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GUIDELINES FOR
MANAGEMENT OF TROUT STREAM HABITAT
IN WISCONSIN

SUMMARY: MAIN PRINCIPLES IN MANAGING TROUT STREAM HABITAT

General

Tailor habitat management to the individual stream. This requires thorough examination of the stream and its trout, a diagnosis of problems and a plan for the "cures" before the work is done.

Preserve and restore the natural character of streams and their landscapes. This is essential to the quality of angling.

Meanders and/or riffle-pool "stepping" characterize all natural watercourses. Both appear to result from the same hydraulic processes. Through such horizontal sinuosity and vertical undulation, the channel meets some of the trout's life requirements. Pools at meander bends or at the foot of riffles or other plunges, provide protective depth. The riffles serve as spawning grounds, nurseries and food-producing areas.

Health of the Stream

A major aim of habitat management could be termed "health of the stream." Health is defined as "the capacity for self-repair." Eliminating dams and protecting stream banks against livestock on some streams are relatively inexpensive measures with great impact in enabling self-repair. Encouraging flood control and managing stream bank vegetation are important in allowing the stream to function as trout habitat, but more costly.

Vegetation

Not only protection but control of stream bank vegetation is often advisable to maintain favorable trout habitat. The trout-sheltering characteristic of natural channels are enhanced by the right kinds of vegetation, mainly the low stream-edge plants that drape into the water.

These and beneficial aquatic plants cannot grow well in dense shade of trees and tall bushes. Overshading is an especially acute hazard along small streams. Meadow creeks with low shrubs and grasses appear to have the best all-around combination of productivity and protection.

Therefore, remove woody vegetation from banks of small streams where groundwater seepage is adequate to keep summer temperatures moderate.

In-stream Alterations

Make the current work for you.

In low gradient streams, keep the water moving. Remove dams and other obstacles to flow (but do not remove meanders!). When building in-stream structures, do not impede the current unnecessarily.

In high gradient streams, make plunge pools. Pools scoured out by water plunging over large rocks or logs may look turbulent, but near the bottom they are quiet, protected resting places for trout.

Spawning Grounds

To aid spawning, protect and enhance naturally occurring stream bed gravel rather than trying to bring in and deposit new gravel. Experiments in building artificial spawning beds have not yet resulted in a method that meets the requirements of feasibility and of compatibility with the natural landscape.

Flood Control

Combat floods by reducing overland runoff back in the drainage basin above the stream, not solely by reinforcing stream banks.

GUIDELINES FOR MANAGEMENT

OF TROUT STREAM HABITAT

IN WISCONSIN

By

Ray J. White and Oscar M. Brynildson

CONTENTS

INTRODUCTION

Much can be done to improve trout fishing by making streams more suitable places for these fishes to live. The need is obvious on many streams. In this bulletin we present some principles and techniques to guide fish managers toward achievement of that objective.

Improving trout habitat in Wisconsin will be largely a task of restoration, for many of our rivers and creeks have been abused. Although two major threats, pollution and irrigation[1], have been kept fairly well under control, much trout water has lain deteriorated since the days of dam-building and stream-straightening. Heavy grazing and trampling by cattle and impoundment by beaver have continually mutilated our streams. In contrast, an obstruction of trout-producing capacity in some creeks is the canopy of trees and tall brush, grown so dense that it shades channel and banks excessively. In such places in-stream aquatic plants and low plants essential for hiding cover at the stream's edge develop poorly.

Thus, it is the physical and vegetational shortcomings of our streams that appear to be the most common curable hindrances to trout abundance. Therefore, this bulletin deals mainly with measures to improve the channel, the banks and the plant life for welfare of trout.

In view of the increasing demand for recreation in Wisconsin and the rising public concern over resource waste and landscape blight, it could be said that our damaged streams now represent an even greater neglect — and an even greater opportunity — than in the past. They are not beyond repair. Given the chance, water, soil and plants can interact with effects that mold good trout habitat. With protection and a little help even a badly disfigured former trout stream can transform itself back into a rewarding place to fish — and into a harmonious part of the landscape.

For about 15 years the Conservation Department has had a substantial statewide program of habitat management for trout. At the outset, information upon which to base the program was scanty, especially biological information. Much has been learned. Habitat managers developed better methods for planning and construction, and they discarded some methods found in the literature of the 1930's which proved ineffective or even damaging.

In addition, reactions of trout populations to habitat changes, natural and man-made, were studied in some of these streams in the management program. Here lay the authors' main responsibilty. Four creeks totalling 30 miles were most intensively investigated[2]. For 8 to 10 years on each stream we collected data on density, size and reproduction of resident trout. Electrofishing was the method for population inventory. Spawning sites were recorded each autumn. In some years harvest of trout by anglers was also recorded. In regard to habitat, observations were made on streamflow, vegetation and physical effects of deliberate alterations, among other factors.

The mass of data collected has not yet been analyzed in detail, but the general results are apparent: Increases in wild trout stocks took place in each stream following habitat management. The success of anglers rose as well. The most rapid and worthwhile reactions to management occurred in waters having high basic biological productivity, but damaged for trout by farm animals, impoundments or dredging. Greater streamflow during years of ample precipitation benefitted trout populations; decreasing streamflow affected them adversely.

Protected and controlled vegetation at the stream edges appears to have played a major role in achieving the increased trout stocks. This holds important implications for the Department stream management program. To assure public access for public fishing, state ownership of lands is being secured through purchase or lease along more and more miles of stream bank (most stream *beds* and *waters* are constitutionally open to the public). In many cases this removes the disturbances attributable to farming. A tour of these streams reveals much of the vegetational "strangulation" touched on above (and treated more fully under "Measures to Increase Hiding Cover"). Rather than simply protection, periodic control of stream bank vegetation is becoming a major need in the habitat management program.

Habitat can also be enhanced by building various shelters for trout and deflectors to dig pools. The initial cost of such structures is high, and they must be inspected and repaired periodically.

But we hasten to warn against overmanagement. Many Wisconsin streams remain relatively untouched by agriculture and urbanization. These unspoiled waters, especially the larger ones, are highly valuable from esthetic standpoints. More effort should go into preserving these

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[1] Pollution and irrigation are dealt with briefly under "The Resource"; otherwise seldom discussed. Pollution is amply covered in other literature. Irrigation is still under study as a water-loss problem.

[2] Main waters studied were McKenzie Cr. which flows through northwestern forest and marsh and contains brown trout; Big Roche-a-Cri Cr., a brook trout stream in the central sand plain; Black Earth and Mt. Vernon Creeks in southern farmland. Short-term studies of special problems were made on Trout Creek in the south; Dell Cr., south central; Prairie R., north central.

streams and their surroundings than into alteration of them.

Within each stream also, the fish manager must respect qualities of "stream personality" cherished by anglers who have fished it for years, for much besides abundance of trout and skill of angler enter into trout fishing's quality and meaning: Unique scenic setting, the sounds of nature, the overall character or mood be it sylvan, pastoral or swampy. Solitude is important; the angler wants to feel, for a few hours at least, that he has a peaceful corner of the world to himself. A varying waterscape also enriches a day's sport. The swift run, the riffle, the slow dark pool, the slough, the wooded reach, the meadow — each offers different challenges, different thrills. For the fish manager to serve his clients well, he must keep these aspects of the trout stream prominently in mind, as well as seeing to it that the stream maintains a substantial stock of trout. Reconciling productivity and natural beauty will often be difficult.

In this bulletin we seek to stress principles of management, not just methods. Preliminary examination, planning, and preservation of natural appearances were among the points D. J. O'Donnell advocated in 1948 when he wrote *Stream Habitat Control*, a set of guidelines for Wisconsin's budding habitat management program. We re-emphasize these aspects and bring out changes in approach since the 1950's.

The specific techniques discussed in the chapter on "Measures" do not constitute a recipe of "The Answers" to be applied cookbook-fashion to any stream by a novice. Rather, the sound approach in habitat management is to carefully determine for each stream the factors that are limiting trout abundance, and then to carry out the appropriate remedies. The judgment of habitat ills and the conduct of cures requires trained personnel.

From fundamental fields such as trout biology and stream hydrology more than from the very specialized field of habitat management itself, we bring into the text and/or bibliography a small selection of the many applicable references—those believed to have the most up-to-date information and to be of most direct use to the fish manager. We attempt no historical review of the subject. Especially stressed is material on physical processes in streams, the actions of water and sediments. These are of basic importance to stream management, and understanding of them has increased considerably in the last few years. Pertinent statements from recent books on this topic are assembled in Appendix A for the reader's concentrated study.

Even as we write this, further research into effects of environmental changes on trout populations is being conducted to follow out clues gained in the earlier work and to explore related aspects. Of special interest in this regard is the study at Lawrence Creek in central Wisconsin. Here, the impact of management is being scrutinized more closely, both physically and biologically, than in previous studies. To enable calculations of total weights of trout produced in the stream each season or year, the trout population is being inventoried more frequently than once or twice each year as was the procedure in other studies. Sampling is also done for production studies of insect larvae and other small organisms that dwell in Lawrence Creek. The need for such measurements of biological production is becoming increasingly recognized in fishery science. Those at Lawrence Creek will be useful not only to evaluate the management there, but will be a beginning toward understanding productivity in our streams. Such knowledge, as we emphasize from several standpoints in following chapters, is sorely needed to gauge the potential trout resource in the state and to plan management programs.

Thus, additions to the biological and physical foundations of habitat management should soon be forthcoming. Refinements of the methods we present as well as completely new techniques are awaited. In the meantime, out on the streams we hope this bulletin will serve well.

PURPOSE OF TROUT HABITAT MANAGEMENT

The aim of habitat management on trout streams is to provide the most favorable living conditions possible for trout without destroying natural beauty. Better living conditions will mean that the stream will support a greater abundance of trout through better survival, better growth and perhaps through better reproduction. Survival, growth and reproduction require shelter against predators, fertile water, sufficiency of living space, favorable water temperature, and gravel stream bed for spawning. The ultimate goal, of course, is to provide opportunity for sport fishing of high quality.

Habitat management is not building access roads for fishermen, posting signs on fishing grounds, and providing picnic facilities. These activities, while often necessary or desirable from the total management viewpoint, contribute nothing to the welfare of the trout. In the streams themselves, "development work" designed solely to make fishing easier is contrary to the real purpose of habitat development; moreover, it deprives the fisherman of the opportunity to exercise his skill and sportsmanship.

THE RESOURCE

Wisconsin has an appreciable amount of trout water, which constitutes a sizable public resource. Virtually all of it is open to public fishing. The state controls these highly esteemed waters, and the Conservation Department is charged with their management. Since our climate of severe temperature extremes and erratic rainfall is unfavorable to trout, the trout water is largely attributable to good underground storage of the rain that does fall and to the dependable discharge of groundwater into streams. Damages from sewage, industrial wastes, pesticides, irrigation pumpage and road building have been kept fairly low. The devastation of wasteful logging and fires is almost a thing of the past. Cattle, dams, dredging and floods have been greater or at least more continual problems.

There are 1,475 trout streams in Wisconsin comprising almost 9,000 miles. This is about one-fourth of our 34,500 miles of "navigable"[1] rivers and creeks. Most trout streams are in the north, but those in the south are more fertile and productive. Variety of stream types is a prime characteristic of the trout fishing opportunity Wisconsin offers. Swift water, slow water; wild streams, streams in agricultural areas (or even in urban settings); meadow streams; forested streams; brook trout streams, brown trout streams, streams with runs of "steelhead" rainbow trout, streams with mixed populations.[2]

This diversity of stream types poses a variety of problems for fish managers in their operations to maintain suitable habitat for trout. Many streams in the north lack enough food for desirable trout growth. There also, beaver are an especially great problem. Southern creeks, though rich in nutrients, are often plagued by drifting silts that render gravel unsuitable for spawning. The coulee streams of the western unglaciated region have steep beds, swift current interspersed with deep pools, large springs and nutrient-rich water. But the channels are so frequently devastated by floods that habitat manipulation in the absence of flood control measures may be futile.

Small creeks support the bulk of trout fishing in Wisconsin. That 9,000 miles of trout water are spread over almost 1,500 streams shows that most of the trout zones of our streams are under 10 miles long. We have only a handful of long trout rivers; the Peshtigo, Wolf and Bois

Northern stream

Southern stream

Coulee stream

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[1] Since, in Wisconsin, the legal criterion for "navigable" water concerns its ability to float a mere 12-foot-long "saw log," almost all waters are navigable. A landowner may refuse anglers permission to cross his land, but may not hinder an angler moving through his land in a navigable stream or on its bottom.

[2] Threinen and Poff (1963) described this variety in detail and related it to topography, climate, glacial geology, bedrock geology, soils and land use by humans.

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The phenomenon of mid-continental climatic extremes also applies to Wisconsin's rainfall. During the droughts which affect our region from timeto time, stream flow diminishes, living space for trout shrinks, pools become shallower and less protective, and much submerged shelter is left high and dry.

Another way that the hot summer droughts influence trout is through the effects on the vegetation of surrounding land. Turf that should hold the soil does not endure Wisconsin's dairy farming as well as it would were the climate cooler and more dependably rainy. Our stream banks erode rapidly when grazed.

Stream valleys often have a slope too gradual for trout reproduction. Not only are the slowly flowing waters severely cooled, but silts and sands deposit on the stream beds, often rendering whatever gravels may be present useless for spawning.

Wisconsin's climate and terrain are thus of marginal quality compared to those of the prime trout-producing regions of the world such as the British Isles, some other parts of western Europe, New Zealand, Tasmania, the far southern Chileno-Argentinian region and the northwestern North American coast, all of which are favored by a temperate, moist, ocean-influenced climate and generally steeper terrain. Parts of the American West, even though hotter than Wisconsin on summer days, maintain larger, longer trout streams partly because of snowmelt from nearby mountains and partly because the very dry western air leads to strong cooling, due to rapid evaporation and, at night, to radiation of the water's warmth into the atmosphere. Wisconsin's humid summer air, on the other hand, has a "hot house" effect: It lets the sun's ray through to heat earth and water almost as well as the western air, but is much more effective in hindering the outward (longwave) radiation of heat.

Some parts of the maritime regions mentioned above do not actually receive greater average annual precipitation than Wisconsin, but rain occurs more regularly. In northern Germany where landform is much like Wisconsin's and where precipitation is also about 30 inches per year, a ground-soaking rain can be expected almost every week. There, low flows are an almost unheard-of problem, and the stream bank turf is obviously in much better shape, even in dairying areas.[1] This comparison is, however, not completely accurate, for north European agriculture is more respectful of land and waters than is ours. Grazing of stream banks is under noticeably better control. On a broader scale, the erosion-control farming pleaded for in Wisconsin is a centuries-old tradition in northern Europe.

The Wolf River. Such large trout rivers are rare.

Brule Rivers being the best known.

The relatively short trout zones are largely due to our hot summers, making the water too warm after it leaves areas of high groundwater discharge — usually, but not necessarily, the headwaters. Warming is further aggravated when flow becomes slower in flatter terrain away from the source, or when streams are impounded.

Extreme cold in winter, on the other hand, causes heavy ice cover in all portions of streams except those with very strong groundwater discharge. In the parts of streams that remain near the freezing point for several months, winter growth of trout is nil and there are indications that eggs developing in the stream bed gravels undergo excessive mortality. Fine drifting ice particles found under very cold conditions, called frazil ice, are suspected as a cause of death among trout in Wisconsin.

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[1] Stream habitat improvement appears to receive relatively little consideration among German inland fishery "counsellors." Perhaps the better climate and more vigorous vegetation lessens the need. Perhaps also these counterparts to our fish managers are preoccupied with pollution, dredging and damming problems.

The hundreds of dollars per mile per year rental of private fishing rights may have something to do with it.

With all these disadvantages of climate and topography, what is then the basis for the fine trout fishery that Wisconsin does have? Undoubtedly our major assets in this regard are abundant groundwater and fertility. Storage of rain and snowmelt water in underground geological formations is excellent in many parts of the state, helping to compensate for drought. Even during a series of years having frequent droughts and subnormal precipitation, such as the 1951-58 period, and even in our poorer trout streams, enough water is maintained for some trout to "hang on" until rain is plentiful and populations can once again thrive. Trout are prolific. Given one or two years of ample rainfall, populations may bounce back to abundance.

In many cases this groundwater is rich in plant nutrients, the basis of a food-chain leading to rapid growth and high productivity of trout. This situation is found particularly in the south, west and central parts of the state. Here the streams, short as they may be, often sustain wild trout populations which, both in terms of individual size and in terms of total weight per acre, rank among the best to be found in small streams throughout the world.

The biological productivity of a stream, i.e., its capacity to support production of organic matter, is a key to the potential abundance of trout. However, a stream's capacity for producing trout must surely depend not on the total amount of food that occurs, but on some lesser amount, the *available* food. Determining availability is the necessity that the food be exposed to the trout, and the quite practical requirement that this be in such a place that he can obtain it without being preyed upon himself. A stream can be highly productive of food fauna, but so shallow and shelterless that few trout survive to eat much of it.

Many southern Wisconsin streams appear to be in delicate balance between high production of trout owing to high trout food production (plus moderate water temperatures), and poor production of trout owing to lack of hiding cover (often plus silted gravels and extreme summer water temperatures). Land use tips the balance. A few cows, a few hours of dredging or one dam can ruin the habitat. By the same token, small efforts in the right direction can do much to rehabilitate it.

Years of contact with trout fishermen in the field has shown us that most of these sportsmen want to believe that the fish they catch have been spawned, hatched and grown in the stream — true products of the land and its waters. From more than an economic standpoint, therefore, we consider streams that sustain substantial populations (over 50 lbs. per acre) of wild trout to be the more valuable ones. We stress the word "substantial." Some soft-water streams of northern Wisconsin have ample spawning habitat and myriads of wild brook trout, but are so cold during

winter and barren of food the year round that the trout fail to reach even 6 inches during their third summer of life. In contrast, long stretches of some central and southern streams lack good spawning habitat and have few wild trout, but possess the conditions for extraordinarily good growth (moderate water temperature and abundant trout food); here brook trout attain 8 to 12 inches in their third year! Such streams as the latter type constitute a potential for trout fishery management that should not be completely disregarded even though the fish in them cannot be wild trout. There is at present little hope of developing wild populations in them, since satisfactory ways of building spawning grounds have not yet been found.

Considering now just those streams which have basically low organic productivity, it stands to reason that a body of water can produce only small total weights of fish if it offers a meager food supply. Although information on food fauna in such Wisconsin streams is lacking, indications from trout population studies on chemically poor streams are that installations of hiding cover may result in a slightly higher number of trout, but practically no change in weight of trout per acre (except where hiding cover is very deficient). It would therefore seem that if worthwhile standing crops of trout are to be achieved in streams of low basic trout food productivity, survival-promoting techniques will probably have to be supplemented by measures to increase fertility of the water. How and where this can and should be done are problems for future investigation.

Large streams 100 feet wide and larger present different management problems than do creeks. Less intensive habitat control may frequently be appropriate, often because any manipulation at all might be esthetically undesirable, and sometimes because such large water simply won't need it. A sufficiency of deep water areas may often exist. As channels are wide, trees will not shade them excessively. Neither do toppled trees pose such a menace to habitat as in small Wisconsin streams, for they can often furnish fine shelter for trout without damming the flow. Alteration of the larger trout rivers could spoil wilderness qualities appreciated not only by anglers, but by canoeists, campers and others. The appropriate management of scenic large trout waters will in large measure be preservation. This includes protection against beaver in tributary streams as well as protection against dams, roads, pollution and other products of civilization.

Some of these "civilized" menaces, namely pollution and irrigation, warrant a few words at this point. Pollution, be it from domestic sewage, industrial wastes or pesticides, is a rising and widespread problem. However, laws to control it are becoming increasingly effective, thus there are good chances for reducing pollution where it does exist in trout water. On the whole, Wisconsin's trout seem to face less danger from pollution than do fishes in the "warmwater" rivers. The trout zones of our streams are most often

in small upstream waters, ones that did not support water traffic and that usually constituted poor sites for large towns in the days of settlement a century ago. (Unfortunately, however, they were attractive as village saw and grist mill sites.) Moreover, the state's population has long centered in the urban southeast, away from the main trout stream regions. The human population continues to shift in that direction and some of our best trout stream areas now have fewer residents than in 1900.

Pumping water directly from streams for the expanding practice of crop irrigation has been even more effectively controlled by strict water-use laws. Careful watchdogging by several state agencies and by the citizenry has played a large part in this control. This leaves our trout resource relatively undamaged by irrigators, compared to the devastation from that source in western states. But the threat is not removed. Consumption of groundwater for irrigation is on the increase. This drawdown of the groundwater table is presently under study as a streamflow-reducing factor and as a source of damage to trout habitat. Precise measurements of this damage are not yet at hand and may be difficult to get. The heavy dependence on groundwater for maintaining suitable temperatures and spawning habitat is, however, already well recognized, as is the importance of substantial flow to trout shelter (depth plus abundance of submerged hiding places), living space and supply of nutrients. It is logical that any factors reducing these flows would be detrimental.

Hazards of grazing, dams, dredging and floods are covered in later chapters.

Wisconsin's 9,000 miles of trout water constitute no overabundance. Michigan has 13,000 miles, New York boasts 17,000 miles, and western states must have still more, yet Wisconsin is one of the leaders in fishing license sales. To meet this demand and to counter our disadvantages of climate and terrain, we will probably have to manage trout stream habitat more intensively than might be the case elsewhere.

THE MANAGEMENT APPROACH

Principles

Follow Nature's Lead

Do not construct devices just because they are "in the book." Let nature call the shots. For the observant habitat manager, the needs of the trout and the characteristics of the stream itself will be the truest guides to good management. The lay of the stream will suggest the best locations for structures. Expend only enough effort to achieve the reasonable potential of the stream. Habitat management is fundamentally a problem of biology, not engineering. Rather than trying to improve on nature, we will do well to open the way for nature to improve the stream herself — an efficient and esthetic practice.

Treat Each Stream Individually

No two streams are alike. Each has its own distinct character — and its own special problems. Although some basic similarities among streams exist, one must temper general recommendations with individual judgments. Each stream should have its own tailored management plan.

Keep the Whole Stream in Mind

Manage habitat with regard for the way the *whole* stream functions as trout habitat. To develop short, miscellaneous sections without knowing their role in the stream's ecology can be wasteful. For instance, to alter riffles in a section comprising the only spawning habitat might injure the whole stream's population. On the other hand, it would be futile to make special efforts to preserve as spawning grounds some riffles such as we have seen, where few trout spawn and where eggs develop slowly and survive poorly owing to severe and prolonged cold each winter. Make a thorough examination to identify ecological zones: steep, riffled sections or slow marshy sections or cascades, etc. Then decide how each might be altered to function better within the entire habitat.

Preserve Natural Character

To enhance the quality of fishing opportunity, maintain the natural character of streams. We repeat the warning against overmanagement and artificiality expressed in the introduction, and point out again that it will often be difficult to reconcile the need for preserving "stream personality" with the urge to raise its trout productivity by radical alterations. Be prepared to tone down intensity of management for the sake of the natural aspect. The instream structures recommended in this booklet can be built inconspicuously.

Personnel

Habitat management is a job for professionals, and standards are high. Improper manipulation of habitat can

seriously damage our trout streams. Davis and his co-workers (1935) put it well thirty years ago: "Only a man familiar with trout and their ways can hope to develop a stream in such a manner as to provide the most favorable conditions possible for their welfare."

Since the ultimate goal is to provide opportunity for sport fishing of high quality, the best man to accomplish this will be one who, by being a trout fisherman, has a thorough appreciation of the sport.

Planning and layout of habitat development programs should be the responsibility of a professional biologist experienced in trout stream ecology. He should also be available to advise at all stages of the work and to evaluate the effects of development. The main difficulty in habitat management will often lie not in devising a treatment to solve an immediate problem, but in foreseeing the consequences of each possible treatment.

Ideally, the fish managers or biologists who supervise the prescribed alterations of habitat should be well grounded in practical trout ecology and highly experienced in habitat development. Their staffs should include technicians trained in surveying and mapping, as well as foremen skilled in carpentry and mechanics.

Paid employes generally do better work than volunteers. The enthusiasm of volunteers quickly wanes and one cannot count on them for sustained or skillful effort. Amateur efforts such as work days by sportsmen's clubs, boy scouts and school groups have often been unsatisfactory. These groups should not be discouraged, but unless skilled supervision is available at all times confine their efforts as much as possible to tasks such as removing trees, building fences and hauling supplies. Without this kind of intense supervision, special "classroom" areas might be set aside on the less vital trout streams in which these groups could practice habitat development.

Planning

Habitat management should be carefully planned and should be carried out according to the principle of "look before you leap." After finding the streams with trout potential in their area, the biologist and fish manager should even more carefully examine each stream individually to diagnose ailments and prescribe remedies before alteration is done. Reducing erosion to protect spawning habitat, for example, is pointless in a stream that lacks gravel.

The overall approach should include several steps:

1. *Select* streams through a statewide or regional survey of habitat and trout populations.
2. *Examine* the individual stream's fish population and significant environmental factors in detail.
3. *Diagnose* specific problems of each segment of the stream.
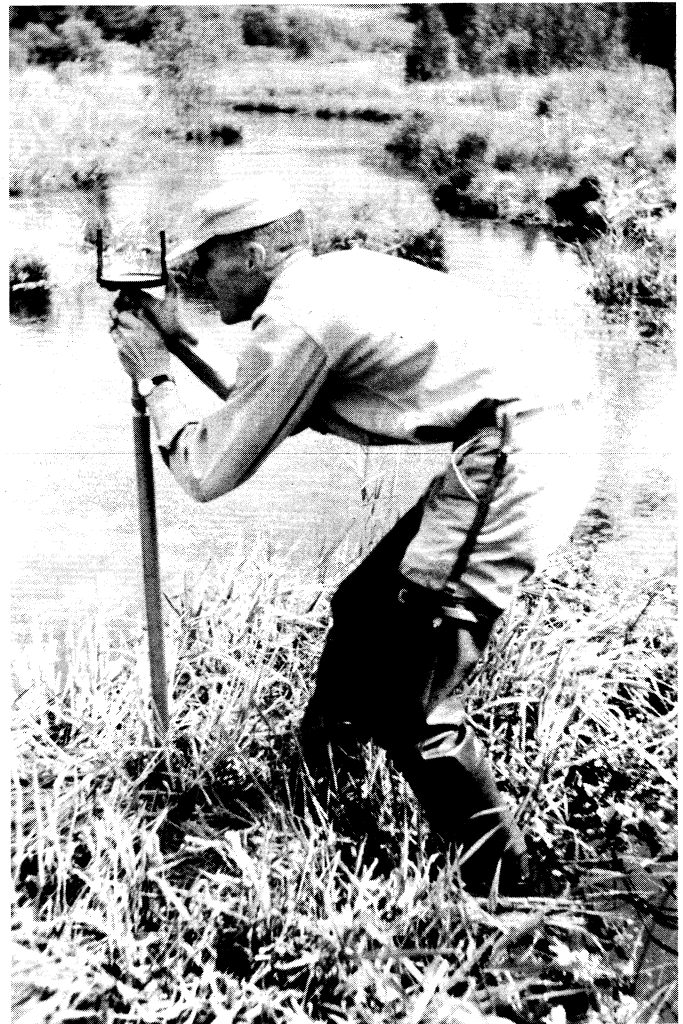
"... look before you leap."

4. *Prescribe* treatments for these problems and prescribe their sequence. Give priority to treatments that will have the greatest effect for the least expenditure of effort.
5. THEN *treat* according to plan.
6. *Inspect and repair* regularly through a continuing maintenance program.

Diagnosis of specific shortcomings of the habitat and the prescription for management depend on the aquatic biologist and the fish manager during preliminary examination: diagnosis will be entirely their judgment of deficiencies in the habitat; prescription could include their own innovations plus choices from the techniques we discuss. In this bulletin we discuss all steps in this approach except diagnosis and prescription.

We cannot manage the trout fishery wisely until we know the extent of the resource. The most effective management would be to concentrate first on streams which are most valuable to Wisconsin's trout fishery. We suggest

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the following criteria for judging a stream's value — i.e., is it worth managing?

1. Present capacity for growth and natural reproduction of trout.
2. Present "carrying capacity." (See Glossary, Part II, Appendix C.)
3. Potential capacities at various intensities of management (e.g., preservation only, control of vegetation, control of vegetation plus construction of in-stream devices) for supporting wild trout populations.
4. Unique qualities of habitat; for instance, those afforded by Wisconsin's scarce large trout rivers such as the Bois Brule.
5. Occurrence of wild brook trout populations in regions where brown trout have taken over most streams.

An extensive survey of Wisconsin's trout streams and their fish populations could provide the information needed for these judgments. This is now possible through electrofishing and techniques of habitat analysis. Until such a survey is carried out, selection will have to be made with less statewide perspective.

Where all other environmental factors are suitable for trout, fertility of water — and attendant trout food production — should be major considerations in evaluating trout streams. We emphasize again that lack of nutrients will often be the factor limiting production of trout and it may be futile to select such water for habitat development geared mainly to create hiding cover. Results will, of course, be especially insignficant in streams already having fair or ample hiding cover. Total poundage of wild trout in physically damaged but fertile Black Earth and Mt. Vernon Creeks in southern Wisconsin increased several-fold when the streams were protected from cattle and when their hiding cover was augmented; whereas, in part of relatively infertile McKenzie Creek (northwestern Wisconsin), having fair natural hiding cover, many added shelters appeared to modestly increase survival of larger-sized trout, but failed to raise significantly the total poundage of trout.

Carrying capacity for trout should also be carefully considered in selecting streams for habitat development. Choose a stream for development only if physical and biological surveys show that the prospects for increasing the year-round carrying capacity for trout are high. We stress the phrase "year-round." It would be useless to alter habitat for higher production of trout if the stream's carrying capacity usually decreased drastically in some season, as through icing or loss of protective cover (in-stream vegetation) in winter; or through some often-recurring disaster, such as flash flooding. This could cancel any increase in summer production achieved by altering the habitat. Select streams having potential for increased natural reproduction in preference to streams which must be replenished through stocking, but potential year-round carrying capacity should be a primary consideration.

When inventorying fish populations of streams under consideration for habitat management, it is advisable to make estimates by mark-and-recapture electrofishing. Such estimates require 2 electrofishing runs and involve calculations by the Petersen formula. In streams this is an especially efficient and reliable way of estimating total populations and of determining size- and age-structures of stocks present. Other relatively reliable methods of obtaining the same information are the "virtually complete collection" procedures such as making 3 or more electrofishing runs while holding all captured fish in cumbersome live boxes, or poisoning - and - collecting. But these have obvious disadvantages of laboriousness and damage to the fish populations. Owing to size- and species-selectivity of electrofishing gear, the "one-run survey" gives misleading indications of total populations and of their size- and age-structures. Therefore, the one-run survey is a poor basis for management decisions and we recommend against using it.[1]

Though he can delegate much of the labor, the directing biologist should maintain control over the biological and physical examination of the streams. To be thoroughly familiar with the stream, he and the fish manager should take part in the electrofishing examination, and they should walk the complete length of the trout water plus any water above it—in the channel as much as possible— (1) during April (least vegetation at this time and stream can best be seen), (2) in midsummer, (3) in November to observe spawning (this is late enough to find all general areas used for spawning and (4) in midwinter when the air temperature is —10°F. or lower in order to inspect for ice cover if present.

An adequate examination would thus cover key events on each stream throughout a complete year, ideally, beginning in March or April and extending into the following January or February (see schedule of examination, p. 57).

Appendix B contains more detailed recommendations for the procedure of examination.

Methods of treatment constitute the bulk of this paper and will be discussed in the sections following.

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[1] Moreover, catching-efficiency of electrofishing gear also varies according to chemical content, temperature and velocity of the water; according to cross-sectional area and bed material of the channel; according to skill of the electrofishing crew and according to how well sky-lighting, water turbidity and water depth allow the crew to see the fish. These factors vary from one stream to another. Even in the same stream they differ from one reach to another and from day to day. Therefore, the one-run electrofishing survey is also misleading in comparisons between streams or between different sections or years on the same stream. The second (recapture) run is essential to measure the total bias of these factors and to allow adjustment by the Petersen formula.

STREAM MANAGEMENT TO PROTECT AND IMPROVE TROUT HABITAT

In many streams that are free of pollution and severe floods, and where temperatures are tolerable to trout the year-round, the key to survival of trout is enough places for hiding from predators and from each other (to minimize territorial competition, if not also cannibalism). Collectively we call these places "hiding cover." The basic habitat requirement for reproduction is gravel riffles for spawning, though factors other than amount of gravel and its quality apparently help to determine the size of each year's new crop of young trout. In seasons when water temperatures favor good growth of trout, the keys to growth are ample food and sufficient living space. Therefore, the following basic managements are recommended:

Basic Management						
Provide more cover	Less predation	→	Better survival	→	More trout	
Increase the amount of stream available for trout to use	More room to grow in	→	Less competition for space	→	Better growth and survival	→ More and bigger trout
Make naturally occurring gravels more available to spawning trout	Better reproduction	→	More trout			
Increase fertility of water	Better supply of food	→	Better growth			

Of these four general procedures, concentrate on the first two. Sound measures to achieve hiding cover and enlarge living space stand to yield better spawning grounds and more food as by-products. Amount of plant and rock surfaces for food fauna to grow on will be increased, and often more light will reach the stream and its banks. Methods to directly boost reproductive and food-producing capacity are not yet well developed. Keep in mind how management influences the interrelated factors: cover, living space, spawning grounds, food, temperature and change in stream flow. In short, be "trout-oriented" rather than "method-oriented."

Practice the principle of moderation; do not expend efforts to manipulate already excellent habitat which needs merely protection. Often with small effort natural forces can be put to work, namely the current and vegetation, to accomplish the same results as expensive structures.

Measures to Increase Hiding Cover and Living Space

We consider hiding cover and amount of space together because measures to create hiding cover will often bring about increases in the amount of stream that trout can inhabit. In many streams the total volume of the channel far exceeds that portion which trout can effectively use. Much of the channel may be too shallow for large trout to swim into; other parts, of insufficient depth to furnish protection from birds and mammals. Adding brush shelters at the channel edge and perhaps deepening the channel slightly would open such areas to trout, give them a greater volume of water in which to live.

Natural protective cover develops best when the stream is protected from flooding. Floods break down overhanging banks, carry away brush and logs and otherwise destroy hiding places. While the debris that floods pile up may often shelter trout, these accumulations impound reaches having low gradient, often with the result that silt deposited behind them inundates spawning beds and food-producing surfaces of rocks and vegetation.

Good stream bank cover.

Protecting and Managing Stream Bank Vegetation

When vegetation binds the stream banks they erode less rapidly and the current digs a deeper stream channel—one that protects trout better. A sturdy turf will often form overhangs. These are excellent shelter. In any case, plants on the stream bank together with emergent plants such as watercress, can form an ideal fringe of hiding places for trout at the water's edge. Grasses and low brush are best for this; they should be protected from shade and grazing.

Trees and high brush shade out the plants composing this beneficial turf. Like other parts of a forest floor under a dense canopy of foliage, a heavily shaded stream is nearly barren. It produces little food and is often wide and shallow. It lacks channel-constricting in-stream aquatic vegetation and cover-providing stream bank vegetation. Trees also damage small streams by toppling across them, making debris-catching obstructions and tearing up the bank in the process. Trees in the wet soil along streams have shallow, weak root systems (willows are an exception.) Remove trees shading the water and banks of those streams which will not be excessively warmed by the sun; that is, those receiving a sufficient inflow of spring and seepage water.

Do not plant trees — except where there is reasonable evidence that summer water temperatures are lethally high

Nearby section of the same stream just after fence was put up. Although photographed in spring when conditions were at their worst, heavy grazing had, in previous years, prevented development of vegetative cover much beyond what is shown here.

12

A densely shaded stretch of Mt. Vernon Creek with a raw, continually eroding mud bank
for most of the year.

The same stretch of bank developed a turf after the trees were removed and banks sloped.
The grass is still in the first spring of growth, has not yet attained its full length and value
as hiding cover, but has already withstood a spring flood.

Stream bank tree tipped back away from channel. Its plate-like root system heaved many feet of shoreline. Thus, shallow "wide-spreads" result, or the course of the channel may be changed drastically. Such events ruin wing-deflectors and other installations — another reason why trees should often be removed at the outset of a stream improvement program.

lowing livestock. They not only eat plants, but trample them and in the process also cave in trout-protecting overhangs of the bank. Fencing cattle away from our streams is one of the primary needs in managing Wisconsin's trout resource. It is an inexpensive way of letting nature take its own course to improve habitat for trout.

Grasses mixed with broad-leaved annuals appear to be best for development of food-producing turf on the bank. In streams less than 15 feet wide, rely on grasses and annuals exclusively to provide hiding cover and bank protection; keep the brush out. On streams 15 to 30 feet wide, very low bushes will not cause damage, but high bushes such as alder should be cut regularly or eliminated.

Reed canary grass, *Phalaris arundinacea* is proving to be a highly important grass for stabilizing the soils of Wisconsin stream banks and for providing overhanging cover for trout. It has long been used to protect waterways in Europe and much of the seed for stands in this country was imported from Sweden, though some varieties of reed canary grass are native to North America. Reed canary grass grows in dense, continuous stands 2 to 8 feet in height. At all seasons a bank-lining fringe of it drapes into the water; even in winter and early spring when brown and withered, this fringe remains durable. The tough system of roots and runners hinders erosion and traps sediments washed downstream during high water. Reed canary grass withstands a wide range of moisture conditions, even grows under water for extended periods. Best growth is attained on moist cool sites, but this grass will also thrive on upland soils. That it is one of the earliest grasses to begin growth in springtime is a further advantage—many other shelter-providing plants do not develop until much later. Reed canary grass can be cut to prevent excessive growths without damaging the turf; however, it will not withstand

for trout and that temperatures can only be reduced by shading with trees. Discourage persons engaged in reforestation from planting trees beside trout streams.

Controlled burning of stream bank vegetation holds promise as an important tool to hinder trees and promote grasses and other low plants. The methods for applying fire as stream bank management are, however, not yet developed. The hand-held mechanical brush cutter is at present a useful tool. Selective use of herbicides is being explored as a means of controlling brush on stream banks.

Protect the stream and its banks from grazing and wal-

Controlled burning holds promise.

Protect stream banks from grazing.

Reed canary grass provides good shelter at the edge of a stream.   J. M. Conrader

heavy grazing. Heavy stands of this grass in the upper reaches of streams sometimes hinder angling during late summer, but its superiority in protecting an overwinter trout population for good fishing the next spring and early summer may often outweigh the seasonal inconvenience to some anglers. Reed canary grass sometimes dams extremely small channels. Therefore, do not seed this grass along streams less than 4 feet wide.

Sedges (*Carex* sp.) appear to be less beneficial. In many areas they seem to provide patchy cover because their moisture tolerance range is relatively narrow, and hence provide less protection against stream bank erosion. However, since many species of sedges exist, perhaps useful ones can be found and utilized in stream bank management. Low-growing types would be especially desirable in the narrow headwaters of creeks, for they would not obstruct fishing or choke small waterways as does reed canary grass.

Bluegrass (*Poa pratensis*) with its short blades and weak, shallow root system, is even less desirable. This native of the Old World makes at best only a scanty fringe of hiding cover for trout; its turf is too weak to protect even moderately steep banks against washout. Rapidly eroding and slumping outer banks of stream bends characterize creeks in bluegrass meadows.

15

Willows (*Salix*) have proven to be useful bank protectors and providers of hiding places for trout, *if periodically controlled by basal pruning*. The leaves, branches and twigs of willow can be counted on to furnish little cover for trout; it is the roots that are important. Willows are our most aquatic tree. Many types of willows maintain relatively deep, tough root systems when growing on stream banks. The dense mass of roots forms a bank with many inverse ledges and grooves that trout can hide beneath. These root systems are effective in preventing bank erosion; you can often find willow root banks that have borne the surging water at a stream bend for several decades.

But to develop and maintain the dense stands of saplings necessary to have a continuous "root-revetment," willows require basal pruning. According to Tesch (1962), writing of German streams where this is a highly developed practice of bank protection, basal pruning should be done at intervals of about 3 years.

Large willow trees on the other hand, can damage a trout stream. By their own shade they prevent themselves from growing in dense continuous stands—and their shade inhibits in-stream vegetation. The roots of these lone trees provide only short patches of cover for trout. Limbs easily split off of large willows, fall into the stream and cause detrimental dams. A dense stand of low willow brush binds the stream bank better, but does not slough limbs into the streams and does not overshade the stream.

Many kinds of willows grow in North America. Some may prove to be very helpful in stream management; others, useless. An investigation should reveal types suited to various purposes and conditions, as in Kirwald (1964).

A dense stand of low willow brush binds the stream bank, and does not shade the water.

Limbs of large trees split off and dam up the stream. Spawning grounds become covered with silt.

The large willow with wide-spreading branches shaded both banks, leaving them barren of vegetation. Note the good growth of grasses in the foreground outside of the shaded areas.

On the same stream, a similar stream bank illustrates a good job of management. The willow on the right has been cut back. Removing shade produced by willows is a major part of the overall management of this part of the stream. Note resprouting of willow stumps on the right after two years of growth. They will need pruning soon.

16

The lower branches of young alders are alive and drape into the water, providing good trout cover.

Alders that have grown too high have long stems that completely arch a stream 25 feet wide, creating dense shade and providing no hiding cover.

Alders (*Alnus*) serve as submerged hiding cover only when their branches actually drape into the water. Alders are ideal shelter only on streams wider than 40 feet. On smaller streams they give too much shade to the stream bed and shade out their own lower branches, the ones which would serve as shelter. Even on larger streams, the beneficial lower branches of alder are often missing because the ice encasing them in winter has torn them away. Prevent alders from forming dense, continuous thickets along small trout streams.

The protection of stream bank vegetation from shade and livestock will also protect aquatic plants in the stream. These provide excellent hiding cover for trout, but unfortunately most of these plants die out in winter and do not flourish again until mid or late springtime. Watercress (*Nasturtium officinalis*), an import from Europe, is a principal aquatic plant important as trout shelter. This plant occurs in the hard water streams of western, southern and eastern Wisconsin, but is at best sparse in the north. In summer and autumn when it flourishes, it provides in many streams the principal cover for trout — and substrate for animals that trout eat. But cress withers and drifts away in November or December leaving the channel barren until it starts growing again the next spring.

Submerged aquatic plants such as *Elodea*, *Veronica* and water buttercup (*Ranunculus*) likewise cannot thrive in shade. These appear to provide less desirable hiding places than watercress, but they are more dependable as year-round cover. They flourish in summer, and often do not die out completely in winter.
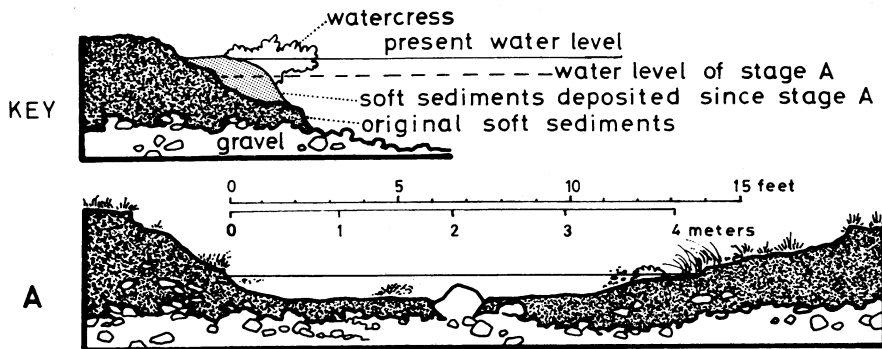
A small book, "Gewasserpflege" (Management of Waters) by E. Kirwald (1964) is to our knowledge the only general reference on control of stream-, river-, and lake-bank vegetation and its uses in stabilizing soils and landscaping. Although written primarily for the highway engineer, the farmer and the forester, it would also be of aid to the fish manager. It is presently available only in German, but possibilities for an English edition are being investigated.

Watercress along the bank, *Veronica* and *Elodea* in the middle of the stream. In protected streams, a variety of plants can grow.

Some stages in natural development of a fertile lowland Wisconsin trout stream from overgrazed (A) to very productive (D-E-F) to overforested (G&H) when protected from grazing. A hypothetical 14-foot wide cross-section plus adjacent bank shown.

The complete sequence from stage A to stage E-F has been observed on Black Earth and Mt. Vernon Creeks near Madison.

Later succession — stages G and H with many intermediates — is to be seen on other streams. Details of this succession vary from stream to stream, especially after stage E-F, but the passage from predominantly herbaceous to predominantly woody vegetation generally has the same detrimental effects. Good management for trout — and other wildlife — would be control of vegetation to maintain stages D-E-F.

KEY

watercress
present water level
————————water level of stage A
soft sediments deposited since stage A
original soft sediments
gravel

0   5   10   15 feet
0   1   2   3   4 meters

A

MIDSUMMER CONDITIONS UNDER HEAVY GRAZING BY LIVESTOCK:
Bank vegetation and watercress grazed and trampled. Banks eroding, and stream bed mostly covered by shifting silts. Submergent plants grow poorly. Whole surface of water and stream bed exposed to sun. Greatest depth in cross-section only 9 inches (22 cm). These conditions offer trout no shelter, no place to spawn, little food, and frequently unfavorable temperatures.

B

MIDSUMMER CONDITION AFTER 2 TO 4 YEARS OF PROTECTION AGAINST GRAZING:
Bank vegetation forming a turf. Abundant watercress at edges of stream constricts channel, thus deepening and speeding water. Soft sediments scoured from much of stream bed and trapped in cress beds. Submergent plants thriving. Only about half the former stream width exposed to sun. Greatest depth about 20 inches (50 cm). Trout have ample shelter beneath watercress, beside rock, and among submergent plants. Firm stream bed and many plants provide substrate for many animals that trout eat. Newly exposed gravel is a place to spawn.

C

LATE IN THE NEXT WINTER:
Watercress has withered and drifted away. The silts it held slump into the channel, smothering many of the trout eggs buried in gravel and preventing fry from emerging into stream. Food is scarce. Broad surface of water exposed to cold. Shelter for trout almost as poor as at stage A and will not redevelop until May or June.

D

MIDSUMMER CONDITION IN ABOUT 3RD TO 5TH YEAR AFTER GRAZING HALTED:
Further scouring of fine sediments from stream bed. Silt bars at stream edges being tied down by reed canary grass with its tough system of roots and runners. Watercress flourishing, and submergents at peak of development. Only 4 feet of stream width exposed to sky, and this shaded much of day by high grasses. Greatest depth in cross-section about 2 feet (60 cm). For trout, shelter, food, and spawning gravels are ample.
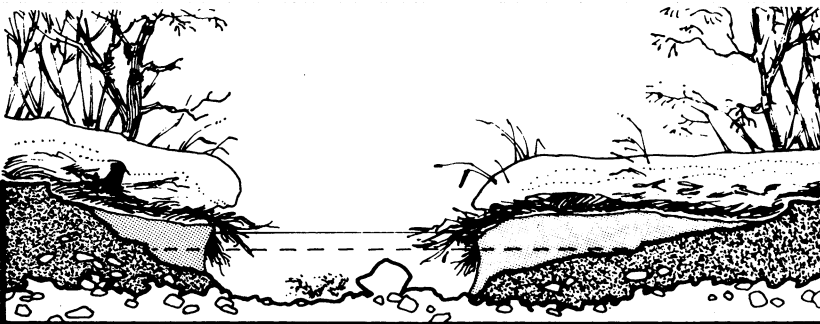
E
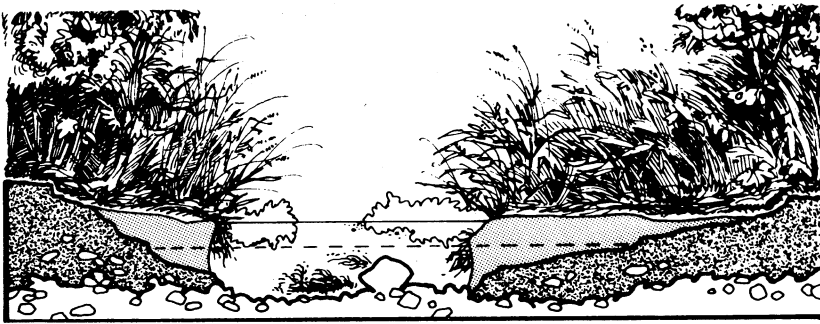
MIDSUMMER A FEW YEARS LATER:
Silt bars further stabilized by turf. Channel narrowed by 40% to 50% since stage A. Only 2 feet of stream width exposed; therefore submergents less abundant. Also less volume of watercress due to shade of taller plants. Woody vegetation starting to dominate.

F

LATE WINTER DURING STAGES D AND E:
Turf still holds bank materials firmly. Overhanging fringes of matted grass provide shelter for trout. Gravels remain clean enough to allow normal hatching and emergence of fry.

G

MIDSUMMER 10 TO 20 YEARS LATER:
Alders or other high bushes predominate (saplings of ash, elm or maple at left). Turf completely shaded out. Water level high due to clogging by debris. For trout, food may be scarce, shelter is excellent beneath banks, among roots and fallen branches.
But:
Innermost rows of alders will soon tip into channel, further clogging flow and destroying overhanging bank. The largely vegetational processes of bank-building will not be repeated as long as shade persists.

H
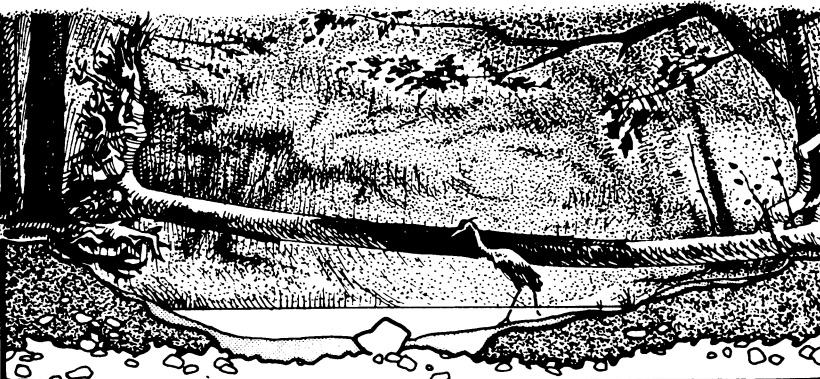
MANY YEARS LATER:
Mature forest . . . Dense shade. Few plants on forest floor. Banks have eroded, channel has spread and silts again cover stream bed. Channel less than 1 foot deep. Little shelter for trout. Even trees undermined by current and toppled across the stream may provide poor hiding cover. Conditions almost as bad as in stage A.

Constructing Devices to Maintain Sufficient Channel Depth and Cover

A deep channel protects trout from many terrestrial and aerial predators. Deep areas in the stream bed, or pools, occur naturally as parts of the meandered channel pattern of even slow-flowing streams as well as in the pool-riffle undulation of steeper stream beds. Both the meandered pattern and the pool-riffle sequence can be enhanced to create protective cover for trout. Modify the meandered pattern with deflectors and bank revetments to create a deeper channel. These same devices can also be used effectively to enhance the pool-riffle conformation. In streams of relatively high gradient, certain types of low dams (less than about 3 feet high) can also be used to deepen pools.

In constructing devices in low gradient streams, avoid damming the water — and be sure the devices do not destroy rifflles; riffles are essential for spawning and are desirable for food production. A good rule of thumb is to maintain a depth of 8 inches in "protected water," that is, water which has ample rocks, vegetation or other hiding cover. Open water should be at least 18 inches deep. Upon elimination of grazing or excess shade, vegetation will often achieve this deepening by narrowing the stream. If not, use single-wing deflectors and revetments of large rock to scour deeper runs and pools. Do not create pools longer than a distance equal to five channel widths; this appears to be an approximate limit of pool length under natural conditions, since pools or riffles are normally repeated every 5 to 7 channel widths. To set 4 or 5 channel widths as the maximum pool length in habitat manipulation may help avoid creating the deep, quiet waters that often serve mainly as habitat for suckers.

Dredging, digging, and blasting do not have long-lasting effect in removing light sediments from streams. Only where the bottom is composed of rock, rubble or peat could digging or blasting be used effectively to deepen the channel. If light sediments clog a stream channel, it is because the current is insufficient to carry them away. If sand or silt are dug out of the stream without removing the downstream obstacles that prevent more rapid flow, new sediments will drift in from upstream to fill the newly deepened channel. Use deflectors and revetments to control sediments present in the channel. These devices put the current to work.

In construction, build solidly. Use durable materials having a natural appearance. Rock is the preferable material for in-stream structures. Take care in selecting the rock to be used above water. Certain limestones, and perhaps other rocks soon crumble due to freezing and thawing. Keep woodwork completely under water or it will rapidly rot. Avoid weak, soft or readily rotted woods. Use oak when possible.

A shallow, sandy, spread-out stream . . .

. . . was narrowed and deepened with wing-deflectors and bank covers. Note the dark protective pool in the bend at the left (below).

20

Again, avoid unnecessarily obstructing flow in lowland streams, do not build debris-catching structures.

Wing-Deflectors

These are the best all-around devices for modifying channels. Basically, they are artificially abrupt and erosion-resistant upper or leading edges of "point bars" (see Glossary, Appendix C). A well-constructed system of wing-deflectors is durable and inconspicuous. Such an alternating series keeps the current moving swiftly and the channel moderately deep. It makes the current scour deeper pools at bends. The sand and silt scoured off the stream bed will be collected in point bars off the ends of wings downstream. Such a series of deflectors, because they are placed alternately on each side of the stream, conducts the current in a sinuous course. This not only looks natural, but is natural channel pattern.

Build deflectors in a roughly triangular shape solidly filled with rocks and soil, rather than in a peninsular shape (such as also achieved with single logs or sheet piling). This is to protect the stream bed and banks against damage by high water. Since water spills off an obstruction at right angles to the last surface it touches, downstream edges of triangular structures conduct high water back into the stream. On the other hand, peninsular structures cause high water to plunge toward the stream bank eroding holes between wings and bank. These holes become dead water pools when the water recedes. They become badly heated in summer and often harbor undesirable fishes.

When designing deflectors, observe two important prin-

Flimsy construction does not pay ten years later. Simply deflecting the current with plank wings wasn't enough. The bank has been eroded back several feet and winter ice formations have lifted the structures (see especially the plank in the background). Now most of the current goes under or around the structures and the stream remains wide and shallow.

ciples: (1) They should guide the current rather than dam it, and (2) They should have no protrusions on which drifting debris can accumulate.

Any device that impedes the flow of the current and collects floating debris is a hazard to trout habitat in our low gradient streams. In effect, a debris-collecting device is, or eventually will be, a dam. Deflectors should gently guide the current into a self-deepening, scouring action. There is no "correct angle" for a deflector (though some

Wing-deflectors in a stream, showing alternating pattern.

THALWEG

WRONG

WRONG

RIGHT

PENINSULAR WING
EROSION

PENINSULAR WING WITH CHUTE

TRIANGULAR WING

NORMAL STREAM FLOW

THALWEG

EROSION

FLOOD

Performance of various kinds of wings under normal streamflow and flood conditions. (Water course straightened to simplify the diagram.)

stream improvement manuals may advocate a 45° angle). Suit the angle and length of wing to the velocity of water and depth desired.
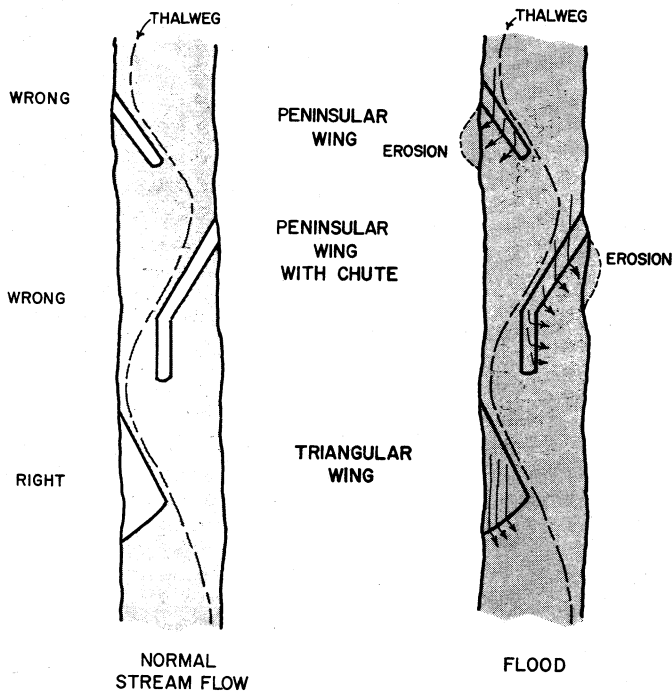
Do not build deflectors at crests of riffles; there they will dam the stream more than if built part way down the riffle, at its foot or in slack water beyond. The crest of the riffle already impounds the pool above it. Rather, deepen pools by deflecting current into them.

Build deflectors low enough to allow the bulk of abnormally high stream flow to pass over the top. High deflectors concentrate floodwater, hence tend to erode stream bed materials excessively and to damage the wings. Let your guide be the water level during early summer base flow in a year of normal rainfall. Deflectors should not protrude more than about 10 inches above this level.

Bank Covers

Bank covers are artificial, overhanging ledges, at the outside of bends where the current sweeps along the bank. They make ideal hiding places for larger trout — and for smaller trout if root tangles or brush are woven into them.

The fish manager has several choices in constructing bank covers and wing-deflectors: (1) a series of alternating isolated wing-deflectors; (2) the above plus isolated bank covers at each intervening stream bend; and (3) a combined construction of bank cover and wing-deflector, the wing being an extension of the bank cover.
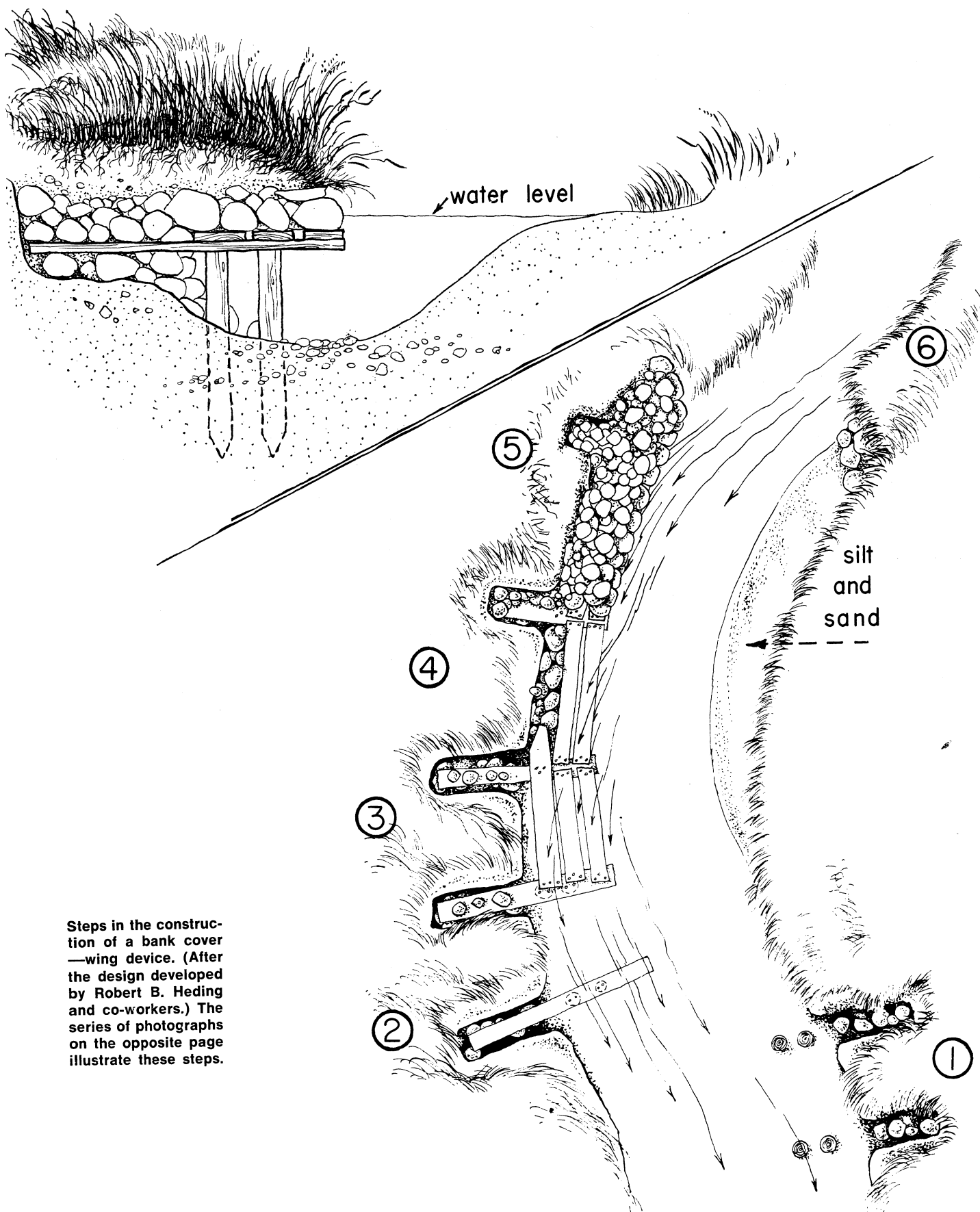

Silt and sand collect at a point bar extension of a wing-deflector. The view here looks downstream from one deflector. Brush is placed along the convex bank at this point to help tie down the fine sediments. Grass will soon cover the bar and make it a permanent part of the stream bank.

Bank cover

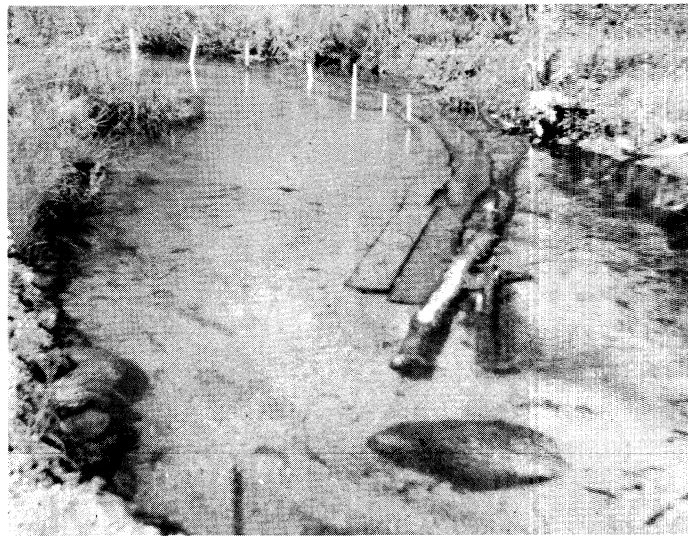water level

silt
and
sand

⑤

④

③

②

①

⑥

Steps in the construction of a bank cover —wing device. (After the design developed by Robert B. Heding and co-workers.) The series of photographs on the opposite page illustrate these steps.

1 Jetting the pilings.

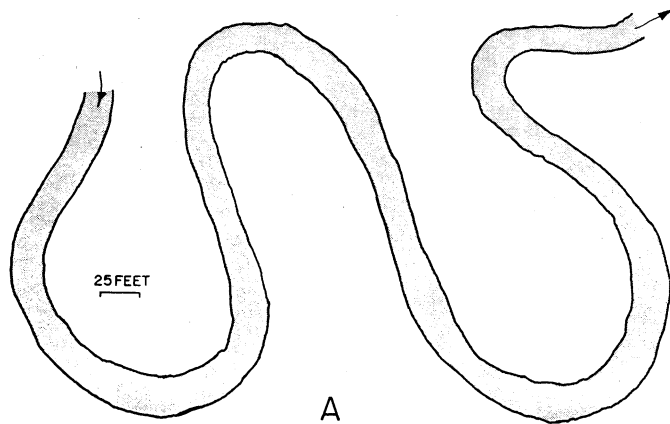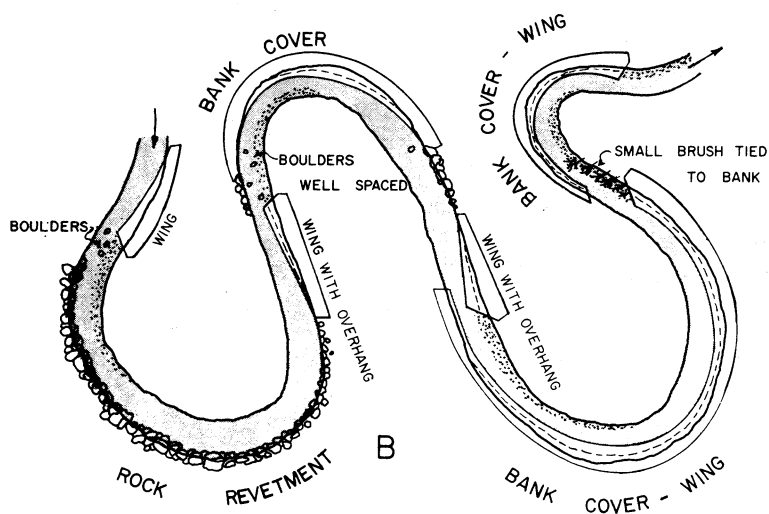**3** Spiking down the longitudinal planking.

2 Laying the stringers.

4-5 Revetting with rock behind the overhang and covering with rock.

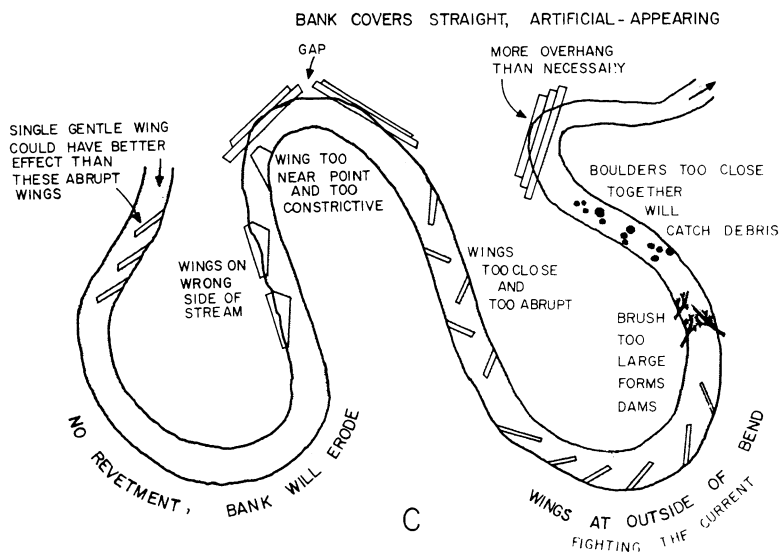**6** Covering finished device with soil and sod.

25

A

25 FEET

Meandering section of stream.

B

BANK COVER

COVER - WING

BANK COVER - WING

BOULDERS

BOULDERS WELL SPACED

SMALL BRUSH TIED TO BANK

WING

WING WITH OVERHANG

WING WITH OVERHANG

BOULDERS

ROCK REVETMENT

BANK COVER - WING

Same section showing various beneficial devices correctly placed in relation to channel pattern and in relation to each other.

1. **Wing and rock revetment (left)**

2. **Wings with overhang and bank cover (center)**

3. **The bank cover—wing combined into a single overhanging structure (last 2 bends).**

C

BANK COVERS STRAIGHT, ARTIFICIAL - APPEARING

GAP

MORE OVERHANG THAN NECESSARY

SINGLE GENTLE WING COULD HAVE BETTER EFFECT THAN THESE ABRUPT WINGS

WING TOO NEAR POINT AND TOO CONSTRICTIVE

BOULDERS TOO CLOSE TOGETHER WILL CATCH DEBRIS

WINGS ON WRONG SIDE OF STREAM

WINGS TOO CLOSE AND TOO ABRUPT

BRUSH TOO LARGE FORMS DAMS

NO REVETMENT, BANK WILL ERODE

WINGS AT OUTSIDE OF BEND FIGHTING THE CURRENT

Same section showing examples of poor construction, poor placement, poor combination or detrimental omission of various devices.

26
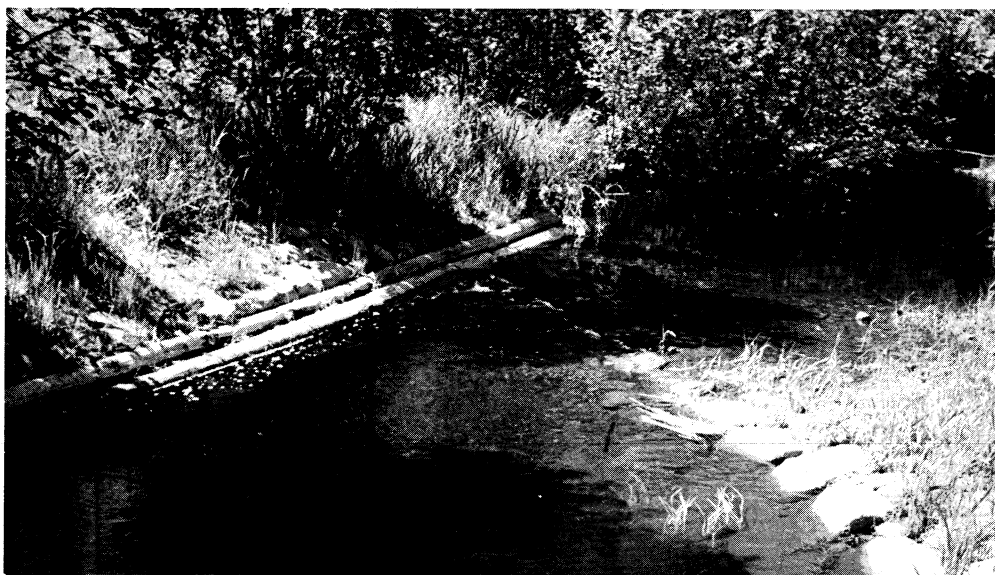
On a high gradient stream you can shoot the current beneath a bank cover by means of a subsurface rock wing-deflector, angled to let the water fall toward the bank. A rock wing-deflector provides cover and substrate for trout food.

Dense stippling in diagram shows deepest area of stream bed scoured out by the concentrated current.
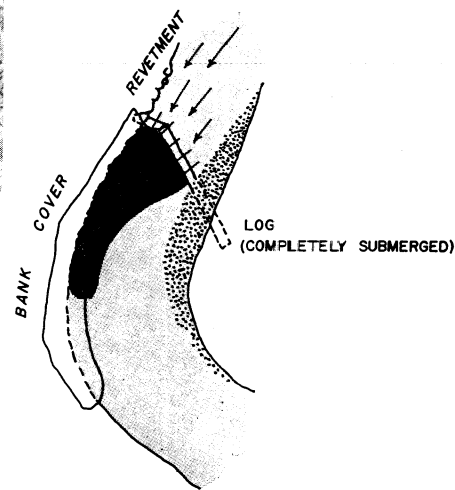
Low Barriers or Dams

Low barriers or dams can be used on high gradient streams to deepen pools. The pool-riffle sequence appears to be characteristic of streams with a gravel bed. In streams which are rather steep and straight, this undulating channel bed provides sheltering depth of water in pools; the shallower, swifter areas are called riffles. Trout spawn on riffles. Geologists have found that the processes leading to formation of pools and riffles are closely related to formation of meanders (Leopold and Langbein, 1966). It was a trout stream biologist, T. A. Stuart (Scottish Home Dept., 1959), who discovered that the pool-riffle sequence repeats at intervals of 5 to 7 channel widths. Geologists have since verified that this is the tendency in all streams and that 5 to 7 channel widths is also the interval between analogous points of meanders (Leopold, Wolman and Miller, 1964). For more details on the pool-riffle sequence, how it is formed and how it relates to physical processes in streams, see Appendix A.

Even waters such as rapids, which appear to flow so violently that trout could not dwell in them without constant exertion, have numerous calm pockets in the turbulence caused by boulders and other irregularities of the stream bed. Dr. W. Einsele of Austria (pers. comm.) demonstrated these resting places on film by sowing the current with many small floats. Few of them moved downstream at a velocity even approaching that of the apparent main current. Most were caught in slow eddies or came to rest in quiet water such as pools. The important aspect of steep natural streams is the "stair-stepped" form of their beds. The water does not shoot directly downslope for long distances, rather it plunges for short distances over rocks, ledges, and steep riffles, its energy dissipated in plunge pools beneath.

In a comprehensive treatise on current velocity in limnology, Einsele (1960) points up the importance of jumbled boulders in steep stream beds by comparing the velocities of these natural streams with velocities in similar streams which had been dredged into smooth channels. These "regulated channels" lack calm pockets and hiding cover for trout — and they lack trout. Trout are abundant, however, in the characteristic stair-stepped channels of natural streams. In mountain creeks whose stream beds were steep and frequently disrupted by floods, plunge pools constituted the major hiding cover of the stream and contained the most substantial concentrations of brown trout — though in fact, trout seemed to occupy almost every conceivable hiding place in shallower, faster water (observation of White during electrofishing with Einsele).

The Hewitt ramp (Hewitt, 1934) appears to be a superb pool-forming device for high gradient streams—but it can

The important aspect of steep natural streams is the stair-stepped form of their beds.

be safely used only in such streams. This device would more properly be termed a "plunge" or "ledge" rather than a "dam," for the important pool it forms is the plunge pool below, not an impoundment above.

In no case should the Hewitt ramp impound water for an upstream distance greater than 5 channel widths; preferably it should not impound any water. Do not place these ramps on spawning riffles. Build successive Hewitt ramps no closer than 5 to 7 channel widths.

Part of the water falling freely over a ledge tends to surge back and scour beneath the ledge. While the Hewitt ramp permits this action of the water, it is constructed to prevent excessive undermining and collapse. We infer from the research of T. A. Stuart (1962) on the swimming

and leaping of fishes over obstacles, that two characteristics of the Hewitt ramp permit free movement of trout: (1) the natural, undercut plunge-pool is the type from which, because of a standing wave of turbulence, the trout can most easily leap upward, and (2) the sloping, "ski-jump" is the best shape to permit natural movement of trout downstream over the device.

If the Hewitt ramp is constructed on a hard stream bed and the water will not scour a deep pool rapidly, dig out a pool which is 1.25 times the height of the waterfall. According to Stuart's observations, this is the depth to which free-falling water will eventually erode, and is the depth which provides the proper standing wave and quiet water at the bottom of the pool.

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The sturdy basic construction of the Hewitt ramp is shown in the above figure. The log forming the ramp is well anchored in both stream banks by triangular footings. Excellent placement of ramp well downstream in the riffle avoids impounding the stream (right). Crest of riffle can be seen in the upper right (Photos from Minn. Dept. of Conservation).
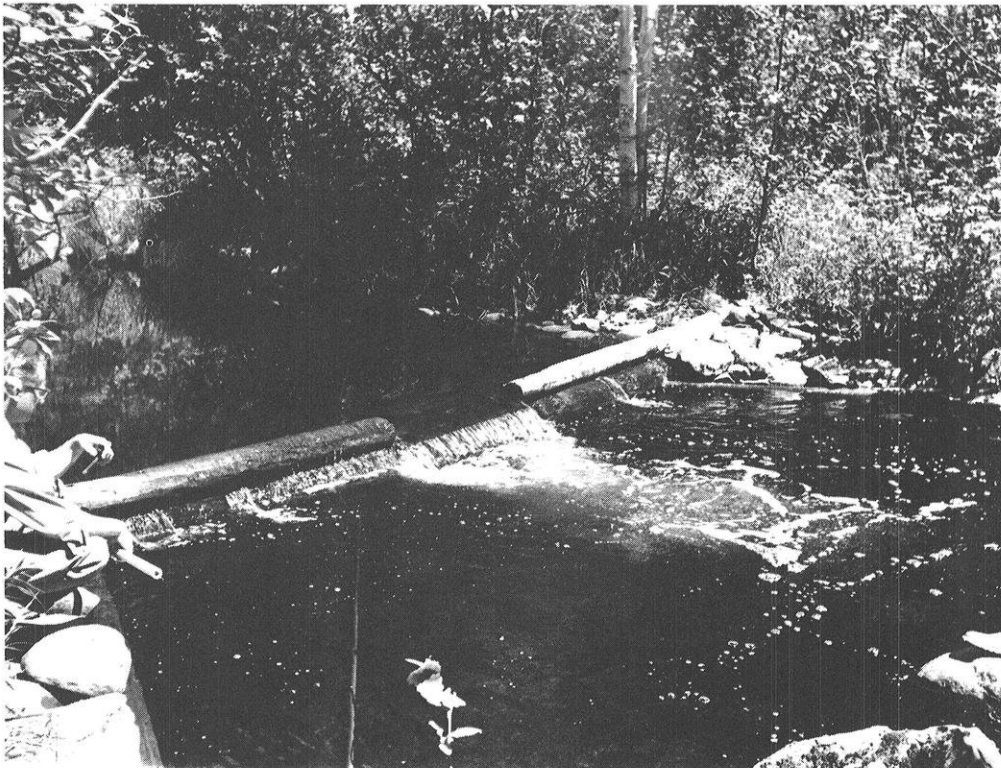
Drawings below diagram construction of the Hewitt ramp.

A

B
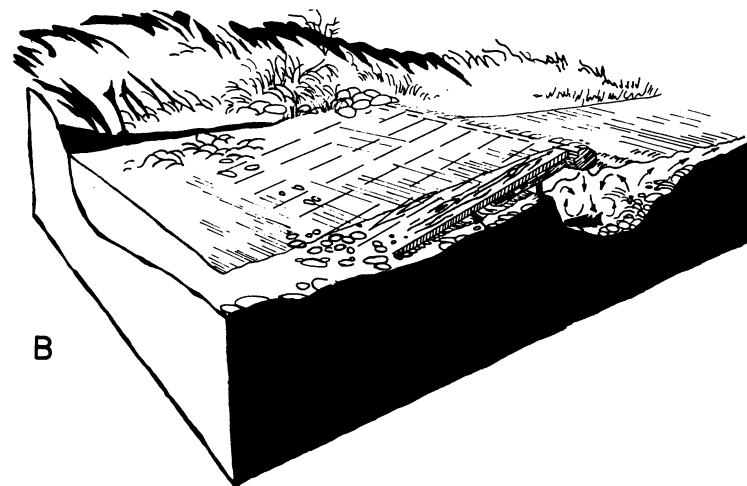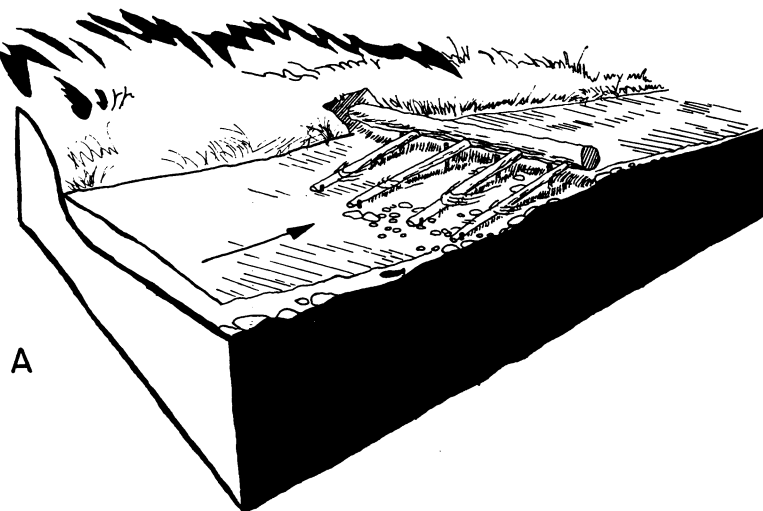
Another form of low dam which is desirable because of its natural appearance. It is made from rocks available at the stream site, and is an imitation of the natural stair-step pattern of very steep stream beds. (Minn. Dept. of Conservation)

A low, log dam — less desirable because of wooden construction.

In ideal situation, falling water enters the pool at nearly a 90° angle. A standing wave lies rather close to the waterfall, good position for trout to use its upward thrust in leaping. Plunge-pool depth is 1.25 times the distance (h) from crest of waterfall to water level of the pool.

A

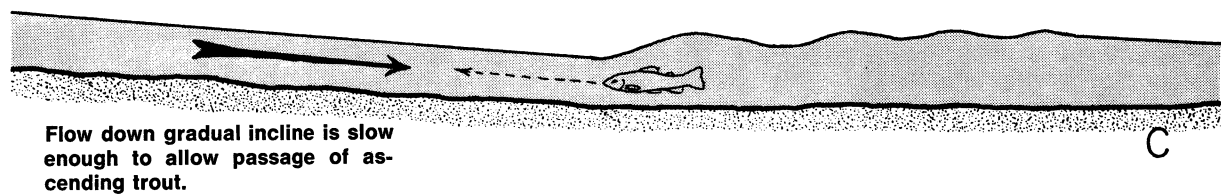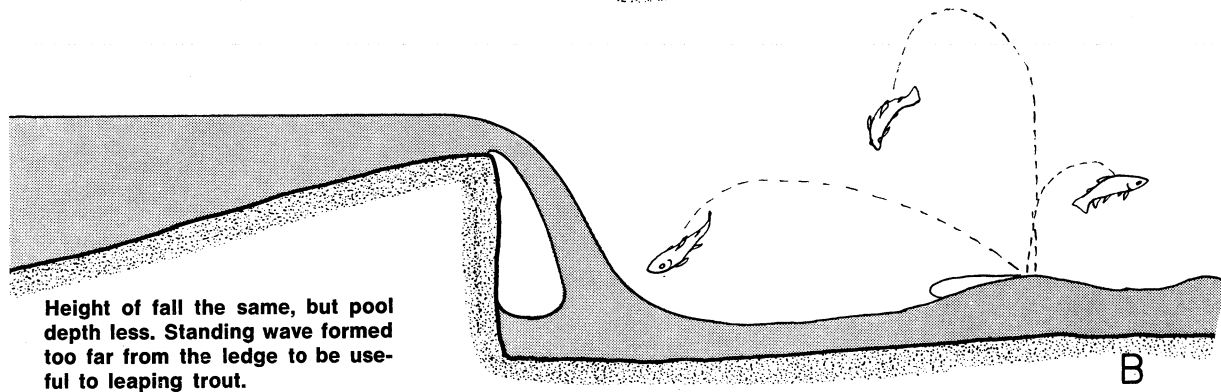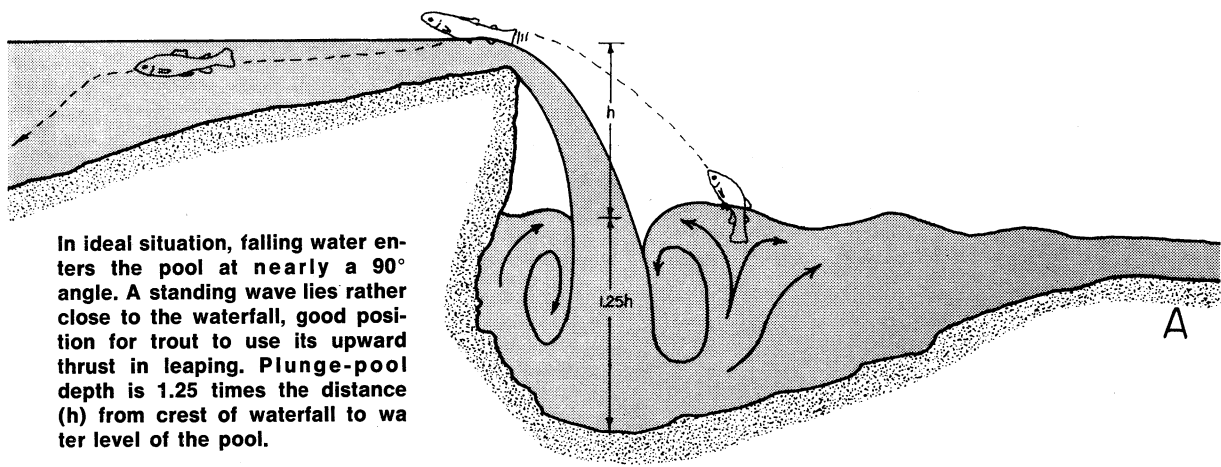Height of fall the same, but pool depth less. Standing wave formed too far from the ledge to be useful to leaping trout.

B

Flow down gradual incline is slow enough to allow passage of ascending trout.

C

Flow over steeper incline is more than trout can swim against for much distance. Trout may even be repulsed in standing wave at foot of incline. They sometimes leap futilely from the standing wave.

D

Shorter barrier with outflow over steep incline may be ascended by trout with difficulty.

E

MOVEMENT OF TROUT OVER OBSTACLES
(Diagrams drawn after Stuart, 1962)

STREAM WIDTHS

0   1   2   3   4   5   6   7   8   9   10   11   12
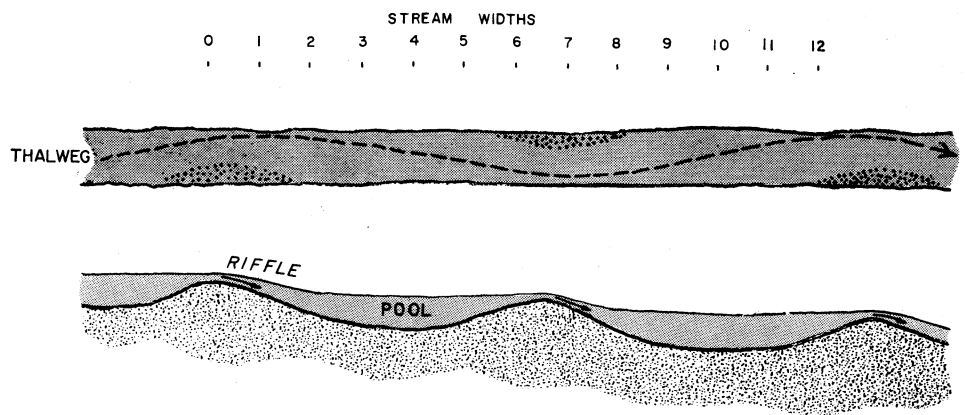
THALWEG

A

Unaltered conditions (af-
ter Leopold and Lang-
bein, 1966). Vertical
scale exaggerated. Note
sinuous course of thal-
weg. Riffle crests lie just
upstream from points
where thalweg is nearest
the bank. Distance be-
tween riffle crests is 5-7
stream widths. Thalweg
wave length is about 12
stream widths.

RIFFLE

POOL

UNDERCUT

THALWEG

POINT BAR
DEPOSITION
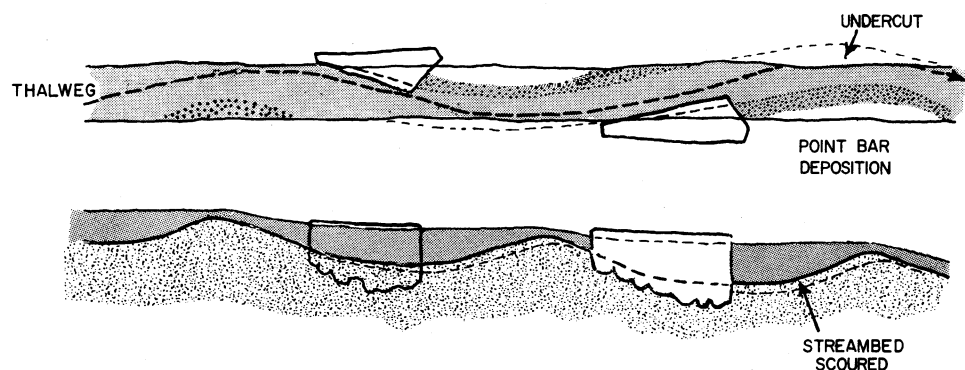
B

Wing-deflectors added
to increase meander and
to dig pools deeper
(rock revetment also
needed, but omitted to
simplify diagram.) Wings
placed well below riffle
crests so that pools will
not be impounded. Note
gradual angle of wings
— submerged face
(dashed line) almost
parallel to thalweg.

STREAMBED
SCOURED

THALWEG
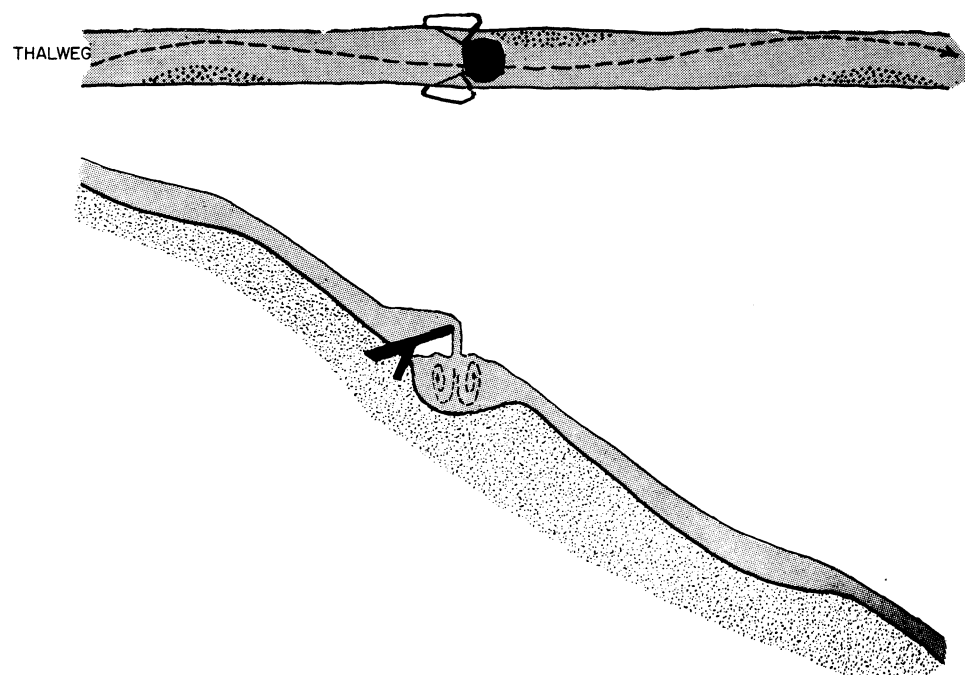
C

A much steeper channel
(vertical scale also ex-
aggerated). Placed well
below riffle crest, the
Hewitt ramp impounds a
minimum of water, but
creates a deep plunge
pool. Hewitt ramp (size
shown) would not have
been suitable for use in
stream section A; no
matter where placed, it
would have caused im-
poundment of long
reaches with resultant
deposition of silts on
spawning gravels.

CHARACTERISTICS OF STRAIGHT CHANNELS, AND PLACE-
MENT OF DEVICES TO ENHANCE THEM AS TROUT HABITAT.
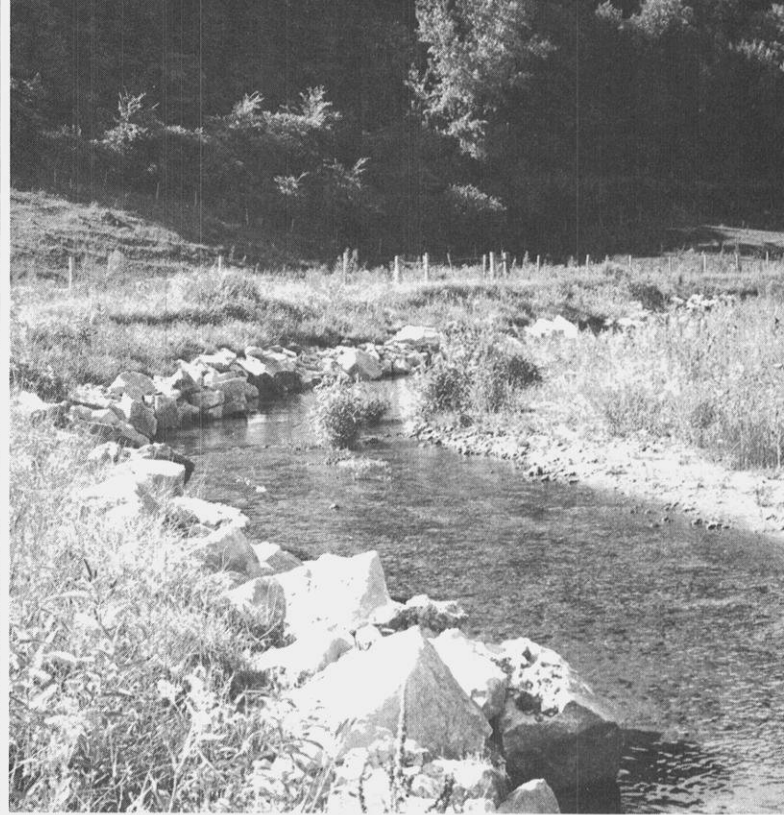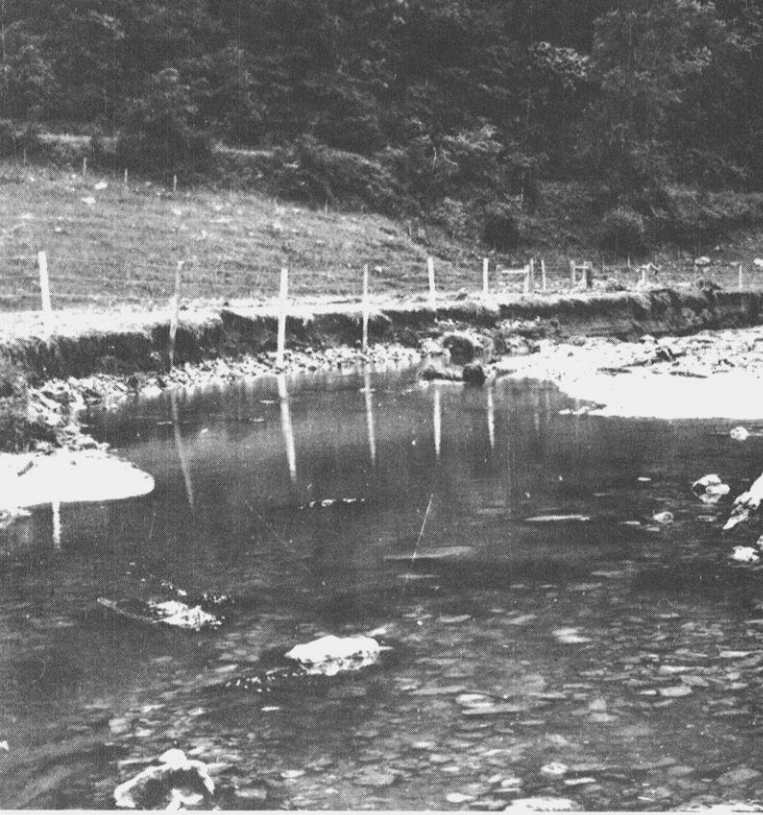
The stream on the left has been damaged by grazing and floods. The rapidly eroding stream bend provides little hiding cover for trout. At the right the same stream bend after revetment with rock (rip-rap). Note that the rocks are jumbled and provide numerous hiding places of various sizes for trout at the water's edge. The current, working against the stream bank which no longer erodes, has now dug a deeper channel. The fence is set well back behind the crest of the stream bank and a healthy turf now helps to protect the bank.

Rock Revetment

Rock revetment or "rip-rap" is a simple protection of the bank, and is often used primarily as a means of controlling bank erosion. This technique also has direct bearing on trout habitat in that it can cause deepening of the stream bend pool, and can itself, if properly constructed provide hiding places. Ideally the higher portions of the revetment rocks will become covered by turf.

Avoid building revetments as a mason would a wall. A jumbled mass of rocks has a more natural appearance and will provide many more hiding places for trout.

Note that the bank covers already discussed are basically rock revetments with even more cover built into them.

Materials other than rock have proven nowhere near as effective. A thin barrier along the stream bank such as is shown in the photo at right gives the stream an artificial appearance, is not durableand does not achieve its purpose. Floods scour between barrier and bank. The wood deteriorates rapidly because it is exposed to air. (See Fig. on p. 26).


There appears to be no substitute for rock.

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Installing Submerged Shelters

Brush submerged in the current of a stream along the bank provides the best general hiding cover for trout of all sizes. In brush they find a maze of hiding places — and our electrofishing has time and again shown us that they really use it. Here in these "snags," as anglers know them, trout can safely wait for the current to drift food to them, or they can dart into the open stream, grab a morsel and quickly return to shelter. Submerged brush hides trout from terrestrial, aerial and aquatic enemies—perhaps just as importantly, it protects them from cannibalism and it may reduce territorial conflict.
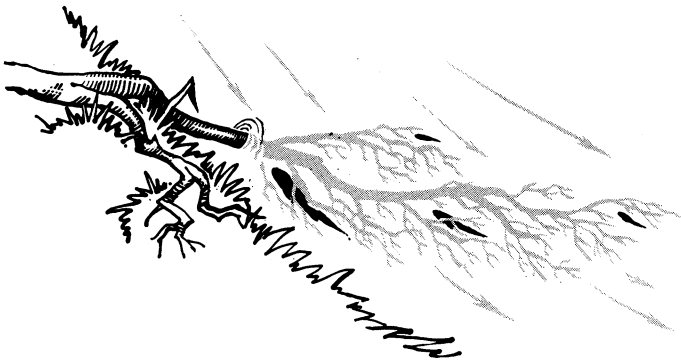
Therefore, build brush shelters to augment submerged brush occurring naturally in the stream. Our studies on McKenzie Creek indicated that trout of all sizes used brush shelters, but that especially large numbers of fingerlings

were found in them. Along small streams, cut brush right off the banks. Secure it carefully along the edges of the stream in a manner that will not dam the flow. Use tree-tops too. In large streams, whole trees, trunk and all, can be used. Fasten the butt ends to the bank and let the fine branches trail downstream in the current. Use only the more durable woods such as oak; even these will deteriorate in 4 to 5 years. Alder brush is handy because it grows along most streams, but it is one of the least durable woods; use it only if you can replace it about every 2 years. To cut and properly install bushes and treetops requires much manpower; to maintain brush shelters requires repeated work. This is costly, but remember that brush appears to provide shelter for more trout per foot of stream than any other type of material.
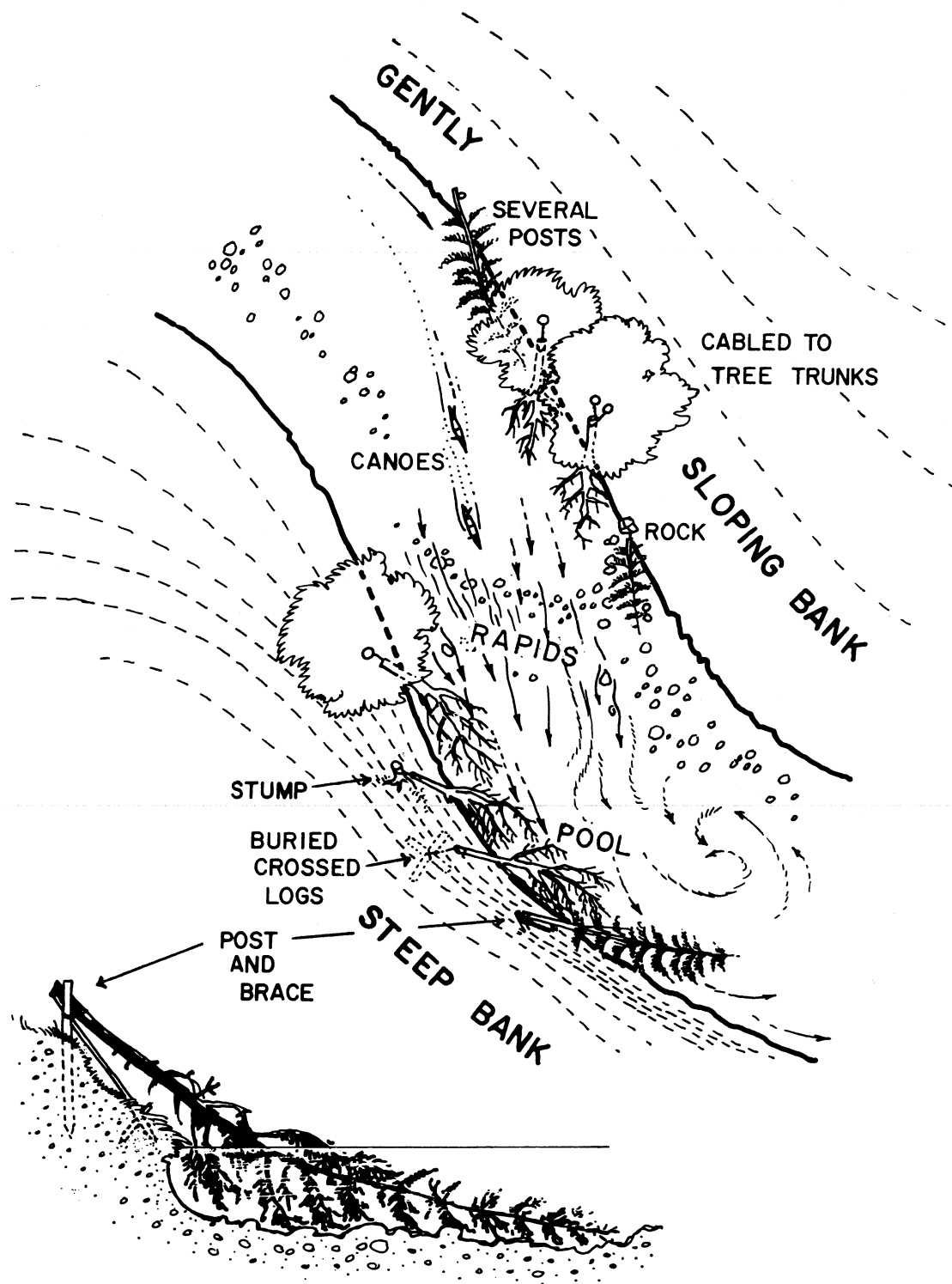
In larger streams, live bushes can have the same effect if they drape into the water. Therefore, the need for special brush shelters at the edges of these streams may not be great. (See section on management of stream bank vegetation.)

Use submerged logs and boulders to make hiding places for larger trout. Fasten logs solidly into the stream bank and align them almost parallel to the flow. In small, slow-flowing streams, be especially careful to place boulders so that they do not dam the stream.

Incorporate hiding places into deflectors and revetments. Use live vegetation and an integrated arrangement of brush shelters, logs, boulders, rip-raps of angular rock, and specially built overhangs.

Small trees installed in a large trout stream are excellent shelter. These are attached by cables (here, of exaggerated length) to tree trunks and other fixtures on the bank, and can rise and fall with fluctuating water levels. When butt-ends are kept slightly above the shoreline, less debris will accumulate on them, and the whole installation will be more streamlined. High water may often heave trees up onto bank. This and rotting are maintenance considerations. Keep cables as short as possible to reduce unsightliness and tripping hazard, but at least one foot should be left between anchor and tree-shelter to allow free-play.

GENTLY

SEVERAL POSTS

CABLED TO TREE TRUNKS

CANOES

SLOPING BANK

ROCK

RAPIDS

STUMP

BURIED CROSSED LOGS

POOL

POST AND BRACE

STEEP BANK

Some Nonrecommended Devices

The following devices and materials have often been used to maintain channel depth but have had detrimental effects, often outweighing the advantages to trout habitat.

V-deflectors are constrictive devices sometimes used to make pools. These provide more problems than benefits. Debris easily clogs them. Beavers use them as foundations for their dams. Fishermen trying to "improve" habitat, place rocks in the throats of V-deflectors to make dams. Small boys do the same just for the joy of damming. Trappers pile stones in these deflectors to form places for muskrat sets. When functioning normally, a V-deflector "speeds" the current, but only for a short spurt.
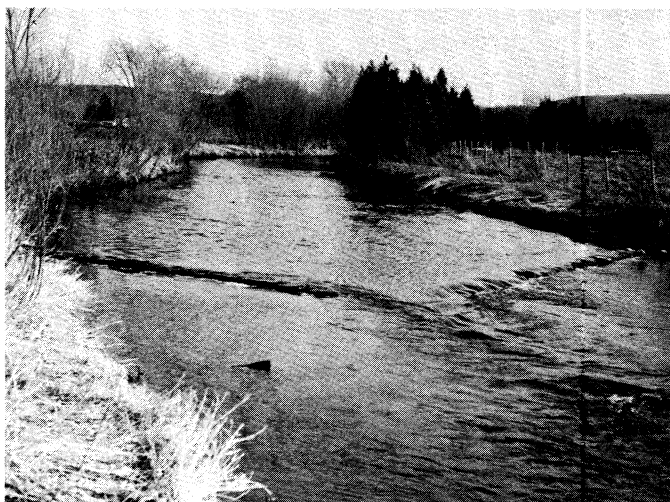
Digger-logs directly oppose the current. They often collect debris and become dams. Never use them.

A-deflectors are also obstacles to flow. They will be damaged in floods and will accumulate debris. Their worst feature is that they widen the channel by forcing the current outward against the banks at both sides and causing erosion in two directions at once.

I-deflectors have the same disadvantages as A-deflectors. Do not use them unless they are completely submerged and streamlined so as to avoid catching debris. While I-deflectors are fine submerged hiding places for trout, they must be made so painstakingly that they will often be uneconomical. The log I-deflector installed approximately parallel to the current as pictured will certainly catch debris and be a nuisance.

Sheet-piling or "Wakefield sheeting" does not provide overhang for protective cover and it leaves the device with an unnatural, straight face which spoils the natural aspect of the streams. Wood sheet-piling is much less permanent than rock, especially when, as is often the case, it projects above water and can rot. Sheet-piling is sometimes needed to construct fish barriers, bank protectors, and water control structures.

Concrete, ugly and artificial, has at present no place as a material for devices in trout streams. Perhaps some day a use for it in foundations of bank-covers or wing-deflectors may be found, but it can never be used as an exterior material without ruining the natural appearance of trout streams.

PENINSULAR
WING
DEFLECTOR

(DURING HIGH WATER,
BANK WILL ERODE AND
POOL WILL FORM HERE)

LOG BANK—COVER
(LOGS PROJECTING ABOVE
WATER ARE SUSCEPTIBLE
TO ROTTING)

V—DAM
OR
V—DEFLECTOR
(WILL CLOG AND DAM)

MID—CHANNEL
DEFLECTOR   OR   A—DEFLECTOR
OR   INVERTED   V—DEFLECTOR
(WILL CLOG, DAM, AND WIDEN
STREAM)

DIGGER—LOG
(WILL CLOG AND DAM)
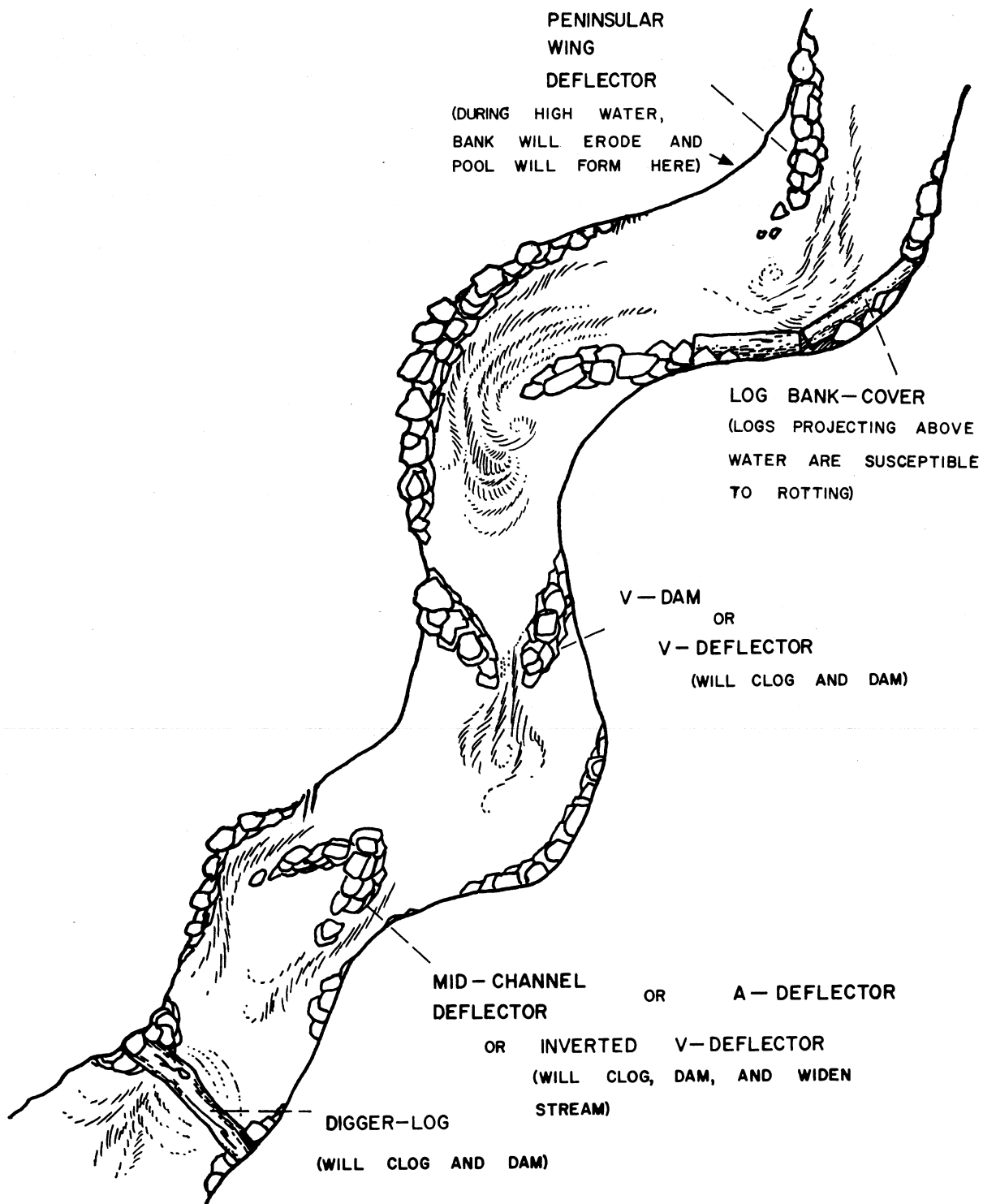
Some nonrecommended or improperly constructed devices.

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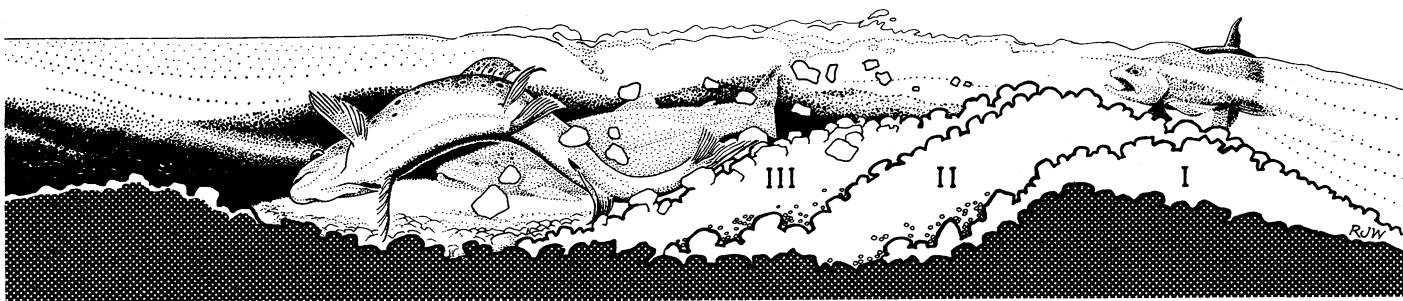
Female brown trout (left) digs a redd in autumn at the crest of a riffle. Violent flailing of the gravel with her body draws pieces up into the current which carries them downstream into a pile. The dominant suitor of the moment hovers close by, fending off rivals and ready to fertilize eggs when they are extruded into the redd pit against the pile of clean gravel. A smaller male, repeatedly repulsed, wheels for another charge.

This female is digging her third redd of the season. Roman numerals designate gravel piles of each redd, shown in cut-away view with individual pebbles omitted in order to emphasize location of eggs. Eggs laid against pile I are covered by gravel of redd II; eggs in redd II are covered by gravel of redd III. Dark cross-hatching indicates undisturbed stream bed. Eggs will develop during winter. Fry hatch early in spring and live in the gravel while they still have yolk sacs before wriggling out into the stream.

Measures to Protect and Restore Spawning Habitat

At the present state of knowledge, sound management to improve reproduction of wild trout is simply to preserve and enhance existing gravel beds and to restore spawning grounds ruined by dams. Streams sustaining high wild populations have large amounts of stream bed gravel. Attempts to duplicate this in streams lacking gravel would be very costly. Some hope for artificial spawning beds lies in the possibility that smaller deposits of gravel, if of better quality and distribution than in natural streams, might produce young trout more efficiently.

Environmental influences on natural reproduction are complex: size and texture of stream bed materials, stream-flow volume, conformation and gradient of channel, temperature, and perhaps other factors. Until we understand these plus behavior of spawning trout and the reasons for high mortality of trout fry in the wild, we should go slowly on programs to build artificial spawning beds.

Less risky ways to improve habitat for natural reproduction will be to reduce floods, remove dams, preserve riffles and promote growth of aquatic plants as cover for young trout. Wing-deflectors can be placed to make the current scour sand and silt off of gravel. Hiding cover at the edges of spawning beds is desirable. Spawning is hazardous for trout. They often locate nests in water only 6-12 inches deep and exposed, therefore, to predators. Refuge should be made available nearby.

Trout reproduction in the wild is relatively inefficient. Only 2 percent of trout eggs become fingerlings (McFadden, 1961). Using data from an excellent trout stream, Lawrence Creek (Hunt, McFadden and Brynildson, 1962; Hunt, 1966), we found that in a very good year an average of 7 or 8 nine-month-old fingerlings were produced per square yard of stream bed gravel. More commonly, only 2 or 3 fingerlings per square yard were produced.

Using these figures and present costs of gravel, trucking, labor and hatchery trout, we calculated that the 30-year amortized cost of sustaining trout populations by building and taking care of artificial spawning beds *might* be slightly less than the cost of stocking hatchery-reared fingerlings to achieve the same populations. This, however, does not take into account the catastrophic failures of reproduction that occur in some years due to winter floods. In gravelly stream beds, pieces are drifted downstream from riffle to riffle by high water. With no supply of drifting gravel from upstream, it is doubtful that isolated artificial deposits would last long. Another problem is siltation of gravel beds. Our attempts to build spawning beds in Dell Creek, Wisconsin, were unsuccessful due to siltation. Many mistakes are likely to be made in placement of artificial beds. All in all, the uncertainties make it unlikely that trout populations can (at this time) be boosted by this means.

Aside from economic risks, the gravel-retaining structures that would often be necessary to reduce drifting, would probably give the stream an undesirable appearance. Pictures we have seen of artificial spawning beds for salmon on the Pacific Coast (known to be successful), show little resemblance to a natural stream.

Black Earth Creek near Madison, Wisconsin, affords an example of restoration of *natural* habitat for spawning followed by sharp increases in number of wild brown trout fingerlings. Here, a mill dam was removed in 1956 and the stream banks fenced against cattle for about 5 miles below

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the former pond. Fencing was completed in 1957. As the fence-protected vegetation changed channel form, more and more gravel became uncovered. Each year more of the stream bed was used for redd sites. Autumn populations of fingerlings were 3- to 7-fold higher during 1959-62 than they had been in 1954-56.

Meager as it is, knowledge gained to date on selection of spawning habitat by various trout species may be of use in habitat management. Brook trout spawn in coarse sand as well as gravel, but with the apparent requirement of upwelling groundwater. Brown trout choose riffles seemingly without heed of upwelling. Rainbow trout seem to select deeper water than the other two species. Stuart (1953a) demonstrated that the hydraulic characteristics of the stream bed at the crests of riffles where brown trout most often spawn, promote downward flow of stream water through the gravel. This circulates oxygen to the eggs. Our observations on the Prairie River, Wisconsin, indicated that brook trout chose as redd sites, quiet waters aside the main current, but with obvious springs upwelling. Brown trout, in contrast, built redds in riffles of the main channel adjacent to areas of brook trout spawning as well

as in riffles far downstream where there appeared to be little increment of groundwater — and where in winter the stream was thickly covered by ice. Here, thermistor probings into redds revealed temperatures of 32°-36°F. lasting for several months in winter. Brown trout eggs brought from a hatchery and buried in screen boxes next to these downstream redds developed slowly and survived poorly, whereas eggs developed rapidly and survived well when similarly buried next to the brown trout redds upstream where winter water temperatures were warmer.

In lower Big Roche-a-Cri Creek, Wisconsin, a slow, flat stream having mostly sand but some gravel in the bed and having no visible springs, White (1959), probing with thermistors in winter, found that the temperature in the gravel redds was warmer than that in nearby materials, and that this was apparently due to upwelling groundwater. In a Michigan brook trout stream, Benson (1953) found similar indications by burying mercury thermometers. In the same stream Latta (1965) found year-to-year correlation between groundwater levels and number of young-of-the-year brook trout, but no correlation between groundwater and number of young *brown* trout.
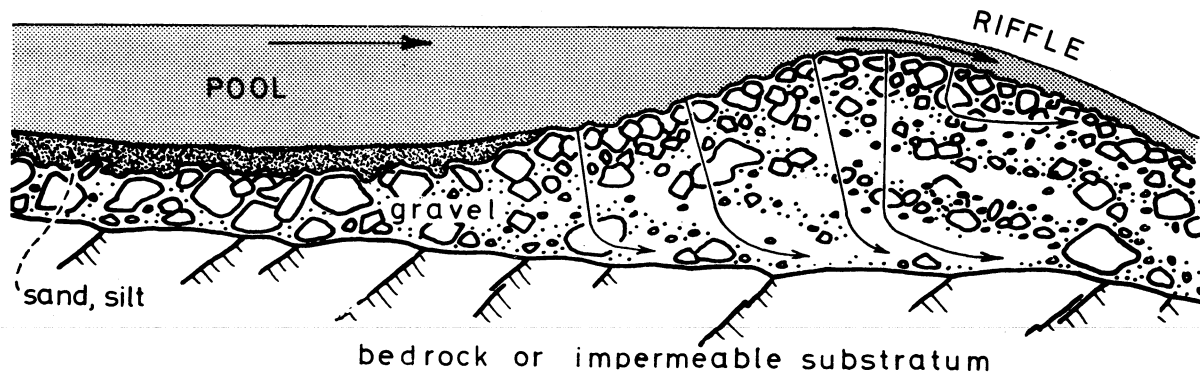
Intra-gravel flow of stream water near the crest of a riffle. (Modified after Stuart, 1953a.) Water moves downward into gravel at right angles to the stream bed surface. Brown trout often spawn near riffle crests. Irregular sizes of the component gravel particles are important to stability of riffle and redds (Leliavsky, 1954; Stuart, 1960).

Measures to Improve Production of the Food Supply of Trout

It appears to be neither feasible nor esthetic to artificially propagate, cultivate and feed food organisms to trout in streams, but we can suggest measures to improve natural production.

Let Light Reach the Stream

To promote growth of food, permit adequate light to reach the stream and its bank. Preserve riffles. Promote growth of aquatic vegetation and, of course, protect the stream from floods. Plants such as watercress support sev-

eral hundred times more food organisms per foot of stream than does sand; many more than even the rocks in riffles (Tarzwell, 1936). There is little published information on production of insects in different terrestrial habitats, but one entomologist interviewed, felt that a mixture of low shrubs (less than 3 or 4 feet high), grasses, sedges and forbs, might produce a better supply of terrestrial insects than would trees and high shrubs. He thought it likely that conifers would produce less trout food than almost any other vegetation.

Enrich Stream Water Cautiously

We have seen naturally infertile streams that support substantial growth of trout only below the point where they receive sewage from a town. Growth of trout food organisms can be phenomenal in water enriched by proper amounts of nutrients. Many streams of northern Wisconsin lack the nutrients required to sustain a worthwhile trout fishery and might be beneficially enriched during the growing season without damaging their appearance.

The amount of nutrient injected into the stream must, however, be kept small enough to avoid "stream eutrophication," an abundance of aquatic plants that deplete oxygen at night to levels intolerable for trout. After dark, plants do not produce oxygen as they do during daylight; instead they consume it by respiration. An overabundance of plants sometimes robs streams of almost all oxygen at night and the trout die. Such conditions occur where the plants are well supplied with nutrients, as from too much sewage effluent.

Measures to Improve Water Temperatures

While streams selected for trout management should be only those having favorable water temperatures (or those which, upon removal of dams, will develop good temperatures), stream temperatures may sometimes be favorably altered. Try to keep temperatures within the range for rapid growth of trout (45° to 65°F.). The principles in such control are to reduce direct heating by the sun in spring and summer and to reduce loss of heat by outward radiation in cold weather. To achieve this moderation of temperatures, remove dams, increase spring flow, narrow the water surface by altering the channel and by developing low vegetation on the bank — and as a last resort, shade the surface of the stream. Tall grasses, forbs, low shrubs (less than 3 or 4 feet high) and emergent aquatic plants often provide adequate shade. Such vegetation on a small stream can be as effective as tall trees on a broad river.

Release impounded springs so that they flow more quickly to the stream. Some springs arise far back from the stream and follow an indirect, shallow or braided channel before entering it. Straighten and narrow the channel of outflow if that will significantly shorten exposure to sun and air. In some cases it will be practicable to tile springs from their source to the main stream. Protect springs and their channels from livestock. The vegetation that grows up around them will shade the water. Foster grasses rather than trees and shrubs in these areas. Trees and other woody and broad-leaved plants growing by a stream and its springs pump directly from the groundwater supply. Such transpiration may be a significant drain on the summer water supply for a stream. A single large elm can transpire 500 gallons a day; therefore, three such trees may mean a loss from the groundwater table of 1 gallon per minute! Our broad-leaved plants are water-wasters, grasses are water-conservers.

A large spring wells up in the depression beneath the forked tree trunk in the background. The beneficial effect of the inflow of spring water into the stream is indicated by the growth of watercress. The stream above (background, right) has none.

The charge of 32° water from snowmelt brings about the coldest temperatures and most rapid change in temperature a trout must withstand each year.

The stream kept open because of good springflow even though on this sub-zero day a border of hinge ice has formed.

In a reach of stream with insufficient seepage of groundwater, ice covers the stream. Here investigators dig through the ice to reach eggs incubating in brown trout redds in the stream bed. Development and survival are poor.

Fencing

Build fences well back from the stream bank. Ideally one should build them above the flood channel so that they will not catch debris or be torn down during high water. Place the fence far enough from the stream to allow trucks and other equipment to pass along the stream during later operations to control vegetation and construct in-stream devices. Even where land is very expensive, try to protect a width of at least one rod behind the *crest* of the bank (not the water's edge).

We have seen "stream-protecting" fences so close to the stream that in many places the banks were grazed bare despite them; a cow can stretch her head 3 feet through a fence. Keep fences well back from the outside banks of bends or the stream may soon undermine the fence. Revet banks which erode away so rapidly as to endanger the fence.

Barbed wire fences, necessary as they are to habitat management, inconvenience anglers and blemish the land-scape—fences with steel posts especially. Building plenty of stiles and planting fencerows with food and cover (shrubbery not trees!) for wildlife can help alleviate these disadvantages. The unattractiveness of steel posts can be lessened by painting them dark green or brown. For scenic reasons alone, wooden posts may sometimes be called for, or they may be needed as corner post assemblies for steel post fences, or where the land is too marshy to hold the thin steel posts.

Chemically-treated wooden fence posts are more durable and have proven to be more economical than untreated wooden posts. Although the initial cost is higher, treated posts last from 30 to 50 years. In contrast, untreated posts often rot through after only 10 to 20 years.

Where livestock or machinery must cross the stream, construct special passes in the fence. Livestock-crossings have been a difficult problem in Wisconsin's trout habitat management program. It is hard to build crossings that will contain livestock, yet permit debris to pass down-stream without getting hung up during high water. Cattle often learn to push through swinging wooden "flood-gates." Then the farmer often wires the gates together — making a debris-catcher. Wooden floodgates also deterio-rate rapidly and need much maintenance. The cables they are hung on sag badly; inspect these each year and adjust them if necessary. The wooden washers usually used to space the gates go to pieces quickly. Use a tougher ma-terial. In many instances, one can make a simple, satisfac-tory stock-crossing by stringing a few lightly supported

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Build fences well back from the stream bank.

strands of barbed wire across the stream. String the low-est strand high enough to allow debris to pass beneath during normal flow. Such crossings are not intended to withstand floods; after each flood they will have to be restrung. Locate cattle and machinery crossings, if pos-sible, where the stream bottom is firm and where the banks slope gently. If you must pave the bottom with gravel, dig it out first so that the finished level will not protrude above the normal stream bottom to form a dam. Bevel the path leading down the stream bank into the crossing and pave it if it is so steep that it will erode. Build crossings wide enough that livestock do not bunch up, panic and become injured when crossing during high water. Several references on fence construction are listed in the Bibliography.
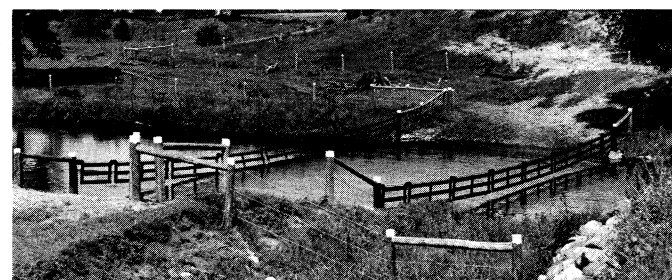
Cattle crossing with floodgates to allow debris to pass down-stream during floods.

Floodgates performing during a flood.

A cattle watering area which can be folded back out of the way of floods when cattle are not in the pasture.

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MAINTAINING WHAT HAS BEEN PROTECTED AND IMPROVED

A sound program of management entails upkeep; that is, systematic inspection and repair. Large expenditures to protect and restore habitat will be money down the drain if a small amount is not spent each year thereafter to completely inspect the channel and fences for deterioration, and then to repair them.

Completely inspect each managed stream to detect debris-dams, damaged fences and damaged in-stream structures at the following times: (1) in spring after run-off of snowmelt water, (2) in fall after the fishing season —anglers may have dammed spawning beds—and (3) immediately after every flood.

Continued control of stream bank vegetation should be a major part of post-development maintenance.

Maintenance patrols will be in good position to check for pollution, illegal ditching, evidences of poaching and illegal irrigation.

THE SEQUENCE OF MANAGEMENT

The correct sequence for applying the various management practices we have described, will differ according to each stream. There can be leeway, but to prevent confusion, some special considerations are worth keeping in mind. Some treatments can be carried out at most any time, while others must await certain prerequisite steps.

1. Remove any dams as soon as the opportunity arises on any existing or potential trout stream in Wisconsin. No elaborate preliminary survey is necessary. Often it may be impossible to adequately assess the potential of a stream for trout until the dams are eliminated and stream bed materials, temperature regime and other factors of habitat become evident.

After the preliminary examination has reached a stage where one can definitely say that the stream deserves management:

2. Implement measures to control floods and watershed erosion at any time.

3. Exclude livestock from the stream bank, taking care to construct stream bank fencing in such a way that it will not interfere with future management in the streams.

4. Alter spring outlets if necessary.

After the examination is finished, alterations could be started:

5. Remove trees and brush where shade is not needed to maintain tolerable water temperatures during the summer.

6. Construct wing-deflectors, other channelization devices and hiding cover.

7. Carry on with a program of maintenance.

SPECIAL HAZARDS TO TROUT HABITAT

Although certain hazards to trout habitat have been brought out previously, we discuss here three other types of stream manipulation, some of their effects on streams and some ways of coping with problems that they cause. These are of widespread importance for they have a bearing on most of the measures to protect and improve trout habitat.

Damming

Much might be done to inexpensively restore good trout habitat in Wisconsin by removing dams. Impoundments, whether built by humans, by beaver, or by accumulation of floating debris, are detrimental to trout habitat in most of our low gradient streams and in many streams of higher gradient. In Wisconsin, hydro-electric dams and dams once used to power grist mills and sawmills have destroyed much trout water, but the damage is not irreparable, for current and vegetation combine to develop trout habitat in stream channels reclaimed from impoundments. Many dams on our trout streams are obsolete and they could be removed. Their usefulness has been supplanted by more modern facilities. Real estate developers, power interests, and would-be fish pond builders must be discouraged from damming Wisconsin trout streams and their feeder springs.

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Many dams are obsolete and should be removed.
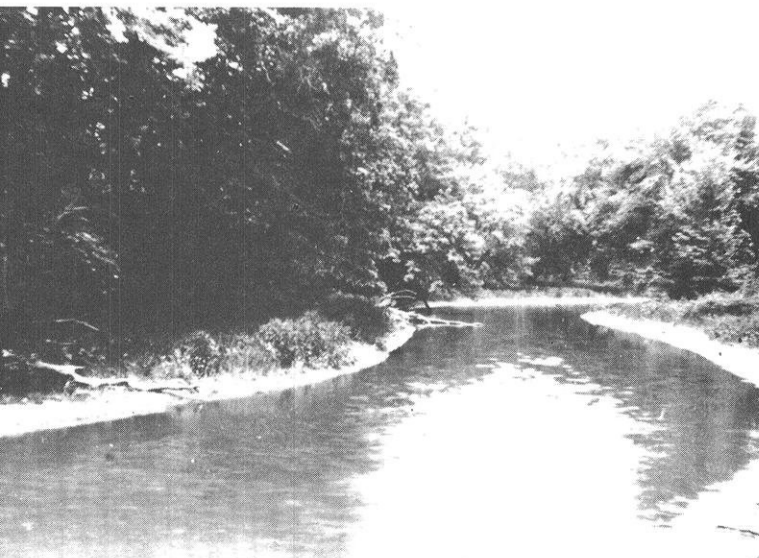
Fluctuating water levels are often the result of dams. They leave the protective vegetation on the stream bank high and dry.

Sometimes the downstream effects of damming are striking!

Beaver dams are at present probably an even greater source of damage to trout water. This problem is especially acute in northeastern Wisconsin.

To the detriment of trout streams lying below dams, impounded water usually warms too much in summer and freezes in winter. Algae flourish in impoundments. Impoundment-produced algae can create such turbidity in the stream below that growth of rooted aquatic plants is inhibited. Upstream also, the trout population may suffer because the impoundment destroys spawning beds. The deeper water behind a dam may provide a good place for trout to live and grow for a few years, but often the pond soon fills with silt and the trout disappear. Many of Wisconsin's trout streams are of such low gradient, that removing even obstructions only 6 inches high helps to moderate temperatures and to speed the current, which uncovers gravel needed for spawning.

Remove obstructions such as fallen trees that decrease current in lowland streams. Do not build structures that slow the current enough to cause siltation upstream from the structure. Only on high gradient streams will low dams designed to create pools benefit trout habitat.

When a dam is removed, silt flushes from the old pond bottom into the stream below. Therefore, avoid removing a dam in autumn or winter. This could disturb spawning downstream and smother trout eggs with silt. Remove dams in springtime about the time grasses start to grow. This will be after spring runoff floods and will allow a full summer's growth of vegetation to tie down the pond bottom silt. Then, during the next fall's spawning season, erosion will be at a minimum and hopefully the turf will be tough enough to withstand the next spring's flood.

Beaver impoundments have the same detriments as all other dams. The problem is widespread; locating and removing beaver dams on trout streams is a continuing operation.

When a beaver dam is removed, a thorough job should be done. Do not merely "knock the top off." We have found that to remove beaver dams effectively, one must pull out all sticks imbedded in the stream bottom. This is work to be done by hand. Be sure to remove food-caches and debris lodged in the pond bottom behind beaver dams. Unless this is done, sediments will seldom be adequately scoured away.
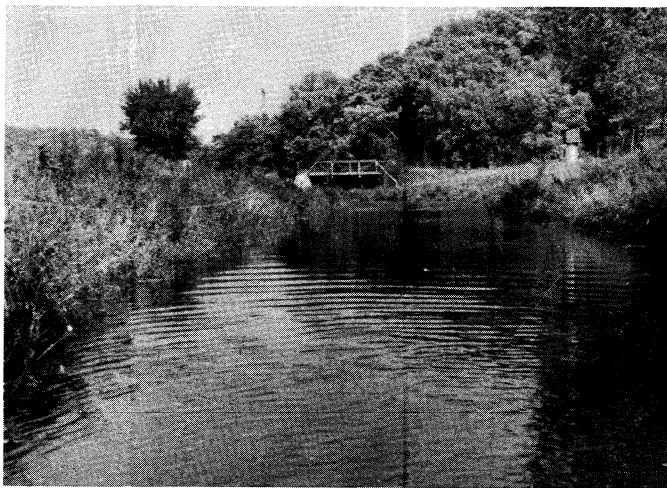
The mill pond, which froze (right) each winter.
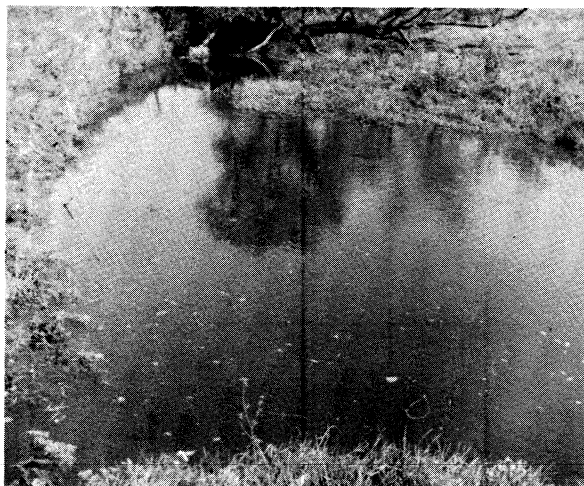
Close-up view of the pond water: bluegreen algae (Oscillatoria) and diatoms were produced in such great quantities in the warm, fertile pond that they rose to the top in unsightly masses. The scum poured over the dam causing turbid water downstream.

The water was released when the dam was permanently opened.

Former pond viewed from upstream. Excellent hiding cover and spawning grounds developed in 5 years after dam opened. Stream below became clear; beneficial vegetation developed; and wild brown trout populations mainly replaced sucker populations.

Stream has silted in above the dam.

Beaver impoundments have the same detriments as all other dams.

Drawdown reveals damage in the pond: stream bank and aquatic vegetation are lacking and mud covers spawning gravel.

Stream-Straightening and Land Drainage

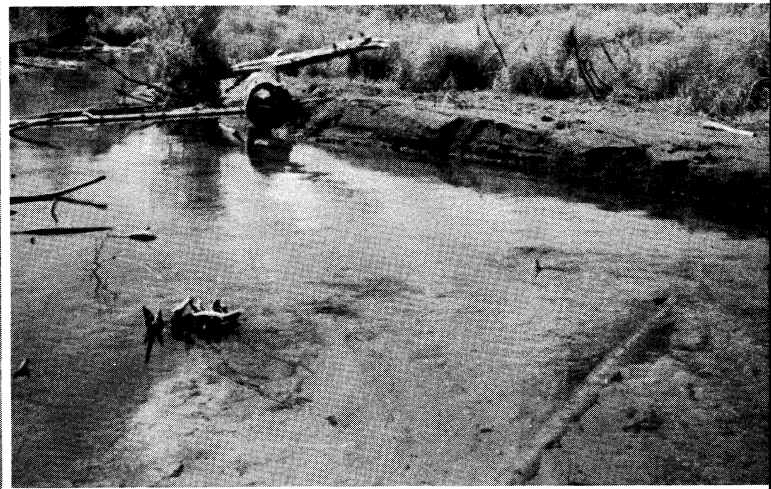Stream-straightening is, by many people's definition, a type of "drainage." Regardless of how such dredging is categorized, it is usually an immediate and clear-cut detriment to trout habitat. Drainage in general is a diffuse subject and will be treated only briefly at the end of this section.

Through straightening, much stream is simply lost through shortening; the straight channel may often be less than half the original length. The deep, sheltering pools at the bends of meanders will no longer exist. Channel ditchers often dig a smooth stream bed without riffles and lacking protective boulders, ledges and plunge pools. The result is a trout desert. It can take years before a beneficial pool-riffle undulation of the stream bed redevelops, and this will take place only in gravel-bedded streams. In sand and silt-bedded channels, pools will form below obstruc-

tions or when the channel has again developed meanders, as it will eventually do, but the process is very slow.

The channel dredged straight, though "neat and orderly," is contrary to nature and lacks the charm of a natural stream. As we have pointed out a sinuous course is the natural condition of streams. (See also Appendix A.)

Stream-straightening is contrary to "water conservation," though it is sometimes included in this category by those who would eliminate meanders to simplify farming or to "channelize floodwaters." This is not flood control. Concentrating floodwaters into a straight trough eliminates the resistances of a naturally meandering channel; it fails to dissipate the energy of the high water, as does an irregular course. Straightening the flow carries floodwaters more quickly out of the area, but it dumps them with increased fury onto land downstream.

Stuart (1960) cites ways in which dredging upsets the groundwater hydrology of an area.

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Fortunately, stream-dredging is illegal in Wisconsin without permission from the Public Service Commission. This Commission obtains information from the Wisconsin Conservation Department on potential damage to trout habitat before granting a permit. There are signs that dredging is falling into disfavor with other governmental conservation and agricultural agencies.

But many once-productive reaches lie dredged and straightened, relics of previous days. Where the temperature and fertility of these channels remain at trout-producing levels living conditions for trout can be improved by restoring the meandered channel pattern, and in the steeper streams by restoring the pool-riffle undulation of stream beds. Where the channel cannot be restored to the former meanders, at least the sinuosity of flow can be increased and deeper spots in the stream bed carved by installing deflectors and revetments. To add further shelter, incorporate bank covers in these devices. Where the stream has a gravel bed, dig the gravel up a bit and pile it to form riffles at intervals of 5 to 7 channel widths. The pools between should be somewhat longer than the riffles. For even better pools in high gradient streams build Hewitt ramps (p. 27) where they will impound water for no farther upstream than 5 channel widths. Plant reed canary grass along the embankments where needed.
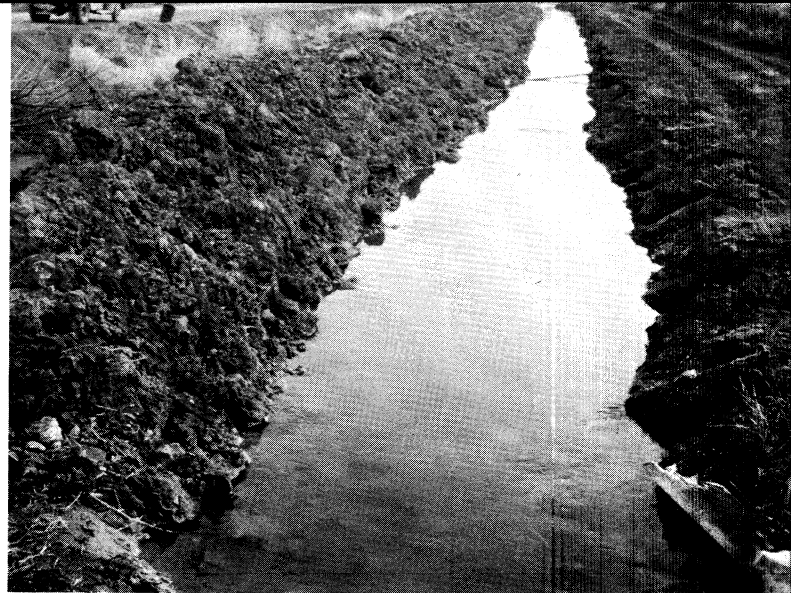
We stress that streams should not be dredged in the first place. By suggesting measures to alleviate the damage, we imply no justification for stream-straightening. (See also Appendix A.)

"Drainage" in the general sense of the word cannot be pinned down to a simple set of procedures and effects. There are several ways to manipulate the groundwater level, and the effects on surface waters may vary widely according to local hydrologic conditions. Since the quality of Wisconsin's trout streams is so heavily dependent on groundwater supplies though, it stands to reason that drains on this resource will often be detrimental. Dredging drainage channels in bogs can sometimes create trout water where there was none previously (Stuart, 1960), but this might often at the same time diminish the groundwater supply of good trout streams in the vicinity.

Freshly dredged stream. Research showed that trout populations decreased sharply and never recovered.

After several years, banks developed vegetative cover, but stream still looks artificial (above). Curvature partially restored in a straightened stream channel (below). Here trout increased several fold after the devices were installed.

Floods

Reduce overland runoff and promote "soak-in" to benefit trout streams.

Floods damage protective cover for trout, they wash away food organisms, they sometimes strand the trout themselves and, if they occur during the incubation of trout eggs, the swirling waters can wipe out a whole generation. The powerful snow-melt floods of winter sweep away some trout nests and wash silt into others. The silt smothers eggs or prevents fry from emerging. Whenever

The power of high water.

floods can be controlled or reduced, these damages should lessen. Flood control is the most needed stream management in the frequently flood-swept coulee streams of western Wisconsin. To control floods in these streams, detention dams with slower water release and higher detention capacity than current specifications require, would be needed. It is questionable, however, that they are economically feasible solely to protect trout streams.

In a stream subject to frequent severe flooding, it may not be worth trying to develop trout habitat until this source of damage is eliminated. To best protect trout stream habitat, combat floods before they reach the stream. The correct place to control fast runoff is back in the drainage area above the trout water.

"Detention dams" are structures that temporarily catch runoff water and release it slowly so that the stream channel is not damaged. These can be effective in protecting trout habitat if they release runoff slowly enough and above the trout spawning areas. Engineers commonly design them to keep water level at bank full stage during periods of runoff. In steep terrain where detention dams are most often needed, this stage appears to be high

enough to damage in-stream structures—trout redds certainly. More information is needed to indicate what water levels would be desirable. Detention dams across the main channel in trout water sections do not benefit trout habitat above the dam, and such a dam will probably damage spawning and food-producing areas upstream by depositing silt on the "dry pool" area temporarily covered with detained runoff.

"Retention dams" release runoff water only down to a certain pond level, then retain some of it. This may provide a fishery for warmwater fishes, sometimes even for trout. Such dams should be carefully designed to prevent escape of fishes and to guard against release of lethally warm water into trout streams when high water occurs.

Avoid straightening of streams below outlets of detention and retention dams. This destroys trout habitat and the natural character of streams. Unfortunately, engineers are inclined to recommend such ditching, purportedly to "take the water away from the damsite faster," and farmers like this straightening because it gives them a piece of land more adapted to mechanized tilling than when the stream meandered across it.

The aftermath.

APPENDIX A

Physical Processes in Streams

Flowing water and the stream bed are principal features of the stream-dwelling trout's environment. To effectively manage trout streams, the fish manager must have an understanding of how water flows, how it affects and is affected by stream bed form and materials.

Here, drawing from 3 recent publications written by geologists and engineers, we present information that should be useful to fish managers in working with streams. The sources (authors and page numbers) of statements are shown in the right-hand margin. Most statements are paraphrased; direct quotations are enclosed in quotation marks.

LWM = Leopold, L. B., M. G. Wolman and J. P. Miller. 1964. Fluvial processes in geomorphology. Freeman Press: 522 p.

LL = Leopold, L. B. and W. B. Langbein. 1966. River meanders. Scientific American, 214 (6):60-70.

LEL = Leliavsky, S. 1955. An introduction to fluvial hydraulics. Constable, London: 257 p.

The two principal external forces acting on water in an open channel are *gravity* pulling the water downslope and *friction* between the water and the stream bed and banks resisting downstream movement. LWM 152

Velocity of water depends not only on steepness and roughness of the stream bed, but on the depth of water. A large, deep river with the same gradient as some brook will run much more rapidly than the brook. The Mississipi with very gradual slope has a terrific current. LWM 157

The total resistance to flow in natural channels involves the *size of particles* on the surface of the bed and banks, *vegetation, curvature* of the channel, *obstructions* and *changing forms* in the bed such as sand and silt waves. LWM 161

As velocity of the water increases, these objects have increasingly greater force in resisting flow; the results are eddying, secondary circulations and dislodging of the objects themselves. The flow resistance of roughnesses on bed and bank increases as the square of the velocity, a principle which applies to all turbulent flow with few exceptions. The shape and material of a stream bed have the following types of resistances: LWM 162

(1) *Skin resistance* which depends on roughness of the surface that water flows over and on the velocity of the water. LWM 162

(2) *Internal distortion resistance* involving eddies and secondary circulations set up by bends of the stream, bars, individual boulders, undulations of the bed and protuberances of the bank. Internal distortion resistance also varies approximately with the square of velocity. LWM 162

(3) *Spill resistance* caused when water backs up behind an obstruction and plunges abruptly to a diminished velocity. Spill resistance increases much more rapidly than the square of velocity. LWM 162

Experiments have shown that channel curvature alone can cause resistance equal to or surpassing skin resistance. LWM 163

That brings us to consider the shape of channels.

Channel Form

To describe channel patterns geologists use the general terms *meandering, braided* and *straight.*

Natural streams are "seldom straight through a distance greater than about 10 channel widths." When one says "straight channel," he usually means relatively straight, irregular, slightly sinuous or nonmeandering. LWM 281

Braided channels are those that divide into several channels which successively meet and redivide. LWM 281

Single channels with a high degree of *sinuosity* are referred to as meandering channels. Sinuosity describes a stream's contortedness in the horizontal plane. Sinuosity is actually a technical term as Leopold et al., use it, a comparison of channel length to valley length. It is the ratio of the distance measured in the water to the distance measured across bends right down the valley. Leopold et al., found some streams with a sinuosity of 1; that is, the stream ran almost straight down the lowest part of the valley floor and, therefore, this ratio was 1 to 1. At the other extreme they found channels so contorted that they were four times longer than LWM 281

the valley they traversed, a sinuosity of 4. Streams with sinuosities 1.5 or higher are arbitrarily termed as meandering; and below 1.5 as straight. There is no sharp distinction between the patterns, meandering, braided and straight; rather, along its course a stream may pass from one type to the other.

A meandering course is the one flowing water tends to take whether cutting through the rock of the Grand Canyon or threading its way across a swamp or gushing down a glacier or even when streaming as an ocean current; for instance, the mighty Gulf Stream of the Atlantic has a meandering course.　LWM, LL general

Even where the channel seems straight, the line of maximum depth, termed the thalweg*, wanders back and forth from near one bank to the other. A tendency for lateral cutting of the stream bank results from alternating bars of sediment deposited along the channel banks; this is the beginning of a meandering pattern.　LWM 282
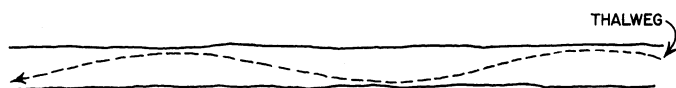

A stream takes on the typical meander shape, mathematically described as a "sine-generated curve," because this is the type of curve involving the least work in turning. The path allowing water to do the least work will be the one most likely to be followed. Of course, obstructions to flow often cause streams to depart from this most probable shape, but the tendency is always to resume it.　LL 60

Thus straight streams tend to develop a meandering pattern, but meandering streams seldom develop straight reaches.　LWM 307

Meander length is related to the square root of dominant discharge.　LWM 296

Channel width, meander length and *radius of curvature* all appear to be closely related. "Meander length ranges from 7 to 10 times channel width. Measured along the channel itself, distances between analogous points of waves are larger, varying from 10 to 16 times the channel width." Thus, successive crossovers (2 per meander) are spaced 5 to 7 widths apart. This matches the spacing of successive riffles found by Stuart (1953) in studies of trout streams. Since crossovers are relatively shallow, and bends deeper, they are quite comparable　LWM 296 -297

*See Glossary, Appendix C, Part I
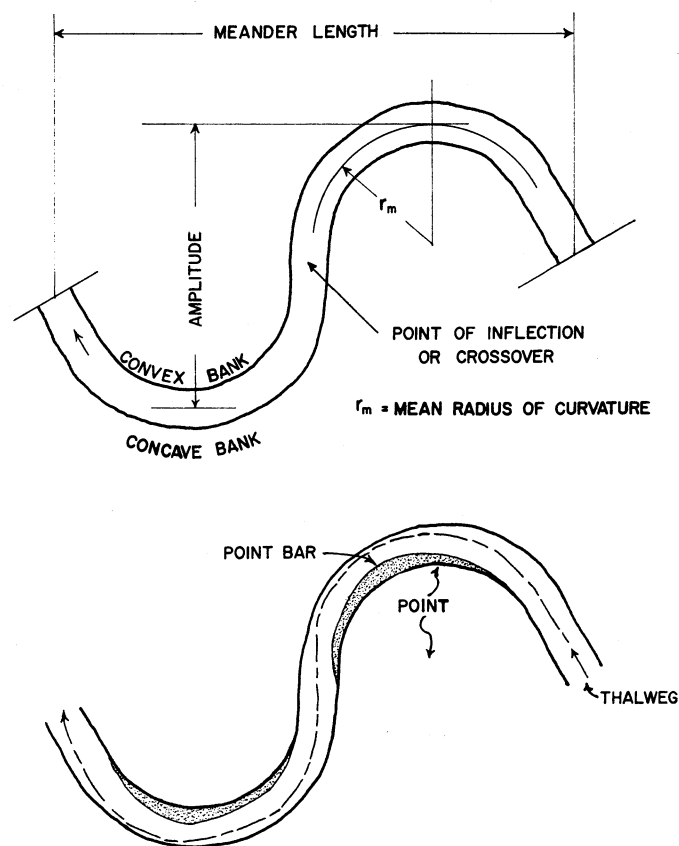
Elements of meanders and some of their relationships.

to riffles and pools in a straighter reach. Because bed profile in meanders is so similar to spacing of riffles and pools, Leopold et al. hold this to be further evidence that the processes leading to meanders are operative in straight channels.　LWM 203

Amplitude of meander correlates poorly with channel width.　LWM 297

". . . higher sinuosity is associated with small width relative to depth, and with greater cohesiveness in channel boundaries . . ." (Thus, when unstable stream banks are reinforced with turf, rock and other tough materials, it follows that not only a deeper stream should develop but a more sinuous one. The increased curvature of stream caused by installation of wings and other devices may not be unnatural, as is sometimes feared.)　LWM 297

The ratio of radius of curvature to width ranges from 2 to 3, a small variation. "It is this constancy that makes . . . maps of river bends look alike regardless of scale." Lay a map of the Mississippi next to one of a meandering creek, each drawn to a scale making meander length equal. You will see little difference.　LWM 298

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When ratio of curvature to width is near 2, LWM 298
the stream has minimum resistance due to cur-
vature. As radius of curvature is reduced in a
channel of uniform width, the main flow moves
closer and closer to the outer, concave bend.
Maximum velocity in a bend occurs below the LWM 299
water surface and just downstream from the
axis of the bend. This is the place where ero- LWM 301
sion is most severe and where revetments most
often fail.

Cross-sectional shape at the crossover is not LWM 299
completely symmetrical but is slightly deeper
near the bank which was concave in the bend
above. The high velocity that hugged that con-
cave bank still persists, though diminished,
when curvatures becomes zero at the cross-
over.

The same process probably also accounts for LWM 299
the skewed shape of point bars. The main point
bar deposition occurs downstream from the axis
of the bend.

CONVEX OR INSIDE BANK   **CONCAVE OR OUTSIDE BANK**
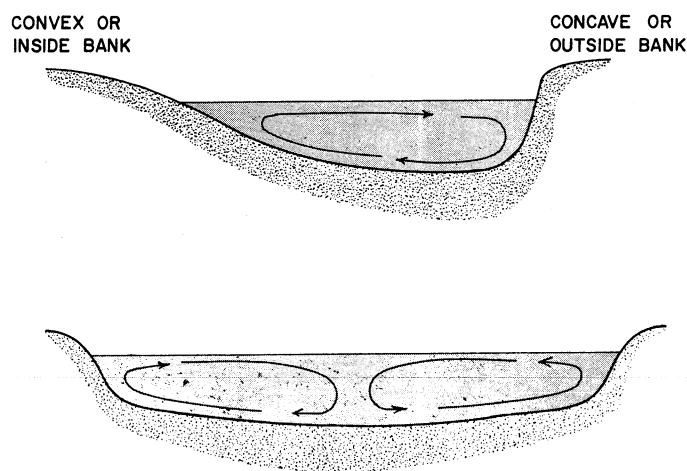
(Top) Transverse flow near the bend of a meander. Surface water spirals toward the outer or concave bank.

(Bottom) Transverse pattern of flow in a relatively straight channel — convergence of the two spiraling cells at the surface near the center of the stream.

Pools and Riffles

A straight or nonmeandering channel usually LWM 203
has an undulating bed. It "alternates along its
length between deeps (pools) and shallows
(riffles) at a repeating distance of 5 to 7 widths."
The same holds true for meandering channels
as explained above. "The alternating pool and
riffle is present in practically all perennial chan-
nels" having "bed material larger than coarse
sand, but it appears to be characteristic of
gravel bed streams—whether the gravel is pea
size or the size of a man's head."

For pools and riffles to exist, the bed must be LWM 209
composed of particles varying in size—that is,
a range in sizes of gravels and sands. This is
probably because a mixture of sizes makes a
more cohesive channel bed and bank. "Chan-
nels in uniform sand or silt have little tendency
to form riffles and pools."

The gravel bars forming riffles in rivers gen- LWM 203
erally are lobe-shaped "and slope alternately
first toward one bank and then toward the
other. The low water channel then bends
around the low point or nose of each and thus
tends to have a sinuous course even within the
banks in a reach which is generally straight."

"The position of most gravel bars remains LWM 215
nearly fixed . . . though sandbars and dunes LWM 208
tend to move downstream." During studies as
long as 7 years, Leopold, et al. found no indi-
cation that riffles move downstream with time.
This is not to say that pieces of gravel do not
move. Pieces of gravel picked off of one riffle
during high water are replaced from upstream.
Thus individual stones move, but the riffles re-
main stationary.

"The material of the bed tends to be some- LWM 203
what larger on the riffles . . . than in the pools."

Average length of pools may be somewhat LWM 203
longer than of riffles in the same stream. The
one stream cited had pools 1.6 times the length
of its riffles.

Leopold, et al. credit T. A. Stuart, the Scot- LWM
tish trout and salmon biologist with discovering 206-207
the periodic spacing of riffles and pools. As they
relate it, he "found that water flowing through
gravel of a riffle provides aeration essential to
the incubation of fish [trout] ova (Stuart 1953,
p. 408). Being concerned with the effect of di-
version and realignment of certain gravel
streams in Scotland on their ability to main-
tain trout, Stuart noted that the new stream
beds dredged by a dragline were, when just
constructed, of uniform depth and without
pools and riffles. With the aim of producing the
usual pool and riffle sequence, he directed the
operator of the dragline to leave piles of gravel
on the stream bed at intervals approximate to
riffles—that is, 5 to 7 widths apart. After a few
flood seasons these piles had been smoothed out
and presented to the eye a picture that in all
respects appeared natural for a pool and riffle
sequence. Moreover, the riffles so formed have
been stable over a number of years of subse-
quent observation."

Erosion, Movement of Sediments and Cross-sectional Shape of Channels

"... Channel form will vary markedly with character of the bank material." When stream banks become more resistant to erosion, the stream digs itself a deeper, narrower channel. LWM 248 LWM 202

"The shape of the cross-section of a river channel ... is a function of the flow, the quantity and character or composition of the materials that make up the bed and banks of the channel. In nature the last will usually include vegetation." LWM 198

Cross-sections of riverbeds are found to be most often rectangular rather than having a U-shape. The beds become more and more rectangular as they get larger downstream, since width increases downstream faster than does depth. LWM 202

The cross-sectional shape of channels is seldom symmetrical. This was explained previously in the section on meanders. LWM general

As a stream increases in discharge along its course, the channel could become increasingly wide, keeping its depth and velocity constant, or it could increase its velocity keeping depth and width constant. Actually width usually increases along the course of a river in a more consistent manner than depth and velocity do. LWM 248

As discharge increases at one point in a stream, not only does the water level rise, but the stream bed is scoured lower. In humid regions, and especially where stream channels are carrying gravel, the rising discharge of flood runoff does not scour the bed to any appreciable depth in the usual flood rise. Generally speaking, one can expect that a bank-full stage will scour a gravel bed down to a depth of 1 to 2 particle diameters. In sandy streams, however, particularly if they are ephemeral, the stream bed scour is much larger relative to the water-surface rise than in the previous case. Such stream beds tend to be scoured to a depth of about ⅓ of the amount the water rose. Expressed another way, at the peak of the flood approximately ¼ of the depth of water was accommodated by bed scour. LWM 299 (and Leopold, pers. comm.)

Material drifts in to replace this scoured material gradually after the peak of flood, much more gradually than the recession of water level. Thus, refill is much slower than scour. LWM 230

Rapidly fluctuating *changes* in stage (not simply a high volume of discharge) contribute greatly to the erosion of banks due to processes involving greater transport of sediments. LWM 294

To start a sediment particle moving requires much more force than to keep it in motion. Therefore, the "scouring power" of a given water velocity is less than its "carrying power." General

"The force required to start particle movement depends not only on the average velocity, but also on the depth-slope product, the larger particles being most sensitive to changes in velocity and smaller particles to changes of depth-slope product." LEL 68

"Of two mixtures with the same average size of grain, the less uniform will be, within certain limits, that which possesses the greater immovability; because its grains will fill the voids and thus produce a cementing action on the larger grains." LEL

"For larger particles the significant factor [in moving it] appears to be the velocity at the boundary between the thin laminar sublayer and the main mass of turbulent water above it. So long as the radius of the particle is larger than the thickness of the laminar layer, the sixth-power law incorporating this velocity holds good, but for smaller particles the drag and the hydraulic lift are the decisive consideration." It should be understood that sixth-power law relates to maximum size of particle which will be carried as velocity increases. It does not relate to the total sediment load as a function of velocity. LEL 68

The sixth-power law, roughly stated, says that the carrying power of the current varies as the sixth-power of the velocity. Therefore, doubling the velocity increases the carrying power 64 times!

The following table, adapted from Leliavsky, p. 232, shows the sizes of stream bed materials that various velocities of water can transport.

| Material | | Diameter | | Mean Velocity | |
General Terms	Leliavsky's Terms	(Inches)	(mm.)	(ft./sec.)	(cm./sec.)
		0.00002 —	0.005 —	0.49 —	15
Silt	Silt				
		0.002 —	0.05 —	0.66 —	20
	Fine sand				
		0.01 —	0.25 —	0.98 —	30
Sand	Medium sand				
		0.04 —	1.0 —	1.80 —	55
	Coarse sand				
		0.1 —	2.5 —	2.13 —	65
	Fine gravel				
		0.2 —	5.0 —	2.62 —	80
Gravel	Medium gravel				
		0.4 —	10.0 —	3.28 —	100
	Coarse gravel				
		0.6 —	15.0 —	3.94 —	120
	Fine pebbles				
		1.0 —	25.0 —	4.59 —	140
	Medium pebbles				
		1.6 —	40.0 —	5.91 —	180
	Coarse pebbles				
		3.0 —	75.0 —	7.87 —	240
	Large pebbles				
		4.0 —	100.0 —	8.86 —	270
Rubble	Large pebbles				
		6.0 —	150.0 —	10.83 —	330
	Large pebbles				
		7.8 —	200.0 —	12.80 —	390
Boulders					

APPENDIX B
Examining the Stream Prior to Habitat Alteration

The biologist's examination calls for observing the stream in hip boots or waders. Next to legs and eyes, the pencil and note pad are the most important tools. A standard mercury thermometer, some recording thermometers, a measuring tape, other mapping gear, a flow meter and a boat full of electrofishing gear are also essential.

Cursory Preliminary Survey

To familiarize himself with the stream and to observe any obvious factors which might preclude habitat management, the biologist should walk — in the channel as much as possible—from the lower end of the proposed development area up to the source of the stream. He may wish to note such things as pollution, extreme temperatures, possible spawning beds, and obstacles to electrofishing equipment. He should also survey the drainage area of the stream and its tributaries. On most streams, the biologist will have a better view by making this survey in spring or fall at a time when foliage is sparse.

Mapping

A detailed map is a basis for planning both the examination and the possible management.

Establish reference stations by measuring the center line of the channel with a tape, placing markers (substantial posts or large painted blazes) at 100-yard intervals from the stream's source to the lower end of the area to be examined. It is most practical to number the markers beginning with number 1 at the source; the highest number should be at the downstream limit of the study area. The study area can then be extended downstream at any time and still have station numbers in correct sequence. These station markers will provide permanent reference points for all future mapping, examination, and development. The interval between markers is termed a "station." Refer to it by the number of the marker which lies at its upstream end.

Prepare a drainage basin map by field observation, but with the aid of air photos and USGS topographic maps. It should show:
1. The stream channel.
2. Tributaries.
3. The pattern of overland drainage.
4. Major spring areas.
5. Roads and trails.
6. Locations of erosion.
7. Sources of pollution or enrichment of the water.
8. Wetlands and ponds.
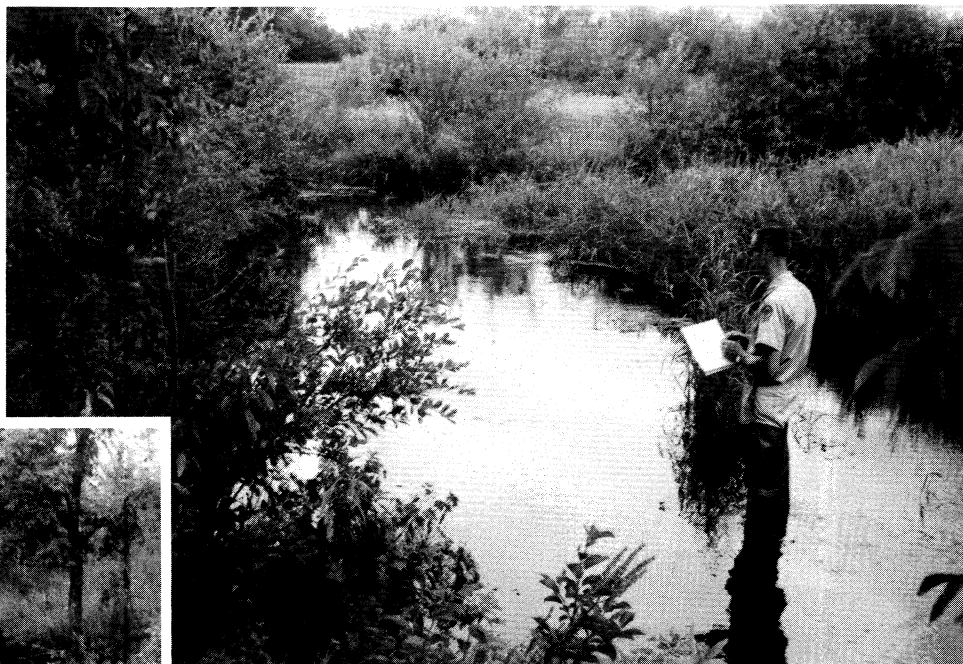
A stream mapper for the Wisconsin Conservation Department habitat management program. Tape measure, compass, pencil, straightedge and clipboard are his equipment.

9. Outline of the floodplain.

10. Boundary of the watershed.

Where great detail of structures is desired *draw a stream map* by plane-table methods at a time when there is neither flood nor severe drought. Choose a scale which will show the stream to be at least one inch wide on the paper. This will allow room for sketching in plans of structures. First draw a base map to show in outline:

1. The waterline.

2. The high water channel if it is distinct plus the edges of any prominent terraces.

3. The station markers.

4. Other important landmarks.

Use reprints of this base map in the field to draw other maps of:

1. Bottom types (gravel, silt, rubble, etc.)—at the same time, rough notation should be made of the state of the bottom fauna.

2. "Water-types" (springs, pools, flats, riffles, runs, rapids and falls) and their depths.

Use additional copies of the maps when noting ice conditions, vegetation and spawning, and when planning placement of structures.

Draw a vertical profile of the source-to-mouth gradient by running levels with a transit. Record at least the elevation of each 100-yard station marker, but the more detail, the better.

Maps of property lines will often be needed for adminis-

trative purposes. These, however, should not be confused with the basic drainage basin and stream maps described above.

Streamflow

Measure the volume of streamflow during baseflow periods in summer and winter with a Gurley meter at approximately 1-mile intervals or at points where one might expect water temperature problems. Measure the discharge of all tributaries at the point where they enter the stream. Install staff-gages at some of the stations selected for streamflow measurement. Record the height of the water on these gages as often as possible. Consult a Wisconsin Conservation Department or USGS engineer to learn how to establish rating curves and how to convert stage readings to discharge. If detailed questions about fluctuations in streamflow arise, install an automatic water level recorder and calibrate it to give continuous streamflow data.

Observe flooding from snowmelt water and after heavy rains, and if possible, measure streamflow. Assess damage to trout habitat and spawning grounds. Ask the USGS, Soil Conservation Service and local residents about the stream's history of floods and their destructiveness.

The biologist's report should contain a record of all flow measurements made. Graph the downstream pickup of streamflow volume (seepage profile). Comment on flooding.

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Temperature Conditions

Install thermographs or maximum-minimum thermometers in as many locations as possible along the stream, particularly in spots where you would expect to find temperature problems. Begin temperature measurements at the earliest possible date and *continue them for at least two years.* To know daily maximum and minimum water temperature is most useful. "Spot" measurements with a hand thermometer, even if combined into a lengthy record, fail to give temperature extremes, thus are of less usefulness. It is the extremes reached and the rapidity of temperature change that most affect trout. The travel involved in maintaining max-min registering mercury thermometers makes their use more costly than installing automatic thermographs.

Observe ice conditions in January or February on a day of —10°F. or colder following a night when it has been that cold. Walk the stream completely from the lower end of the trout water (or below it) to the source. On a stream map, draw the extent of surface ice with notations as to its thickness and completeness of coverage. Inspect riffles at twilight to see if anchor ice is forming.

The biologist's report should contain a tabular or graphic summary of temperature records, comments on ice observations and his assessment of their meaning for trout and habitat development. Keep in mind the amount of rainfall during the preceding months or year. Abnormally high autumn rainfall may, for instance, result in abnormally high groundwater discharge and keep much more stream open than usual during the following winter.

Vegetation

Roughly note on a map the types of aquatic and bank vegetation present during mid or late summer. Include remarks on how much of the stream is shaded. Note the extent that livestock have damaged vegetation.

The biologist's report should include an assessment of the effects of vegetation on trout habitat in the various ecological zones along the stream: in wooded reaches, meadows, marshy stretches, etc.

Hiding Cover

Walk the stream completely in April, the season when vegetation is most likely to be scarce, and in fall when aquatic vegetation will probably be most lush to assess the amount of protective cover available to the trout and what might be done to improve it. Do this if possible for two years. On the stream map, mark locations of undercut banks, pool depth, logs, submerged brush, rocks and submerged ledges and comment on their quality. Assess generally the trout cover value of bank vegetation as well as submerged and emergent aquatic plants.

Electrofishing to inventory a trout population. In the small boat is a 230-volt direct current generator (rear), a tub to hold the catch, and a covered compartment for gear (front). Three men probe for trout with stainless steel loop electrodes at the ends of fiberglass handles — light, maneuverable gear. With small handnets they pass fish back to larger net of man at right who is harnessed to boat.

To avoid tangling and snagging on stream bed, electric lines are tied to waists and kept taut by spring-loaded reels attached to boat. With such gear the crew can thoroughly fish about ¼ mile of stream per hour (not including stops to measure and weigh the catch — a second group of men often does that).

The biologist's report should include maps and general comments on protective cover summarizing conditions in individual sections of the stream.

Pollution and Fertility

Collect water samples at several significant stations along the stream during summer baseflow. This will give not only a rough idea of basic fertility, but may indicate substances endangering trout during the time of greatest warmth and lowest nighttime oxygen depletions when their toxicity may be most damaging. Have the water samples analyzed for the following: calcium, magnesium, ammonia, nitrate, nitrite, orthophosphate, potassium, sodium, sulfate, chloride, iron, pH, alkalinity.

The Fish Population

Estimate the population of each species of fish by mark-and-recapture electrofishing at some time between June 1 and October 15. Before June 1, young-of-the-year may not react to electrical gear well enough for estimation. After October 15, electrofishing may disturb spawning. The electrofishing should cover the entire existing or potential trout-water area of the stream. Do this station by station and keep the records separately for each station on printed data sheets.

Design data sheets carefully to suit the objective of the inventory and the methods of analysis to be used. A data sheet designed for convenience in the field as well as for later transfer of data onto cards for machine processing

STREAM

SECTION   STATION   SHEET

DATE   RUN

FISH SPECIES SYMBOL AND CODE

Brook trout   E - 1
Brown trout   B - 2
Rainbow trout   R - 3

PE ITEM   SYMBOL   CODE

	SYMBOL	CODE
Capt'd on 1st run and marked	M	1
Capt'd bearing only 1st run mark	R 1	2
Capt'd bearing only 2nd run mark	R 1	3
Capt'd bearing both 1st & 2nd run marks	R 2	4
Unmarked fish capt'd on 2nd run	U	5

FINCLIP   SYMBOL   CODE

	SYMBOL	CODE
Adipose	A	1
Right ventral	RV	2
Left ventral	LV	3
Right pectoral	RP	4
Left pectoral	LP	5
Dorsal	D	6
Anal	AN	7
Half clip	H	8
None	—	0

PE Item Symbol	Code	Species	Sex M-1 F-2	Fin Clip Symbol	Code	Length (inches TL)	Weight (grams)	Coeff. of Condition (R)	Age Group	Year Class	Origin W-1 H-2		PE Item Symbol	Code	Species	Sex M-1 F-2	Fin Clip Symbol	Code	Length (inches TL)	Weight (grams)	Coeff. of Condition (R)	Age Group	Year Class	Origin W-1 H-2
1																								41
2																								42
3																								43
4																								44
5																								45
6																								46
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is shown here (the actual size of this form is 9½ x 11¾ inches). Programs are available for rapid machine tabulation and calculation of the data necessary for population estimates and for analyzing length and weight data.

Measure each fish to the nearest 0.1 inch. If age groups are not clearly evident in the length frequency distribution, take scale samples. Take a representative sample of weights at each station.

To the extent possible, determine the age-structure, calculate the population estimates of wild trout within each age group by 0.5 inch groups. From this, one can analyze the age and size-structure of the population.

Mark all hatchery-reared fish stocked in a stream which is to be examined. If possible, mark all trout put in the stream for several years before the examination. Use a different fin clip to distinguish each year's stock.

The biologist's report should state his prognosis for population increase under various types of management. He should comment on influences the other fishes may have on the trout.

Trout Reproduction

Fingerling production will be roughly revealed through the population estimates by electrofishing.

Map the location of trout redds by walking the entire channel from the lowermost limit of trout water upstream to the source. Check all tributaries. Trout redds can best be seen by *wading in the stream* in an upstream direction. If the stream is wide, angle back and forth across it. Redds located under the bank cannot be seen from atop the bank.

Gear the dates of redd-mapping to the species of trout present. On brown trout streams, count redds preferably

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during the last week of November, but not earlier than November 10. Mid-November counts will be necessary on some northern streams which freeze over in November. If brook trout are present, make a count in late November and early December. Should freeze-up dictate an earlier date for a count of brook trout redds, a second count in nonfrozen parts of the stream may reveal new redds in early December. Observations at these dates will usually give a good indication of the areas used for spawning, but will not be a total count because spawning may not be completely finished. Rainbow trout redds are more difficult to find because they may be often in deeper, swifter water than brook or brown trout redds and because we do not have adequate information on the dates of rainbow trout spawning in Wisconsin. The usual period, however, appears to extend from late February through April.

Other pertinent notations on the map might include barriers to migration, detrimental drift of silt on the stream bottom, evidence of poaching on the spawning beds and obstacles to streamflow (such as debris dams) which impound possible spawning habitat.

Investigate mortality of eggs in cases where the fingerling crop, as determined through electrofishing, appears to be poor even in streams well-utilized for spawning. This can be done by carefully marking individual redds with metal stakes during the fall mapping, then returning in midwinter to excavate the eggs.

Schedule for Examination

1. *Cursory examination* — soon as possible after examination is ordered, preferably during a low-water period of spring or fall when trees and shrubs do not have leaves.
2. *Temperature measurements*—continuous. Begin any time, but as soon as possible after cursory examination.
3. *Measure streamflow* at intervals along the stream during winter baseflow if feasible.
4. *Obtain air photos* as soon as possible after cursory examination.
5. *The first spring:*
   a. Measure center line by tape and install station markers.
   b. Observe spring runoff and the effects of floods.
   c. Make basic map of stream channel after spring runoff but before foliage is heavy.
   d. Map cover, bottom types and "water types" before in-stream vegetation is abundant.
   e. Run levels by transit to determine profile.
   f. Map the drainage area.
6. *The first summer:*
   a. Observe the vegetation after foliage is out and aquatic vegetation has developed.
   b. Electrofish for population estimates of fish after June 15.
   c. Observe floods caused by heavy rains.
   d. Measure streamflow at intervals along the stream during a period of baseflow if such measurements were unfeasible or of unsatisfactory quality the previous winter.
7. *Autumn:*
   a. Map brown trout redds during late November.
   b. Map brook trout redds during late November and early December.
8. *Winter:*
   a. Map ice conditions in January or February.
   b. Excavate trout eggs if necessary.
   c. Report findings and recommendations.
9. *The second spring:*
   a. Conduct any necessary follow-ups to initial mapping or observations.
   b. Make another observation of the spring runoff of snowmelt.

APPENDIX C

Glossary of Terms Pertaining to Stream Management

PART I: PHYSICAL AND HYDROLOGICAL TERMS

AGGRADATION: Progressive deposition both within the channel and on the floodplain. The antonym is degradation. See also "channel scour and fill."

AMPLITUDE OF MEANDER: See diagrams on page 50.

ANCHOR ICE: See "ice types."

AQUIFER: A water-bearing rock or soil formation capable of storing water and allowing water to pass through it.

ARTESIAN WATER OR ARTESIAN FLOW: Flow from a well due to natural internal pressure.

BASE LEVEL OF A STREAM: The elevation at which a river's distal portion joins a major body of water; the level of its mouth.

BED LOAD: That portion of the total sediment load whose immersed weight is carried by the solid stream bed. See also "suspended load."

BRAIDED CHANNEL: Divided into several channels, which successively meet and redivide. Braiding may be an adjustment to debris load too large to be carried by the single channel. Braided channels often occur in deltas of rivers or in the outflow from a glacier.

BASEFLOW: Discharge of water in a stream at a time when no runoff of precipitation is taking place. See "discharge" and "runoff."

CASCADE: See "water types."

CHANNEL PATTERN OR FORM: See page 49.

CHANNEL SCOUR AND FILL: "Words used to define cutting and sedimentation during relatively short periods of time, whereas . . . *degradation* and *aggradation* apply to similar processes that occur over a longer period of time. Scour and fill involve times measured in minutes, hours, days, perhaps even seasons, whereas aggradation and degradation apply to persistent mean changes over . . . years." (Leopold, Wolman and Miller, 1964: 227.)

CONCAVE BANK OF A BEND. The outer bank. See diagrams on page 50.

CONVEX BANK OF A BEND: The inner bank. See diagrams on page 50.

CROSSOVER: The point of inflection in a meander. The point where the thalweg intersects the center line of the stream in crossing from near the outside of the next bend. See diagrams on page 50.

CUBIC FOOT PER SECOND (cfs): The unit of stream discharge used in North America. It represents one cubic foot of water moving past a given point in one second.

Expressed another way, it is the rate of discharge of a stream whose channel is 1 square foot in cross-sectional area and whose average velocity is 1 foot per second.

CUBIC FOOT PER SECOND PER SQUARE MILE (cf sm): The average number of cubic feet of water flowing per second from each square mile of area drained, assuming that the runoff is distributed uniformly in time and area.

cfs-DAY: The volume of water represented by a flow of 1 cubic foot per second for 24 hours. It is equivalent to 86,400 cubic feet or 646,317 gallons, and represents a runoff of 0.0372 inch from 1 square mile.

DEGRADATION: See "aggradation."

DISCHARGE: Rate of flow expressed in volume per unit of time, for instance, in cubic feet per second or liters per second. Discharge is the product of the mean velocity and the cross-sectional area of flow. See "mean annual discharge."

DISSOLVED LOAD: The chemical load contained in stream water; that acquired by solution or by decomposition of rocks followed by solution.

DRAINAGE AREA OR DRAINAGE BASIN: That area so enclosed by a topographic divide that surface runoff from precipitation drains into a stream above the point you specify. (The term "watershed" is commonly misapplied to the drainage area.)

EVAPOTRANSPIRATION: Water returned from the land or surface waters into the air through direct evaporation or by transpiration of plants.

FILL: See "channel scour and fill."

FLAT WATER OR "FLATS": See "water types."

FLOOD: Discharge overflowing the banks of a stream.

FLOODPLAIN: A strip of relatively smooth land bordering a stream and overflowed at time of high water. Though the floodplain is generally composed of finer material near the surface than at the base, this gradation in particle size is by no means universal. The floodplain in general is formed by the progressive building streamward of point bars. In most rivers the deposition of fine grained material during overbank flow is not a process which contributes importantly to floodplain deposit (L. B. Leopold, pers. comm.).

FRAZIL ICE: See "ice types."

GAGE HEIGHT: See "stage."

GALLONS PER MINUTE: A unit of stream discharge

commonly used in fish hatcheries. One gallon per minute = 0.0022 cfs. One cfs = 449 gallons per minute.

GRADIENT: See "stream bed gradient."

GRAVEL: Stones larger than sand, but smaller than rubble. See table of stream bed material sizes on page 53.

HINGE ICE: See "ice types."

HYDROGRAPH: A curve showing discharge against time.

ICE TYPES:

ANCHOR ICE: Ice formed on the stream bed materials when, due to outward radiation in the evening, they become colder than the water flowing over them.

FRAZIL ICE: Needle-like crystals of ice that are slightly lighter than water, but carried below the surface due to turbulence. This causes a milky mixture of ice and water. When these crystals touch a surface that is even a fraction of a degree below freezing, they instantly adhere and form a spongy, often rapidly growing mass.

HINGE ICE: A marginal sheet of surface ice attached to the bank materials and extending toward the center of a stream but not spanning it completely.

INFILTRATION: That part of precipitation which soaks into the ground. See also "runoff" and "recharge."

INTERNAL DISTORTION RESISTANCE: See "resistances to flow."

LAMINAR FLOW: A flow in which all particles or filaments of water move in parallel paths.

LONGITUDINAL PROFILE: A curve showing vertical fall of stream bed or water surface measured along the course of the stream.

MEAN ANNUAL DISCHARGE: Daily mean discharge in units per second averaged over a period of years. "Mean annual discharge usually fills a river channel to about one-third of its bankfull depth . . . " (Leopold, Wolman and Miller, 1964:243).

MEAN VELOCITY: The average velocity of water in one vertical segment of a cross section of a stream. Surface velocity is usually much stronger than bottom velocity. A velocity equal to mean velocity is most often found at 0.6 of the depth at any given point in the stream. (The mean velocity can be approximated by multiplying the surface velocity, determined by a float, by the factor 0.8. L. B. Leopold, pers. comm.)

MEANDER: A reach of stream bent to a sinuosity greater than 1.5 times the length of a straight reach covering the same down-valley distance. See pages 49 to 50.

NORMAL FLOW: An ambiguous term. May mean "baseflow" or "mean annual discharge."

OVERLAND FLOW: See "runoff."

OXBOW: A looping river bend cut off from the main flow by a new channel broken through the neck of its enclosed peninsula.

PHREATOPHYTES: Plants growing on or near the stream bank with their roots in the groundwater and decreasing streamflow by transpiration during their growing season.

PLUNGE POOL: Depression in stream bed material scoured out by the action of falling water.

POINT BAR: Sediments deposited at the convex bank of a stream bend. See diagrams on page 50.

RADIUS OF CURVATURE: See diagrams on page 50.

RAPIDS: See "water types."

RECHARGE: Water that is added to the groundwater reservoir, for instance, that part of infiltration which reaches the groundwater table.

RESISTANCES TO FLOW: See also page 49 for more explanation.

INTERNAL DISTORTION RESISTANCE: The resistance to streamflow caused by discrete boundary features that set up eddies and secondary circulations. Bars, bends, boulders, undulations of the bed and protuberances of the bank have this effect.

SKIN RESISTANCE: Resistance to flow due to roughness of the stream bed materials. Depends also on velocity of the water.

SPILL RESISTANCE: Caused when water backs up behind an obstruction and plunges abruptly to a diminished velocity.

RIFFLE: See "water types."

RILL: A furrow eroded in soil by runoff water.

RUBBLE: Stones larger than gravel, but smaller than boulders. A mixture of rocks with diameters of about 3-8 inches (7.5-20 cm.) would be termed rubble. See table on page 53.

RUN: See "water types."

RUNOFF: Water from precipitation flowing above or below ground to a surface water without entering the groundwater table.

SURFACE RUNOFF or OVERLAND FLOW: Runoff water flowing over the land surface.

SUBSURFACE RUNOFF: Runoff water flowing beneath the land surface.

RUNOFF IN INCHES: Shows the depth to which the drainage area would be covered if all the runoff for a given period were uniformly distributed on it.

SAND: See table on page 53.

SCOUR AND FILL: See "channel scour and fill."

SEDIMENT DISCHARGE: Rate of flow of sediment contained in a stream, expressed as volume or weight per unit time. Sediment discharge includes "suspended load discharge" and "bed load discharge." Suspended load discharge is the product of streamflow discharge and concentration of suspended sediment.

SEDIMENT TRANSPORT: The rate of movement of sediment through a given reach of stream.

SEEPAGE PROFILE: A graph showing discharge at various points along a stream's course (ideally on one given day). From this can be seen the downstream increase (or decrease) in volume of streamflow.

SEEPAGE RUN: The process of measuring discharge at various points to obtain a "seepage profile."

SILT: In common usage, silt designates sediments finer than sand. See table on page 53. Technically, however, silt is a specific grain size, finer than sand but coarser than clay.

SINUOSITY: The ratio of channel length to direct down-valley distance. See page 49.

STAGE (also known as water level or gage height): Elevation of water surface above any chosen reference plane.

STREAM BED GRADIENT: The vertical distance a stream falls per unit of distance it flows horizontally. Commonly expressed as feet of fall per mile or meters of fall per kilometer.

SUSPENDED LOAD: That part of the sediment load whose immersed weight is carried by the fluid. See also "bed load."

THALWEG: The down-channel course of greatest cross-sectional depths. The thalweg wanders from near one bank to near the other bank. See diagrams on page 50. From old-fashioned German spelling: *Thal* = valley, *Weg* = way or path.

TRANSPIRATION: The release of water vapor into the atmosphere through the green tissues of plants.

WATER LEVEL: See "stage."

WATER QUALITY: A general term denoting a category of properties that water has. Commonly used in reference to chemical characteristics and temperature of the water. It can logically be the title of an organization which deals with these aspects of water and can even serve as a general heading in a paper, but the term is often misused; for example, "Dog Creek lacks water quality" is an obscure way to say that it gets too hot in summer for trout. "Water quality" is a vague term and should be used sparingly. Where you mean "water temperature" or "chemical content" or "pollution," say so.

WATERSHED: A convex surface such as a mountain or hill which sheds water from one high point or ridge into several streams which may form its boundary. "Watershed" is commonly confused with "drainage basin": a concave surface collecting precipitation into *one* stream.

WATER TYPES:

POOLS: Water of considerable depth for the size of stream. Pools generally have slowly flowing water and a smooth surface, but they may often have a swift, turbulent area where the water enters them.

FLATS: Water with slight to moderate current and with an unbroken surface, but with less depth than pools.

RIFFLES: Shallow water with rapid current and with flow broken by gravel or rubble. Also known as "stickles."

RUNS: Moderate to rapid current flowing in a deeper, narrower channel than a riffle. Flow less turbulent than in a rapids or cascade.

RAPIDS: Those parts of large streams and rivers which are relatively swift and shallow with a bed of boulders. Analogous to riffles of a smaller stream.

CASCADES: A reach of stream in which steep gradient and a bed of large rocks combine to produce a very irregular rapid flow, often with some white water. A cascade may be somewhat deeper and narrower than a "rapids."

PART II: BIOLOGICAL TERMS

AGE-GROUP: Animals of a certain age in years, usually designated by Roman numerals. For instance, young-of-the-year (animals which have not yet reached their first birthday) are in age group 0, yearlings are in age group I, 2-year-olds in age group II, and so on.

BIOMASS: The weight of the standing crop of a specified organism present in a specified space at any one time. Usually expressed as weight per unit area.

CARRYING CAPACITY: As used in this paper, it denotes the amount of trout (or other organism) a stream has the resources (available food, hiding cover and space) to sustain over a given time. Carrying capacity may vary from season to season and year to year. Carrying capacity, as used here, does not involve reproduction. Carrying capacity may vary according to age or size structure of the population, that is, the carrying capacity for trout less than 8 inches long may be higher or lower than for those over 8 inches. Likewise carrying capacity can be related to behavior of the animals in question; for instance, during a season or age in which trout congregate in schools, or a stream's carrying capacity for them may be higher or lower than during seasons or life stages in which they take up territorial behavior.

COVER: An ambiguous term used sometimes to mean "vegetation cover of the land" and sometimes to mean "places where animals can hide from predators." Therefore, the term, if unqualified, is meaningless.

EMERGENT PLANTS: Aquatic plants with parts protruding above the water surface.

ENVIRONMENT: Apart from the dictionary definition: Surrounding; surrounding objects, region, or circumstances, Andrewartha (1961) has brought the word into perspective for ecological use. He represents an animal's environment in 4 major components: (a) Weather, (b) Food, (c) Other animals—and pathogens, (d) A place in which to live. (See "habitat." This term cannot, in its strict sense be applied to the latter category.) Some environmental items may fall into more than one of these components (some of the "food" may be "other animals," for instance), but this breakdown serves well as a basis for ecological study and discussion. Andrewartha has found that he can think of the environment of any animal in terms of these 4 components and the interactions between them. Since parts of an animal's environment are animals of his own kind, and since the density of the population must be regarded as part of the environment,

the confusion in speaking of a population being a part of its own environment can be avoided by speaking always of the environment of an *individual*.

EUTROPHICATION: See "stream eutrophication."

HABITAT: Loosely used now, but the strict (Eltonian) concept was that a certain habitat (an area with rather uniform physiography, vegetation or other animal-influencing quality) has a certain community of animals. For most fishery biologists and managers in America, however, the word "habitat" probably brings into mind a view of an animal's environment, the central aspect of which would be Andrewartha's (1961) component: "A place in which to live" (see "environment"), but which would include a few other things around the fringes. The fringe aspects might be food, competitors for the food, and some of the animal's predators (not fishermen). In keeping with variability of meaning within the profession, we have used "habitat" in various ways in this bulletin.

HABITAT MANAGEMENT: Here: Manipulation of physical, chemical and vegetational qualities of a body of water and its drainage basin with the objective of controlling living conditions for one or several kinds of animals. Fishery personnel have now and then suggested introduction of fish foods, control of predators and removal of competitory fishes as appropriate activities for the fish habitat management program. These are not, however, within the scope of this bulletin. As practiced some places, habitat management seems to include all fishery practices not covered under regulation of fishing, rearing and stocking of fishes and control of fish diseases.

HIDING COVER: Used in this paper to mean places where animals can hide from predators.

PRODUCTION: Growth in weight by all fish in the population during a specified period of time including growth by fish that died during the period.

PRODUCTIVITY OR PRODUCTIVE CAPACITY: General terms meaning the capacity of a stream to sustain production of a certain weight of some organism over a certain period.

REDD: An area of stream bed dug out by a female trout before spawning and in which she buries her eggs after spawning.

REPRODUCTIVE CAPACITY: The capacity of a stream or part of a stream to provide for reproduction of an organism. For instance, one section of stream may have 1,000 fingerling trout per year (measured in a given month) and another only 100.

STANDING CROP: The number or weight of organisms present per unit space at a given point in time, e.g., trout/acre, pounds of trout/acre, trout per mile, pounds of trout/mile. Units involving weight are synonymous with "biomass."

STOCK DENSITY: Used interchangeably with "standing crop."

STREAM EUTROPHICATION: The development, due to ample supply of plant nutrients, of an abundance of aquatic plants so great that their respiration depletes oxygen at night (no photosynthesis then) to levels intolerable for trout and other animals with high oxygen requirement. (It remains somewhat questionable whether this process is truly "eutrophication," for "lake eutrophication" is a slightly different process: oxygen is depleted in dark lower layers by oxidizing organic matter "raining" down from highly productive (light-receiving) upper layers.

SUBMERGENT PLANTS: Aquatic plants having all parts submerged beneath the water surface.

YEAR CLASS: Those animals born or hatched within a given year. Designated as "1961 year class," for instance.

REFERENCES

Besides references actually cited in the text of this publication, additional material is included here which the fish manager may find helpful in gaining insight into the ecology of his streams. The more highly recommended general references with direct bearing on trout stream management are starred (*). In regard to stream improvement as such, only a few of the less obsolete guides are listed.

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- 1934. Hewitt's handbook of stream improvement. Marchbanks Press. N.Y. 82p. (Though old, the 2 works by Hewitt, experimenter and superb angler, present concisely some interesting methods of trout habitat manipulation. Some of the techniques are still sound and useful, others quite outmoded or even damaging.)

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Management of Stream Bank Vegetation and Construction of Fences

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