SEDIMENT: THE CRITICAL ASPECT OF FUTURE WATER QUALITY IN THE ASPEN, COLORADO REGION

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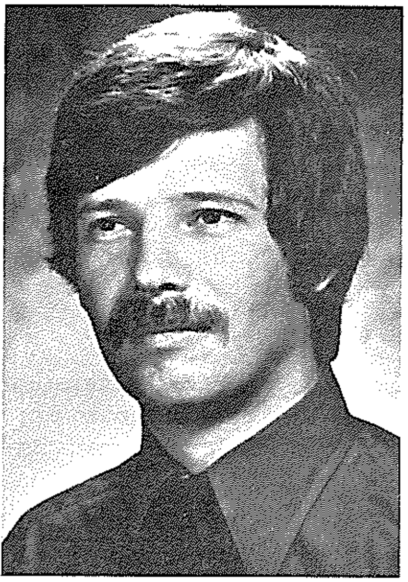
Biographical Sketch



I am a senior, graduating in May from the University of Colorado. I will receive two degrees: a B.S. in Civil Engineering and a B.A. in Russian with a minor in political science. Concentrating on water pollution control, I plan work towards an M.S. in Sanitary Engineering at the University of Colorado starting in September, 1971. Army service, 1960-1963, Washington, D. C. Member of student chapters of Chi Epsilon, ASCE, FWPCA, and AWWA. Also a member of the Sierra Club, Trout Unlimited, and the Federation of Fly Fishermen. Single.

Abstract

The new development of resort and transportation facilities in the Aspen, Colorado area will raise the peak population of the Upper Roaring Fork Valley by over 300% by 1985. This development should avoid degrading the Roaring Fork River because of the river's unique importance for recreation.

This paper discusses possible indicators of environmental impact and assesses the present condition of the river based on available information and observations. It is concluded that the ability of the river to endure new development depends largely on the amount and timing of sediment discharges. Turbidity is proposed as an indicator of environmental impact with respect to the river.

The paper examines problems associated with turbidity from an engineering and and ecological point of view, and identifies the principle sources and causes of sedimentation in hilly terrain. Guidelines are given for earth moving and soil protection related to seasonal variations in the aquatic environment.

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Finally, the paper explores the implications of the legal standard on turbidity, and concludes that the quality of the river is protected if the standard is enforced.

Scope of the paper

This paper discusses the environmental impact of the development in the upper drainage of the Roaring Fork River near Aspen, Colorado, from the standpoint of water quality. Concentrating on the turbidity of the river as one index of environmental impact on water quality, although not the only one, we shall examine the sources, effects, and control of sedimentation which development may produce. Finally, we shall compare the limits placed on the turbidity of the river by its ecology, recreational uses, and the law.

Indices of environmental impact

New development planned for the upper drainage of the Roaring Fork River will provide lodging and slopes for 84,000 more skiers by 1985, as a conservative estimate. This increase of about 300% will come from the development of several areas listed in Table 1.

Construction on this massive scale is reasonably expected to have an extensive impact on the local environment. The specifics of this impact, however, are a matter of guesswork unless we have factual comparisons with the environment that existed prior to construction. The task of halting or repairing environmental damage which careless development may cause will clearly limit the freedom of individuals in some respects, so that there is need for decisions to be as well-informed and equitable as possible.

The indices or indicators of environmental impact which may help to guide these decisions should ideally provide a continuous monitoring of conditions, so that adjustments need not wait until a project is completed. (In the case of Aspen development, that would be a waiting period of fifteen years.) The indicators should also meet four other criteria:

1. They should reveal the impact of development on the most important environmental assets and resources.

2. They should reveal this impact as directly and unambiguously as possible.

3. They should allow quantitative comparisons with the conditions before development, from which qualitative comparisons may be deduced.

4. They should be measurable by competent investigators.

The correct indicators would vary with the type of development and the local environmental resources which are to be conserved. In the Aspen region, these are mainly the resources which are used for public recreation. Table 2 lists the resources, some quality criteria related to use, and some of the impact indicators which seem most promising. Individuals rank them in different orders of importance, so that one should attach no significance to the order in which they are listed in Table 2.

Table 1. New Development Being Contemplated for the Upper Roaring Fork Valley, Colorado.

Area		Capacity
Aspen Snowmass	8,000	(now 7,000; total 15,000)
Aspen Haystack	15,000	to 25,000
Aspen Wildcat	26,000	(initially planned 35,000)
Hunter Creek	10,000	
Owl Creek	10,000	to 15,000
Smith Ranch	5,000	to 7,000
Upper Reudi	10,000	
Total:	84,000	to 101,000

Table 2. Vital Environmental Resources and Environmental Impact Indicators for the Aspen, Colorado Region.

Activity	Asset	Quality Criterion for Use	Impact Indicator
Skiing	Slopes; lifts	Lift lines less than 10 minutes long	Injuries per skier day; seasonal basis
Fishing	Roaring Fork River	Angler spacing over six per mile	Turbidity; B.O.D.; Dissolved Solids
Hiking, Camping	Wilderness trails	Hiker spacing over four per mile	Litter density per mile of trail
Touring	View from Highway 82	Visual amenity	Percent open land converted to motels, trailer courts, billboards

Note: To supply data for a Development Plan, an environmental inventory has been in progress since November, 1969, under the direction of Mr. Charles Wolcott of Aspen.

Table 2 lists only three parameters for evaluating water quality; this list may eventually need to be expanded, for the Roaring Fork River will carry three times its present load of sewage effluent. Certainly no single measurement will do for appraising overall water quality, particularly if the sewage treatment units installed are the package-plant type. Such plants typically operate at about 80% efficiency in removing pollutants, but often range from 50% down to 20% efficiency if neglected.

The ecological effects of sewage pollution are both well known and predictable. How severely turbidity affects an aquatic environment, however, depends on the river in question. We do not suggest that turbidity applies equally well to all rivers as an indicator of environmental impact. To learn whether it applies to the Roaring Fork River, we must consider the nature of the river itself, how sediment might enter it, and what effects the sediment would have.

Description of the Roaring Fork River

The upper reach of the river, some 18 miles between Aspen and Basalt and draining a basin of some 500 square miles, is perhaps most remarkable for its productivity. The unusually large fishery which it supports, over 84 pounds per acre, makes the river quite important to the tourist economies of Aspen and Basalt. Table 3 lists the main wildlife of the river. It is typical of mountain rivers in this region, although the Roaring Fork is perhaps better conserved than most other rivers of its size.

The chief uses of the river are now irrigation and fishing, although it once supplied water for gold refineries near Aspen. Drinking water comes from its tributaries, rather than from the river itself.

Table 3. Principal Wildlife of the Upper Roaring Fork River, Colorado.

Animals:	Muskrats Deer Beavers
Birds:	Ducks Herons Water Ouzels
Fish:	Trout Whitefish Sculpins
Aquatic Insects:	Mayflies Caddisflies (The peak biomass density of these organisms (April) is 30 to 35 grams per square meter; samples show even balance among the families down to the confluence with the Crystal River, where siltation has eliminated stoneflies, mayflies, and most of the caddisflies.

Table 4 summarizes the results of monthly tests conducted by the state health department, based on a three-year average. We may assume that the upper reach of the river is actually purer than shown in Table 4; because in the 44 miles from Aspen to Glenwood Springs where the samples were collected, the river passes three towns, swells from the accession of the Frying Pan and Crystal rivers, warms up, broadens out, and becomes considerably more turbid. Certainly the upper reach is clearer, as we see from Figure 2.

Figure 3 shows the mean flows of the upper reach at two points. First, at the Aspen gauging station. Second, at Basalt some 18 miles downstream. The point of this figure is that there is a large accession of tributary flow along the upper reach of the river. The volume of this accession allows us to predict that disturbed soils in the highlands drained by these tributaries will create a good amount of turbidity in the river below.

Table 4. Water Quality Characteristics of the Lower Roaring Fork River, Glenwood Springs, Colorado. Period 1968-1970.

Characteristic	Range	Mean
Temperature	32° to 69° F	43.9° F
pH	7.4 to 9.4	8.0
Dissolved solids	195 to 430 mg/L	273 mg/L
B.O.D.	0.6 to 2.0 mg/L	1.3 mg/L
Total coliform	17 to 3000 /100 ml	1116/100 ml
Dissolved oxygen	varies with temperature;	saturated
Turbidity	varies with flow; see Figure 2.	

We may conclude that the Roaring Fork is a relatively pure, or very mildly polluted mountain river1/ in a good state of conservation and of much value as an environmental asset. It would make an interesting study to determine its economic worth, although some residents of Aspen regard it as priceless, and we have observed them to treat it as though it were.

Turbidity and environmental impact

We have proposed turbidity as one indicator of environmental impact and briefly described the Roaring Fork River. Let us next consider turbidity itself, from the standpoint of its effects, sources, and control.

A. Measurement of turbidity

Turbidity, the physical measure of light scattering through water, results from suspended solid particles. By far the greatest component of turbidity in natural waters is sediment.

1/ See Smades, 1969.

Turbidity may be measured with either the Jackson Candle, which measures the reduction of transmitted light; or with electronic turbidity meters, which measure the light scattered at some fixed angle. Both techniques are described in Standard Methods. The unit of measurement is the Jackson Turbidity Unit (JTU).

The size of particle transported by water varies roughly with the square of velocity (Leopold, et al., 1964), so that it is not surprising to find that the fuller the river, the more turbid it is, particularly in undisturbed watersheds (Leaf, 1966; Weisel and Newell, 1970). Turbulence keeps most of the finer particles suspended; larger particles bounce and roll along the bottom as bed load when the river reaches about 3/4 bankful (Hynes, 1970).

The net effect is to move the riverbed continuously downstream, where it comes to rest in pools, behind dams, and finally forms deltas projecting into the sea. Our efforts to control this migration fly in the face of inevitable processes which have persisted over geologic time. One may not conclude from this, however, that no harm comes from accelerating these processes; or that attempting to halt them is a waste of money.

B. Prevalence and costs of sedimentation

Turbidity is a much greater pollutant than one might expect, considering the inert nature of most sediment. The cost of clarifying muddy drinking water to the tolerable level of 5 JTU is $15 million per year (NACRF, 1970). A loss of reservoir capacity from siltation of $50 million per year comes at a time when the demand for water supplies is expected to double by the year 2000. The annual volume of sediment transported by water in the United States may amount to about four billion cubic yards, the equivalent of the top 0.4 inch of New Mexico.

The damage to aquatic life is also considerable, although we have no idea what it is worth in dollars. Hynes (1970) and others have observed that silt blankets on stony riverbeds both decrease the fauna and alter it. Very short periods of siltation have reduced the aquatic life of the Oka River in Russia. One study measured a loss in overall productivity of 58% and a 70% decrease of aquatic insects caused by erosion from a highway construction site near the Red Cedar River, Michigan (King and Ball, 1964).

The ecological damage to rivers seems particularly untimely now, when the public demand for outdoor recreation is expected to triple within thirty years (NACRF, 1970). It is temporary, of course; for we know that sediment finally washes downstream, restoring the river to its original state. That is true in the long run only. In the short run, which is the time-scale of living organisms, including people, the sediment may appear to be permanent.

C. Sources and mechanics of sedimentation

There are basically two kinds of erosion: natural and accelerated. The acceleration may be very great. There is evidence, for example, that sediment yields from watersheds undergoing suburban development can be up to 500 times higher than in rural areas (NACRF, 1970). The most careful possible logging in an experimental forest raised the sediment yield about ninefold (Leaf, 1966).

Rainfall has enormous power to dislodge exposed soils. A basin which gets 15 inches of rainfall endures an impact of about one million tons per square mile. The sheet erosion caused by rainfall often comes when the river is low, which greatly aggravates blanketing, bacterial coagulation, and chemical adsorption problems.

Snowmelt, on the other hand, erodes chiefly by means of enlarging its own drainage channels; it also comes in the spring when aquatic organisms are the least vulnerable to turbidity (Hynes, 1970a).

The wash load of turbidity in a stream at any time depends on the rate at which fine particles become dislodged, entrained, and transported from the watershed (ASCE, 1965). This in turn depends mainly on rainfall intensity, ground cover, topographical relief, and the properties of the soil itself, including cohesiveness, size, and specific weight.

The result of all these considerations is that some soils are more erodible than others; but that any soil may be eroded into waterways if it is subjected to enough disturbance.

In summary, we have described briefly the Roaring Fork River, and we have discussed turbidity at some length. We have reviewed the measurement of turbidity; the extent of sediment problems; the damages it can inflict, particularly ecological damages to aquatic life; and last the main causes of accelerated erosion into rivers.

The discussion so far allows us to draw four basic conclusions:

1. That turbidity is sufficiently direct and unambiguous to meet our criteria for indicators of environmental impact. As we have seen, the logging of skiing slopes, clearing of lands for mountain lodgings, building of new roads, and widening of old ones may reasonably be expected to accelerate erosion in the Aspen region. Without a determined and perhaps expensive effort to control it, this acceleration may be great enough to inflict considerable harm on the river.

2. That the main mechanisms of sediment damage would be blanketing, reduction of photosynthesis, and lowering of overall productivity by impairment of sight feeding efficiency. In the presence of three times the current sewage effluent load, bacterial coagulation would heighten the blanketing effects.

3. That the ability of the river to endure extensive development in its drainage basin depends in part on the timing of sediment discharges. That is, the problems caused by sediment are most severe when the river is low, usually in the summer and fall. They are the least severe when the river is high with snowmelt in the spring, for the ecology of the river has evolved under conditions of natural turbidity which are normally prevalent at that time.

4. That turbidity is a central and, to the ecology of the river, a critical aspect of water quality. This is not to say that it alone is sufficient for evaluating the impact of development on the aquatic environment.

D. Control of sedimentation

With these conclusions in mind, let us next consider how engineering skills may serve to control sedimentation in waterways.

This topic has received extensive study since the 1930's from the point of view of conserving reservoir capacity and farmland (ASCE, 1969). Interest in the control of smaller amounts of sedimentation for the sake of water quality is relatively more recent. A 65-page guidebook published last year by the National Association of Counties Research Foundation (NACRF, 1970) gives a good introduction to the problem. A discussion here of the various legal, administrative, and engineering control measures would needlessly duplicate much of the valuable material in this guidebook. Instead, we shall consider briefly the signs of impending erosion problems, and some of the strategies for minimizing them.

1. Indications of sediment problems

The first sign of a problem is likely to be an increase in turbid or muddy runoff after a rainfall (ASCE, 1969). This runoff may be traced upstream to its source to determine whether it is natural or accelerated.

On the land, a first sign is the appearance of V-shaped rills over one inch deep in disturbed soils (Packer and Christiansen, 1964). Shallower rills often start at the tops of slopes but dwindle out; the rills deeper than one inch tend to widen and cut. Observation of various soils and slopes in Colorado shows considerable variation from the one-inch average (plus or minus 75%); but one may take as a rule of thumb that the runoff concentrates enough in rills one inch or deeper to exceed the infiltration capacity of most mountain soils in this region.

These are the two main signs of impending or active erosion, but an experienced eye can usually spot others. For example, any bare, loose embankment may be expected to erode; and whether or not this sediment will enter a watercourse depends on local conditions which one must judge individually, based on common sense and a knowledge of the terrain.

2. Control strategies

The structural measures used in practice to control erosion seek either to dissipate flow energy or to divert it from erodible material. The common structural devices include bench terraces, diversions, downspouts, outlet channels, drop structures, sedimentation dams, and storm drains (ASCE, 1969; NACRF, 1970; McCullough and Nicklen, 1971).

There are also at least six natural impediments to soil transport which are commonly available on construction sites but which are often not utilized.

The following guidelines for logging roads seem to be fully applicable to other earthwork in controlling sediment (Packer and Christiansen, 1964):

1. To minimize the chance for sediment to enter watercourses, avoid disturbing the adjacent soil and cover with equipment. Cuts and fills should be as far away as possible from natural drainage channels.
2. The low point of roads and other graded surfaces should not occur over deep fills.
3. Downspouts may be necessary to protect the face of unstable fills.
4. Logs and slash should be windrowed along the toe of fill areas to trap sediment and dissipate flow energy. Although the faces of fills often have protective rip-rap or vegetative cover, the worst erosion may occur where flows concentrate at the toe. There is no good reason for wasting the slash from right-of-way and cleared lots which could serve to obstruct sediment; yet it is common practice to do so.

Finally, in addition to structural measures, we have operational measures. The imaginative planning of construction phases may frequently take advantage of the seasons to ensure that sediment can only reach the river when it can do the least harm; that is, only during the high-water stages of snowmelt. Slopes should be stabilized with grasses or mulch, and control structures should be in place, before snowmelt ends and certainly before the advent of torrential summer rains.

This principle applies as well to work within live streams. It does not seem to be possible to perform this work during summer or fall without inflicting considerable damage to the river environment. This work should be performed during the late winter or early spring, when aquatic organisms are least vulnerable and before the snowmelt brings heavy ice flows to interfere with construction.

Conclusion: Turbidity and the Roaring Fork River

We have discussed the general problem of sedimentation and some of the control measures which may serve to minimize pollution from sedimentation in rivers. Let us turn finally to the specific case of the Roaring Fork River and the question of what safeguards it has. In other words, does the law protect the river against sediment damages? The whole controversy of pollution and effluent standards is currently receiving much thought, and we do not have a conclusive answer to this question. Instead, we shall briefly compare two ways of interpreting the standard, its implications, and the experience of other states.

The standard on turbidity for the Roaring Fork River reads as follows: (Colorado Water Quality Standards, Section II B, Paragraph 1, c):

> "No turbidity shall exist in concentrations that will impair natural or developed fisheries."

There are at least two ways to interpret the word "fishery" in this rule.

First, it may signify a recreational site; and its impairment would mean that the river is too turbid to be fishable.

Second, the word "fishery" may designate all the aquatic debris, algae, and organisms leading up to fish. Impairment of the fishery in this sense would follow from any increase in turbidity above the historical normal for that time. Significant and noticeable impairment, however, would be associated with the decrease in photosynthesis and sight feeding efficiency which occur at about 5 JTU in the Roaring Fork River.

Both interpretations seem logical, and perhaps both apply. We may conclude in either case that the standard is sufficiently stringent if it continues to be enforced.

There is little doubt that summer and fall turbidities will far exceed the upper safe limit of 5 JTU if the development contractors fail to employ the precautions available to them. In this season, there are enough fishermen on the river to provide continuous monitoring; one may expect that violations of the standard will be traced upstream, reported, and prosecuted. If so, project owners may protect themselves against work stoppages by using pollution abatement engineers (McCullough and Nicklen, 1971), or by otherwise ensuring that their contractors avoid violations of the standard. There is no question that the State Water Pollution Control Division of the health department intends to enforce the standard.

In conclusion, we have seen that turbidity is a significant factor in river ecology and that it may serve as an indicator of environmental impact under certain conditions. Turbidity, however, is only one aspect of water quality, and only one aspect of environmental quality. We should note that the Environmental Protection Agency, which is charged in Executive Order 11514 to develop various indicators of environmental quality, does not rely exclusively on turbidity, or even on water. It seems possible for the Aspen region to undergo considerable crowding, littering, and other forms of degradation without much harm to its river. There may be strips of motels and trailer courts, neon signs, traffic jams, crime, and winter smog without great damage to the river as a recreational asset.

Water, then, is like a key; but not the only key on the ring. To unlock the full potential for a quality environment in America, as we all desire to do, we must turn all of the keys together.

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