The Wilderness Society 4260 E. Evans Avenue, Denver, Colorado 80222
Western Regional Office Phone (303) 758-2266

April 30, 1975

Dr. Robert J. Behnke
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, Colorado 80521

Dear Dr. Behnke:

As you know, The Wilderness Society and four other conservation organizations have appealed the proposed timber management plans of five Colorado national forests, the Arapaho, Routt, Gunnison, Rio Grande, and Grand Mesa/Uncompahgre, to the Chief of the Forest Service, John McGuire. We are now in the process of preparing our case.

The five national forests with plans under appeal contain sixty-six nonselected roadless areas which in turn contain approximately 1.5 million acres of unprotected wilderness lands. Many of these areas exceed 40,000 acres in size, and contain both forested and alpine habitats. The Wilderness Society believes that the Forest Service has committed these areas to timber operations by their action of including their timber in calculations upon which an annual allowable cut is based. In addition, twenty-seven areas have been earmarked by the agency for logging and roadbuilding operations within the next ten years although there has been, as yet, no individual environmental impact statements filed on any of the areas as was required in the court order settling the suit, Sierra Club vs. Butz.

The arguments put forth by the appellants include two areas in which we believe you are qualified to comment. First, it is our opinion that the Forest Service has not adequately considered the environmental effects of the timber plans as is required by the National Environmental Policy Act through the environmental impact statement process. Second, because the impact statements are weakest in the assessment of environmental damage to fish, wildlife, recreation, and water, we maintain that this indicates that the agency has failed to coordinate land management properly with regard to all uses of the forest as it is required to do by the Multiple-Use Sustained Yield Act of 1960.

As you are an aknowledged authority on fish, particularly the native species of the Rocky Mountains, we would like you to examine the environmental impact statements filed by the Forest Service for their timber plans and answer a series of questions which we believe would have bearing on this case.

I believe that you already have a copy of the Final Environmental Statement for the Rio Grande N.F. Timber Management Plan. This should give you a general indication of the environmental impact statements which have been filed. Since we are short of statements, I have xeroxed pertinent sections from the other four statements. For the Arapaho and Gunnison, I have enclosed the entire section entitled "IV. Adverse Environmental Effects". For the Routt and Grand Mesa/Uncompahgre I have enclosed only the portion of the "Adverse Environmental Effects" section which pertains to fish and wildlife. If you would wish to see any other sections or borrow the entire statement, please do not hesitate to contact me and I will see that you get them. In addition I have supplied you with some crude maps which were contained in the environmental impact statements which show the approximate locations of logging sites and roadbuilding areas.

After reading these statements carefully, please answer the following questions. We would appreciate receiving your response within sixty days so that we will have time to prepare our document. Please feel free to include in your answers any information which you feel is pertinent but which we did not specifically cover in the question. And we would like you to be as detailed as possible.

Question 1. The five appealed forests include drainages of the Colorado River (and Gunnison River), the Rio Grande, and portions of the South Platte watersheds. What native trout are indigenous to these areas? What is their present status?

Question 2. The National Environmental Policy Act states that environmental impact statements are to assess possible environmental damage to "the fullest extent possible", a requirement which has been strictly interpreted by the courts. How do you evaluate the treatment of fish in general and native species in particular in these five environmental impact statements?

replacement
temp - turbidity
hydrology

Question 3. In what ways can timber harvesting affect native fish populations? Can native trout be affected even if a strip of vegetation is left untouched along streams? In particular, we would like you to direct your comments to changes brought about by logging itself, changes brought about by road construction, and indirect changes such as opening areas up to grazing. - increased use - [illegible] -

Question 4. Logging operations and road construction often result in new roads and increased access. What are the effects of increased access for fishermen on populations of native fish?

Rio Grande
work
- internalize
- WICHE
-

Question 5. In the areas of wilderness, preserved or unprotected, can native fish species be restocked? Can a restocking program be carried out successfully in developed areas?

1 unique genetic diversity genetic pool potential
2 recreational exp. - place higher value

Question 6. What are the economic benefits of native fish populations? Are they less "valuable" than hatchery raised species or introduced species?

Question 7. Under true "multiple use" management, what do you believe should be the role of fisheries and native populations? What dangers, if any, exist when a single use dominates over the others?

If there are other areas of importance which you do not believe have been addressed in these questions, please make any additional comments which you believe are appropriate. We are very appreciative of the time which you have given us.

Sincerely,

Tim Mahoney

Tim Mahoney
Project Consultant

COLORADO'S

AQUATIC WILDLIFE HABITAT INVENTORY

1. 7,100 miles of trout streams of which 6,300 miles flow through public land and 800 miles flow through private lands which are open to public use by agreement.

2. 45% of the total trout stream milage open to public fishing is made up of headwater streams which are less than 20 feet wide and where fish production ranges from 8 to 60 pounds per mile with few fish ever exceeding 12 inches in length.

3. 38% of the total trout stream milage open to public fishing is made up of streams 20 to 50 feet wide and where fish production ranges from 5 to 100 pounds per mile with few fish ever exceeding 14 inches in length.

4. 17% of the total trout stream milage open to public fishing is made up of streams 50 to 300 feet wide and where fish production ranges from 10 to 200 pounds per mile with few fish ever exceeding 16 inches in length.

5. 5,400 miles of the total streams open to public use are wild trout streams while 1,700 miles are stocked with catchable size trout.

6. Lakes - There are 1,900 high elevation, natural lakes (15,350 acres), of which about 400 lakes are barren. 75 are stocked with catchable size trout and 1,450 are stocked with fingerlings.

7. There are 252 man-made cold water reservoirs and ponds (10,400 acres), 90 of which are stocked with catchables and 162 are stocked with fry and fingerlings periodically.

8. There are 109 man-made warm water reservoirs and ponds (57,000 acres), 28 of which are stocked with catchables (mixed species) and the remainder are stocked with fry and fingerlings periodically.

1 mi. x 8 ft. = 1 acre

16 ft. = 2 ac.

5280 – 52,800 = 1.
15 ft 8
26400 43000.
5280 42240
79200

News of Forestry Research
R. M. F. & R. Exp. Sta.
Apr. 2, 76

Improving & speeding the nationwide inventory and evaluation of forest & related resources - objective of new USDA F.S. R&D program at R.M.F.&R. -- Dr. Richard Driscoll serves as Mgr. for Resources Evaluation Technique Program.

Resources include timber, water, range forage, fish & wildlife habitat & recreation

— Why - National demands for wood & products increasing - . Forest & Rangeland Renewable Resources act of 1974 - USFS required to take a leadership role in making assessments for planning purposes

ROBERT J. BEHNKE

DEPARTMENT OF ZOOLOGY/ENTOMOLOGY

PS:8(75)rev

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26 April 1976

Mr. G. D. Schuder
324 Link Road
Waynesboro, VA 22980

Dear Mr. Schuder:

At your request I will comment on Trout Unlimited's Timber Management Policy.

The U.S. Forest Service, as any large organization attempting to meet conflicting demands, such as multiple-use, suffers from beaurocratic schizophrenia and improved federal legislation is needed to force compliance with their own policies and guidelines in many instances.

For example, at some levels and in some areas, the U.S.F.S. has been a leader in gathering information to implement good multiple-use management to preserve and enhance fisheries values. Your own participation in the Trout Habitat Symposium sponsored by the SE Forest Experiment Station, the policy on fish habitat protection and restoration developed by Region VI of the U.S.F.S. and my own involvement with the U.S.F.S. in writing a manuscript on habitat management for rare trout, are examples indicating a sincere desire by some U.S.F.S. personnel to truly implement multiple-use management with proper emphasis on the aquatic ecosystem.

However, I find again and again that at the local level (district and regional) the administrator-decision makers, fail to carry out these policies and guidelines to protect streams in respect to road building specifications, adequate riparianlvegetation protection and cutting on steep slopes resulting in the loss of populations of rare, native trout.

This is why I believe a new federal law is necessary to force compliance in those regions under the control of the "old guard" forester type.

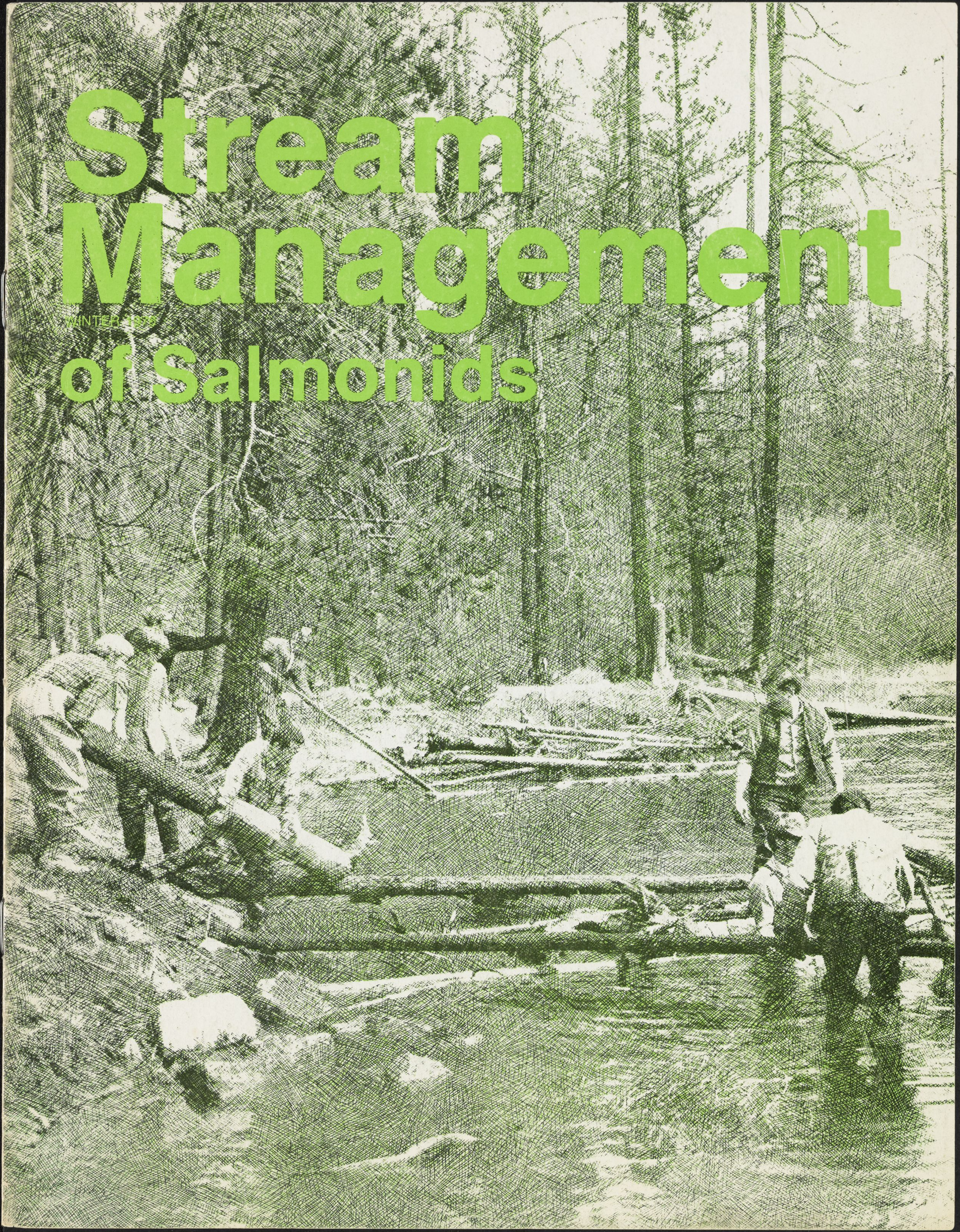
I would urge that a policy be written to the effect that in multiple-use management, any activity must be planned in such a way to ensure that the natural biotic diversity is maintained. This would, of course, protect habitat for threatened and endangered species and protect a watershed from complete devastation.

Sincerely,

Robert J. Behnke

Stream Management of Salmonids

WINTER 1976



A Stream Improvement Project

by William A. Flick

What is more refreshing and tranquil than a stream flowing beneath towering trees with rays of sunlight filtering through and reflecting off the water like millions of miniature diamonds? It is such a spot that fishermen dream about, mentally envisioning the super hatch with the monster trout that finally slides quietly into the net. For the average angler such areas are as rare as the monster trout. The norm is a discolored stream with raw eroded stream banks, a few empty beer cans, and perhaps an old tire thrown in for good measure. Such streams are not aesthetically appealing, nor are they producing trout at maximum capacity. Correcting these conditions and restoring a stream to good trout production are a common goal for fishing organizations, but few fully understand the reasons why a degraded stream is unproductive or what line of attack would be most effective.

Few successful businessmen solve a particular problem in their organization by making changes with out first looking into the many facets that make the business run determining how suggested changes may affect the other segments of the company. These same people, however, in the role of conservationists often neglect to evaluate the complicated makeup of a stream's biological community and the role each part plays in producing a healthy, viable unit. There is far more to improving a degraded stream than building V-dams or planting willows.

A Stream Problem

Let us assume that we are fortunate enough to live in a small community bordering the Adirondacks of New York State where we had moved ten years ago to get the kids and wife away from the city environment with no thought, well almost none, to the presence of a fair trout stream running through the village.

In recent years we have noted a deterioration in the angling and this came to a head last spring during the annual "opening-day fish and drink out." The trout catch on these excursions is always minimal, and the highlight of the day takes place in the warmth of the local pub where the trout are almost always rising. Last year the talk was more serious and centered on the deterioration in the local stream. It was decided, after the second bourbon, to establish a formal organization (a Trout Unlimited chapter, if you like) and contact the State fishery organization relative to improving fishing in the local stream.

In due course proper organization was completed and a professional biologist met with us on the stream. It turned out to be Martin, our local biologist, who is also an avid flyfisherman and possesses a keen knowledge and love of his work. After several stops along the stream we sat down in the shade of an ancient maple that once knew the stream when it harbored only brook trout and ran clear and cool all summer. As we sat enjoying the serenity Martin explained the complex nature of a stream system and how it functions.

The Stream Community

The life in a stream is interrelated and complex. It depends on the basic nutrients, plus radiant energy from the sun, to produce plant tissue. These in turn are utilized by the other portions of the aquatic community, such as the insects. The fish feed on the insects, and mammals (including man) and birds prey on the fish. Waste products (an inappropriate term) and dead individuals are in turn utilized by bacteria and fungi to restore nutrients to the system. This chain of events, which actually is more complicated than described, is often referred to as the food chain or food web, and destruction or reduced populations of one will affect the others.

Most invertebrates and plants require a stable, specific type of environment, and shifting bottom sediments are not favorable to small plants that cling to the stones or to the insects that feed on them. Silt in the water from erosion may smother these plants and insects, or it may cut down on the sunlight necessary for photosynthesis. If the basic food supply for trout is lost, there will not be a thriving population for angling.

The fast water, or riffle area, is often subject to the ravages of high water, but it can also be the most productive food-producing section of a stream in a stable watershed. The currents in a riffle continually bring in fresh nutrients and carry away waste products; the variety of organisms fround in this environment is amazing. Although riffles produce many food organisms for trout, they often lack the shelter these larger members of the food chain require. Thus, a really good stream will have a series of alternate pools and riffles. This factor is very important when looking at a stream relative to trout production.

The importance of a stabilized stream bottom cannot be stressed too strongly. The final product that interests the angler, trout, has an extremely critical stage in the gravel. Loss of natural reproduction for two successive years can seriously deplete the population. To better appreciate the vulnerability of eggs and fry, let us look at their history.

In October or November a female brook or brown trout digs a pit in the gravel. When the nest site is ready the female

COVER PHOTO BY MILTON J. GRIFFITH

releases the eggs, at which time they are fertilized by the male. The eggs sink to the bottom and are then covered with gravel by the female, where they remain until spring. During this period the eggs must be surrounded with well-oxygenated water. Sand or silt settling over the spawning bed during any part of this six-month period can cut off the supply of fresh water and oxygen, and the eggs or fry will suffocate. Shifting gravel can uncover the eggs, or during some stages of development a sudden jar will cause instant death. It is easy to see why a degraded stream may have little natural reproduction.

As fry develop into fingerlings and to adults they are maneuverable but need a good food supply and favorable temperatures. An adequate food supply is dependent upon a healthy stream community; temperatures reflect the amount of groundwater or springwater available and/or the amount of shade to protect the water from excessive heat from the sun.

It is thus apparent that a healthy and viable trout stream is dependent on many factors. A good pool and riffle relationship, whether through natural conditions or man-made structures, will not be a good trout producer if water temperatures are often above 80°F, spawning conditions are poor, or food production is low.

As Martin was filling his pipe a dragonfly floated by on its raft, a peeled poplar stick. Pointing to this beaver stick, Martin exclaimed! "Beaver are becoming more numerous resulting in many small spring tributaries being seriously damaged by beaver impoundments." Tributaries, even though small, can provide spring-hole areas where trout can survive during periods of warm weather and they help to reduce temperatures in the main stream. Beaver dams on these streams, however, can cause increases in water temperature to over 80°F due to sluggish flows with broad expanses of shallow water exposed to the sun as a result of beaver activity. In addition, there is the problem of increased siltation, and in some instances complete blockage of spawning migrations occurs. Large man-made impoundments may be just as bad unless they contain cool deep water utilizing bottom drawoff to keep the stream below the dam cool. Any improperly designed or placed impoundment, even though present for only one or two years, may also flood and drown trees so that shade will be destroyed and the water seriously heated even after the dam is gone. For that matter anything that removes stream cover, whether it is cutting or grazing by cattle, is detrimental to stream temperatures, as well as contributing to increased bank erosion.

A clap of thunder indicated a storm was developing up in the valley and, as we broke up, Martin promised that the department would make an electrofishing survey. This would determine carry-over of trout from one year to the next and evaluate natural reproduction as indicated by the presence of trout below the size stocked annually. Although the department would like to look at the entire stream system in detail, it could not due to the miltitude of environmental programs in progress and the lack of both manpower and money. Martin suggested that our group could play an important role by surveying the entire watershed and mapping areas where cover was lacking, erosion was present, dams were obstructing natural streamflow, or grazing was destroying banks and cover. In addition, data on stream temperatures during periods of warm weather would be extremely valuable. Following our survey, he would help us look over the data and, if warranted, would lay out a restoration program.

The Survey

The next few weeks found us neglecting our fishing as we became engrossed in a project that hopefully would benefit future angling. A U.S. Geological Survey quadrangle map of the area was obtained and teams were selected to cover the various tributaries and the main stream. On a master map we marked areas lacking bank cover, all dams believed to be causing obstruction to fish migration and excessive warming of stream temperatures, areas where erosion was evident, sections that were grazed, areas of the stream which were spread out and extremely shallow, points where the stream split into several channels, and extended sections of riffles. After each warm spell we took a series of water temperatures in the main stream and the tributaries, with particular reference to the points where the tributaries entered the main stream. Before we had finished our survey it was evident that the stream was in much poorer condition than any of us had imagined. In the past we had restricted our fishing to the better sections of the stream and had not fully noted how much was actually unproductive water. We also did not realize how many sections of the tributaries, which are important nursery areas for a stream, were lacking good trout habitat and cover due to old beaver impoundments, grazing, and poor land use. During the same period Martin and his crew, with the help of several club members, electrofished the main stream and tributaries.

In late July again we met formally with Martin and went over the master map and looked at the electrofishing data. We found the stream definitely lacked trout from natural reproduction and that carry-over of stocked fish from the previous year was poor. Obviously something was seriously wrong and from the data it looked as though high water temperatures could be a major factor.

The Program

Martin spent considerable time with us going over various rehabilitation practices and, to the surprise of some members, building of stream-improvement structures was not the first step. The initial projects were to be directed toward improving stream temperatures and stabilizing stream-bank conditions. Although some of the work would not show instant results, it would be extremely beneficial in upgrading stream habitat and would not completely deplete our meager funds. Some stream-improvement structures would be necessary, but they could be spaced out over several years with only key ones started immediately.

Our first step was to contact the various landowners throughout the problem areas we had indicated on the map and explain our objectives to them. This phase of the program was essential as cooperation of farmers and other owners through which the stream flowed was vital to the success of our program. By using a tactful approach, we met little resistance, and in some cases owners volunteered help and equipment. Prior to actual construction of improvement structures we also had to obtain permits from the Department of Environmental Conservation.

Impoundments and Obstructions

The least expensive part of our project was the removal of old beaver dams and obstructions to eliminate areas where water flow was seriously impeded. A couple of potato hooks were broken in this phase of the program but the job went quickly, and, in some instances, improvement of the stream temperature in the tributaries was immediately noticeable. In two sections a chain saw was necessary to cut trees that lay across the stream, causing the stream to split into several channels. In one small stream we actually got in with hoes and shovels and dug out the old stream channel that had become completely silted as the result of beaver impoundments.

Although it was possible to remove a number of old beaver dams, there were two active colonies that required different tactics. We found there was absolutely no use in removing a dam where beaver had set up housekeeping. If we tore out the dam during the day they would patch it up during the night. We also learned not to leave tools around as they would be used for patching material. On one stream the beaver dam was on State land and we contacted the Division of Wildlife to live trap the animals and move them to another area. Removing these animals and then the dam prevented the destruction of a stand of mature trees and restored an important spring brook to trout production. Another beaver colony was on private land and the owner and his wife had initially considered them as sacred as cows in India. After explaining that the flooded trees would take approximately 100 years to replace, they agreed to open the land to trapping during the next beaver season. It turned out this same landowner belonged to a trout fishing preserve in Vermont that subsidized trappers for every beaver they caught. In most instances, at least in the Northeast, beaver and trout are not compatible. The first year or two a beaver impoundment may provide good angling, but the long-term effect is usually detrimental to trout habitat.

Streamside Cover

There were many areas on both the tributaries and the main stream where bank cover was completely lacking. Some sections consisted of exposed gravel where the stream had washed away the organic soil years ago, and in these areas plans were made for planting rooted stocks of purple osier willow (*Salix purperea*) the following spring when they could be obtained from the State nursery. These grow rapidly when planted in a manner that assures continuously moist root systems, and they can reach a height of ten feet in about six years. If sufficient preferred rooted stock is not available, cuttings from native willows can serve the same purpose. Willows grow quickly, provide cover and gradually crowd the stream, thereby reducing channel width. This speeds the current, resulting in the water action digging small pools behind rocks. In addition the roots bind and hold the soil together reducing erosion. In some instances crowding of the stream channel could become excessive and necessitate cutting the willows back, but such a problem would be a welcome change.

We found only two areas where the shoreline contained organic soil suitable for grading and planting grasses, such as reed canary grass or hairy vetch. This was done after spring high waters had subsided and, luckily, rains were sufficient to provide quick rooting. Back from the shoreline a short distance, shrubs, such as silky dogwood and native trees, were planted. Plantings of this type are common in parts of the country where groundwater is abundant and stream temperatures and levels fluctuate only slightly. However, in the Northeast willows are usually preferable.

Fencing

It did not take long to realize that wherever cattle were allowed to graze to the water's edge there was invariably an area of raw bank. It was obvious that if we were going to be successful with our plantings, it would be necessary to make arrangements to fence the area a short distance back from the stream. To accomplish this took a selling job with the farmers, and in some instances we had to furnish the fencing (fortunately one member of the group owned a hardware store and furnished the material at cost). In fencing it was necessary to leave watering areas for the animals in places that they had habitually used. Actually, most owners were completely cooperative when they realized that our plantings and fencing would likely prevent the stream from cutting into their pastureland during periods of floods.

Erosion

Although considerable bank erosion was occurring along the streams with permanent flows, several gullies showed signs of erosion that brought topsoil into the system. A recently logged and burned area likewise needed attention. Plans were made for obtaining larch and pine the following spring to provide stabilized soils in these areas. The Soil Conservation Service was extremely helpful in evaluating this problem and it was found that trees could be obtained from the State nursery.

Spring Holes

Cool tributaries that enter a main stream are collecting points for trout during periods of very warm weather. Such areas may mean the difference between trout survival or summer mortality yet are very often overlooked even by professional biologists. The stream survey indicated cool flowing tributaries were not beneficial to the main stream due to conditions where the two flows joined. At one tributary mouth there was no pool because gravel had filled in what had once been an important spring hole. Here a low log dam was planned for construction in the main stream where a pool would be created at such a location that the cool tributary stream could enter in the still water created by the digging action of the dam. The location of the entrance of the cool tributary water would be very important. Cold water is heavier than warm water, and if currents do not cause mixing the cold water will settle on the bottom, creating favorable water temperatures for trout survival.

At another tributary a gravel bar resulted in the tributary water fanning out in a thin layer so that there was no concentrated flow; the cooler tributary water was thus quickly diluted with the larger flow of warm water from the main stream. Here it was necessary to channel the tributary water to concentrate the flow so it entered the main stream in an area of deep water. In fact, it was only a matter of days before we noted trout concentrating at the point where the tributary entered the main stream. In some instances it is necessary to pipe the tributary out into a quiet part of the pool, but this is only done as a last resort due to problems with the pipe plugging or becoming air-bound.

Stream-Improvement Structures

Martin had indicated to us that stream-improvement structures can increase the carrying capacity of the stream considerably, providing other environmental conditions are favorable, but that they are expensive and do require some maintenance. In addition to increasing the carrying capacity, they are necessary in some locations to prevent bank erosion, reduce the width of a stream channel, provide cover and create pools. Although we had neither the time nor money to start such projects immediately, a series of such structures were planned for the coming years. During the low-water periods of the summer we located on the master map the points where such structures should be constructed.

Bank Erosion

At one point the stream was cutting into a stream bank and each spring fertile loam was falling into the stream and washing downstream. This point was adjacent to an old stone quarry and it was an ideal spot to bring in boulders of assorted sizes to protect the bank. By placing large-size material at the water's edge we not only would protect the banks but would provide good trout habitat.

Another location had a high, eroded bank but the lack of large stone indicated a log crib would be more appropriate. Logs for the crib would come from local cedar or hemlock, but if this had been absent we could have used preservative-treated wood material, but at a greatly increased cost. This structure would have to be securely anchored into the banks and bottom as it would be subject to strong currents during high-water periods. The crib would be filled with stone, and tree plantings would be made along the edge away from the stream to provide shade. This structure would be expensive and would take some time to construct, but it would furnish trout cover, as well as protect the bank.

Just downstream from the crib, additional bank erosion was also occurring. Here a gabion (wire enclosure) was more suitable and would hold stones and rubble in place and protect the bank. This would serve as a deterrent to bank erosion but probably would furnish little in the way of trout habitat.

In-stream Structures

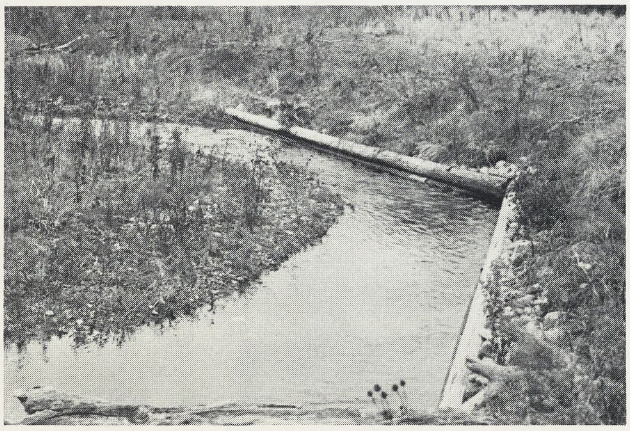
There were several sections of the main stream and tributaries where extended sections of riffle provided little holding water for trout. In these sections we planned to put in low dams which would create pools on the downstream side. Areas of very slight gradiant would be a poor choice since they would merely back water up, causing settling of silt and create little in the way of a pool on the downstream side. The structures would have a low profile (not over one foot) to prevent impounding water behind them. The width of the stream was also considered, since the wider the span, the greater the cost would be.

In the main stream we planned two log dams at suitable locations where the banks were of sufficient height to prevent end runs. As the stream bed was fairly wide, a notch would be cut in the middle of each dam to concentrate streamflows during the periods of low water. The stream bed at the points chosen had fairly loose gravel, and it would be necessary to stabilize the stream bottom on the upstream side by planking to prevent undermining of the structure. In cases where the stream bottom is extremely soft, mud sills can be used as a base for the dam as further protection against undermining. The ends of the dam would be anchored into the banks and the base logs anchored into the stream bottom by pinning the logs with pipe driven as deeply as possible into the stream bed. Since most of the structure would be underwater, native pine or hemlock would be used which would last for many years.

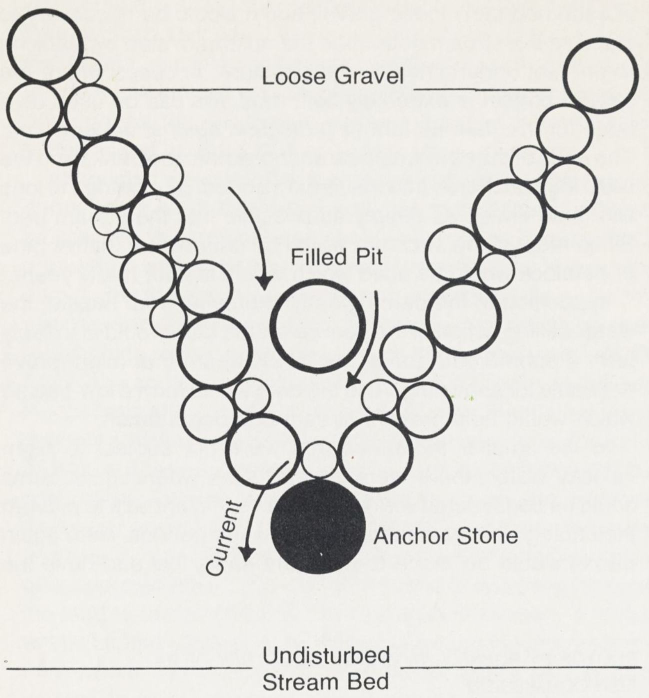
In addition to the dams greatly improving trout habitat, the water-stilling action of the pool below the dam would also likely form a submerged gravel bar downstream that might prove desirable for spawning. Also the dam would form a low-bed sill which would help prevent stream-bed degradation.

In the smaller tributaries that were not subject to high-velocity water, there were several sites where small dams could be constructed with boulders of sufficient size to prevent their being washed out during high-water periods. Here again efforts would be made to keep the dams low and have the

PHOTO BY CHRIS BAKER



PHOTOS BY RUSSELL W. GETTIG, COURTESY OF PA. FISH COMMISSION



water passing through the center of the structure, thus concentrating the streamflow during the periods of low water. Small log dams could also be built on the smaller tributaries with an opening in the center to allow water to spill over in a small area and the turbulence below would dig out a small pool. In all cases, sites and design would be such that water would not flow around the ends and damage the stream banks or cause the stream to change its course.

Deflectors

In the main stream we found several places where the stream bed needed to be narrowed or where several stream channels existed, giving the appearance that the water did not know just where it wanted to go. In these locations a deflector or jetty would be built to direct the flow toward the center of the stream. In one location staggered deflectors would be used on both banks to bounce the water back and forth. These deflectors would be triangular in shape and would be log cribs filled with stone or gabions. Care would have to be used in their construction to prevent undercutting of the structure because stream velocity at such locations would be high and would be interrupting the existing streamflow and would be changing its direction.

Spawning Areas

In the main stream and most of the tributaries there were numerous areas of gravel that would be suitable for spawning once the stream bed had become stabilized as a result of plantings, stream and bank structures, and the removal of beaver dams. In one small stream, however, we had excellent water temperatures and a very stable flow but the bottom was composed of large stones. Some gravel was present but was bound in by the stones, which also prevented trout from digging redds. We were told that little work had been done with improving spawning areas within streams by artificial means. However, Martin indicated some simple structures had been used in a similar situation to improve spawning conditions for salmon in a Canadian stream. We decided to follow that design and cleared the large stones from a V-shaped area. The design was such that the point of the V was directed downstream with an opening of approximately 18 inches at the apex; the base of the V at the upstream side was approximately five feet wide. The stones removed from the interior were used for the walls of the V, and the gravel was then loosened with a pick allowing the sand to wash out. At the downstream end a pit approximately eighteen inches in diameter was dug to a depth of 12 inches and filled with loose, washed gravel. A large stone was placed on the lower side of the pit to prevent the gravel from being washed out. With this design, water would seep through the gravel and hopefully the trout would be as pleased with the structure as we were.

Conclusion

It is still too early to know the outcome of our story since much work remains, but everything points toward an upgraded rather than a degraded stream.

Hopefully trout fishing will improve in the very near future. The bank cover should grow rapidly and small trout are now abundant in the tributaries where at the time we removed the beaver dams there were none. The points where the cool tributaries join the main stream are now holding areas for trout during periods of warm weather, and water temperatures are excellent in all the tributaries and improving in the main stream. The work was not easy and not inexpensive, but improved angling in future years will be ample reward. The ancient maple may not again see a pure culture of brook trout in the stream, but it should see cooler and clearer water, and brown trout from natural reproduction may soon be rising off its roots.

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Stream Management for West Coast Anadromous Salmonids

by David W. Narver

Introduction

Stream management on the West Coast of North America is directed basically towards maintaining or reestablishing as many as possible of the natural attributes contributing to production of anadromous salmonids. Unfortunately, the natural productive capacity of the majority of these rivers and streams has been severely altered by hydroelectric dams, irrigation projects, flow diversions, mining, logging, highway and railroad construction, domestic and industrial pollution, and overfishing. As a consequence, most West-Coast expenditures in what could be broadly classified as stream management have been diverted towards preventive and remedial action of major environmental changes, i.e., screening irrigation ditches and industrial intakes, pollution abatement, spawning channels and hatcheries — the latter often as mitigation for hydroelectric developments. Management of natural streams that have not experienced environmental change has been rare in the West, with the exception of construction of fish-passage facilities over obstructions and development of environmental protection guidelines and/or legislation.

The stakes are extremely high. Annual commercial landings of anadromous salmonids for the Pacific Coast of North America are in the order of 79.5 million fish with a landed value (to the fisherman) of over $200 million (nearly $300 million wholesale). The annual sport catch of salmon and steelhead in recent years is in the order of 2.8 million plus unknown numbers of Dolly Varden and cutthroat trout. The value of this extensive and growing sport fishery is grounds for strident academic argument. Suffice it to say, it is extremely valuable! In addition the annual subsistence catch of salmon by native peoples in 1970-72 was 723,000 in Alaska and about 399,000 in British Columbia.

Average annual commercial landings (000's of fish) since 1966 by state, province and species are:

	Chinook	*Coho*	*Chum*	*Sockeye*	*Pink*	*Steelhead*
Alaska	601.5	1,698.2	5,666.7	14,166.7	23,500.0	2.0
British Columbia	1,302.8	3,969.1	2,922.2	5,566.7	11,100.0	20.0
Washington	478.4	1,485.0	316.7	1,800.0	2,500.0	27.0
Oregon	342.3	1,113.4	—	+	150.0	6.5
California	479.3	313.9	—	—	4.9	—
Total	3,204.3	8,579.6	8,905.6	21,533.4	37,254.9	55.5

Average annual sport catches (000's of fish) in recent years along the Pacific Coast are:

	Chinook	*Coho*	*Other salmon*	*Steelhead*
Alaska	12.7	40.0	56.3	1.4
British Columbia	117.1	215.6	21.6	35.0
Washington	310.8	572.2	127.6	275.0
Idaho	8.7	—	—	21.0
Oregon	160.3	267.2	+	200.0
California	142.2	42.0	—	150.0
Total	751.8	1,137.0	205.5	682.4

This paper is slanted towards the British Columbia experience, a view which probably is not as biased as it first appears. British Columbia has about 16,000 miles of coastline (including major islands), 1600 streams and rivers supporting anadromous salmonids, and a population and industrialization that is large in the south and sparse in the north. Current problems and pressures in southern British Columbia are similar to those that northern California, Oregon and Washington have been experiencing for the last several decades, while current and proposed environmental changes in northern British Columbia are similar to those facing Alaskans now and in the near future.

The orientation of this paper is primarily toward the sport species of anadromous salmonids — chinook and coho salmon, steelhead and cutthroat trout and Dolly Varden. Chum, pink and sockeye salmon will be treated only briefly as they are primarily of commercial interest, even though in Washington, British Columbia and Alaska much of what might be included as stream management (for example, spawning channels and stream clearance) has been devoted to these species. While mention will be made of hatcheries, egg incubation boxes, rearing ponds and other artificial techniques of short-circuiting nature in fish production, I do not consider them as true stream-management technology. In fact some fisheries administrators and managers in the past have opted for the politically expedient path of artificial propagation rather than the more difficult avenue of concentrating on the maintenance of healthy natural streams and fish stocks.

Fig. 1. Fish on! — winter steelhead.

Adult Habitat Requirements

River migration is of major concern

The accessibility of the spawning grounds to adult anadromous salmonids is a basic and long-standing concern. Hundreds of fish-passage devices (ladders, fishways) exist at locations that were originally either complete barriers or restricted fish movement under certain flow conditions. For example, in Oregon alone there are fish-passage facilities at 56 natural and 79 man-made obstructions not including those of the main Columbia and Snake River dams. In British Columbia there are 28 fishways plus many falls where blasting was conducted to help salmon passage. The construction of fish-passage facilities is only appropriate after a thorough biological study of the upstream area to assess the additional spawning and rearing area. A benefit-cost analysis should be the major influence in whether or not the passage is constructed but only after all costs and benefits are taken into account. Much depends on which anadromous species is being managed and what resident species (their recreational potential) exist above the obstruction. An impressive body of knowledge exists for both European Atlantic salmon and North American Pacific salmon on the technical aspects of designing and constructing fishways.

Stream clearance, mainly of old logging debris, is a major activity of every fisheries agency on the West Coast and often constitutes the bulk of stream management. This activity is usually aimed at maintaining or improving passage for adult salmonids but on occasion it may be to maintain or rehabilitate spawning areas.

High temperatures critical

While most adult salmonids can tolerate stream temperatures in the low 70s for short periods of time, ideal spawning temperature is in the mid-50s. Most races are apparently adapted genetically to fairly specific temperature ranges, but, in abnormal years or as a result of environmental change, unusually high temperatures encourage secondary infection and/or delay in migration or spawning. The International Pacific Salmon Fisheries Commission (a joint United States and Canada commission charged with the management and research of pink and sockeye salmon in the Fraser River, British Columbia) built a temperature-control dam and siphon at the outlet of a lake tributary to the Horsefly River. The purpose was to maintain stream temperatures below 57°F to reduce bacterial (columnaris) infections that were thought to be contributing to major pre-spawning mortalities of sockeye salmon (up to 50%). While the temperature-control facility is effective, it turns out that infectious gill disease and perhaps other pathogens, not as strongly influenced by high temperatures, are major contributors to the mortalities.

A largely inadvertent improvement in stream conditions for salmonids occurred in the Sacramento River, California, after Shasta Dam was built. The cooler water provided from deep in Shasta Lake has resulted in increased returns of steelhead and chinook salmon. It is estimated that the steelhead run to the Sacramento may exceed 200,000 in some years.

In general, as discussed later, temperature problems are minimized by maintaining maximum shading on the stream and its tributaries. This means maintaining and encouraging streamside vegetation and discouraging streamside logging, grazing and road building. The primary mode of stream heating is via solar radiation; if you do not want warm water, keep the stream shaded. Some situations are unlikely to be improved. For example, in some summers the Snake River has temperatures in the mid-70s for a few weeks causing the entire Snake River summer chinook run of about 150,000 fish to accumulate in the cooler Columbia River water at the confluence of the two rivers until temperature of the Snake declines below 70°F.

Cover for refuge needed

Adult salmon and trout need cover or hiding areas in the stream during upstream migration. This need depends on time of year and runoff pattern of the stream. In coastal streams for late fall-, winter- or spring-running fish, such as late coho and chum salmon and winter steelhead, cover is less of a problem than for summer- and early fall-running fish, such as summer steelhead, pink salmon and spring and summer chinook salmon. In these streams during the winter months the rivers tend to be high and off-color providing plenty of cover, but in the late summer, when streams are low and clear, cover in the form of log jams, deep pools, white water, boulders and undercut banks becomes critical (see stream-discharge figure). Streams east of the Cascade Mountains (Coast Mountains in British Columbia) have a very different discharge pattern than do the coast streams. These dry interior streams are very low

Fig. 2. Old logging and natural debris forming a complete block for adult steelhead and coho salmon to 8 miles of upstream spawning and rearing area.

and clear during the winter with large freshets in the spring (snow melt) and to a lesser extent in the fall. Winter cover, as well as summer cover, is critical in these streams. Other than to take measures necessary to maintain the above aspects of cover, little active stream management is undertaken in the west. Bulldozers and gabions (rock-filled wire frames approximately 4 x 4 x 8 feet) are used in New Brunswick to create adult holding water for Atlantic salmon, but not on the Pacific Coast. In the west machinery is discouraged from operating in streams, and the rapid and frequent fluctuations of most west-coast rivers probably makes the use of gabions impractical on all but the smallest streams.

An interesting stream-improvement project was undertaken on the Adams River, British Columbia, which produced as many as 15 million returning sockeye salmon in one year (1958). Up to 500,000 sockeye spawn in 2½ miles of stream below Adams Lake — actually about 305 acres of spawining gravel. The lower part of the river divides into two major channels. To ensure a constant supply of water over all of this limited but extremely valuable spawning gravel, flow deflecting weirs were constructed by the International Pacific Salmon Fisheries Commission. These devices appear to have been successful.

Water quality influences adults

The sensitivity of adult salmon to water quality when homing to their natal streams has been demonstrated frequently. Certainly, adult salmon have been killed by a variety of chemicals and industrial pollutants. In addition, the flesh of fish can be badly tainted to the point of affecting palatability for human consumption — a situation that sometimes arises with spring chinook salmon in the Willamette River below Portland, Oregon. Adult chinook salmon in some British Columbia fiords are known to avoid pulp-mill effluent to such a degree that the normal (pre-pulp mill) timing of their migration is affected. Adult Atlantic salmon apparently avoided for a time the Northwest Miramichi River in New Brunswick when old mine waters inadvertently entered a tributary stream. On the same river, changes in the timing of migration of adult Atlantic salmon in the late 1950s were caused by careless spray operations for spruce budworm in which DDT entered the river. This chemical sensitivity of adult salmonids is probably best exemplified by studies done on homing sockeye salmon in Bristol Bay, Alaska, and coho salmon in tributaries of Lake Washington near Seattle. These studies showed conclusively that these fish homed to the tributary from which they migrated to the lake as fry (sockeye) or to the ocean as yearlings (coho) by olfactory perception of aromatic, dissolved organic compounds on which the fish had imprinted at time of migration.

Probably the most noteworthy of the stream-management achievements in recent years in the west has been pollution abatement and the associated recovery or reestablishment of salmon and trout populations. The brightest of these success stories is Oregon's Willamette River — probably because much of the river was dead from a salmonid point of view. This was primarily a pollution-control program that started in the early 1960s and substantially reduced the raw domestic and industrial sewage entering the river. The resulting improved river conditions provided the opportunity to reestablish fall chinook salmon in the Willamette. This race, once exceedingly abundant, was extinct in the Willamette in 1965. By introductions of hatchery stock, the run increased rapidly; in 1974, 34,200 fall chinook passed the Oregon city falls near Portland. Coho, steelhead and spring chinook runs in the Willamette have also increased, in part due to pollution abatement.

While hardly a stream-management problem, the fight to save the dwindling stocks of anadromous salmonids in the upper Columbia River is being affected by supersaturation of nitrogen — the result of numerous hydroelectric dams. Measures to control this problem have met with little success. Well over 90% of the steelhead and chinook smolts from Idaho are not surviving the downriver migration. A short-range step is more downstream trucking of smolts trapped at the mouth of the Clearwater River after they have imprinted on the home stream.

Gravel environment influences reproduction

A primary requirement for the reproduction of stream salmonids is clean gravel from ½ to 5 inches in diameter depending on the species. Clean gravel with high porosity is required for the ready exchange of stream and intra-gravel water — highly oxygenated stream water to the developing eggs and intra-gravel water removing metabolic wastes from the embryos. Much of the focus of anadromous salmonid research and management in the last 20 years in the west has been directed at the effect of gravel quality on embryo and alevin survival and resulting fry quality. This emphasis is largely a result of the readily observed phenomenon that logging, road building, intensive grazing, and mining usually increase suspended sediment loads in streams. Controlled laboratory studies conducted as a result of these studies have demonstrated a close relationship of increasing amounts of fine material (<1 mm) in the gravel and decreasing survival of fertilized eggs to fry. The evidence from field studies, particularly in our frequently fresheting west-coast streams, is not so convincing because of great variation. Primary management efforts have been directed at improved logging methods and keeping road construction away from streams. Concern for the anticipated deterioration of spawning gravel quality as influenced by logging reached a ridiculous climax in the early 1960s in southeast Alaska with the development of the riffle sifter, a hydraulic gravel cleaner mounted on a tank chassis. The fate of this intensive stream-management scheme is vague, but the riffle sifter itself was banished to California some years ago.

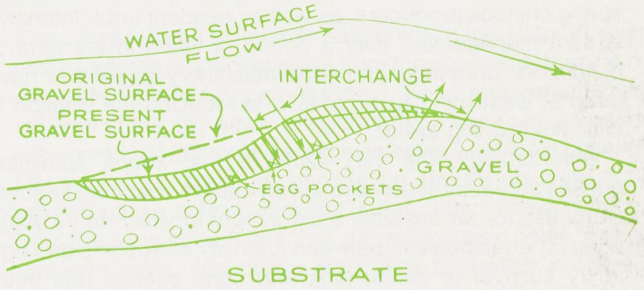


Fig. 3. Diagram of salmonid redd or nest showing the vital interchange between surface and intra-gravel water (courtesy R. W. Phillips).

It may be that in many non-lake coastal streams, characterized as they are by high gradients and frequent freshets accompanied by considerable bed-load movement, fine sediments do not accumulate in spawning gravel, i.e., they tend to

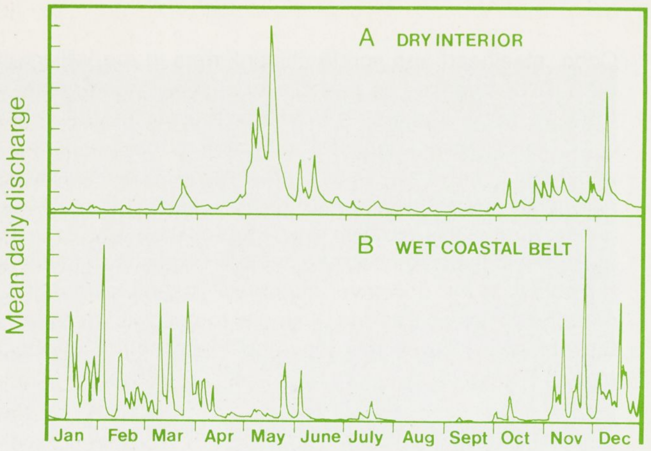


Fig. 4. Generalized mean daily discharge of two similar-sized small anadromous salmonid streams — in the western wet coastal belt and in the dry interior. Note the frequent winter-spring freshets and low summerflow typical of the coastal stream (B) and the spring (snowmelt) freshet, fall peak and low winter flow of the eastern stream (A).

be self-cleaning. However, our interior streams have a very different hydrologic regime (similar to eastern seaboard streams) with a peak runoff in late spring, low discharge all summer, and a small increase in fall prior to freeze-up (see stream-discharge figure). This type of stream may be most severely affected by the accumulation of fine sediment. Severe siltation occurred in the last decade in the Clearwater River, Idaho, as a result of poorly planned logging roads and in the Intiat River in eastern Washington as a result of a forest fire. Both streams are important as summer steelhead and spring chinook producers, as well as resident trout. Intensive stream management over a period of years in the form of bulldozers, drag lines and other machinery appears to have been at least partially successful in reducing the siltation in critical spawning areas.

Unfortunately, the very attribute that keeps spawning gravels of coastal streams relatively clean — frequent freshets — makes for an unstable environment in which to incubate eggs. The relationship between intensity of freshets and egg to fry survival of chum, pink and coho salmon has been documented and surely applies to other salmonid species. Eggs of salmon and trout are deposited from a few to 20 inches deep depending on the species and nature of the substrate. While the situation is complicated, in general, during an intense freshet the top layer of gravel is moving. At points in the stream, influenced by channel morphology and discharge, gravel shifts may occur as deep as two feet. Most anglers have had the experience of standing at the edge of a stream riffle during high water and hearing rocks moving in the stream. It is little wonder that these observations on the adverse influence of fine sediments on the one hand and high flows on the other led biologists, in the 1950s, toward thoughts of flow-control techniques and finally to artificial spawning channels.

Juvenile Habitat Requirements

All of our anadromous salmonids that are of major interest to anglers in western North America spend from three months (fall chinook salmon) to three or four years (northern steelhead) in the nursery streams before seaward migration. One might assume that considerable stream-management efforts would be aimed at this juvenile freshwater stage. While it appears that much can be done in stream management aimed at maintaining or increasing natural salmonid production, the truth is that relatively little has been done on the west coast. Potential stream-management measures can be separated into those directed at summer and winter habitat.

The basic strategy of every individual juvenile salmonid of anadromous stock is (1) to obtain the fastest possible growth with the least expenditure of energy, and (2) avoid being eaten by predators or prematurely transported to the ocean. This requires an abundance of both easily obtained food and readily available hiding places.

Summer growth rate important

The importance of a rapid growth rate cannot be overemphasized. All wild anadromous salmonids have an approximate critical size for seaward migration. Among species that spend at least one year in fresh water, if this critical size is not reached by spring of the first year they may spend another entire year in fresh water with its attendant high mortality rate. This critical length for seaward migration in wild fish seems to be about 60 mm for coho and 110 mm for steelhead on Vancouver Island, British Columbia. However, of any group of smolts only the largest, on the average, survive to adult stage.

Juvenile salmonids in streams are generally strongly territorial. The limiting factor to summer carrying capacity is living space as modified by available food and cover — usually at lowest streamflow in late summer. The growth experienced by a group of fish of a particular age and species in any year has a wide range depending on each individual's ability to locate and defend a feeding station. The smaller and/or later emerging individuals in both coho and steelhead are often unable to establish territories and disperse out of the system — at least until they locate an unoccupied territory. A colleague, Dr. John Mason, has shown that among coho these nomads are entirely viable when placed in an environment with excess living space. The point is that the number and size of territories are closely dependent on the food abundance of the stream. All things being equal (such as adequate cover and parental spawning success) the late-summer standing stock of juvenile salmonids of any species (number of fish per unit area) will be highest in those streams with the greatest abundance of food.

Streamside vegetation plays major role

Juvenile salmonids tend to be opportunistic in feeding habits, utilizing stream benthos (immature aquatic insects) by foraging over the bottom or taking drifting organisms (including the adult or subadult aquatic forms) that have fallen or flown from the streamside vegetation. Regardless of the exact mode of feeding, the energy has been transferred from sun to fish via two basic pathways which are not mutually exclusive. The most important pathway leading to fish food in woodland streams is solar energy — terrestrial photosynthesis (in streamside vegetation) — leaf fall into streams — colonization by microbes (bacteria and fungi) — grazing by immature insects. Thus, in woodland streams most of the insect production is based on leaf litter trapped in the stream. The second pathway leading to fish food is in-stream algae or periphyton (the slime that makes wading anglers curse) which may play a role in the summer as a food source for aquatic insects — its importance depends on how open the stream is to solar radiation, the chemical composition of the stream water, and how much leaf litter is available. Thus the maintenance of deciduous streamside vegetation from a fish-food point of view is a major aspect of stream management.

Streamside vegetation also has a role in shading the stream, thereby preventing excessive temperatures. Studies on the effects of logging show that serious increases in summer daily maximum stream temperatures can occur where the streamside vegetation has been removed, especially in streams with low summer flows. Elevated temperatures are associated with increased metabolic activity on the part of fish, insect life and disease organisms. In some situations salmonid production might be increased by the careful removal of some streamside vegetation to actually warm the water. However, the likelihood of increased secondary infections in juvenile salmonids is real. When rivers get over 70°F dead and diseased fish can often be found. Temperature regulation is another reason for the major role of streamside vegetation in stream management.

A third attribute of streamside vegetation during the summer growing period is its refuge value. Overhanging vegetation, especially trailing in the water, and undercut root systems provide good temporary shelter from predators particularly when these are combined with clean debris accumulations and large, clean rubble.

For these three reasons — food, temperature, cover (in addition to bank stabilization to reduce erosion) — the maintenance or reestablishment of streamside vegetation is a major part of stream management on the west coast. The actual protection of existing vegetation is of primary concern to biologists reviewing logging and road-construction plans. While in some areas and on some streams adjacent vegetation is inviolate, streamside logging is still proposed in most regions.

Management of summer habitat

There are numerous management techniques for maintaining the most effective trophic (food) pathways leading to growth of juvenile salmonids in streams. These include developing streamside vegetation for both optimum leaf litter and temperature, controlling flow, adding suitable rock to increase insect production and/or living space for fish, cleaning gravel to increase insect production, fertilizing to increase algal production and decomposition of leaf litter, introducing organic matter (grain, hay, leaves, etc.) to increase insect production, supplemental feeding of juvenile salmonids, and semi-natural rearing channels. Other than the management and/or protection of streamside vegetation in some areas, none of these techniques are beyond the research stage for west-coast streams and some have not even reached that level.

One of the major problems of west-coast streams is that the vast majority of the organic debris (leaf litter that is the main basis for insect and thus fish production) introduced into the stream is transported out of the system by frequent freshets. Theoretically, stabilized flow projects should alleviate this transport problem, but the negative aspects of flow control in terms of siltation of the gravel/rubble substrate must be kept in mind as discussed earlier. Such flow-control projects should lead to increased insect production. Unfortunately, of the several flow-control projects for salmon enhancement with which I am familiar no adequate assessment of the changes in stream nursery capacity has been made.

The management of streams to increase summer carrying capacity has not been attempted seriously in the west for anadromous salmonids. Such should be relatively easy for juvenile coho that require mainly increased pool/riffle frequency. There seems to be even more possibility of managing the rocky bottom of streams for trout species. Some of our west-coast streams have limited numbers of adult steelhead, apparently because of limited living and hiding places in the stream for age I and II juveniles (parr). Taking a cue from some work being done in New Brunswick for Atlantic salmon, the introduction of large angular rocks in the correct density could be an inexpensive way to create more winter and summer habitat for parr. On the Tracadie River in New Brunswick nine acres of shallow, gravelly river were covered with large angular rocks up to four feet in diameter. Parr density in these areas increased in two years from zero to 30-60 parr per 100 square yards. The benefit/cost ratio is extremely favorable. Some preliminary work in this area is underway in British Columbia and has been conducted in Idaho. The creation of clean, stable debris jams of limb-size material might be practical for some streams and for some species.

There is little research on and no management use is made of fertilization or gravel cleaning to increase insect production in natural streams. However, research on the introduction in the stream bottom of artificial energy sources, such as alder leaves, straw and grain, indicates that substantial gains in secondary production are possible. How much this approach might be useful to management is not clear.

Some research has been, and is being, done on schemes involving supplemental feeding in both natural streams and artificial rearing channels. Initial results suggest marked increases in both average size and standing stock of coho at the end of one summer, but such gains could be nullified by lack of adequate winter hiding space. This area definitely has some important management possibilities but to date has only been followed on a pilot basis.

Management of winter habitat

The primary need of juvenile salmonids in the water in west-coast streams is a hiding place from the constantly fluctuating streamflows and from severe cold. Food requirements are minimal at the low winter temperatures. These refugia needs are somewhat different among salmonids — at least between *Oncorhynchus* (salmon) and *Salmo* (trout). Juvenile coho salmon utilize quiet backwater areas, often some distance from the main stream channel, as well as deep pools, deeply undercut roots, and debris jams. The backwater areas are often dry in the summer with an organic bottom. Juvenile cutthroat and rainbow (steelhead) trout do not use the same quiet backwater areas as do coho, although they will frequent deep pools, debris jams, root systems and small tributaries with much cover. As parr, these trout seem to require large, clean rubble or bouldery areas under which they find refuge. On the coast during the winter an almost continuous stream of wet Pacific storms results in rapidly fluctuating streamflow, and juvenile trout tend to move out of the main stream into small tributaries for the winter. Conversely, in the dry interior streams between the Cascade (Coast Range in British Columbia) and Rocky Mountains winter streamflows become very low and stable with small tributaries shrinking. In adapting to these interior conditions, juvenile salmonids move out of the tributaries in the fall to spend the winter in the main streams. Trout fry use almost exclusively the rock and rubble near the stream margin for winter cover.

These overwintering requirements of juvenile salmonids provide great opportunities for intensified stream management. At present the management emphasis is on minimizing the amount of fine sediment entering the stream, maintaining the natural stream-bank vegetation and preserving small tributaries. Much more positive management measures can be taken.

For coho it is possible to establish winter backwater on the valley floor that is connected to the stream at high water. This could be built under the guidance of a biologist and perhaps an engineer at the time of logging, when equipment is readily available. In Carnation Creek, an experimental stream on the west coast of Vancouver Island, a series of old beaver ponds, dry in the summer, were populated by juvenile coho after the first fall rains. Overwinter survival of coho in this area was over twice that of the entire stream system.

In some stream sections positive management measures also can be taken to improve overwinter survival of juvenile sea-run trout. Perhaps the addition of rock to increase summer carrying capacity might also provide improved winter refuge. Gabions might be useful in some situations in providing better winter cover. Rock riprap along roads has been found to be an important wintering area for juvenile trout; this should provide a hint for future emphasis.

Stream Management and Salmonid Enhancement

Pressures and implications of enhancement

I do not include the actual techniques of artificial propagation under stream management, but the broad ramifications of enhancement schemes, such as hatcheries, incubation boxes and spawning channels, have an extremely important role in stream management. It is important to put these schemes into proper perspective.

The pressures for enhancement programs are very real to anadromous salmonid managers on the west coast. These are a result of both the rapidly appreciating value of salmon and sea-run trout to both commercial and sport fisheries and allied industries as well as some rather recent technological advances in salmonid propagation, i.e., control of hatchery disease and dietary problems, development of efficient, inexpensive egg-incubation systems, the apparent high benefit/cost values of some spawning channels, and the development of improved fish-marking methods, such as the magnetized, color-coded nose tag. Intensive hatchery programs for salmon and steelhead exist in Idaho, Oregon, Washington and California; a ten-year, $300 million federal/provincial salmonid enhancement program is developing in British Columbia; and increasing political pressure to produce more salmonids artificially is being experienced by Alaskan biologists. (The latter with its abundance of lakes and streams is a ridiculous situation inspired in lieu of the severe curtailment of commercial fishing that is severely required but is politically unpalatable.)

The impact of intensive enhancement schemes can be substantial. The broad-scale steelhead hatchery program in Washington, for example, has created annual catches of nearly 300,000 fish but has also assisted in creating a vastly increased number of fishermen, including a segment that can only be classed as meat fishermen. With foreign steelhead stocks being dumped into most western Washington streams, what has happened to the native stocks — those stocks so well adapted to each specific stream? While they still exist in most streams, the best bet is that they ultimately lose out — if not by genetic swamping, then to overfishing for the more abundant hatchery fish. Unfortunately, while there is some evidence supporting both evils, the truth is that we really do not know and are not likely to know without a substantial, long-term research program.

Most of our west-coast river systems contain three to seven species of anadromous salmonids. Once a commitment is made for enhancement in a major river system, it must be on a multi-species, multi-stock basis. Doubling the adult abundance of one species in such a system can spell trouble for other stocks and species. An excellent example is the sockeye salmon of Babine Lake, a tributary of the Skeena River in north-central British Columbia. An $8 million development of three spawning channels has, as planned, doubled the number of returning adult sockeye. Most of this additional production is surplus and must be harvested. Consequently, the gill-net and purse-seine fisheries in the lower Skeena River and nearby marine areas have increased markedly. Unfortunately, other stocks of sockeye, plus several stocks of pink salmon, chinook salmon and summer steelhead, enter the river at the same time as the Babine sockeye. These other stocks and species have not been enhanced and many may now be overfished by the Babine sockeye-oriented fisheries. Gill nets are notoriously poor at selecting between salmonid stocks and species! What sort of stream management is required? Enhance all of the stocks of all the species that share a common time of entry with the Babine sockeye? Perhaps, this is the answer unless the gill-net fishery can be managed precisely enough to permit adequate escapement of all the lesser stocks. This is a hard lesson in what must be avoided in future enhancement programs. A way of avoiding this problem is to undertake enhancement programs on commercial species mainly in isolated, small, single-species systems.

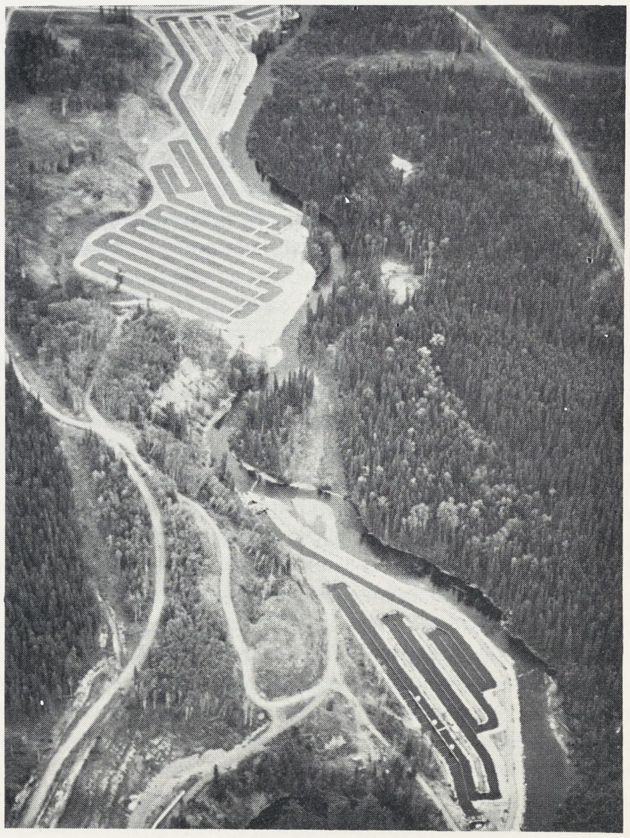


Fig. 5. The two sockeye salmon spawning channels on Fulton River, a tributary of Babine Lake, British Columbia.

Role of spawning channels

Artificial spawning channels have a role in the stream-management program where the natural spawning area is limited or has been damaged and where the nursery area is under utilized. Thus, spawning-channel developments have been aimed mainly at pink and chum salmon whose progeny, after emergence from the gravel, moves almost immediately to the sea and at sockeye salmon (and kokanee) whose progeny moves immediately to lakes. Spawning channels are generally not suitable for species that spend at least one year in fresh water, such as coho and spring chinook salmon. sea-run cutthroat trout and steelhead. They may have some potential for fall chinook salmon whose progeny spends about three months in the river before migrating to the sea. Note that spawning channels have little potential in the management of our major anadromous sport fishes.

About 17 salmon spawning channels are currently operational on the Pacific coast, ranging up to 1½ miles in length and accommodating well over 100,000 adults. Of the 13 in British Columbia seven are for sockeye, one for kokanee (landlocked sockeye), one for chum, three for pink, and one for chinook. Other operational spawning channels are in the State of Washington with one for pink, one for kokanee and two for chinook. These channels operate with a wide range of successes both among sites and among years at a single site. A relatively successful sockeye channel at Babine Lake, B.C., is Fulton River No. 1 where over seven years the average egg to fry survival is 45% (20 to 69%) compared to that of the natural stream (with flow control) of 17% (12-30%). In addition to the successful channels, most agencies have their share of white elephants which were complete failures and are being used as hatcheries, rearing channels, etc.

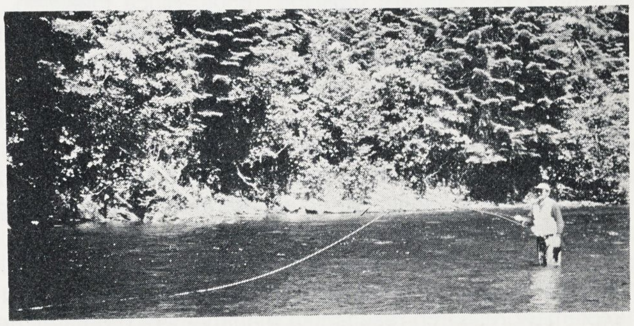
Major problems encountered in development of spawning channels are cover and holding areas for adults, achieving adequate distribution of spawners, composition of gravel, gradient, temperature embryo development rate, and accumulation of organic (mainly algae) and inorganic fines as a result of controlled flow (no cleansing freshets). Of these problems the last two seem to have the greatest potential for continuing concern.

If the temperature regime of the artificial spawning channel does not match that of the natural stream, fry may enter the nursery waters too early or too late. On average the peaks of natural fry migration into the lake (sockeye) or ocean (pink and chum) coincide with the development of the spring bloom of zooplankton. Entry of fry into the nursery waters too early may be more critical than when it is too late. Unfortunately, in engineering these long concrete-and-gravel channels, it is extremely difficult to design for an absolute replica of the temperature regime in the natural stream. Further, nearly all spawning channels are devoid of any shade, making conditions (temperature and light) optimal for algal growth.

Essentially all spawning channels are designed to provide two attributes: clean gravel and flow control. As has already been pointed out, in natural streams these are somewhat mutually exclusive. It turns out that the two are also difficult to obtain simultaneously in spawning channels. The flow-control aspect is designed to minimize freshets that cause shifts in spawning gravel. At the same time it is those very freshets in a natural stream that act to keep the spawning gravel clean. The problem of maintaining high-quality gravel is very real; in the absence of freshets the spawning gravel accumulates fine organic material. As a result the survival of eggs to emergent fry in most artificial spawning channels drops rapidly over a short period of years *if the gravel is not cleaned artificially*. For example, in the Fulton River channel No. 1 (Babine Lake) the survival dropped progressively from 1966 to 1968: 69, 49, 45 and 20%. Annual cleaning was started after 1969 with substantial improvements in survival. In most channels cleaning entails the physical removal of the gravel or at least the disturbance of the gravel with mechanical or hydraulic techniques accompanied by highest possible flow.

Conclusion

The art of stream management for anadromous salmonids in western North America is really not very far advanced. Most stream-management effort has been negative in the sense of struggling to maintain the attributes of the natural stream in the face of possible environmental change caused by logging, road building, mining, agriculture, grazing and urbanization. In fact, to a degree, some fisheries administrators have abdicated much responsibility for stream management in favor of the politically expedient route of hatcheries. Most positive stream management on the west coast has been in the form of fish-passage facilities and stream clearance. Relatively little has been done in other areas of stream improvement, such as stream-bank plantings to provide leaf litter and temperature control, manipulation of stream morphology to provide more hiding and feeding areas for fish, and fertilization and/or introduction of organic detritus to increase insect production. These have all been shown to have potential, at least in other areas of North America, and await development, testing and evaluation for use in the management of anadromous salmonid streams in the west.



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Dr. Narver was born in Portland, Oregon, and served in the U.S. Air Force. He became a Canadian citizen in 1973. He takes an active interest in fishing in addition to his professional involvement.

His professional work and scientific publications include studies related to the sockeye salmon in Babine Lake; the effects of logging on stream salmonids; the sockeye salmon in Alaska; and other studies on steelhead, rainbow, and cutthroat trout.

Protection of Salmon and Trout Streams in Logging Operations

by Richard L. Lantz

Resources produced in a watershed are interdependent and the activities of man in utilizing one resource can affect others. Therefore, watershed management in the broad sense is concerned with all of man's terrestrial activities that can impact water quality and aquatic resources. This subject encompasses many areas of concern, from agriculture and overgrazing to zoning for subdivision control.

In the Pacific Northwest, logging is one of the major activities that can affect aquatic resources. Industries based on timber and fish have flourished in the Northwest since pioneer days, and these industries are still vitally important to our economy. However, as we make more demands on, and become more aware of, our environment, logging practices that were acceptable or overlooked in the past are no longer acceptable to a concerned public.

Research into the impacts of logging on the aquatic environment was sporadic until the 1950s. Since that time, a number of agencies have become involved with research into the effects of logging and road construction on fish and their habitat. Examples of such studies include work done in Alaska (James, 1956; Meehan et al., 1969; Sheridan and McNeil, 1968), British Columbia (Narver, 1972), Oregon (Brown, 1973; Fredriksen, 1970; Froehlich, 1971; Hall and Lantz, 1969; Rothacher et al., 1967), and northern California (Kopperdahl et al., 1971; Burns, 1972).

As knowledge increased and public concern resulted in legislation establishing water-quality standards, methods to implement research results into management programs developed. In Oregon, the Wildlife Commission (now the Department of Fish and Wildlife) completed guidelines for stream protection in logging operations (Lantz, 1971) as the result of a long-term research program on the central Oregon coast.[1] The guidelines were endorsed by the Department of Forestry, and passage of the Oregon Forest Practices Act in 1971 added impetus to coordination and implementation efforts.

Research has shown that forestry and fishery management need not conflict. It is possible to manage watersheds for the continued production of timber, fish and high-quality water. However, protecting streams requires considerable effort and active on-the-ground coordination between state and federal land-management agencies and private industry. In Oregon, emphasis has been placed on prevention of physical damage to streams rather than on rehabilitation.

To provide some perspective on the subject of protecting salmon and trout streams in logging operations, we will briefly consider the freshwater requirements of salmon and trout, the basis for stream protection, results and management implications of Oregon's research into the effects of logging on aquatic resources, implementation of the Oregon Forest Practices Act and efforts of federal agencies concerned with timber harvesting to provide increased protection for water quality as part of their land-management programs.

The Freshwater Requirements of Salmon & Trout

The West Coast Douglas-fir region supports five species of anadromous salmon and two species of anadromous trout as well as resident fish. Resident fish remain in freshwater all their lives, but those that are anadromous come as adults from the ocean into freshwater streams to spawn (Figure 1). Anadromous salmonids of particular importance in Oregon include coho (silver) and chinook (king) salmon, steelhead trout (winter- and summer-run fish), and coastal cutthroat trout. Their young live in freshwater streams for at least one year before going to the ocean and can be affected by logging operations. Therefore, it is important to protect the stream environment at all times of the year.

Salmon and trout require a high-quality environment, preferring clean, cool, well-oxygenated streams. Adults move onto gravel beds during the fall and winter when streamflows are high, and spawning gravel requirements are relatively critical (Figure 2). The female chooses a site for spawning, periodically turns on her side, vigorously arches her body, and loosens the gravel with her body and tail movements. Soon she has completed digging a spawning nest, called a "redd". Once the nest is ready, spawning can take place. After spawning, the female moves slightly upstream and dislodges gravel onto her eggs. Hatching time is dependent upon water temperature, and in Oregon's coastal streams, juvenile salmonids normally absorb their yolk sacs and emerge from the gravel into the stream within three to four months.

Small headwater streams are major producers of salmon and trout (Figure 3). In many cases, such streams contain most of the spawning gravel found in large river systems. Most of Oregon's salmon and trout production comes from these upstream watersheds, the majority of which are forested. Conflicts can arise because such streams look insignificant in the late spring and summer when many logging operations are under way, but the same streams are significant in the fall and winter when adult fish are moving upstream through high water to spawn. Protection of such streams is vital to the

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[1] This article summarizes concepts developed in the guidelines and implementation procedures outlined in a presentation at the 1974 Wild Trout Symposium sponsored by Trout Unlimited.

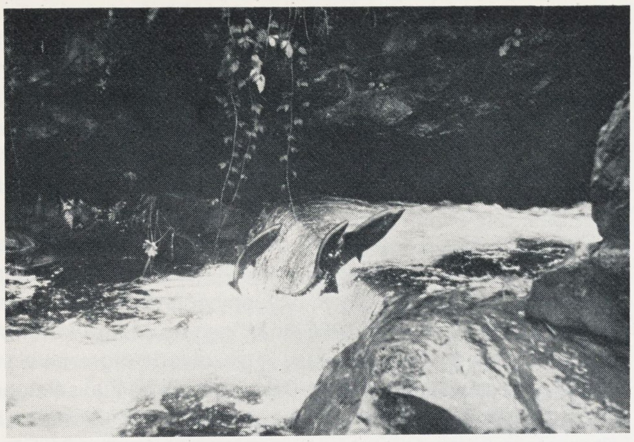


Figure 1. Coho salmon adults move upstream from the ocean into small coastal tributaries to spawn. Courtesy of U.S. Forest Service

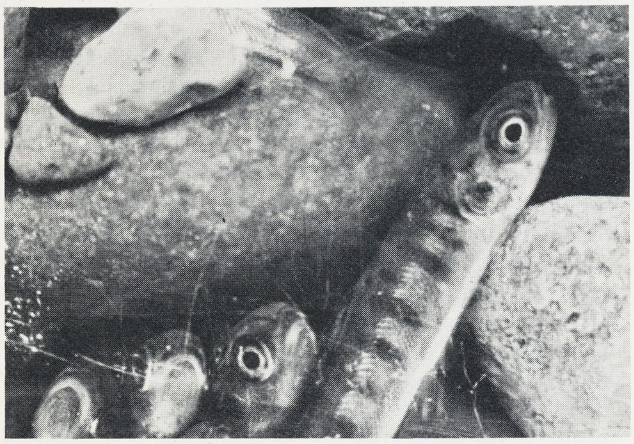
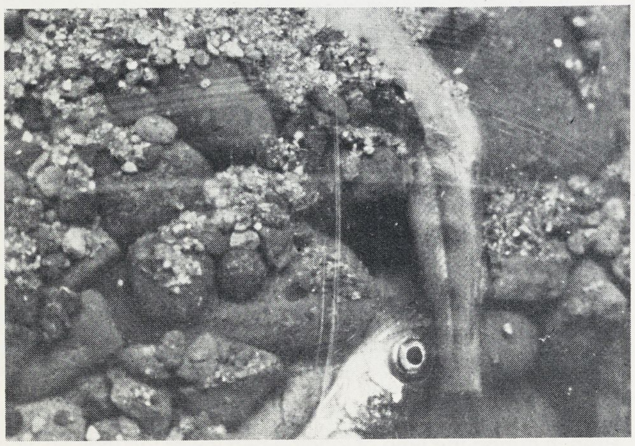


Figure 2. Clean gravel that does not contain fine sediment results in the best survival of eggs and fry (above). In contrast (below) sediment has filled in the gravel where juvenile coho salmon were developing. When the time came to move out of the gravel and into the stream to feed, the fish were trapped and died. This can be an important mortality factor (Phillips et al., 1975).



continued natural production of salmon and trout.

Except for a few fisheries, the bulk of the Pacific Coast catch of salmon and trout is a result of natural reproduction. Loggers sometimes suggest that habitat damage is unimportant because someone can always build another fish hatchery. It is important to understand that hatcheries play a significant role in fishery management, but that they supplement natural reproduction and do not replace it. In addition, maintaining a hatchery involves many costs that are not present when fish spawn and rear under natural conditions, and adequate hatchery sites are limited. Therefore, again it should be emphasized that the future of the majority of our salmon and trout resource depends upon how streams are protected.

Streams are Public Resources

Oregon's streams, and the fish in them, belong to the public regardless of who owns the adjacent land. When logging activities affect a stream, resources that belong to all of us are affected.

Laws exist that protect fish and the water quality of streams. For example, the 1967 session of the Oregon legislature authorized the State Sanitary Authority (now the Department of Environmental Quality) to formulate water-quality standards. General water-quality standards developed since then establish specific limits below which Oregon's water will not be degraded and provide for fines and/or jail sentences for each day of violation. Special standards supercede general standards and have been developed for some Oregon rivers. It is also important to note that our water-quality laws contain a non-degradation clause which says that emphasis will be on preventing water-quality changes and maintaining a quality environment rather than on attempting to correct problems already created.

Figure 3. Small streams can be important spawning and rearing areas for salmon and trout and should be protected.

Of particular importance to fish and the timber industry are standards relating to stream temperature, dissolved oxygen levels in surface waters, and suspended sediment loads. Oregon's general water-quality standards state that water temperature changes cannot exceed 2°F in any case, and where temperatures are already 64°F or above no change is allowed. Dissolved oxygen levels cannot be reduced below six parts per million. On those streams where turbidity standards apply, suspended sediment loads cannot be increased above natural background levels (i.e., the level upstream from the activity causing concern) when the background is less than thirty Jackson turbidity units (J.T.U.). When the background level is above 30 J.T.U. a 10 percent increase is allowed. Jackson turbidity units are a visual measure of suspended sediments now accepted as the standard in Oregon. Changes exceeding such standards have been known to occur after logging has taken place in a watershed.

Research Results & Management Implications

The Alsea Watershed Study, a long-term interagency research program in the Douglas-fir region of the central Oregon coast, was initiated by the Governor's Committee on Natural Resources in the late 1950s. Pre-logging studies began in 1958, access roads were constructed in 1965, logging took place in 1966, and post-logging field studies were terminated in 1973.

The broad objective of this program was to evaluate the effects of two patterns of clear-cutting on water quality and fish populations in three small headwater streams. These streams are all relatively small, with minimal summer streamflows ranging from 0.1 to 0.2 cubic feet per second (cfs). For perspective, 0.01 cfs is slightly over four gallons per minute or about the flow one would get from a garden hose, and yet these streams support good spawning populations of coho salmon and coastal cutthroat trout each winter.

Clear-cutting of an entire watershed (Needle Branch — 175 acres) where no streamside vegetation remained was compared to clear-cutting in patches on a larger watershed (Deer Creek-750 acres) where about 30 percent of the area was harvested from three units and vegetation was left along the stream (Figure 4). The third watershed (Flynn Creek-500 acres) remained as an unlogged control unit. A control stream was needed to insure that any changes observed were due to logging activities and not to natural variation. After logging took place in 1966, major changes in the physical environment of the stream draining the entirely clear-cut watershed were documented. By comparison, changes that occurred in the stream draining the patch-cut watershed where streamside vegetation remained have been relatively minor.

Primary changes noted in the stream environment following logging of the Needle Branch watershed included: (1) a significant decrease in dissolved oxygen content of surface waters during the summer of 1966 when logging debris was in the stream; (2) a long-term decrease in dissolved oxygen levels in the sub-gravel waters measured during the time that salmonid embryos were developing in the gravel; (3) an increase in stream temperatures from a pre-logging maximum of 61°F to a post-logging maximum of 85°F with daily fluctuations as high as 29°F after logging compared with pre-logging fluctuations of 4°F or less; (4) an increase in suspended sediment loads.

Coastal cutthroat trout populations, as estimated from mark-recapture data during the summer low-flow period, decreased to about 30 percent of their pre-logging levels for eight years after logging occurred in the Needle Branch watershed, and there is no indication that trout numbers are yet returning to pre-logging population levels (Figure 5). In contrast, coho salmon were less affected by logging in the Needle Branch watershed and their response to logging was more variable than that of cutthroat trout. Coho biomass and net production rates increased in Deer Creek and Needle Branch following logging. However, average lengths, weights and condition factors were low in coho juveniles the summer after logging occurred, and coho fry and fingerling that reared in Needle Branch during the time of logging had lower fecundities when they returned as adults (Moring & Lantz, 1975).

The four physical changes that occurred in the stream draining the completely clear-cut watershed could have largely been avoided. Each change has implications for stream protection and management, and each will be discussed. In the aggregate, these alterations could have been minimized by (1) keeping streamside vegetation intact, and by (2) taking precautions to control soil disturbance and erosion, particularly that associated with roads.

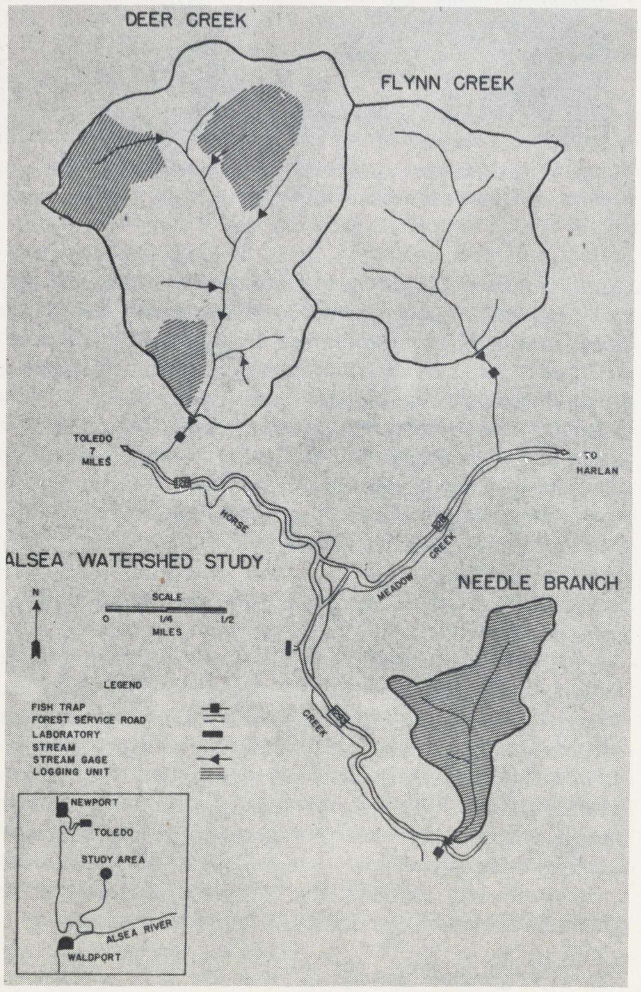


Figure 4. Map of the Alsea Study watersheds.

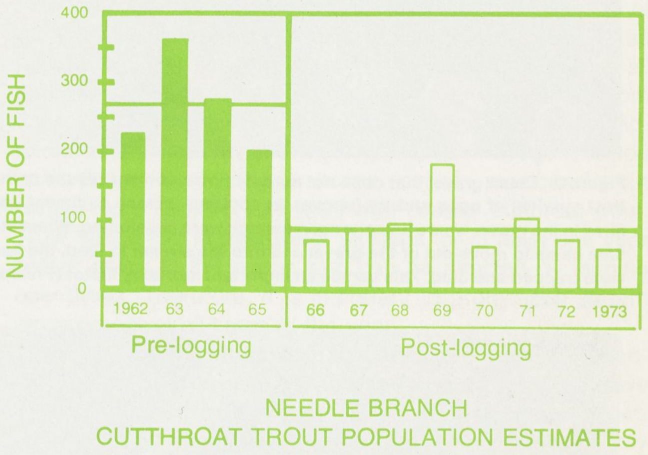


Figure 5. Coastal cutthroat trout populations in Needle Branch decreased after the entire watershed was logged. Comparable changes did not occur in either Deer or Flynn Creek.

Surface-dissolved oxygen refers to the amount of oxygen available in the surface waters of a stream. Dissolved-oxygen levels less than one part per million were recorded in Needle Branch during the summer that logging occurred, and low levels persisted for several weeks in about one-third of the stream available to salmon and trout. Juvenile salmon placed in this portion of the stream quickly showed stress symptoms and died, but fish were able to survive above and below the area of oxygen depletion. A substantial improvement in oxygen content of the surface waters was noticed after debris was cleared from the stream in mid-September. Oxygen returned to approximately pre-logging levels by November with the advent of the high streamflows. Surface-dissolved oxygen levels since that time have remained high, and are comparable to levels in the stream draining the unlogged watershed.

The dissolved-oxygen decrease could have been avoided if logs and logging debris had been kept out of the stream at all times. Logging debris ponded the stream and it could not reoxygenate itself by flowing over riffles. Therefore, every effort should be made to keep debris out of streams in order to maintain adequate oxygen levels, provide access to spawning grounds for adults, and to keep migration routes open for juveniles that are moving to the ocean.

Salmon and trout eggs need adequate dissolved oxygen in water flowing through stream-bed gravel in order to hatch and develop. A substantial reduction of dissolved oxygen in the water flowing through gravel in Needle Branch was documented after logging occurred. The oxygen decrease occurred during the time that eggs and young salmon and trout were developing in the gravel. Oxygen levels in the sub-gravel waters have remained low for a number of years after logging. There were no comparable changes in the streams draining the patch cut and unlogged watersheds.

Decreases in sub-gravel dissolved-oxygen levels can be associated with increases in the amount of organic debris in the gravel environment following logging (Figure 6). In practical terms, this means that yarding through a stream or felling timber into a stream should not be permitted. Such practices break down stream banks and streamside vegetation and deposit bark, needles, and twigs in the stream bed. For fish-habitat protection, trees should be felled and yarded away from the stream channel.

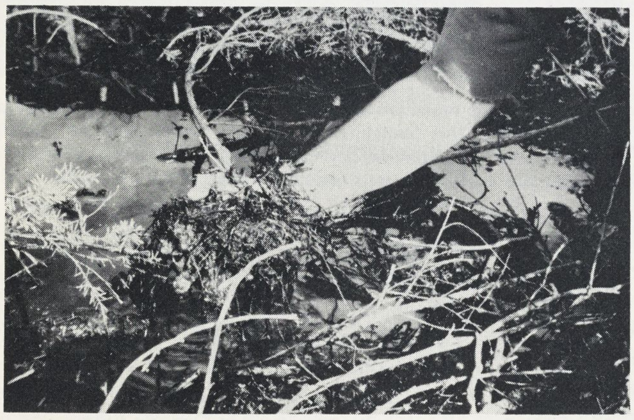


Figure 6. Felling trees into the stream channel deposits material in the stream bed. Yarding through streams breaks down stream banks and knocks down streamside vegetation. The organic debris and sediment brought into the gravel environment can result in a decrease in sub-gravel dissolved-oxygen levels. Trees should be felled and yarded away from streams.

Salmon and trout are poikilothermous (i.e., their body temperature is normally about the same as that of their environment). Therefore, stream temperature increases can affect salmonid populations in numerous ways, many of which are detrimental. For example, high temperatures can kill salmon and trout directly, increase the virulence of many diseases of fish, provide a habitat that favors less desirable species, such as dace and suckers, inhibit spawning activity or block spawning runs into a stream, affect the quality of food available, and alter the feeding activity and body metabolism of fish (Lantz, 1970). Therefore, temperature changes can influence the productivity of a stream by affecting the number of fish or the species present and their physical condition.

Water temperature increases are caused primarily by increased exposure of a stream to the sun's rays (Brown, 1971). Thus, the shade provided by streamside vegetation is the most important factor influencing changes in water temperature over which the land manager has some control, and canopies of vegetation should remain along streams in all logging operations where fish and water-quality considerations are involved or can be affected in downstream areas (Figure 7).

Figure 7. Keeping streamside vegetation intact will eliminate or minimize three of the four major stream habitat changes associated with logging on the Needle Branch watershed. Removing streamside vegetation can influence water quality and also eliminate important wildlife habitat.

A relatively narrow vegetative buffer strip can often provide the shade needed for fish-habitat protection and will also reduce stream-clearance needs and dissolved oxygen problems in surface and sub-gravel waters. It is not necessary to leave commercial conifers along the stream if shade can be provided by shrubs and other less valuable species and if the conifers can be removed without damaging or destroying streamside vegetation.

From an economic standpoint, fishery values can often equal or exceed the value of commercial Douglas fir within 100 feet on either side of a stream. This is the conclusion reached in a technical report prepared by the Bureau of Land Management (Sadler, 1970). Similarly, an economic evaluation in Washington concluded that 100-foot-wide vegetative strips, which included commercial timber, yielded a benefit/cost ratio of 1/1. However, 50-foot-wide strips containing commercial conifers yielded a benefit/cost ratio of 2.5/1 in favor of fish-habitat protection. Partial buffer strips 50 feet wide, where the more valuable commercial trees were selectively removed, resulted in an 11.3/1 benefit/cost ratio favorable to the fishery (Gillick et al., in press). Therefore, there can be no doubt that buffer strips of streamside vegetation are an important watershed management tool; and that salmon and trout produced in streams, which usually occupy about 0.5% or less of a watershed's surface area, yield a significant annual economic return to society.

Corridors of streamside vegetation are also important to wildlife. Such areas are used by elk and deer as travel lanes, provide cover near a water source, and increase the variety of habitat available to all species near recently logged units. Under intensive forest management, streamside corridors are one area where snags can be left for cavity-nesting birds and other non-game species. Leaving non-commercial streamside vegetation intact provides many benefits and begins to approach true multiple-use management of the natural resources produced on our watersheds.

Increased sediment loads into streams can have detrimental effects on fish, their habitat, and their food (Cordone and Kelley, 1961). Muddy stream conditions can also seriously disrupt sport fishing and angler success and have an adverse impact on local economies that rely on water-oriented recreational uses.

Although erosion occurs in undisturbed watersheds, man's activities within a watershed often accelerate erosion and increase stream sediment levels when compared to undisturbed areas (Fredriksen, 1970). Increased erosion and stream sedimentation can occur from a number of causes including yarding activities, landing failures, exposure of soil from slash burning, and inadequate or untimely road maintenance. However, no forest-management activity carries with it more potential for soil and water degradation than does road building (Bakke et al., 1973).

Landslides associated with logging roads are a significant source of stream sedimentation throughout the Northwest (Figure 8) and can eliminate some of the benefits derived from other positive land-management practices, such as maintaining buffer strips. For example, during a cooperative study of the effects of logging on a small tributary to the North Fork of the Coquille River, streamside vegetation remained intact following logging of a 100-acre clear-cut. However, two major landslides from roads reduced coho-salmon fry populations from more than 1,000 fish before logging to about 60 coho in the 1,000-foot study unit after the road failures. Removal of large logging debris from the stream cost the administering agency $46,540 — or more than 12% of the value realized from stumpage for the entire 100-acre unit. There was no way to remove sediment from the stream-bed gravel.

The sheer size of Oregon's logging road system illustrates the scope of the potential for watershed degradation. Currently, there are about 110,000 miles of logging roads in Oregon (EPA Region X Report, 1975). This compares to a total of about 36,000 miles of state and county roads. In addition, there are approximately 3,500 miles of new logging roads built and over 2,000 miles rebuilt each year. In other words, at the present rate, every seven years there are more miles of logging road built and rebuilt in Oregon than miles of road currently existing in county and state ownership. Much of the logging-road construction is in steep country with at least pockets of unstable soil.

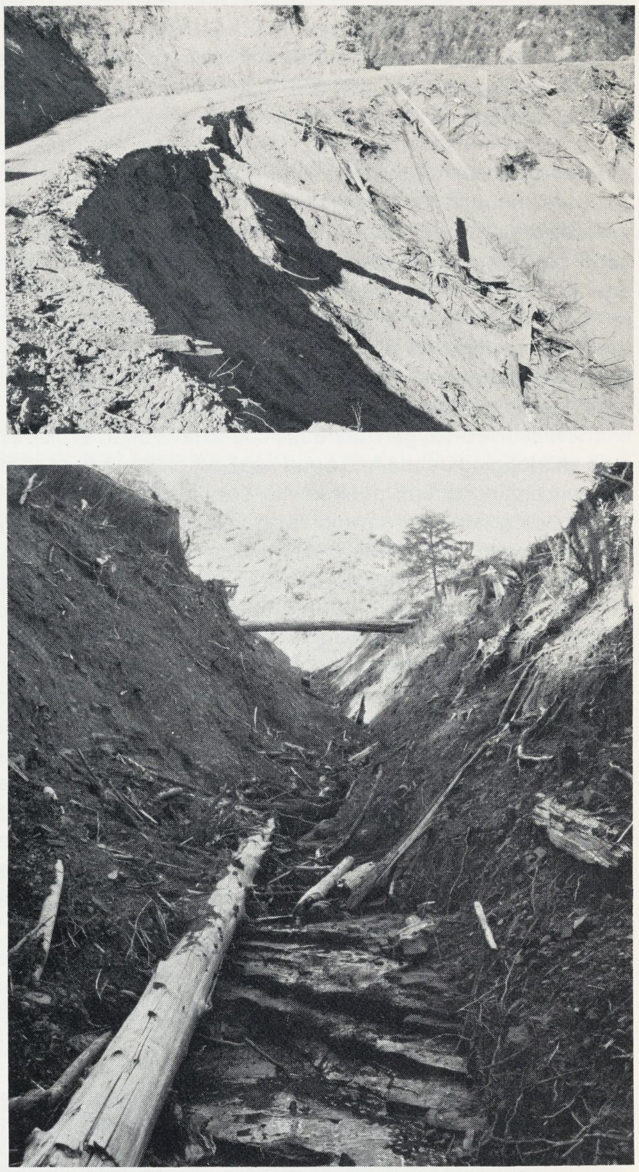


Figure 8. Logging roads are major contributors to increased sedimentation in streams. This landslide started at a mid-slope road (above), scoured out a canyon (below) and carried large quantities of debris and sediment into one of Oregon's coastal streams.

There is no easy way to eliminate or minimize sedimentation to streams from logging roads. The basic need is to develop a practical method that can be used by foresters in the field to aid in identifying high-risk areas during the planning process. The U.S. Forest Service recently established a task force on one of its forests in an attempt to deal with this concern. Practices that control sediment problems should be incorporated into every logging plan and implemented on the ground. This can involve extensive interdisciplinary and interagency coordination.

The Oregon Forest Practices Act

In 1971 the Oregon legislature passed the Forest Practices Act which updated the Conservation Act of 1941. The original Conservation Act spoke only to reforestation. In contrast, the 1971 Forest Practices Act sets minimum standards in five major areas which include reforestation, application of chemicals, slash disposal, road construction and maintenance, and timber harvest operations.

The Act applies to all private timber holdings in Oregon and has been supported by the forest industry. The legislature allowed one year to publicize the Act, develop operational rules, and train personnel before the law became fully effective on July 1, 1972.

The Oregon Department of Forestry was given responsibility for enforcing and administering the Act, and they appointed three regional committees to develop rules to implement the Act. The rules contain words that are subject to personal interpretation (i.e., whenever or wherever practical, significant numbers of fish, etc.); however, the Act does require compliance with state water-quality standards as administered by Oregon's Department of Environmental Quality, and the rules place emphasis on stream- and water-quality protection measures.

Streams were classified into two categories. Class I streams are waters which are valuable for domestic use, or are important for angling or other recreation and/or used by significant numbers of fish for spawning, rearing or migration. Class II streams are headwater streams or minor drainages that generally have little or no direct value for angling or other recreation, and their principal value lies in their influence on water quality or quantity downstream in Class I waters.

The Act placed a considerable enforcement burden on the Department of Forestry although most of the effort required has been in preventive activities, including training and inspections prior to operations. The Department of Fish and Wildlife input into the Act originates between our district biologists and the forest-practices officers. This input is coordinated at the staff level through our Environmental Management Section.

Some of the problems encountered with the Act result from the fact that the legislature did not provide the Department of Forestry and other cooperating agencies with additional manpower to handle their added responsibilities. The Department of Forestry has utilized its fire-control and farm-forestry personnel as forest-practice officers. Currently, existing personnel are only able to get to about half of the active logging operations and are falling behind in their preventive training program. More training in, and a better understanding of, water-quality criteria is needed. The ten-day voluntary notification procedure does not allow adequate lead time in many cases to get coordinated responses from all interested agencies.

Some strong points of the Act are that it has received relatively broad support from the timber industry, and the Department of Forestry has an excellent working relationship with other state agencies involved, such as the Department of Fish and Wildlife and Environmental Quality. The timber industry supported this legislation because it gave the industry a chance to get effective but practical regulations at the state level, to get coordinated input from one agency, and to have a strong voice in developing the rules.

In general, my impression of the Act is that it is working in Oregon. It is not perfect, and there are problems to be solved, but this relatively new legislation does provide a means for developing a coordinated approach to timber harvest operations on private land that was previously lacking.

Coordination with Federal Agencies

More than half of Oregon's land is owned by the federal government. The U.S. Forest Service and the Bureau of Land Management administer large acreages of valuable forest lands which contribute significantly to the fishery resource base of the Pacific Northwest and provide high-quality water for both on-site and downstream uses.

The Oregon Forest Practices Act does not apply to federal lands. Both federal land-management agencies, however, have formal agreements with the appropriate state organizations and policy statements that say they will meet or exceed state water-quality standards. This provides the basis for a cooperative effort to implement water-quality protection measures. In addition, both agencies have soil scientists, hydrologists, and fishery and wildlife biologists on their staffs to provide inputs into the planning process as well as during on-the-ground reviews of difficult sites.

Region 6 of the U.S. Forest Service has been a leader in trying to apply multiple-use land-management principles to its forest practices. It has developed a stream-classification system that encompasses four stream classes. Class I streams require the highest level of protection since they include domestic water supplies, recreational sites, or streams used by large numbers of fish for spawning, rearing or migration. Class IV streams are primarily important insofar as they affect downstream areas (i.e., the intent in these areas is to prevent landslides, or debris accumulations that would contribute to mass soil movement). Classes II and III are intermediate.

Management goals for each class of stream have been defined in the Forest Service manual as part of its Streamside Management Unit (SMU) policy. The SMU concept does not imply that no activity will occur near streams but stresses the need for applying special care in management — for example, such as the use of certain contract clauses to require that timber be felled and yarded away from streams. The Bureau of Land Management does not yet have a stream-classification system or a formalized SMU system.

The stream-classification system which developed as part of the Oregon Forest Practices Act (Classes I and II) and the U.S. Forest Service's stream classification system (Classes I through IV) are compatible. By agreement, Oregon's Class I streams include the Forest Service's Class I and II streams, and Oregon's Class II streams include the federal government's Class III and IV streams. The basic difference is the degree of land-management activity that each agency can prescribe for each class of stream. Implementing such guidelines in the field is similar for either system providing that there is agreement on the stream classification assigned.

The Wildlife Commission's input with the Forest Service and Bureau of Land Management originates at the local level between our district biologists and the district ranger's and area manager's staff, respectively. Timber-sale-plan reviews are held annually in the office, and allow for continuity as the plans develop. Our input is most meaningful for sales about two years in the future, where plans are well developed but can still be modified. After the annual meeting, suggestions for fish and wildlife habitat protection as related to specific sales are sent to the federal agency in writing and included in its environmental analysis reports.

We are making progress together utilizing streamside buffer strips, preserving meadows that are important as habitat for big game, and coordinating the timing of logging activities on critical elk and deer winter ranges while still harvesting timber. There is a need to make more progress together in minimizing sedimentation and mass soil movement from roads into stream systems. Region 6 of the Forest Service recently instituted a fish-habitat management policy that strongly addresses this area of concern. When the policy is fully implemented, we will have come a long way together toward the protection of salmon and trout streams in logging operations.

Summary

Public concern and private initiative have resulted in the establishment of state water-quality standards and legislation such as the Oregon Forest Practices Act. Research into the effects of logging on aquatic resources has provided a factual basis upon which to develop watershed management programs. Implementing such programs requires a continuous effort and effective working relationships between state and federal land-management agencies, concerned citizens, and industry. Emphasis has been placed on prevention of damage to streams rather than rehabilitation and on training sessions and active on-the-ground coordination.

Keeping streamside vegetation intact during logging operations is a major tool for fish-habitat and water-quality protection which also benefits wildlife. Sedimentation of streams, which often results from landslides associated with logging roads, can eliminate some of the benefits of vegetative buffer strips and is a major concern. The scope and magnitude of the task of reducing stream sedimentation is large.

Oregon's watershed management program is not perfect but has come a long way in a relatively short time. If resource managers can maintain this momentum, Oregon's land can then truly be managed for the continued production of timber, fish, wildlife and high-quality water. The approach used here to implement a more balanced forest management program should be applicable to other land-management practices and other areas.

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Acid Drainage and the Stream Environment

by William G. Kimmel and William E. Sharpe

Introduction

The introduction of acid materials into trout streams occurs to varying degrees in many parts of the United States. Since these substances invariably have a degrading effect on water quality, the problem of acid pollution is a legitimate concern to those interested in preserving and improving stream habitat for salmonids. This concern can be manifested in two major goals — first, the prevention of acid formation and its entry into streams and, second, the reclamation of currently polluted waters. This article will review the nature of the problem, its ecological consequences, and remedial measures.

The sources of acid pollution (excluding the relatively new phenomenon of acid rain) can be divided into two major categories — natural acidity and acid mine drainage. Natural acidity may be defined as that which arises from undisturbed (by man) organic sources, such as bogs, while acid mine drainage originates from mineral deposits exposed by human earth-moving activities. For our purposes, the cases of acid generation from naturally exposed mineral strata would be considered acid mine drainage.

As an unfortunate consequence of similar geologic origins, both types of acid pollutants frequently enter soft-water streams of low alkalinity. Both acid mine drainage and natural acidity are frequently generated from areas underlain by sandstone, shale, or granite formations which have little or no carbonate minerals. Streams draining these areas exhibit low concentrations of the carbonates and bicarbonates which are needed to buffer or resist changes in pH and, hence, may be severely degraded by relatively small quantities of acid. These freestone streams often flow through picturesque mountain country and provide habitat for native brook trout populations. By contrast, the limestone hard-water streams, rich in carbonates and bicarbonates, could handle considerably larger quantities of acid without significant impairment of water quality.

Acid-damaged streams are generally characterized by pH values below 6.0 and exhibit reduced numbers and kinds of aquatic life. Naturally acid streams receive the drainage from bogs which contribute the relatively weak organic acids (and possibly small amounts of sulfuric acid) while sulfuric acid predominates in streams polluted by acid mine drainage. The naturally acid stream landscape is often aesthetically pleasing while the acid-drainage landscape may be barren and littered with spoil piles. The chemical changes brought about in receiving waters by the two types of acid pollution are also quite different in nature and scope.

Comparative Chemistry of Naturally Acid and Mine-Acid Waters

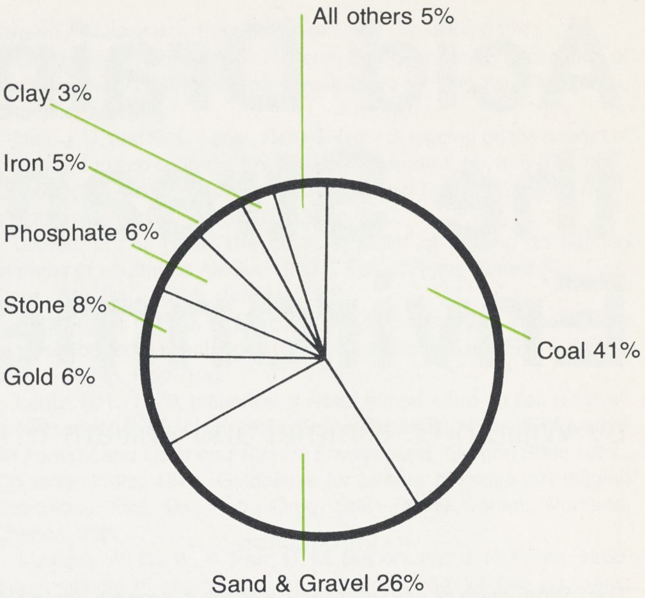
	Natural acidity	Acid mine drainage
Stream	Sinking Creek (Centre Co., Pa)	Tributary to Cold Stream Run (Centre Co., Pa)
pH	4.5	3.3
Total alkalinity (ppm)	0	0
Total acidity (ppm)	10	180
Iron (ppm)	1.0	46
Sulfate (ppm)	2.0	265

Much attention has been focused on the problem of acid mine drainage because its effects can be locally and regionally severe and can render water unfit not only for aquatic life but also for industrial use and public consumption.

Natural Acidity

Natural acidity in streams most frequently results from the introduction of drainage from bog areas. The actual mechanism for the generation of acidity in bogs is not fully known. Bogs are most commonly encountered in areas where sandstone and granite formations predominate and the drainage thereby is low in dissolved solids. The formation of a bog requires abundant water, high humidity, and a production of plant material which exceeds decomposition. These conditions may be met where accumulations of water occur in lowlands or valleys or at the outflows of springs. A typical case of bog formation may be seen in the late stages of a lake succession as the basin is eventually filled in by sediments. The shoreline vegetation advances and the lake becomes very shallow. As time passes, the decomposition of plant masses changes the chemical condition of the water and renders it suitable for colonization by bog species, such as the peat mosses and other forms. Acid formation has been explained variously as due to the production of excess carbon dioxide which forms carbonic acid in water, dissolved humic acids from decaying vegetation, and the activity of sulfur bacteria which produce sulfuric acid. Perhaps all these processes contribute at various times to varying degrees.

Strip-mining can adversely affect land and water resources.



Total 3.2 million acres

Percentage of U.S. land (as of Jan. 1, 1965) disturbed by surface mining of various commodities. (From "Surface mining and our environment." 1967. Strip and Surface Mine Study Policy Committee, U.S. Dept. of Interior, p. 53.)

Streams emanating, or receiving drainage, from bogs characteristically exhibit pH levels from 3.5 to 6.0 and are a brownish or coffee color. Populations of aquatic insects and fish are usually depressed both in numbers and diversity while the overall ecosystem is low in productivity. However, the desirable flora and fauna are rarely eliminated in these situations — a phenomenon frequently encountered in streams receiving acid mine drainage. The principal limiting factor to aquatic life is probably the activity of the hydrogen ion which may exceed the tolerance level of some species. Pollution from natural acids is relatively minor in scope and degree when it is compared with that of acid mine drainage.

Acid Mine Drainage

Acid mine drainage may result from the extraction of lead, barite, zinc, and manganese ores, but the principal source in the United States is associated with the mining of anthracite and bituminous coal. Coal mining has had a tremendous impact on the American landscape. Of approximately 3.2 million acres in the United States disturbed by surface mining, coal mining accounts for the largest percentage.

Both the strip-mining and deep-mining extraction techniques produce significant quantities of acid. Appalachia has some 5000 miles of streams rendered useless for fishes because of acid mine drainage with 2500 of these in Pennsylvania alone.

Drainage from abandoned and working mines often contains not only sulfuric acid but also toxic heavy metals, such as iron, aluminum, zinc, copper, and a heavy silt load. While the chemistry of acid formation is complex, the basic scheme involves the iron and sulfur compounds (marcasites and pyrites) often associated with coal deposits. During mining operations, these compounds are exposed to air and water in the presence of iron-oxidizing bacteria and are converted to sulfuric acid and ferrous sulfate. The water carries these substances in solution into the groundwater reservoir and thence into surface streams via springs. During this time the ferrous sulfate may be oxidized to the ferric form and then hydrolyzed to ferric hydroxides. Precipitation of the slightly soluble hydroxides results in the deposits of "yellow-boy" frequently observed on contaminated stream bottoms.

The various types of toxic physical and chemical conditions resulting from acid mine drainage pose multiple threats to aquatic organisms. First, the elevated hydrogen-ion concentration (low pH) may be toxic as in the case of naturally acid streams. Second, the presence of heavy metals may be lethal to many organisms, and this effect seems to be intensified at low pH levels. Third, "yellow-boy" slime coats bottom-dwelling organisms and destroys their habitat. Finally, siltation from the earth-moving activities associated with surface mining also plays havoc with the stream ecosystem. The summation of all these effects often produces a sterile environment devoid of life. Values of pH less than 3.0 and high concentrations of such other substances as iron and sulfates are frequently encountered. An extensive survey of Pennsylvania streams polluted by acid mine drainage revealed no fish present below pH 4.5, eight species present at pH 5.0, and 34 species present at pH 6.0 (Cooper and Wagner, 1973).

The severity of acid pollution from surface mining is highly variable and dependent upon many factors. One of the key parameters is the nature of the rock and soil material overlying the coal seam. Studies in West Virginia have shown that certain sandstones have a higher potential to produce acid materials than others. Prior evaluation of such data would be helpful in determining whether or not to mine certain areas and how much reclamation costs will be.

Acid formation is not necessarily encountered in every coal mining operation. In some areas the drainage from surface mines is alkaline in character. A number of lakes in eastern and central Ohio contain this type of mine drainage and support fish populations. Such waters are often ballyhooed by members of the surface mining industry as examples of the quality of reclamation work that they are performing. However, there is a very simple reason for this reclamation success. The overburden in these areas contains extensive deposits of limestone which when brought to the surface and exposed to chemical weathering neutralizes any acid that might be present. Unfortunately, such limestone formations are not often found in association with coal fields.

Abatement of Acid Pollution

With the exception of attempts to improve the productivity of bog lakes in the Midwest with lime, most efforts to control acid pollution have focused on mine-drainage problems. Treatment technologies are directed toward either the prevention of acid generation or the neutralization of existing discharges. Among the former strategies belong techniques for sealing abandoned mines, diversion of water from mining areas, and contouring and revegetating mined lands. In the latter category are the various measures for neutralizing existing discharges or improving them through dilution.

Prevention of Acid Formation

The prevention of acid generation requires a considerable physical and financial effort coupled with engineering expertise. A great deal of research has been, and is being, conducted by state and federal agencies and mining companies on this problem. Since air, water, and a source of sulfur materials are required for the production of acids, the limitation of any of these factors should inhibit formation. Attempts have been made to exclude air from abandoned deep mines which are above the water table (mines located below the water table are already isolated hydrologically) by various sealing measures. This approach has met with limited success due to the difficulty of creating the tight seals which are necessary. Acid-forming reactions can be achieved at very low oxygen pressures.

The complete isolation of these mines from drainage inflow would eliminate another of the factors necessary for acid generation. This approach also is limited due to the many and diverse ways in which water can enter a mine. Steps to divert water around exposed surface-mining areas through drainage channels and backfilling are useful measures. In addition, the segregation of pyritic materials at the time of mining is important. When the surface mine is backfilled these materials are placed in the pit first and covered with the remaining fill, thus isolating them from contact with the air. Pumping of water from operating mines is also valuable because it reduces the time water remains in contact with sulfur materials. New mining procedures, such as the block cut, also serve to minimize potential pollution from surface-mining activities.

One of the most successful methods of controlling acid mine drainage from abandoned, shallow drift mines has been to surface mine the affected area. In so doing the old drift mines are collapsed and filled with overburden, thus greatly restricting the oxidation of pyritic material and subsequent acid formation. A project of this type has been underway on the Youghiogheny River watershed in Pennsylvania for many years. Resulting improvements in water quality have led to the stocking of trout and smallmouth-bass fingerlings in a thirty-mile section of the river. Anglers are now once again catching legal-size trout and bass from the restored Youghiogheny.

Due to the difficulties inherent in these measures, the prevention of acid generation can best be achieved through stringent standards. Environmentally sound mining practices coupled with effective reclamation techniques are the goals of proposed federal strip-mining-control legislation which:

Provides for the orderly submission, review and approval of effective State programs and a minimization of bureaucratic requirements during the review period. The emphasis should be placed on an evaluation of the effectiveness of pre-Act State programs through the development of qualitative performance criteria.

Establishes a fund for the reclamation of abandoned strip mines and a program which compliments, rather than competes with, pre-Act State programs.

Provides for consultation with the State on the development of initial and permanent regulatory procedures and standards.

Requires the submission of reclamation plans detailing the use to be made of land following reclamation; a plan for surface-water drainage; a plan for backfilling and revegetation; and steps to be taken to comply with applicable air- and water-quality laws.

Requires the filing of performance bonds (which should be held in the State under an approved State program) to assure completion of reclamation plans.

Requires mine operators to restore land to the approximate original contour; preserve and restore topsoil; minimize the disturbances to the prevailing hydrologic balance; stabilize waste piles; and insure safe disposal of dangerous materials.

Requires adequate public notice on permit applications; provides the public the right to appeal decisions to award or deny permits; and provides for citizen suits for alleged violations of the Act.

Provides for adequate civil and criminal penalties.

Authorizes the Secretary of the Interior to issue separate regulations for certain anthracite coal mines if such mines are regulated by environmental protection standards of the State.

Revegetation of Surface-mined Lands

Reclamation procedures commonly involve backfilling, burying pyritic materials, contouring the surface to its original slope, and revegetation with suitable species. Of these measures the most difficult is the reestablishment of vegetation. Mine spoil is an exceptionally harsh environment for plants. It may contain aluminum and acidity in toxic amounts, it has practically no organic matter, and it is low in nutrients. In addition, the dark coloration of many spoil materials causes them to absorb solar energy and to get extremely hot on sunny summer days — in fact, tree seedlings may be killed. Given these conditions it is little wonder that plants cannot grow on many surface-mined areas.

The rapid establishment of vegetative cover on surface-mined areas is essential in lessening the sediment and acid pollution of lakes and streams. Evaporation and transpiration losses from vegetation help to cool the surface of mine spoil and most importantly reduce the amount of water that percolates downward through the spoil material and becomes acidified. Established vegetation also shades the spoil surface allowing for increased growth of associated plant life.

Once vegetation is established on surface-mined lands the long process of topsoil formation can begin. The addition of organic matter from vegetation adds vital nutrients to the soil, improves its water-holding capacity, and helps to neutralize acidity. In time these gradual improvements will restore the land to usefulness and markedly reduce the generation of acid waters and harmful sediments that pollute adjacent streams.

Various soil amendments have been utilized to aid in strip-mine revegetation. Sintered fly ash from coal-fired electric generating plants has shown promise as has the use of municipal sewage effluent and sludge. Dramatic increases in growth have been demonstrated with combined application of these two by-products of conventional sewage treatment.

Sewage effluent and sludge can aid in spoil revegetation.

Some research has indicated that applications of ordinary whitewash to reduce spoil surface temperatures markedly increase the survival of tree seedlings and grasses. Standard hydroseeding procedures are also used to establish cover on mined areas, but such applications often fail to produce a permanent grass cover.

Revegetation projects on unreclaimed mine spoil areas may be a worthwhile endeavor for conservation organizations. Considering that some of the best soil amendments now known are considered waste products, and therefore available cost free, the expense of such an effort should be minimal. Tree seedlings and wildlife food shrubs are available free from many state agencies. Add to this plenty of hard work, and a relatively inexpensive and extremely valuable club project can be successfully carried out.

The Reclamation of Acid-polluted Streams

Since the prevention of acid formation has been difficult and costly to achieve, continuing efforts are aimed at improving the quality of existing drainage. Probably the simplest approach to the problem is dilution of the polluted water with larger volumes of clean water. In this technique a reservoir is constructed on a non-polluted tributary to a polluted stream, and water is released from this reservoir in sufficient quantity to dilute the acid drainage into the affected stream. This may improve the quality enough for other uses or may be a first step to further chemical treatment.

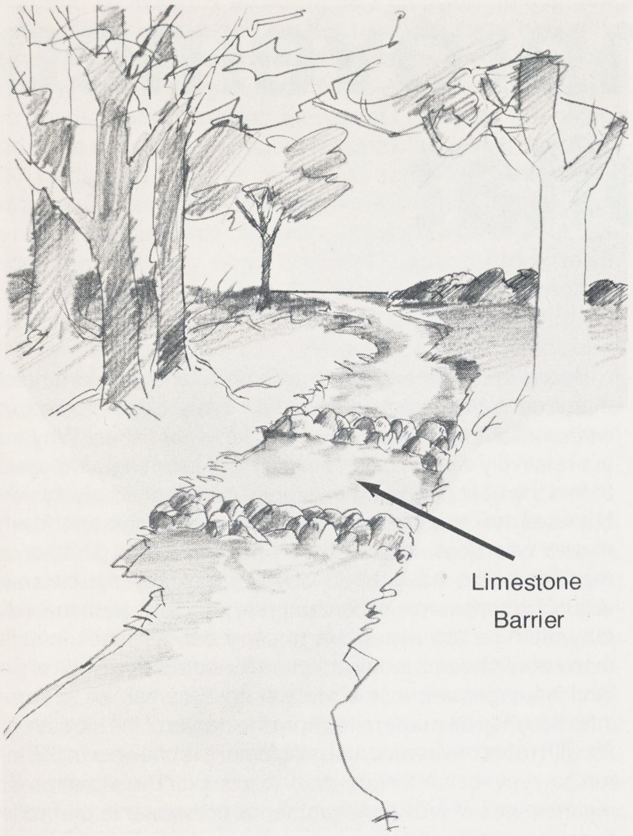
Sophisticated technologies, such as reverse osmosis, ion exchange, and chemical-biological treatment, have been, and are being, used to renovate acid water. Many techniques produce sludges which can be expensive and troublesome to dispose of. Neutralization of acid drainage is more commonly achieved through the use of strong bases or carbonate materials, such as limestone. Treatment systems utilizing limestone offer the distinct advantages of being relatively inexpensive and simple to construct.

Most early attempts at using lime or limestone to neutralize acidity were directed toward improving the quality of bog lakes in the Midwest. Such bodies of water are usually poor producers of fish due to low pH, color which inhibits light penetration, and low nutrient levels. Lakes were treated with lime and limestone, and some success in increasing pH, total alkalinity, hardness, conductivity, and color removal has been reported. However, the desired increase in fish production was not achieved in proportion to the cost of the program.

Neutralization attempts in streams have been largely undertaken to ameliorate the effects of acid mine drainage. Both lime and limestone are used to neutralize acidity. Liming machines, which pump a slurry of lime and water into the stream, are effective short-term solutions. However these machines use large quantities of rather costly lime and require almost constant attention; consequently, their usefulness is limited.

Crushed limestone is a considerably less expensive neutralizing agent and much attention has been devoted to its use in acid-water neutralization. Perhaps, the simplest method is the scattering of limestone aggregate in the stream bed to achieve some neutralization as the stream flows over the rubble. This technique is hampered by iron hydroxide ("yellow-boy") scale formation on the individual chips (when the iron concentration exceeds 1 ppm) which decreases the reaction surface.

A method to overcome scale formation was developed in West Virginia and involves the use of rotating drums partially filled with limestone aggregate. The drum is rotated by streamflow, much like a water wheel, causing the individual chips to grate against one another, thus preventing scale buildup. Elevations in pH of as much as two units have been achieved by this method. Follow-up studies in the treated areas revealed that there was an increased survival rate of native brook trout and successful reproduction.



Barriers of crushed limestone may aid in reclaiming acid streams.

One of the most difficult aspects of acid water treatment is the number and variety of sources. Frequently these are small and widely dispersed throughout a watershed — a condition which renders treatment of the individual discharge by conventional means very difficult. A partial solution to this problem may be achieved through the installation of barriers of crushed limestone. This technique, which was pioneered at The Pennsylvania State University, has had some success in experimental installations. A neutralization project of this type may be of particular interest to conservation groups because of the relative ease of installation and low cost. In effect, barriers of limestone aggregate are placed in the acid stream and neutralization is achieved as water passes through the barrier. The intent is not to dam the stream but to maximize contact between the limestone and acid water. This technique is limited by the same factors inherent in other in-stream systems utilizing limestone aggregate — streamflow, iron concentration, and quantity of stone required. Iron concentrations in excess of 1 mg/liter will cause coating of the individual stones and will reduce overall efficiency. High streamflows require tremendous quantities of aggregate, and flows in excess of the design criteria will pass through untreated. Consequently, this system is applicable only to small discharges of low iron content. However, by treating small acid tributaries, desired results can be achieved on the main stream. Sources of natural acidity generally do not have high concentrations of iron, and the total acidity to be neutralized is usually far less than in the case of acid mine drainage. Hence, favorable results should be achievable with smaller systems.

Because of these limitations, care should be exercised in planning a stream-improvement program with this method. First, the type of fishery-management strategy to be implemented should be considered. The steam in question must meet the minimum requirements for stocking of trout if there were no acid pollution present. In this context, temperature must be within the range capable of supporting trout. Obviously, if the stream is inherently unsuitable for trout for other reasons, a neutralization program will be a bad investment. Because streamflow varies so greatly both intermittently and seasonally, the level of pH to be achieved and the length of time it is to be maintained are important considerations.

Seasonally functional limestone barriers can be installed consistent with current put-and-take trout-stocking policy. Barriers implemented for this purpose would be designed to provide adequate treatment only during periods of low flow. Stocking would coincide with these low-flow periods, and fish which were not harvested by the time streamflow increased and pH dropped would be lost. This method of providing a seasonal fishery would be susceptible to sudden deteriorations in water quality caused by storms. If a year-round fishery is to be maintained, the barrier system must be designed to accommodate periods of peak flow and consequently would be much larger.

Overview

The current emphasis on energy self-sufficiency in this country means that increased exploitation of coal reserves will be a certainty in the years ahead. Extreme care will be necessary in the extraction of coal if the destruction of aquatic habitat that has occurred in the past is to be avoided in the future. The yellow and red streams of Appalachia are a living testimony to the destructive potential of uncontrolled coal mining. The nation can ill afford to commit additional water resources to a similar fate. A concerted effort by federal and state agencies, the mining industry, conservation organizations, and concerned citizens is necessary to insure that the valuable resource represented by trout waters is preserved and enhanced.

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Dr. William G. Kimmel has served as ecologist with the Pennsylvania Technical Assistance program since receiving his doctorate in 1972 from The Pennsylvania State University. His research interests include the effects of acid drainage on aquatic invertebrates and the productivity of flowing waters. Dr. Kimmel also serves on the scientific advisory board for the Pennsylvania Council of Trout Unlimited.

In-Stream Improvement of Trout Habitat

Robert L. Hunt

Cold, oxygen-rich, pollution-free water is an obvious characteristic of streams that support wild, self-sustaining populations of trout. But trout streams are much more than clean, cold water running downhill. Stretches of even good streams may be nearly devoid of trout, despite suitable physiological conditions for survival.

Water and space are going to waste. Whether anything practical can be done to remedy such situations, however, is dependent first of all on identifying the causes of such waste. Lack of spawning grounds or spawners, poor hatches of eggs, sparse food production or unavailability of in-stream food that is produced, natural or man-made barriers that prevent migration, over harvest by anglers, or unusually high natural predation are some of the potential ailments. But oftentimes only one basic ingredient of healthy habitat for trout is missing: *insufficient shelter* of the kind trout need to establish a homestead (territory) to settle down to the business of growing and surviving to spawning size. The remedy in such situtations is simple and there may be no other management alternative, but it could be costly: implementation of an in-stream habitat-development program designed to make such stretches alluring to trout.

Habitat development, man's effort to improve living conditions fortrout, has proven to be a successful technique for increasing stream trout populations and enhancing the sport fisheries they sustain. Before we consider in detail an application of this management tool, however, let's briefly review a few relevant aspects of trout behavior.

Wild stream-dwelling trout normally exhibit strong territorial behavior, with each individual staking out a portion of the stream as its homestead and defending that property from instrusion by other trout of equal or smaller size. Territory size is primarily determined by body size and species of trout, i.e., territory size increases as the trout grows larger and some species are more tolerant of neighbors. Factors, such as the degree of visual isolation from neighboring trout, amount of locally available food, season of the year, and water velocity, also influence territory boundaries. Evolution of such behavior in stream trout is believed to be a mechanism that assures holders of territorial rights of an adequate food supply and a reasonably safe place to live. Unless growth and survival of some individuals of each generation to spawning size is assured, the species cannot perpetuate itself.

If a stream is physiologically tolerable to trout and if there is suitable spawning habitat, the number of trout a stream can support (its carrying capacity) is ultimately determined by the number of suitable territories it contains for trout of various sizes. Unfortunately, from the view of the fisherman and management biologist, most streams inherently contain fewer desirable territories for large trout than for small ones. The most desirable sites are seldom vacant for long.

Because of their economic and sport-fishery importance for many centuries, trout and salmon have been studied and written about more than any other family of fishes. Why trout are relatively easy to catch one day and seemingly impossible to fool the next remains a mystery (and hopefully always will), but what makes a trout happy with its environment and what makes one trout stream more productive than another are mysteries that have been substantially solved. However, within the constraints of contemporary society, such remedies may often be too expensive to carry out. Illnesses infecting many trout streams today are often the complex results of poor land management in the watershed. Sources of in-stream infection may be many miles from the banks of the sick stream. As with most environmental problems, it is cheaper in the long run to prevent an illness than to cure it. Preservation and maintenance of those environmental components that collectively constitute healthy watersheds and good in-stream habitat for trout (and therefore good trout fishing) are much cheaper than rejuvenation of a degraded environment.

At the other end of the ecological scale, our growing knowledge of trout stream ecology is also revealing ways that even the best streams could be made better. New Zealand's Mataura, England's Test and Itchen, Montana's Armstrong Spring Creek and Madison River, or the Brule and Evergreen in Wisconsin could all be managed to produce more trout without degrading their natural beauty. No stream has a perfect combination of features such that every foot of stream bottom is included in the territory of a trout. In fact, it is highly probable that trout occupy no more than 25% to 50% of the space in the best of trout streams.

From the practical viewpoint of most resource management agencies, attempts to upgrade environmental quality of trout streams are usually aimed at those streams somewhere in the middle of the scale of trout carrying capacity. At the extreme low end, it is reasoned that too much financial effort would be needed to attain even a modest level of productivity, while at the upper end further enhancement management would be simply frosting on the cake, nice but not necessary. Best return per dollar invested is most likely to come by concentrating on streams that appear to have considerable potential for increased carrying capacity, especially for trout large enough to support a sport fishery. Let's look then at an example of this management strategy to improve the trout carrying capacity of a moderately good stream by improving in-stream living conditions for trout, with emphasis on what was done and what the results were.

The Lawrence Creek Story

Lawrence Creek is a 3.4 mile-long brook trout stream in central Wisconsin. Its average width is about 23 feet and discharge at its mouth is approximately 25 cfs at normal flow. Gradient is moderate, only ten feet/mile. The lower half of the stream meanders through a marsh-meadow and the bottom is primarily sandy. Holes three to five feet deep are common at the bends. Spawning sites are scarce. However, the upper half of the steam has two excellent spawning riffles, one about 400 yards long and one about 200 yards long. These two areas usually supply enough recruits to the rest of the stream to use up stream-wide carrying capacity for larger trout. Between the spawning areas is another upper meadow reach with numerous deep holes. The upper mile of stream flows through a cut between two oak ridges. Lowland adjacent to the stream is fringed with alder. Lawrence Creek is noted especially for its abundance of lateral feeder springs, lush growth of aquatic vegetation, clear water, stable flow and tasty trout. All in all, a picturesque little trout stream that is the favorite of many Wisconsin trout fishermen.

In 1955, research on the stream was initiated by the Wisconsin Department of Natural Resources and continued for the next 15 years. Much of the financial support for this research came from funds provided through the Federal Aid in Fish Restoration Act, more popularly known as the Dingall-Johnson Fund. Several investigations were also carried out by university graduate students that also contributed to knowledge of the life history, ecology and management of wild brook trout. A major study lasting ten years involved a thorough evaluation of in-stream improvement of trout habitat.

It was apparent during the late 1950s that trout habitat throughout the upper mile of Lawrence Creek was gradually deteriorating, largely through natural processes of stream erosion, slumping of low, soft stream banks and insidious filling of the pools with sand as the stream widened and flow velocity diminished. Adequate shelter for larger trout was steadily decreasing as well as the number of trout. Lush growths of aquatic vegetation continued to provide shelter in the summer and fall, especially for small trout, but as aquatic vegetation died away during the winter there were only a few good sheltered pools where trout could find desirable homesteads through the winter and spring until vegetational growth resumed. In the spring of 1960, there were only 75 pounds of trout in this mile of stream (20 lb/acre), nearly 50% less than it held the previous spring and 80% lower than two years prior. A good stretch of stream was showing signs of increasing ill health.

During the next three years (1961-63), the trout population, sport fishery and stream environment were carefully monitored to document predevelopment conditions. Renovation of the stream section began in March, 1964, and continued steadily through September until the entire channel of the upper mile had been altered by installation of stream-bank cover and current-deflector devices. Postdevelopmental studies were then initiated and continued for another six years (1965-70).

Detailed maps of the stream channel made prior to alteration pinpointed two essential ingredients of the environment that were in short supply, especially for catchable-size trout: (1) natural pool areas attractive to adult trout, and (2) protective overhanging shelter for trout to hide under. Work by the development crew was, therefore, concentrated on creating new pools, scouring and enlarging existing pools, constructing artificial overhanging streambanks, and firming up those that provided natural cover. A series of 86 paired bankcovers and current deflectors were constructed. Hundreds of five-foot-long oak pilings were positioned vertically in the stream bottom; 38,000 board feet of oak planking was then nailed underwater to the pilings to form platform shelves running parallel with the natural streambanks. Some 6,000 tons of rocks were then placed on top of the platforms to form new erosion-resistant banks. Each device helped to narrow the stream channel and gently guide the current in an accentuated meander pattern from one device to the next opposite device. Tons of dirt were placed on top and behind the rocked-over platforms, and mats of field sod were added as top dressing to hold the dirt in place and hasten the recovery of a more natural aesthetic appearance to the altered stream. Within two years it was difficult for most fishermen to detect that streambanks were really not the way nature had fashioned them.

Habitat and Trout Population Changes

When the job was done, average width of the stream had been reduced by 50% and average depth had increased by 65%. Pool area was nearly three times as great, due to creation of new pools and expansion of existing ones; collectively, pools comprised 25% of the total area of stream bottom as compared with only 5% before development. Much of this pool area was located beneath the refurbished overhanging streambanks which supplied 400% more protective cover than existed prior to development. Nearly one third of the total streambank now had at least a foot of flowing water beneath it (Fig. 1).

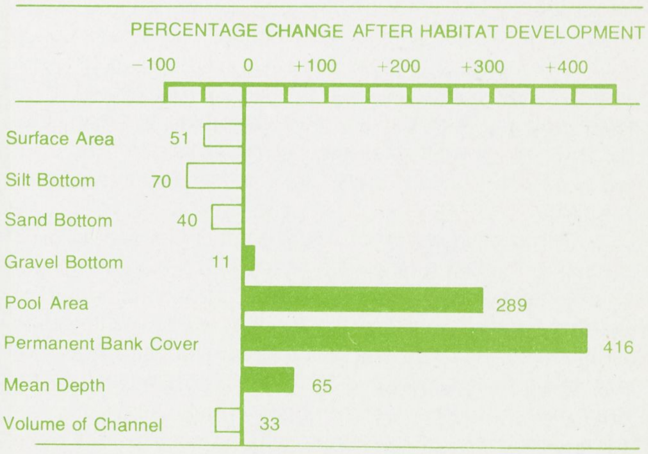


Figure 1. Changes in stream morphometry produced by in-stream habitat development.

Improvements in the trout population did not follow as rapidly as transformation of the physical features of the stream, but this was to be expected. An increased trout carrying capacity had been developed, especially for catchable-size trout, but natural recruitment of such trout would take five to six years to be fully realized. However, records from the semiannual electrofishing inventories indicated steady progress toward the goal of filling the new niches created for larger trout.

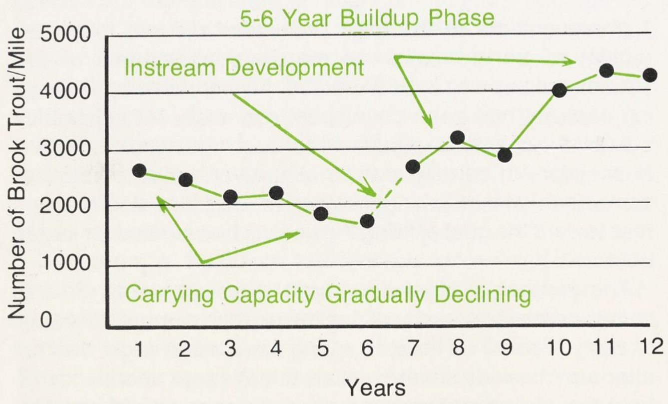
The number of legal-sized trout (over six inches) in the spring increased steadily during the postdevelopmental years of study (Table 1). The sixth spring there was a slight decline after a particularly severe winter, but average abundance of trout over six inches was nearly three times as great during the fourth through sixth years after development as for the three years preceding development (1638/mile vs. 562/mile). Brook

Item	Predevelopment Avg. (1961-63)	Postdevelopmental Years (1965-70) 1st	2nd	3rd	4th	5th	6th
Number/mile over 6 inches	562	953	1176	1261	1477	1837	1600
Number/mile over 8 inches	118	230	343	285	380	368	471
Total Number/mile	1747	2671	3325	2648	4044	4327	4306
Total Pounds/mile	130	208	272	245	361	385	346

Table 1. Comparisons of Number and Weight of Brook Trout Before and After Completion of In-stream Habitat Improvement of One Mile of Lawrence Creek.

trout over eight inches did not reach peak abundance until the sixth spring after completion of in-stream development (Table 1). Average abundance of brook trout over eight inches for the fourth through sixth years of the postdevelopmental study was 406/mile, or 240% more than average abundance for the predevelopment years. Total number and weight of trout of all sizes peaked during the fifth spring of the post developmental period at values of 4327 trout/mile (2326/acre) and 385 pounds/mile (207/acre). Thus, in terms of trout of all sizes, development raised carrying capacity by nearly 200%, but more importantly, much of this increased carrying capacity was utilized by trout large enough to be of interest to anglers. Water, space, and other environmental components of the altered channel were being put to better use to produce a product of interest to man. Prior to alteration of channel characteristics, there was one legal-sized trout/295 sq. ft. of stream bottom. After development there was a legal-sized trout for every 49 sq. ft. of stream bottom. Space/trout for trout of all sizes was reduced from 95 sq. ft. of stream per trout to 19 sq. ft./trout.

Stockpiling of more larger trout occurred despite a 200% increase in harvest. Fishermen liked the development work too. The developed section became the favored portion of Lawrence Creek to fish. Prior to alteration, it received less than 20% of the total fishing effort on the stream, but after development was completed nearly 50% of the fishing activity on the stream was in the developed section. And, despite the increase in number of fishermen and probability that more novice anglers were attracted to fish there, catch/hour did not decline.



Schematic generalization of trout carrying capacity trends before and after completion of in-stream habitat development in the upper mile of Lawrence Creek.

Why In-stream Development Worked

A more detailed examination of trout carrying capacity within the rehabilitated section was also conducted to ascertain why some 100-yard stretches consistently held more trout than others. Five factors were identified as being important, positive influences on carrying capacity for legal-sized trout, namely: average depth of the 100-yard stretch, volume of water present (in cubic feet), average depth of pools, amount of pool area, and amount of overhanging-bank shelter. The last two environmental components were especially important in determining the extent to which carrying capacity was raised by development. Reaches of stream having highest densities of trout had numerous deep pools and plenty of shelter under the bank for trout.

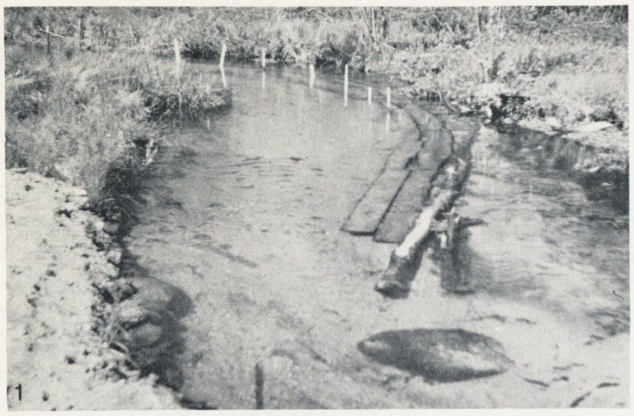
Although the improvement project was considered to be intensive for this kind of remodeling effort, no portion of the stream appeared to be overdeveloped. The best 100-yard stretch held as many as 340 legal-sized trout weighing 252 lb/acre, yet even this high carrying capacity probably could have been raised by building additional stream-bank covers and current deflectors. The ultimate in trout habitat was not attained.

Construction of the devices was such that much of the existing and added pool area was beneath the overhanging artificial banks of the devices, and the strongest threads of water currents glided along the outside edge of the devices. Thus, three of the primary factors influencing selection of territories by catchable-size trout were met: (1) quiet holding areas of sufficient depth, (2) protective overhead cover, and (3) close proximity to sources of drifting food. From such preferred niches, trout could make short forays into the faster currents to intercept food drifting by and then dart back again to their holding stations beneath the banks.

Addition of hundreds of vertical wooden pilings and thousands of feet of planking for the device substructures also provided much increased attachment area for aquatic invertebrates, especially for caddisfly and mayfly nymphs. More than 800 sq. ft. of gravel substrate was also washed free of covering sand, an environmental change having two healthy influences. Successful spawining was subsequently documented on some of these new pockets of gravel. Exposed gravel substrate also provided desirable attachment areas for trout food organisms. Abundance of one of the food organisms especially important in the year-round diet of trout increased nearly 70%. Nymphs of the case-building caddisfly, *Brachycentrus americanus,* increased from an average yearly density of 29/sq. ft. to 49/sq. ft.

Development also improved the availability of food for trout by concentrating the drifting food supply close to or into the holding areas under the bank. Since stream trout rely heavily on drifting food, it does little good to have a stream produce an abundance of trout food if most of it is out of reach of their foraging range. Development helped to remedy this environmental shortcoming.

The most important responses of the trout population that contributed to its buildup were decreased movement of trout out of the developed section and much better overwinter survival of trout that chose to remain there. Fall to spring carryover of young-of-year trout increased from 52% to 70%. Most of the survivors, as yearlings the next spring, would soon grow to legal size to bolster the sport fishery, and if they survived through the summer would also contribute to the spawning population that fall. Prior to habitat modification, loss of trout overwinter was especially severe for trout two years of age or



(1) Typical pattern of wooden substructure for stream-bank cover deflector. Planks are supported by pilings in the stream bottom.

(2) Overlay of rocks to provide stable, erosion-resistant bank. Dirt and sod are added on top of rocks to complete the device.

(3) One year after completion. Natural vegetation has restored aesthetic beauty. Much of flow is now passing beneath the overhanging, undercut bank.

older, that portion of the population especially desirable to preserve for the sport fishery. Fall to spring loss of such trout was reduced from the predevelopment average of 90% to only 30% during postdevelopmental winters.

Analyses of changes in the trout population according to age group rather than size categories revealed gains in all age groups, gains due in large part to better overwinter survival, as just discussed, but also due to better survival during other seasons of the year, too. Ages three and four showed especially impressive gains (see Table below), but the nearly 300% increase in abundance of age two trout was probably the most important benefit for the trout fishery which is highly dependent on trout of this age during the first few weeks of the angling season when fishing effort is greatest.

	Age Group				
Item	I	II	III	IV	Total
Avg. No/Mile Before Development (Spring 1961-63)	1503	234	8	1	1746
Avg. No/Mile After Development (Spring 1968-70)	3200	916	118	12	4246
% Increase	113	291	1375	1100	143

As buildup of more spawning-age trout continued, more eggs were produced, too. Estimated egg deposition in the developed section during the fall, 1968-70, spawning seasons increased by 88% over the predevelopment average (from 183,000 to 344,000 annually). Thus, the development effort provided more spawning area and more spawners to utilize it.

Growth rates of young-of-year trout improved slightly after development, but growth of yearling and older trout decreased somewhat (15-20%). Exact causes for these growth changes were not determined, but the decline in growth of older-age trout was probably a reflection of increased competition for food as the number of trout increased. As a result of the beneficial influence of development on survival, however, much more of the weight of trout flesh produced each year was available to anglers. More trout lived longer and continued to convert food into trout flesh. From the predevelopment average of about 260 pounds of trout flesh produced yearly, only 10% (25 lb/season) was removed by anglers. After the population had adjusted to its new carrying capacity, about 370 pounds of trout flesh was produced annually of which 25% (92 lb/acre) was cropped by anglers. Thus, on the basis of weight of trout removed, the postdevelopmental harvest was 3.7 times greater and utilization of the weight of trout produced was 2.5 times greater after development (Fig. 2).

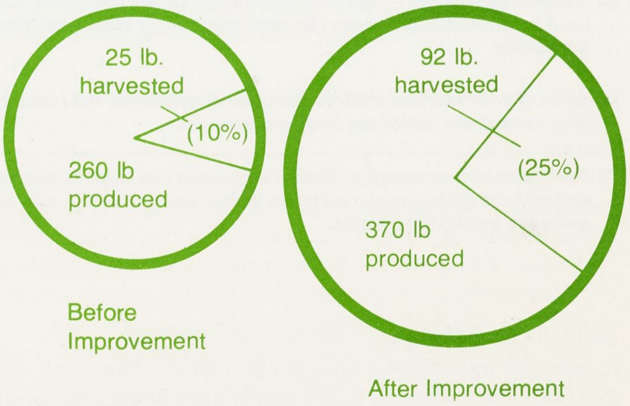


Figure 2. Changes in the pounds of brook trout produced and harvested annually after the trout population had adjusted to the improved carrying capacity in the developed section of Lawrence Creek.

(4) Before development — stream channel wide and shallow. Rock to be used in constructing devices has been temporarily stockpiled along the stream.

(5) Soon after completion of stream-bank cover deflectors. Note overlapping pattern and narrowing of stream channel.

(6) Two years after completion. Natural vegetation has largely obscured any artificial character of the stream-banks. Much of flow is now beneath the overhanging banks.

Economics of In-stream Habitat Development

It was an expensive management effort. The cure cost $26,000. Approximately 6,550 feet of bank cover and current deflectors had been installed at an average cost of $4.00/linear foot. Labor costs accounted for 70% of the total; vehicle and heavy-equipment costs accounted for another 20%. Only 10% of the expense went for materials to build the devices.

Was this kind of stream-management investment worth it? Was it worth $26,000 to reverse the downward trend in environmental quality, in aesthetic appearance of the stream, and in production of trout? Would it have been better to let the stream alone and let nature take its course; to be satisfied with the fact that it still supported a moderately good fishery for wild brook trout? And what about the alternative management strategy of periodically stocking the stream with hatchery-reared brook trout to temporarily bolster the catch?

On the basis of producing more wild trout to fish for as opposed to stocking comparable numbers of domestic trout, it might be difficult to convince many of today's fishermen that the developmental price tag was worth it. Matching the natural production of an additional 2500 trout each spring (the level attained five years after development) could be accomplished by spending $900/year in hatchery-reared trout, a procedure that could be continued for 30 years (at today's costs) before the cost of development would be equalled.

Before opting for this alternative, however, it is important to realize that the wild trout population was at carrying capacity before development was initiated. Where would the additional 2500 stocked trout live if the habitat they needed was already occupied? Contests for what decent habitat there was would simply be accentuated. Consider also that 30 years of stocking would do nothing to maintain or improve the environmental quality of the stream for either wild or stocked trout. The priority scale might also be tipped in favor of spending money to maintain and preserve environmental quality by considering the fact that many trout fishermen prefer to fish for, catch, and perhaps eat wild trout if they are given the choice of fishing in a stream that produces such opportunities as opposed to fishing a stream that no longer supports an adequate wild trout population. Unfortunately, there is little good information available on how much such a preferred choice is worth in terms of dollars or any other tangible unit of measure that would be helpful in deciding how to allocate funds fairly that are available for trout stream management.

What is it worth to a trout fisherman to fish for wild trout in aesthetically pleasing surroundings? What is it worth to see several hundred wild trout in a day's fishing? (And, parenthetically, what will it be worth 25 or 50 years from now?). If it is worth as little as $5.00/day for such an experience, only 5,200 additional angler trips to Lawrence Creek would be needed to pay off the investment made in habitat improvement. At the rate of attracting approximately 300 more anglers/season during the 1965-70 period, that investment will pay for itself sometime during the 18th year after development, even if there is no increase in future use or increase in the recreational value of trout fishing. Eleven of those 18 years have passed. and physical condition of the improvement devices appears to have deteriorated very little. Barring unforeseen catastrophes, there is every reason to believe that present habitat quality for trout will continue to exist for several future generations of anglers to enjoy.

Epilogue

The story of in-stream habitat improvement in Lawrence Creek is one that could be repeated for several rehabilitated trout streams in Wisconsin, some of which hold brook trout, some hold brown trout, some mixtures of both. Hopefully, it will be a story that will apply with increasing frequency to a growing list of streams in many states that have conditions responsive to such in-stream management: streams that have water going to waste yet are physiologically suitable for trout in every way. Procedures have been worked out for turning such streams into ones that have a *consistently productive habitat*. Moreover, if cost of labor, the major expense in development, continues to increase, it is reasonable to put more emphasis on development now, not later.

Consistently productive trout habitat throughout a stream — that, in a nutshell, is the goal of in-stream habitat development: deliberate enhancement of those known environmental factors that contribute to the well-being of trout and amelioration of those environmental factors that suppress their inherent capacities to grow, survive, and reproduce.

Lawrence Creek

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Author of several papers and technical bulletins on the life history, ecology and management of wild brook trout. Major research projects involved evaluations of: (1) various size limits, bag limits and lure restrictions for managing brook trout fisheries, (2) in-stream habitat development, and (3) dynamics of the production processes of growth and mortality that determine the poundage of trout produced annually.

Present studies include (1) management potential of vegetation manipulation along small trout streams (removal of brush and trees to create more meadow-like habitat), (2) half-log devices to provide cheap in-stream shelter for trout, and (3) catch and release fishing regulations.

Addendum

It has been a pleasure to work with the outstanding authors of the articles making up the informative supplement, *Stream Management for Salmonids*.

It is inevitable that stream management must mean manipulation of the environment, in this case the stream where trout or other cold-water salmonids live. Desirable manipulations are not necessarily easy to accomplish, and in too many cases what we have done in management of the stream for our favorite species of fish is what appeals to us, the anglers, rather than what is important to the fish. Too often the results are nicer places to fish at or in rather than improvement of the environment for the trout or salmon.

If we consider that most of the best water for trout, for example, is found in streams that have suffered the least change by man, then we might conclude that the less change we make the better.

As a matter of fact, this is true in many cases. The streams would be better producers if we kept our hands off rather than in our enthusiasm deciding that the fish want or need a change. There are many exceptions to this, but most are exceptions because we are dealing with streams that have already undergone considerable degradation as a result of man's activities.

Now, this is not entirely correct because if we construct a dam in a free-flowing stream and draw cold water from the bottom we might establish a cold-water fishery below the dam. This is considered, by cold-water fishermen, to be good. Usually the warm-water fishermen do not complain too loudly because they can fish in the lake. In spite of the fact that everyone might be reasonably happy, it is equally true that the dam constitutes a significant change in the stream's environment.

There are very extreme views about stream management, from forget it to build dams or gabions everywhere. It is not too difficult to conclude that if we can raise trout in hatcheries and stock them to be caught why bother with stream improvement. The need to stock could be each week, each weekend, over every holiday during the fishing season, when visiting dignitaries are in the area, when fishing clubs have scheduled tournament or the chamber of commerce sponsors a big-fish contest.

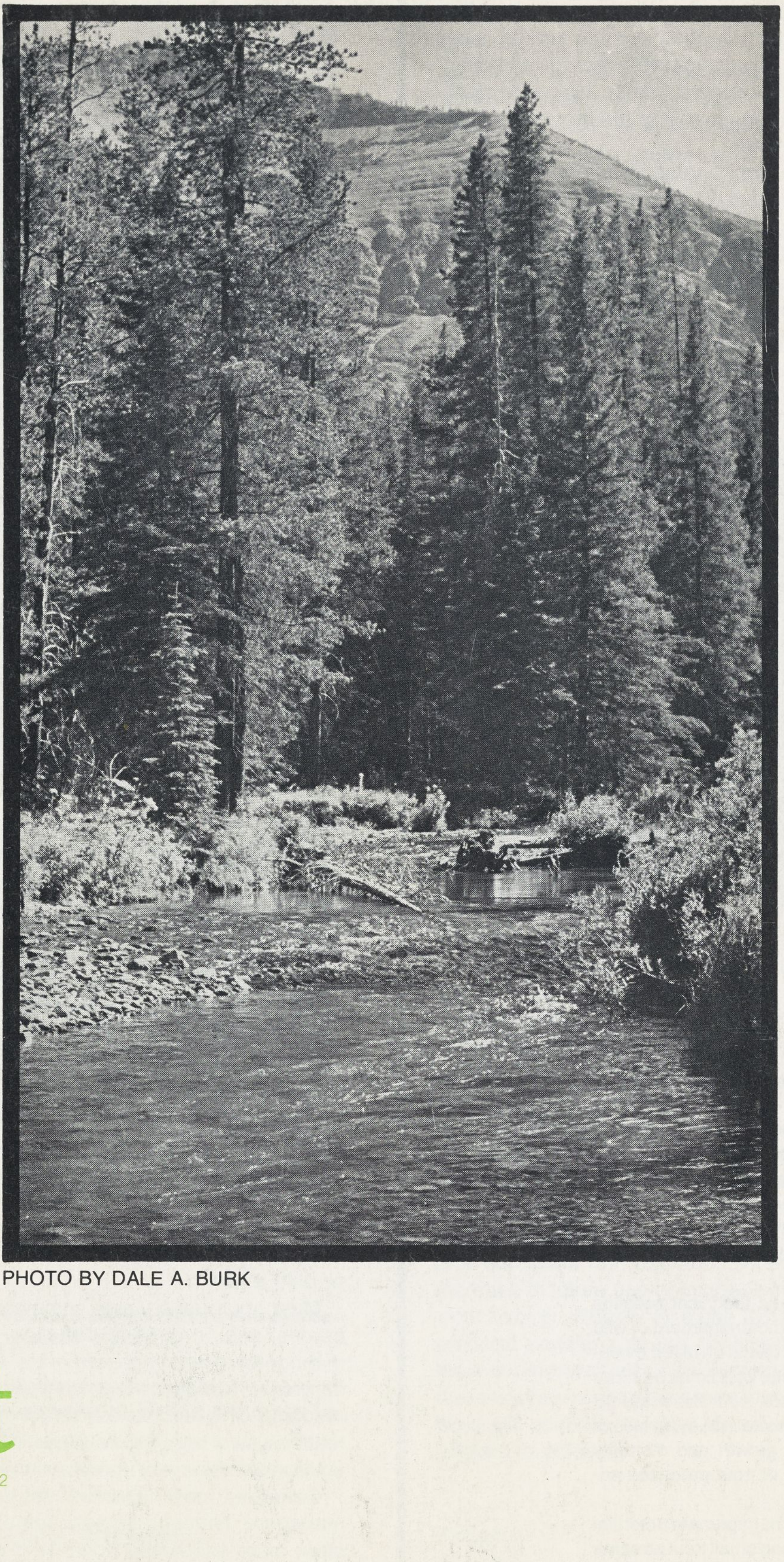
There are those who would eliminate the hatchery and improve all natural habitats, let grow what will grow and limit the fishing by regulation to match what is available. Everyone would fish for stream-bred trout (or whitefish) and keep none or only a few.

Most of us have views somewhere in between these extremes, and, in general, fisheries managers agree that the management and improvement of the environment is indeed important. It may, in fact, be the number one priority. Most recognize the hatchery as a tool of management and agree that the use of regulations is less important than controlling the environment but very important when dealing with fishermen.

Generally, most fishermen demand more regulations than managers. Although anglers demand fish to fish for they are often more concerned about who gets how many of them.

If *Trout* does a third supplement in its series of topics treating salmonids it will of necessity have to deal with regulations and rules and lean more to the social and behavioral aspects of fishing than to the biological. It will have much less to do with the fish and much more to do with the fisherman.

ALVIN R. GROVE



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