fahey and Coker (1992)
Fairchild et al. (1987)
Geddes (1988)
Gerba and McLeod (1976)
Grissinger and McDowell (1970)
Hellstrom (1991)
Kirk (1985)
Malins et al. (1984)
O’Neil and Scera (1971)
Schiebe, Ritchie and McHenry (1975)
Wallen (1951b)

5.0 WATER QUALITY STANDARDS AND CRITERIA

Alaska Department of Environmental Conservation (1978)
Cairns (1967, 1968)
Canadian Council of Ministers of the Environment (1994; 1995)
Chapman and McLeod (1987)
Chilibeck, Chislett and Norris (1993)
Committee on Water Quality Criteria (USEPA) (1972)
Department of Fisheries and Oceans (1983)
Environment Canada (1994)
European Inland Fisheries Advisory Commission (1964)
Iwamoto et al. (1978)
Kirk and Akhurst (1984)
Lloyd (1985; 1987)
McKee and Wolf (1963)
Ontario Ministry of Transportation and Communications (1980)
Singleton (1985)
Wells (1920)
West (1914)

6.0 REMEDIATION

6.1 General

Anderson (1980)
Avnimelech and Menzel (1984)
6.2 Floating Silt Barriers

Chiliback, Chislett and Norris (1993)
Ontario Ministry of Transportation and Communications (1981)
Rivers and Allen (1975)

6.3 Flushing

Carling (1994)
Cederwall and Svensson (1976)
Meehan (1971)
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Milhous (1990)
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6.4 Mitigative Guidelines

Adamson and Harris (1992)
Agriculture Canada and OMAFRA (1994a; 1994b)
Bethlahmy and Kidd (1966)
6.5 Reservoir Operation

Cassidy and Holmes (1981)
Eustis and Hillen (1954)
Kemmerer and Batten (1982)

6.6 Sediment Traps

Bell, Eadie and Robbins (1984)
Bloesch and Burns (1980)
Chen (1975)
Davis (1978)
6.7 Streamside Buffers

Aull et al. (1980)
Barfield and Albrech (1982)
Barfield et al. (1979)
Barker (1975)
Barling and Moore (1994)
Barton, Taylor and Biette (1985)
Bohn (1989)
Castelle, Johnson and Conolly (1994)
Climnick (1985)
Cooper et al. (1987)
Coutts et al. (1978)
Cramer (1974)
Dillaha and Hayes (1991)
Dillaha et al. (1986)
Ermand, Newbold and Roby (1977)
Ghaffarzadeh et al. (1992)
Gurtz et al. (1988)
Hayes et al. (1979a; 1979b)
Heede (1990)
HSP Inc. (1992)
Kao, Barfield and Lyons (1975)
Kemper et al. (1992)
6.8 Wetlands

Barten (1987)
Boto and Patrick (1979)
Brown (1984)
Burton, Moulton and Kretsinger (1989)
Carr (1994)
Castelle, Johnson and Conolly (1994)
Chescheir et al (1991)
DeLaune, Patrick and Buresh (1978)
Dieter (1990)
Gilliam (1994)
Johnson (1991)
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Jolly (1990)
McIntyre and Naney (1991)
Oakland (1983)
Ontario Ministries of Natural Resources and Municipal Affairs (1992)
Reinelt, Horner and Wittgen (1990)
Strecker et al. (1992)
Striegel (1987)

6.9 Erosion Control

Agriculture Canada and Ontario Ministry of Agriculture and Food (1994a)
Aitken (1936)
Allegheny County Department of Planning and Development (1973) Anderson (1980)
Baldwin and Johnston (undated) Barnett, Diseker and Richardson (1967)
Nova Scotia Department of the Environment (1989)
Ohio Department of Natural Resources (1991)
Ohio State University (undated)
Ontario Conservation Authorities (1981)
Ontario Ministry of Agriculture and Food (1986)
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Ontario Ministries of Natural Resources, Agriculture and Food and Environment (undated)
Ontario Ministry of Transportation and Communications (1985)
Pennsylvania Department of Environmental Resources (1976)
Posey (1957; 1973)
Quigley et al. (1974)
Rogers, Golden and Halpern Inc. (1981)
Sarles and Emanuel (1977)
Sita et al. (1993)
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Stratton (1985)
Swanston (1976)
Swerdon and Kountz (1973)
U. S. Army Corps Engineers (1962)
U. S. Department of Transportation (undated; 1977)
Wildlife Habitat Canada and Ontario Federation of Anglers and Hunters (undated)
Williams (1960)
Glossary of Terms

The following are generalized definitions which are often associated with the topic of suspended sediments and their impacts on aquatic organisms:

**Adsorption** - The adhesion of one substance to the surface of another. Clays, for example, can adsorb phosphorus and organic molecules.

**Allochthonous** - Materials (i.e., organic matter and sediment) that enter a lake from the atmosphere or drainage basin.

**Anaerobic** - Describes the processes that occur in the absence of molecular oxygen.

**Autochthonous** - Materials produced within a lake i.e., autochthonous organic matter from plankton versus allochthonous organic matter from terrestrial vegetation.

**Bedload** - the load of bed material in the bed layer where suspension is impossible for fluid-dynamic reasons. Sediment grains in the bed layer are not vertically supported by the flow but rest on the bed almost continually while sliding, rolling and jumping along.

**Bedload function** - the rate at which various discharges will transport the different grain sizes of the bed material in a given channel.

**Bedrock** - all exposed rock.

**Benthos** - Macroscopic organisms living in and on the substrate and bottom sediments of lakes and streams.

**Boulder** - All rock over 10 inches (25 centimeters) in diameter.

**Buffer Strip** - A vegetation fringe left intact along a stream, river or lake. Buffers protect the aquatic environment by filtering sediments as well as providing erosion control.

**Clay** - A material of organic origin (aluminum silicates) with a greasy feel between the fingers and no apparent structure.

**Current** - a flow of water.

**Detachability** - the ease with which soil particles can be detached and transported. This is an inherent soil characteristic.

**Detritus** - An organic material in which large remnants (sticks, leaves, remnants or decayed aquatic plants, etc.) originating from the metabolic activities and deaths of terrestrial and aquatic organisms, are common.

**Effluent** - Liquid wastes from sewage treatment, septic systems or industrial sources that are released into surface waters.
Embeddedness - Fine sediment deposited between and on the surface of larger substrate particles.

Erosion - Breakdown and movement of land surface, by water, wind, ice and gravity. This process is often intensified or accelerated by human activities. There are two general types of erosion:

(i) Sheet Erosion - detachment of material from the land surface from raindrop impact and its subsequent removal by prechannel and overland flow.

(ii) Channel Erosion - removal and transport of material by concentrated water flow.

Grassed Waterway - A grassed channel that is designed to carry stormwater away from a point where it is likely to cause erosion.

Littoral Transport Rate - The rate of transport of sedimentary material parallel to or perpendicular to the shore in the littoral zone. This is usually expressed in terms of cubic meters per year.

Loading - The total amount of material (sediment, nutrients, oxygen demanding material, etc.) brought into the lake by inflowing stream, runoff, direct discharge through pipes, groundwater, the air and other sources over a specific period of time (often annually).

Longshore Sediment Transport - The mechanism by which material is moved parallel to the coast or shoreline by wave-induced processes.

Macrophytes - Rooted and floating aquatic plants, commonly referred to as waterweeds.

Marl - A light gray, calcareous material derived principally from algal activity and mollusc shells.

Muck (Ooze) - A soft material largely of organic origin with silt and clay intermingled which accumulates on the lake bottom.

Organic Matter - Molecules manufactured by plants and animals and containing linked carbon atoms and elements such as hydrogen, oxygen, nitrogen, sulfur and phosphorus.

Photic Zone - The lighted region of a waterbody where photosynthesis takes place. This extends down to a depth where plant growth and respiration are balanced by the amount of light available.

Riparian Zone - The area where land meets water. It is a transition zone containing both elements of aquatic and terrestrial ecosystems.

Rubble - Rock material between 3-10 inches (8-25 centimeters) in diameter.

Gravel - Rock material between 1/8 inch and 3 inches (in diameter)

Sand - Material of crystalline rock origin less than 1/9 inch (0.3 centimeters) in diameter but still large enough to be palpable as grit.
**Secchi disc** - A metal or wooden disc painted black and white in alternate quadrants, and lowered horizontally into the water column on a marked line to measure water transparency. The average of the depth at which it disappears on lowering and reappears on raising is taken as the Secchi disc reading.

**Sediment** - Particulate matter, transported from its site of origin by air, water or ice, which is in suspension or has come to rest on the earth's surface. This includes bottom material in a lake that has been deposited after the formation of a lake basin. It originates from remains of aquatic organisms, chemical precipitation of dissolved minerals and erosion of the surrounding land.

**Sedimentation** - The process of subsidence and deposition of suspended matter carried in water by gravity; usually the result of the reduction of water velocity below the point at which it can transport the material in suspended form.

**Silt** - Loose sediments, rock particles, mud, clay and other inorganic material of various origins which is finer than sand, settles rapidly and may be transported by bedload movement.

**Substrate** - The materials making up the streambed or lake bottom; usually described as bedrock, boulders, cobble, gravel, sand and silt.

**Suspended Solids** - Silt suspended in the water column is probably the most prevalent of the suspended solids. It generally results from runoff where land has been disturbed by plowing, excavation or erosion.

**Suspension** - A mode of sediment movement in which the particles weight is supported by the surrounding fluid.

**Turbidity** - The degree of opaqueness of the water due to the amount of fine matter in suspension. The particles that cause turbidity may also determine apparent colour.

**Water Bar** - A soil barrier constructed on logging roads, trails and landings to help minimize the volume and velocity of water flowing over exposed soil and divert water to reduce erosion.

**Watershed** - A region or area bounded by a water parting or draining ultimately to a particular course of body of water.