REC-ERC-72-17

ECOLOGICAL IMPACT OF WATER RESOURCE DEVELOPMENT

A Technical Session of the Symposium, "Water, Man, and Nature"

Coordinated by
D. A. Hoffman
Engineering and Research Center
Bureau of Reclamation

June 1972

MS-230 (8-70)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
REC-ERC-72-17

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
Ecological Impact of Water Resource Development—A Technical Session of the Symposium, "Water, Man, and Nature"

5. REPORT DATE
June 1972

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Coordinated by D. A. Hoffman

8. PERFORMING ORGANIZATION REPORT NO.
REC-ERC-72-17

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Engineering and Research Center
Bureau of Reclamation
Denver, Colorado 80225

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Cosponsored by:
Engineering and Research Center, Bureau of Reclamation, Denver, Colorado 80225; and American Institute of Biological Sciences, 2900 Wisconsin Ave. NW., Washington, D.C. 20016

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT
Four papers describe a sequence of ecological impact analysis, ranging from predicting the consequences of planned management programs to descriptions and evaluations of ongoing programs. Use of preproject ecological surveys, bioassays, and laboratory scale models are described. Structures to increase fish habitat in changed river channels are evaluated; recommendations for increasing or maintaining the level of production in changed river systems are presented. These papers were presented at the symposium on Water, Man, and Nature, cosponsored by the Bureau of Reclamation and the American Institute of Biological Sciences at Colorado State University, Ft. Collins, Colo, August 30-31, 1971. Has 34 references.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- / bibliographies/ *ecology/ environmental effects/ *water quality/ planning/ aquatic environment/ fish/ man/ natural resources/ *water resources development/ *highway effects/ hydraulic models/ spoil banks/ reservoirs/ natural resources/ limnology/ *canal construction/ stream fisheries/ *reservoir operation/ stream channels

b. IDENTIFIERS-- / McClusky Canal, N Dak

c. COSATI Field/Group 13B

18. DISTRIBUTION STATEMENT
Available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151.

19. SECURITY CLASS (THIS REPORT)
UNCLASSIFIED

20. SECURITY CLASS (THIS PAGE)
UNCLASSIFIED

21. NO. OF PAGES
28

22. PRICE

REC-ERC-72-17

ECOLOGICAL IMPACT OF WATER RESOURCE DEVELOPMENT

A Technical Session of the Symposium, "Water, Man, and Nature"

Coordinated by
D. A. Hoffman

June 1972

Applied Sciences Branch
Division of General Research
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Rogers C. B. Morton, Secretary
Ellis L. Armstrong, Commissioner

TABLE OF CONTENTS

FOREWORD

This report comprises papers presented by K. L. Dickson and John Cairns, Jr., Virginia Polytechnic Institute and State University; R. D. Estes, Bureau of Sport Fisheries and Wildlife; T. E. Mann, Bureau of Reclamation; and J. R. Barton, D. A. White, P. V. Winger, and E. J. Peters, Brigham Young University. The papers were presented at the technical session of the symposium, "Water, Man, and Nature," cosponsored by the Bureau of Reclamation and the American Institute of Biological Sciences. The symposium was held during the 1971 AIBS meeting at Colorado State University, Fort Collins, Colorado.

The primary objective of the symposium was to provide an opportunity for ecologists, water resource engineers, economists, planners, and others to discuss their mutual and individual objectives, viewpoints, and constraints. Thus, the symposium provided a means of establishing communication between ecologists and engineers, as well as defining the problems and research needs in ecological and environmental aspects of water resource development.

The format of the symposium consisted of a panel discussing the engineering, ecological, agricultural, and industrial aspects of "Water, Man, and Nature," a technical session on "Ecological Impact of Water Resource Development," and a session consisting of eight workshops, each concerned with a specific ecological impact subject.

A proceedings of the panel and workshop sessions has been published as "Water, Man, and Nature," by the U.S. Government Printing Office, Washington, D.C. Technical session papers were not included. Because the technical session papers were a valuable part of the symposium and contribute to the knowledge of water resource management, they are published separately here without editing or revisions.

Dale A. Hoffman, *Symposium Coordinator*
Bureau of Reclamation

ECOLOGICAL DATA FOR WATER RESOURCES MANAGEMENT

Kenneth L. Dickson and John Cairns, Jr.
Biology Department and Center for Environmental Studies
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

Ecologists must be willing to take a chance and predict the ecological consequences of alternative schemes for water resources management if we are to realize the maximum beneficial use of our resources. Historically, ecologists have lagged behind their engineering colleagues in developing prediction capabilities for a number of reasons. Unfortunately, the operational characteristics of ecosystems are poorly understood when compared to the engineers systems. Engineers can predict that with so much concrete, steel, etc., and with a given amount of labor and money, a dam can be built on a river which will enable them to regulate flow behind the dam. The flow figures can be predicted with reasonable accuracy, and when the dam is built, the performance is generally within the original estimate. However, due to the complex chemical, physical, and biotic interactions of an ecosystem prediction of the ecological consequences of any activity is more involved. The ecologist has developed only relatively recently rather primitive prediction systems for complex natural environments.

Another reason that ecologists have lagged behind engineers is that appropriate channels of information exchange between them have not always been open. Two contrasting philosophies have existed in the past which have hindered the ecological management of our water resources. Engineers, water resource economists, and industrialists have generally had a construction philosophy of life which has conflicted with the conservationists or protective philosophy. Those who build powerplants, dams, reservoirs, canals, etc., have used the technology of the time most economically appropriate with the expectation that what they are building will have a very short life span in terms of geologic time, and that when the structure is outmoded or uneconomical, it will be torn down or replaced. Plans are also strongly time dependent, and once completed must be initiated in a relatively short time period or they will become outdated. Complex sets of conditions involving technology, financing, land acquisition, power demands, etc. prevail thus the engineer is often characterized by a time and tide wait for no man attitude. The conservationist, on the other hand, realizes that once a rare species endemic to any area is lost it is gone for all time, and that ecosystems once damaged may be difficult, if not impossible, to restore to their original condition.

Fortunately a new awareness on the parts of the advocates of both philosophies that our life support system on earth has two components, one industrial and the other ecological, has forced ecologists and engineers to work together. We currently realize that the survival of our present social system depends upon our ability to develop a harmonious relationship between these components.

Those people involved in water resources management realize that some of the frustration and public outcry about water resources projects could have been avoided if proper consideration was given to ecological information before construction. Present trends in legislative action combined with the ever growing concern over the quality of the environment, increase the probability that the "environmental impact" of any new water resources development will be closely scrutinized. It is the purpose of this paper to briefly present some ecological information that should be considered along with other parameters in water resources management.

PRECONSTRUCTION ECOLOGICAL SURVEY

One of the common problems of water resources development is to select a project site which allows maximum use with minimal or no environmental degradation. In order to get this type of information it is necessary to develop a series of prediction systems which will allow an ecologist to rank the potential construction sites. That is to indicate to plant management personnel at which sites the proposed plant is likely to cause the most ecological damage and at which the least damage will result. Perhaps one of the best ways to obtain important types of ecological information to be used in water resources management is through a preconstruction ecological survey.

A preconstruction survey should be carried out by a team of chemists, ecologists, engineers, and taxonomists to get a complete picture of the chemical, physical, and biological condition above and below the potential site location. If adequate background data are to be generated, the team should consist of one or more chemists, a bacteriologist, an algologist, a protozoologist, one or more invertebrate zoologists (including an aquatic entomologist), an ichthyologist, and a sanitary engineer. Since this involves a number of well-trained people, it can be moderately expensive. The exact cost would depend on a number of factors including the size and structure of the river and the number of species likely to be encountered. Obviously, the lower Mississippi is a more difficult river to survey than a small river that one can throw a rock across. In addition, a stream already degraded by pollution is likely to have fewer species resulting in less cost for identifying the various organisms collected than an unpolluted stream with a very high number of species. Before such a survey is comtemplated, it is well to have a preliminary survey by a generalist accustomed to dealing with these problems who can make a firm estimate of the costs involved and place reliable time estimates on completion of the project.

A survey of this nature will provide a wide variety of information essential to making an informed choice between prospective project locations. It will establish a baseline of biological, chemical, and physical water quality which can be useful in determining the waste assimilative capacity and other beneficial uses of the system. If one views the waste assimilative capacity of a river as a natural resource then it is logical, in view of our present population size, to make rational use of that capacity along with other uses such as water supply, recreation, and asthetics to derive the maximum beneficial use from the system. Regardless of current trends in legislative action related to "effluent"* standards versus "stream" standards we feel that a new project site should in part be chosen with the potential intent of making use of the receiving capacity of the system since we feel that a strong stream standards trend will eventually occur in legislative policy.

A preconstruction survey will determine preexisting man-made ***or natural*** stresses on the receiving system. In order to avoid unjustified blame for environmental degradation there is no better defense than preconstruction data. Preconstruction data which documents the water quality is extremely valuable particularly in receiving systems which are already partially under stress from other waste discharges. It is essential to establish the presence of natural stress on a system and thus avoid blame after project construction is completed and operations begin. Natural stress can take place from siltation and the introduction of organics from leaf litter, to thermal changes due to the introduction of underground aquifers. This data will protect the innocent but will help convict polluters. A company which has collected such data is usually much more careful in its waste treatment than one which hasn't.

How many water resources projects do you know that are located near critical spawning areas of striped bass, just above or in the middle of an important fishery, in an area where the aquatic life is particularly vulnerable, and the like? Many of these situations could have been avoided through a preconstruction survey before site selection was made. Based on the survey, the ecological risks and benefits associated with each site could be determined. Alterations in design of waste discharges could have received valuable input information based on this identification of valuable wildlife resources. For example, in some cases, it might be desirable to design waste discharge systems so that the waste is held against one bank of the stream or river leaving a free channel on the other side where migratory fish could pass through the area.

A preconstruction survey is a convincing demonstration that the resource developers are sincere in their efforts to protect the environment. The information derived from the survey can often furnish information about the ecological history of the area and make some predictions about future trends, all of which are useful to engineers designing the waste disposal system and to the administrator concerned about public relations.

Through identification of critical physical, chemical, and biological parameters the preconstruction survey can help water quality personnel predict the consequences of various types of mixing zones upon project operations. This is an important factor from a regulatory as well as public relations viewpoint. For example, should an attempt be made by an industry to make its effluent channel along one side of a river

---

*An effluent standard attempts to protect an ecosystem by regulating the quality and quantity of the waste—a stream standard attempts to protect an ecosystem by regulating the impact of the waste upon the receiving ecosystem.

allowing a waste-free zone of passage for migratory fish or should the same industry try to achieve maximum dilution as soon as possible? Answers to questions like these can be based on more than mere speculation if a survey had been conducted.

PREDICTIVE BIOASSAY

Of equal importance to the preconstruction survey in project site selection is the availability of toxicity information based on a predictive bioassay. Even if a building site for an industry has been selected, but before construction begins or preferably before final designs of the plant are approved, some bioassays should be carried out. These should be carried out with a simulated plant waste as close as possible in quality to the anticipated operating waste under the worst possible conditions (high temperature, low flow) likely to exist in the receiving system. Ideally, these bioassays should contain at least three elements of the food chain, i.e., primary producers such as algae, invertebrates, and a fish. Although a waste doesn't kill fish directly it may ultimately affect their survival due to its toxicity to an intermediate in the food chain. However, other elements of the aquatic community besides fish deserve protection on their own merits. For example, the loss of algae may impair the ability of the aquatic system to receive and transform organic wastes.

Predictive bioassays can be useful in helping determine a site selection for a variety of reasons. For example, an industry having a discharge containing heavy metals should consider locating in an area where the hardness of the water is high since for zinc the 96 hour TL_m in hard water is 10.1-12.5 ppm for the bluegill sunfish where the 96 hour TL_m in soft water is 2.9-3.8 (McKee and Wolf, 1963).

When conducting predictive bioassays, water quality of the proposed site location should be used since there are documented examples of synergistic interactions resulting in increased toxicity. If a plant is considering locating in a system already receiving heavy metal discharges and plans to add additional heavy metals, then a predictive bioassay using a test water similar in quality to the receiving water is essential since, for example, the toxicity of zinc combined with copper is 10 times their individual toxicity (Doudoroff, 1953).

Predictive bioassays can be used to allow the plant to make maximum nondegrading use of the system, to identify potentially hazardous interactions, and to see if preliminary waste treatment design is likely to be adequate and, if not, can be used to estimate the degree of additional treatment required.

No longer can an industry be solely concerned with determining the acute toxicity of its waste products. Bioassays of industrial wastes have progressed from short-term tests using a single species with death as an end point to long-term tests involving several species and even communities of organisms. The use of respiration, growth, reproductive success, electrocardiograms, and movement patterns or other functional changes will undoubtedly replace the use of death as a criterion of response. The length of time for tests is increasing and acute toxicity determinations are rapidly being replaced by chronic bioassays. The latter require more time and money but provide valuable predictive information concerning the "biologically safe concentrations" of various toxicants and thus should be considered in plant site selection if enough lead time if available.

SIMULATION TECHNIQUES

The development of simulation techniques involving the use of scale models becomes increasingly important as our population grows and more intensive use is made of the finite space available to us. In the past when we damaged an environment seriously, we could move on to a new undamaged environment and avoid most of the immediate consequences of poor management. Perhaps the last big movement of this sort in the United States was the exodus from the Dust Bowl. However, since most of the ecosystems of the United States are at or near tolerable stress levels, we no longer can go to virgin territory and escape our environmental mistakes. As a consequence, we can make fewer mistakes without immediate penalty than we could in the past. One of the obvious protective measures we might take to prevent major ecological or environmental problems is to simulate prospective new uses in scale or laboratory models and restrict most of our mistakes to these. This practice is too common in engineering (for example, the U.S. Army Corps of Engineers river models at the Waterways Experiment Station, Vicksburg, Mississippi) and industrial circles that it would hardly need mention were it not for the fact that ecological scale models or environmental simulation systems are not now commonly used. However, ecologists now are becoming quite interested in developing scale models to simulate various environmental systems and the practice should become increasingly common in the future. Of course these suffer the weaknesses of all scale models and are still in primitive stages of development. They need not be extremely expensive and may be used to generate data which could be useful in preventing large scale mistakes. Many of the events which have occurred in Lake Erie could probably have been simulated in models.

An example of a scale model we commonly use in our laboratory is a "stream" to which we have attached a unit which simulates temperature increases in a steam electric powerplant condensing system (Figure 1). Water from the stream is passed through the condenser system and then through a series of plexiglass troughs where algal and protozoan communities are

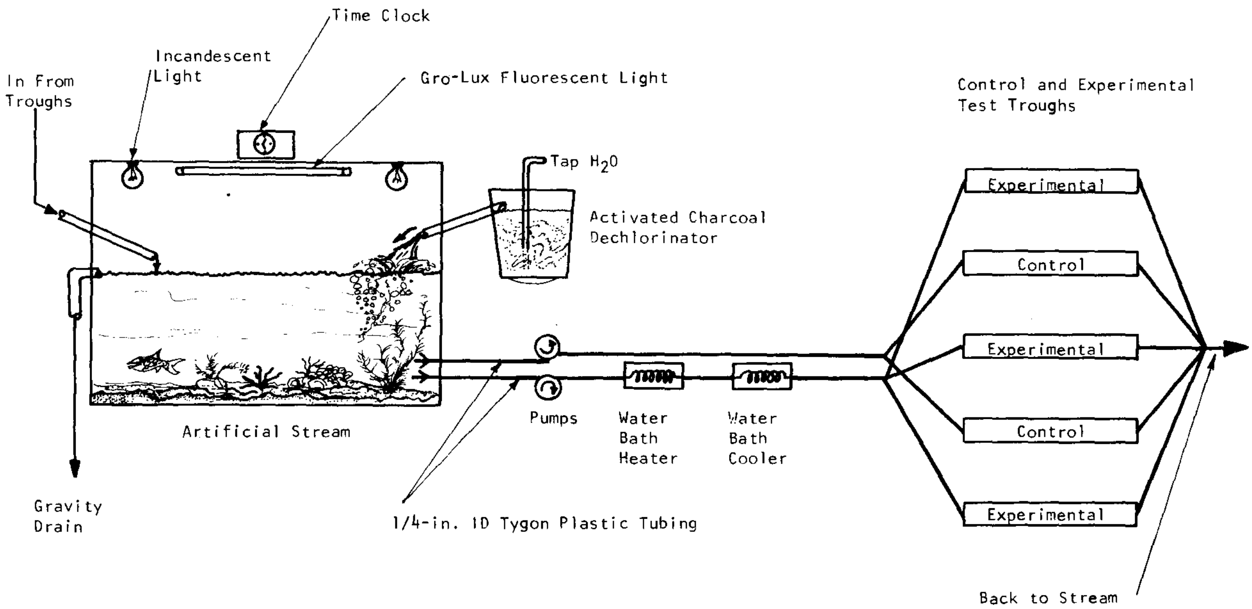


Figure 1. Scale model system for simulating the effects of passage through a steam condensor on microorganisms.

established. These experimental troughs are compared to control troughs, and some predictive information on the effects of water passage through the system on downstream community structure can be determined.

ECOLOGICAL QUALITY CONTROL TECHNIQUES

Since we are a society almost compulsively dedicated to change, we are desperately in need of adequate prediction systems. The preconstruction survey, predictive bioassay, and scale models previously discussed allow the ecologist to make some of these predictions and help to identify the various alternatives used which might be made of the environment and to estimate what the consequences of these will be. If these techniques were utilized in prospective water resource projects, we would be on our way to having adequate environmental planning. However, environmental planning alone will not be effective unless good quality control techniques are developed, as well as adequate environmental management practices.

Just as in an industrial process where there is a system of checks and balances to insure quality control we must begin to develop the capabilities for environmental quality control together with an equitable environmental use plan. Environmental quality control will require rapid biological, physical, and chemical information systems to provide a continuous flow of information that will enable us to predict unfavorable changes in our water resource systems. Of the three types of information systems previously mentioned, the development of rapid biological monitors providing continuous information has lagged behind the other two in development. We can continuously monitor in a river many useful physical and chemical parameters. However, the development of rapid biological information systems, both in-stream and in-plant, is essential to the maintenance of adequate environmental quality control. We need to know the effects on biological organisms of a waste discharge before it enters the receiving stream as well as the biological effects after it enters the stream, and this information should be produced rapidly. Present systems are much too slow in view of the fact that the constituents of a waste stream are likely to vary from hour to hour and from day to day. Potentially disastrous materials should be detected before they enter a receiving stream and at the very least, before substantial damage has been done in the receiving stream itself. Several potentially useful methods for rapid in-plant monitoring are being explored (Cairns, et al. 1970) and one rapid in-stream method is now operational (Cairns and Dickson, 1971). The in-plant methods just mentioned use changes in heart rate, breathing signal, and movements of the entire fish within a container to detect sublethal concentrations of toxicants in a waste discharge. If successful, these and other "early warning" in-plant systems could be used to determine the toxicity of a waste before it left the plant so that the appearance of a harmful concentration of a toxicant would activate a control system and shunt the waste immediately to a holding pond or recycle it for additional treatment. This continual information about the toxicity of a waste should enable sanitary engineers to identify periods of operation likely to produce the most toxic wastes as well as identifying those components of the production process which contribute most of the toxicity.

Full development of useful early warning systems with rapid information feedback will probably take a number of years and will require the close cooperation of a variety of disciplines. No doubt the early developmental period will have its share of failures, but it is highly probable that effective systems can be produced and that their use will substantially improve environmental quality control. Since the ultimate test of the effectiveness of a waste treatment process should be in the receiving stream, in-stream early warning systems also should be developed to insure a continual flow of information.

SYSTEMS MANAGEMENT OF WATER RESOURCES

Present advances in biological monitoring combined with physical and chemical monitoring capabilities indicate that in the near future we can develop and operate a river basin with varied water resource uses to maximize beneficial use without ecological damage. Figure 2 illustrates a river basin management system which includes reservoirs, agricultural uses, industries and towns, etc. Conceptually, utilizing a central control center and rapid physical, chemical, and biological monitoring systems ecological damage could be prevented, through the operation of the system as a whole rather than each water resource user being concerned only with his own discharge. If an industry in the system had a spill of toxic material which was rapidly detected through the continuous monitoring systems, the following activities might be coordinated by the control center:

1. Upstream reservoirs could increase discharges for dilution of toxicants.
2. Municipal water users could curtail use of water and depend on reserves until toxicity was dissipated.
3. Downstream industries could shunt to holding ponds to prevent synergistic interactions.

Obviously the water resources management scheme just outlined is optimistic and depends on the cooperative activities of State and Federal government as well as private users of water resources. However, we are rapidly approaching the time when technology is available to do this job. Implementation of such a program to protect and wisely utilize our water resources now depends on the sincerity of our nationally stated goal of an improved environment.

LITERATURE CITED

McKee, J. E. and H. W. Wolf, 1963, *Water Quality Criteria* The Water Resources Agency of California, 1-548

Doudoroff, P. and M. Katz, 1953, *Critical review of literature on the toxicity of industrial wastes and their components to fish*, II. The metals as salts. Sewage & Indus. Wastes 25:802-839

Cairns, John, Jr., Kenneth L. Dickson, Richard E. Sparks, and William T. Waller, 1970, *A Preliminary Report on Rapid Biological Information Systems for Water Pollution Control*, Jour. Water Poll. Contr. Fed., 42(5): 685-703

Cairns, John, Jr. and Kenneth L. Dickson, 1971, *A Simple Method for the Biological Assessment of the Effects of Waste Discharges on Aquatic Bottom Dwelling Organisms*, Jour. Water Poll. Contr. Fed., 43(5): 755-772

Cairns, John, Jr., 1970, *New Concepts for Managing Aquatic Life Systems*, Jour. Water Poll. Contr. Fed., 42(1): 77-82

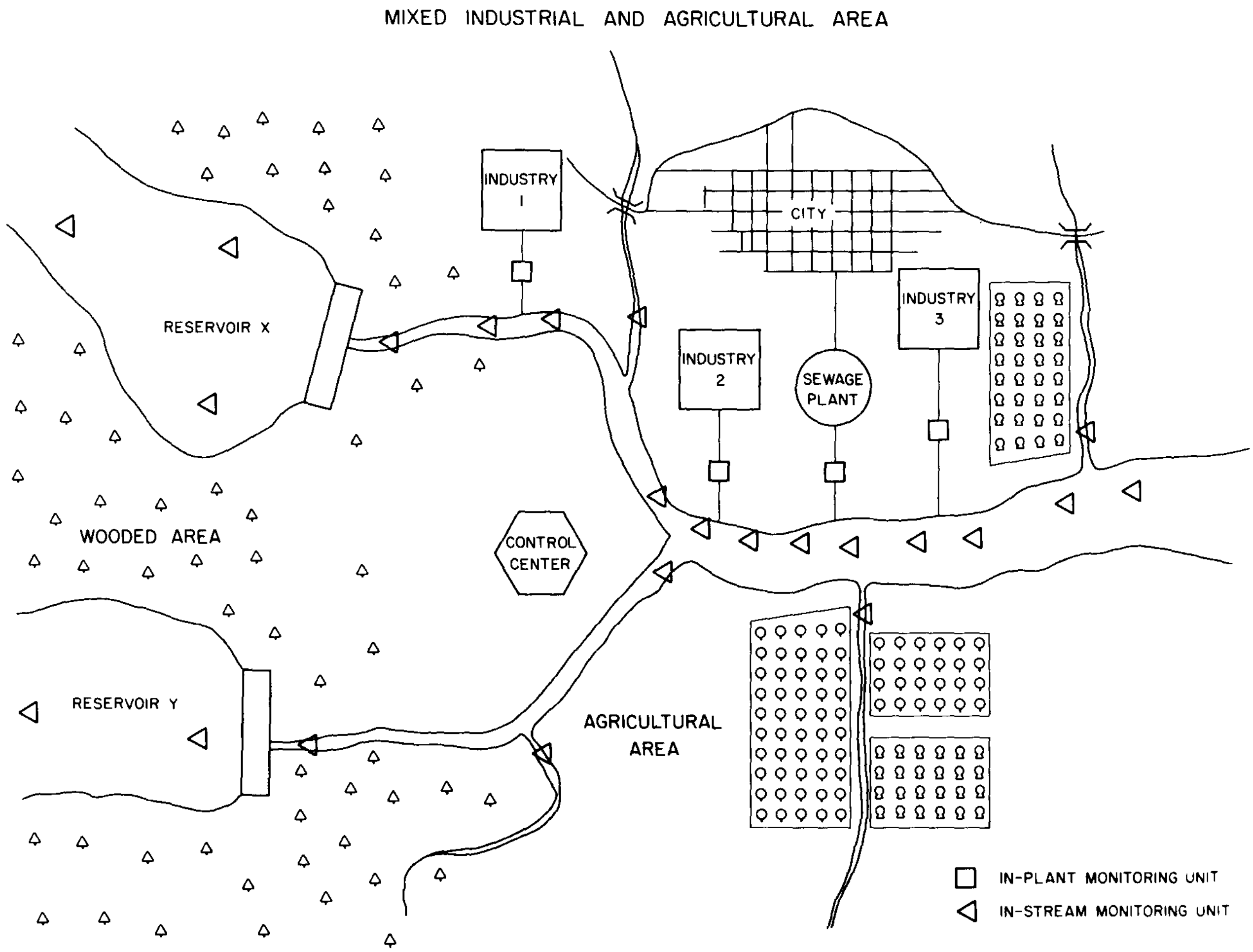


Figure 2. Diagram of a coordinated River Basin Management Scheme.

ECOLOGICAL IMPACT OF FLUCTUATING WATER LEVELS IN RESERVOIRS

R. Don Estes
Bureau of Sport Fisheries and Wildlife
Virginia Cooperative Fishery Unit
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

The littoral zone is the most important area of a reservoir from the standpoint of fishes and other higher animals and plants. This is especially true in deep, stratified reservoirs, since most of the bottom can support only anaerobic life. It is in the littoral zone where most fish spawn and where their young find protection and food. Since young fish are found in the littoral zone, larger predator fish can also be expected to frequent the area. With few exceptions the higher aquatic plants are found in the littoral zone. These plants give support and protection to a group of plants and animals which are important in the food cycle of fishes, as well as other aquatic animals. Plants also afford protection for young fishes and are spawning sites for many species of fishes. The littoral zone is also important for the exchange of nutrients between land and water. Thus, changes which occur in the littoral zone of a reservoir will have an impact on the aquatic ecosystem, especially the fishes.

One change that occurs frequently in the littoral zone of a reservoir is a change in the water level. Reservoirs usually require the use or eventual release of water for hydroelectric power production, for domestic and industrial water supply, for irrigation, or flood control. Seldom does the demand for the water coincide with the supply; therefore, changes in the volume of water occur. Even reservoirs designed for nonconsumptive usage of water, such as navigation or recreation usually undergo some fluctuation of water levels. Most of the work on the ecological impact of water-level fluctuation in the past has been largely confined to studies by fishery biologists, aquatic entomologists, or engineers concerned with shoreline erosion. Only recently have studies been conducted to determine the impact of fluctuating water levels on recreational usage, shoreline development, water quality management, or the water table. This paper will be concerned only with the impact on the aquatic community, especially the fishes.

The greatest concern to fishery biologists regarding fluctuation has been the effects on the reproduction of fishes. This is especially true in the southeastern states where the nest-building Centrachidae are the most important group of sport fish. Most game and fish commissions in the southeast have agreements with private power companies and public power agencies to stabilize water levels during the spring, primarily to insure the successful spawning of the black bass. Results from numerous studies on reservoir fishery management indicate that the general consensus is that water-level fluctuation may cause loss of Centrachidae eggs but usually not a complete failure of a year-class (1, 2, 3, 4, 5, 6, and 7). Recently (8) it was found that largemouth bass and bluegill can reproduce in Leesville, a pump-storage reservoir in Virginia, with weekly change in water level from 6 to 8 feet with occasional changes up to 10 feet. This may indicate that these species have more flexible spawning requirements than previously thought. However, it now appears that over a period of years reproduction of these species may not have been sufficient to sustain a viable population. Additional surveillance of this fishery should provide much needed information of the effects of water level changes on Centrachidae populations.

Stabilization of the water level of Lake Mead has recently been achieved in order to benefit the reproduction of largemouth bass (9). Not only is the reservoir stabilized during the bass spawning season, but the water level is raised into terrestrial vegetation during the summer to provide cover for the young bass. Water-level fluctuation is also reported to have caused the destruction of lake trout spawning beds in Canadian reservoirs (10 and 11). The water level of these reservoirs receded during the fall and winter, making it particularly destructive to the fall spawning lake trout whose eggs take several weeks to hatch. Water-level fluctuation was reported to be responsible for poor reproductive success for six species of fishes, including sauger and northern pike, in some Missouri mainstream reservoirs (12). Losses of walleye eggs has been attributed to water-level fluctuation in some northern lakes (13). The failure or near failure of gizzard shad year-classes in Leesville Reservoir was thought to be due to water-level fluctuation, which in turn resulted in poor growth of largemouth bass (8). A rising water level over submerged vegetation is reported (14) to have caused virtual failure of northern pike spawning in a large reservoir in South Dakota in 1966. This was associated with a decreased temperature in the shallow spawning areas, resulting from a drop in air temperature.

Although there are many instances of adverse affects on fishes caused by receding water levels, there are also many instances of beneficial affects to the fishery. There has been some success in controlling undesirable fish species such as carp and yellow perch by manipulation of water levels. Fall and winter drawdowns have been used to control the number of small fish by concentrating the fish in smaller area without the benefit of riparian vegetation for cover. This has often resulted in increased growth of predatory fishes with an accompanied increase in sport fishing harvest.

It is generally accepted that a drawdown will often result in a recycling of nutrients back into the water. These nutrients may come either from aquatic plants and other organic matter on the bottom or from the release of nutrients in the bottom soil. However, with the increasing problem of eutrophication in many of our lakes and streams, additional nutrients may not always be desirable.

Water-level changes usually have some affect on the aquatic plants in the littoral zone and in some instances have affected the terrestrial plants. Since some plant growth is considered desirable cover for fish and fishfood organisms, as well as spawning media, water-level changes may have a profound effect on the fish populations. On the other hand, aquatic plants can at times become a nuisance; in which case, water-level changes may be used to control some species of plants. Water rising into plants may serve as a stimulus for some fish to spawn. However, there have been reports of young fish being killed when freshly flooded plants decayed and greatly reduced the oxygen in shallow areas. No attempt will be made to discuss the techniques of controlling undesirable aquatic plants by planned water-level control. The effects of normal water-level fluctuation on plants varies considerably. Frequent changes are more likely to discourage any higher plant growth in the littoral zone and often have caused extensive shoreline erosion, with the resulting adverse affect on terrestrial plants. Less frequent changes, such as the slow summer drawdown of some TVA reservoirs favors growth of perennial plants and some annuals, without being completely destructive to the aquatic plants.

Closely associated with the impact on plants is the impact on some fishfood organisms which depend on plant life for food and shelter. In large, deep reservoirs, especially those thermally stratified, the littoral zone supports most of the benthos, those large invertebrates which comprise a large percentage of the diet of many important fish species. Even the large carnivorous fishes depend on these invertebrates in their early life stages. Another important group of organisms associated with aquatic plants is the periphyton, those plants and animals needing attachment for survival. The periphyton may begin the food chain for the higher animals by serving as food for some of the invertebrates. If the fluctuation of the water level of a reservoir is drastic enough to prevent the growth of aquatic plants, there may be a severe loss of habitat for these important groups of organisms. If fluctuation is gradual, this loss can be partially offset by the addition of terrestrial insects and similar organisms to the diet of fishes. In a newly flooded reservoir in Arkansas it was found that terrestrial organisms made a substantial contribution to the diet of several species of fishes (15).

Not all benthos is associated with plants; many are found in the bottom mud. Changes in water levels have a very profound affect on these organisms. For example, lake trout in some of the hydroelectric power reservoirs in Alberta, Canada, have become very scarce, partly because of the effect of water-level fluctuation on the littoral benthos (11). Some benthos are more tolerant of fluctuation than others, and the overall effect on benthic populations is related to the time, duration, and degree of the drawdown. In a study on two large Missouri River reservoirs it was found that some benthos migrated in response to water-level fluctuation, while others did not. Significant loss of migrating benthos occurred by the organisms being drawn through the reservoir turbines (15).

Fluctuating water levels may cause some physical changes to the limnology of reservoirs, which in turn affects downstream biota. An example of limnological change is the affect that the weekly water-level cycle of Leesville Reservoir had on the temperature of the water being discharged from the dam. During a 6-week period in the spring, water is released hourly from Leesville to augment the flow in the Roanoke River for the striped bass spawning run. The reservoir was full on each Friday as a result of a week of water being discharged from an upstream reservoir, Smith Mountain Lake. Water from Leesville is pumped back into the upper reservoir on weekends to be recycled again the following week for peaking power purposes. Due to the pumping, the water level of Leesville is lowered 8 to 10 feet over the weekend. Since the water is released from Leesville through gates at the top of the dam, the elevation of the reservoir has an effect on the temperature of the water being released, as the reservoir has a shallow thermocline. It was found that the temperature of the water being released may change 2^{o} to 4^{o} C from Friday to Monday. It is known that striped bass are sensitive to small temperature changes during their spawning run, thus the changes in water levels in Leesville may have affected the spawning of striped bass downstream.

There are many problems associated with changes in water levels in reservoirs; however, the use of water-level fluctuations for enhancing the usefulness of reservoirs is promising. Biologists need to conduct additional studies on water-level changes in order that this technique in reservoir fishery management might become a more useful tool. Better communications between the biologists and engineers is also sometimes needed. Optimum use for all users can be approached only when fishery management and reservoir management become integrated.

LITERATURE CITED

Jackson, S. W., Jr., 1958, *Comparison of the age and growth of four fishes from lower and upper Spavinaw Lakes, Oklahoma*. S. E. Assoc. Game and Fish Comm. Proc., 11:232-249

Kimsey, J. B., 1957, *Fisheries problems in impounded waters of California and the Lower Colorado River*. Trans. Am. Fish. Soc. 87:319-332

Parsons, J. W., 1957, *Fishery management problems and possibilities on large southeastern reservoirs*. Trans. Am. Fish. Soc. 87:333-355

Patriarche, M. H., 1952, *The fishery in Lake Wappapello, a flood control reservoir on the St. Francis River, Missouri*. Trans. Am. Fish. Soc. 82:242-254

Pollock, C. W., 1965, *A Study of the young-of-the-year largemouth and smallmouth bass in Dale Hollow Reservoir, Tenn*. M. S. Thesis. Tenn. Tech. Univ. 42 p

Rosebery, D. A., 1950, *Game fisheries investigations of Claytor Lake. A main stream impoundment of New River, Pulaski County, Virginia, with emphasis on Micropterus punctulatus (Rafinesque)*. Ph.D. Thesis. V.P.I. Blacksburg, Va., 268 p

Wood, R. and D. W. Pfitzer, 1960, *Some effects of water-level fluctuations on the fisheries of large impoundments*. Internat. Union Cons. Nature & Natural Resources. Theme I (4):118-138

Estes, R. D., 1971, *The effects of the Smith Mountain pump storage project on the fishery of the lower reservoir, Leesville, Virginia*. Ph.D. dissertation V.P.I., Blacksburg, Va., 151 p

Hoffman, Dale A. and Al R. Jonez, 1971, *Lake Mead, U.S.A.* Presented at Symposium on Manmade Lakes, May 1971. Knoxville, Tenn., 45 p Mimeographed

Martin, N. V., 1955, *The effect of draw-down on lake trout reproduction and the use of artificial spawning beds*. Trans. 20th N. A. Wildlife Conf. 263-271 pp

Miller, R. B. and M. J. Paetz, 1959, *The effects of power, irrigation, and stock water developments of the fisheries of the south Saskatchewan River*. Canadian Fish Culturist. 25:13-26

Benson, Norman C., 1968, *Some effects of water management on biological production in Missouri River mainstream reservoirs*. Presented at Am. Soc. Civil Engineers Specialty Conf., Jan. 1968, Portland, Oregon. 17 p Mimeographed

Mraz, Donald, 1968, *Recruitment, growth exploitation and management of walleye in a southeastern Wisconsin lake*. Dept. of Natl. Resources, Tech. Bull. No. 40, Madison, Wisconsin, 38 pp

U.S. Dept. of the Interior, 1970, *Progress in Sport Fishery Research 1969*. Div. of Fishery Research, B.S.F. & W., Resource Publication 88, 288 p, U.S.G.P.O. Wash., D.C.

Cowell, Bruce C. and P. L. Hudson, 1968, *Some environmental factors influencing benthos invertebrates in two Missouri River reservoirs*. Proc. Reservoir Fishery Resources Symposium, Univ. of Ga. 541-555 pp

Rawson, D. S., 1948, *Indices to lake productivity and their significance in predicting conditions in reservoirs and lakes with disturbed water levels*. 27-42 pp in The Investigation of Fish-Power Problems. Univ. of British Columbia, Vancouver.

MANAGEMENT OF WASTE MATERIAL FROM McCLUSKY CANAL FOR ENVIRONMENTAL ENHANCEMENT

Theodore E. Mann, Project Manager
Missouri-Souris Projects Office
Bureau of Reclamation
Bismarck, North Dakota 58501

McClusky Canal is the major artery of the Principal Supply Works for the Garrison Diversion Unit which is part of the Pick-Sloan Missouri Basin Program. The Garrison Diversion Unit is a multipurpose development that will ultimately irrigate a million acres of land in North Dakota. The initial stage development, authorized in August 1965, and now underway, will furnish irrigation water for 250,000 acres of land in central North Dakota, municipal and industrial water for 14 towns and cities, recreation development for five major water impoundments, and water for fish and wildlife developments in 36 major areas and a number of small ones. About 60 percent of the waterfowl habitats to be developed in new areas will be due to losses caused by construction of the unit. The remaining percent will represent an enhancement. An additional 200 cfs capacity is provided in the McClusky Canal to deliver water to fish and wildlife areas during periods of critical water supply and extreme drought.

Approximately 871,000 acre-feet of water will be diverted annually for the initial development from Lake Sakakawea (Garrison Reservoir). This is the Corps of Engineers 23 million acre-foot-capacity impoundment created by Garrison Dam on the Missouri River about 55 miles north of Bismarck, North Dakota. A three-unit 2,050-cfs-capacity pumping plant will lift water from Lake Sakakawea through an embankment to the 430,000 acre-foot-capacity regulating reservoir called Audubon Lake (Snake Creek Reservoir). From this lake, water will flow by gravity through the 74-mile long McClusky Canal to a second regulating reservoir (Lonetree) of 410,000 acre-foot capacity set on a high point that drains into three river systems (Souris, Cheyenne, and James). Two major canals lead from the second regulating reservoir to a system of canals, laterals, and pumping plants for serving water to the lands to be irrigated.

At present three major contracts are active for construction of portions of the principal supply works. The first of this group was awarded July 1, 1968, for a bid of about $7.4 million to build the Snake Creek Pumping Plant. In March 1970, a contract for nearly $8.0 million was awarded for the first reach (3A) of McClusky Canal, a 15.4-mile long section and on June 17, 1970, a second contract was awarded for about $2.9 million for the second reach (3C) of the canal, some 2.4 miles long. Additional reaches of the canal will be awarded in a scheduled sequence.

Over the many years of planning for the Garrison Diversion Unit, some 30 studies were made to determine the most economical method of moving water from Lake Sakakawea to the Lonetree Reservoir, a straight line distance of about 35 miles. These plans consisted of various combinations of pumping plants, relift plants, tunnels, and canals; but none was cheaper to construct and maintain than the present plan. The present canal line follows old marshy glacial melt water channels but has to cross a low divide with a cut up to 110 feet deep to get from the Missouri River to the Lonetree Reservoir site. Crossing this barrier has been one deterrent of plans made even before 1900 to transport water from the Missouri River to large areas of irrigable land in North Dakota.

The present route of the McClusky Canal was accepted as the most practical in 1956. At that time it was recognized that the 55 million cubic yards of excavation required for the route, of which 80 percent would be wasted, would be a major undertaking. Also the route would require initially enough right-of-way to allow for depositing waste when the canal would be enlarged to furnish water for the ultimate million acre development. A right-of-way width in excess of 2,000 feet was found necessary in some areas to allow for proper waste deposition.

In normal small canal excavation, waste is deposited on each bank at approximate right angles to the point where the material is being removed. This method was not practical on the McClusky Canal especially in the deep cut areas because of the chance of creating slope instability and drainage problems and most important the later difficulties of dressing, draining, and maintaining the unsightly and very undulating ridges of waste that would upset the natural environment.

Soon after the project was authorized in 1965, studies were started to determine a system of waste disposal that would modify or eliminate the above problems. Criteria were established for seeding and the disposal of waste that would return the areas flanking the canal to near natural conditions, develop a native wildlife habitat equal to or better than previously sustained, and provide mitigation for any ecological damage to the area.

Waste disposal banks were designed to have a maximum longitudinal slope of 6 percent, a transverse slope of 2 percent away from the canal, and a bank height in accordance with the stability of the canal side slope materials (Figures No. 1, 2, and 3). Flat slopes were used to prevent serious erosion, allow for maintenance when necessary, and to present a more pleasing appearance. Waste bank width to depth was set at a ratio of 6:1 which governed until a waste bank depth of 30 feet was attained. When this depth was reached the depth was then the governing factor with a normal maximum of 30 feet and in isolated cases a depth of 50 feet was allowable. Canal bank stability was a major factor in determining the distance to set the waste banks back from the canal excavation and the disposal depth. Detailed laboratory analyses of the materials to be excavated were made from core samples removed in the geological study of the canal route. The analysis provided information as to slope stability for different degrees of slope, types of material, and moisture conditions. Many points along the deep cut section of the canal were studied by use of a computer program to determine the most economical cut slope. This study would probably not have been feasible employing conventional manual methods, since it involves complex mathematical relationships with repetitive solutions, and a large computer system. It was determined that cut slopes of 2:1 (2 feet horizontal to 1 foot vertical) would be stable under most conditions with the most critical time occuring during the initial excavation and before stable drainage conditions had been attained.

Initial stage waste banks are designed to accommodate the ultimate widening and deepening of the canal. Ultimate stage waste which will be about one-third of the initial waste will be deposited on top of the initial waste banks. Stability is not expected to be a problem at that time since the canal banks will have had several years to drain and season.

The large amount of computations required to balance excavation and waste bank disposal and stay within the longitudinal free haul distance of 1,000 feet dictated the use of a computer. With the aforementioned criteria in mind a computer program was developed that would accommodate all of these parameters. Actually, a total of 10 computer programs are used in obtaining the total required information. Items that are computed include quantities of excavation, embankment, compacted embankment, scarification, stripping, lining, and all of the coordinates associated with these terms that are required to define them. To be able to better visualize what the final designed feature will look like the computer is used to plot the cross sections and catchpoints.

On future studies of canal routes we hope to employ a technique that is being developed at the present time for highway route studies. This technique involves the use of a cathode ray tube (CRT) which is interfaced with the computer. To use the technique one superimposes the designed canal section on the terrain cross section at a given point. This plotting is then projected on the CRT with only the final, as constructed, lines showing. A movie is made of each of the sections as they are projected on the CRT as one moves along the canal route. The effect of seeing the several sections on the screen is that one is traveling down the completed canal. This should result in a more pleasing appearance of the final canal route since such previewing should eliminate abrupt changes, irregularities, and poor waste distribution, and the chance to make changes for a review before construction.

Preparation of the waste banks and the canal cut slopes to receive seeding is part of the canal construction contract provisions. Topsoil from the canal excavation, and if necessary from waste bank areas, is required to be stripped before excavation starts and to be stockpiled for later spreading on the waste banks and canal slopes. After the waste banks and canal slopes are dressed to final grade and section, topsoil is spread and compacted by rolling to a depth of 6 inches normal to the slopes and 3 inches on surfaces that are nearly horizontal.

Contacts were made with the Soil Conservation Service, Bureau of Land Management, Bureau of Sport Fisheries and Wildlife, Agricultural Experiment Station, and other State agencies to obtain the best information for returning the canal area to near natural conditions. Requirements for seedbed preparation, seeds, sowing, fertilizing, and mulching were developed from these contacts and made a basis of the specification provisions.

Reach 3A of McClusky Canal which is 15.4 miles long will require over 15 million cubic yards of

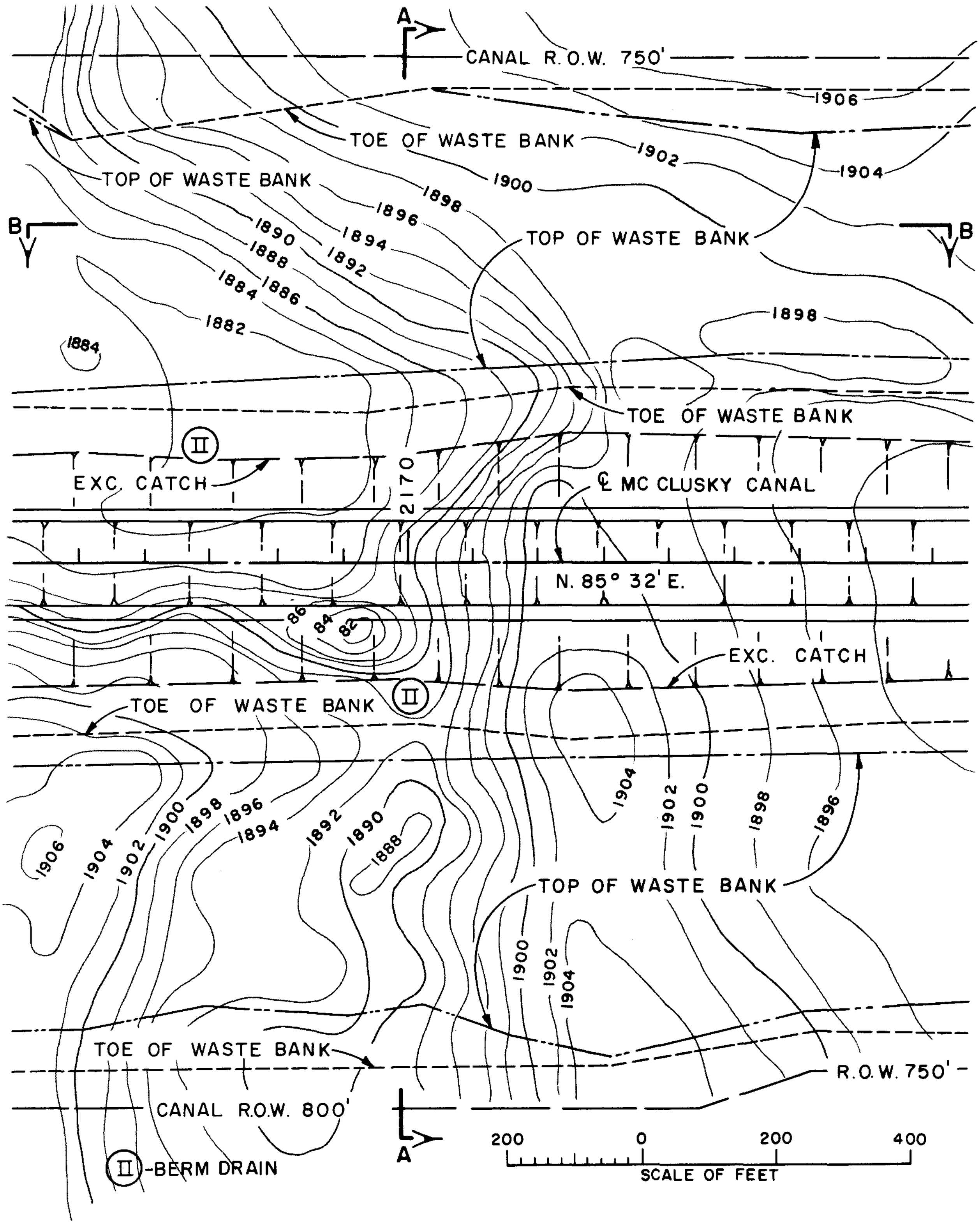


Figure 1. Plan in vicinity of Sta. 21-70+00, McClusky Canal, Garrison Division, Garrison Diversion Unit, North Dakota.

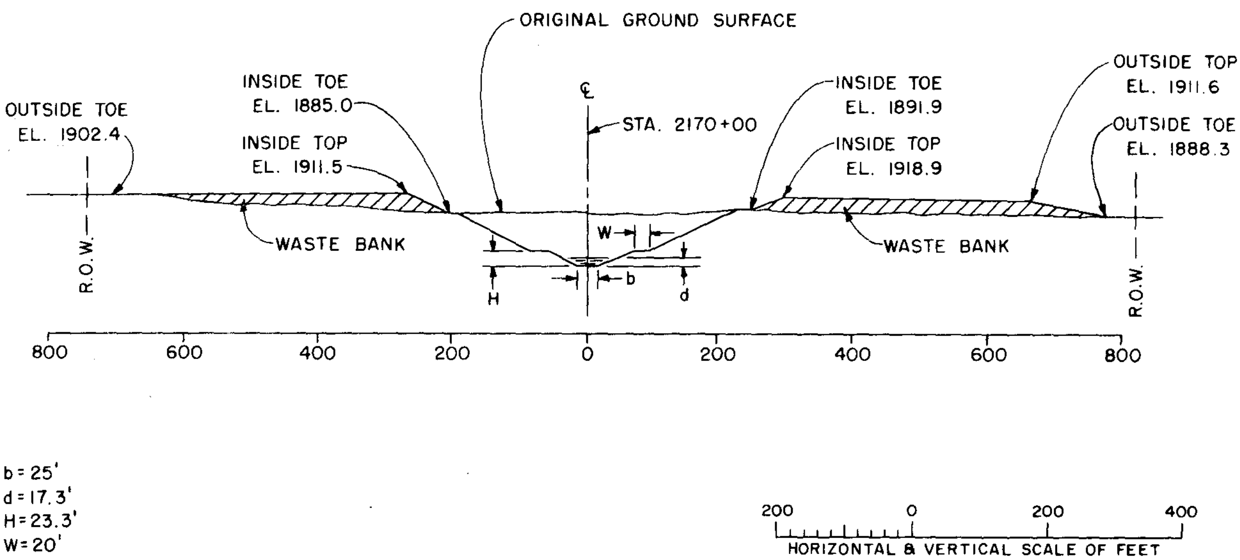


Figure 2. Cross Section A-A, Sta. 2170+00, McClusky Canal, Garrison Division, Garrison Diversion Unit, North Dakota.

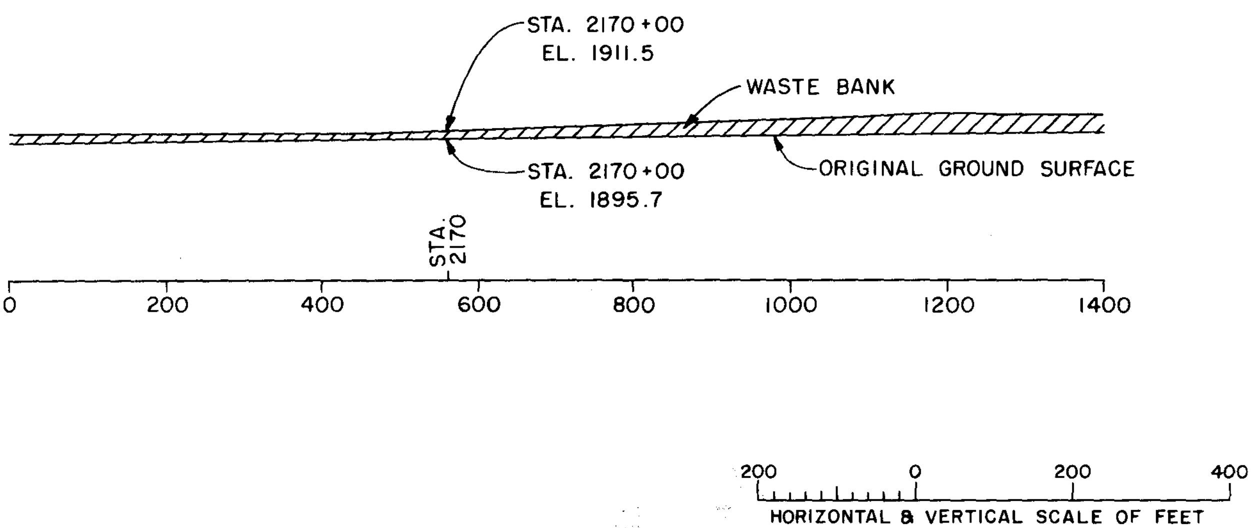


Figure 3. Longitudinal Section B-B of waste bank, vicinity of Sta. 2170+00, left side, McClusky Canal, Garrison Division, Garrision Diversion Unit, North Dakota.

excavation. Covering of waste and excavated areas is estimated to require about 640,000 cubic yards of topsoil which will result in about 1,400 acres being seeded. Various methods for sowing seed are provided for depending on the slopes, accessibility, and site conditions. These methods are drilling, hydroseeding, and broadcast by mechanical or hand methods.

Seed requirements for 1 acre are as follows:

Kind of seed	Pounds per live seed per acre
Green needlegrass	5
Little bluestem	1
Side oats grama	2
Western wheatgrass	5
Slender wheatgrass	5
Nurse crop (wheat, oats, or barley)	1/2 bushel

Fertilizer requirements per acre are 30 pounds of actual nitrogen and 50 pounds of actual phosphorus which may be applied before or partly during seeding operations. After seeding a minimum of 2 tons of hay or straw mulch is required to be placed and anchored by use of a mulch treater that will penetrate to a depth of 3 to 4 inches in a 6- to 12-inch grid.

Bid items were contained in the specifications for placing, spreading, and rolling topsoil for seed bedding and for seeding. These bid items along with requirement for stripping and stockpiling topsoil amount to $374 an acre for the contract on Reach 3A and $440 an acre on Reach 3C. These values extended for the total acreage to be seeded will amount to about $523,000 for Reach 3A and $206,000 for Reach 3C.

It is expected that the seeding of the waste areas along the McClusky Canal will restore the right-of-way to near natural conditions and develop a strip that will provide an excellent wildlife habitat. Plans are now being considered to plant trees and brush in selected areas where they will not interfere with canal operation.

When the McClusky Canal is completed it is expected that this 74-mile-long strip will develop into a parkway representing native conditions in North Dakota.

THE EFFECTS OF HIGHWAY CONSTRUCTION ON FISH HABITAT IN THE WEBER RIVER, NEAR HENEFER, UTAH

James R. Barton
Department of Civil Engineering
David A. White, Parley V. Winger, Edward J. Peters
Department of Zoology
Brigham Young University
Provo, Utah

INTRODUCTION

The growing need for land in the United States has resulted in a number of conflicts of interest. In the western United States, one of these conflicts has arisen between highway construction and sport fishing. Since much western fishing is stream fishing and the valleys worn by these streams make good road beds, it was inevitable that problems would arise.

Highway construction can be detrimental to a river in several ways; namely,

1. Shortening the channel length by straightening a meandering channel.
2. Removing cover necessary for the fish.
3. Exposing the channel to erosion which may increase the turbidity of the stream, which in turn may harm aquatic life.
4. Affecting the aesthetic qualities of the river.

The present study was designed to evaluate the influence of highway construction on the Weber River in northern Utah. Data on invertebrates, fishes, and hydrology were gathered to compare areas changed by highway construction with those that were not changed by this construction work. Eight study reaches were established, four in areas that were not to be changed and four in changed areas (Figure 1).

Objectives. The main objectives of this study are the following:

1. To study the effects of the channel changes on the fish and invertebrate populations of the river.
2. To evaluate the hydraulic effectiveness of the various structures in creating a good fish habitat.
3. To compare the various types of structures used and make recommendations on their relative effectiveness.
4. To develop concepts that can be used in designing future projects where river channel changes are needed.

METHODS

Hydraulic features of the river such as profiles, slope, sinuousity, and discharge were measured from June 1968 to December 1970. Aerial photographs were used as a means of determining changes in the river since 1938. Flow records of the discharge from Echo reservoir were obtained from the USGS water supply means.

Invertebrate populations were measured using a circular quarter meter squared bottom sampler. Samples were collected once a month from August 1968 to December 1969. Samples were collected from two unchanged sections and two changed sections.

Fish populations in the Weber river were almost impossible to sample by conventional fish-shocking techniques such as wading. Because of the need to sample fish in all habitats a method of shocking from a boat controlled by ropes from the shore was devised (Figure 2). Because of the mobility of the fish populations about 5 miles of the river consisting of equal areas of changed and unchanged portions of the river were shocked. Data from two shockings are included in this paper.

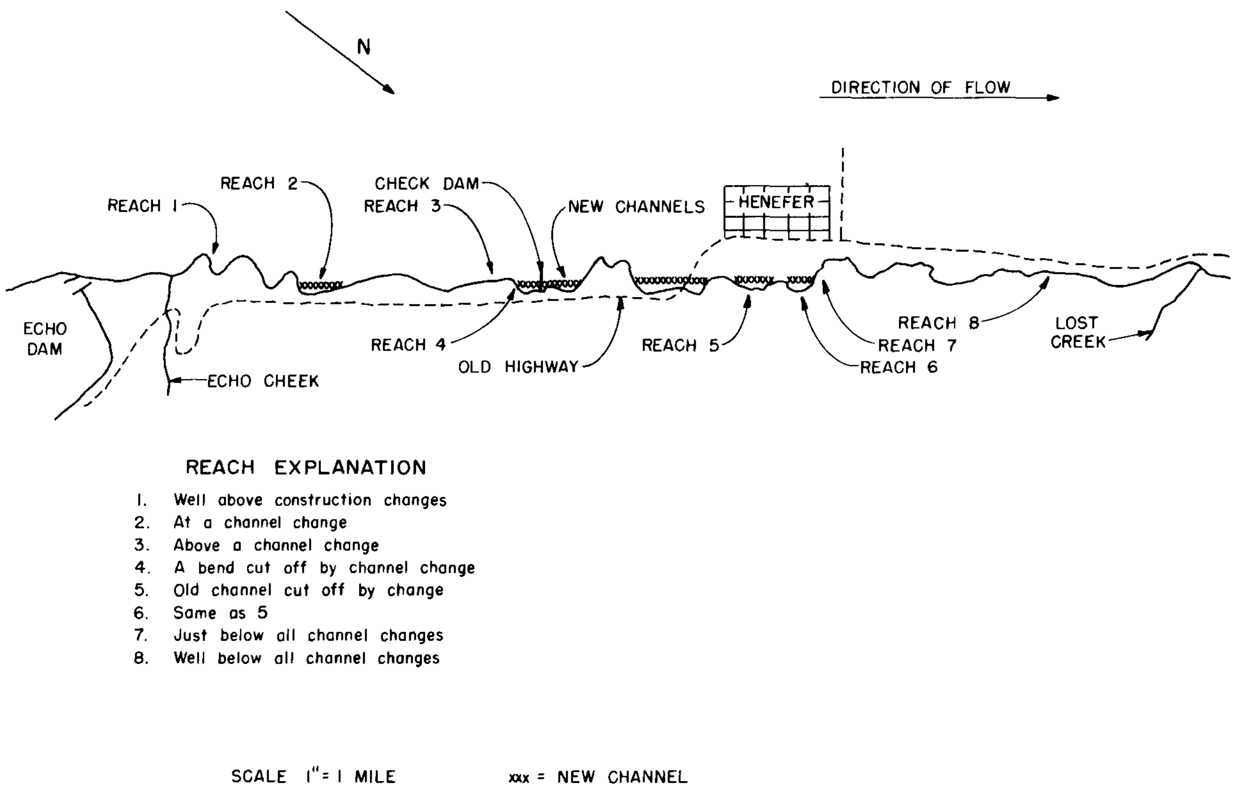


Figure 1. Map of Weber River showing study reaches, Weber River Study.

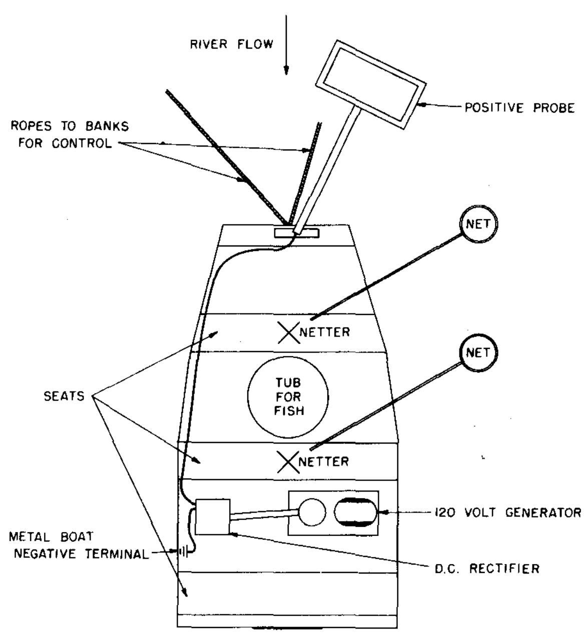


Figure 2. Diagram of boat and equipment used in the electrofishing.

Invertebrate and fish-collecting stations were compared by means of the ordination technique proposed by Bray and Curtis (1957). No attempt was made to compare with the past biology of the river but, sections that were not changed by the present construction were used as control areas.

RESULTS AND DISCUSSION

Since 1938, the river has undergone a number of channel changes which have slowly shortened the length of the channel. These changes were determined from a study of the aerial photographs taken of this area in 1938, 1952, 1967.

There has been a decrease in length of 0.8 miles during the last 30 years of which 0.44 miles was due to the present highway construction. The overall slope changed from 0.00356 to 0.00391. Over this same period, vegetative cover was reduced by about 60 percent. This loss was mainly the result of agricultural uses.

The alinement of the new freeway in the Henefer Valley required five channel changes as shown in Figure 1. The changes consisted of building five straight sections of channel varying in length from 900 feet to 2,400 feet. The new channel had a bottom width of 70 feet and side slopes of 45^{o} with the horizontal. Thirty-eight wire gabion deflectors and seven wire gabion check dams were built into the lower three sections (See Figures 3 and 4). The wire gabion structures consisted of heavy wire mesh cages placed in a trench excavated into the bottom of the channel so that the top of the gabion extended about 9 to 18 inches above the floor of the channel. The cages were then filled with rocks varying between about 2 and 6 inches in diameter. A wire mesh cover was placed on top of the cages and wired closed. The top of the gabion was about 3 feet wide and the structures were placed as shown in Figures 3 and 4. In addition to the gabion structures, rocks weighing from 1,500 to 4,000 pounds were placed at random in the channel with the structures. The rocks were placed downstream and behind some of the structures while a few were placed in the main stream of the current.

In the two upper changed sections, one located just below Study Reach 4 and the other at Study Reach 2, the structures were built of large riprap rock instead of the wire gabion types. One of the structures in Reach 4 was a concrete diversion dam shown as the check dam of Figure 1. Below the concrete check dam, one section was filled with large boulders varying from about 1 to 3 tons. Forty boulders were placed at random in about 500 feet of the channel. Below the random rocks, three rock check dams were placed at 200-foot intervals. Below the check dams, three rock deflectors were placed at 45^{o} to the channel sides with a spacing of 200 feet between them. The riprap protecting the sides was not placed in the upper changed section during the first year. After a rather high spring runoff it had eroded to a width of about 100 feet and so the sides were finally stabilized at the 100-foot width instead of the 70-foot width. In the changed channel at Reach 2, six rock deflector structures were built but access problems have made it impossible to evaluate this section. Alterations in the five changed sections of channel provided a rather wide variety of structure and channel width combinations and the resulting habitat represents a rather wide range of habitat conditions.

Vegetation was removed along the rechanneled areas. New vegetation was planted which consisted of a row of Russian olive and broad-leafed cottonwood trees planted 30 feet apart and 10 feet back from the edge of the bank. It will be several years before the effectiveness of the revegetation program can be evaluated.

After 1 year of operation, the new channels had developed slopes and profiles as shown in Figures 3 and 4. The slope and the profile was measured along the thalweg which is the main path of thread of the current of the stream as it flows. These figures also show that holes were above and below each check dam and near the end of most of the deflectors.

The failure of some of the deflectors was due to improper placement and spacing which resulted in their sedimentation.

The structures built of riprap in the upper changed section near the concrete check dam were effective in creating holes. The three check dams in series produced good habitat because the uneven flow through the large rocks was effective in cutting good holes. The riprap structures were less expensive than the wire gabions. Therefore, when good riprap material is available, it would seem wise from an economic viewpoint that consideration should be given to building the structures with large riprap material.

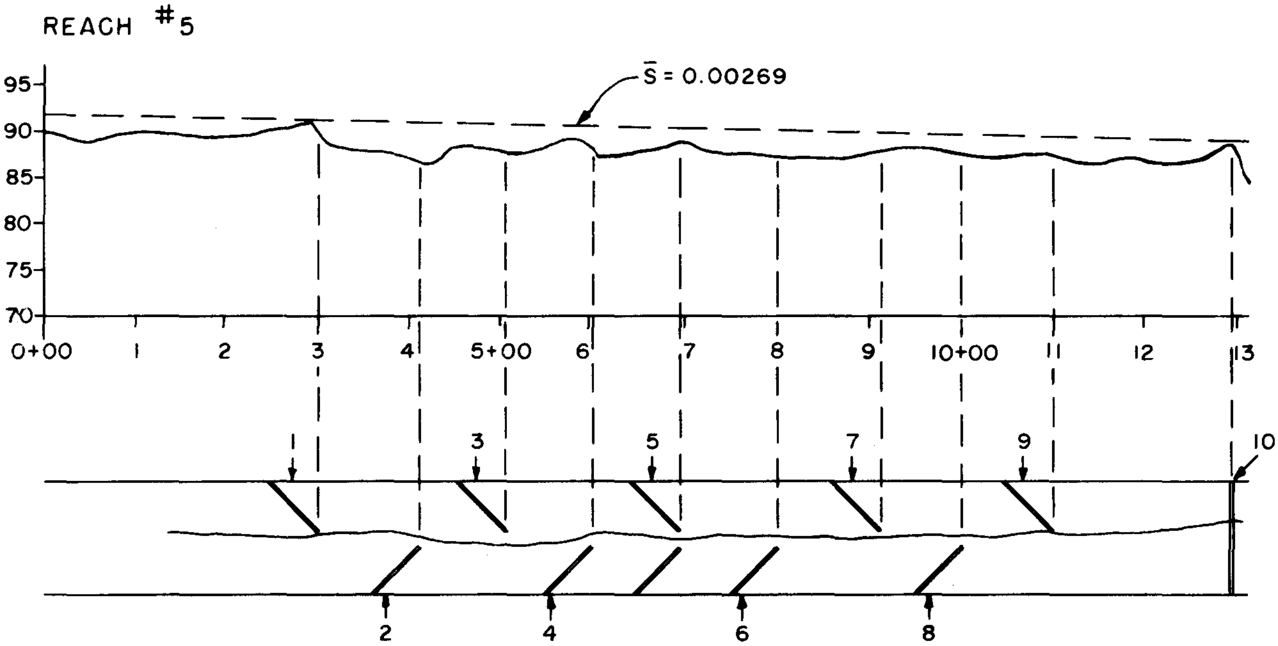
Random boulders which were placed on the downstream side of delfectors were not effective. They were in zones of low velocity and so there was no scour around them to form a good hole. The large rocks which were placed out in the faster water did a fairly good job of producing some good holes.

About 90 different species of macroinvertebrates have been identified from the Weber River but only about 12 were commonly taken in the bottom samples (Table 1). The invertebrate population of the newly constructed areas and undisturbed areas showed no difference in species composition. The differences in the percent occurrence in the changed and unchanged

Table 1

List of the organisms commonly taken in the bottom samples on the Weber River in the changed and unchanged sections. The percentages represent the percentage of all the samples taken in which that particular organism was found.

Organism	Unchanged (percent)	Changed (percent)
Ephemoroptera		
Baetis spp.	100	86
Ephemerella spp.	90	91
Heptagenia spp.	48	85
Paraleptophlebia sp.	33	51
Tricorythodes sp.	16	31
Plecoptera		
Isoperla sp.	79	77
Trichoptera		
Hydropsyche spp.	100	91
Hydroptilidae	84	69
Diptera		
Chironomidae	99	91
Simuliidae	64	64
Rhagionidae	33	9
Tipulidae	26	23



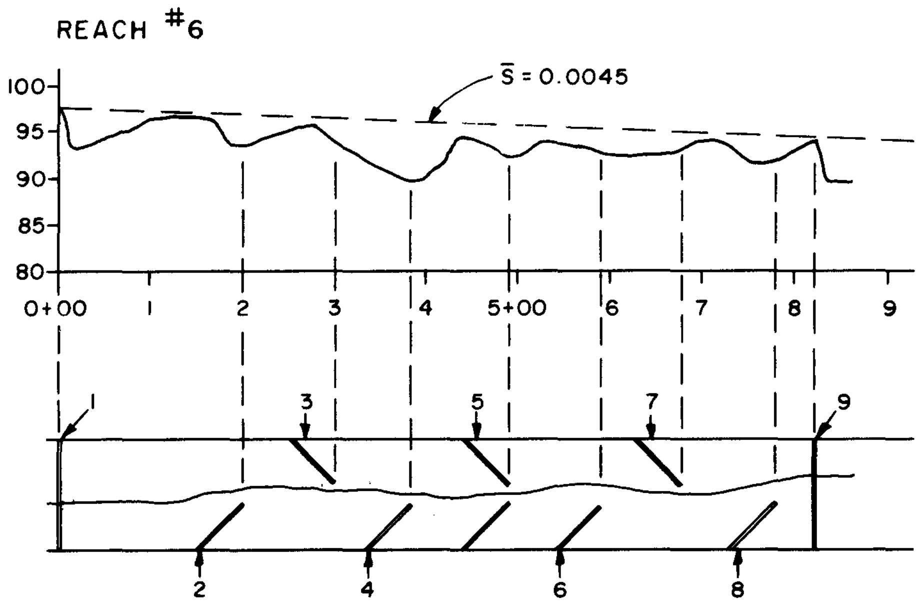


Figure 3. Thalweg plan and profile, Weber River—November 1, 1969.

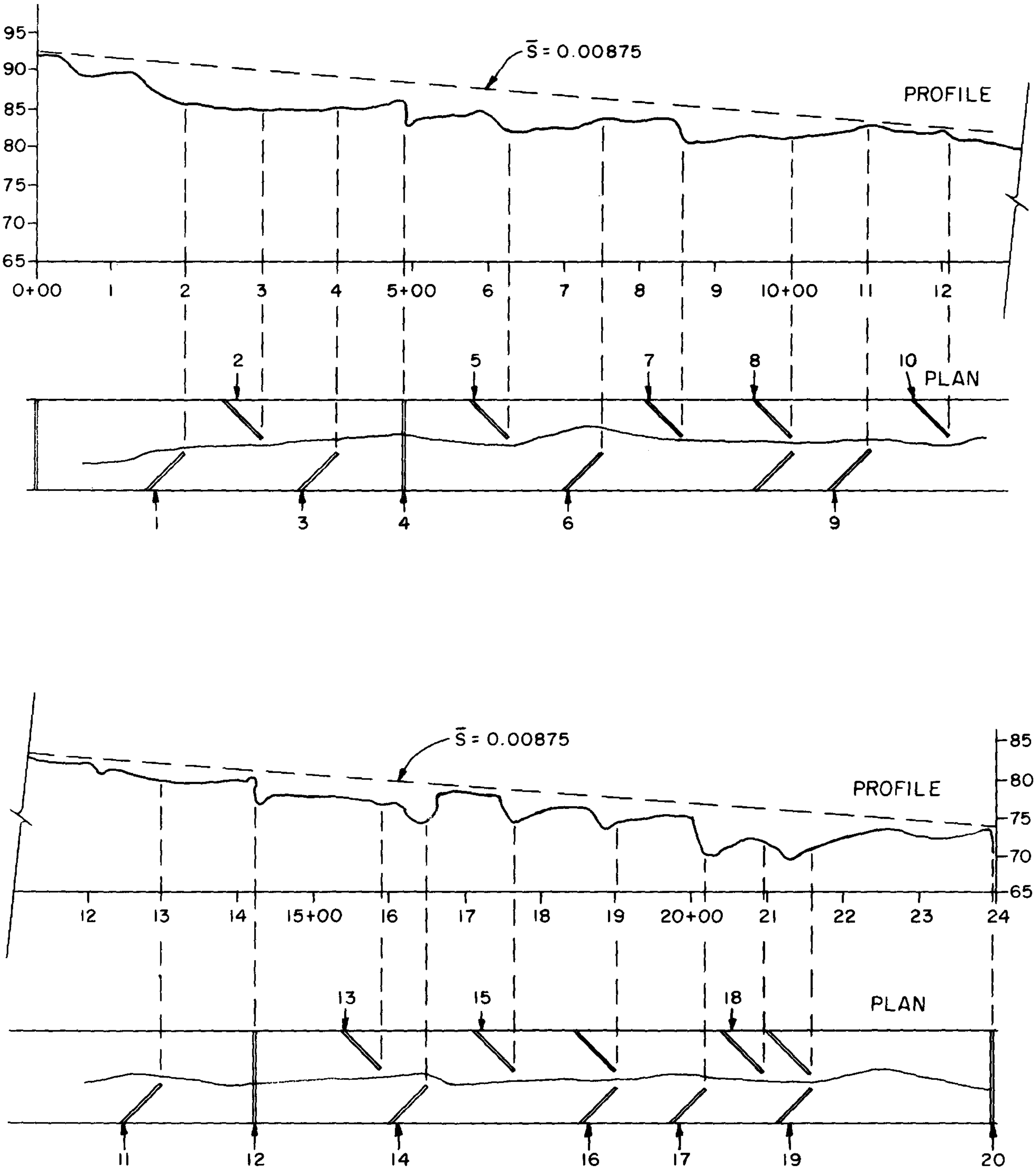


Figure 4. Thalweg plan and profile, Weber River.

areas by some of the different organisms can be explained by differences in their movement into an area. The organisms which had a lower percent in the changed than the unchanged area are not found in the drift as often and tend to invade an area more slowly than the organisms that are commonly found in the drift. Colonization of new or denuded areas is mainly via the drift which is movement of the organisms downstream in the free water phase of the stream.

The numbers and weights (wet) of organisms in the changed and unchanged portions of the stream follow each other rather closely except during periods immediately following rechannelling which occurred in November and December of 1968 (Figures 5 and 6). The invertebrate populations in the changed areas established themselves in comparable levels with the unchanged areas within 6 months.

The ordination comparison of the changed versus the unchanged areas shows that no distinct difference exists between them (Figure 7). The scattering of the changed and unchanged points indicates that the changed and unchanged sections of the river are similar in species numbers, weight, and composition. The values used on the ordinates of the graph are relative only to each other and have no known significance except to separate one sampling unit from another.

Thirteen species of fish have been collected from the Weber River (Table 2), but only the seven species listed in Table 3 were captured regularly and efficiently enough to provide reliable information on their distribution and abundance.

Since Mountain whitefish made up 67 percent of the total population by number and 62 percent by weight the Weber can be rather adequately described as a Mountain whitefish stream. If we include Mountain whitefish as game fish, 85 percent of the fish in the river are of a game species.

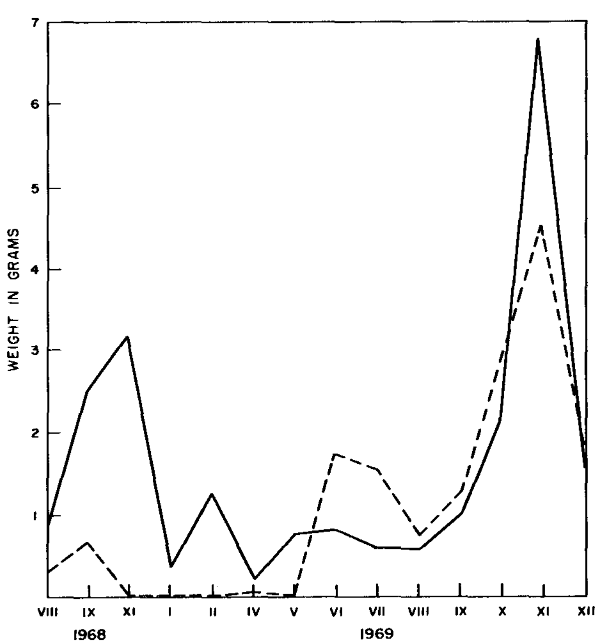


Figure 5. Total weight of the invertebrates collected in a quarter meter squared bottom sample from changed (----) and unchanged (———) sections of the Weber River, Summit County, Utah.

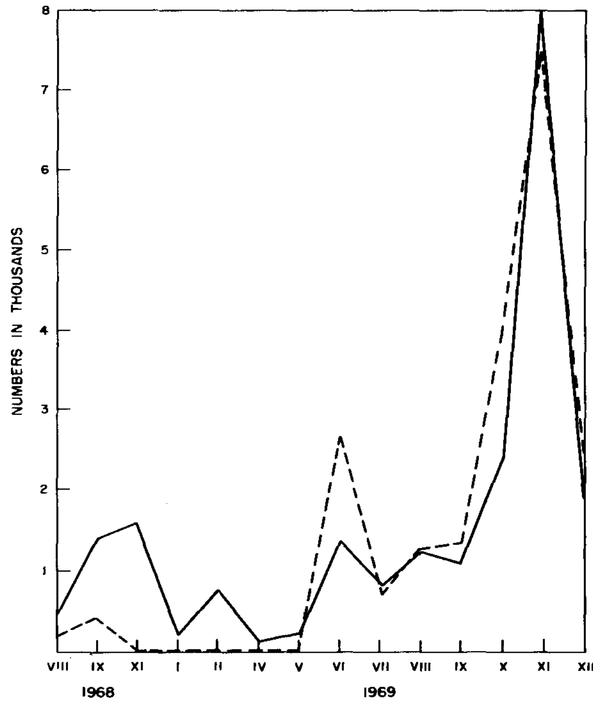


Figure 6. Total numbers of organisms collected in a quarter of meter squared bottom sample from changed (----) and unchanged (———) sections of the Weber River, Summit County, Utah.

A comparison of fish populations in changed and unchanged portions of the river showed no significant decrease in populations per acre in the altered channels (Table 3). Table 3 also shows that the average composition of the population in the changed areas was as good if not better than in the unchanged area. From this it appears that the structures are creating hydrologic conditions that can produce suitable habitat for game fish. It also seems evident that the altered channel sections in the Weber River can be manipulated to support standing crops of game fish equal to that of unaltered sections. However, it must be remembered that the present alterations shortened the river 0.44 miles with a resultant loss of 4.2 acres of fish habitat. This amount of area could have supported an additional 1,170 game fish weighing 1,017 pounds.

Analysis of the ordination diagram (Figure 8) revealed that all stations which had a game fish: rough fish ratio of less than 50 percent were located to the left of the 5 on the X axis. This seems to indicate that the habitat in these areas is better suited to suckers and carp than to game fish species such as trout and whitefish. This indicates that at these locations, conditions prevail that we should not strive for if we are modifying the stream for better trout or whitefish

Table 3

Percent of numbers, estimates of populations, percent of weight, and estimates of standing crops by species for changed and unchanged areas of the Weber River, Utah, fall 1970.

Changed Areas

Species	Percent of population	Population estimate	Percent of total weight	Estimated standing crop/acre
Whitefish	69.33	261.25	65.52	218.13
Cutthroat trout	10.11	38.10	8.59	28.66
Rainbow trout	8.69	32.75	8.59	28.66
Brown trout	0.19	0.72	0.12	0.40
Utah sucker	3.12	11.76	5.92	17.66
Chislemouth sucker	8.46	31.88	10.91	36.40
Carp	0.42	1.58	0.94	3.14

Unchanged areas

Species	Percent of population	Population estimate	Percent of total weight	Estimated standing crop/acre
Whitefish	66.15	217.77	57.83	192.76
Cutthroat trout	7.99	26.20	6.19	20.63
Rainbow trout	10.34	34.33	8.43	28.10
Brown trout	0.23	0.76	0.25	0.83
Utah sucker	5.06	16.65	8.99	29.97
Chislemouth sucker	8.10	26.66	10.94	36.47
Carp	2.05	6.75	7.37	24.59

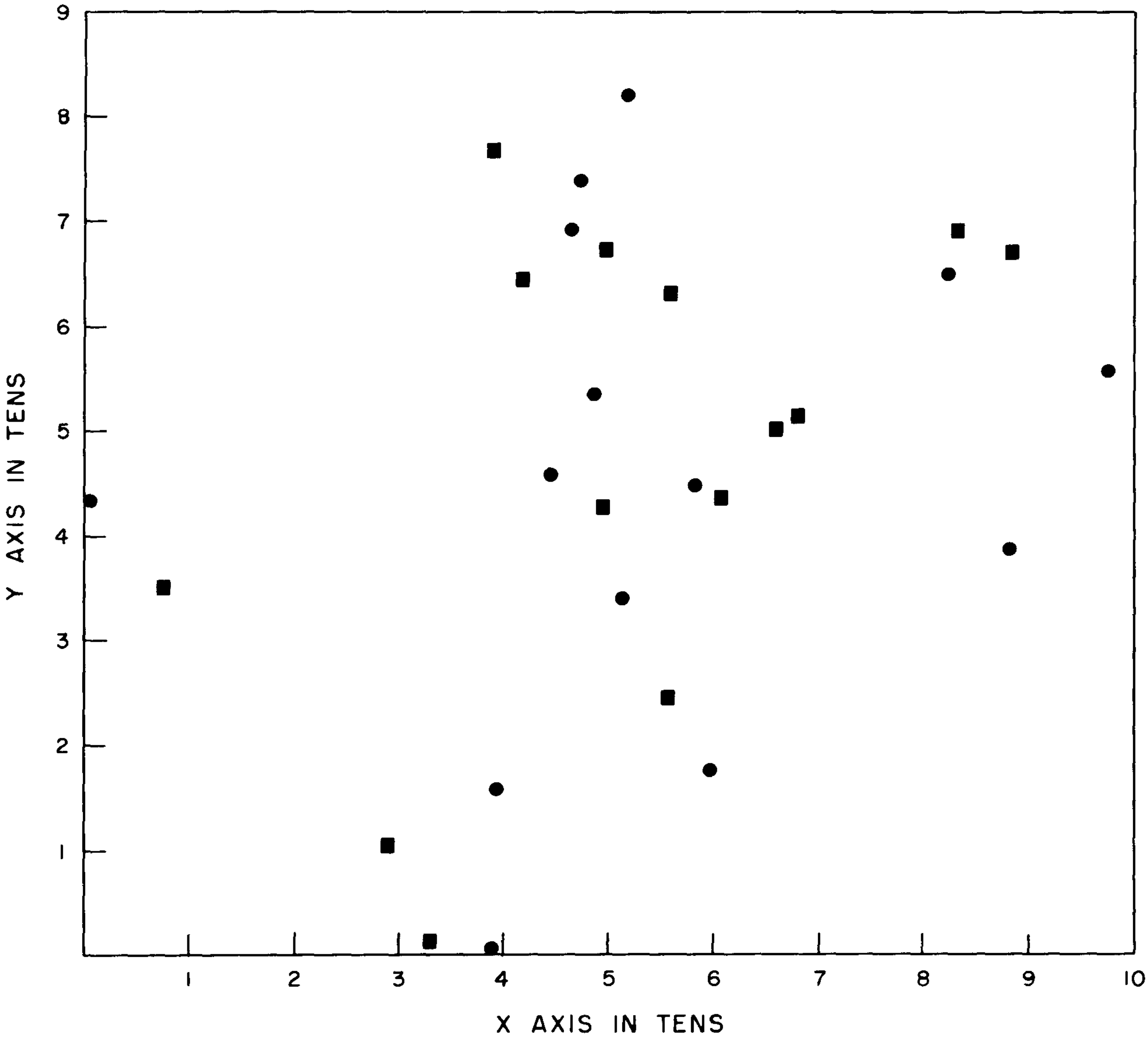


Figure 7. Ordination points showing similarity and dissimilarity of changed (●) and unchanged (■) sections of the Weber River during different months of the year. (Based on invertebrate data.)

Table 2

A list of the species of fish found in the Weber River between Echo Dam and Devil's Slide, Utah, (1967-1971) (*Bailey, et al. 1960) (**Smith, 1966).

Scientific name	Common name*
Salmonidae:	
Prosopium williamsoni (Girard)	Mountain whitefish
Salmo clarki Richardson	Cutthroat trout
Salmo gairdneri Richardson	Rainbow trout
Salmo trutta Linnaeus	Brown trout
Cyprinidae:	
Cyprinus carpio Linnaeus	Carp
Gila atraria (Girard)	Utah chub
Rhinichthys cataracta (Valenciennes)	Longnose dace
Rhinichthys osculus (Girard)	Speckled dace
Richardsonious balteatus (Richardson)	Redside shiner
Catostomidae:	
Catostomus ardens Jordan and Gilbert	Utah sucker
Catostomus (Pantosteus) discobolus (Cope)**	Green sucker
Catostomus (Pantosteus) platyrhynchus (Cope)**	Mountain sucker
Cottidae:	
Cottus bairdi (Girard)	Mottled sculpin

production. On the other hand, points in the ordination located to the right of 5 on the X axis have fish populations which are predominately made up of game fish species. The Y axis separated the location with high trout nontrout ratios from those with lower trout nontrout ratios. The highest trout nontrout ratios are found low on the Y axis and the low trout nontrout ratios are the higher values on this axis. However, each station with a good composition of game fish does not necessarily have the same standing crop per acre. Of all the locations where fish were tagged during the fall of 1970, location No. 439 (Table 4) had the best combination of species composition and standing crop of any section of the river. Location No. 439 had a total standing crop of 2,527 pounds of fish per acre which was composed o: 67 percent whitefish, 27 percent cutthroats, and 6 percent rainbow.

Research now in process has been designed to characterize the physical perimeters of the specific areas which have indicated their ability to produce good standing crops of desirable fish species. This should lead to better ecological descriptions of species requirements. It will also help us predict where to place structures to get them to do the best job under the existing hydrologic conditions.

CONCLUSIONS

1. The results of this study indicate that the structures built into changed channels of the Weber River have been effective in producing fish habitat that is comparable to, if not better than, the habitat of the unchanged sections.
2. Deflector structures placed in the backwater area of a check dam and on the inside of a bend in the river will not be effective in producing good habitat.
3. The decrease in the length of the river is one of the disadvantages of channelization. Where feasible, consideration should be given to maintaining the overall length of a stream.
4. Structures made of large riprap material are often more economical and they produce good fish habitat.
5. Invertebrates colonized the new river bottom and produced equivalent numbers and species after 6 months.
6. Fish populations were essentially equal in changed and unchanged areas 2 years after the construction.
7. More work needs to be done to establish the best combination or system of structures which will create a good habitat over a given length of river channel.

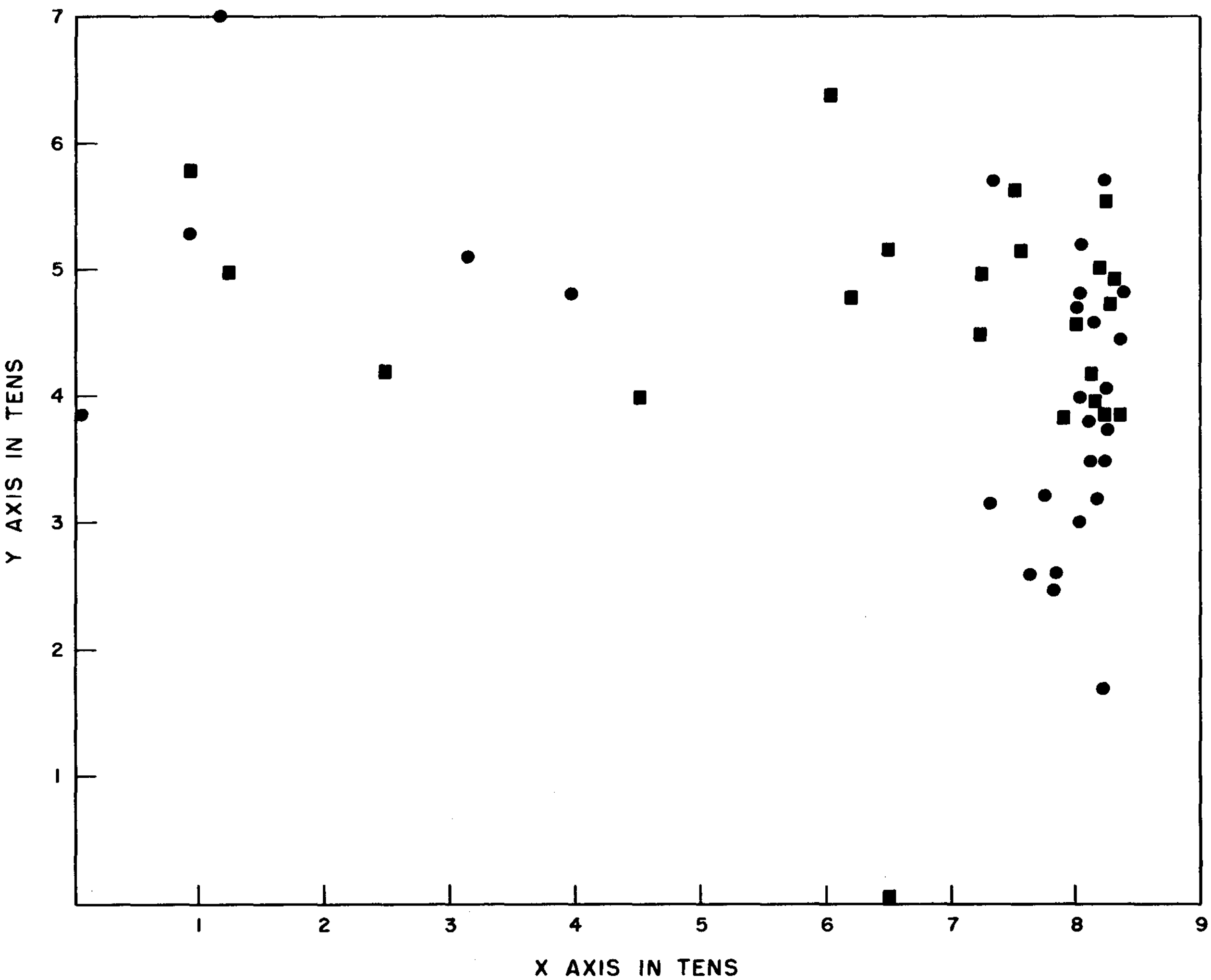


Figure 8. Ordination of fish-tagging locations on the Weber River (see Table 4 to locate a specific dot or square) (dots = changed areas; squares = unchanged areas).

Table 4

Ordination coordinates (X and Y) and estimated standing crops in pounds per acre of the tagging and release locations on the Weber River, fall 1970 (*C = changed, U = unchanged; **indicates best station in this section of river).

Location	Type of area*	Axis X value	Axis Y value	Estimated standing crop/acre
283	C	83.09	48.05	86
285.5	C	76.14	25.86	424
290	C	80.50	30.25	292
206.5	C	81.97	38.09	120
314	C	81.87	35.50	176
324	C	83.66	39.25	123
332	C	80.98	37.64	198
338	C	81.63	34.22	469
343	C	79.94	51.73	1,051
350	U	75.25	57.58	695
368	U	82.50	49.35	310
375	U	83.61	47.97	813
377.5	U	75.44	52.60	1,884
386.5	U	72.09	45.01	106
389	U	82.80	56.18	1,202
406	U	81.70	38.67	123
409	U	83.13	49.01	609
414	C	73.13	57.78	683
415	C	39.74	48.08	2,826
416	C	9.69	53.30	4,311
419.5	C	0.00	44.51	3,033
428	C	31.05	51.61	619
433	C	78.10	25.16	166
439	C	78.49	25.80	** 2,527
452	C	77.81	34.40	67
458	C	73.28	31.66	130
466.5	C	80.29	47.40	79
483	C	80.53	39.66	157
497	U	81.82	42.64	100
504	U	9.50	58.74	854
512	U	64.75	52.12	740
523.5	U	62.33	48.23	456
539	U	45.35	40.54	284
549	U	12.08	49.99	897
587	U	24.31	42.26	162
605	C	82.08	35.45	125
620	C	82.28	38.05	56
627	C	11.22	70.90	1,215
642	C	82.10	17.45	107
655	C	80.93	48.74	162
667	C	82.02	57.31	228

SELECTED REFERENCES

Alvord, W. and J. C. Peters, 1963, *Channel changes in thirteen Montana streams*. Montana Fish and Game Comm., Fisheries Div. 22 p

Bailey, R. M., et al. 1960, *A list of common and scientific names of fish from the United States and Canada*. A.F.S. Special Publ. No. 2, 102 p

Barton, J. R., D. A. White, P. V. Winger, and E. J. Peters, 1971, *The Effects of Highway Construction on the Hydrology and Hydrobiology of the Weber River near Henefer*. Report to Utah Division of Fish and Game and Utah Department of Highways, 116 p

Bayless, J. and W. B. Smith, 1960's, *The effects of channelization upon the fish populations of lotic waters in eastern North Carolina*. Div. of Inland Fisheries, North Carolina Wildl. Res. Comm., Raleigh, 14 p

Bray, J. R. and J. T. Curtis, 1957. *An ordination of the upland forest communities of southern Wisconsin*. Ecol. Monogr., 27(4) : 325-349

Elser, A. A., 1968, *Fish populations of a trout stream in relation to major habitat zones and channel alteration*. Trans Amer. Fish Soc., 97(4) : 389-397

Greeley, J. R. and C. M. Tarzwell, 1932, *Methods for improvement of trout streams*. Amer. Forests, 38(8).

Hunt, R. L., 1969, *Effects of habitat alteration of production, standing crops and yield of Brook trout in Lawrence Creek, Wisconsin*. Symposium on salmon and trout in streams. Institute of Fisheries, Univ. of British Columbia, Vancouver, 388 p

Kennedy, H. D., *Colonization of a previously barren stream section by aquatic invertebrates and trout*. The Prog. Fish Cult., 17(3) : 119-122

King, D. L. and R. C. Ball, *The influence of highway construction on a stream*. Mich. Univ. Agric. Exp. Stat. East Lansing, Res. Rep., 19 4 p

Shetter, D. S., O. H. Clark, and A. S. Hazzard, 1946, *The effects of deflectors in a section of a Michigan trout stream*. Trans. Amer. Fish Soc., 76 : 248-278, Prog. Fish Cult., 9(1) : 62-63 (Abstr.)

Smith, G. R., 1966, *Distribution and evolution of the North American catostomid fishes of the subgenus pantosteus, genus catostomus*. Mus. Zoo, Univ. Mich., Misc. Publ. No. 129, 132 p pl & figs

White, R. J. and O. M. Brynildson, 1967, *Guidelines for management of trout stream habitat in Wisconsin*. Wis. Dept. of Nat. Res. Div. of Res. Tech. Bull No. 39, 65 p

ABSTRACT

Four papers describe a sequence of ecological impact analysis, ranging from predicting the consequences of planned management programs to descriptions and evaluations of ongoing programs. Use of preproject ecological surveys, bioassays, and laboratory scale models are described. Structures to increase fish habitat in changed river channels are evaluated; recommendations for increasing or maintaining the level of production in changed river systems are presented. These papers were presented at the symposium on Water, Man, and Nature, cosponsored by the Bureau of Reclamation and the American Institute of Biological Sciences at Colorado State University, Ft. Collins, Colo, August 30-31, 1971. Has 34 references.

ABSTRACT

Four papers describe a sequence of ecological impact analysis, ranging from predicting the consequences of planned management programs to descriptions and evaluations of ongoing programs. Use of preproject ecological surveys, bioassays, and laboratory scale models are described. Structures to increase fish habitat in changed river channels are evaluated; recommendations for increasing or maintaining the level of production in changed river systems are presented. These papers were presented at the symposium on Water, Man, and Nature, cosponsored by the Bureau of Reclamation and the American Institute of Biological Sciences at Colorado State University, Ft. Collins, Colo, August 30-31, 1971. Has 34 references.

ABSTRACT

Four papers describe a sequence of ecological impact analysis, ranging from predicting the consequences of planned management programs to descriptions and evaluations of ongoing programs. Use of preproject ecological surveys, bioassays, and laboratory scale models are described. Structures to increase fish habitat in changed river channels are evaluated; recommendations for increasing or maintaining the level of production in changed river systems are presented. These papers were presented at the symposium on Water, Man, and Nature, cosponsored by the Bureau of Reclamation and the American Institute of Biological Sciences at Colorado State University, Ft. Collins, Colo, August 30-31, 1971. Has 34 references.

ABSTRACT

Four papers describe a sequence of ecological impact analysis, ranging from predicting the consequences of planned management programs to descriptions and evaluations of ongoing programs. Use of preproject ecological surveys, bioassays, and laboratory scale models are described. Structures to increase fish habitat in changed river channels are evaluated; recommendations for increasing or maintaining the level of production in changed river systems are presented. These papers were presented at the symposium on Water, Man, and Nature, cosponsored by the Bureau of Reclamation and the American Institute of Biological Sciences at Colorado State University, Ft. Collins, Colo, August 30-31, 1971. Has 34 references.

REC-ERC-72-17
Hoffman, D A
ECOLOGICAL IMPACT OF WATER RESOURCE DEVELOPMENT
Bur Reclam Rep REC-ERC-72-17, Div Gen Res, June 1972. Bureau of Reclamation, Denver, 28 p, 13 fig, 4 tab, 34 ref

DESCRIPTORS—/ bibliographies/ *ecology/ environmental effects/ *water quality/ planning/ aquatic environment/ fish/ man/ natural resources/ *water resources development/ *highway effects/ hydraulic models/ spoil banks/ reservoirs/ natural resources/ limnology/ *canal construction/ stream fisheries/ *reservoir operation/ stream channels
IDENTIFIERS—/ McClusky Canal, N Dak

REC-ERC-72-17
Hoffman, D A
ECOLOGICAL IMPACT OF WATER RESOURCE DEVELOPMENT
Bur Reclam Rep REC-ERC-72-17, Div Gen Res, June 1972. Bureau of Reclamation, Denver, 28 p, 13 fig, 4 tab, 34 ref

DESCRIPTORS—/ bibliographies/ *ecology/ environmental effects/ *water quality/ planning/ aquatic environment/ fish/ man/ natural resources/ *water resources development/ *highway effects/ hydraulic models/ spoil banks/ reservoirs/ natural resources/ limnology/ *canal construction/ stream fisheries/ *reservoir operation/ stream channels
IDENTIFIERS—/ McClusky Canal, N Dak

REC-ERC-72-17
Hoffman, D A
ECOLOGICAL IMPACT OF WATER RESOURCE DEVELOPMENT
Bur Reclam Rep REC-ERC-72-17, Div Gen Res, June 1972. Bureau of Reclamation, Denver, 28 p, 13 fig, 4 tab, 34 ref

DESCRIPTORS—/ bibliographies/ *ecology/ environmental effects/ *water quality/ planning/ aquatic environment/ fish/ man/ natural resources/ *water resources development/ *highway effects/ hydraulic models/ spoil banks/ reservoirs/ natural resources/ limnology/ *canal construction/ stream fisheries/ *reservoir operation/ stream channels
IDENTIFIERS—/ McClusky Canal, N Dak

REC-ERC-72-17
Hoffman, D A
ECOLOGICAL IMPACT OF WATER RESOURCE DEVELOPMENT
Bur Reclam Rep REC-ERC-72-17, Div Gen Res, June 1972. Bureau of Reclamation, Denver, 28 p, 13 fig, 4 tab, 34 ref

DESCRIPTORS—/ bibliographies/ *ecology/ environmental effects/ *water quality/ planning/ aquatic environment/ fish/ man/ natural resources/ *water resources development/ *highway effects/ hydraulic models/ spoil banks/ reservoirs/ natural resources/ limnology/ *canal construction/ stream fisheries/ *reservoir operation/ stream channels
IDENTIFIERS—/ McClusky Canal, N Dak