UNION INTERNATIONALE
POUR LA
CONSERVATION DE LA NATURE
ET DE SES RESSOURCES

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SEPTIÈME RÉUNION TECHNIQUE DE L'U.I.C.N.
SEVENTH TECHNICAL MEETING OF I.U.C.N.

ATHÈNES - ATHENS. SEPT. 1958

VOLUME IV.

# Conservation du Sol et de l'Eau
# Soil and Water Conservation

**RESSOURCES AQUATIQUES NATURELLES**
**NATURAL AQUATIC RESOURCES**

1960

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THEME I

# Conservation du sol et de l'eau
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## RESSOURCES AQUATIQUES NATURELLES
## NATURAL AQUATIC RESOURCES

BRUXELLES - BRUSSELS
1960

The success of the Symposium on « The influence of soil and water conservation on natural aquatic resources », Theme I (*d*), rests in large measure upon the assistance received from the Fisheries Division of the Food and Agriculture Organization of the United Nations and the General Fisheries Council for the Mediterranean.

Their provision of an outline for the theme and a list of contributors who were asked to prepare papers on specific aspects of this theme provided the foundation for a well-ordered meeting and for this series of papers which constitutes a comprehensive and integrated review of an all-important subject.

The Food and Agriculture Organization has also furnished a financial contribution towards the printing of this volume. The warmest thanks of the Union are extended to F.A.O. for all the assistance given which contributed greatly to the smooth running and valuable results of its 7th Technical meeting.

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Le succès du Symposium concernant le Thème I (*d*), « Les résultats de la conservation du sol et de l'eau sur les ressources aquatiques naturelles » est dû en majeure partie à laide apportée par la Division des Pêcheries de l'Organisation des Nations Unies pour l'Alimentation et l'Agriculture et par le Conseil Général des Pêcheries pour la Méditerranée.

La préparation d'un plan de travail destiné à guider les discussions et d'une liste d'experts chargés de contribuer à une étude sur les différents aspects de ce thème ont rendue possible la bonne ordonnance de la Réunion ainsi que la présentation des nombreux rapports contenus dans ce volume qui constitue un aperçu homogène de ce problème de première importance.

L'Organisation pour l'Alimentation et l'Agriculture a également fourni une aide financière en vue de l'impression de ce volume. L'Union est heureuse de lui exprimer ici son entière gratitude pour l'ensemble de cette intervention qui contribua grandement à la réussite de sa Septième Réunion Technique.

« *The participation of the Food and Agriculture Organization in the meeting and in publishing the papers does not necessarily imply endorsement by F.A.O. of the views expressed, which are those of the authors.* »

« *La participation* à *cette Réunion de l'Organisation de l'Alimentation et de l'Agriculture ainsi qu'à la publication de ces rapports ne signifie en aucune façon que la F.A.O. accepte la responsabilité des points de vue exprimés par les auteurs. Ces derniers font état ici de leurs opinions personnelles.* »

THEME I*d*

# LES RÉSULTATS DE LA CONSERVATION DU SOL ET DE L'EAU SUR LES RESSOURCES AQUATIQUES NATURELLES

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# THE INFLUENCE OF SOIL AND WATER CONSERVATION ON NATURAL AQUATIC RESOURCES

Theme I. — **SOIL AND WATER CONSERVATION**

d) **The influence of soil and water conservation on natural aquatic resources (from headwaters to, and including, estuaries).**

## OUTLINE

A. — *Introductory report:* Definition; Basic elements.

Definition of soil and water conservation (i.e. wise use).

Definition of aquatic resources (both plant and animal but not including marine resources).

Brief summary of the uses of water and soils and the changes which man wishes to bring about in them (flood and erosion control — pollution control).

B. — *The effect of land and water use on the aquatic environment :*

Examination of usual types of land and water conservation or management, such as :

various soil conservation measures including : defence against rain, splash and run off, afforestation and range management, contour and terrace cultivation, soil or cover treatment, etc.;
drainage works (may diminish and alter stream courses);
engineering constructions, including :

dams (whether for irrigation, production of power, flood control, etc.);
diversions or conduits (canals, tunnels, etc.), levees, dykes, flood walls, reinforcement of bank slopes;

dredging operation;
pollution control.

C. — An examination of the methods whereby deleterious effects of land and water use practices on aquatic resources can be minimized and, wherever possible, made to increase the resources :

analysis of methods that have actually been tried;
suggestions for those that could be tried and for ensuring their acceptance by water and soil conservationists.

d) **Les résultats de la conservation du sol et de l'eau sur les ressources aquatiques naturelles (depuis les bassins de réception jusqu'aux estuaires y compris).**

## PLAN DE TRAVAIL

A. — *Rapports d'introduction :* Définitions, éléments du problème.
Définition de la conservation (ou utilisation judicieuse) du sol et de l'eau.
Définition des ressources aquatiques (animales et végétales). Les ressources de la mer en dehors des estuaires sont exclues.
Résumé des différentes utilisations des terres et des eaux, et des principaux problèmes de conservation qu'elles posent :
- lutte contre l'érosion;
- lutte contre les inondations;
- problème de la pollution des eaux.

B. — *Les effectifs de « l'utilisation des terres et des eaux » sur les habitats aquatiques et leurs populations.*
Étude des procédés classiques d'aménagement ou de conservation des terres et des eaux tels que :
- les méthodes de conservation du sol (lutte contre le ruissellement, reboisement, aménagement des pâturages, culture de niveau, banquettes, couverture du sol, etc.);
- les travaux de drainage (conséquences qualitatives et quantitatives sur les cours d'eau);
- les ouvrages d'art :
  - barrages (pour irrigation, électricité, régularisation des rivières, infiltration, etc.);
  - les dérivations et conduites forcées;
  - les digues, épis, consolidation de berges, canalisations;
- les draguages;
- les mesures contre la pollution des eaux.

C. — Examen des méthodes pouvant limiter les conséquences fâcheuses sur les ressources aquatiques de certains modes d'utilisation des terres et des eaux pour permettre autant que possible d'accroître au contraire ces ressources :
- analyse des méthodes effectivement expérimentées;
- suggestion de méthodes nouvelles, conciliant les impératifs de la conservation des sols et des eaux et ceux de la production de ressources aquatiques.

# AN INTRODUCTION TO THE THEME AND A SUMMARY OF THE BACKGROUND AND EXPERIENCE PAPERS [1],

BY

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## GENERAL REPORT

A. — **Definition of soil and water conservation and' natural aquatic resources.**

The earth and its inland waters, whether they be flowing or standing, are in continual transformation, by natural, physical, chemical and biological agents. Meteorological agents degrade mountains, rivers transport the products of erosion and modify their courses, lakes are gradually filled, alluvial deposits carried by floods enter the sea to form temporary lagoons. And with these physical changes there are corresponding changes in the flora and fauna.

In defining nature conservation we could take it to be either the maintenance of a static, unaltered condition or the continuance of a state in which no checks or obstacles are placed in the way of natural transforming agents. However, in considering rational protection of nature, it is impossible to believe that one could really maintain nature in a static condition, nor would it be possible for man to allow the modifying agents full freedom to change the earth's surface. Nature conservation involves, rather, the control of natural phenomena so as to avoid or limit the more dangerous consequences caused by physical and biological agents on soil and water.

Nature must also be protected from the modifying actions of man, who — for the very sake of his existence — must continually change the surface of the earth and regime of the waters. Until a short while ago, vast areas of the earth's surface were still retained in a more or less natural state, since man's works took place on relatively restricted areas. But with the increase in population and the necessity

(1) The summary is based upon two principal background papers and upon a variety of experience papers contributed especially for this Symposium and reproduced separately.

to provide more food and work, and the extension and intensification of roads and other means of communication and transport, questions of soil and water conservation have arisen on every surface of the globe. No area can now be excluded from the needs of conservation, and the necessity for measures for protection have increased in urgency.

Soil and water conservation and protection against the consequences of man's action are both to be considered as closely related types of nature conservation, and natural aquatic resources are directly dependent upon them.

Which types of soil and water conservation measures can influence natural aquatic resources ? Which aquatic resources is it important to preserve ? These are questions which we must answer.

There are two ways of approach to the conservation of soil and waters. One is to protect the natural landscape for aesthetic, recreational and cultural purposes; the other is to protect the natural production of minerals, food and energy for the economic benefit of mankind, and to ensure their soundest or most rational exploitation.

Man's action on land and water is directed toward the :

*a*) utilization of minerals taken from the earth's surface or its depths;

*b*) utilization of natural vegetation (forests, prairies) and its substitution, by agricultural practices;

*c*) utilization of natural fauna and the breeding of domestic animals;

*d*) modification of the earth and its waters to create new ways of communication or transport or to improve the natural ones;

*e*) occupation of areas, both on the land and in its waters for his settlement and his other activities such as industrial development;

*f*) utilization of waters as a source of energy;

*g*) use of water for irrigation, domestic and industrial purposes;

*h*) use of water for the discharge of domestic and industrial wastes;

*i*) regulation of waters for sanitary and hydraulic purposes;

*j*) use of water for fishculture ([1]).

Our purpose is to see how these actions influence the living

([1]) Suggestion made by A. Maar (S. Rhodesia).

aquatic resources of inland waters, both flowing and lotic. The following are to be considered :

*a*) the activities of deforestation or reforestation with the consequent increase or decrease in erosive and alluvial deposits, in general all the works of mountain regulation, (terracing, protection against landslides and erosion), regulation of the course of mountain torrents, of floods and silt sedimentation;

*b*) the drying up of swamps or wetlands and agricultural reclamation — in general, all the agrarian activities connected with irrigation, fertilization and substitution of cultures;

*c*) the construction of dams and impoundments for the production of electric power, the use of water for domestic or industrial or irrigation purposes and for the purpose of fishculture;

*d*) the embankment and regulation of streams for navigation, or to protect the surrounding land from floods and erosion;

*e*) the diversion of water by means of canals and new waterways;

*f*) the regulation of estuaries and littoral lagoons to protect the land from tides and waves.

It is to man's interest that he preserve the living and non-living resources of the waters in order to obtain the most benefit from them. In part, this can be attained by maintaining the natural state and in part through its modification.

Often a use of natural resources brings about adverse changes in the aesthetics of the landscape. Therefore, the final goals to try for in the preservation of nature can be either aesthetic or utilitarian. Natural surroundings can be kept for naturalistic, recreational or touristic purposes, or they can be exploited for the production of energy and materials.

In such works one generally aims for the most important interests which usually are neither aesthetic nor naturalistic. The touristic and fisheries' interests, although profitable, have in general appeared less important than the industrial interests. Therefore we often see industrial establishments which spoil the landscape, alter natural conditions and contribute to the destruction of living resources. In most cases it is not possible or advisable to limit the industrial development or means of communication for purely aesthetic reasons or for the protection of the natural scene. However, it is possible to limit the harmful changes, moderate the disadvantages and preserve especially interesting areas from change, and to dedicate certain of these for recreational, touristic or cultural purposes by creating natural parks or faunistic and floristic sanctuaries.

In addition to the uses of water by man for navigation, transport, and production of energy or for alimentation, for irrigation, for the drainage of wastes, for recreation and for sport, there is another use of considerable importance — as a medium for plant and animal resources. Our purpose is essentially to see how this last-mentioned use can be protected and preserved in relation with all the other soil and water conservation measures which interest man.

Preservation of the floristic and faunistic resources of water can be accomplished by maintaining their equilibrium and adaptations to the surroundings. Every community and biological association is adapted to its surroundings, forming with these a harmonic system. Any intervention of man disturbs and alters this system. The natural biological equilibrium has been realized gradually by processes of adaptation and selection; therefore, it is the most suitable for the condition of a given surrounding and has the best probability of preservation, through regular fluctuations, without frequent ruptures or catastrophic increases or diminutions.

A natural equilibrium does not, however, always correspond with man's interests. Often, in fact, modifications and alterations in the biological equilibrium and natural communities prove to be more advantageous to him; just as the productivity of agrarian culture is usually higher than that of spontaneous vegetation and just as rationally exploited forests or tree farms produce more revenue than natural forests. So, also, may the returns from aquiculture or of pisciculture in open waters be more productive than the exploitation of natural and uncared-for aquatic resources.

The conservation of aquatic plant and animal resources may apply therefore to their preservation in a more or less unaltered state and to their rational exploitation. The natural resources of the waters can be, in fact, protected for naturalistic and scientific purposes, for recreational and touristic purposes or for economic purposes, i.e., the production of foods or other benefits to humanity.

The various aspects of preserving the living resources of waters are taken up in the report of Meehean, of which we shall speak later. Both the living resources of waters and those relating to waters, such as game mammals and water fowl which live in or near water, are considered from the economic or recreational point of view, the latter being of particular interest in the United States.

All these points of view must be taken into consideration; the living plant and animal resources of inland waters must be protected — both under the aspect of nature conservation and that of producing resources for the desires and needs of mankind.

Depending then on the necessities and possibilities, one or the other aspect may prevail. We cannot consider water areas as being designed only for food production, nor only as recreational areas, nor solely as sanctuaries for flora and fauna.

### B. — **Effects of man's modifications of soil and waters on the aquatic environment and the natural living resources of inland waters.**

No background paper, nor any paper based on personal experience was prepared for the first part of this theme, but we possess a background paper by P. A. Larkin and numerous other papers for the second part of this summary. Papers on this theme have a tendency to deal mainly with certain specific points. This is due to our choice of authors and also because some aspects of the problem are of particular interest to certain scholars and institutions.

Larkin examines separately the effect man can have :

*a*) on the productivity of aquatic environments,
*b*) on the requirements of aquatic organisms, and
*c*) on the requirements of the fish population (stocks).

As regards productivity, he considers lakes and flowing water separately.

For lakes, the factors determining productivity are :

morphometry,
climatic factors,
chemical or edaphic factors,
biotic factors.

The morphometric characteristics can change with modifications of area, depth, shoreline, slope of the shore, fluctuations in water level, and with alterations resulting from damming lakes to create reservoirs.

While climatic factors generally cannot be influenced by man, the morphometric changes he introduces can react on the thermal behaviour of a lake and on its physical surrounding. These changes can influence the conditions of oxygenation of the waters and the nutritive and suspended substances.

The edaphic conditions of lakes can be changed by the use of organic or inorganic fertilizers which bring about changes in the trophism of a lake, penetration of light, etc.

The biotic factors can be modified when, by diversion of water, new organisms are introduced, or by creating conditions unsuitable for certain plant or animal species or advantageous for others.

All these factors are so interrelated that a single morphometric change such as that caused by the building of a dam, can directly or indirectly influence the productivity of a lake. The enlargement of a lake's basin or the creation of a new one, an increase in the trophism of the lake, etc., are all factors which can have favourable or unfavourable consequence on productivity.

Similar factors influence the productivity of streams. Headwater soil conservation projects and main stream storage devices, when resulting in a seasonal stability in the flow of waters, often increase productivity. The construction of pools, which leads to increased water temperature as the flow ceases, can also contribute to an increase in productivity.

Edaphic factors play primarily the same role in rivers as in lakes. A moderate quantity of electrolytes and of dissolved organic matter may favour production, but an excessive quantity of the residues of human activity is harmful.

Floating substances reduce light penetration and thus damage the bottom flora and fauna. Therefore, measures which reduce erosion, or the creation of pools, help to improve the inhabitability of streams.

Among the biotic factors which can influence the productivity of rivers one must consider both the organisms which live in the water and also the communities on the surrounding land areas. Forest protection, the extension of cultivated areas and the type of agriculture practised have a strong influence on the living resources in the waters.

Larkin lists as requirements for aquatic organisms a certain quantity of water, a moderate and stable temperature regime, abundant oxygenation, dissolved nutrients without excessive variation in pH, and a substratum free from disturbance or excessive deposits of organic or inorganic substances. There must be no toxic chemical substances. Any alteration from these requirements can be harmful, leading to alterations in the composition of the aquatic communities and the disappearance of many or all of the plant and animal species.

Conservation of stocks of fish used by man depends on the condition of growth and recruitment, on natural mortality and on exploitation by fishing.

Changes in the factors which condition the temperature of water can influence the growth ratio. This also applies to factors which change the abundance and availability of the planktonic or benthonic food organisms. Recruitment is influenced by the access to spawning and rearing areas. Obstructions to migration toward spawning areas can have very harmful effects on the species.

Stocks of fish can be very impoverished by measures which increase natural mortality or facilitate the easy capture of fish.

Measures for soil and water conservation can also alter the relation of predation and of competition among species and in this way modify the stocks. Particular attention is called to those measures which can favour the appearance of new species or determine the disappearance of existing species.

According to Larkin, soil and water conservation measures can have the following effect on aquatic resources :

*a*) Headwater soil and water conservation programs are usually advantageous in that they are beneficial to aquatic environments;

*b*) Main stem dams can create new areas of fish production, but they can also destroy runs of migratory fish;

*c*) Pollution is in general disadvantageous and should be strictly controlled.

The special experience papers received and which relate to this section of the Symposium consider the effects of :

*a*) dams and impoundments,
*b*) the diversion of waters by means of canals,
*c*) pollution.

Dams and impoundments are planned and built for purpose of irrigation, to create reservoirs for domestic, agricultural or industrial use, to produce energy, and to regulate the flow of running waters to prevent floods or alleviate droughts.

These latter means of using dammed water are not generally followed by the loss of quantities of water. Hydro-electric plants usually return the water to the rivers or run it through artificial canals where it can be used again for fish production. Sometimes, however, the water held back by dams is a total loss, or nearly so, as regards its use for the production of aquatic resources. With agricultural irrigation, part of the water is lost, and this is also true of water used for industrial or domestic purposes.

Dams and impoundments can improve the production of living resources by the creation of new exploitable water masses or produce dangerous effects by the obstruction to migratory runs. In the Palearctic and Nearctic regions they particularly affect the fluvial migrations of sturgeon, eels and salmonids.

Meehean mentions the effect of dams in preventing migrating fish from reaching their spawning grounds or preventing the descent of the young fish. Any delay to upstream or downstream migration can affect reproduction or survival of the young. Dams can also drown out the spawning grounds and so render them useless.

He also points out that reservoirs created by dams often destroy valuable stream fisheries, such as for salmon and trout and favour instead the production of sedentary species less valuable for sport and food. Dams can also affect the growth of submerged or shoreline vegetation and thereby influence the life of the fish indirectly. They may also creat new states of thermal stratification with effects on the oxygenation of the water. Especially harmful from this point of view are some of the deep impoundments from which the water is drained from the bottom.

Meehean also remarks on the beneficial effects of dams in controlling floods and thereby preventing the dispersion of fish to areas which later would dry up.

In particular, he mentions the example of the Roanoke River Basin in Virginia and North Carolina, and the necessity for co-ordinating the various interests connected with the use of water and aquatic resources, and for well-balanced projects for soil and water conservation.

Various writers have considered the question of dams as obstacles particularly to the migration of salmon and trout. Runnstrom reports on it for Sweden, Aass and Sömme for Norway, McGrath for Ireland, and Royal and Cooper for British Columbia.

Runnstrom speaks of the hydro-electric power stations of the river Indalsalven and of others in Norrland (Sweden) where, in place of former rapids, a series of power-station dams has been built, separated by stretches of slow flowing water. The level of lakes formed by the dams is regulated according to the demand for electrical energy, with annual fluctuations sometimes as much as 20 meters. These fluctuations influence the reproduction of fish, the production of benthonic fauna, the growth of the fish and the fishing.

The variations in level lead to the destruction of spawning grounds, with a notable loss of roe for fall-spawning fish (particularly brown trout) and may obstruct migration.

While the first flooding of new areas by dams increases the quantity of planktonic and semi-planktonic organisms as a consequence of an increase in nutritive salts and, therefore, primary productivity, in later years — due to the increase in water level during the summer and the decrease during winter — conditions become worse because of the reduction of bottom flora and fauna. There is, therefore, a reduction in fish growth, especially in that of char and white fish. On the whole, there was no reduction in the stocks of these fish, but the growing conditions were much poorer.

Trunks, branches and roots of submerged trees interfered with net fishing in these lakes.

In Swedish rivers the dams interfere especially with the migrations of salmon. The disappearance of rapids has destroyed the spawning places of the salmon : dams interfere with or cause delay to the migration of spawners and to the descending smolts. Smolts are also injured by turbines and more exposed to predators. As a consequence, the Indalsalven River has lost its importance as a smolt producer, which vitally affects salmon fishing in the Baltic. Generally speaking, the salmon fishing in Swedish rivers has been destroyed and only through very expensive means, which will be discussed later, will it be possible to provide salmon for sea fishing.

Aass deals with the effects of impoundments in Norwegian rivers on food and growth, reproduction, migration, size and composition of stocks and on fishing.

Especially detrimental is the lowering of the basins of lakes and the fluctuation in water level which can destroy the animals on which the fish feed and change the vegetation which aids indirectly in the development of benthonic fauna.

Lowering the water level of a lake reduces the growth of fish. There can be a regulation of the production, but often stability is not reached again for many years. Flooding of dry lands can increase growth, but this also can have variations in successive years.

Impoundments are often detrimental to spawning and to the development of fry. Fish such as perch and pike which spawn in the spring can find better spawning grounds and consequently may be aided by impoundments. Damage is greater to char and trout which spawn in the autumn. Barrages, moreover, prevent fish migrations and facilitate their capture because they are concentrated in restricted areas.

According to Aass, impoundments probably do not influence planktonic production. Plankton-eating fish are therefore less affected than carnivorous fish. For this and other reasons impoundments can alter the balance between the various species. Perch, white fish and char are less damaged than trout, and char, in particular, can make better use of the plankton and the deep water fauna.

With the varying fluctuations in the level of the basins, the output was found to be rich in some years and poor in others, with consequent abundant and poor year classes. Some age classes prevail for several years.

Impoundments can also be detrimental to fishing because of changes in depth, currents, and the presence of submerged shrubs and trees.

Sömme is concerned with the effects of hydro-electric impoundments on the upstream migrations of fish that spawn in Norwegian waters. Dams, even when equipped with ladders and fishways, prevent and delay these migrations, and this delay is also detrimental to spawning.

Barrages also impede the downstream migrations of spent and young fish. Many descending fish are damaged passing through turbines or turbulent areas which are formed below dams.

Diversions of water courses for hydro-electric purposes which reduce the flow of the stream can also be detrimental because this, too, can delay migration so that fish arrive too late at spawning areas. Due to diversions, trout frequently spawn in areas that eventually dry up, so that eggs and young fish are destroyed; sometimes young fish die in the rapids which freeze because of reduction in water.

McGrath is concerned with obstacles to salmon migrations in Ireland. Such impediments can also be caused by low mill-dams which are numerous in Ireland. These cause concentrations of fish and very often delays; when the current is too slow fish are not attracted. Barrages constructed on the lower reaches of rivers can obstruct migration completely. Other dams include tidal barrages erected to exclude tidal flow from low-lying estuarine rivers for the prevention of flooding.

Fish must often use up too much energy to pass barrages, or their migrations are delayed; sometimes they are too crowded on available spawning beds — it being impossible to reach others. In some cases the delay in passing dams, due to overcrowding, may be the cause of diseases. Many fish are also killed by turbines or damaged by abrasions, turbulence, etc., in passing spillways.

Royal and Cooper deal with hindrance to the migration of salmon in the Pacific Northwest.

Investigations made on one run of *Oncorhynchus nerka* demonstrated that a delay of three to six days in ascending could be crucial to spawning. These fish do not eat during migration; they consume their reserves of fat and proteins and so often reach the spawning area in an exhausted state. Many dams are, therefore, detrimental to the upward migration of fish. The decline of salmon has been particularly great in the Columbia River where there has been a decrease in the commercial catch of about 80 per cent. from 1911 to 1956. (The situation is complicated here — not only by the construction of dams but by the effects of fishing pressure, water diversions, pollution, deforestation, etc.)

At dams where long periods elapse without surface spill, the downstream migration is often delayed as it may also be by the slowness of the current in artificial basins. This can result in a scarcity of food and delayed adaptability to salt water.

Barrages and artificial lakes can alter the thermal system of a water course. An artificial lake with thermal stratification can make the river downstream warmer or colder, depending on whether the outlet is deep or superficial.

Basins created in rivers that transport abundant organic substances may produce a decrease in the water's oxygen content. A river can thus become unsuitable for residence or migration. On the other hand, reservoirs may be useful in clearing the water of silt.

Different effects of dams and impoundments are observed in river systems where migratory fishes are not the main representatives of the fish fauna.

Wiebe describes the effects of the multi-purpose impoundments of the Tennessee Valley Authority (T.V.A.) composed of a large number of reservoirs on the main river and on its tributaries with a total of 600,000 acres of productive water.

The main stream reservoirs are relatively shallow without thermal stratification and bottom stagnation. The storage reservoirs of the tributaries are, however, deeper and thermally stratified. In the latter the bottom fauna is for the most part reduced to those species (some annelids and midges) that can exist under anaerobic conditions. However, despite the limited bottom fauna in these storage reservoirs, several valuable fish species live and form extensive populations based on the existence of plankton-feeding forage species.

In both the mainstream reservoirs and in the storage reservoirs the water is subjected to fluctuations caused by the use of water to generate electricity or because the water level is manipulated for the control of malaria mosquitoes. The minimum levels are however attained in winter during dormancy of the fishes. Therefore these fluctuations are not dangerous to the fishery, although they are adverse to snail and sometimes mussel populations.

The impoundments have created approximately half a million acres of additional fishing waters, and in the new lakes the fishery is at least fifty-fold that of the unimpounded rivers. Anglers take about eight million pounds of fish annually and commercial fishermen another six million pounds. No artificial propagation is practised..

The quality of the fishery has also been vastly improved. Fishes that are more appreciated for a sport fishery (*Micropterus* and others) have increased particularly in the main river reservoirs. In the storage reservoirs, the production differs in quantity and quality with a large population of rough or non-game fish species.

A further production of living resources is afforded by water fowl. The Tennessee Valley system has established an important wintering ground for ducks and geese.

Wood and Pfitzer deal with the more specific problem of the effects produced by variations in level of large impoundments and report on observations made with rotenone samples in Old River Lake, Arkansas, and other reservoirs situated on tributaries of the lower Mississippi River in Alabama and Tennessee. These fluctuations affect the prevalence and relative abundance of predators and forage fish, as well as game and rough fish. The effects of fluctuations in the water level depend more on time, area and the duration of flooding than upon the vertical extension of the fluctuation. Effects can also be influenced by the topography and soil conditions.

Fluctuations, when not controlled rationally, can be deleterious to fish. When applied rationally, they can be useful to fishery management. Naturally, such a control can be practised more easily in reservoirs operated for flood control than in those created for hydro-electric purposes.

Problems concerning barrages have also been studied in other environments where the effects can be completely different. This is especially true of the tropical and sub-tropical regions of Africa where important migratory species such as salmonids are absent.

Maar deals with the problem in Southern Rhodesian rivers, stating that there are on the whole few data on the biology of fishes for regulated inland waters in tropical regions. Southern Rhodesia is an exception as the data go back for relatively longer periods.

In Southern Rhodesia many water storage dams have been constructed for various uses : domestic, agricultural, industrial. Because of the strong evaporation, basins are usually deep, with a reduced surface. The water is used during the dry season, so that the water reserve is at a minimum in November-December. Generally speaking, the construction of such basins favours the production of fish. These dams regulate and give a continuous character to water flow in the rivers, and fish dwell in the reservoirs themselves. River fish soon invade the new dams and after two rainy seasons the stock is established. First predatory fish predominate and then a new equilibrium is established. Especially suited to life in these dams are *Tilapia mossambica, T. melanopleura* and *T. macrochir,* also the Mormyridae, *Barbus* and *Labeo.* Predatory fish should be excluded.

Damas describes another example of the effects caused by a tropical African river barrage, on the Lufira a tributary of the Congo. In 1926 a barrage for hydro-electric purposes was constructed, which formed a lake about 400 square km in surface area, but lacking in depth — with the characteristics of a marsh extensively covered with partly floating vegetation. The lake basin produced a great increase in the fisheries (*Clarias*, *Tilapia*, etc.). The most important species is *Tilapia macrochir*. The highly eutrophic environment, with phenomena of decomposition and reduction of oxygen, threatens to make life gradually impossible for fish and to destroy the natural production of the lake.

As can be seen, barrages in tropical rivers generally do not have the detrimental effects of those in Palearctic and Nearctic regions because they do not prevent migrations of anadromous fish. In fact, they are usually beneficial as they create new conditions of life for fish. However, there are certain biological consequences which should be controlled and eventually eliminated.

Another group of problems concerns the effects caused by water diversions by means of canals, for hydro-electric or irrigation purposes.

Wales deals with damage to fish attracted into diversion conduits. When the diversion is made for generating electricity, cooling, or other industrial purposes, the fish can easily be injured by turbines or other mechanical devices. Or, if the canal dries up the fish may be stranded — with consequent death. Usually it is better to prevent fish from entering such canals or conduits or to remove them before they get to where water is used.

These derivation canals are usually less suitable for fish than are natural water-courses. The water flows more rapidly so that there is less development of fauna and the temperature is altered. The banks, being more regular, do not offer resting or sheltering places for the fish, which is an unfavourable condition. Especially detrimental is the diversion of water from rivers which are nursery grounds for fish.

Sometimes these diversions permit the invasion of certain fish into new environments where they are harmful or become unwelcome guests, creating a new and unfavourable balance.

A major effect of stream diversion is, of course, that the natural stream is reduced in size, and this drying-up or partial drying-up of streams is the greatest danger of diversion to aquatic life.

This point is discussed by Curtis in a basic study undertaken in Northern California to provide factual data for the determination of the quantity of water necessary to preserve aquatic life in a river from which water had been diverted. In the Pit River a dam was constructed for water diversion by means of a tunnel leading to a power house from where the water returned to the river. Between the dam and the power house the water of the natural channel was very much reduced, with consequent damage to sport fishing for rainbow trout. It was considered necessary to allot the river sufficient water to maintain in good condition the trout and the benthonic fauna on which they feed. The study discusses the physical changes which take place in a river — in its depth, water velocity and area of submerged bottom — as the volume of the stream changes, and relates these to the central problem.

A similar examination was made for the North Fork of the Feather River, also in Northern California.

Trautman considers another problem, that of the migration of organisms through canals and diversions into a completely new environment, and gives two examples : the Welland and the Ohio Canals.

The Welland Canal, constructed by the Canadian Government in 1825, enabled some species to ascend from Lake Ontario to Lake Erie. In 1856 the eel, *Anguilla rostrata* (Le Sueur), was found in Lake Erie which it had never reached before. In 1931, the alewife, *Pomolobus pseudoharengus* (Wilson), was found, and later on this species appeared also in Lakes Huron, Michigan and Superior.

The greatest damage was caused by the parasitic sea lamprey, *Petromyzon marinus*, which was previously present in Lake Ontario but could not ascend Niagara Falls. The first sea lamprey was found in Lake Erie only in 1922 (Dymond); in 1935 its reproduction was ascertained in tributaries of Lake Erie. In Lake Michigan the first appearance was recorded in 1936, in Lake Huron in 1937 and in Lake Superior in 1946. Great damage was caused, especially in Lake Michigan. In 1944, 6,498,000 pounds of lake trout, *Salvelinus namaycush* (WALBAUM), were caught in this lake; in 1955, only 55 pounds. The species has nearly disappeared because of the lampreys, and other species have also been damaged. The delay of over a century in the appearance of the sea lamprey in the upper lakes can be attributed to the difficulty of the reproducers meeting in the new spawning places.

The Ohio Canals were constructed in 1825 between the Ohio River and Lake Erie. These canals and the reservoirs which were built along them have brought about an increase in habitat for some fish and therefore an increase in fishing, besides permitting movements of fish from the higher to the lower Ohio basin.

Meehean also deals with the effects of diversions in his paper. Diversions can alter the volume and speed of rivers and reduce their aquatic life. Other forms of river regulation, to assist navigation or to prevent floods, can have detrimental results because they prevent the seasonal invasions of areas suitable for the spawning and feeding of fish, and the dredging of rivers is also harmful. Such water regulation is also injurious to aquatic birds which live in marshy or periodically flooded zones. From this point of view, drainage of marshy areas is usually harmful when measures for the conservation of living resources are not considered at the same time.

Another aspect of the damages caused by water regulation is presented by Deelder and Van Drimmelen who refer to the decrease in fish stocks in Holland on the lower reaches of the Rhine and Meuse rivers, both as a consequence of pollution following increased industrialization, and principally following construction of weirs to prevent the penetration of salt water.

The reduction and virtual disappearance of salmon is very serious, due especially to the construction of weirs and partly to pollution and the destruction of spawning grounds. Eel fishing has also decreased decidedly because of pollution and the presence of weirs which have prevented elvers from ascending to feeding areas. Eel fishing is also hindered by navigation and river regulation.

Moretti, with respect to the rivers of the Central Appenines in Italy, considers the effects of hydraulic works (hydro-electric basins, small agricultural lakes, barrage dams, canalizations, forced conduits, galleries, water intakes, etc.) together with industrial pollution. Usually they are waterways with a limited flow, which are greatly affected by any such regulation.

In torrent-like water-courses, repeated barrages break up the habitats and form small lake-like spots in which lentic communities replace the rheophyllic communities.

Artificial basins, with increased plankton, favour the eutrophication of waterways. Downstream from these basins, because of sedimentation, the water is clearer and, according to the season, may be warmer or cooler. As a result there are substitutions in the flora and fauna. In other cases, the damming of torrential streams produces a stationary regime, without the seasonal interruptions of the original state.

Fish culture has been favourably affected in small lakes and artificial basins.

Among the rivers of this region, the one in which a fishery has been most damaged is the Nera, an affluent of the Tiber, because of barrages at water intakes and particularly of industrial pollution. Pollution caused by human communities brings about eutrophication through the formation of putrid waters often uninhabitable for certain species.

The problem of pollution and physical and chemical changes in water has also been discussed in other Symposium papers.

The report by Liepolt deals with the consequences of river-training works on the life in the fresh water and of the most suitable conditions for the development of the flora and benthonic fauna.

Sylvester deals with the general problem of changes in the quality of water due to artificial works on waterways. He refers to an investigation made by the University of Washington for the U.S. Fish and Wildlife Service to evaluate the changes in water quality resulting from multi-purpose dam construction and concomitant water uses in the Columbia River Basin, especially for irrigation and the production of hydro-electric power.

The quality of water is altered by the construction of reservoirs, the return of spent irrigation waters, the discharge of domestic sewage and industrial wastes. In general, reservoirs reduce turbidity and change the water temperature. They may slightly increase or decrease the dissolved constituents. After water has irrigated the soil, it is richer in minerals and has different physical characteristics. A major change is, of course, caused by pollution. Changes in vegetation in the surrounding zone, for example, from coniferous to deciduous trees, can also change the colour and organic load of the water. Important changes in the quality of the water are also caused by works that modify erosion and, therefore, alter the silt content.

Liebmann deals with the influence of sewage waters on fisheries and gives us a detailed classification. The detrimental effects may proceed from toxins, from oxygen deficiencies, from shifts in biological balance and from the deposition of taste-influencing matter in the fish.

Toxic substances and the ones causing oxygen depletion may result in the disappearance of certain organisms necessary to fish life or produce a mass development of others that are dangerous to fish. The latter may clog the gills, produce metabolic substances that are poisonous to fish, clog fish nets or accumulate as organic sludge. Other substances accumulate especially in the tissues of the fish giving them a disagreeable taste.

Tarzwell also deals with river pollution, due not only to sewage and industrial wastes but to silt and eroded materials, the heating of water and radio-active materials.

Organic wastes can be useful to fish production when present in limited quantities; they are harmful when they are too abundant and deplete the oxygen.

Suspended materials may produce a turbidity that reduces the penetration of light and, therefore, reduces photosynthesis and productivity. They may cover spawning areas, reduce or modify benthonic fauna, and fill lakes and reservoirs.

Dissolved salts may not be harmful if physiologically balanced; they become harmful when they are concentrated enough to have an osmotic effect. The salts of heavy metal are usually toxic.

Insecticides, some synthetic substances, organic and cyanides, are very toxic.

Putrescent substances are harmful because they reduce oxygenation.

The discharge of hot water can cause the disappearance of some species and favour the appearance of others; it can change the chain of nutrition, increase or decrease productivity and bar the way for the migration of certain species .

Wastes from human populations can spread pathogenic organisms. Industrial wastes, dead organisms and certain living ones can give an unpleasant taste or smell to the water.

Some plants and animals can concentrate radio-active substances.

Another type of chemical action that is eventually dangerous to the aquatic fauna is described by Lhoste — that derived from the use of chemical herbicides. These are largely employed in rivers, irrigation canals and reservoirs in order to remove the obstacles to water movement or to fish development produced by the invasion of a too intensive vegetation. Sometimes herbicides are also used to control the development of mosquito and simuliid larvae.

Most of the chemical herbicides when employed at moderate rates are not directly dangerous to fish. It is necessary, however, to take into consideration that aquatic plants are necessary to oxygenate water, for the primary production of organic matter and to offer protective shelter to fish fry. As a consequence of the indiscriminate use of herbicides a rupture of biological equilibrium can therefore be produced.

We can quote the example of Lake Orta, Piedmont, Italy, where the use of copper sulphate (a substance largely employed as a herbicide) produced a long-term diminution of the fish fauna as a consequence of the destruction of phyto-plankton (Monti and Baldi).

Meehean also refers to the effect of pollution from domestic sewage and from industrial wastes (sulphate pulp mill wastes) in the Roanoke River.

Another problem is that connected with the conservation of estuaries and lagoons — of special interest to those regions (Holland, the Upper Adriatic and Denmark) where a large shore area, covered by shallow brackish water, is to be reclaimed for agricultural purposes.

Muus considers this problem for Danish estuarine waters and compares their value as producers of fish with the anticipated values to be realized after their conversion into agricultural land.

This problem is especially felt in the Venetian region — as I myself have often had occasion to mention; especially with regard to the fisheries for wild stocks in the lagoons of the Upper Adriatic and to fish culture (eels, mullet, etc.) in brackish waters, locally called « Vallicultura ». Reclamation programs are often injurious to these activities, as is industrial pollution and the insufficient oxygenation caused by non-renewal of sea water especially during the summer months.

Meehean refers also to the damage to aquatic plant life caused in Currituck Sound, Virginia, U.S.A., in 1917, by the increase in turbidity caused by dredging coupled with fluctuations in salinity caused by alternate inflows of salt and fresh water. The separation of fresh from sea water re-established better conditions in the area which is important for water-fowl hunting and sport fishing. He considers this to be an example of the damage that can be caused to aquatic resources by water development without adequate multiple-purpose planning.

### C. — **The methods whereby the deleterious effects of water- and soil-conservational practices on aquatic resources can be minimized and, wherever possible, made to increase the resources.**

Dill and Kesteven, in their background paper, outline in detail the question of which remedies to apply to alleviate the damages to the living aquatic resources produced by certain water- and soil-conservational practices.

It is necessary to :

*a*) ensure reproduction and recruitment of fish and other aquatic stocks,

*b*) encourage their growth,

*c*) reduce their mortality, and

*d*) preserve the ecosystem — modification may be necessary — that will provide the best production of aquatic stocks.

The authors stress that in most instances one cannot set the interests of a fishery completely against those of a project using the waters for other purposes, unless the fishery interests prevail over those of the project. It is preferable to diminish or find a remedy for the damages caused to the fishery and the living resources. It is better to examine the situation before starting construction, so as to include the measures for protection or even augmentation of the resource in the project.

If it is impossible to preserve a substantial part of an original aquatic stock one may consider the substitution of a new stock or some other compensatory action.

Methods to minimize damage by dams and other barriers to the movements of fish are considered. These are : means of ensuring free passage of fish over dams, prevention of injury to young fish by turbines, and impeding the entry of fish into diversion channels.

When planning river-basin development one must consider ways of minimizing the effects of dams as impediments to upstream or downstream movement and changes in flow that may reduce spawning grounds, decrease or increase the zones which produce nutriment for fish, cause changes in the speed of the water, temperature, chemistry, turbidity and capacity of self-purification.

One must not risk sudden and untimely variations in the flow of the water released from a dam. A constant release could be recommended but an increase in quantity and speed at certain moments might serve to attract the fish as, at other times, a reduction in quantity might be advisable.

As thermal stratification is often present in artificial reservoirs, it may be necessary to use either surface spill or low-level discharge in order to provide water of the desired temperature in the stream below the dam.

While the construction of a dam seldom produces lasting and harmful changes in the water chemistry, diverted waters used for irrigation or industry and then returned to the waterway may have chemical characteristics which can damage aquatic life.

Damage to aquatic stocks in artificial reservoirs may also be caused by fluctuations in water level. These cannot usually be prevented but may be controlled so that the consequences are less serious, and the complete emptying of basins should be avoided. Sometimes damage is prevented by construction of inner barrages or secondary basins, which may, however, promote the development of less desirable species.

Damage and destruction of fish in diversions or conduits must be prevented by the use of screens or other protective devices.

Canalization systems and the creation of new waterways can provide new habitats for aquatic animals. It is necessary, however, that such canals have the right conditions of current cover, temperature and bottom for aquatic life. With proper changes, the productivity of these canals can be increased.

Chemical substances can eliminate undesirable fish introduced through diversions or new waterways between different basins. There may be times, when constructing new basins, when it will be preferable to destroy existing undesirable fish and substitute a new population.

The regulation of rivers in their lower courses may result in the disappearance of areas suitable as the feeding, spawning and nursery grounds for freshwater fish. When, as a consequence, conflicting interests arise among fisheries, agriculture and soil conservation interests, one must find out which measures one should adopt to reduce the damage and which compromises to make.

The detrimental effects of industrial pollution can be alleviated by sedimentation or neutralization of the wastes, by discharging them only when rivers are in flood, or when the water temperature is low or when reproduction is not taking place. Insecticides have been deleterious to fisheries when not used with care.

When natural propogation has been damaged one must resort to :

*a*) artificial reproduction and re-establishment of stocks,

*b*) creation of new spawning areas,

*c*) transfer of runs.

In other cases, soil and water conservation practices may be advantageous to aquatic production because new productive areas are created — as has happened in the reservoirs of the Tennessee Valley Authority and in other regions (Colorado River, or in India).

When water resources are in danger or have been damaged, one must apply :

*a*) methods to alleviate detrimental effects (fish-passes, screens, etc.),

*b*) methods to re-establish damaged habitats,

*c*) methods to compensate for the loss of water suitable for aquatic production,

*d*) methods which may offer a substitution for a destroyed resource (hatcheries).

It is desirable that all waters be used for the production of aquatic stocks and that these be considered from the multi-purpose point of view as economic, nutritive, recreational and aesthetic resources in conjunction with the aims of soil and water conservation projects which use water for other reasons.

For the exploitation of aquatic resources *Dill* and *Kesteven* recommend that wherever possible :

*a*) all new waters be utilized for fisheries,
*b*) fish populations be treated as crops to be harvested,
*c*) the exploitation of areas not or insufficiently exploited be facilitated,
*d*) conflicts between sport and professional fishermen be resolved,
*e*) the new basins be designed so as to facilitate the use of fishing gear,
*f*) species of undesirable fish should be controlled.

Various experience papers deal with the special aspects of these problems.

Runnstrom in his paper deals with measures of protection against damage caused by dams. With reference to the intense hydro-electric exploitation of Swedish salmon rivers in Norrland, he considers that the construction of fishways is no longer useful. The only way to preserve the salmon of the Baltic is that of replacing the fluvial phase of the salmon with artificially propagated fish which are reared to the smolt stage and liberated at the mouths of rivers. Investigations show that with such a method there is the possibility of producing and maintaining an adequate stock of salmon in the Baltic on a sound economic basis. However, even if this should be possible, the country will suffer a loss with the disappearance of the salmon from the rivers.

Lindroth deals with the same question — the possibility of preserving a stock of migratory salmonids even when the spawning areas have been eliminated. He details methods of rearing young salmon to the smolt stage and provides some figures on the recapture of marked smolts.

Sömme also lists measures to protect fish whose migration has been impeded by dams : fish-passes, transport of fish past the dams, moving curtains of cables with a low electric charge, artificial freshets to stimulate migration. He, too, considers the planting of fry to be insufficient and says that salmonids should be liberated as large fingerlings or as two-year old smolts.

McGrath refers to the remedies used in Ireland to facilitate the passing of dams. Relatively simple fish-passes are sufficient for low mill dams. For the higher dams for hydro-electric purposes, the construction and placing of fish-passes must be studied carefully. They must have easy entrance so as to attract the fish.

Another type of barrier is the tidal barrage for the exclusion of tidal flow from low-lying estuarine rivers for the prevention of flooding. Such a barrage with flap gates that prevent the entry of tidal waters exists in the Fergus River, at Clarecastle, County Clare. Since this barrier prevents salmon from ascending the river, it was necessary to provide special structures for their access. Screens put up to stop smolts from entering the turbines are not sufficient in themselves, and a by-pass channel through which the smolts can pass is also necessary. The pool into which they fall on the other side of the dam should be deep enough to prevent harm to the fish.

Deelder and Van Drimmelen deal with fish-passes that permit elvers to pass weirs. In Holland, cyprinids, pike, perch and pike-perch are important for sport fishing, so that their passage through weirs should be facilitated. Deelder deals particularly with fish-passes on the Rhine and the Meuse.

In Holland the problem of fish ascending a river is aggravated by the continuous increase in the number of dams, locks and sluices separating marine from inland waters and making the latter less saline. Thus, a special obstacle is created for the ascending of elvers. To remedy this, the sluices of the Afsluitdijk, which separates the North Sea from the Ijsselmeer, are manoeuvred so as to permit the entrance of the elvers with a minimum passage of salt water.

Van Someren also deals with damage caused by barrages for hydro-electric, irrigational or storage purposes. He deals particularly with the migrations of salmon in Scotland and with the need to help fish to pass dams and barrages and, through the use of screens, to prevent fish from entering draft tubes and turbines.

Stuart examines protective measures introduced in Scotland against the effects of drainage works for flood control and agricultural purposes which are usually detrimental to salmon and trout fishing.

In drainage canals in which the water velocity is increased and silt kept in constant motion, the fauna is destroyed, spawning beds disappear, and there are no resting places for fish or shelter from predators. While it is preferable from a fishery point of view that drainage channels should have a sinusoidal course, a rectilineal one will usually be adopted for economic reasons. It can be shown however that such rectilineal channels can be adequately modified, without incurring additional costs, to favour the spawning of Salmonidae and conserve water.

Clay gives an example of flood control measures which have been achieved without harm to anadromous fish, in the Okanagan River Flood Control Projet: this was obtained by maintaining the required original physical conditions during the spawning and incubation periods and by providing ready access over the drop structure to the spawning areas above.

Different problems are found in tropical regions.

Van Someren compares the observations made in Scotland with those pertaining to East Africa. He refers especially to Kenya and the reservoirs constructed, first to preserve the water for irrigation during the dry season and, second, for the production of hydro-electric energy.

The migrant species are *Anguilla nebulosa labiata* and *Barbus* in rivers flowing towards the Indian Ocean; and anadromous migrations are made by various species of *Labeo* and *Clarias* for which it will be necessary to construct fishways over dams in the rivers. Even low barriers are insurmountable for these fish.

To prevent great losses of eggs and fry during the periods of reproduction, the flow of water in the irrigation basins should be continuous and the bulk of it recovered in the principal waterways. Dry-foot crops with intermittent irrigation can be dangerous to fish; water crops such as rice, which need continuous irrigation, are advantageous; in fact, new forms of fishing are made possible, i.e., rotational crops of fish and rice.

Similar problems are exposed in Daget's report on the barrage of Markala on the Middle Niger. The growth of the fish is rapid when the river is in flood and interrupted with the coming of the dry season. At the end of the dry season reproduction occurs. The fish are scattered when the river is in flood, assembling again during the dry season. Anadromous non-productive migrations then take place.

The barrage of Markala, constructed at the highest point of the natural flood zone, disturbed the migration of fish but not their reproduction which takes place below the dam. A passage through the dam has not improved the situation to any extent.

Such problems require a different approach from that used in temperate regions because it is not a question of arranging for spawners to pass but to ensure the passage of enormous shoals of fish in search of food.

Beauchamp deals with the utilization of Lake Victoria for fishing and agricultural purposes.

This lake contains the plankton-feeding species *Tilapia esculenta* and *T. variabilis* which utilize plankton. Once this plankton settles to the bottom it remains fixed and cannot be utilized — thus causing a loss to the economy of the lake. In order to increase the quantity of fish, a phytophagous species, *Tilapia zilli*, was introduced to eat the shore vegetation (papyrus) and thus create spawning areas suitable for the reproduction of the plankton feeders.

Some parts of the shore, thickly covered with vegetation, can be reclaimed. The irrigation waters from these cultivated areas would increase the Phytoplankton. The mud at the bottom of the lake, very rich in organic substance, could be pumped and utilized as fertilizer.

Worthington deals with the problems pertaining to the improvement of the Nile waters and other African rivers such as the Volta in Ghana and the Zambezi in Rhodesia. For the Nile there are already the natural reservoirs of the Victoria, Edward and George, Albert and Tsana Lakes. For the other two rivers such reservoirs must be constructed. Thus, enormous extensions of water will become available for the production of aquatic resources, but there will also be involved other biological changes which will create hygienic problems including risks to health. Other problems needing adequate measures are those relating to water pollution.

Pentelow points out the difficulty, as industrialization increases, of preventing the discharge of polluted waters.

Only certain effluents can be evaporated and transportation of all wastes through conduits to the sea is impracticable. It is advisable to limit the quantity of water and use the same water as many times as possible in the same industry. Whenever possible, waste waters should be purified before discharge and organic substances oxidized. This can be done with percolating filters or through the activated sludge process.

Inert matter can be removed by physical means. There are various ways of eliminating the poisonous substances. Usually the water does not need to be purified; one must determine to what degree it has to be purified in relation to economic requirements. It is therefore necessary to know what degree of pollution can be tolerated by aquatic life.

Tarzwell also deals with pollution control. The problem must be studied and adequate measures should be taken in the light of a full awareness of the necessity for multiple water use. Remedies must be suited to local conditions and necessities and must be economically feasible.

Many facts must still be determined concerning the tolerance of fish to certain noxious agents. The problem is complex because the toxicity of many waste products depends on the characteristics of the water into which they are introduced (temperature, turbidity, pH, oxygenation, hardness, total alkalinity, etc.).

Water quality criteria must be established and enforced if the beneficial uses of waters are to be preserved.

## General Conclusions.

This review paper has dealt with the conservation of living aquatic resources from the point of view of conservation of the habitat and the natural biological equilibrium.

Aquatic resources are continually endangered and damaged by the growing economic necessities of man in relation to industry, navigation, ways of communication in general and agriculture, and whenever possible, it is necessary to protect these resources, minimize injury, and provide substitutions for those that are damaged.

With respect to those effects of water and soil utilization projects that are harmful, it is important that the interests of those concerned with aquatic resources be respected as well as the interests of those concerned with industry and agriculture.

Whenever possible, it is best to preserve natural habitats and balances or modify them as little as possible and restore them if altered. However, if economic conditions impose radical changes on habitat and equilibrium, it is necessary to determine the most practical way in which they can best be substituted for by new habitats and new balances. In order to achieve this purpose, the natural environments must be studied carefully before carrying out any program of soil and water conservation because although much is known of the living aquatic resources, much research is still needed.

Furthermore, each environment has its own characteristics, so that there cannot be a general solution — but each case must be studied separately.

A program for the protection of natural resources, integrated with all projects for the utilization of water for hydro-electrical, irrigation, industrial or other purposes, can prevent damage at the initial stage, and thus eliminate the need for subsequent remedies.

## Acknowledgments.

I wish to thank Dr. G. L. Kesteven and Mr. Wm. A. Dill of F.A.O. for having prepared an outline for the Symposium, for having placed me in touch with many of the contributors and for having prepared an excellent background paper for Part C.

I would like to thank Dr. P. A. Larkin for his extremely good background paper for Part B and all the contributors of experience papers.

I also wish to thank Mr. M. J. Girard of F.A.O. who has performed the secretarial work and directed the correspondence with the participants.

## COMPTES RENDUS DES DISCUSSIONS
## SUMMARY OF DISCUSSIONS

*Président-President:* P. A. LARKIN (Canada).
*Vice-Président-Vice-President :* G. ATHANASSOPOULOS (Grèce).
*Secrétaire-Secretary :* C. J. MCGRATH (Ireland).
*Rapporteur général:* U. D'ANCONA (F.A.O.).

### Séance du 15 septembre 1958, 9 h.
### Session of 15 September 1958, 9 a. m.

*The Chairman* declared the meeting open. He recalled that in accordance with the programme framed by Mr. D'Ancona the study of the theme was based :

— on a general report (Mr. D'Ancona) first stating preliminary definitions (Point A of the working plan) and then summarizing the whole of the reports dealing with points B and C of this plan.

— on two background papers (general survey of the problem), one relating to « The effect of various conservational measures or works on the aquatic environment and on the stocks of that environment » (point B of the working plan; author : P. A. Larkin, Canada); the other dealing with « Methods of minimizing the deleterious effects of water- and land-use practices on aquatic resources » (W. A. Dill and G. L. Kesteven, F.A.O.).

— on thirty-one special reports (regional examples, personal experiences, specific questions).

In the first session, the Rapporteur General assisted by the authors of the two background papers would make a brief statement summarizing the theme and endeavour to draw the general conclusions arising as a result.

In the second session, the authors of the special reports would be asked to speak. There would then be a general discussion and finally, resolutions would be submitted and discussed.

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*The Chairman* then called upon the Rapporteur General to address the meeting.

*Mr. D'Ancona* thanked his collaborators. He went on to introduce his report, of which he summarized the first part, dealing with the elements of the conservation of soil and water and of natural aquatic resources.

*The Chairman* thanked Mr. D'Ancona and went on to outline the main points of the background paper of which he was the author.

*The Rapporteur General* again rose to speak and summarized the special reports dealing with this part of the study.

*Mr. Dill* (F.A.O.) then introduced the third part of this study in a statement based on the background paper he had drafted in collaboration with Mr. Kesteven.

Complementing the statement by Mr. Dill, *Mr. D'Ancona* made reference to the special reports relating to this third part. Finally, he read the conclusions arrived at in his general report.

*The Chairman* asked that the texts of the resolutions to be discussed at the second session should be remitted to the Secretary before the commencement of this session.

He then asked the meeting if there were further points to be raised in respect of the statements heard.

*Mr. T. A. Stuart* (Scotland) asked to make an amendment to the summary of his paper appearing in the general report, modifying his statement to the effect that drainage channels should not be rectilineal but should have a sinusoidal course to form suitable zones for spawning.

*Mr. A. Maar* (S. Rhodesia) asked that in the enumeration of man's actions on land and water made by Mr. D'Ancona at the beginning of his report, the use of water for pisciculture should be added. Likewise, a little further on, pisciculture should figure as one of the possible objectives for the construction of dams and hydraulic installations. He pointed out that in Rhodesia a number of dams had been built exclusively for fishery purposes.

*Mr. D. Hey* (South Africa) raised the question of three problems existing in South Africa and which had not been mentioned in the reports :

1. The increasing water usage by riparian owners leading to severe reduction in the flow of water or even to streams drying up completely.

2. Although many excellent large reservoirs were being built fisheries were prohibited for public health reasons.

3. The question of speed-boats on inland waters and their effects on the fisheries.

*Mr. E. B. Worthington* (United Kingdom) supported Dr. Hey's statement concerning the growing risk to aquatic life of recent developments in overhead irrigation techniques which involve pumping large quantities of water from small streams.

He went on to say that this had recently become a problem even in Great Britain, in spite of the wet climate. It concerned many other countries and might be an appropriate subject for a resolution.

*Mr. D'Ancona* agrees to this proposal.

*The Chairman* then asked Mr. C. H. Clay (Canada) to comment on this problem of the reduction of the flow of water caused by irrigation, a question that Mr. Clay had himself studied in Canada.

*Mr. C. H. Clay* (Canada) stated that in British Columbia this was a problem connected with the conservation of the Pacific salmon and resident trout. What appeared to be necessary in the first place was a rational method of determining how much water should be left in a stream to support fish life to any desired degree. Research had not yet developed such a method. The question of recognizing the need for leaving sufficient water for fish-life was a matter of government policy.

With the question in mind of defining a general attitude in face of the problem of aquatic resources, *Mr. H. H. Shoemaker* (United States) moved that a number of important questions of principle should be put before the next technical meeting of I.U.C.N. He said that the necessity of producing more food and energy and of developing aesthetic facilities for an expanding human population was recognized by all, but, he asked, in face of this problem which is of the highest interest to I.U.C.N., would it not be appropriate to put to ourselves the following questions :

1. Should we adopt, in our approach to I.U.C.N. problems, a philosophy recognizing that man has an ethical responsibility to a Nature of which he is only a part ?

2. Can a policy be adopted regarding the approval or disapproval of introductions of exotic species ?

3. Recognizing the threat to communities of plants and animals and other aspects of nature arising from the inevitable increase in world population, should not I.U.C.N. invite scientists to intensify their efforts to study and record present natural conditions and to ensure the preservation of these records for future generations ?

*The Chairman* asked members to consider the question of proposals for other resolutions which might be discussed at the next meeting.

*The Chairman* declared that in his opinion the essential principles to be followed in the matter of the conservation of aquatic resources were as follows :

— the need for adequate planning for the development of natural watersheds, taking account of all possible resource uses;
— measures to be taken to avoid pollution of water-courses and to rectify it wherever it occurs;
— further efforts to increase our knowledge in this field.

*The Rapporteur General* added that it would be useful to emphasize in the resolutions the need for coordinating production and protection. He agreed with the Chairman as to the necessity of multi-purpose planning, which must include the problem of conservation and improvement of living aquatic resources, and of fishery productivity in particular.

*The Chairman* thanked the assembly and adjourned the meeting.

## Séance du 16 septembre 1958, 9 h.

## Session of 16 September 1958, 9 a. m.

*The Chairman* asked the rapporteurs present to comment the papers submitted.

The following addressed the meeting in turn :

*Mr.* C. *H. Clay* (Canada) author of the report: « The Okanagan River Flood Control Project ».

*M. A. Lindroth* (Sweden) author of the report: « Anadromous fish conservation in a Swedish salmon river ».

*Mr. C. J. McGrath* (Ireland) author of the report : « Dams as barriers or deterrents to the migration of fish ».

*Mr. A. Maar* (S. Rhodesia) author of the report : « Dams and drowned-out stream fisheries in Southern Rhodesia ».

Mr. *T. A. Stuart* (Scotland) author of the report : « The influence of drainage works, levees, dykes, dredging, etc., on the aquatic environment and stocks ».

*Mr. E. B. Worthington* (United Kingdom) author of the report: « The influence of soil and water conservation on natural aquatic resources ».

In a paper presented at the meeting on scientific research of the dam-basins of Northernmost Finland, *Mr. Niilo Söyrinki* (Norway) said that seasonal variations in the head of water were hindering the economic use of the water courses of Northern Finland.

It was planned, as a corrective, to build ten regulation basins with a total area of 1,100 square kilometres on the upper reaches of the River Kemijoki and its tributaries.

About 100 farms in this sparsely populated area would be flooded and the owners resettled in the neighbourhood. The important question of conducting research for the purpose of determining compensation was one in which the Finnish League for the Protection of Nature had taken action. But it was no less vital, said Mr. Söyrinki, to take the inventory of the vanishing fauna and flora of the dam basins. Another important question was the effects of the flooding on the forests and on the fish and wildlife of the area. Experts had already been working last summer under a joint programme planned by a research council directed by the speaker to conduct research into these questions. One of the main themes was the study of the vegetation and the wild life of the Aapa moor, the largest peat bog in Finland and Scandinavia, which would be flooded by one of the dams.

Mr. Söyrinki went on to speak of the climatic changes which these great masses of water might cause. It could be expected that the local climate would become milder, particularly in the autumn. As the basins would be mostly emptied before the spring thaw, thick blocks of ice would remain, melting slowly, and causing the climate to become unusually cold at the beginning of summer.

Mr. Söyrinki said in conclusion that it was of the utmost importance that such vast projects, affecting nature conditions on a large scale, should be carried out under strict scientific control and that, in the case at point, the engineers would have completed the project without consulting the biologists if the Finnish League for the Protection of Nature had not taken charge of the matter.

The authors summed up the main points of their reports (see appendices). A number made additional comments.

*Mr. A. Lindroth* (Sweden) said that Swedish rivers emptying into the Baltic had already lost, in 1955, one third of their natural smolt production capacity and it was estimated that a further third would be lost by 1965. This was the reason why salmon conservation methods in Sweden had been concentrated on the artificial production of smolts. The cost of an artificially reared smolt amounted to about 2 Swedish Crowns. On the. basis of an estimated 10 Salmon, at an average value of 40 Crowns each, recaptured per 100 smolts released, the ratio of costs to profits would be in the proportion of 1 to 2. In reality, however, said Mr. Lindroth, the returns from this investment for the country producing the smolts were less certain than appeared: they were obviously determined by the natural survival rate of fish released, but depended also on what was done by other countries having fishery activities in the Baltic.

*Mr. McGrath* (Ireland) said that the diversion of the River Shannon for hydro-electric purposes had resulted in a marked decline in the run of spring Salmon. The spring run had previously represented 40 % of the total, but had dropped to only 4 % subsequent to hydro-electrification. Efforts were therefore made to offset these consequences by the proper regulation of river flow, (as in the case of the River Clady), and by building fish passes. The Borland Fish Lock on the River Liffey at Leixlip, County Dublin, had been the first of its type ever built. Salmon apparently experienced no difficulty in passing through it, but both upstream and downstream migrants seemed to have trouble in finding their way in. It was his personal experience, Mr. McGrath said, that in certain conditions the Borland Pass seemed to give rise to problems, for the discharge of a large quantity of water was necessary to attract fish into the bottom chamber; when, however, the water had to fall from any height, excessive turbulence was created which discouraged fish from moving up the shaft. Mr. McGrath also referred to the problems which arise in the designing of fish passes, when drainage waters are pumped into the river, so as to make the passes effective over wide ranges of rapidly changing water flow. It had proved essential to provide large pools in the river-bed at the outlet of the passes so as to form zones in which fish moving upstream could assemble or rest before entering the pass.

He went on to say that when river-beds underneath bridges were paved with stones to prevent the foundations being undermined by scour, steps had to be taken to facilitate the passage of fish over the stones. Where low concrete walls had been constructed across the river channel to dissipate the energy of the water, it had been found necessary to notch the crests so as to provide an outlet by means of which fish could escape downstream in low water.

On the other hand, in the fissured lime-stone areas of the West of Ireland, long stretches of river had been known to disappear below ground at times of low river discharge. In one case, at Crossmolina

(Mayo), a stretch of six miles of river-bed containing valuable spawning grounds had dried out with heavy loss of the young fish.

*Mr. McGrath* concluded his statement by stressing the need for developing drainage channel sections to meet drainage requirements without adversely affecting aquatic resources.

*Mr. A. Maar* (S. Rhodesia) quoted the example of Southern Rhodesia to show the valuable use to which reservoirs could be put for the production of fish. In Southern Rhodesia, dams had been built for the conservation of « waste » or run-off water which otherwise would have been a complete loss (as soon as the rainfall was more than 35 to 50 mm., the soil became saturated and could no longer hold the water). This was a form of water conservation which raised no problems from the standpoint of natural aquatic resource protection. It was, moreover, a valuable source of fish production and for this reason was being widely developed. Figures quoted in respect of the production of fish were astounding : an average of 400 lbs. per year and per acre; they obviously varied with the size of the dam and the fertility of the catchment area. The stocking rate was 30 lbs. of mature tilapia per acre. The production capacity of the reservoir could be raised by using fertilizers : production could then reach 1,500 lbs., and the stocking rate 100 lbs. of mature fish. It was the supply of fish food which limited production in this case. If fertilizers were applied at the same time as artificial feed was given, the production limit could be pushed up to 5,500 lbs. with a stocking rate of 700 to 800 lbs. per acre. In this case it was no longer the food supply but space that limited production.

*Mr. E. B. Worthington* (U. K.) emphasized the great diversity of conditions in impounded waters illustrated by two extremes of fish production : 2 to 3 pounds per acre and per year in Norway (Mr. Aass) and up to 5,500 lbs per year and per acre in Southern Rhodesia (M. Maar). He suggested that many of the great works in controlling water should be related more closely to the even greater works achieved by Nature. The example of the drainage basins of the African continent was instructive in this respect. They had set the scene for the unique evolution and speciation of 2,000 or so species of African freshwater fishes. Mr. Worthington went on to speak of the natural reservoirs of the White Nile which compare strikingly with the catchment basin of the Blue Nile where gigantic natural erosion had allowed the development of the Egyptian civilization. The series of major dams and other works of water control being added to this natural system are steadily enlarging the aquatic resources.

Finally, *Mr. Worthington* opened the general discussion by drawing attention to two examples of recent accidental introductions of exotic species which presented a serious threat to aquatic resources, namely : *Eichornia crassipes,* now established in most African catchment areas, and a species of *Argulus* which had appeared as a fatal parasite of eels in the Venetian Lagoon.

*Mr. D'Ancona* stated in this respect that according to an identification by the U. S, National Museum, they belonged to the species *Argulus recticulatus* which had previously been known only in Congo Rivers : this parasite may have been transported to the Venetian Lagoon by migratory birds.

*Mr. Th. Monod* (France) made a statement on the biological aspect of the question :

1. It should not be thought that although there were no salmonidae in the great tropical rivers, these waters did not contain migratory species which were perfectly capable of existing (middle reaches of the River Niger, etc.).

2. With reference to the introduction of species which may prove harmful in a given environment, a singular instance was that of a lamellibranchial mollusc (*Anomia ephippium*) which had caused damage to an electrical plant in Dakar.

3. If the association of pisciculture and rice-growing could be favourably envisaged, it should not be forgotten that there were fish species harmful to rice (example : various Charcides present in the middle reaches of the River Niger).

*Mr. Athanassopoulos* (Greece) asked the Rapporteur General if he could explain the decrease in the numbers of elvers (young eels) entering the rivers, which had been observed throughout the whole of Greece, and what measures could be taken in this respect.

Replying to this question, *Mr. D'Ancona* said that the decrease in the numbers of elvers seemed to be a general phenomenon in European rivers. Dams were increasing the difficulties of the upstream migration of elvers and of the downstream migration of mature eels, especially females. It was becoming more and more difficult for them to reach the sea but there was little to be done to remedy the position. It was, on the other hand, possible and advisable to protect elvers and to distribute them in lakes and ponds to ensure their development and thus improve production.

M. D'Ancona also referred to the progressive disappearance of the sturgeon and expressed surprise that no comment on this disappearance had been made at the meeting.

*Mr.* W. 5. *Hoar* (Canada) spoke of the problems which the use of the rivers of the North-West Coast of North America for the development of power projects presented for fishery resources in the area. The greatest fisheries resources were based on a genus of highly specialized migrant salmon *Oncorhynchus* which used the rivers primarily as a nursery and exploited the rich resources of the Ocean for growth. Two of the species were so specialized that they had to reach the sea at a very early stage of development or perish. The Pink Salmon *O. gorbuscha* was an extreme case. After its first schooling it lost its hiding behaviour and swam in surface schools. It then became extremely vulnerable to predator attacks in fresh water and any area of impounded water which slowed its migration to the sea might seriously endanger the species. With one exception, all five species were obligatory migrants and the inevitable delays which the construction of power projects caused in the migrations presented a serious problem.

*Mr. H. Luther* (Finland) remarked in respect of the transport of aquatic organisms and their introduction to waters in which they Were previously unknown, that ships' ballast (water shipped as trimming in certain ports and discharged in others) was a medium that had as yet been little studied. It was supposed, however, that *Eriocheir sinensis* (the Chinese Crab), a notoriously harmful species, had been introduced to European waters in this way. It was perhaps alsoi the case of the « oyster thief », the alga *Colpomenia peregrina*, and if the *Argulus* recently found in the Venetian Lagoon were the American species it may very well have been introduced with trimming water pumped into the Lagoon. In any case, said Mr. Luther, it seemed important to pay greater attention to the study of this way of propagating organisms which was liable to have very serious consequences.

With further reference to the subject of exotic species, *Dr. D. Hey* (South Africa) said that the Inland Fisheries of Cape Province had been based on the acclimatization of species introduced to these waters. There had also been undesirable introductions which were to-day creating a serious problem (such as Carp and Bluegill Sunfish). Dr. Hey suggested that the problem of « exotics » in all its aspects should be studied by I.U.C.N. at one of the next Technical Meetings.

*Mr. E. B. Worthington* (U. K.) drew attention to two points in relation to fish passes :

— at the Jebel Aulia dam, a fish pass had been installed, primarily for the migration of Lares, but biologists had not been adequately consulted in respect of the construction and it had turned out to be inefficient : the entry was too far from the sluice water and this point had been illustrated in other papers submitted at the present meeting;

— at the Owen Falls dam, no fish pass had been considered necessary, but it happened that small, relatively inactive fish managed occasionally to pass through the turbines in still water when the turbines were stopped for cleaning.

Supporting Dr. Hey's statement, *Mr. A. Maar* (Rhodesia) emphasized the fact that the introduction of exotic fish to the African continent had always been very much questioned and that it had been conducted without sufficient scientific control. As regarded the association of fisheries with rice-growing, Mr. Maar stated that with a moderate stocking rate (30 lbs of *Tilapia mossambica* per acre) an increase was obtained in the yield of the rice-fields (6 %); with a higher stocking rate the rice yield was diminished. With these moderate stocking rates, the yield in fish was low (150 to 250 lbs per acre); it would be of interest to be able to increase the stocking rate, and therefore the productions of fish, without adversely affecting the rice crop, or to arrive, in other words, at a better adaptation of combined rice-growing and fish raising. It was to be noted that under certain conditions. *Tilapia mossambica* was also capable of completely destroying the rice fields.

*Mr. A. Lindroth* (Sweden) pointed out that over-saturation of water in aerial gases, such as occurred at overflow dams and natural waterfalls as a result of dissolving gas bubbles, could have adverse effects on fish. Fish mortalities had been recorded in Swedish rearing stations, caused by this oversaturation. It was, moreover, said Mr. Lindroth, easy to avoid the risk by allowing the waters supplying the hatchery to recover their normal gas content through aeration.

*Mr. Ahmed Abdel Nabi* (Sudan) thanked Mr. Worthington for his reference, in his report and in statements made verbally at the meeting, to the problem of the development of the Nile which was of great importance for the Sudan. He went on to point out that Sudanese Government services were aware of the questions raised by the construction of dams in relation to fish migration. When the Sennar and Jebel Aulia dams had been constructed, there had been no Fisheries Department. This situation had since been remedied and an Inland Fisheries Research Institute had been established in 1957 under the general Programme for the Development of Resources. A Sudanese hydrobiologist was at present taking a F.A.O. study course in the United States. Biological research work had already been started by Khartoum, University to some extent and good results had been obtained.

*Mr. W. A. Dill* (F. A. O.) made a statement in respect of two special points :

1. The usefulness of fish-culture in rice-fields was a difficult matter to appraise in a general way because it was practised under very variable conditions in different parts of the world which were not easily comparable. The Indo-Pacific Fisheries Council was collecting information on the subject.

2. As regarded the introduction of exotic species, it was generally believed that there was a better chance of success, from, the survival standpoint, when dealing with fish than with other living creatures, birds or mammals for example. This belief increased the danger, for the consequences of these introductions might prove very serious for the natural aquatic fauna. A special case was that of introductions which had been brought about mistakenly through misidentification of the species, of which Mr. Dill gave a number of examples.

Remaining on the subject of the introduction of exotics, Mr. *McGrath* (Ireland) recalled the investigations of Went (1957) which indicated that Pike (*Esox lucius*) was a species that had been introduced into Ireland. It was now very widespread and was a serious predator on salmonid fish. The investigations of Toner (1957) into the stomach contents of pike removed from one Irish lake had shown that the 6.4 tons of pike so removed had consumed in the previous twelve months 64 tons of brown trout (*Salmo trutta*) which, according to Toner, represented a loss of about 16,000,000 ova to the spawning stock of the lake. Similarly, Healy (1957) had arrived at the conclusion that Dace (*Leuciscus leuciscus*) and Roach (*Radius rutilus*) had been introduced to the Munster Blackwater, where they were now very widely distributed. Examination of stomach contents had indicated that the Dace in particular was a very serious competitor for the food of the salmonid group.

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The list of speakers being closed, *the Chairman* of the Session turned to examine the drafts of the resolutions. Agreement was finally reached on a statement prepared by Mr. McGrath, to which a restricted committee is to give a definite form (see Conclusions appended).

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*The Chairman* then gave a short summary of the debate. He emphasized that the discussion had shown how aquatic resources, like terrestrial resources, were influenced in the most profound way by the different human activities in the fields of conservation and of the development of natural resources. There was no question that concern for the protection and the productivity of aquatic environments fell in the sphere of interest of the I.U.C.N.

The discussion had also shown that the study of aquatic environments and the effects on them of man's activities were active fields of investigation in many parts of the world at the present time. Some of the projects of resource development might harmfully influence these environments and much of the investigation to date had been devoted to finding remedies to these effects; efforts had been made to encourage their widespread adoption. In other parts of the world, great advantage had accrued from conservation works and many major developments have created new aquatic areas of great productivity.

But the diversity of problems in the adequate protection of aquatic resources had also underlined the great need for further investigation and for still more intensive research. It was to be hoped that I.U.C.N. would continue in the future to attend to the problems relating to aquatic resources and have further discussions on the subject.

Upon this conclusion, the Chairman declared the meeting closed.

# THE EFFECT OF VARIOUS CONSERVATIONAL MEASURES OR WORKS ON THE AQUATIC ENVIRONMENT AND ON THE STOCKS OF THAT ENVIRONMENT

BY

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BACKGROUND PAPER

The structure of any natural community of plants and animals living in a particular area is determined by :

*a*) the opportunities that have been available for distribution of organisms;

*b*) the nature of the physical and chemical environment of the area and;

*c*) the biological interplay between the organisms — which takes place in the specified physical chemical environment.

Over long periods of time plant and animal communities may evolve, and in the shorter run, shifts in physical and chemical conditions may favour first one group of organisms and then another. But characteristic of organic associations is a relative stability which provides some basis for describing their structure and predicting effects of man-made changes to the environment. Accordingly, environmental changes are best classified by their effects on organisms and on organic communities rather than by the reasons for which the changes are made. For example, an understanding of the role of turbidity in stream productivity and the biology of the stream organisms provides insight into the effect of any type of project that might change turbidity (power dams, pollutions, placer operations, soil conservation measures, etc.).

In this outline, an attempt is made to describe probable effects of man-made changes by considering present knowledge of :

*a*) the productivity of aquatic environments;

*b*) the requirements of aquatic organisms;

*c*) the requirements of fish populations.

At each of these levels, reference is made to examples of conservation works which have caused the type of effects in question.

**Lakes**

Four groups of factors are instrumental in determining levels of productivity in lakes. First of these groups is factors of *lake morphometry.* Productivity per unit area lessens with increases in mean depth, area, slope of shoreline and fluctuations of water level, and is enhanced by increases in irregularity of shoreline. Thus, enlarging a lake basin by constructing a storage dam will usually increase the productive area, but this gain will be offset by a decline in per unit area productivity. A substantial increase in shoreline irregularity, or formation of a new shoreline with lesser slope may augment productivity. Where the size of a lake basin is small in relation to the volume of inflowing water, an increase in lake volume may temper the deleterious effect of excessive rates of « flushing ». Morphometric indices can thus give a valuable first approximation of general effects on productivity of a proposed change to a lake environment.

*Climatic factors* are the second determinant of lake productivity, Temperature, length of growing season, duration and intensity of solar radiation, wind and rainfall, all directly influence production of aquatic organisms. While man's conservation activities may not directly influence the climate to which a lake is exposed, by changing lake morphometry they greatly modify the interplay of climatic factors and water movements, in this way causing extensive changes in physical lake structure. Thermal structure, extent and duration of thermal stratification, heat budget, efficiency of circulation of dissolved gases, nutrients and suspended solids may all be different in a new lake from conditions in the original lake basin.

Third of the groups of factors determining lake productivity is the *edaphic influences.* Greater quantities of dissolved electrolytes and suspended organic matter are associated with higher levels of production. Supplementing natural inflow of lake nutrients with inorganic and organic fertilizers, both common consequences of conservation projects, results in increased productivity, but if done in excess can cause dislocation of lake metabolic processes. Culturally influenced lakes of this type are increasingly common as a by-product of man's activities. Large quantities of coarse suspended material can greatly limit light penetration and hence productivity.

*Biotic factors* are the fourth group of productivity influences. The combinations of organisms that comprise the biological community can determine both total production and size of crops of desired species. Lakes may be naturally deficient in certain floral and faunal elements and on the other hand may be free of undesirable species. Conservation projects that involve diversion of water (and hence organisms) to new drainages may have beneficial, negligible or catastrophic effects. Similarly, modification of a lake environment may indicate the desirability of introduction of species new to the region.

All of the groups of factors influencing lake productivity are interrelated in many and complex ways, so that a change in any one of them is not without far-reaching consequences in other facets of lake biology.

From present experience several types of effects of man's activities on lake productivity can be observed.

Many existing dams have lessened lake productivity by increasing lake-level fluctuation, or changing morphometric dimensions in unfavourable ways. Some reservoirs that have been formed where naturally only streams existed have virtually created a new productive aquatic environment. Artificial eutrophication of lakes has been observed in various degrees with both favourable and unfavourable consequences. In general there is a paucity of the type of information on lake biology in relation to man-made changes which would enable confident prediction of characteristics of the modified or newly formed lake. It is important to realize that while our fund of knowledge is growing in these fields, further studies are needed in which assessments of effects of changes involve an integrated appraisal of lake biology both before and after the event.

**Streams**

In running waters, productivity is influenced as in lakes by physical factors of morphometry and climate, and by chemical and biotic factors.

*Morphometric factors* in streams comprise all of the changes of physical dimensions commonly associated with position of a stream in a drainage system and its geological age. High productivity per unit area is associated with gentle slope, slow current, and stability of flow; all of which factors provide suitable permanent substrates for attachment and growth of stream-living organisms. Typically, productivity is highest in the lower reaches of drainage systems. However, in small headwater streams the steep gradient is often irregular. In addition, small volume of flow in relation to stream width may prevent excessive velocity in the centre of the stream. In consequence headwater creeks may provide proportionately more suitable habitat for aquatic organisms than larger streams of greater flow and lesser but more uniform gradient. Production in all running waters is strongly related to the lowest seasonal levels of flow. Thus all conservation works contributing to seasonal stability of stream flows result in increased production, whether they be headwater soil conservation projects or main stream storage devices.

The influence of *climatic factors* on streams is tempered by the distances the streams travel and the « climate » of the stream's point of origin. High temperature and ready light penetration encourage high productivity. Hence streams which originate from large lakes are characteristically very productive. Reservoirs which provide settling basins for silt or which provide warmer water downstream, enhance productivity.

*Edaphic factors* play primarily the same role in streams as in lakes, with increasing quantities of dissolved electrolytes and dissolved organic matter fostering higher production. Excessive fertilization from human activity can produce parallel changes to eutrophication of lakes, the dislocation of natural stream metabolism resulting, in extreme instances, in the production of a community of « plant and animal weeds ». Suspended coarse material and silt in streams not only reduces light penetration, but may scrub algal growth from gravel, compact bottom sediments preventing percolation, and smother stream bottom organisms. Soil and conservation measures which minimize erosion prevent excessive siltation in streams. Similarly, reservoirs by providing silting basins can cause improvement in downstream habitat.

As in lakes, the particular complement of organisms in streams may determine the degree and rate of conversion of nutrients into organic matter. Added to these *biotic factors* are the substantial contributions of allochthonous organic matter, both plant and animal, from the surrounding terrestrial communities. Productive levels in natural streams in forested areas may largely depend on these outside sources. Conservation practices aimed at providing watershed plant cover may in this way increase stream production.

Streams have not received as intensive study as lakes, but the beneficial effects of conservation measures and conversely the harmful effects of abuses of stream resources have been dramatic. In consequence, though the detailed pattern of stream biology is not well known, there is adequate experience on which to base predictions of major effects.

### Requirements of aquatic organisms

Communities of aquatic organisms have certain requirements which are usually provided in natural habitats. Many conservation practices either introduce artificial elements into natural situations or are aimed at removing man-made products from aquatic habitats. Some examples have already been given in the previous section. Aquatic organisms must have water — reduction in stream flow or fluctuation in lake levels essentially represent restriction of aquatic habitat. Associated with a sufficiency of water are qualitative requirements which influence both the number and kind of organisms which can live in an aquatic environment.

Limited *temperature* tolerances are well known for aquatic organisms. Extremes of temperature can exclude virtually all organisms, violent fluctuations in temperature are tolerated by only a few, and most productive aquatic environments are characterized by a relatively moderate and stable temperature regime.

*Oxygen* requirements of aquatic organisms are typically high and commonly can be defined precisely for particular species. Adequate appraisal of oxygen requirements should involve consideration of temperature, quantities of other dissolved gases (particularly $CO_2$) and description of the organism's ability to do work over a range of values for the contributing factors. Organic matter and a great variety of chemical wastes have a high « oxygen demand » and primarily for this reason they may be classed as pollutants.

Organisms require *dissolved nutrients* but excessive *acidity* or *alkalinity* or excessive quantities of dissolved electrolytes can eliminate most groups of aquatic organisms even if they occur for only a short period. Even moderate or small changes in pH can restrict occurrence of many aquatic organisms.

A *substrate* free of mechanical disturbance, abrasion and excessive quantities of organic or inorganic material from outside sources is required by the majority of aquatic organisms.

Most organisms require a medium free of *artificial chemical* toxins. Heavy metals, cyanides, mercaptins, phenols, chemical insecticides and herbicides, free halogens, oil wastes, and a host of other by-products of man's activities are toxics for which neutralization or exclusion are usually the only conservation measures.

The consequences of alteration of any of these major requirements of stream organisms are both quantitative and qualitative. Various species have different preferences and tolerances. Changes to the species composition of the aquatic community are often the first indicator of man's effects. Progressive deterioration is associated with elimination of more and more of the original flora and fauna and may culminate in a completely barren environment. The species of particular interest and use to man may be among the first to be displaced. A very detailed knowledge of their biology and their interrelations with other organisms is necessary to understand their loss or to predict the effects of a projected change to the environment. The last section of this brief review discusses this particular problem in relation to fish populations exploited by man.

### Requirements of fish populations

In simplest terms, a stock of fishes, exploited at a stable level, satisfies the equation : growth plus recruitment equals natural mortality plus fishing mortality. Changes in environment which influence these parameters will be reflected in the stock by changes in abundance and availability to fishermen.

*Growth* depends on the excess of anabolism over catabolism. Changes in factors related to rate of catabolism such as oxygen concentration, temperature and conditions of physiological stress may result in changed growth rate. Growth is highest when a particular combination of these factors permits most efficient work. A change in the temperature regime of a lake or stream may thus render the environment much less suitable for a particular species of fish, although production of all species of fish, or of all aquatic organisms may be enhanced by the same change in temperature. Perhaps a more common (and better known) effect of a change in environment is a shift in the relative abundance and availability of food items with its associated consequences on anabolism. A great number of examples are available of changes in growth rate of fish in altered environments. In general, increases in productivity result in accelerated growth rates. Raising of lake levels is often accompanied by an immediate increase in growth rate but this may be only a temporary phenomenon and caution in interpreting results is advisable. Decreases in growth rate occur both from lowered productivity or from more subtle changes to the environment. Fish characteristically feed in stereotyped ways on certain items of food in particular places. In a changed environment fish may not utilize the new food resources because (*a*) the food may occur in zones which the fish will not enter, or (*b*) the food items available may not be acceptable to the fish.

In some instances a particular item of food may play a key role in growth at one stage of development. Certain plankters may be necessary at early growth stages; bottom organisms may be required to accomplish a transition from plankton feeding to a piscivorous adult diet, or a particular fish may be a preferred prey species; in any of these instances the effects of the change in environment on abundance and availability of key food species may be of major significance.

Adequate *recruitment* to a stock depends on existence of and access to suitable areas for spawning and rearing. Migratory species can be decimated by obstructions in their migration routes to spawning areas. The familiar example of species of Pacific salmon (*Oncorhynchus*) provides abundant information on which to assess the effects of conservation measures. Salmon are capable of only limited « athletic » performance. A multitude of considerations delineate the specifications of successful fishways, fishladders, fish lifts and so on. At present there exists no entirely satisfactory and economical method of assisting adult migrants up past a series of dams. Delay of adults results in reduced effectiveness or failure at spawning. Similarly the downstream migration of the young is occasioned by delays in reservoirs and losses over spillways and through turbines. Methods of minimizing these losses by guiding migrants to safe by-passes are currently being studied intensively, as yet with no complete success.

The requirements of the spawning area may be very precise not only for salmon but for other species of fish. Spawning mechanisms are adapted to features of the environment. Deposition of eggs may occur only when particular behavioural patterns can be followed. If spawning occurs at other than the optimum time of year or if temperature regimes depart from the natural, early developmental stages may suffer severe losses. Fluctuations in water levels in lakes and streams may have great significance in causing losses of unhatched eggs and juveniles.

Losses of the type mentioned above lead naturally to a consideration of mechanisms of compensation in *natural mortality* schedules of fish populations. Theoretical models, based on broad practical experience, suggest that fish species vary in their ability to respond to increases in mortality at early stages of development by increased survival at later stages (or vice versa). But evidently, any continued additional factor of mortality must eventually find compensation in increased fecundity. While this may be within the biological capacity of the species it may take so long as to witness economic ruin of the fishery. To date, attempts to provide appropriate compensation by artificial methods, such as hatcheries, have been expensive, only partially successful and fraught with a multitude of unforeseen problems. Any increase over natural mortality rates in fish populations in new environments should thus be viewed with concern, for the only satisfactory compensation would appear to be in lessened exploitation of stocks by man.

*Fishing mortality* may be influenced directly by changes in environment. In response to new conditions there may be new patterns in the distribution and movement of fishes that will frustrate traditional fishing methods. Some of these may be temporary effects offset both by gradual settling down in the fish population and development of new techniques by the fishermen. Other effects may mean permanent shifts in levels of fishing mortality. Flooding of standing timber in reservoirs can greatly restrict the pleasure, convenience, economy and safety of both angling and commercial fishing. More subtle changes may render fish particularly susceptible to capture at certain seasons and may necessitate restrictive regulations. Conversely changes in regulations may be necessary to allow exploitation of a population with changed growth rates.

In the final synthesis of effects of conservation works or other structures on fish populations it will be necessary to consider the complex interrelations of the desired species with its *predators and competitors.* Changes in environment may either favour or discourage growth of populations of these other animals. Moreover, new forms may be introduced by diversion of water from other drainages. The interaction of various species combinations in fresh water environments has been the subject of much observation and speculation. The only appropriate generalization might be that it is simpler to explain what has happened than what will happen. In some instances undesirable species have become dominant after changes to natural waterways, in other cases the desired species has gained advantage and in still other situations the opportunity for artificial manipulation of environment has been used to control undesirable forms. The complexities of community structure in fish populations are perhaps the most challenging fields for present day fisheries research.

## CONCLUSION

Man's activities can change aquatic environments by :

*a*) modifying factors which determine productivity;

*b*) limiting the occurrence and abundance of aquatic organisms in general;

*c*) limiting the occurrence and abundance of specific aquatic organisms.

The effects of any conservation measures or works should be gauged by consideration of which of these types of changes it will create or rectify. In general, headwater soil and water conservation programmes by regulating run-off and reducing siltation are usually beneficial to aquatic environments. Main stem dams may create new productive fishing areas but may also decimate runs of migratory fishes. Pollution control programmes almost invariably result in improvement in production of desired organisms. But both for these types of measures and for a number of other types of conservation projects the effects on aquatic environments cannot easily be predicted from general principles or from experience elsewhere. Each project will have particular effects that can only be anticipated by detailed knowledge of the environment to be affected. Armed with this kind of information the aquatic biologist can suggest measures that will minimize harmful effects and capitalize on any opportunities for improvement. It will always be desirable to reassess the completed project and to revise programmes accordingly. Finally there is a continued need to seize upon these projects as opportunities for both applied and fundamental research. They represent experiments on a scale that is rarely available to the investigator.

# MULTIPLE PURPOSE PLANNING FOR AQUATIC RESOURCES

BY

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Originally, the exploitation of natural resources was a simple process. Irrigation was accomplished by dropping a log in a furrow across a stream to divert water; industrial use of water was negligible considering the supply; pollution was small in comparison with the amount of flow; coastal lowlands and swamps were not thought to be of any value; wetlands in agricultural areas were considered suitable only for draining.

With the rise of industrial technology and the explosion of populations, enough problems have arisen to make us realize that our water supply is not inexhaustible and that the exploitation or conservation of one resource can have important effects upon others. Of all these resources, water use has increased to a point where it is becoming one of our most precious commodities. The use of water has more than doubled in the last 25 years, and the requirements of modern industry and irrigation have increased at a much greater rate.

We now have programmes for conservation of agricultural soils, of waters, of forests, of fish and wildlife, and most of the other natural resources. The purpose here is to examine some of these programmes, especially those dealing with conservation of soil and water, with particular reference to their effects on natural aquatic resources.

Natural aquatic resources include not only fish and wildlife species designated by law to be harvested for sport and private use, but also commercially harvested fin fishes and shellfishes and the more important fur-bearing animals. Some plants must also be included.

Aquatic environnments of many types provide the habitat essential to such important game species as waterfowl, rails, and shorebirds. and to our most important and valuable fur-bearing animals such as mink, muskrat, beaver, and otter. In many sections of the country, important wetland areas also are our most productive habitat for bear, deer, wild turkeys, and squirrels. In addition, marshes and densely vegetated wetland areas frequently constitute an important part of winter habitat needed for pheasants, quail, prairie grouse, rabbits, and other upland game. These are the resources upon which 16.2 million people depend for recreation.

All of our fishery resources, both sport and commercial, are, of Course, dependent upon aquatic habitats. Indeed, the coastal estuaries and coastal marshes are vital nursery grounds for important commercial and sport fishes, some of which were once thought to be entirely marine in nature. The sport fisheries provide recreation for 23 million people and the commercial fisheries produce 4,750 million pounds of food fishes. Over 2.85 billion dollars were spent in 1955 on sport activities related to hunting and fishing.

Soil and water conservation, as here used, includes all the numerous efforts currently being made to protect, manage, and use these resources in such ways that they will continue to provide maximum benefits to the human race, now and in the future. Practices advocated and used include a vast array of land treatment and water control measures such as reforestation, cover cropping, terracing, contouring, drainage, channel alteration, and dredging for navigation. Also included is the construction of impoundments for a variety of purposes including livestock watering, irrigation, flood control, pollution abatement, navigation, production of hydro-electric power, municipal water supply, and fish, wildlife and recreation.

Each of these water-use purposes is worthy in its own right and meets an important human need. However, each one also has some effect on natural aquatic resources, and such effects can be beneficial or detrimental. Reforestation, cover cropping, terracing and similar practices prevent erosion, stabilize soil, and hold water where it falls so that it may percolate slowly into the ground. The effect of such practices is generally beneficial since severe erosion contributes to stream turbidity which, in turn, prevents penetration of the water by sunlight. Without light penetration of water, photosynthesis by both the higher aquatic plants and the microscopic forms is eliminated. These microscopic plant forms are the basis of the food chain for virtually all fin fish and shellfish resources.

Soil erosion further contributes to silting of important stream riffles, smothering the abundant insect life important to fish. In estuaries, silting due to soil erosion frequently eliminates important shellfish and aquatic plant beds.

Practices which retard flood run-off through detention of the flow by impoundment can be either good or bad for natural aquatic resources, depending upon the consideration given these resources in planning, development, and operation of the project. Such impoundments usually have sport or commercial fisheries, or both. Sometimes, these are all profit no matter how mediocre in quality, while in other cases valuable high-quality stream fisheries for such species as trout, salmon, or smallmouth bass, which are highly prized sport fishes, are covered and destroyed forever, to be replaced by a reservoir fishery only mediocre at best. At the same time, these reservoirs may produce an abundance of « rough » fishes. These are less desirable in the United States and have little market as food.

Frequently, the effects of a major impoundment may be vastly more influential on the resources of other portions of a stream than at the actual impoundment site. For example, at high dams anadromous fish such as salmon, trout, striped bass, shad, or herring may be blocked from their ancestral spawning grounds because fish passage is not feasible. This results in reduced reproduction and smaller runs in the future. Usually, the impoundment inundates valuable spawning area, in addition to blocking the runs. At dams, where fish are passed upstream by fish ladders or lifts, mortalities occur to both upstream and downstream migrants. Generally, it is considered that the most serious problem is the safe passage of young migrants downstream over high dams.

Irrigation and power diversions also are hazards to fish unless adequate screening facilities are provided. Even these measures may not be completely effective. Diversion of streams or the alteration of flow patterns may result in permanent or frequent de-watering of stream channels which eliminate virtually all aquatic life. Intrusion of saline waters into estuarine areas may result from stream diversions, and alteration of flows may cause important changes in salinity patterns resulting in major damage to nursery areas and other natural aquatic resources.

Deep lakes or impoundments are frequently subject to thermal stratification during certain seasons of the year. Discharges of the de-oxygenated water from the bottom of such reservoirs may result in destruction of fish and other valuable aquatic resources downstream, particularly if flows are reduced during hot weather when oxygen demand of aquatic life is high. This is especially true when they are coincident with severe pollution loads.

The control of major floods generally is beneficial to aquatic life; however, flood control by flow regulation, leveeing, and methods which deny the frequent overflow of natural bottomland areas may cause considerable harm to aquatic resources. These are the areas that serve as spawning and nursery grounds for some of the most valuable food fishes. Seasonal flooding of bottomlands is the basis of productivity for many important stream fisheries.

In many sections, the major waterfowl wintering habitat available is the swamp forest shallowly flooded during the natural overflow periods. Some of the most important and mast-producing species of hardwood timber are native to the overflow bottomland swamps of major streams. They are best adapted to growth under natural conditions found there and produce much food for ducks.

Water developments for navigation in many instances have been extremely destructive to aquatic habitats of major importance to waterfowl, fish, and shellfish. An example of this was the dredging of the navigation channel in Currituck Sound, North Carolina, between 1918 and 1932.

Currituck Sound and its uppermost tip, Back Bay, in Virginia, comprised one of the most important traditional wintering grounds for waterfowl on the Atlantic Coast. It was a major wintering ground for the Canada goose, whistling swan, greater snow goose, coot, and a host of ducks, particularly the much sought redhead and canvasback. One of the most productive black bass fisheries in the United States also existed there. The basis of these important resources was the unrivalled abundance of submerged aquatic plants flourishing there.

For this shallow body of water, nature had provided a small watershed, the run-off of which delicately buffered the saline waters from Oregon Inlet far to the south, and the occasional overflows of ocean waters across the barrier beach to the east. These conditions, combined with nominal tides ruled by the wind, formed ideal chemical and physical conditions for the growth of wild celery, widgeongrass, sago and clasping-leaf pondweeds, bushy pondweed, and other valuable submerged aquatic plants. A host of insects, Crustacea, molluscs, fish and other life thrived in the luxuriant growth.

In 1917 a tidal lock was removed from a man-made cut connecting the North Landing River at the head of Currituck Sound with the Elizabeth River flowing north to Hampton Roads. Also, the controlling depth of the intracoastal waterway across Currituck Sound was lowered from about six feet to 12 feet. Between 1918 and 1932 over 12 million yards of spoil material were pumped from the waterway channel by hydraulic dredge and discharges into the Sound.

The resulting turbidity from the dredging, combined with the fluctuation of salinities, caused by salt water flowing in from Hampton Roads, alternating with fresh to brackish water flowing up from the south (depending upon wind and tidal conditions), dealt a near mortal blow to the abundant aquatic plant life of the Currituck-Back Bay area. Furthermore, following destruction of the plant life which had held wave action to a minimum, the increased wave action readily resuspended the layer of fine sediment deposited on the bottom during the dredging, thus perpetuating for years the turbid condition. The tidal guard lock at Great Bridge subsequently was restored in 1932 by Congressional mandate, and gradually this great area has made a partial recovery. Although again one of the great waterfowl hunting and sport fishing areas of the nation, it is far below the natural productive potential that it enjoyed prior to 1917.

This is an outstanding example of the destructive influence to aquatic resources which can result from water development without adequate multiple-purpose planning. Fortunately, some of this loss was recoupable through corrective measures. In many cases, once construction is completed, correction of damaging features is not feasible, even though losses could have been prevented at little or no added expense by adequate multiple-purpose planning in the early stages.

Drainage of areas for numerous reasons has caused widespread damage to various natural aquatic resources. Much of the drainage of course is justified in order to maintain good agricultural land in production, or to abate health hazards in heavily populated areas. However, much drainage in the past has destroyed valuable wildlife areas needlessly and to the detriment of ground water supplies and to the carrying capacity of farms for livestock. A considerable amount of such drainage is continuing today, some of it private, but much of it under a programme of Federal subsidy.

It is questionable whether such drainage can now be classed as a conservation measure in the United States, since it usually results in increased agricultural production at a time when Federal programmes are in operation to reduce production of agricultural surpluses. It is further obvious that, in areas of low rainfall, drainage of pothole areas may be a loss of valuable natural water resources. People of this area forget the droughts of the 1930's and the need for water resources to maintain stock and keep agriculture at a high level. Also, the loss of natural storage basins resulting from the majority of drainage, speeds the water downstream, often through straightened channels, to increase flooding of lower reaches, thereby increasing the need for impoundment, or for other flood control measures. A vicious circle indeed, and in any case, one in which natural aquatic resources are invariably lost.

A major problem in the planning for natural aquatic resources in multiple-purpose projects is the limited time available in which to conduct the studies necessary for intelligent biological recommendations. To begin with, in many instances, before the effects of a project upon fish and wildlife resources can be determined, it is necessary to know in relatively complete detail what the design and operation of the project will be. This means that the planning agency must be far advanced in its engineering studies before the fish and wildlife agencies can even begin their analysis of probable effects, and their development of recommendations to benefit aquatic natural resources.

In addition, there are still major gaps in our knowledge of the life history of some of our most important fish and wildlife species, the distribution, population density, and degree of human utilization they can withstand. There are complex hydrological problems involving density currents, thermal stratification, silting and the effects on downstream currents and salinity patterns for which no solutions are readily available.

None of these problems is insurmountable, but frequently much time and money are necessary to find the desired answers. In all too many cases in the past, neither time nor money was available in sufficient quantity, largely because our present laws do not provide adequate recognition of aquatic resources in water-development projects. It is hoped that legislation currently before the Congress will correct this deficiency.

Frequently it has been necessary to base planning recommendations for fish and wildlife on inadequate data. An outstanding example of this, and of the difficulty of correcting problems created by projects for which initial multiple-purpose planning was not adequate, lies in the Roanoke River Basin in Virginia and North Carolina. The most important spawning ground of the striped bass in North Carolina waters is located in the vicinity of the Roanoke River fall line at mile 129. The striped bass is a fish of substantial significance in both the commercial and sport fisheries of the Roanoke River and in the coastal sounds of North Carolina, into which the Roanoke empties. In 1952 the U.S. Army Corps of Engineers impounded the 87,900-acre Kerr Reservoir. It was authorized for flood control and hydro-electric power by the Congress. In 1955 the Roanoke Rapids Dam was constructed by a private power company under Federal license at mile 137, just above the striped bass spawning areas. A second private power development is proposed for the 33 miles of unimpounded stream between Kerr Dam and Roanoke Rapids Reservoir.

Rather severe sulphate pulp mill wastes were being discharged into the Roanoke River immediately below the site of Roanoke Rapids Dam at the time the Kerr Dam and Reservoir Project was constructed. Domestic sewage and other industrial wastes were also being discharged in this portion of the stream at that time. Federal and State fish and wildlife agencies recognized this problem and, in 1946, recommended for the operation of Kerr Reservoir minimum discharges considered adequate to protect the striped bass resource, especially during its annual spring spawning season.

By the time that Kerr Reservoir was constructed and in operation, however, the discharge of mill wastes into the river had increased tenfold. The minimum flows recommended for the protection of the striped bass resource were no longer adequate.

The license for the construction of Roanoke Rapids Dam was issued with the stipulation that the same recommendations for seasonal minimum flows as in Kerr Reservoir be observed.

Soon after Roanoke Rapids Dam was completed and placed in operation, the effects of inadequate planning and consideration for the fishery resources were apparent.

The discharge of oxygen deficient water from the bottom of the stratified reservoir, when combined with a high bio-chemical oxygen demand caused by pollution and high temperatures during summer, resulted in near anaerobic conditions in the river on week-ends when power was not being generated, and only minimum flows were maintained. The result was kills of fish and other aquatic life for some distance downstream. This was a severe threat to highly important aquatic resources.

Various steps have been taken over the past five years to provide answers on which corrective measures could be based. A cooperative study was organized by Federal and State fish and wildlife agencies and public health agencies, the Corps of Engineers, the power company, and other industries discharging wastes into the Roanoke.

In an attempt to avoid the discharge of oxygen-deficient water, the power company constructed a curtain wall around the turbine intakes at its Roanoke Rapids Dam to block subsurface water layers and force discharge from the surface layers which contain water of better quality. Studies of the effects of this weir are not yet complete, but indications are that under certain conditions thermal density currents may be set up which result in the discharge of water of even poorer quality than that obtained without it. The study is continuing and construction of the third dam proposed for the area is being delayed, pending a satisfactory answer.

The complexity of hydrological and biological problems involved on the Roanoke River is great, yet it is typical of those involved in many major water developments. The fishery resource is of major proportions, and the other water uses are of such importance that in 1956 the Congress authorized a re-study of the original project with a view to including fish conservation as a feature of the project along with other purposes.

The Currituck Sound and Roanoke River situations as described above are merely two of many cases which could be cited to illustrate the complex interrelationships between natural resources of all types. It illustrates the need for coordination between those interested in the various uses of water and in the present and future development of water resources. Our experience to date in these and other situations involving natural aquatic resources clearly indicates that these valuable resources can be preserved provided they are given adequate consideration in the basic planning for conservation of other resources such as soil and water. Generally, aquatic resources are a non-consumptive use of of water as opposed to consumptive use by irrigation, for example. Consequently, in the overall development of a river system a well-integrated programme for the benefit of aquatic resources does not detract from other uses of water. Without coordinated planning, the best efforts of fish and wildlife conservation agencies to preserve them may be futile. Because of the rapidly expanding use of water for industrial, irrigation, and other purposes, aquatic and wildlife resources will be greatly diminished if such planning does not take place.

Experience to date also emphasizes the need for including clear-cut authority for consideration in the basic authorities for all water conservation programmes affecting soil and water resources. Without such authority, truly multiple-purpose planning is rarely achieved.

# HYDRO-ELECTRIC POWER STATIONS AND FISHING

BY

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As in other industrialized countries, electric power consumption in Sweden has been growing at an extremely rapid rate. During the last few decades it has been increasing at the rate of 6.5 per cent a year, thus doubling itself every eleven years. There is no reason to expect a decreased consumption in the future. In Sweden by far the greater part of the demand for electric power is met by water-power, and although atomic power will no doubt be employed in the not too distant future, experts are nevertheless of the opinion that water-power will still be needed as a supplement during the heaviest load periods. We can thus expect a rapid exploitation of the still remaining reserves of water-power in the country.

In southern Sweden, most of the available water-power has already been in use for a considerable time, and during recent years building operations and projects have been concentrated mainly on our large rivers in Norrland, especially the Rivers Indalsaven and Angermanalven which are now almost fully exploited. In the years to come development projects will be centred more on the Rivers Umeälv and Luleav.

If we take as an example the case of the Indalsalven, we observe that it has altogether lost its original character. The former rapids have entirely disappeared, and the main river is now a kind of stairway with power-station barrages separated by damming stretches of slow-flowing water. Also the rhythm of the natural discharge of the water has been altered. The water of the great spring floods is stored in the larger lakes by means of regulating dams, and these storage basins are then tapped during the winter, when the demand for electric power is at its greatest. The damming of the water in the summer and its tapping in the winter cause great changes in the level of these regulated lakes. The following account is based on the broad lines of our experience with the regulation of lakes and the influence of power-stations upon fish and fishing, together with compensatory measures which might be taken.

## I. — **Regulation of lakes**

Regulation of a lake is effected usually by building at its outlet a barrage which dams the water above the normal high-water level. This is often combined with a lowering channel dug in the outflow, which brings the level below normal low-water level. According to the topographical conditions, the height of regulation varies considerably from lake to lake. The most extensive regulations imply variations of the water level of up to 20 metres. The lowest water level is reached in April, when the dam gates are closed in order to store the spring flood water which is then tapped during autumn and winter. In some cases a certain minimum outflow through the dam is stipulated, but often all the water is retained during the time when the storage basin is filled, the stretch of the river immediately downstream being at times left dry.

Regulation of a lake will influence, among other things, the reproduction of fish, the production of its food supply in the shape of benthonic fauna, its growth, and methods of fishing.

### The reproduction of fish

The most important fish in our lakes in Norrland are brown trout, char, and whitefish (spawning in autumn), and grayling, pike, and perch (spawning in spring).

Considering first such species as char and whitefish which spawn in the autumn in relatively shallow water upon a bottom of gravel and stones, these will find after the regulation of the lake that their spawning places now lie at a greater depth. One might therefore expect a shifting of the spawning towards a higher level, and that a major part of the roe would come above the water and die during the winter tapping. It has, however, been noticed that the spawning does not depend upon the depth, but rather upon the nature of the bottom. Thus, in spite of the greater depth, the fish continue to spawn partly in the old places after the damming. In so far as suitable bottoms come into existence in the newly submerged areas. part of the spawning will also take place there. There is therefore no doubt that some of the roe will be destroyed. For the char in Lake Torron, where the height of regulation is 14 metres, it has been calculated that up to 50 per cent of the roe will dry up during the winter. In spite of this, the number of char in this lake has not decreased after a regulation which has now been in operation for 20 years. The high mortality of the roe is obviously compensated for by a greater survival of the fry. Among the many lakes which have been examined in our country we do not know of one case of a great decrease in the numbers of char and whitefish caused by the changes in water-level as a result of regulation. We have on the contrary evidence of a rich year class of these fish during the first year of damming. This is most probably connected with the increased production of nutrition during the first years of the regulation, which will be dealt with below.

The roe of fish which spawn in the spring is not exposed to drying up, as at this time the water level is rising. The grayling, for instance, which in Lake Torron had previously spawned mainly in the outlets of brooks, after regulation found new extensive spawning grounds in those parts of the submerged area where erosion had exposed suitable gravel bottoms. The grayling has in fact maintained itself very successfully in this lake. This is due either to the fact that it has found better conditions for spawning, or to the fact that a stronger species acquits itself better in the competition for a reduced food supply. The pike, on the other hand, which spawns on bottom with vegetation, is in a more precarious position. In regulated lakes the high-water period is generally later than in those not regulated, and often does not reach the areas with vegetation at the usual spawning time of the pike. It has been observed that the spawning of this species can be postponed for a couple of weeks, but if by this time the water has not reached the vegetation area, no spawning will be possible. The spawning conditions of the pike are thus adversely affected by the strong influence of regulation on aquatic vegetation.

The species most seriously affected by regulation, however, is trout. As a result of the occasional drainage of the outlet of the lake below the dam, important places for spawning and growth are destroyed. The dam furthermore forms an obstacle to the trout's entry into the lake. The damming-up of the lower reaches of the afferent brooks reduces the spawning places within these areas also. Experience also shows a great decrease in the number of trout in regulated lakes. For a reasonable safeguard to production in the reaches of the river below the dam a certain continuous drainage combined with the insertion of a fish-ladder into the dam is required. This is, however, offset by certain disadvantages, the cost of the fish-ladder and the loss of water usually greatly surpassing the sales value of the fish. Attempts have instead been made to compensate the damage to the stock of trout by the artificial stocking of the lake with fry or one-summer-old fish. These measures have, however, not proved efficient. The release of one-summer-old trout, marked by clipping of the fins, or of older trout marked with plastic discs has shown that the reared fish have a very poor rate of survival after their release in the lake, probably due to the fact that it cannot successfully compete with the natural fish stock.

### Production of food supply for the fish

During the first years of the submersion of new areas by damming a great increase occurs of semi-pelagic and pelagic Cladocera, e.g. *Eurycercus.* Also a great number of terrestrial insects and worms find their way into the lake. It is obvious too that greater quantities of nutritive salts are conveyed into the lake, and experiments by the radio-carbon method which have recently been begun by the Limnological Institute at Uppsala have shown an increase of the primary production during the first year of damming. The first years of damming are thus accompanied by an increased production of nutrition. This is, however, of short duration, and conditions soon deteriorate.

The higher water level in the summer and the drainage during the winter cause the disappearance of the aquatic vegetation, which in the lakes of Norrland consists mainly of *Isoetes.* In the area which is laid dry during the winter, the bottom fauna becomes impoverished. *Ga.mm.aTUS,* which is important as food for the fish, disappears. The same thing happens with a number of important larvae of insects, while other groups are greatly reduced. A series of examinations of changes in the bottom fauna of a lake, in which the water level was lowered in winter to 3 metres below the normal low-water level, has given a preliminary estimate of a 60 per cent reduction in food supply. Also the turbidity which is caused by erosion can contribute to a lowering of food productivity in these lakes.

### Effects on the growth of fish

The above-mentioned changes in productivity of the lake are reflected in the growth of the fish. During the first years of damming the fish move to a larger extent to the new bottoms, and there nourish themselves on the terrestrial fauna washed out by the water. The result is a greatly increased growth. After 2-3 years, however, there is a rapid deterioration in growth, especially noticeable in char and whitefish.

Examinations of the feeding habits of char in regulated lakes have shown a decrease in the proportion of bottom fauna in the diet and an increase in plankton. In extreme cases, regulation can lead to the dwarfing of char and whitefish. Instead of causing a decrease in the stock of these fish, as was previously often supposed to be the result, the stock becomes too large for the altered nutritional conditions. The rapid deterioration in growth can be partly accounted for by the already mentioned fact that the good food supply during the first years of damming can give rise to rich year classes. Even 20 years after the regulation of Lake Torron, the growth of char is still greatly impaired in comparison with the time before the regulation. The introduction of reared fish, which has often been resorted to, is obviously inappropriate in such a situation. The only remedy lies in an intensification of fishing in order to thin out the stock. For species such as char and whitefish, therefore, regulation does not as a rule involve a decrease in the stock of fish, but by the impaired growth brings about a decrease in production.

#### Impediments to fishing

In the course of regulation of lakes rather large expanses of woodland are frequently submerged. Stumps and roots are left behind, even if the timber is cut down prior to the regulation, and most of the loose residue is burnt. In more exposed areas stumps and roots can be loosened by erosion in the course of years, while in the more protected coves they can remain *in situ* for several decades. These stumps and the branches and twigs which float into the lake obviously constitute a great hindrance to fishing, and considerably increase the wear on fishing gear, especially nets. Fishing with a sweep-net is often made altogether impossible. These more difficult conditions often lead to a decreased intensity of fishing, since the fishermen do not want to risk their gear. Experiments with new types of gear for regulated lakes are in progress. The draining of the rapids has also resulted in the disappearance of many areas which were of value for sport fishing.

### II. — **Power-Station dams**

Most of the power-stations are located along the main river. The fish which are concerned here are species coming up from the sea, like salmon, sea trout, and whitefish. From the economic point of view the salmon is by far the most important.

Our rivers in Norrland represent the most important spawning areas for the Baltic salmon. The ascent into the rivers usually begins in mid-summer, and spawning takes place in autumn in running water. After 2-4 years the smolt, which now has a length of 10-12 centimetres, goes down to the sea. The rich supply of food in the sea (small herring, sand-eel, stickleback, etc.) assures a very rapid growth so that after three years in the sea the salmon has reached a weight of between 8 and 12 kilograms. From the rivers in Norrland the salmon migrate all over the Baltic Sea, and stay to a large extent in its southern parts. Salmon are caught both in the rivers and in the sea. Of the total catch a quarter seem to be taken in the rivers, and the rest in the sea and along the coast.

Remunerative fishing for salmon in the Baltic Sea depends entirely upon a sufficient production of smolt in the rivers. The barrages of the power-stations not only form obstacles to the ascent of salmon to the spawning areas, but the damming also leads to a disappearance of the rapids where the salmon spawns and grows. The character of the stock of fish changes in these dammed areas : fish like brown trout and grayling, which spawn in rapids, disappear, and warm water fish, such as pike and perch, take their place.

As long as the river is only in part exploited for the production of electric power, and as long as spawning places are left above the power-stations, it is worth while building salmon ladders or, as is fairly common, to catch the salmon on its way to spawn, and to transport it in motor tanks past the barrages. In this case some of the descending smolt are, however, exposed to destruction when passing the turbines and also the storage basins with their predatory fish. With complete exploitation the river loses all importance as a natural producer of smolt, and there is no longer any point in the erection of constructions to facilitate the ascent of the salmon. In this case fishing for salmon in the rivers has to be abandoned altogether. The problem is then to maintain the sea-fishing of salmon, which is of great importance to the livelihood of the fishermen along the Baltic coast, not only in Sweden, but also in the other countries along the Baltic Sea. To deal with this problem « The Migratory Fish Committee » was formed in 1946, in which both the fisheries and the power-stations were represented.

After a discussion of different measures, the only solution to the problem was considered to lie in a replacement of the river phase of the salmon's existence by artificially rearing in troughs and ponds up to the time when the smolt are ready for emigration, and then releasing them in the mouths of the rivers.

For some years extensive experiments have been carried out with the marking of reared smolt, the aim being to find out whether or not a stock of salmon of normal size can be maintained in the Baltic Sea by such a method of hatching. The experiments are also intended to determine whether or not the value of the catch of reared salmon corresponds to the cost of the hatching. These experiments are finally intended to compare the different methods of hatching and release. It is calculated that the operation would pay for itself if about 5 per cent of the liberated smolt were caught. Up to the spring of 1957, 276,647 smolt have been marked, and of these, 5,078 salmon with a total weight of 16 tons had been caught up to June 1956. A great many of the marked salmon are still in the sea, and will give additional recaptures. The results of different experiments with marking have varied according to the methods of hatching and release. Thus release in the spring has given considerably better results than in the summer and autumn.

The percentage of recapture could be increased also by means of better methods of hatching. The release in the spring of 1953 resulted in a recapture of 7.3 per cent (or 281 kilograms for every 1,000 smolt), whereas the following year produced a recapture of 9.8 per cent (or 447 kilograms for every 1,000 smolt). The release of 1955 seems to promise still better results. Thus the recapture of the fish marked during the last years has exceeded the percentage considered necessary for making the hatching an economically paying proposition. It would thus appear that a stock of salmon can be maintained in the sea by the liberation of hatched smolt ready for migration.

The release of smolt has given much better results than that of brown trout of corresponding age in inland lakes. This seems to be connected with the rapid growth of the salmon after its entry in the sea. On account of the great increase in weight a relatively small percentage of recapture of salmon can give an economically satisfactory result.

With the aim of putting into practice these salmon-rearing activities which resulted from experiments for the protection of salmon stock, an assessment has been made of the average yield of the larger rivers both by weight and number of fish ,and also of the distribution of the areas of reproduction. The number of smolt released is based upon the ratio : 100 smolt to 1 salmon caught in the river. Thus the damage to reproduction in 1965 corresponds to 2.2 millions of smolt which have to be replaced by hatching. The implementation of this programme requires a yearly catch of 11 tons of mature female salmon, of 9 million of roe, and 1,700 tons of food, of which 400 tons are liver and spleen. The ripe salmon are caught on special fishing occasions at the lowest power-station in the river. The power enterprises consider this programme technically possible, and have built, or are building, large salmon hatcheries. The greatest difficulty will probably be found in the procuring of food. Also fish diseases might give rise to disagreeable surprises. For this reason a specially trained fish pathologist will devote himself entirely to the control and checking of diseases which may turn up among the hatched fish.

Even if it should be possible to save the sea salmon-fishing industry through this very large-scale operation, the country will nevertheless suffer a great loss by the disappearance of salmon from its rivers.


## Summary

Fishing in Sweden, especially in the watercourses of Norrland, is greatly influenced by the extensive regulation of lakes and by the dams of hydro-electric power stations.

In connection with the regulation of lakes, the greatest effect is on the stock of fish which spawn in rapids, through the loss of places for their spawning and growth. The fluctuations in water level bring about an impoverishment of the bottom fauna, and the production of fish food drops. This results in the slower growth of fish. Fishing with nets is rendered difficult in the drowned woodlands. The division of rivers into stairways that results from the power station dams damages the areas of spawning and growth of salmon. Extensive experiments with rearing and release of smolt are in progress, and experiments with marking have proved that it is possible by this means to maintain a stock of salmon in the sea,

# THE EFFECTS
# OF IMPOUNDMENT ON INLAND FISHERIES

BY

PER AASS

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Out of Norway's total freshwater area, between one half and a third has been impounded up to date, and the natural run-off of most of our larger rivers has been disturbed. By far the greatest number of impoundments are being carried out for the purpose of storing water for hydro-electric powerworks. In some cases the water level is only raised, but usually the lakes are also lowered below the previous water level.

In Norway precipitation comes as snow during the winter, and water is accordingly saved during the spring and summer months for use during the cold season. Already existing lakes are used as water storage basins. Only a couple of typical barrage dams have been constructed in order to create artificial lakes. Most of the impounded waters are typical salmonid waters with cold, clear water and few species of fish. They have a poor production of fish food and in most storage basins the natural annual yield of fish is between 2 and 3 lbs per acre.

It seems natural to characterize the effects of impoundment on fisheries in the following groups : Food and growth, propagation, migrations, size and composition of stock, and fishing.

### Effects on food and growth

In the long run the effects on fish food fauna will be practically the same, whether the impoundment consists in raising or lowering the level of the lake. Only the height of the regulation affects the degree of changes in the food fauna. Some species exhibit poor ability to withdraw with the lowering of the water level, and those that mainly inhabit shallow waters will be greatly reduced in number or killed off entirely. The organisms have no possibility of hiding in moist bottom material because the long-term drainage occurs during the winter, and the organisms will freeze to death. *Gammarus lacustris,* which is perhaps the most important of bottom organisms in Norwegian lakes, will be strongly affected by level variations of a few metres only, and variations of about 8 metres will usually result in total extinction of the species. In one lake, the lowering of the water level by 5 ½ metres reduced the number of *Gammarus* to one fourth in the course of one year. Among the snails, the Lymneids are most sensitive to variations in the water level, but even at extreme variations they do not seem to disappear entirely. The Planorbids manage somewhat better. Lamellibranchs suffer a nearly total loss in the regulated zone, but there are always ample reserves of these species in deep water. The more agile insect larvae always survive to some extent, the Ephemerids being the most important to fish.

The more indirect effects of water storage on the food fauna caused by the destruction of lake vegetation are not quite clear. It must be assumed that they are fairly serious, considering the role of vegetation as a hiding place and food production for bottom organisms.

The character of the water storage will be decisive as regards the immediate effects. Drainage of the storage basin will reduce the food fauna immediately and the growth and quality of the fish will be influenced in the first season. On the other hand, raising of the water level will flood areas of formerly dry land, and this will increase the food supply in various ways. Animals that live in the soil will be accessible to fish, and there will also be an increase in the amount of permanent water inhabitants. It is the various species of Cladocera that respond to the storage in this way, and among them *Euryceccus lamellatus* is the most important fish food animal. This increment is of limited duration only, and no food organism has as yet been observed capable of replacing in the long run the lost resources of food.

Along with the reduction in the food quantity also goes a deterioration in food quality. Fluctuations of the water level will cause erosion of the exposed beaches, and in most cases the area between the high- and low-water levels will change from soft bottom to a barren boulder beach. The fauna invading this area during a rising water level will be a rock fauna, less accessible to fish and probably of inferior value as compared to the crustaceans. In a number of lakes where the fish have been compelled to change from bottom fauna to plankton feeding, the result has been slowed-up individual growth.

Rapid variations of water level below the storage basins do not seem important to Tipulidae, Oligochaeta and Plecoptera, whereas ephemerid and trichoptera larvae are rapidly killed. Larvae of chironomids and simulids die quickly in the air, and are accordingly among the organisms that suffer most from drainage. A few rapid lowerings of the water level in the course of a year will not destroy next year's production of the organisms, but how frequent lowerings will influence the size order of the next generation is unknown. Re-colonization of drained areas that are again flooded will take approximately 20 days provided the areas were dry for only a short time (i.e. less than 10 hours).

Reduced availability of food may influence the quality and the rate of growth of the fish. Thus, the lowering of the water level by 5 ½ metres in a trout-char lake (*S. trutta* and 5. *alpinus*) was accompanied by an annual decrease in length increment in trout by ½ cm, and the condition factor (Fulton) fell from 0.97 to 0.90. The stock of fish, however, is to a certain extent capable of adjusting itself to the altered food conditions, and accordingly such growth reduction does not always follow. In a number of lakes where the impoundment was accompanied by substantial migrations out of the lake, the growth of the fish in the highly reduced stock rose again to the previous normal. The period of stabilization after an impoundment is dependent on the height of the drainage, but where water level variations in a trout lake are between 10 and 20 metres, fifteen or twenty years may elapse before a stable rate of growth is re-established.

In a few instances water storage may lead to increased growth. Such will be the case where large areas of dry land are drowned, but even then the increment of growth is a temporary phenomenon. In two lakes, that were raised by 12 and 18 metres respectively, the length increment of trout rose during four years from five to seven centimetres annually. The total yield of the larger fish rose to unknown heights. The rate of growth, however, soon decreased again as a result of the impoverishment of the erosion zone. After only seven years, it has sunk far below the original rate.

Under certain circumstances, impoundment may lead to lasting increase in the growth rate of fish or anyway in part of the stock. Species that show tendencies to stunted growth as a result of overpopulation may develop satisfactory growth rates if spawning facilities are sufficiently reduced. In a few lakes with mixed fish populations the reduction of bottom fauna has compelled trout to eat more fish, which they previously did not do. As a result the maximum size of trout in the lakes rose from 1 kg to 10 kgs. On the other hand, however, the portion of the stock that does not feed on fish is meagre and of poorer quality than before.

Even though it cannot be denied that hydro-electric impoundment has greatly reduced the available food for fish, it would be unjust to conclude that the total loss in the annual yield is due to this factor alone. Loss of spawning areas as well as increased difficulties in fishing may bring the yield below what food conditions might permit.

**Effects on propagation.**

Impoundment leading to total water abstraction from a river bed is fatal to species of fish that depend on running water. If, however, the impoundment only reduces the water flow, permanently or periodically, the stock of fish may in many cases be surprisingly well maintained, depending partly on propagation, partly on downstream migrants. In two lakes, 20 and 25 square kilometres respectively, spawning facilities for trout have been reduced to a minimum. Sport fishing, however, is still possible, because fish constantly immigrate down the considerable stream that feeds the reservoir. In many lakes the loss of spawning areas has been more or less compensated by the reduced amount of available food, so as to maintain growth at the previous level. Attempts to maintain the individual number at the previous level by means of artificial stocking has in several cases resulted in evidence of overpopulation.

Impoundments need not necessarily destroy the spawning facilities in the streams. In rivers harassed by frequent floods or devastating uprooting by ice, an even water flow is frequently aimed at. Barriers to spawning migrations may also in some cases be flooded so that fish have access to new spawning areas.

Fish that spawn in still water, may frequently have their spawning areas enlarged. Erosion may greatly increase the gravel and shingle areas necessary for the spawning of char. Spring spawners, like perch (*P. fluviatilis*) and pike (*E. lucius*), may be able to extend their spawning areas over flooded land when the dam is holding the spring flood back. In such case, fry may prosper with ideal shelter and availability of food among the remaining vegetation.

Even though spawning facilities may still be present, the final result may be destruction. The metamorphosis from ovum to small fish may last long enough for if to be interrupted by variations in water level, if these are considerable. This applies to lakes and rivers alike. Comprehensive winter drainages may appear just as destructive to the propagation of char as river droughts to trout. Drying up of roe or fry is immediately fatal, but lowering of the water level may also have a different effect. If fry or young fish are forced to leave their inshore shelters and enter areas with an even bottom, they will more easily succumb to predators.

Finally, there are cases when both the spawning and the development of fry have been successful, but where the return of both parent fish and offspring is barred by an obstacle. Both generations are cut off unless proper fish passes have been built.

### Effects on migration

The impoundments, as described above, often tend to prevent spawning migrations because of dam constructions, obstructions of the outlets from lakes, drying up of river-beds, etc. In addition to the effects on propagation, such fatalities have had serious economical consequences. Regular congregation of fish in a small area makes fish more susceptible to capture, and probably the catch of fish during their spawning migrations was man's first exploitation of stocks. If such possibilities vanish, it is not always feasible to exploit economically even stocks that are maintained artificially.

Experience, however, supported by tagging experiments, is that even young, sexually immature fish, migrate. Trout frequently move during the summer from the lake to the stream below. An impoundment allowing trout to wander out, but obstructing their return may give rise to easy fishing in the pools immediately below the barrage.

On the other hand, water storages may also cause even comprehensive migrations to begin. They are downstream migrations and attain maximal intensity during the spring. It is mainly char that have been observed to wander, and also to a lesser degree trout. These migrations start a couple of years after the impoundment, attain their maxima after two or three years, after which they gradually cease, apparently because the stock has been reduced. Markings and nettings have revealed that a lake may be almost depleted of char if conditions are unfavourable. In one such case 25 per cent of all marked char had been recaptured within a year below the barrage, whereas the corresponding percentage for trout was only five. The output of fishing in this lake declined in the course of three years to five or six per cent of the previous optimal catch. In recent years three to six per cent have been recaptured as migrants within a year of the marking, but there is a tendency towards increased migration after the stock in the lake has recovered. The present yield is now 20 to 25 per cent of the previous maximum.

Char gather in the current below the dam and are easily caught there. Thus a new fishery has arisen, exploiting a species of fish which was previously difficult to catch in desirable quantity.

The migrations are no doubt due to the impoundments, but it is not clear what factor or factors set them moving. They probably start as a reaction to the totally altered conditions for feeding in the lake, and they contribute towards a regulation of stock versus food supply. As regards the extent of the migrations, the exact position of the outlet seems to be of importance. As char are apt to follow a current, tapping near the bottom will tend to draw more fish out of the lake than surface spillwater.

**Effects on size and composition of stocks**

The decrease in total weight of catch that frequently appears after some years of impoundment should not be uncritically interpreted as decrease in the size of the stock. Frequently it is the average weight of the fish which is reduced, and not the number of fish. Changes in methods of harvesting almost invariably follow an impoundment and may influence the output. In Norwegian storage basins no research has been conducted with the purpose of ascertaining exact figures for changes in the stock of fish, but it is known that variations have appeared after an impoundment.

Ordinarily this change manifests itself as an even increase or decrease, but in cases where it is mainly propagation that has been disturbed, variations in the water level may create changes between rich and poor year classes. This has been observed in a char lake which is normally drained 22 metres. One winter the drainage was limited to 12 metres. Many spawning areas thereby escaped the usual drying-up. Two years later an abundance of young fish, all born in the exceptional year, appeared in the catches, and in the ensuing four years this rich year class completely dominated the catch. Since these fish made their first appearance when two years old, they have constituted the following percentage of the total catch : 40, 78, 84, 87, 75, 21 and 5. A similar incident also occurred later, and during the three last seasons this year class has constituted 51, 88 and 79 per cent respectively of the total catch.

The balance between species in waters with more than one species of fish is frequently disturbed by impoundments, and trout is almost invariably the loser. The production of plankton is probably not influenced by impoundments. Those species of fish that utilize this source of food, either as young or throughout life, are in a favourable position, provided they are capable of maintaining their rate of propagation. Species spawning in still water have the best chances. A number of species fulfil both these conditions, among them perch and whitefish (*Coregonus lavaretus*) which have both managed to establish plentiful stocks in impounded waters. In recent years, however, char seems to arouse the greatest interest. In a number of large storage basins char has prospered to the detriment of trout, irrespective of the height of the impoundment. In one lake, lowering of the level by 5 ½ metres sufficed to cause char to increase from 60 to 68 per cent of the catches in four years, though the spawning areas of the trout were hardly affected. In lakes with great differences between high and low levels, char will be considerably more dominant, and the percentage of trout may drop to 15 or 20 per cent. This superiority is caused by the ability of the char to utilize the plankton and the deep water fauna of chironomid larvae and mussels which are left unaltered by the impoundment. Furthermore, the propagation of char is only rarely a complete failure. Being capable of large yields, and being at the same time popular among anglers, char is a species which may be introduced with advantage into suitable storage basins.

**Effects on methods of fishing**

An impoundment may in one sweep render all traditional fishing places useless because it alters currents and depth conditions. In rivers, a low or uneven flow of water may create such difficulties for fishing that it becomes almost entirely unprofitable. Traditional fishing places in lakes may frequently be replaced by new ones that are more favourably situated as regards depth. But this is only one difficulty overcome. The character of the bottom is the all-important factor for fixed engines and nets. The bottom of natural lakes is mostly smooth because it is covered by millennium's deposit of silt, whereas the flooded land of recently impounded lakes is covered with vegetation identical with that of the surrounding shores. As most basins are filled in the spring, most of the season's fishing is carried out in a full magazine. Seining and gillnetting mostly has to be operated in shallow waters. Accordingly, for the use of these types of gear, one has to operate in the flooded areas.

This has everywhere caused serious and lasting difficulties to the fishing industry, even if the trees have been removed. Roots and bushes are left anyway, and it appears that the flooded vegetation is extremely resistant to the alternating influence of water and air. Only where strong erosive activities from ice, surf and running waters are fully active will the beaches be cleared fairly quickly. We do not know how long vegetation may remain in sheltered areas, for no impoundment has lasted long enough to reveal this. Our first large storage basin was established 52 years ago, and the bottom is still littered with remains of bushes and heather. Webbed gear will thus for many decades be apt to fasten in crags, and the wear is excessive.

The extent of these difficulties varies with local conditions, but net fishing will hardly pay at all in impounded forest lakes until such clearing methods are used as will permit easier operation of net gears.

Another factor contributing to fishing difficulties is constituted by all the pieces of wood and roots adrift in storage basins. They are apt to stick persistently to the web, thus increasing the time needed for cleaning the nets. Such pieces also sink down and litter a bottom that was previously clean. Fishing on an old lake bottom of this kind eleven years after the impoundment resulted in increased expenditure for repairs of N.kr. 2 per net per night, because branches and roots drifted in and tore the nets. Norwegian nets are approximately 25 metres long and 1 ½ metres deep. In the worst cases the cleaning of one net took a whole hour.

Even a mere lowering of the previous level may cause drifting crags to disturb the fishing. In forest lakes many twigs and branches are deposited in the bottom material. When erosion sets in, much of this will be laid bare and will be set drifting along the bottom. The lakes' own vegetation will also be set adrift because ice tears it loose from the bottom. All methods of angling will suffer from the same difficulties. Hooks fasten into crags and drifting wood, but not to the same extent as net gear.

By and by the dead drifting vegetation will float down the streams and create obstacles to fishing in the rivers as well. But living vegetation is frequently more of a nuisance to river fishing, than dead. Previously unheard-of quantities of drifting algae interfere with all sorts of fishing gear and render it unfit for fishing in a very short time. Many kilograms of slimy wet algae may infest a gillnet, and besides making it unfit for fishing makes its cleaning a hopeless task. We do not know whether impoundment directly promotes the growth of these plants, or whether their occurrence over a long period each season is due to the cessation of spring floods. Certainly the flood water, which is now retained in the storage basins, formerly had a strong cleaning effect on the river bed and may have removed most of the algae, but nobody has been able to observe it directly.

# THE EFFECTS OF IMPOUNDMENT ON SALMON AND SEA TROUT RIVERS

BY

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Impoundment for hydro-electric purposes affects salmon and sea trout rivers in various ways according to the type of impoundment in question.

1. Barrage dams. These are mainly built in the rivers for the purpose of concentrating the drop of the river into one steep step, where a power station utilizes the drop.

2. Diversion of water from one river system to another is used in order to increase the stable flow of water in one river system so as to facilitate the utilization of the potential power effect.

3. Stabilization of water flow mainly consists in the construction of dams at the lower end of lakes in order to collect water in the wet season for use in the dry season, thus tending to increase the low-water flow and interrupt floods (water storage).

All these encroachments alter the natural conditions in the river systems in various ways and affect the normal functions of the fish that live in them.

1. Barrage dams block the upstream migrations of adult salmon and sea trout to their spawning areas. Even where efficient ladders or fishways have been established, such dams will in most cases cause delays which may impair the fitness of fish for efficient spawning. Barrage dams create lakes on the upstream side, thus drowning previous spawning areas and reducing the river's capacity for the production of fry. It is unknown to what extent the artificial lakes may affect further upstream migrations of the fish.

Equally important are the effects of barrage dams on the downstream migrations of spent and young salmon and sea trout. The rate of migration may be influenced by the still areas, and the by-pass problems are complicated. Much research has recently been spent on attempts to guide downstream migrants into safe by-passes to prevent damage by passage through turbines. To my mind this target is at least as important as it is to provide easy passage for upstream migrants through barrage dams. Whether or not downstream migrants will be damaged by the passage through turbines, by passing over the spillway, or by being knocked about in the turbulent water underneath the dam, depends on a number of circumstances : the height of the dam, the type and rotating speed of the turbines, the size of the fish, etc.

2. Water diversions may be needed for a number of reasons, among them hydro-electric development, irrigation or a number of other purposes. Only diversions for hydro-electric purposes will be considered here. A number of Norwegian salmon rivers are suffering from effects of this type. The results are mainly reduced average flow of water, removal of flood peaks or all floods, and more pronounced low water periods.

The most serious effects of water diversion to anadromous fish are delays in upstream migration. This delay may even cause disturbance to spawning activity, the fish arriving late in their spawning areas and in a more or less exhausted condition. In general, the Atlantic salmon as well as sea trout ascend the rivers and reach their spawning areas well ahead of spawning time. Only a minor fraction of the stocks arrive just in time for spawning. Thus, for efficient spawning, delays seldom cause such disastrous effects to salmon and sea trout in Scandinavia as they do to Pacific species of salmon, which frequently spawn directly on arrival in their spawning areas. Nevertheless, delays for salmon and sea trout bound for Norwegian rivers mean that they remain longer in the sea, where they are exposed to intensive commercial fishing. This means increased exploitation of the stocks of spawning fish and may have disastrous effects (in Norway about 85 per cent of the total catch of salmon and sea trout is in the sea, only about 15 per cent in the rivers).

Reduced flow of water may mean that spawning redds are dried out and that the eggs may perish from drought or frost. If an autumn spate coincides with spawning time, fish may be lured into spawning in shallow water. This was clearly demonstrated in the Eira River (W. NORWAG) in the 1953-1954 season. 38 per cent of the average flow of water in this river system has been conducted to a power station outside the original drainage area. During an autumn spate sea trout spawned in several areas which later dried up, and approximately 35 per cent of the spawn was thus destroyed. Salmon spawn deeper and the loss of salmon redds was slight (SÖMME, 1954).

In the same river salmon and sea trout parr have been observed to die in frozen-up rapids.

Reduced river area may also cause a decrease in feeding areas and food supply for young fish. It is probable that any reduction also in the volume of water affects the food supply, as part of the bottom fauna feeds on plankton (e.g. net spinning Trichoptera, Simulidae, Lamellibranchiata, etc.).

Reduced water flow may influence river temperatures. In Norwegian rivers, the danger is not so much from increased summer temperatures as from reduced winter temperatures. Especially dangerous is the formation of ice on the river bottom caused by undercooling of water. Such ice may tear loose, wander downstream, form barrages, tear up the river bottom and cause local flooding of large areas. Spawning redds may be torn open or covered with shifting gravel, as has been directly observed in natural waters (Orkla River, Norway).

3. Water storage, without diversion, is widely used in the Scandinavian peninsula. Its effects are quite different from the effects described above. The purpose of water storage is to keep the water flow through the power station as even as possible, storing flood water and increasing the minimum flow.

The reduction of floods may mean delay in the upstream migration of fish. In return, however, keeping the water flow fairly constant means creating ideal conditions for the propagation of anadromous fishes. To parr of both species it means an even food supply, no harmful floods, no shifting of river gravel.

Stocks of salmon and sea trout in well regulated rivers often show tendencies to increase, and fluctuations in the stocks tend to decrease [examples : Etne River, Hordaland; Nid River, Trondheim, both in Norway; Sacramento River, California (MOFFETT, 1949)].

There may, of course, also be adverse effects from such undertakings, if for instance the dam prevents fish from having access to large suitable spawning areas, or if the fish are delayed too long outside the river mouth from lack of floods that can bring them up. Unfavourable temperature changes may also occur.

In most cases, the utilization of water for hydro-electric development is detrimental to the stock of fish. A great deal of research is necessary in order to enable us to balance the loss, if possible.

Probably the first coutermeasure to be taken by man to reduce damage by barrage dams was to construct fish passes which enabled the fish to pass the barrage.

Capture of fish on a large scale below the barrage has also been employed in order to transport the fish past the dam. But rarely have these steps been adequate in preventing any form of damage to the stock of fish.

A great many devices have been tried to create safe by-passes for fish moving to the sea past barrages, but no system hitherto tried has been completely successful or can be considered to operate successfully for all species of anadromous fish. Perhaps the most successful device so far constructed is a moving curtain of cables with a low electric charge (BRETT, 1957).

Artificial freshets may be employed successfully to prevent delay in upstream migration (HAYES, 1953).

Methods for maintenance of salmon and sea trout runs by means of artificial propagation are steadily improving. It is generally accepted that hatching and liberation of fry is inadequate and that a stock of salmonoid fishes can only be maintained by the raising of two year old smolts or large fingerlings. The per piece cost of the raised fish is an economical problem, but recent experience in Sweden seems to confirm that it may be possible to replace natural propagation in a river by means of artificial propagation.

The complex scope of hydro-electric development versus the maintenance of fish stocks and anadromous fish migrations should encourage large-scale research programmes. Research should not only be directed to solve the immediate problems at hand, but also towards a more intimate knowledge of the physiology and general behaviour of anadromous fish (BRETT, 1957).

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# DAMS AS BARRIERS OR DETERRENTS TO THE MIGRATION OF FISH

BY

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The river system plays a vital role in the life cycle of the migratory species of fish as it is the only means by which they can reach their spawning areas and so perpetuate the species. The conditions suitable for the spawning of some species of migratory fish and for the development of their young, such as areas of cold silt-free water, of suitable depth and velocity, flowing over beds of gravel of proper size and composition, are to be found mainly in the upper reaches of river systems, while for other species the conditions suitable are to be found only in the sea.

There is a movement of migratory fish (salmon, sea trout and eels) (1) up and down Irish river systems throughout the year, with peaks occurring at certain periods of the year which vary in time and intensity according to the particular species under consideration. These movements are primarily reflections of the stage of physiological development reached by the fish but in the main are initiated by the occurrence of suitable hydrologic conditions in conjunction with favourable climatic ones.

When a dam is erected across a river course the physical barrier it presents to the fish stops their upstream movement to an extent depending on the nature and height of the structure and similarly prevents or makes hazardous their downstream movement unless arrangements are made to prevent this happening.

The problem presented by each dam varies with the particular circumstances : the purpose for which it was erected; the type and height of the dam structure; whether it stands alone or is one of many in the same river course.

High dams give rise to greater problems than small dams not alone for the fish which have to overcome them but also for those responsible for making provision to ensure the safe passage of fish across them.

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(1) Salmon = *Salmo salar* L.; Seatrout = *Salmo trutta* L.; Eel = *Anguilla anguilla* L.

It has been established that salmon cease to feed actively when on the spawning migration and are dependent on their stored energy to enable them to travel to the spawning ground and to overcome any obstacle placed in their path. This stored energy provides also for the development of the sex products; the actual spawning operation; the subsequent battle for survival and the passage downstream, where applicable. Attention has been drawn to the need, therefore, to ensure that the demands on this energy imposed by man-made obstructions are not so great that the fish are deterred from travelling as far as they would under natural conditions and thus are prevented from making use of all the available spawning areas.

Delays such as are likely in rivers in which there are high dams or where there is a series of dams along the river course may cause the fish to arrive on the spawning grounds in such an exhausted condition, or may retard their arrival to such an inopportune time for spawning, that the operation is adversely affected.

Overcrowding of spawning beds in the lower reaches of the river can arise from the fish being delayed and result in considerable wastage of spawning effort due to repeated use of the same spawning beds in a spawning season by successive runs of fish.

The difficulty experienced by fish in surmounting a dam and the effect of the structure on fish stocks need not necessarily be measured by the height of the dam alone. In many rivers in Ireland there were at one time many low mill-dams which were formed by building boulders loosely across the river course in order to divert the flow and to utilize the head of water created to drive mill water-wheels for the grinding of corn. Due to the leakage of water through the interstices of these boulders little or no water flow passed across the crest of the dam except at times of high discharge in the river. The flow downstream of the dam, was little affected by it so that the salmon could move upstream quite freely. When they arrived at these dams they were obstructed and prevented from moving any further to the spawning grounds. Concentrations of fish resulted which favoured poaching and also gave rise to conditions which encouraged outbreaks of disease among the fish due to overcrowding.

These obstacles have been eliminated over the years by sealing the interstices in the boulders and by the provision of groyne type fish passes on their downstream aprons where necessary.

In most Irish rivers the obstructions to be faced by the migratory fish consist of low mill-dams which vary in height from place to place but generally range from 6 to 10 feet. By the use of stepped pool type fish passes with central notched overflow weirs in each pool, or by the groyne type fish pass, wherever site conditions are suitable, the problem presented by these mill-dams is overcome without difficulty, provided particular care is taken to site the fish pass so that its entrance is easily found, is attractive and easily entered by the fish.

The highest dams which have to be surmounted by salmon in Ireland are located in rivers which have been harnessed for the generation of electricity. To facilitate the movement of fish across these dams fish passes of the stepped pool type have been employed at Parteen Weir, height 26 feet, on the River Shannon; the White submerged orifice type pass on the River Erne, at two dams, average working head 94 feet and 33 feet; the Borland Fish Lock type pass on the River Liffey, 57.75 feet average working head, and on the River Lee, at two dams, average working head 97 feet and 44.7 feet. Passes based on variations of the fish lock principle to fit in with site conditions have been built at Ardnacrusha Power Station, on the River Shannon, average working head 93.39 feet, and on the Clady River, County Donegal.

As in other countries the chief difficulty experienced with fish passes at hydro-electric dams in Ireland is that of ensuring that the entrance will be readily found by the fish and be attractive enough to induce them to enter in preference to passing on to other more attractive flows near at hand.

The problem stems from the fact that the unidirectional flow of the river downstream from the dam which exerts a directive influence on the fish, leading them on to the spawning grounds, is replaced by a many-directional flow caused by the discharge from the turbines. In the midst of all this confusion the outflow from the fish pass which forms a very small proportion of the total discharge has to be found by the fish and be such that the fish are encouraged to proceed against it into the pass.

This is a problem which arises in particular with fish passes of the Borland type and of the White type though it is a matter of conjecture what importance should be attached to it in view of the recorded numbers of fish which have gone through passes of this type in a season; River Liffey, 2,375; River Lee, 2,420; and in the case of the White Pass on the River Erne, 6,283.

At certain stages in the cycle of operation of the Borland Pass, fish are barred from entering it, and should salmon wish to move upstream at these times and be prevented from entering the pass, the tendency will be to move elsewhere in search of a passage even with the by-pass of the pass operating. When the pass is open again to the fish they are likely as not to be away from the zone of influence of the discharge.

It has been observed that any discharge of water from a height on to the surface of a tail race attracts fish to it. Similarly a discharge from the spillway attracts the fish also, though in this case the volume of flow may be the chief factor in its doing so. Nevertheless this has encouraged the belief that in the welter of flow at surface or sub-surface level as occurs at a power station, a beacon in the form of falling water is required at the entrance to the fish pass as a focus for the fish to attract them to it.

In one case where a Borland type of fish pass was operating at a power dam and the turbines were not yet in commission it was observed that when the crest gates of the spillway were opened very slightly, so that only a very thin film of water passed down the surface of the spillway and caused a slight agitation on the water surface of the tail race below, salmon immediately congregated at this place. Salmon were likewise noted to congregate below a small outflow which discharged on to the surface of the tail race each time it occurred.

Many instances similar to these observed over a period of years have encouraged the belief that, in conditions such as obtain in the tail races of hydro-electric stations in Ireland, the entry of fish into a fish pass discharging into one would be greatly expedited if the outflow from the pass had the volume, visual character and impact on the surface of the tail race which can be provided by the form of Denil type pass used in Sweden; provided, of course, that care was taken in the siting of the pass in accordance with standard practice.

It is considered that such an arrangement would be particularly beneficial where fluctuating water levels in the tail race have to be provided for, as the pattern of outflow from this type of fish pass is little affected by changes of this nature. In particular it is believed that much benefit would result if it were possible to combine a Denil type pass outlet with a Borland pass main unit.

Where a dam has been erected to facilitate the abstraction or diversion of the flow of the river, the amount of water abstracted and the degree of control exercised generally over water flow passing downstream from the dam : each has an important bearing on its effect on fish life and on the measures necessary to offset any damage likely to be caused by it. This has now been established beyond question.

In the River Shannon the average annual flow of which is about 7,000 cusecs, a weir was built across the main river at Parteen, which diverted the major part of the flow of the river to the generating station at Ardnacrusha from whence it returned to the original river course again. A canal head race was constructed to convey the flow to the generating station, a distance of 7 ½ miles, and a tail race was excavated to convey it back again to the river, a distance of 1 ½ miles. The overall length of the diversion was 9 miles.

A fish pass was provided at Parteen Weir but no fish pass was provided at the dam at the generating station, average head 93 feet, possibly in the belief that fish delayed there would drop back downstream and run the original channel.

When the turbines went into operation only that flow which was not required by the turbines was allowed down the old river channel past Parteen Weir. The minimum flow in this channel was established by order however to be 353 cusecs with a further possible reduction to 247 cusecs in exceptional circumstances.

Thereafter the flow in this part of the original river channel was reduced to the more or less uniform discharge allowed past Parteen Weir together with whatever inflow came from two tributaries in this stretch of river, the Kilmastulla River and the Mulcair River.

Before the construction of the weir at Parteen important spawning beds in the River Shannon were located in the stretch of channel downstream of this weir where also was conducted the famous angling for large spring salmon. The reduced flow in this part of the river caused part of the channel to dry out for all or part of the year, including the spawning season, and this affected the spawning beds and thereby the spawning effort. The early-running and large fish have been greatly reduced in numbers while the late-running or summer fish have suffered little reduction.

Most of the salmon entering the river on the completion of the scheme of hydro-electrification were attracted by the major flow and travelled up the tail race in preference to the old river channel. Some of these fish did drop down river again and went up the old channel to spawn. The majority did not. In course of time it became evident that only limited numbers of fish passed through the fish pass at Parteen to the upper reaches of the catchment. While on the other hand there was over-stocking of the spawning beds in the Mulcair River. This has encouraged the belief that in the reduced flow of the main channel, the attraction of this river to running fish was greatly enhanced, especially to fish that may have been delayed overlong at the power station. Of course there was the need to replace the reduced area of spawning ground in the old channel as well.

A fish pass on the fish lock principle has lately been completed at Ardnacrusha Power Station and a programme of restocking of the upper reaches of this river is to be undertaken together with a campaign of predator reduction in the main river through which the smolts must pass. It is believed that by these means the river will be restored to its former status as a salmon river.

In the River Clady, County Donegal, the harnessing of which is now nearing completion, the flow of the river is likewise being diverted by a canal head race to supply a generating station. Unlike the River Shannon, however, the outflow from the turbines will not rejoin the original river channel and the flow in the river downstream of the diversionary dam will be much reduced in volume in future years.

By means of a study of the times and conditions suitable for angling in former years as well as by an investigation into the flow conditions found suitable for the various migrations in the river, a pattern of flow has been established which is to be discharged downstream of the diversion weir at the appropriate time of the year. Natural occurring spates are to be availed of as far as possible in the process. By this means it is hoped to preserve, though on a much reduced scale, the original flow character of the river and it is hoped that the run of fish will be maintained by these methods.

Where the dams are erected for the supply of water for domestic needs or industry much depends on the quantity to be abstracted and how and where and in what condition it will be returned again. There is no problem if the quantity is small (or, if it is large, where it is returned again at or near the dam), provided nothing has been done to it in the process to make it harmful to fish life.

Where the amount to be abstracted is large and this does not find its way back to the river again serious difficulties arise unless special steps are taken such as have already been discussed in the case of the Clady River.

One particular problem at present under consideration concerns an important salmon river where it is proposed to erect a barrage at the head of the tideway.

This will divert water to supply an important industrial concern. The water will not be returned to the river. The quantity of water required will be such that the entire low flow of the river will eventually be abstracted. At certain times of the year there will thus be no outflow from the river and at other times there will only be an outflow of an amount which is now considered to be low flow. Only at time of high discharge in the river will there be any significant though much reduced outflow from it.

The problem is complicated even further by the fact that the river in question enters a large estuary into which flows another major river. Furthermore the affected river will have to pass across extensive tidal sloblands in which it will have to keep scoured its present outflow channel.

It has been argued that the proposal will mean the extinction of the river as a salmon river as it is believed that the volume of outflow will no longer be sufficient to preserve the identity of the river for the incoming fish, or to attract them, in the conditions prevailing in the estuary, and that the attraction of the flow from the other major river will eventually divert all incoming fish to it. Various ways of preventing this happening are at present being studied in the hope of finding a solution to the problem.

The nature and seriousness of the obstruction offered to migratory fish by dams erected for purposes other than that of the generation of electricity depends as much on their function as on their height. The tidal barrage which is erected for the purpose of excluding tidal flow from a low-lying estuarine river for the prevention of flooding is a case in point.

The tidal barrage across the River Fergus at Clarecastle, County Clare is a concrete structure 20 feet high in which there are 10 tidal flap gates each 6 feet wide by 10 feet high, set into prepared openings in the main structure, from the soffit of which they are suspended by a hinged arrangement which permits their movement outwards and back.

During low tide levels the head of water in the river at the back of these gates causes them to swing open and river discharge takes place. When the water level downstream of the barrage rises to a level higher than that in the river, due to tidal action, the gates are automatically closed tight in the opes so that very little water flows upstream thereafter. When the tide falls again the head of water which has built up upstream forces the gates open and the impounded waters are discharged before the next rise of the tide.

The problem of maintaining the run of salmon into this river was tackled by erecting a chute 2 feet wide and of quadrant longitudinal section in a specially prepared opening in the barrage. This chute pivots about a horizontal axis supported by the barrage and is fitted with a float arrangement which causes the lip of the chute to rise and fall with the tide, within certain limits. The floats are adjusted so that the lip of the chute is always at a certain depth below the level of the water downstream and a constant inflow is thus ensured at all stages of the tide by which fish may enter, if they wish, by passing down the chute with the flow of water. During the construction of the barrage fish were observed to move through a flap gate arrangement similar to that employed in the main barrage which had been provided in a temporary structure erected as part of the main construction work. Contrary to expectations there was a considerable inflow through the flap gate with a rising tide before it finally closed. The fish, therefore, had two means of passing upstream when the barrage was completed. The run of salmon in the river has been maintained but it is. difficult to assess to which of these this can be attributed.

The impoundments created by the dam can likewise affect the fish to an extent and degree depending on the particular circumstances. On the one hand it causes the inundation of part of the available spawning beds to a depth that makes them useless for that purpose, on the other hand it may give rise to conditions in the new environment which may have an adverse affect on the fish. The erection of the dam can also create problems for fish life downstream of it, inasmuch that in the new regime in the river which results, the extent and time of fluctuation in volume of water flow, the quality of the water and the temperature of it may not be as favourable to fish life as was the original natural flow of the river, and indeed in some cases may even be inimical to desirable species of fish life.

Following on the flooding of a reservoir there follows a period of rapid decay of the organic matter covered by the water. As decomposition proceeds, the dissolved oxygen in the water is reduced and deleterious matter is produced. As the bottom of the dam is at the deepest part of the impoundment the concentration is greatest there. These conditions were believed to reach serious proportions as regards fish life in countries of high temperatures only. Unfortunately a period of high temperature coincided with very low water flow in the River Lee after the filling of the reservoirs in 1957 and, unexpectedly, lethal conditions for fish were created so that when the turbines went into operation about 300 salmon were killed downstream of the dam by the discharge.

Likewise in the River Liffey it was found necessary in 1951 to empty the comparatively small balancing reservoir formed by the hydro-electric dam at Leixlip. The emptying was carried out by running the turbine at full discharge and the final stages of emptying were carried out by means of the scour valve at the foot of the dam. Flood conditions were created in the river downstream of the dam for a period of one day by the discharge. This followed on tidal conditions in the sea at which salmon were likely to run from the sea into the river. The result was a considerable movement of fish up the river. These arrived at the dam at the final stages of emptying and were concentrated in the stretch of river below the dam into which all the poisonous elements entered and about 400 salmon were killed.

The dam had been emptied on previous occasions without ill effects on fish life. Unfortunately many minor river drainage schemes had been carried out in the tributary streams upstream of the dam prior to this emptying. The reservoir acted as a settling pond for the silt charged waters and when it was emptied all this freshly deposited silt was unexpectedly stirred up and washed out with the final discharge and killed the fish.

The reservoirs of the River Erne were flooded in 1952. In 1955 there was a period of high temperature. At the same time a large-scale drainage scheme was in progress in the river flowing into the reservoir area so that the water reaching the dam and passing down the fish pass was heavily charged with silt. Salmon were observed to be reluctant to move into the fish pass and those that did move in or that were already in it showed little inclination to move up the fish pass or to leave it. The combination of high temperature, 70°-75 °F, effects of decomposition in the reservoir area, and the silt in the water provided conditions favourable to an outbreak of furunculosis among the fish from which an estimated 300 salmon died in the fish pass.

Following on the flooding of a reservoir built at the head of a tideway a few years ago there were many reports that the salmon were disinclined to enter the fish pass. The netsmen in the estuary below the dam spoke of getting fish in their nets which they said showed signs of being fish that had dropped back downstream from below the dam. These reports have not been so prevalent in latter years. It likewise has been noted that in many cases where fish passes have been built on much more modest scales than that at this hydro-electric dam, reports of the first year's working were not very favourable whereas the reports of later years were quite favourable. This would seem to indicate that there may be some factor in a new pass which deters fish until it has been in operation for some time.

Reports from other countries state that dam impoundments can impede the downstream movement of spent fish and of smolts. The problem seems to arise in these countries, in part, from the temperatures experienced in the waters of the reservoir. This matter has never been investigated in Ireland as no factor had arisen to draw attention to the fact that a problem existed. Furthermore the fact that many lakes occurred naturally in the path of the migrants which, on the face of it, have not been an obstruction to their movement naturally tended to obscure whether or not there was such a problem.

Fish are delayed, however, by the weirs and dams in their paths in most rivers in Ireland. During April and May, when the smolts are descending these rivers, concentrations of them are to be observed directly upstream of low weirs at times of reduced flow in the river and likewise they may be seen wandering about in shoals immediately above hydro-electric dams. It is not possible to say for how long or to what extent these fish are delayed or if the delay is voluntary or enforced.

Trout dropping downstream have been observed to be similarly affected at new concrete weirs built in the execution of an Arterial Drainage Scheme for the River Brosna. It was noted that the water flow across these weirs, due to the form of construction, was in a thin sheet of water and that the fish tailed down to it and then shied away from passing over it. With increased depth of water and flow of flatter surface gradient the fish passed freely.

In fish passes of the White type, that is with the submerged orifice, kelts have been observed to delay in the individual pools so that particular steps by way of emptying the pools are necessary before these fish can be passed downstream.

No such difficulty has been observed in the conventional pool and overfall type of pass especially those with a central notch in the baffle walls between pools.

Recent investigations in England indicate that smolts tend to run with a rise of temperature, principally at twilight and that kelts tend to run with floods associated with a rise in temperature. This would seem to suggest that provision should be made in special outlets from dams at these times by way of increased outflow which could be reduced or stopped at other times to facilitate and encourage the speedy movement of these fish downstream.

Numbers of smolts have been observed each year in the turbine intake well at Leixlip Hydro-Electric Dam. They tend to remain here showing on the surface of the water and generally have to be removed by a dip net. This indicates that smolts do enter the turbine intake as this well is below the intake. The fact that they appear here so soon after entering the intake indicates a readiness to surface again at the first available opportunity and the fact that having surfaced they tend to remain is also of significance especially as regards hydro-electric schemes in which long penstocks are provided with surge towers. It would seem desirable in the light of the foregoing to investigate to what extent smolts are being trapped in these surge towers and if provision would have to be made to exclude them by means of screens.

Large numbers of dead smolts have been found downstream of the smaller turbines supplying individual mills with power and it has been found necessary to insist that screens be provided before these turbines to exclude smolts from them.

It is not sufficient, however, to provide screens alone. Provision must also be made to by-pass the smolts held back by these screens into the river. It is not usually practicable or economical at small hydraulic power units to provide an arrangement of screens such that the flow of water passing through them would be reduced to such a low velocity that the smolts can swim against it for lengthy periods. It therefore becomes necessary to provide a channel beside the actual smolt screen into which the smolts stopped by the screen can pass and by it drop down to the river. Where this is not done it has been noted that the smolts eventually tire and are washed on to the screen where they are crushed by the water flow and die.

It has been established that some species of Pacific salmon will tend to delay migration from a reservoir area until a surface exit is available across the dam but that others will sound to a depth of 65 feet where there is no surface exit. From observations made in Ireland it would appear that Atlantic salmon smolts and kelts exhibit the same preference for a surface exit.

As a rule such an exit is provided by the fish pass at a dam but in certain circumstances it is necessary to make use of the dam spillway gates for this purpose also. Spillways at which discharge occurs at the bottom of the gate should be fitted with smaller auxiliary gates incorporated in the main gate to provide a surface exit, as likewise in the crest of gates with overfall discharge in order to provide an outflow of the character already described in preference to a wide thin flow along the entire crest.

The matter has never been investigated in Ireland, as apart from infrequent reports of kelts being killed in passing down the spillway at a dam where the bed of the river immediately downstream of the spillway is a rock reef, there is no evidence of serious mortality occurring in kelts and smolts at spillways.

In view of the findings in other countries, which have established that spillways can cause appreciable mortality due to abrasions on the concrete face of the spillway, presure changes, turbulence, and impact with obstacles in the way of the fish, the matter will be examined more closely.

As it has been shown that this mortality is reduced considerably where a free fall is provided to a deep pool below, it would appear desirable to provide such conditions below the outlets in the spillway gates already discussed.

It is hoped that this account of difficulties experienced by migratory fish in Irish rivers arising from the construction of dams will be of assistance in preventing similar occurrences in other countries.

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## Summary

The various ways in which the spawning migration of fish can be impeded, prevented or nullified by dams are discussed with reference to actual experiences with Atlantic salmon in Ireland. Proposals for overcoming some of the difficulties are discussed, in particular the improvement of entrances to fish passes for upstream and downstream migrants.

# DAMS AS BARRIERS OR DETERRENTS TO THE MIGRATION OF FISH

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One of the major economic and sociological problems confronting many peoples, as a result of industrial growth in the community, is the disruption of established fisheries through the construction of dams for development of hydro-electric energy or for other purposes. The problem may not be so obvious in some regions where lack of biological knowledge of the fish population prevents prior assessment of the effect of any proposed dams, but it will eventually be just as real as in regions where these facts are fully known. It is generally recognized, with some special exceptions, that dams in rivers frequented by migratory fish are usually detrimental to these fish.

Any discussion of « Dams as Barriers or Deterrents to the Migration of Fish » must necessarily include the river and lake environments created by the dams. There is a tendency to regard the dams themselves as the sole obstacle to migration of fish for which adequate provision must be made. It cannot be stressed too much that this is not the case and that proper environment is just as important to the preservation of a fishery as is the provision of physical means of continuation and completion of the migration.

Any dam without adequate fish passage facilities obviously prevents the migration of fish either upstream, or in some cases downstream. A number of means have and are being employed to provide upstream passage for fish past dams. These include fish-ladders of numerous designs, gravity locks, elevators, and tank trucks, examples of which can be found in many parts of Canada and the United States as well as in Great Britain and Norway. The success of these devices depends on their efficiency in transporting the fish over the dam and delivering them to a point from which they can continue their migration unimpaired in any way. Many such devices are in use today and are often considered to be successful merely because they do pass some fish and have maintained the fishery although perhaps not at optimum or even economic levels of abundance. It is important to recognize that this alone is not the measure of success. To be successful, the device must maintain runs of fish at the same level of abundance as existed prior to the construction of the dam. This means that the fish must not be subjected to any significant and detrimental variations from the normal environment which will prevent them from completing their life cycle in the normal manner.

Thus, when time is of essence during the migration, the facilities must provide for immediate attraction, collection and passage of the fish. This is an extremely important consideration when dealing with Pacific salmon, which do not feed during their spawning migration but rely on body fats and protein for energy. Studies on the Columbia River at Bonneville Dam have shown that adult chinook salmon (*Oncorhynchus tshawytscha*) were delayed an average of 2.6 to 3.0 days in finding and ascending the large fishway system at the dam (1). W. F. Thompson, in his studies of the effect of the Hell's Gate obstruction on Fraser River sockeye (*Oncorhynchus nerka*) determined that a twelve-day delay in the migration of adult sockeye was sufficient to prevent them from reaching their spawning grounds (2). Current research indicates that the tolerance to delay is considerably less than twelve days. For the Early Stuart River run of sockeye a delay of three to six days could be critical. Such delays might allow the fish to reach the spawning areas but leave the fish with inadequate physiological reserves to carry out the pre-spawning and spawning activities successfully. This fact was well demonstrated in 1955 when that cycle year of the Early Stuart run was decimated by a six-day delay at a high water obstruction near Yale (3).

The facility also must not subject the fish to conditions which require greater than normal energy consumption, either due to work done or due to shock from various abnormal conditions such as confinement, mechanical handling, and unusual hydraulic conditions. The additional energy required subtracts from the total remaining for successful completion of the life cycle and can therefore have the same disastrous effects on production as chronological delays. Examination of data from the Columbia River dams indicates a diminishing number of salmon reaching each successive dam (4). While the reasons for this have not been established, they are apparently associated with fatigue and excessive energy expenditure. Control of water temperature in the facility may be vital to prevent lethal temperatures or to maintain optimum metabolic rates and maximum swimming efficiency.

In short, the true measure of success is the ability to maintain the fish stocks at their normal level of abundance, other things being equal. Thus considered, most dams on the migration path of Pacific salmon could be shown to be having a detrimental effect despite all fish facilities provided. The salmon fishery of the Columbia River is an excellent example, although complicated by the effects of fishing pressure, pollution, irrigation diversions, watershed changes due to deforestation and fisheries rehabilitation programmes. Statistics on the catches and escapements of salmon show a tremendous reduction in their abundance after the construction of dams at Grand Coulee and Bonneville. The total commercial catch of all salmon in the Columbia River was highest in 1911 and amounted to approximately 49,500,000 pounds. In 1956, the total catch was about ten million pounds, or a decrease of about 80 per cent from the 1911 catch. By individual species, the catches of sockeye have decreased 94 per cent from the high in 1898, of chinook salmon 81 per cent from the high in 1883, of coho salmon (*Oncorhynchus kisutch*) 95 per cent from the high in 1925, and of chum salmon (*Oncorhynchus keta*) over 99 per cent from the high in 1928.

The 250 foot high Baker Dam on Baker River over which adult salmon are transported in a tank on an aerial tramway, has reduced the salmon runs in that river to a level at which the fish are just able to perpetuate themselves without supporting any commercial fishery. In the period 1905 to 1927 prior to construction of the dam, the average annual production of sockeye was 10,416 whereas in the period 1928 to 1953 the average annual production was only 4,613 fish, a decline of 55.5 per cent.

When a dam is used for river flow regulation and there are extended periods of no spill, or if the only discharge is through deeply submerged outlets not used by the fish, the downstream migration may be delayed sufficiently to cause the fish to take up residence in the reservoir or the fish may be physically prevented from leaving the reservoir. The resulting increased pressure on the available food resources of the reservoir will upset the normal balance in the utilization of this food by the various species in the reservoir and consequently will reduce productivity of the species.

During tests at the Glines Dam on the Elwha River (6) with hatchery-reared coho yearlings and chinook fingerlings released above the forebay of the dam, it was found that over 73 per cent of the fish did not leave the reservoir during the test period of about ten weeks during which time varying combinations of spillway and turbine outflow occurred. At this dam the turbine outlet is submerged 64 feet and it was found that coho yearlings did not sound to this depth. Similar observations with respect to coho have been made at Baker Dam (7) and at Stevens Dam on the White River (8).

Surface spillways or shallow turbine intakes are not considered to be a deterrent to migration, although the mortalities inflicted by use of these exits from a reservoir can seriously reduce the fish population. The following table lists the measured mortality rates at eight dams in the State of Washington and in British Columbia. These measurements illustrate the wide variability in mortality depending on head and spillway and turbine characteristics. One very important aspect of fingerling mortalities during the seaward migration is the fact that there appears to be no opportunity for compensation by a higher survival rate in later stages of the life cycle (5) such as occurs between spawning and the beginning of the downstream migration.

| Dam | Head (feet) | Species | Average Length (inches) | Spillway Mortality (per cent) | Turbine Mortality (per cent) |
|---|---|---|---|---|---|
| Cleveland (Capilano River) | 295 | Coho | — | 57 | — |
| | | Steelhead | — | 69 | — |
| Baker (Baker River) | 250 | Sockeye | 3.75 | 64 | 34 |
| | | Coho | 3.10 | 54 | 28 |
| Puntledge (Puntledge River) | 350 | Steelhead | 4.90 | — | 42 |
| | | Kamloops | 2.70 | — | 28 |
| | | Kamloops | 1.80 | — | 29 |
| | | Pink, chum, coho, spring, kamloops | 1.40 | — | 33 |
| Glines (Elwha River) | 184 | Coho | 4.25 | 8(*) | 30 |
| | | Spring | 2.75 | 6(*) | 33 |
| Ruskin (Stave River) | 130 | Sockeye | 3.40 | — | 10 |
| Elwha (Elwha River) | 100 | Spring | 2.75 | 37 | 0 |
| Bonneville Columbia River) | 60 | Spring | | 15(**) | 15(**) |
| McNary (Columbia River) | 90 | Fall Chinook | 2.40 | 0 | 11 |

(*) The spillway at Glines Dam consists of a free fall or ski-jump where a small quantity of water drops into a large, deep pool.

(* *) It was not possible to separate spillway and turbine mortalities in this experiment at Bonneville Dam.

Where a dam creates a reservoir in which water velocities are a small fraction of the original river velocities, the movement of young fish through the reservoir may be critically affected. If these fish normally depend upon the river current to carry them downstream they may be delayed many weeks in their migration. It is known from work in progress that during the downstream migration these fish are in a physiological state involving a preference for salt water to fresh water. This preference subsequently reduces in intensity if the fish do not enter a salt water environment. Consequently, if the fish arrive in the ocean after the period of preference for salt water they may not be able to survive. The fish may also require additional food during their passage through the reservoir if they increase their swimming activity. Depending on river and reservoir characteristics, the reservoir may not provide a suitable supply of food and the fish will be starved during their migration, perhaps incurring physiological damage and probably increasing the risk of predation. Roosevelt Lake above Grand Coulee Dam on the Columbia River is known to provide a poor environment for salmonoids (9).

Conversely, it might be reasoned that the reduced velocities in the reservoir would provide compensation to upstream migrating fish for delays incurred at the dam. Recent research, however, indicates that salmon maintain a relatively steady rate of migration over a wide range of river velocities within their swimming ability. Data on rate of migration of sockeye in the ocean approaches to the Fraser River also show the same rate of migration as measured in the river (10). Moreover, where reservoir water surface temperatures are higher than temperatures in the natural river during the period of upstream migration, the migration through the reservoir may be delayed.

Apart from obstructing the migration path, dams can affect the habits of fish in a number of ways. Fish, being cold blooded, are slaves to their normal environment temperature, and significant changes in this temperature regime can result in extermination of the species if they are unable to adapt themselves or to migrate to a more favourable environment. Dams which create impoundments in a river which are large, relative to the annual river run-off, can affect the temperature regime in several ways depending on reservoir characteristics and operation of the dam. Deep reservoirs, with low velocities and subject to thermal stratification, can significantly raise or lower the temperature of the river downstream depending on whether the outlet discharges from the surface or from below the thermocline. These temperature changes may, depending on severity, create an unfavourable environment for the existing species of fish, but they may also create an environment favourable to a different species. The Shasta Dam on the Sacramento River in California, which drowned out the upper and cooler reaches of the river used for spawning by chinook salmon, caused much reduced temperatures in the river below due to withdrawal of water from great depth in the reservoir, and thereby produced temperatures suitable for the spawning of spring salmon where they had not previously been able to do so (11).

Large reservoirs which detain river inflow for a period of a month or more can skew the normal time-temperature relationship. This displacement of temperature with respect to time can create an unfavourable environment for existing species, particularly if certain necessary activities timed with the normal temperature regime cannot be successfully completed under the altered environment. Grand Coulee Dam on the Columbia River has caused a temporal displacement of about one month in the occurrence of summer and fall water temperatures (12). This shift has caused water temperatures to be much above optimum during the spawning period of chinook salmon in the Columbia River below Grand Coulee Dam. While no data are available regarding the productivity of these Columbia River salmon, it is known from studies of Fraser River sockeye that such high temperatures reduce the success of spawning and the production of fry (13). Alterations in the normal temperature regime during the period of upstream migration may seriously affect the rate of migration due to lowering of the metabolic rate and swimming speed (14).

If a dam is used to divert most or all of a river from its natural watercourse, the remaining river may no longer be a suitable habitat or migration path for fish either due to lack of water or due to unfavourably altered characteristics of the water. The diversion of Bridge River, a tributary of the Fraser River, from its natural watercourse for the development of power has resulted in the loss of all of the spring salmon runs to the affected portion of the river due to flooding of spawning areas above the dam and lack of water below the dam for transportation. The diversion of the Nechako River, another tributary of the Fraser, by tunnel through the Coast Range of mountains for the Aluminum Company of Canada's power plant at Kemano has greatly reduced the volume of run-off of the Nechako River. This reduction in flow has resulted in an increase in mid-summer water temperatures which results in temperatures that are close to or at the upper tolerance limit for sockeye as they near their spawning grounds (15), (16), (17), (18). On this same project, the flow reductions have greatly reduced the available spawning area for chinook salmon and erratic spills through a small tributary watercourse have resulted in the deposition of large quantities of silt on much of the spawning area during the egg incubation period.

Large reservoirs on rivers carrying substantial amounts of organic materials will concentrate the biochemical oxygen demand of these materials in addition to those present in the reservoir. If the demand is great enough and the reservoir retention period long enough, the dissolved oxygen of the water may be completely depleted. The discharge of this water with low dissolved oxygen content or with dissolved toxic gases resulting from anaerobic decomposition would create a river habitat unsuited for residence or migration. Such a condition has occurred on the Lewis River at Merwin Dam after the initial filling of the reservoir due to decomposition of organic materials left in the reservoir. Depletion of oxygen in a reservoir and the movement of density currents of low dissolved oxygen content through the reservoir have been observed in the Norris Reservoir in the Tennessee Valley Authority project (19).

Reservoirs on rivers carrying a large concentration of suspended sediment might be expected to clarify the river downstream from the dam and, if other conditions are suitable, thereby enhance the river environment for residence, reproduction and migration of some fish. On the other hand, such clarification of a river may remove the protection from predators afforded by the turbid water and decrease the survival of other fish.

In all of these examples, other than physical obstruction of passage, it is seen that the alteration a dam may cause to the existing river environment may be an extremely significant factor in deterring the migration of fish. The situations listed are not all-inclusive but are mentioned only to emphasize the necessity of evaluating the effect of a dam on the normal environment of the species of fish under consideration. Physical obstruction of the migration path is in fact only one aspect of the possible changes in environment. Where one or more dams are proposed for construction on rivers used by migratory fish, satisfactory means of preventing or overcoming these environmental changes must be found if the species of fish affected is to be maintained at optimum productive levels.

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# THE EFFECTS OF IMPOUNDMENTS UPON THE BIOTA OF THE TENNESSEE RIVER SYSTEM

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The statement « Dams and Drowned-out Stream Fisheries » originally suggested as the title for my paper is not descriptive of what has taken place in the Tennessee Valley as the result of river impoundage. Only in one instance, and that in the river below an impoundment, has the construction of a multiple-purpose dam modified the environment to the extent that existing valuable fish species were seriously damaged. The warmwater species, including the valuable black basses ([1]) and the walleye, were driven from the Little Tennessee River because the cold water discharged from Fontana Dam produced an unfavorable environment for these and other warmwater species. This change did not, however, result in a net loss to the fishery of the Little Tennessee River. The modified habitat (reduced water temperatures), although no longer suitable for the original warmwater species, proved to be ideal for rainbow and brown trout species more highly valued by anglers and in shorter supply than the locally displaced warmwater species.

In general, the building of dams in the Tennessee Valley has been of great benefit to the fishery. This statement applies no matter whether we think of the quality (species composition) or the magnitude of the fishery. For this reason I cannot write about a drowned-out stream fishery. Instead, I shall attempt to give you some idea of the character and scope of the T.V.A. river development; its mode of operation, especially as it is related to water-level fluctuations for statutory purposes and malaria control; and finally the general effect of this series of dams upon (1) invertebrate fauna, (2) the fishery, and (3) migratory waterfowl.

In writing this paper I assume that your association does not limit its interest and activities to the maintenance of primitive conditions but is interested in the conservation of natural resources under all conditions — natural or artificially created environments. If this

([1]) For list of common and scientific names of fishes, see appendix.

assumption is warranted, then the association would be interested in the effects of multiple-purpose impoundments, good or bad.

As we shall see later, experience in the Tennessee Valley has shown that the term « multiple-use » as applied to river impoundments need not to be restricted to the usual statutory purposes — navigation, flood control, hydro-power, and national defense — but may also include major recreational opportunities such as fishing and hunting, especially migratory waterfowl. That this was possible was, however, not generally recognized at the time the T.V.A. dam building program was started in 1933.

**The T.V.A. System of Reservoirs.**

The Tennessee River development which is now practically complete as far as dam building is concerned consists of approximately 600,000 acres of productive waters. This system is composed of nine reservoirs on the main river and 17 on tributary streams. (This includes Great Falls — 2,280 acres — tributary to the Cumberland River.) The mainstream reservoirs have a combined area of approximately 448,000 acres and vary in size from 6,420 acres (Hales Bar) to 158,300 acres (Kentucky). The storage reservoirs have a total area of 151,000 acres and range in size from 604 acres (Ocoee No. 3) to 34,200 acres (Norris). For additional details and location, see table and location map.

The division of T.V.A. reservoirs into storage and mainstream types is a logical one, for it is based not only on the mode of operation for flood control and power but also upon certain morphometric, physical, and biological characteristics of these bodies of water. The storage reservoirs as a class are much deeper and have steeper shorelines than the mainstream reservoirs. Also because of their greater depth they are (1) thermally stratified and (2) frequently during the summer exhibit the phenomenon of density (subsurface) currents that may cause an atypical distribution of dissolved oxygen with respect to depth. If and when these stratifications occur simultaneously we have a body of water composed of several strata from top to bottom : stratum 1, relatively warm (above optimum for fish), well aerated; stratum 2, temperature optimum but lack of dissolved oxygen; stratum 3, temperature below optimum but oxygen supply ample; and stratum 4, temperature and dissolved oxygen definitely below optimum. Because fish orient themselves with respect to temperature and dissolved oxygen, these factors have an important bearing upon the success of the fishermen. The result is that poor quality fishing may be due to lack of knowledge regarding vertical distribution of fish.

The mainstream reservoirs, because of their relatively (to area) lesser depth, do not stratify thermally or otherwise. Another difference in the two types is the greater transparency of the water in the storage lakes and, hence, they are better suited for game fish — such as black bass and walleye — than the mainstream lakes.

**Water-level Fluctuation.**

Inasmuch as the T.V.A. dams were authorized for navigation, flood control, and power production, reservoir levels must of necessity be subject to variations. Flood waters cannot be stored in reservoirs that are already full. Again, if water is to be used to operate electric generators, the water levels must recede during certain periods. In the mainstreams reservoirs water levels are also manipulated for the control of malaria mosquitoes. Water-level fluctuations and recession are effective and, if combined with power operations, provide an economic malaria control measure. Irregularities in precipitation and runoff sometimes aggravate these changes in level beyond the normally contemplated limits. It will not be attempted to reproduce here in detail the annual reservoir operation schedules for 25 reservoirs. Only the main features of this program will be attempted at this time.

The reservoir operation schedules are, of course, related to the annual hydrological cycle, the main features of which are locally, reasonably constant; i.e., the flood period is confined to the winter and early spring months. A local flood may come during the summer but floods on the system as a whole are confined to the months indicated above. The general aim is to attain minimum levels (this varies with the individual reservoir) between December 1 and January 1. As far as the fishery is concerned, this means that the lower elevations occur during the winter dormancy of the fishes. The refilling in the storage reservoir may begin in January but extensive refilling of the mainstream pools does not begin until about March. The actual rate of refilling as well as drawdown is determined principally by the amount of rainfall — actual and in prospect — time, and the demand for power. For samples of operation schedules, see chart which shows the graphs for one storage (Norris) and one mainstream (Wheeler) reservoir.

The extent of the annual drawndown varies from one reservoir to another. In the mainstream pools this is normally less than 10 feet — in one of the larger impoundments, Guntersville, it is only two feet. In the storage or tributary reservoirs the winter drawdown is, as the name implies, much greater. It may be as much as 150 feet or more during exceptionally dry periods. It was these extensive winter drawdowns in the storage reservoirs that scandalized and exasperated some people until they realized that these excessively low levels occured only during the winter months when both the fish and the fishermen were dormant because of low temperature.

We have said nothing about water-level fluctuations in connection with navigation — a primary justification for river development by the Federal government. Although we must maintain a navigable channel from Kentucky Dam to Knoxville on Fort Loudoun, the requirements of navigation are met by our operation for flood control and power. It is only the rare occasions when some imprudent skipper of a barge line tries to go across country, i.e., strays from the marked channel, that special releases for navigation become necessary.

We have mentioned water-level fuctuations in the interest of malaria control. We want to add to that here because we have had many complaints about this operation. People have criticized the severe drawdown for flood control but somehow that had to be tolerated although they were convinced that we went too far. Fluctuations for power were considered less excusable but still can be tolerated because electric energy was produced. It was the fluctuation and recession for the benefit of malaria control that just did not make sense, because it was reasoned that these summer operations prevented the growth of aquatic vegetation that might benefit potential wintering waterfowl populations. This reasoning was in error because (1) the vast bulk of the vegetation would have been of the type unacceptable to waterfowl, (2) the relatively high turbidity of water would have precluded the extensive growth of submerged aquatics, and (3) growth of useful aquatics that might have been produced in the absence of level changes for mosquito control would have been dewatered and decomposed by the drawdown for flood control long before the ducks and geese arrived. The result, therefore, of keeping the water levels constant during the summer would have been a very substantial loss of power and a prohibitive increase in the cost of mosquito control with virtually no benefit to waterfowl.

T.V.A. has made one major change in the water-level schedule requested for malaria control since this program was originally conceived and put in operation. Originally the schedule called for an early date for the beginning of water-level recession so that the early broods of anopheline mosquitoes might be destroyed. These early recessions were followed by extensive invasions of the reservoir margin by terrestrial plants, and when high waters came in July and August, as they would at times, flooding of this terrestrial plant growth created a mosquito control problem that was difficult and expensive to control without loss of substantial power production. Actually, considering an entire summer operation, the early recession had been detrimental although it had effectively controlled the early generation of anopheline mosquitoes. For this reason, the early recession was discontinued and levels are now maintained until it is too late for most troublesome terrestrials to begin growth. This change in management is of great benefit to the fishes for spawning and the early growth stages.

Currently the water-level manipulation for the control of the malaria mosquito falls into three categories : (1) In the storage reservoirs and Kentucky Reservoir, the latter because of its size, the need for stranding mosquito larvae is met by recession — the power demands normally are such that no discharge is wasted; (2) in Wilson Reservoir a 1.5-foot fluctuation without recession accomplishes the same objective; and (3) in the remainder of the mainstream reservoirs a combination of « fluctuation » with « fluctuation and recession » is the usual practice. In this operation the fluctuations are one foot in depth and are carried out at one-week intervals. After June 15-July 1 and when it is too late for terrestrial species to start growing, and mosquito breeding becomes heavy, the period of water-level recession begins. During this period the weekly drawdown remains at one foot but instead of returning the full foot on the upswing the return is only about 9/10 of a foot. This results normally in not more than a three-foot lowering of the level between June 15 and October.

**Minimum Levels vs. Conservation Pools.**

In the absence of a clear-cut and biologically sound definition of a « conservation pool » we have modestly refrained from the use of this term and speak of minimum pool elevations instead. These minimum levels have been defined, or have been derived, not on the basis of any recreational use including the welfare of the fishery but rather they are based entirely on reservoir design, requirements of the system for statutory purposes — including navigation, and anticipated runoff. In my opinion, the idea of a conservation pool is not too important insofar as we are concerned only with the T.V.A. system. (1) The mainstream reservoirs (in excess of 2/3 of total water area) automatically have the equivalent of a conservation pool because of the requirement of a navigable channel from the Ohio River to Knoxville on Fort Loudoun. (2) Our own observations on the quality of the fishery during seasons following extreme winter drawdowns have convinced us that drawdowns far in excess of those normally scheduled for flood control and power usually have no adverse effect upon the fishery. As an example, we cite the unusually good fishing on Cherokee and Norris Reservoirs during 1956 following the unusually severe drawdowns during the winter of 1955-1956. The excellent walleye fishing in Norris Reservoir in 1958 made up mainly of the 1956 year class is additional evidence that the unusually severe drawdown in 1956 had no adverse effect upon the fishery.

Some agencies and/or associations, etc., can afford to be generous and maintain relatively higher winter water level than may be required by the fishery and that may be convenient for boat deck operators and fishermen. Unfortunately the T.V.A. is not in this category. (1) We must meet a huge demand for power with somewhat limited facilities at best and (2) we have to earn money to reimburse the U.S. Treasury for funds advanced for the building of dams and power installations. For these reasons we must scrutinize any request for the adjustment of water-level schedules.

**Effect of Impoundment upon the Invertebrate Fauna (Macroscopic) including Mussels.**

Except for the mussel population, these statements are based on limited observations. Some specific studies on the insect fauna and other invertebrates are available but the physical scope of this paper does not afford space for detailed discussion. In general, we may make these statements. In the relatively deep storage reservoirs the bottom fauna is for the most part reduced to those species that can exist under anaerobic conditions — certain species of annelids and midges. This condition exists because (1) most of the insects are not found at depths greater than the annual drawdown and (2) the zone of drawdown, strata of stagnant water produced by density currents, and the bottom stagnation zones overlap especially when the summer inflow is substantially above normal. In the mainstream reservoirs because of the absence of stratification (including bottom stagnation) and a much less extensive drawdown although the bottom fauna may be modified locally a substantial bottom fauna both with respect to species and numbers exist — for instance, large swarms of mayflies are produced annually.

You may well ask how the absence of a substantial bottom fauna affects fish production in the storage reservoirs. The effect upon most species of fish is negligible. The only fishes of value that are affected adversely are the bluegill and other sunfishes. The really valuable species (to the anglers), the basses, walleye, sauger, and crappies, are not affected although the survival rate of fingerling sizes might be greater if insect food were available at certain critical periods. Nevertheless, with only a very limited bottom fauna extensive and fast-growing (growth rate) populations of the black basses, the walleye, the sauger, the striped bass, and crappie (two species) maintain themselves in all our storage reservoirs. The key to this situation is the existence of plankton-feeding forage fishes, principally the gizzard shad and the threadfin shad.

The snail population (Gastropoda) is adversely affected in all T.V.A. impoundments by water-level fluctuation. This may suggest a disturbance of the balance of nature but is really of no significance as long as the production of fish is under consideration. Actually since snails along with wading birds serve as the intermediate host of certain fish parasites, their absence may well be considered beneficial.

The freshwater mussel (a number of species) was the only invertebrate of real commercial value in the Tennessee River system before the dams were built. This is still true; however, the commercial mussel beds are now restricted principally to the midsection of the mainstream reservoirs. Bottom stagnation prevents their existence in the deep storage reservoirs. In the mainstream reservoirs their distribution is limited by too violent water movement in the upper section of the reservoir and by the lack of current in the lower section.

Currently 75 percent of the mussel shells used by the American freshwater pearl button industry comes from the T.V.A. impoundments.

**The Effect of Impoundment Upon the Fishery.**

The creation of additional fishing waters should most certainly be considered a major contribution in the field of aquatic resource conservation and development. This is true especially in a region that possesses few natural lakes and where the principal fishing waters are provided by rivers and lesser streams that even aside from pollution and erosion sediments because of variations in the amount of runoff — floods and droughts — provide an unstable environment. The locale in which T.V.A. operates does not abound in natural lakes. For this reason, T.V.A.'s contribution of approximately half a million acres (see table) of fishing waters is quite significant. Moreover, these impoundments, although subject to water-level changes for statutory purposes, constitute a much more stable and superior environment than the unharnessed river. Even in those instances where the total annual changes in water level is greater than in the original river, these changes are under control and are much less drastic over a given period of time.

Before Norris Dam was built the flow of the Clinch River at the dam site ranged from as little as 150 c.f.s. to as much as 80 to 120,000 c.f.s., depending on the season or rainfall. With such wide variations in flow and the local pattern of distribution of rainfall those sections of the Clinch River system now covered by Norris Reservoir were a couple hundred miles of mostly dry river bed dotted here and there with pools of relatively shallow water connected by trickling streams during much of the summer. Since the dam was built there always remains a substantial residual pool. It is this greater stability together with an increase in depth and in many instances a greatly reduced turbidity that accounts for the fact that on the average the fishery in the T.V.A. lakes is at least 50-fold that of the unimpounded river whereas the increase in water surface is only six-fold that of the original stream bed. This stability, increased depth, and reduced turbidity increases the fish production not only quantitatively but qualitatively as well. It creates a habitat acceptable to black bass, the crappies, the walleye, the sauger, and the white bass where formerly the fish population consisted mainly of sunfish, suckers, and bullheads plus carp and buffalo. Before impoundment not many black bass, crappie, walleye, and sauger were normally taken from the waters of the Clinch River. In contrast with this situation, Norris Reservoir now offers in season as good black bass (largemouth and smallmouth plus some spotted), crappie (black and white), walleye, and sauger fishing as can be found anywhere. Moreover, the statements made here about the improvement of the fishery in Norris Reservoir over the fishery that existed in the Clinch River before impoundment can be made with respect to all storage reservoirs in the system. In every instance the total fish production has been increased — when we speak of a fifty-fold increase we are really very conservative — and the quality of the fishery has been vastly improved. It is this improvement in the quality of the fishery that truly emphasizes the value of the impoundments to the fishery. In America the main interest in the fishery in inland waters is concentrated upon the sport fishery and, hence, the great value of the presence of a vastly increased number of fine fishes — the black basses, etc.

The fish population in the mainstream reservoirs differs from that of the storage reservoirs in several respects. The productivity is greater because the waters are more fertile, mainly because of the discharge of municipal sewage but also because of a more fertile watershed (in part at least). Also the absence of stratification, especially bottom stagnation, permits the development of a permanent bottom fauna — insects, worms, and clams. This bottom fauna provides a large volume of food that is not present in the storage reservoirs. All this results finally in the production of a greater number of fishes. However, the populations differ not only in number but in kind as well. Both types of reservoirs support good populations of white bass, crappie, and sauger but in contrast with the storage reservoirs the mainstream reservoirs support fewer black bass and virtually no walleye but more sunfishes and a large population of food and rough fish species — catfishes, drum, buffalo, carp, some mooneye, and river herring. The presence in large number of these nongame species posed a considerable problem, especially since over a major portion of the Valley their removal could be effected by hook and line only — netting was illegal in artificially impounded waters. As a result, it was feared that these waters would be taken over completely by nongame species, especially carp and buffalo. Fortunately, this has not happened because (1) netting of these nongame species has been legalized despite the vigorous opposition of so-called sport fishermen and (2) the maintenance of a clean shoreline in the interest of effective and economical mosquito control limits the amount of favorable spawning habitat for carp and buffalo. (The catfish are no problem; because of their relatively high market value they are well exploited by commercial fishermen.)

Currently anglers take annually around eight million pounds of fish from the T.V.A. impoundments and commercial fishermen harvest another six million pounds from the same waters. The commercial catch consists mainly of catfish (three species) but buffalo and carp are also taken in quantity.

The T.V.A. lakes are open to year-round fishing of all species and no artifical propagation is practiced.

**Effect Upon Migratory Waterfowl.**

Prior to the advent of the T.V.A. the Tennessee River was not a major route for migratory waterfowl and virtually no birds wintered in the area. The Tennessee River, however, lies along the eastern fringe of the Mississippi flyway. With the building of the reservoirs, and thus greatly expanding the visible water surface. a substantial number of ducks coming down the Ohio River or across country moved up the Tennessee River instead of going on to the Mississippi River to the west. Other birds moving in across the State of Kentucky and east Tennessee were intercepted by the impoundments strung across east Tennessee and northern Alabama.

How did these birds that had accidentally discovered a new home prosper in this new environment ? During the first year of the life of a reservoir they generally fared very well because the accumulation of matured seeds of terrestrial plants throughout the shallow waters and mudflat along the reservoir shore was adequate to sustain them. After the first year the ducks did not fare so well because of a food shortage. The geese, because of their grazing habits, were not seriously affected by the shortage of natural food — matured seeds and tubers of aquatic or mudflat species. Thus, it soon became apparent that although the extensive acreage of the T.V.A. impoundments would attract large numbers of ducks and geese the ducks would not remain long because of the lack of food.

The problem then if migratory waterfowl were to be kept in the Tennessee Valley, was to provide food and this food production would have to be independent of the main body of the reservoir. The mode of reservoir operation, mandatory by the provisions of the T.V.A. Act, precluded the possibility of manipulating the reservoirs proper for the benefit of wildlife. (A gradual drawdown beginning in June and refilling during October and November would have solved the food problem for ducks most admirably.) Under these conditions what were the possibilities ? Briefly, they were : (1) Produce domestic crops, corn, soybeans, millets, cereals, etc., on agricultural lands adjacent to the reservoirs. (2) Produce cultivated and wild plant species behind malaria control dykes which were kept dewatered during the summer and could be reflooded during the fall and winter — total area behind such dykes roughly 15,000 acres. (3) Encourage the growth of useful mudflat secies through the control especially of woody plant species. (4) Provide browse — grasses and grain cereals — within the drawdown zone. The feasibility of this program was soon established. The geese take to these pastures and the ducks feed readily on domestic crops left in the fields. But assuming the feasibility of such a program was established, there still remained the problem of providing the agricultural lands to produce these domestic crops. Fortunately, the T.V.A. held in its custody lands that were well suited — character and location — for this purpose and could be made available.

The waterfowl program in the Tennessee Valley is based on use of the lands mentioned in the preceding paragraph. These lands are used by cooperating agencies, the U.S. Fish and Wildlife Service and the Valley states, to produce food. The upland agricultural acreage is devoted mainly to the production of domestic crops through a system of custom farming. The conservation agencies' share is left in the field. Within refuges the mature crops may be manipulated so as to make them more readily available to the birds; in public shooting areas the crops cannot thus be manipulated and the birds must garner the crops as best they can. (Anti-baiting provision.) However, they manage very well. In the fall of 1956, approximately 155,000 bushels of grain (mainly corn, milo, soybeans, buckwheat, and millet) and seeds were left in the field for the benefit of waterfowl. Extensive areas of goose pasture are provided annually within the drawdown zone and on islands — some permanent and some submerged at normal pool level.

The ducks and geese are using the facilities (food, etc.) provided by the Service and the Valley states on T.V.A. holdings. According to reports of the U.S. Fish and Wildlife Service, the Tennessee Game and Fish Commission, and the Alabama Department of Conservation on waterfowl census, 462,390 birds (37,390 geese and 425,000 ducks) were inventoried on T.V.A. lakes on November 9, 1956. Another indication of the effect of T.V.A. dams on migratory waterfowl is the increase in the sale of duck stamps (all duck hunters must buy this Federal stamp) in the State of Tennessee. Since the advent of T.V.A. this sale has risen from 5,366 in 1937-1938 to 41,406 in 1956-1957. These figures and other observations show that the Tennessee Valley is fast becoming an important waterfowl wintering ground for waterfowl of the Mississippi flyway because of (1) the T.V.A. development and (2) the deterioration of coastal areas.

The effect of Kentucky Reservoir, because it parallels the Mississippi River, is felt over the entire area between the Tennessee and Mississippi Rivers. Because the ducks have the habit of drifting back and forth between the two rivers, the waterfowl population in the intervening area has increased considerably.

Waterfowl experts claim that many years ago during the fall migrations some ducks left the Mississippi flyway at the latitude of northern Alabama and shifted over to the Atlantic flyway. For some unexplained reason this eastward migration was discontinued. It is interesting to note, therefore, that since T.V.A. this pattern of migration has become reestablished.

The waterfowl program in the Valley is a cooperative one. The actual development work is done by the Service and the Valley states. The function of the T.V.A. is to evaluate the possibilities in proper relation to statutory programs. More important than this, however, T.V.A. (*a*) makes lands and waters in its custody available to the state and Federal agencies and (*b*) resolves conflicts that arise as a result of multiple use of the reservoir and the multiple primary interests of the numerous agencies involved.

**Facts about T.V.A. Dam and Reservoir projects** (*a*)

| | Length ([c]) of lake shoreline (miles) | Area ([c]) of lake (acres) | Area of original river bed (acres) | Volume of lake at ordinary minimum elevation (acre-feet) | Volume of lake at maximum controlled elevation (acre-feet) | Useful ([d]) controlled storage in reservoir (acre-feet) |
|---|---|---|---|---|---|---|
| *Main river projects :* | | | | | | |
| Kentucky | 2,380 | 158,300 | 23,800 | 1,991,800 | 6,002,600 | 4,010,800 |
| Pickwick Landing | 496 | 42,800 | 9,600 | 673,000 | 1,091,400 | 418,400 |
| Wilson (*f*) | 154 | 15,930 | 8,800 | 597,000 | 650,000 | 53,000 |
| Wheeler | 1,063 | 67,100 | 17,600 | 802,900 | 1,150,400 | 347,500 |
| Gunsterville | 962 | 69,100 | 12,300 | 855,800 | 1,018,700 | 162,900 |
| Hales Bar (*f*) | 162 | 6,420 | 3,800 | 135,290 | 147,660 | 12,370 |
| Chickamauga | 810 | 34,500 | 9,500 | 375,900 | 705,300 | 329,400 |
| Watts Bar | 783 | 38,600 | 10,300 | 754,400 | 1,132,000 | 377,600 |
| Foot Loudoun | 360 | 14,600 | 4,500 | 277,200 | 386,500 | 109,300 |
| *Tributary projects :* | | | | | | |
| Apalachia | 31 | 1,123 | 386 | 50,000 | 58,700 | 8,700 |
| Hiwassee | 180 | 6,120 | 1,000 | 73,300 | 438,000 | 364,700 |
| Chatuge | 132 | 6,950 | 107 | 18,500 | 240,500 | 222,000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ocoee No. 1 (f) | 18 | 1,900 | 170 | 58,200 | 91,300 | 33,100 |
| Ocoee No. 2 (f) | — | — | — | — | — | — |
| Ocoee No. 3 | 24 | 604 | 260 | 2,850 | 8,700 | 5,850 |
| Blue Ridge (f) | 60 | 3,290 | 182 | 14,500 | 200,800 | 186,300 |
| Nottely | 106 | 4,180 | 170 | 13,200 | 180,200 | 167,000 |
| Norris | 800 | 34,200 | 3,000 | 286,000 | 2,567,000 | 2,281,000 |
| Fontana | 248 | 10,670 | 1,650 | 287,000 | 1,444,300 | 1,157,300 |
| Douglas | 555 | 30,600 | 3,170 | 94,400 | 1,514,100 | 1,419,700 |
| Cherokee | 463 | 30,200 | 2,550 | 92,300 | 1,565,400 | 1,473,100 |
| Ft. Patrick Henry | 37 | 893 | 338 | 22,800 | 27,100 | 4,300 |
| Boone | 130 | 4,520 | 718 | 46,700 | 196,700 | 150,000 |
| South Holston | 168 | 7,580 | 485 | 118,800 | 744,000 | 625,200 |
| Watauga | 106 | 6,430 | 335 | 51,600 | 678,800 | 627,200 |
| Great Falls (a) (f) | 120 | 2,270 | 850 | 5,100 | 54,500 | 49,400 |
| Totals | 10,348 | 598,880 | 115,571 | 7,698,540 | 22,294,660 | 14,596,120 |

(a) All in Tennessee Valley except Great Falls which is in Cumberland Valley.
(c) Full pool elevation.
(d) Useful controlled storage is the volume between the ordinary minimum elevation and maximum controlled elevation.
(f) Acquired: Wilson by transfer from U. S. Corps of Engineers in 1933; Hales Bar, Ocoee No. 1, Ocoee No. 2, Blue Ridge, Great Falls, and Columbia by purchase from TEP Co. in 1939; Wilbur and Nolichucky from ETL & P Co. in 1945. Subsequent to acquisition, TVA heightened and installed additional units at Wilson, Hales Bar, and Wilbur.

Taken from TVA Handbook, 6-19-57.

**Summary Statement.**

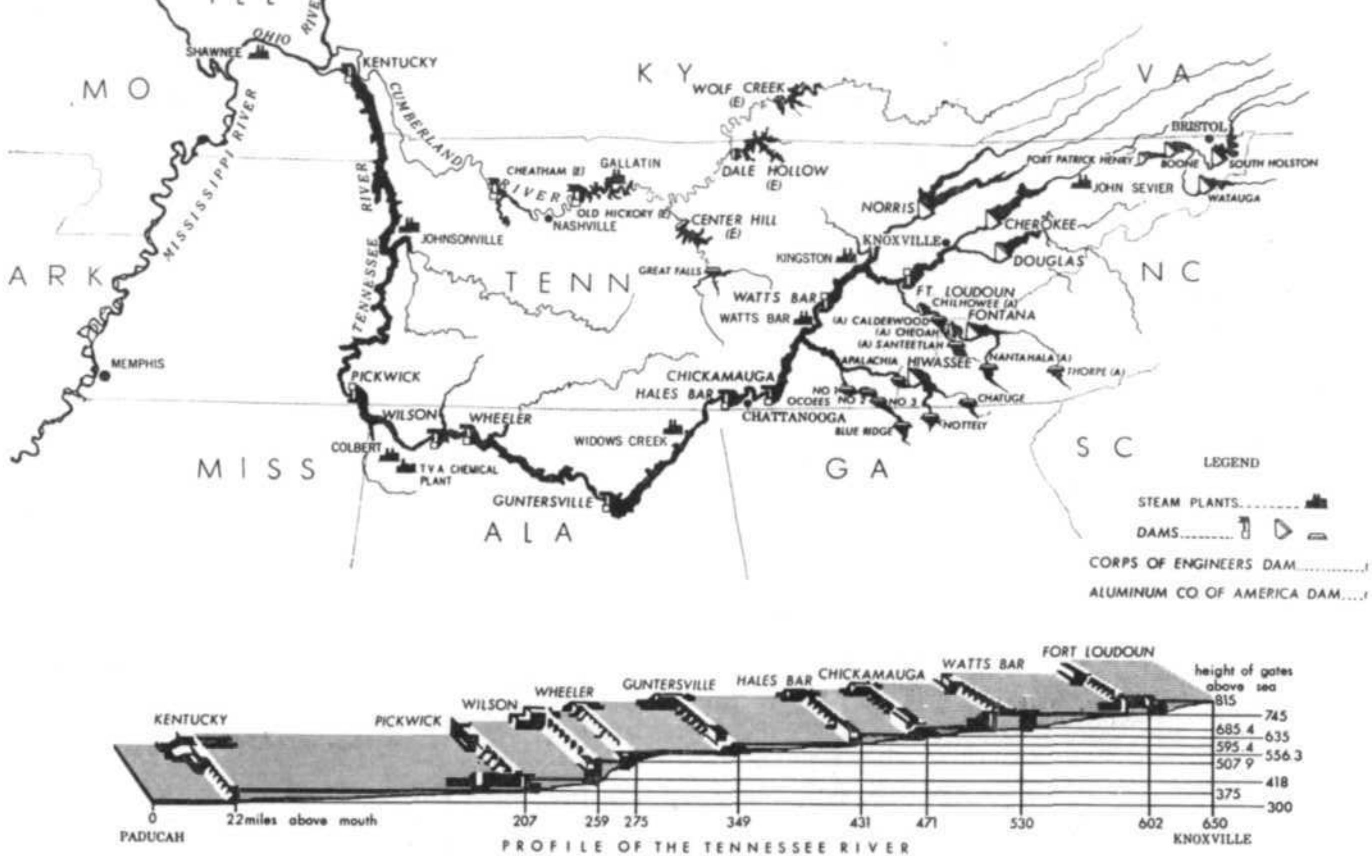
The T.V.A. development has resulted in a vastly improved fishery in the Tennessee River Valley. The fishery has been expanded at at least 50-fold, but more important, the quality — more fine fish desired by anglers — of the fishery has also been improved as a result of river impoundment. Special mention might be made here of the fine black bass (especially the northern smallmouth) and walleye fishery, the great increase in the crappie fishery, and the virtually explosive expansion of the sauger and striped bass fishery in the mainstream impoundments. The establishment of a large wintering population of ducks and geese is another tangible result of river impoundment. And although this later development required the use of lands beyond the reservoirs proper, the land without the reservoirs would not have effected this change.

**COMMON AND SCIENTIFIC NAMES OF FISHES REFERRED TO IN TEXT**

| | |
|---|---|
| Largemouth black bass | *Micropterus salmoides.* |
| Smallmouth black bass | *Micropterus dolomieu.* |
| Spotted black bass | *Micropterus punctulatus.* |
| Striped bass | *Roccus saxatilis.* |
| White crappie | *Pomoxis annulavis.* |
| Black crappie | *Pomoxis nigro-maculatus.* |
| Sauger | *Stizostedion canadense.* |
| Walleye | *Stizostedion vitreum vitreum.* |
| Bluegill | *Lepomis macrochirus.* |
| Rainbow trout | *Salmo gairdnerii.* |
| Brown trout | *Salmo trutta.* |
| Freshwater drum | *Aptodinotus grunniens.* |
| Channel catfish | *Ictalurus lacustris.* |
| Blue catfish | *Ictalurus furcatus.* |
| Flathead catfish | *Pilodictis otivaris.* |
| Carp | *Cyprinus carpio.* |
| Buffalo (species) | *Ictiobus.* |
| Sucker (species) | *Catostomus.* |
| Gizzard shad | *Dorosoma cepedianum.* |
| Threadfin shad | *Signalosa petenensis atchafalayae.* |
| Mooneye | *Hiodon tergisus.* |
| River herring | *Pomolobus chrysochhris.* |

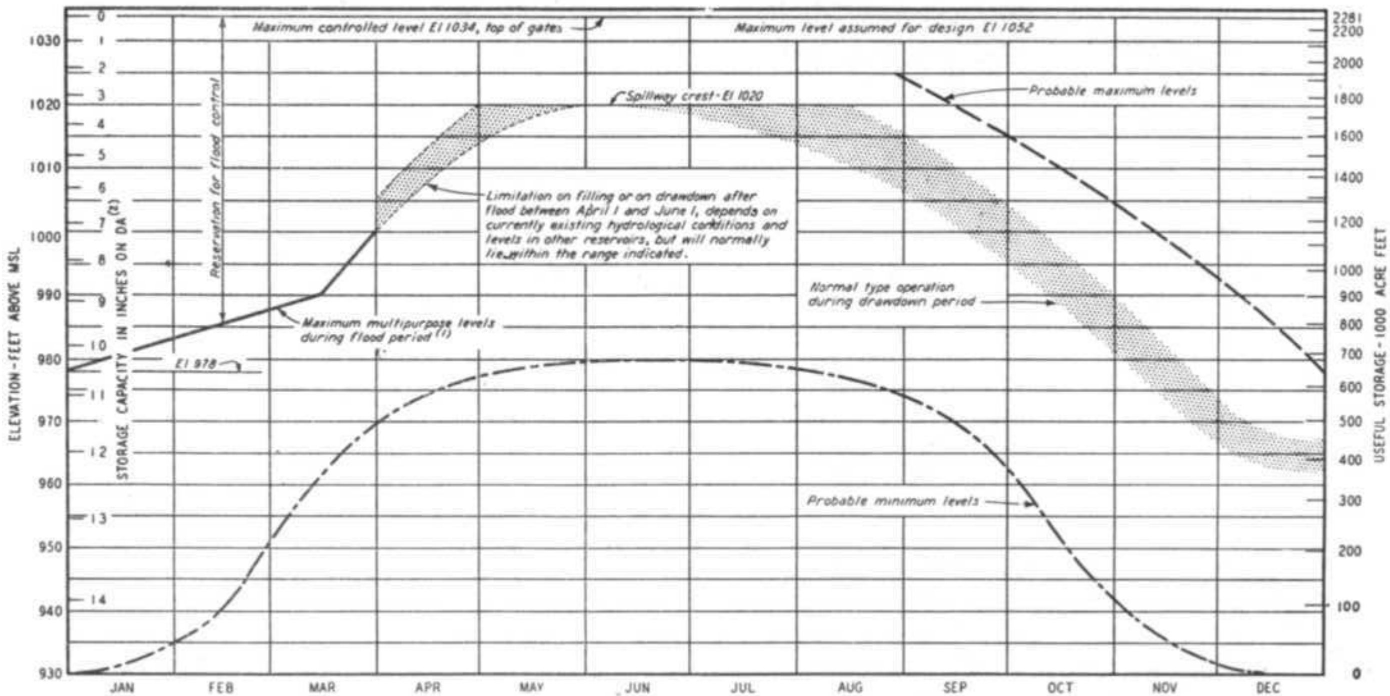
Persons interested in additional information about the T.V.A. development should write to Tennessee Valley Authority, New Sprankle Building, Knoxville, Tennessee, U.S.A.

# TENNESSEE VALLEY REGION

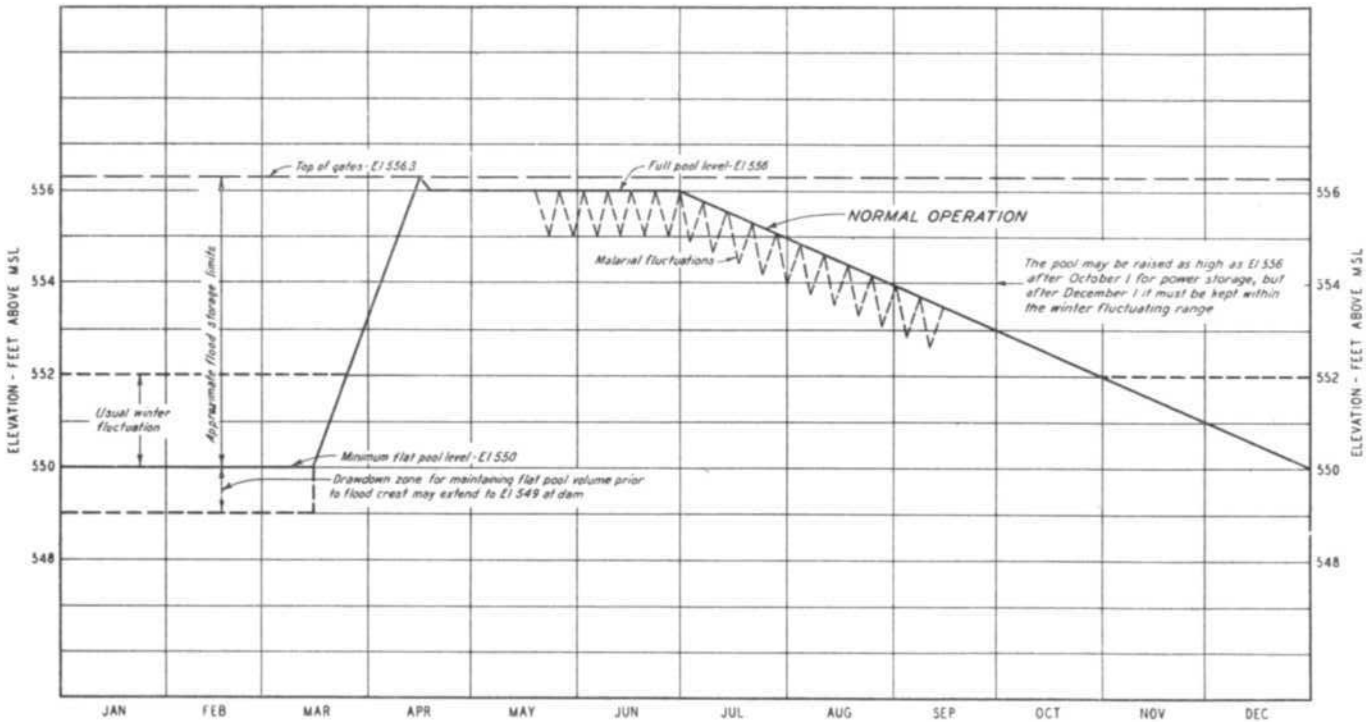


## MULTIPLE-PURPOSE RESERVOIR OPERATION

(Tennessee Valley Authority Water control planning department).




NORRIS PROJECT




WHEELER PROJECT

# SOME EFFECTS OF WATER-LEVEL FLUCTUATIONS ON THE FISHERIES OF LARGE IMPOUNDMENTS

BY

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Bureau of Sport Fisheries and Wildlife, Atlanta, Georgia

## INTRODUCTION

In December 1740, in the colony of Georgia, it was recorded that a corn mill had been finished on the Ebenezer River and that it would grind ten bushels of Indian corn in one day and night (THOMSON, 1953). This was one of the first of many similar water mills to be built by early Americans on the creeks and rivers throughout the new nation. It symbolized the beginning of a vast programme of river-basin development which later would be undertaken by the United States Government in partnership with State and local agencies.

Two hundred and twenty years later Buford Dam on the Chattahoochee River, Georgia will be complete. It will comprise one of about 1,300 reservoirs and lakes, each with a usable storage of at least 5,000 acre feet. The combined usable storage of these reservoirs will be over 278 million acre feet; the combined surface area at the top of the maximum controllable elevation, over 11 million acres (THOMAS and HARBECK, 1956).

While most of these reservoirs and lakes have been developed for hydro-electric power, flood control, irrigation, and navigation, there has been increasing national emphasis on wildlife conservation and recreational use of water. In the early times the mill pond and tail race of the grist mills were fished by a few boys and older men of the community. Today the reservoirs and their tailwaters afford outdoor recreation to a large and enthusiastic segment of our population. For example, in 1956, the estimated attendance on 127 Corps of Engineers' projects was 71,340,000 visitors, a large portion of which were anglers. Some of the reservoirs support a commercial fishery. This resource, although of secondary importance to recreation, is expected to increase in value as our expanding human populations require more food.

Therefore, it is timely that information be exchanged with respect to the fisheries of large impoundments and factors which limit their production and harvest. In the relative absence of scientific data with respect to the effects of water-level fluctuation, one of the more obvious factors influencing fisheries of large impoundments, there has been much speculation. A review of concepts and experiments, therefore, is presented as the basis for evaluating progress. Moreover, some present day concepts are illustrated by a description of one natural lake subject to seasonal overflow and three large reservoirs.

### Early concepts

When the Tennessee Valley Authority began building dams in 1933, it was popularly believed that the primary reason for decline in angling success following the first two or three years of impoundment was water-level fluctuation. A widely accepted explanation was that with the drawdown of water in a reservoir, nesting areas were exposed, lateral beds of submerged vegetation productive of fish food were left dry, and both young and old fish were often forced into waters unsuitable or even lethal. Another explanation by ELLIS (1937) was that productivity declines when the fixed nitrogen, phosphate, and ionizable salt content of the water derived from organic decay has been exhausted.

### Later concepts

The Rough Fish Problem : The work of Dr. A. H. Wiebe and associates (WIEBE, 1942) revealed that rather than fluctuation, an over-abundance of rough fish constituted the major fishery problem in main-stream reservoirs of the Tennessee Valley system (1). He pointed out that the annual removal of rough fish was about five pounds per acre whereas the total population of these fish was in excess of one hundred pounds per acre. Thus he concluded that the less desirable species would continue to increase at the expense of the game fish (2). How to reverse this trend was the all-important question. Two approaches were explored. One was directed towards greater use; the other towards control of rough-fish species by environmental adjustment.

ESCHMEYER, STROUD and JONES (1944) reported that due to the small catch-per-unit-effort of rough fish in Chicamauga Reservoir, a TVA main-stream project, commercial fishing was unprofitable and

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(1) Rough fish is a term loosely applied to the scale fishes not ordinarily sought by anglers. Among this group are carp, buffalofishes, freshwater drum, suckers, and shad. In this paper the catfishes also are included in this group. The common and scientific names of all fishes referred to are listed in Table 3.

(2) The terms game fish and sport fish are used interchangeably. Among this group are the basses, crappies, bluegill, and other sunfishes, pickerel, walleye, and sauger (Table 3).

therefore could not be expected to bring about a more favourable ratio between game and rough fish. On the other hand, a properly timed drawdown to prevent the reproduction of undesirable species was offered as a possible solution.

The problem was not as acute in the storage reservoirs located on the headwaters of the Tennessee River system. In a special communication received from Dr. R. W. ESCHMEYER (1947), it was stated that several permanent-level pools, which had been impounded for recreational purposes, had provided poorer fishing than the reservoirs which were subject to wide fluctuation. He also suggested that « a winter drawdown apparently limits the abundance of rough fish (by limiting their food) without serious injury to the game-fish populations. »

BENNETT'S (1944) review of the works of various fishery biologists indicated that the quality of sport fishing afforded by a lake was dependent as much upon the type of fish population it supports as upon its productivity. Summarizing his review, good fishing is usually afforded by balanced populations consisting principally of game fish; poor fishing by overcrowded populations and balanced populations dominated by rough fish.

Balanced Populations in Managed Ponds: The most successful pond-fish culture for the production of sport fishing is based on the establishment and management of balanced fish populations as was described by SWINGLE and SMITH (1942). The simplest combination and the one most widely used throughout the United States includes only two species — the bluegill, a forage fish, and the largemouth bass, a predatory species. BYRD and Moss (1956) reported an average catch per acre of 29 pounds of largemouth bass plus 154 pounds of bluegills, redears, and bullheads in eleven State-owned and operated fishing lakes in Alabama that were fertilized and contained balanced fish populations. The water levels in these lakes were held relatively stable.

Expanding Populations in New Impoundments and Overflow Lakes: Another type of fish population which usually affords successful angling is an expanding fish population, defined as « an assemblage of fishes rapidly expanding in numbers, average size, and weight » (WOOD, 1951). Such a population is characteristic of new impoundments and natural lakes which are subject to overflow. It may not achieve balance. Notwithstanding, a readily harvestable crop is produced by rapid expansion; moreover it affords perhaps the greatest opportunity for fishery management in large impoundments since a delicate balance between predatory and forage and game and rough fish is not necessary.

To maintain an expanding fish population, a periodic extreme drawdown was envisaged in a plan for the fish and wildlife development of large impoundments (WOOD, ROBERTS and BOOTH, 1947). This feature of the plan was based on the assumption that in a new environment fish tend to advance through stages of succeeding dominants, as do plants and other animals; also that to re-establish early stages of this succession, a severe shock or disturbance to effect a substantial reduction in the fish population is necessary.

The plan also provided for a seasonal pattern of water-level manipulation designed to simulate natural overflow conditions in the lower Mississippi alluvial valley, whereby it was assumed that the natural productivity of an impoundment could be sustained.

While it was not possible to set up controlled experiments to test these hypotheses, they were supported by additional observations and review of literature (WOOD, 1951).

Managed Fluctuations: BENNETT (1946) described the cycle of transition from good to poor fishing in many stable-level water supply reservoirs in Illinois. He reduced the numbers and total weight of fish in Ridge Lake, Coles County, Illinois, by draining the reservoir in March every other year, replacing only a small part of the population, and subsequently allowing it to expand (BENNETT, 1954 *a*). As a result of this procedure, the annual average catch in Ridge Lake varied from 11 to 30 pounds of largemouth bass per acre, with an average of about 19 pounds per acre during the nine years of operation. The average catch of bluegills, green sunfish, and bullheads added an additional 13 pounds per acre per year.

In 1951 and 1952 BENNETT (1954 *b*) accomplished virtually the same effect by a late summer drawdown following the summer fishing period. In early September of each year the level of Ridge Lake was lowered 15 feet, thereby reducing the surface area from 17 acres to 5.25 acres or 69 per cent. In evaluating the effects, Bennett concluded that while the drawdown was followed by heavy bass reproduction, it was too severe for the bluegill population. The effectiveness of this type drawdown in re-establishing an expanding fish population, however, was demonstrated.

Similar experiments related to a drawdown in late summer and in winter have been conducted by ALDRICH (1946), HOLLOWAY (1949), SMITH (1951), HULSEY (1957) and others with a view towards improving sport fishing by establishing a more favourable ratio between predatory and forage and between game and rough fish. The results of these experiments have been encouraging, and although the reasons are by no means fully understood, many clues have been discovered which aid the better understanding of the significance of water-level fluctuations.

### Present day concepts

To illustrate some present day concepts with respect to the effects of water-level fluctuation, the following areas were selected for discussion purposes : (1) Old River Lake in the lower White River flood plain, Arkansas; (2) Nimrod Reservoir on the Fourche LaFave River, Arkansas; (3) Wheeler Reservoir on the Tennessee River, Alabama; and (4) Norris Reservoir on the Clinch River, a headwater tributary of the Tennessee River, Tennessee. Pertinent data with respect to their pools and drainage areas are compared in Table 1.

### Old River Lake

Old River Lake and the surrounding bottom lands of the White River constitute a natural flood-storage area in the lower Mississippi alluvial valley. The frequency, stage, time of occurrence, and duration of flooding are determined by rainfall and run-off from the watershed and by backwater conditions. Floods which inundate all or a part of the bottom lands may occur during any month of the year. A wide variation in the annual pattern of water-level fluctuation therefore is experienced. Usually, however, waters rise in the autumn months, reach a maximum stage in early spring, and subside to a low stage in late summer, as reflected by the hydrographs for White River in Figure 1.

The average annual fluctuation of White River at St. Charles, Arkansas, and, consequently, Old River Lake is about 22 feet. The total area inundated at maximum stage within a representative segment of the flood plain (White River National Wildlife Refuge) comprises about 98,000 acres. The total permanent water at minimum stage consisting of streams and lakes, of which Old River Lake is characteristic, comprises about 6,000 acres. This reflects a maximum-minimum pool ratio of about 16, the highest of any of the example areas to be described.

The total weight of fish per acre in that portion of Old River Lake sampled by the Arkansas Game and Fish Commission in 1953 was 836 pounds, indicating the highest productivity of any of the example areas (Table 2). About 551 pounds, or 66 per cent, of this weight was composed of edible species ([3]). The ratio of forage fish to predatory fish was only 2.1, a rare relationship in managed fish ponds, which usually have a ratio of from 4-6, but not unexpected

TABLE 1.

Comparison of pertinent pool data (*).

| Unit | White River | Nimrod | Wheeler | Norris |
|---|---|---|---|---|
| Drainage area (sq. mi.) | 23,430 | 680 | 29,590 | 2,912 |
| Elevation (feet above m.s.l.) : | | | | |
| Maximum pool | 160 | 364 | 556.3 | 1,020 |
| Minimum pool | 138 | 340 | 550.0 | 950 |
| Stream bed at dam | | 276 | 498.0 | 819 |
| Surface area (in acres) : | | | | |
| Maximum pool | 98,000 (**) | 12,450 | 68,300 | 34,000 |
| Minimum pool | 6,000 (+) | 2,900 | 41,000 | 12,000 |
| Shallow water (acres five feet or less) : | | | | |
| Maximum pool (++) | 35,000 | 1,300 | 21,800 | 2,000 |
| Minimum pool (++) | 5,000 | 800 | 8,500 | 700 |
| Ratios : | | | | |
| Drainage area-maximum pool | 160 : 1 | 34.9 : 1 | 278 : 1 | 54 : 1 |
| Maximum pool-minimum pool | 16 : 1 | 4.3 : 1 | 1.6 : 1 | 2.8 : 1 |

(*) Maximum and minimum pool data based on patterns of experienced stages in Figure 1 rather than design pool elevations.

(**) Includes all lands and water subject to overflow of White River within White River National Wildlife Refuge.

(+) Includes all permanent water, lakes, sloughs, and streams within National Wildlife Refuge, of which Old River Lake is characteristic.

(++) Calculated from elevation-area curves and tables.

([3]) While all the species of fish listed in Figure 3 are sometimes eaten, the gars, bowfin and shad are rarely marketed or used for food purposes in the United States.

in this natural lake which is subject to overflow from the White River (4).

TABLE 2.

Pounds per acre as calculated from Rotenone samples for years of record.

| Years | Old River Lake | Nimrod Reservoir | Wheeler Reservoir | Norris Reservoir |
|---|---|---|---|---|
| 1946 | — | — | 87 | — |
| 1947 | — | — | 107 | — |
| 1948 | — | — | 51 | — |
| 1949 | — | — | 184 | 79 |
| 1950 | — | — | 200 | 11 |
| 1951 | — | 282 | 91 | 47 |
| 1952 | — | 272 | 185 | 69 |
| 1953 | 836 | — | 261 | 38 |
| 1954 | — | — | 125 | 171 |
| 1955 | — | 228 Drawdown (*) | — | 118 |
| 1956 | — | 153 Drawdown (*) | — | 124 |
| 1957 | — | 131 | — | — |
| Average of all years | 836 | 226 | 136 | 83 |

(*) Controlled drawdown for commercial harvest of rough fishes.

Old River Lake, White River, and other permanent waters of the flood plain provide habitat for the residual or breeding stock of fishes which migrate to the shallow backwaters to feed or to reproduce as the waters rise and overflow a vast area. High stages of long duration usually produce the greatest fish crops. Receding stages favour their harvest by an array of predators and scavengers,

(4) Certain indices used by SWINGLE (1950 and 1953) in the interpretation of the results of his samples are employed in this paper. The ratio by weight of forage species to predatory species (F/C ratio) is a measure of balance or population dynamics. The value or percentage by weight of a given species in the total population is used to reflect species tolerance to the combined influence of environmental factors.

## Patterns of water level fluctuations and marked deviations

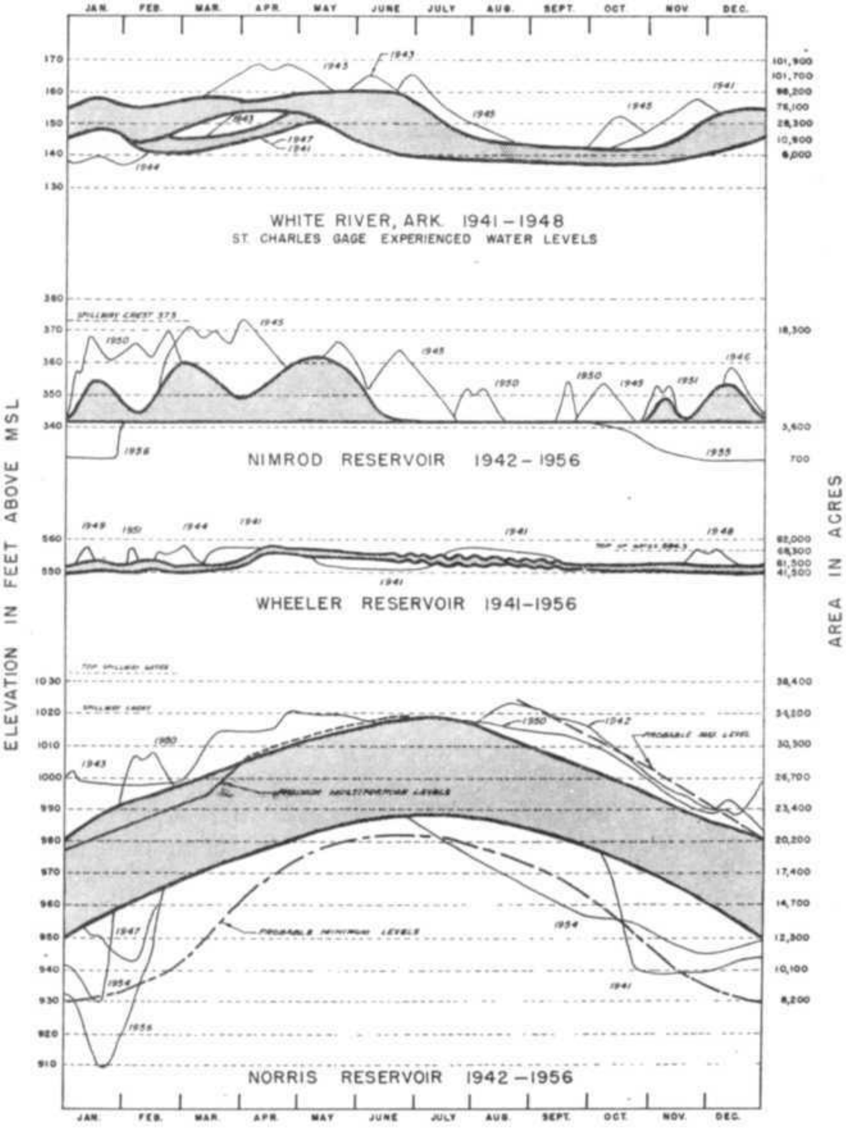


FIG. 1.

which include not only the predatory fishes listed in Table 3 but a variety of turtles, wading birds, hawks, owls, minks, and other animals. BENNETT (1947) also recognized that overcrowding is not likely to persist for long under extreme natural predation.

Since the high stages of this natural cycle of water-level fluctuation often coincide with the spawning season for gars, catfishes, bass, crappies, carp, buffalofishes, and freshwater drum and persist long enough to favour rapid growth, it is understandable why these species are common in the fish population (Table 3). The low stages which usually occur in summer when water temperatures are favourable for the spawning of bluegills and other small sunfishes do not preclude adequate reproduction.

While the weight of fish per acre in Old River Lake was the highest of any of the four example areas when based on minimum pool area, it was the lowest when based on maximum pool area. In appraising the productivity of Old River Lake and its overflow area, however, it must be realized that fish are only one of its many natural resources. The seasonal cycle of water-level fluctuation and fertile alluvial soils of the adjacent bottom lands have favoured the establishment of extensive hardwood forests and abundant wildlife composed of a wide variety of forest game, waterfowl, and fur-bearing species. These resources add to the abundant store of this natural area.

**Nimrod Reservoir**

Nimrod Reservoir is a single-purpose flood-control project on the Fourche LaFave River, Arkansas. It was completed and impounded to the top of its 3,600-acre conservation pool in 1942. Since storm waters are stored above conservation-pool level and gradually released, the pattern of water-level fluctuation in the reservoir closely simulates that of White River and Old River Lake. The vertical rise of 30 feet in water levels is comparable, although the duration of overflow is somewhat less (Figure 1). Waters from the flood-storage pool in Nimrod Reservoir are discharged by early June. This pattern also permits plant invasion within the zone of water-level fluctuation to almost minimum pool level. The chief difference lies in the acre-days of flooding above conservation-pool level since the acreage of Nimrod's maximum pool is only six times that of its minimum or conservation pool ([5]).

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([5]) Acre-days of flooding is a means of expressing extent and duration of flooding. It can be roughly computed by multiplying the number of days the water is above minimum pool level by the average acreage inundated for the period of overflow.

TABLE 3.

**A comparison of principal species by percentage of weight in Rotenone samples.**

| | Species | | 1953 Old River Lake Percent Total | 1955 Nimrod Reservoir Percent Total | 1953 Wheeler Reservoir Percent Total | 1955 Norris Reservoir Percent Total |
|---|---|---|---|---|---|---|
| Rough Fish | Shortnose gar | *Lepisosteus platostomus* | 9.3 | — | — | — |
| | Longnose gar | *L. osseus* | 5.1 | — | — | — |
| | Spotted gar | *L. productus* | — | 8.2 | — | — |
| | Bowfin | *Amia calva* | 5,4 | — | — | — |
| | Sub-total Non-edible Predatory Population | | 19.8 | 8.2 | — | — |
| | Channel catfish | *Ictalurus punctatus* | 14.2 | 7.7 | 6.4 | 1.1 |
| | Blue catfish | *I. furcatus* | — | — | 12.2 | — |
| | Flathead catfish | *Pilodictis olivaris* | 0.6 | 0.2 | 0.3 | 2.0 |
| | Largemouth bass | *Micropterus salmoides* | 6.0 | 4.5 | 3.7 | 1.0 |
| | Smallmouth bass | *M. dolomieui* | — | — | 1.0 | 4.6 |
| | Spotted bass | *M. punctulatus* | 0.8 | 0.1 | 1.0 | 0.3 |
| Game Fish | Black crappie | *Pomoxis nigromaculatus* | 3.6 | 0.3 | — | 2.3 |
| | White crappie | *P. annularis* | — | 4.9 | 0.4 | 1.0 |
| | White bass | *Roccus chrysops* | — | 0.5 | 4.5 | 2.7 |
| | Yellow bass | *R. interruptus* | 0.1 | — | 0.6 | — |
| | Grass pickerel | *Esox vermiculatus* | — | 0.03 | — | — |
| | Chain pickerel | *E. niger* | 0.5 | — | — | — |
| | Sauger | *Stizostedion canadense* | — | — | 0.3 | 0.4 |
| | Walleye | *S. vitreum* | — | — | | 5.5 |
| | Sub-total Edible Predatory Population | | 26.0 | 18.23 | 30.4 | 20.9 |

| Species | | 1953 Old River Lake Percent Total | 1955 Nimrod Reservoir Percent Total | 1953 Wheeler Reservoir Percent Total | 1955 Norris Reservoir Percent Total |
|---|---|---|---|---|---|
| Bluegill sunfish | *Lepomis macrochirus* | 30.7 | 10.4 | 3.2 | 4.8 |
| Redear sunfish | *L. microlophns* | 0.8 | 1.0 | — | — |
| Longear sunfish | *L. megalotis* | 1.9 | 1.3 | 0.8 | — |
| Orange spotted sunfish | *L. humilis* | 0.02 | 1.5 | — | — |
| Green sunfish | *L. cyanellus* | — | 1.3 | — | — |
| Warmouth | *Chaenobryttus gulosus* | 2,0 | 1.0 | — | — |
| Rock bass | *Ambloplites rupestris* | — | — | — | 0.1 |
| Bigmouth buffalofish (Rough Fish) | *Ictiobus cyprinella* | 0.5 | 0.04 | — | — |
| Smallmouth buffalofish | *I. bubalus* | 0.2 | 12.1 | 5.2 | — |
| Carp | *Cyprinus carpio* | — | 0.03 | — | 4.5 |
| Freshwater drum | *Aplodinotus grunniens* | 1.7 | 28.2 | 8.3 | 5.0 |
| Suckers | | 1.6 | 3.6 | 8.6 | 1.3 |
| Bullheads | *Ictalurus* sp. | 1.2 | — | — | — |
| Sub-total Edible Forage Population | | 40.62 | 60.47 | 26.1 | 15.7 |
| Gizzard shad and others | | 13.8 | 10.4 | 41.1 | 62.5 |
| Minnows, darters, etc. | | — | 3.0 | 1.8 | 1.0 |
| Sub-total Non-edible Forage Population | | 13.8 | 13.4 | 42.9 | 63.5 |
| Summary : | | | | | |
| Predatory Population | | 46 | 26 | 30 | 21 |
| Forage Population | | 54 | 74 | 70 | 79 |
| F/C ratio (Forage — Predator Fishes) | | 1.2 : 1 | 2.8 : 1 | 2.3 : 1 | 3.8 : 1 |
| Area Sampled (acres) | | 1.66 | 5.5 | 3.0 | 2.0 |
| Weight of Fish per Acre | | 836 | 228 | 261 | 118 |

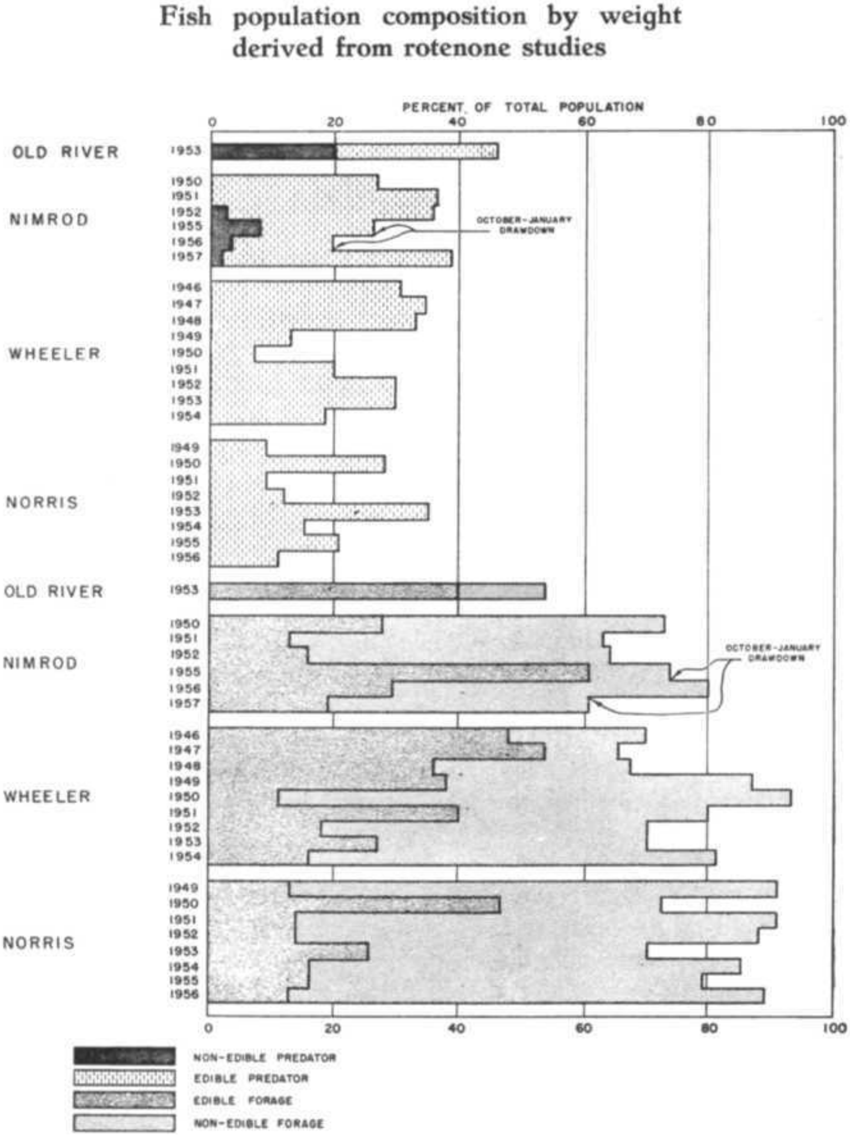
Fish population composition by weight
derived from rotenone studies
PERCENT OF TOTAL POPULATION
0
20
40
60
80
100
OLD RIVER
NIMROD
WHEELER
NORRIS
1953
1950
1951
1952
1955
1956
1957
1946
1947
1948
1949
1954
OCTOBER-JANUARY DRAWDOWN
NON-EDIBLE PREDATOR
EDIBLE PREDATOR
EDIBLE FORAGE
NON-EDIBLE FORAGE

FIG. 2.

Similar species of fishes occur in Old River Lake and Nimrod Reservoir, although in the samples examined there was some difference in percentage by weight of species composing the total populations. There was a considerable reduction, however, in productivity on the basis of the total weight of fish per acre in the areas sampled (Table 2).

In 1955, for example, the total weight of fish per acre in the areas sampled was 228 pounds of which 78 per cent or 180 pounds were edible species. The F/C ratio of 2.8 reflected a slightly heavier forage population than in Old River Lake. An examination of trends prior to 1955 suggested, furthermore, that the forage-fish population was increasing in abundance with a corresponding decrease in the predatory population (Figure 2).

These observations were further substantiated by HULSEY'S (1956) experiments. For several years after impoundment, Nimrod Reservoir was reported to afford excellent sport fishing for largemouth bass and crappies. As the reservoir aged, however, the fish population was dominated by rough-fish species and angling success declined.

To re-establish a fish population composed of a higher percentage of game fish and to enable the removal of the rough-fish populations for food purposes, plans were made by the Arkansas Game and Fish Commission in cooperation with the United States Army Engineers for a fall and winter drawdown during the period from October to January, 1955-1956. The surface acreage of the reservoir was thereby reduced from 3,600 acres at elevation 342 (conservation-pool level) on or about October 4 to 700 acres at elevation 330 (near stream-bank level) on November 30. The drawdown of 11 feet thus effected diminished the lake surface by approximately 80 per cent.

While the lake was being lowered, licensed commercial fishermen, using legal gill and trammel nets of 3.40 inches bar mesh, were encouraged to harvest the fish. The total catch consisted of about 38,000 rough fish weighing approximately 204,600 pounds and 2,600 game fish weighing an estimated 5,200 pounds. The latter were returned to the lake. A total of 58 pounds of rough fish per acre of conservation pool were removed during the drawdown (Figure 3). Game fish caught by commercial tackle and released amounted to less than seven per cent by number and 2½ per cent by weight of the total fish caught. The number and weight of fish escaping through the nets, of course, were undetermined.

Trends prior to 1955 in the composition of the fish population of Nimrod Reservoir according to weight, and the change following the fall and winter drawdown of 1955-1956 are depicted in Figure 2.

Buffalofishes. gars. and freshwater drum made up nearly one half of the weight of all fish collected in 1955. as compared to only 5.4 per cent in the 1952 period. A high survival of young largemouth bass and white bass after the drawdown was observed.

In explanation, HULSEY (1956) described that pre-drawdown data indicated an abundance of rough fish and relatively few game fish. Post-drawdown data of the first summer showed a change in the fish populations towards a higher relative number of game fish.

**Increased catch of fish by commercial fishermen in Lake Nimrod as the water level was lowered, 1955-1956**
(After HULSEY, 1956.)

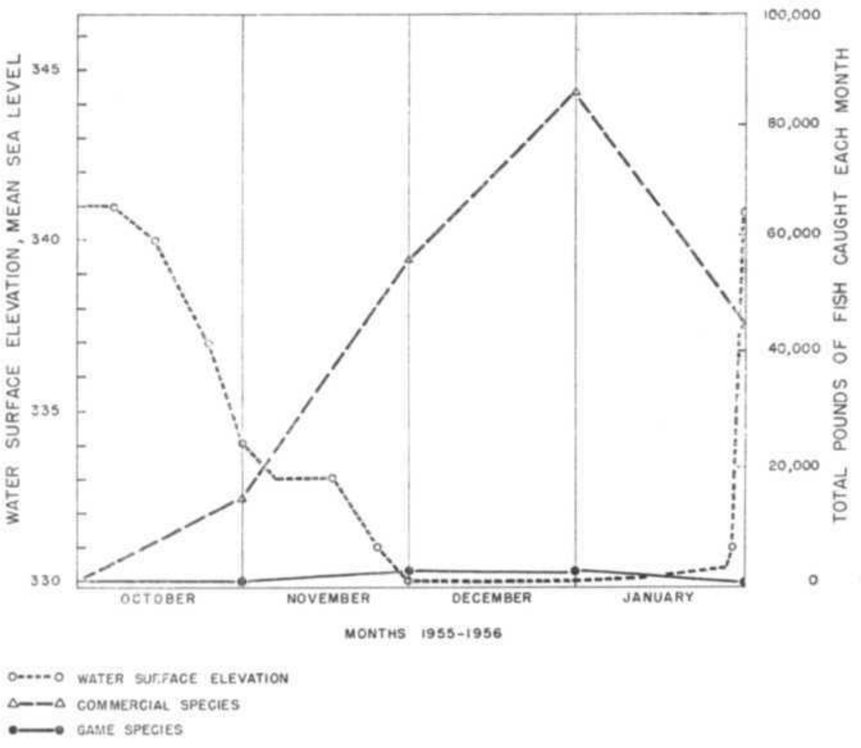


FIG. 3.

There was an increase in the size and number of young-of-the-year largemouth bass and white bass. No young freshwater drum, buffalo fishes, or carp were collected.

The accelerated growth of the young bass was believed to have been due to the clear water and an abundance of young sunfish and minnows available as forage. This was expected. It was also expected that heavy reproduction and survival of carp, freshwater drum, buffalofishes, and channel catfish would occur. This was not true, however, possibly because of heavy predation in the clearer waters. It is reasonable to expect, however, that as the population expands and species succession takes place, the rough fishes will again dominate the population.

In a personal communication received from Mr. Hulsey in 1958, additional information was received confirming the effectiveness of the fall and winter drawdown as a means of re-establishing a favourable ratio between predatory and forage and game and rough fish in a flood-control reservoir. In the future, Mr. Hulsey contemplates a fall and winter drawdown on Nimrod Reservoir every other year. He believes that in this manner an expanding fish population can be maintained and good commercial fishing as well as sport fishing assured.

### Wheeler Reservoir

Wheeler Reservoir, on the mainstream of the Tennessee River, is operated for hydro-electric power, flood control, and navigation. It was impounded in 1936. One of a series of reservoirs in tandem, its water levels can be controlled with little deviation from the planned operation.

For flood-control purposes, the reservoir is held at minimum-pool level from November 1 to about March 31. For efficient power production, the reservoir is raised to the top of the operating pool in May and then slowly and cyclically (for mosquito-control purposes) drawn down to minimum-pool level by about October 31 (Figure 1). While this summer recession permits the invasion of some plants into that zone exposed as late as September, continued recession leaves a large acreage of mud flats exposed until again inundated by rising waters in midwinter.

The average annual fluctuation of Wheeler Reservoir is only about 8 feet; the total area inundated at maximum stages comprises about 68,300 acres; at minimum stage, about 41,000 acres. This reflects an M/M pool ratio of about 1.6, lowest of the example areas. Nevertheless, there is much shallow water with a depth of less than 5 feet because of the flat topography of the reservoir basin (Table 1).

The productivity of this reservoir, although located in a region of more fertile soils than Nimrod Reservoir, is only about 136 pounds of fish per acre, based on rotenone samples collected at near minimum-pool stage by the Tennessee Valley Authority biological staff for the years 1946 to 1954. The percentage of edible fishes in the samples varied considerably. For example, in the 1947 sample it was 80 per cent, while in the 1953 sample it was about 56 per cent. While these and other variations depicted in Figure 2 are partially due to inadequacies of rotenone sampling procedures, there is additional evidence to suggest that the trend has been towards an increase in rough fishes, and more particularly the non-edible forage species, as the reservoir has aged.

In the 1953 samples, freshwater drum, buffalofishes, and suckers dominated the edible forage-fish population, which comprised about 26 per cent by weight of the total sample. Non-edible gizzard shad and related species, comprising 41 per cent by weight of the samples, were the dominant group.

Catfishes comprised the principal species in the predatory population as in the other two water bodies. There were fewer large-mouth black bass, crappies, bluegills, and other game fishes in the samples, which substantiated the prevailing concept that before sport fishing can be improved in Wheeler Reservoir a more favourable balance between game and rough fish populations must be re-established.

Commercial fishing, as practised on Wheeler Reservoir, apparently has had little effect in bringing about a desirable balance. The annual harvest has never exceeded *37* pounds of edible rough fish per acre at minimum-pool stage. A timed drawdown in the spring to prevent carp reproduction, as was once advocated, would not preclude and may encourage the dominance of other rough fishes such as the non-edible gizzard shad. Moreover, since a drastic drawdown to concentrate the fishes and thereby facilitate removal is out of the question in view of the conflict it would impose on primary-project purposes, other means must be found to re-establish an expanding population. Selective treatment with rotenone or other chemicals, as has been employed on some large impoundments, may offer a partial solution if economically feasible.

### Norris Reservoir

Norris Reservoir, the first of the storage reservoirs to be constructed by the Tennessee Valley Authority, was impounded in 1936. Operated for hydro-electric power production and flood control, it has an annual fluctuation of about 70 feet between elevations 950 and 1,020 mean sea level (Figure 1). Following a series of drought years, the pool in January 1956 was drawn down to elevation 910, adding 40 more feet to the vertical fluctuation. Despite this wide fluctuation of water levels, the surface area of the maximum pool is only 2.8 times that of the minimum pool due to the steep topography.

Another distinguishing characteristic of this reservoir is the seasonal pattern of water-level fluctuations which is almost the reverse of that of Old River Lake and Nimrod Reservoir. In Norris, the maximum stage is usually reached in July and is uniformly drawn down to minimum pool stage by December 31. This pattern of fluctuation, coupled with the erosion of the steep banks by wave action, restricts plant invasion within the zone of fluctuation, to a relatively small acreage in protected coves exposed in late summer by normal drawdown. In successive years of dry weather, when water levels fluctuate at a lower plane, plant life further invades the reservoir basin, only to be extinguished when the normal cycle is re-established.

While the decay of these plants when inundated contributes to the food supply of crappies and other fishes (STROUD, 1948), it is unlikely that the overall productivity of Norris Reservoir is substantially increased by this phenomenon due to the relatively small acreage involved.

Other reservoir characteristics also have had a pronounced effect upon species composition. The total weight of fish per acre in the areas sampled in 1955 was 118 pounds, of which only about 37 per cent or 44 pounds were edible. The average weight of fish per acre obtained by rotenone samples for an 8-year period was only 83 pounds. The relative absence of a littoral zone and the great fluctuation of water levels in Norris Reservoir has greatly restricted production of natural food such as aquatic insects, algae, and other forms dependent upon a shallow, weedy shoreline. Thus, bluegills and other sunfish, which were common in Old River Lake, comprised less than 5 per cent of the Norris samples. Carp, which were abundant in the first years of impoundment, spawned with infrequent success and declined. In the 1955 samples, carp composed only 4.5 per cent by weight of the total population. On the other hand, gizzard and other shad, which are principally pelagic feeders, had an E value of 63 per cent.

The predatory fishes, comprising 21 per cent of the population, were composed chiefly of crappies, smallmouth, and other basses. Gars were missing from the samples. The catfishes were few. Two new species assumed importance for angling purposes, the sauger and walleye, which are common in many eastern Tennessee streams. The primary food of these fishes is young-of-the-year gizzard shad.

Trends in predatory and edible forage fish populations in Norris Reservoir during recent years indicated that a near climax relationship had become established. There was little differential in the F/C ratio from year to year nor did the E value of the predatory and forage groups show much change.

To effect much change, it probably would be necessary to modify the pattern rather than the degree of water-level fluctuation. The weight of edible forage and predatory fishes undoubtedly could be increased by a plan of water-level management, which would conform to natural, seasonal cycles. Such management, however, is incompatible with the present project function. Moreover, while sport fishing could be improved, it is doubtful that a commercial fishery for existing species could be developed due to the absence of a large littoral zone.

## CONCLUSIONS

Areas sampled in Old River Lake, Nimrod, Wheeler, and Norris Reservoirs for the years of record, revealed an estimated 836, 226, 136, and 83 pounds of fish per acre, respectively. In these samples, the percentage of edible fishes by weight were 66, 57, 56, and 37. The ratio of the maximum to minimum pool areas (M/M ratio) of Old River Lake, Nimrod, and Wheeler were 16, 4.3, and 1.6, respectively, suggesting that their productivity is markedly influenced by seasonal overflow. The productivity of Norris Reservoir with an M/M ratio of 2.8 is also influenced by overflow, but to a lesser extent than the other waters studied due in part to the unnatural pattern of fluctuation coupled with steep reservoir topography.

Species dominance and relative abundance of predatory and forage and game and rough fishes also were influenced by water-level fluctuations. Old River Lake, with a vertical fluctuation of about 22 feet and an M/M ratio of 16, had the greatest percentage by weight of predatory fishes; Wheeler and Norris Reservoirs were rivals for the lowest. Wheeler Reservoir, with a vertical fluctuation of only 8 feet and an M/M pool ratio of 1.6, was the most stable, an environment in which forage species tend to predominate. Norris Reservoir, with an annual winter drawdown of about 70 feet and an M/M pool ratio of 2.8, was the most widely fluctuating. Although unfavourable to the survival of bottom feeders, including certain game and rough fish species, this wide fluctuation did not prevent the production of a large population of gizzard shad, which are pelagic in nature.

Trends in edible forage and predator fish populations indicated a close relationship from year to year in Norris and Wheeler Reservoirs. If, however, non-edible forage species (gizzard shad) are included in the ratios, they show great annual variation, which may be due more to the inadequacies of sampling techniques than to actual population differences. Thus, it can be assumed that a near climax relationship between these groups had become established for the characteristic patterns of water-level fluctuation in Wheeler and Norris Reservoirs. It also appears that a climax relationship was developing rapidly in Nimrod prior to 1955.

In Old River Lake, subject to White River overflow, stages in fish succession are believed to have been set back by drawdown and subsequent annual harvest of the surplus crop by numerous and varied natural predators and scavengers.

In Nimrod Reservoir the succession was set back in the late fall and winter of 1955-56 and again in 1956-57 by a controlled drawdown which enabled the commercial removal of a high poundage of rough fishes. This also may have conditioned the habitat for the re-establishment of an expanding fish population composed of desirable game species.

A substantial commercial fishery in Wheeler Reservoir apparently had little effect in maintaining an expanding fish population. Moreover, without a drastic drawdown to concentrate the fish, it is unlikely that commercial harvest could maintain an expanding population or the desired ratio between game and rough fish.

The beneficial effects of a timed drawdown to prevent reproduction of such species as carp and buffalofishes in Wheeler Reservoir, as has been advocated, also is doubtful. Reduction in these fishes may simply initiate a corresponding increase in gizzard shad and other non-edible forage species, already excessively abundant. For example, while the winter drawdown of 70 feet or more in Norris Reservoir has greatly reduced the edible forage species, gizzard shad and other non-edible species, comprising about 70 per cent by weight of the samples, were abundant.

Thus, it is apparent that the effects of water-level fluctuation depend more on time, area, and duration of flooding than upon degree of fluctuation as measured in vertical feet. Furthermore, the effects may be accentuated by topography and soil conditions.

Employed without discretion, water-level fluctuation may be deleterious to some desired fishes; on the other hand, with sound application it may be one of the most effective tools in fishery management.

The practical application of managed fluctuation, however, is limited by conflicting uses of water stored in large impoundments. Readily adapted to a project operated primarily for flood control, management of water levels for fishery purposes in a hydro-electric project is restricted.

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## Summary

In view of limited scientific data with respect to the effects of water-level fluctuations on the fisheries of large impoundments, there has been much speculation. Concepts and experiments are reviewed in this paper as the basis for evaluating progress. Some of these concepts are illustrated by a discussion of Old River Lake, a natural lake subject to White River overflow, and Nimrod, Wheeler, and Norris Reservoirs, located on other tributaries of the lower Mississippi River, U.S.A.

Each of the described water areas is representative of a distinct type in the Southeastern United States; each has a different pattern of water-level fluctuation. Available fish population data for each area are related to season, frequency, stage, and duration of water-level fluctuations; also to topography of the reservoir basins.

Gross relationships in the light of previous experience and general knowledge, suggest that productivity, species composition, and ratios of predatory and forage, and game and rough fishes are influenced by water-level fluctuations. Effects on each of these characteristics depend more on extent, time, and duration of overflow above minimum-pool level than upon degree of water-level fluctuation as measured in vertical feet. It is also evident that these effects may be accentuated by topography, soil, and other factors.

Available evidence supports the concept that water-level fluctuation employed without discretion may be deleterious to some desired fishes; on the other hand, with sound application it may be one of the most effective tools in fishery management.

# DAMS AND DROWNEDOUT STREAM FISHERIES IN SOUTHERN RHODESIA

## (Federation of Rhodesia and Nyasaland)

BY

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### INTRODUCTION

There has been more information about fisheries in dams and drowned-out streams from the northern hemisphere — Europe and America — than from any other part of the world, due to the more intensive multiple exploitation of available water resources in those regions (1).

Astonishingly little is known about the present situation of fisheries in regulated waters, dams and rivers, in the tropical regions. Only a few decades ago has a broader interest arisen in fisheries in inland waters of the tropics although water conservation started earlier. It would be, therefore, of interest if I pointed out some facts about fisheries in the tropical regions. In this paper I will confine myself to the fisheries in dams and rivers of Southern Rhodesia of the Federation of Rhodesia and Nyasaland, where water conservation has been practised for over 50 years, exceeding in intensity that in all other parts of Africa, and where fisheries observations and investigations have been made more intensively during the last decade. Aspects of fisheries in Southern Rhodesia should give sound information as a background to conditions prevailing in other parts of the tropics.

As an introduction to the main subject, and in order to make the problems involved more understandable, it is felt that some information about the physiography of the climate, means of water conservation, etc., should be given.

#### Physiography

Southern Rhodesia is a compact land-locked area of 150,333 sq. miles lying between latitude 15°36, and 22°25, south, and between longitude 25° 14, and 33°41, east, thus being actually a tropical country. It extends in the north to the Zambesi River, in the south to the

(1) Reports of the Institute of Freshwater Research, Drottningholm, Sweden, and respective fisheries publications of U.S.A.

Limpopo River, and is bordered in the west by the Kalahari desert of Bechuanaland and in the east by a narrow mountain range of varying altitude. Southern Rhodesia lies in a relatively high region, 21 per cent of which rises to over 4,000 feet above sea level and is surrounded by lower country of from 660 to 2,000 feet above sea level.

According to the prevailing geomorphological and climatological features, there are distinct characteristical regions of practical importance for fisheries. The Highland region of the eastern border has an average of 7,000 feet above sea level. The central region of over 4,000 feet above sea level is known as the High Veld, the region lying at 2,000 to 4,000 feet as the Middle Veld, and the region below 2,000 feet above sea level is known as Low Veld.

**Rivers**

The country is traversed with numerous typical drainage rivers which fall into four groups :

1. tributaries of the Zambesi River;
2. rivers flowing south-east into the Indian Ocean;
3. rivers flowing into the Limpopo River, and
4. those flowing into the land-locked Makarikari basin of Bechuanaland.

Except for some parts of the Zambesi, the rivers of Southern Rhodesia are not navigable. Most of them are reduced to mere streams for the most part of the year, and in some cases the flow ceases completely during the dry season.

Southern Rhodesia has no natural lakes.

## Climate and weather

**Precipitation**

The intensive rainfall is almost entirely confined to the summer season between October and April. During the remainder of the year the greater part of the country receives no more than 1 to 3 per cent of the annual total, with the exception of the south-eastern part of the country and of the eastern border, where the percentage of winter rain approaches 5 to 10 per cent of the annual total in each case.

**Winds**

Surface winds in the country are generally light, the average being 6 to 10 m.p.h. Throughout the year the winds have an easterly component. In September and October the highest and mostly northerly winds are received and in April the lowest and mostly southerly winds prevail. Velocities of 50 and more m.p.h. have been recorded.

#### Sunshine

Days of no sunshine are rare, as are months of less than 5 hours average sunshine per day. The general expectation is of the order of 8 to 10 hours in winter as sky is cloudless, and 6 hours per day in summer, during the rains.

#### Temperatures

The major controlling factor is the altitude, and the second is the latitude combined with the distance from the Indian Ocean. The temperature diminishes by 3° to 4° F. with every 1,000 feet of altitude above sea level, and high temperatures, usually associated with the tropics, are considerably modified on the high plateau. The effect of latitude and distance from the coast is that places of the same altitude are warmer as one goes westward and northward. The cool season occurs in June and July, while October and November constitute the hot season. The onset of rains brings a considerable reduction of maximum temperatures and there is little variation from December to March. At no time of the year is the country affected by air with temperatures below freezing point, but from May to September ground frost of varying intensity may occur, especially on the High Veld and in the eastern moutain region.

### Water resources, conservation, usage

The main water resources derive from rains, as normal flow of rivers either stops completely during the dry season, or is negligible as compared with floods. Water from underground sources has been estimated at only 238,000 million gallons per annum.

The average rainfall over Southern Rhodesia is 26.5 in. while rains of 20 in. to 36 in. a year cover 81 per cent of the whole area of 250,000 sq. miles, which amounts to a total of 214 million acre feet. Only 10 to 15 per cent of that is taken by rivers as run-off, or about 21.4 to 32.1 million acre feet. Infiltration, percolation and total evaporation are responsible for the relatively small amount of rainwater which actually reaches the rivers by run-off. The run-off generally starts after 16 in. to 20 in. rainfall, depending on the character of the surface.

For practical purposes an allowance is made for possible poor rains in two subsequent years and a 25 per cent loss through evaporation of storage water (70 in. to 100 in. a year), which leaves a margin of 7.53 million acre feet of useful water. This figure is two to three times less than in an average year.

In order to secure adequate water supplies for an area for many possible subsequent poor rainy seasons, dams are usually built of a size large enough for storing water from the catchment area during a good season, to cover the need in poor years.

Water resources being regarded as public property, the storing and the use of it is subject to the Water Act.

Dams for water storage already constructed in Southern Rhodesia are as follows :

| | Number | Capacity | Acreage |
|---|---|---|---|
| Large dams (over 1,000 mil. gals) . . . . . . | 11 | 123,000 mil. gals | 16,500 |
| Medium dams (500-1,000 mil. gals) . . . . . . | 8 | 5,350 mil. gals | 800 |
| Small dams (100-500 mil. gals) . . . . . . . . . | 91 | 22,750 mil. gals | 3,000 |
| Minor dams (1-100 mil. gals) . . . . . . . . . | 2,968 | 30,000 mil. gals | 18,000 |
| Dwarf dams (up to 1 mil. gals) . . . . . . . . . | 5,000 | 500 mil. gals | 7,500 |
| Total . . . . . . . . . | 8,078 | 181,600 mil. gals or 650,000 acre feet | 45,800 |

In addition to these dams, 11 dams will be constructed in the very near future, with a total acreage of 96,000 and a capacity of 800,000 million gals, corresponding to 2.9 million acre feet.

It may be of interest to point out that the dams which already exist, together with those being planned, will cover nearly 50 per cent of the minimum available impounded water of 7.5 million acre feet. Taking into consideration the multiple use of water by the growing industry and improved agriculture, such development is regarded as progressive and advanced. As for agriculture, the development of water conservation in Southern Rhodesia confirms the view that more irrigation in the world is applied in the so-called humid countries than in the arid ones, in order to improve the crops.

All dams in Southern Rhodesia are typical water storage dams for extracting water for multiple use.

The size of the dams depends on the amount of water available from the catchment area or the amount of water needed for practical use, which is mostly agriculture. In order to avoid excessive evaporation there is a tendency to build deeper dams, which enable the keeping of a maximum volume of water to a minimum water surface. Evaporation may also be reduced without detriment to the fish by the use of cetyl alcohol.

The maximum depth of the dams is generally from 13 feet to approximately 100 feet, and as the average depth ranges from 4 feet to 35 feet only, the dams should be regarded as shallow lakes. Distinct differences occur in the quality of water. The presence and quantity of dissolved salts and suspended organic matter depends on the type of soils of the catchment area and on the intensity of land use. Most dams in Southern Rhodesia are situated in the High Veld area, as the most settled area, and less in the Middle Veld, and are exceptional in the Low Veld. The intensity of the warming up of the water and the grade of evaporation is in relation to the altitude. The water economy of our dams follows, as a rule, a uniform pattern.

The lowering of the water surface starts in April-May, after the end of the main rains, and as the water is being used during the dry season, the level drops to a minimum in November-December, when the filling starts again with the beginning of a new rainy season. At that stage the water level of the dam has generally dropped to about one fourth of its capacity. Whereas the tapping of the dam water is more or less regular, its filling is most variable, depending mainly on the relation of the capacity of a dam to the amount of inflow water. Some dams are only just filled by the inflow, while others have an inflow exceeding its capacity by many times. The latter applies to smaller and especially to water conservation dams built mainly for the purpose of slowing down the run-off for enriching the ground supply. Here I would like to point out that dams built in connection with rivers cause a perennial flow of water in many rivers, and increase the flow in perennial rivers.

The silting problem of dams has no significance, as the amount of silt carried into the dam by the flow is negligible due to measures taken for soil conservation.

### Suitability of dams for fisheries

Though the dams are originally not constructed for fisheries purposes, they all have a high potential for fish production.. From the production point of view, there is a big variety of dams and their suitability for fish culture could be discussed according to the following aspects.

**The size and depth of a dam**

The size of the dam (see p. ...) and the average depth of approximately 4 feet to 35 feet should not be considered as a handicap for fish culture. Most of the dams can be regarded as ponds, as the maximum size of a dam for intensive fish culture is limited only by economical facilities.

**The bottom of a dam site**

The site of a dam is usually carefully chosen in respect of capacity and conditions for the wall foundation. As a rule, the site of the bottom is covered with trees, shrubs, and scattered rock. It is obvious that such bottom will make the use of fishing gear difficult, if not impossible, and therefore the site of the bottom must be cleaned and smoothed before the dam is filled.

**Water temperatures in the dam**

Water temperature is a decisive factor for the rearing of some tropical fish species for production. Therefore, only fish species introduced from a temperate climate are suitable for rearing in dams of the Eastern Highland region, where cold water prevails. Low winter temperatures of the High Veld also limit the breeding in natural rivers of some tropical species, such as *Tilapia melanopleura* and *T. macrochir*, but they survive in dams and breeding is successful. Higher temperatures of the Middle and Low Veld are more favourable for fish culture.

**Chemical composition of water in dams**

The composition of nutrient salts makes the water, as a rule, biogenical, and the intensity of biogenesis drops towards the end of the dry season. In high rainfall areas the pH does not usually drop much below 6, and the water in the Middle and the Low Veld, also partly in High Veld, is over 7.

**The amount of inflow into a dam**

Rapid inflow exceeding the capacity of a dam in a short time has an adverse influence on fish culture. The plankton is not able to establish due to the quick through flow and the fertility of the water is lost to the dam. Wherever possible the excess inflow has to be controlled.

**The fluctuation of water in a dam**

As the fluctuation of water in our dams has to be regarded as unavoidable, fish culture must be adapted to this condition. The consequences of such a deduction are not as serious as they may seem. Normally, at the end of the water extraction period, there is still water left to about one fourth of the capacity of the dam which is fully sufficient for the survival of stocking fish, provided the rest are fished out in time as production fish. At the same time, the exposed bottom area is available for the melioration.

#### Silting in a dam

Although silting in our dams occurs only to a small degree, it is still a very important factor for success of artificial fertilization.

It should be stressed again, that our dams are built for other purposes than fisheries, and it is, therefore, obvious that there are as listed a few adverse « natural » aspects for fish culture; a reduction of some in most cases is possible.

#### Natural fish production in dams and rivers

The natural fish production in average dams ranges from 250 lb. to 400-500 lb. per acre a year, reaching the figure of 1,000 lb. in dams with most favourable conditions. But as semi-intensive or intensive fish culture can be carried out in most dams, the fish production may be raised to from 1,500 lb. to over 5,500 lb. per acre a year. These figures should impress most delegates from the Northern Hemisphere, although we cannot boast of the natural fish production in our rivers as it equals that of most northern latitudes. The natural fish potential of our rivers is very small in comparison with dams. There is no sign that the building of dams across a river should have a deteriorating effect on the fish stock of the river. I dare say that the contrary is taking place. Firstly, the existing fish stock should only benefit from an improved flow in the river, and, secondly, there is always a possibility for the enrichment of the stocks through improvement in the habitat and spreading of fish from a dam up- and downstream.

#### Natural development of fish population in dams

Dams built in connection with rivers are, as a rule, in no time invaded by fish native to the river in the same specific relation as they occur in the river. Species of potential importance are :

*Mormyrus longirostris* PETERS;
*Gnathonemus macrolepidotus* PETERS;
*Petrocephalus marcusenius* spp.; (*Mormyridae*);
*Hydrocyon vittatus* (CAST);
*Alestes imberi* PETERS (*Characinidae*);
*Labeo* spp.;
*Barbas* spp. (*Cyprinidae*);

*Clarias mossambicus* PETERS;
C. *gariepinus* (BURCH.) (*Clariidae*);
*Tilapia mossambica* (PETERS);
*T. melanopleura* DUM.;
*T. macrochir* BLGR. (*Cichtidae*).

The mentioned species are not distributed in all rivers and the composition of species is subject to variations according to water temperatures (altitude), size of rivers (flow) and other factors, and therefore the initial composition of species invading a dam is variable.

River fishes have generally great vitality in resisting the drastic changes occurring during a year's cycle of their river life, and are easily adaptable to the more favourable life conditions in dams. After two rainy seasons the stock of fish is more or less established, and it always takes the same pattern. Namely, predatory fish predominate in the beginning up to 75 per cent by weight, as actual fishing results have shown. Further development shows a drop in the number of predatory fish as a consequence of diminished resources of forage fish, and this again causes a rise in the bulk of forage fish, etc. Needless, to say, the predominance of predatory fish lowers the total fish production. Here it must be pointed out that birds too, especially cormorants, as well as crocodiles, otters, etc. are a potential menace to fish production.

**Controlled production of fish in dams**

Without artificial interference in the fish population of a dam, especially in bigger dams where existing conditions are more static, the composition of fish species which initially invaded the dam develop into a definite type of population with the growing age of the dam. An analysis of these populations has given an indication as to the most suitable composition of fish population in given circumstances, with the biggest possible fish production in mind. These indications, together with results obtained from combinations of experimental stocking of dams and ponds, which are excluded from free invasion of fish, have led us to the following conclusions :

1. The most suitable fish species for dams are the *Tilapia mossambica, T. melanopleura* and *T. macrochir*. The three species differ in their feeding habits, the first being more or less omnivorous, the second mainly herbivorous, and the third is a planktonophage. They are the most resistant and prolific kinds, and two of them being mouth-breeders, their spawning is not affected by water level fluctuations.

2. Desirable fish species for dams are the species with potential importance such as *Barbus, Labeo* and those of the *Mormyridae*

family. These species can improve to some degree the utilization of some food niches in the dam, especially the latter, in contributing to a more effective exploitation of the benthos.

3. Predatory species must be excluded from a dam as undesirable.

4. For the achievement of best possible production the following rules must be set up for dam management :

*a*) All dams should contain all three kinds of the *Tilapia* species, and it is therefore necessary to stock the missing species of *Tilapia;*

*b*) Apart from the *Tilapia* species, species of the *Mormyridae* family are recommended;

*c*) The predatory fish in dams should be kept at the lowest possible level;

*d*) Cropping at the maximum sustainable level is necessary in order to keep a high standard of production.

The above rules apply in regard to most dams of our country except those of the Eastern Highland region, where the fish management of dams has to follow the pattern applied in a temperate climate.

Water plants in dams are very important for fish production. The common excess of indigenous and exotic plants has a lowering effect on the production of fish; it is a menace for effective fishing and may swamp either a part of, or even the whole of a dam. The control of water plants in dams must be therefore regarded as essential and obligatory.

Submerged and floating plants are generally effectively controlled by *T. melanopleura.* Chemical and mechanical means are used for the control of shore plants, especially *Typha*, *Phragmites* and *Scirpus.* The latter can survive underground without flooding for over ten years.

Water conservation in tropical countries is regarded as favouring the spreading of malaria and bilharzia. In fact, fish culture in dams is a good biological means for the control of mosquito larvae as well as the snail vectors of bilharzia. Firstly, the environment for their breeding becomes remarkably unfavourable through the control of water plants. Secondly, *Tilapia mossambica* being also a larvae eater is known as an excellent mosquito controller. Thirdly, the introduction of *Serranochromis thumbergi* (CAST.), (*Cichlidae*), which is a snail eater (there are more snail-eating species) provides excellent snail control.

In conclusion it could be said, that whatever the main object for conservation of water, all erected dams serve the fisheries as a side line.

The potential of fish production of the total 140,000 acres of dams is estimated approximately at 28,000 tons a year, at 400 lb. per acre.

**Kariba Lake fisheries**

In connection with the Kariba hydro-electric scheme now in progress, there is a dam on the Zambesi River in the process of creation, on a stretch of river 180 miles long, covering approximately 1,300,000 acres with a capacity of 110 million acre feet, which will be the fourth largest lake on the African continent. I would like to mention that the two next largest man-built lakes, both in North America, are the Boulder Dam, with a capacity of 30.5 million acre feet, followed in size by the Grand Coulee Dam with 9.65 million acre feet. Lake Kariba will discharge at the Power Station 37.000 cu/sec. Taking into consideration the inflow from the catchment area of 200,000 square miles, an overflow of the Kariba Dam should take place every fourth or fifth year. The first accumulation of water is expected in 1958 and the dam should fill in 1960-1961 depending on the progress of the building. The maximum fluctuation will be 40 feet affecting an area of 320,000 acres. The maximum depth, at the dam wall, will be 340 feet, while 2,000 acres will have a depth of over 250 feet, and 350,000 acres will be over 100 feet deep. It is found by preliminary investigation and analysis that Lake Kariba will be in many respects more productive than big natural lakes. A fish production of 50 lb. per acre a year only, totalling 30,000 tons a year, is taken as a basis for official calculations, as such a production already justifies the creation of a special organization for fisheries development of the Lake. The actual production should be many times higher. As a first step towards the fisheries development £ 3 million have been assigned for the cleaning of a part of the bottom from vegetation; this work has to be finished before the respective areas are flooded. The next important step will be the development of a fish population. The natural development will certainly take the usual pattern, although in a more complicated form due to approximately 87 fish species inhabiting the Zambesi basin. The development in a desired direction Will be hampered by the enormous dimensions of the scheme, and by the absence of fishermen, in the beginning, engaged on the needed selective fishing. It is obvious that the development of the fish population will take its natural way in the beginning, but the production can be improved at a later stage mainly through selective fishing, and if necessary by stocking. The scheme will also have to face the problem of spawning facilities for some stream-spawning species. The number of spawning individuals will rise enormously and a shortage of spawning space will be felt. A similar phenomenon has already been observed on some other dams. There is no need for the building of a fish ladder on the dam wall, as no long-range migrating fish species are known in the Zambesi, and the absence of a ladder will not affect the fish population either below or above the wall. Conditions for the fish below the dam will certainly improve by the permanent flow of tail water, which will even out to some degree the flow of the Zambesi below the wall throughout the year.

It should be noted that schemes similar to Kariba are projected in Egypt on the river Nile, in the Belgian Congo and in the French Equatorial Africa on the Congo river, and in Nigeria on the Volta river.

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**Summary**

1. Consideration is given to the development of fisheries in dams and drowned-out rivers of the tropical region, Southern Rhodesia.

2. From the minimum available useful water flow of 7.52 million acre feet in Southern Rhodesia, 650,000 acre feet is dammed already, and it is expected that an additional 2.9 million acre feet will be dammed soon.

3. For water storage there are established 8,078 dams in Southern Rhodesia, making a total of 45,000 acres, and 11 more dams with a total of 96,000 acres will be built in the near future.

4. Although the dams are built mainly for agricultural purposes, they are all suitable for fish culture. A substantial reduction of unfavourable aspects for fish culture in these dams is in most cases possible.

5. The natural fish production in dams is from 250 lb. to 1,000 lb. per acre a year. For fully controlled dams — « ponds » — pond culture methods are appreciable and a production of over 5,500 lb. per acre a year can be reached.

6. The natural development of fish population leads at first to a predominance of predatory species, followed by alternate periods of predominance of non-predatory and predatory species.

7. The following is essential for efficient utilization of a dam for fish culture :

*a*) All dams must have all three kinds of the main production fish : *Tilapia mossambica, T. melanopleura* and *T. macrochir;*

*b*) In addition to the mentioned *Tilapia* species, species of the *Mormyridae* family are recommended;

*c*) Only big species of the *Labeo* and *Barbus* (*Cyprinidae*) species are acceptable;

*d*) All predatory fish must be kept at the lowest possible level.

8. The growth of water plants is very rapid and intensive. Eradication of water plants is essential for fish production.

9. The spreading of malaria and bilharzia through water storage in dams is effectively controlled by intensive fish culture.

10. Fisheries in dams is one of the ways for a multi-purpose utilization of stored water. Fish production in storage dams of Southern Rhodesia may reach 28,000 tons a year.

(NOTE : Kariba Lake fisheries prospects are presented separately.)

# LE LAC DE BARRAGE DE LA LUFIRA

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Dans la traversée des monts Koni, la Lufira, grand affluent du Congo venant de la frontière rhodésienne, subit, en une dizaine de kilomètres, une dénivellation d'environ 165 m. Au début de ce défilé, au lieu dit Mwadingusha, la rivière tombe de 115 m, en deux gradins, dans les majestueuses chutes Cornet. Avant d'arriver à ce point, elle traversait en méandres une cuvette à fond plat d'environ 25 km de diamètre, un ancien fond de lac, visiblement. Il restait encore sur un petit affluent de la Lufira un point d'eau permanent, le lac Tshangalele, de quelques mètres de profondeur et de 5 à 6 $km^2$ de superficie.

L'importance des chutes, le fort débit de la rivière (jusqu'à 300 $m^3$/sec. en crue), la proximité d'une grosse industrie, ont conduit à utiliser la chute pour la production d'énergie électrique. La plaine a servi de réservoir. En 1926, un barrage fut établi en amont des chutes Cornet, barrage de 8 m de hauteur d'abord, progressivement relevé jusqu'à 13 m. Ainsi a été créé un lac de 400 $km^2$ environ, d'un volume dépassant les 1.250 millions de mètres cubes.

La comparaison des chiffres montre immédiatement la faible profondeur moyenne du lac : au niveau maximum, moins de 29 % des eaux ont plus de 3 m de profondeur ! D'autre part, les nécessités de l'exploitation ont amené à plusieurs reprises à baisser le plan d'eau, à diminuer par conséquent la profondeur du lac. Rien d'étonnant, dans ces conditions, à ce que l'ancien réseau hydrographique constitué, à l'exception du petit lac Tshangalele, de rivières à cours relativement rapides, se soit transformé en un énorme marécage, avec les conséquences que l'on devine sur la flore, la faune, la chimie des eaux et les conditions de sédimentation.

A. — Flore : Actuellement, le lac de la Lufira est en grande partie recouvert de végétation : prairies de graminées ancrées au sol ou flottantes, tapis de *polygonum* ou de *nuphars*, roselières. Un survol

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du lac en avion, a permis de constater que la surface d'eau libre ne dépassait guère 5 % le 28 avril 1957. A ce moment, il est vrai, l'extension des prairies était à son maximum. Onze mois plus tard, 30 % de la surface du lac était libre.

Les groupements les plus importants sont les associations à graminées *Vossia*, *Leersia* et *Oryza* principalement. Elles constituent d'immenses bancs et leurs racines enchevêtrées forment des coussins atteignant jusqu'à 60 cm d'épaisseur, coussins qui peuvent flotter et, dans certaines circonstances, s'avancer dans l'eau libre jusqu'au-dessus de la plus grande profondeur du lac. Sur les racines de ces graminées, s'installe une couverture biologique extrêmement forte, diatomées, spirogyres, cyanophycées, mycéliums, bactéries, protozoaires, rotifères et nématodes. De même, les *Typha*, très abondants en certains coins des rivages, se soulèvent parfois du sol pour constituer des îlots flottants dont la base est un humus de plus de 1 m d'épaisseur. Sur ces îlots, s'établissent d'autres plantes, des *Jussieua* d'abord, des graminées ensuite. Enfin, certains *Polygonum* arrivent à s'ancrer par 4 m de profondeur et constituent des prairies qui arrêtent les îlots flottants.

Il n'est nullement certain que ces graminées et ces roseaux puissent se maintenir indéfiniment séparés du sol. La chose est actuellement à l'étude. Mais dans une grande partie du lac, ils peuvent certainement s'ancrer à nouveau et reprendre vigueur. Chaque fois que les exigences de l'industrie ont amené à baisser le niveau du lac, les prairies se sont déposées sur le fond et s'y sont enracinées. Les portions aériennes des plantes ont été en majorité détruites par les feux de brousse, mais, dans la boue humide, les racines et les rhizomes ont subsisté et permis une nouvelle colonisation. Chaque fluctuation du niveau des eaux, chaque élévation du barrage a été suivie d'une prolifération extraordinaire des tapis de *Leersia* et d'*Oryza*.

B. — Faune : Jusqu'à la construction du barrage, la faune de la Lufira et de ses affluents était évidemment une faune de rivières plus ou moins rapides. Sa composition initiale est pratiquement inconnue. Deux faits signalent cependant les transformations qui y furent provoquées : l'augmentation du rendement des pêcheries et la pullulation des moustiques.

Les quelques villages habitant le long de la Lufira ne s'intéressaient guère à la pêche. L'enquête chargée de décider des indemnités à payer aux indigènes pour la perte de leurs droits sur le territoire inondé estima à 10 tonnes par an le rendement des pêcheries. Lorsqu'on s'aperçut de la richesse du lac en poissons, il fallut faire venir des pêcheurs d'une autre province pour exploiter ce nouveau capital.

A l'heure actuelle, 4.000 tonnes de poissons sont pêchées par année dans le lac de barrage et cette quantité tend à augmenter. Lorsque les chutes de pluies sont déficitaires, comme en 1955, le niveau des eaux est fortement abaissé, le poisson se concentre dans l'ancien lit de la Lufira, ce qui donne lieu à des pêches miraculeuses.

Les espèces présentes sont celles qui peuplaient autrefois le réseau fluvial et le petit lac Tschangalele. Il s'agit de *Clarias gariepinnis, Tilapia macrochir, T. melanopleura, T. sparmanni,* un *Serranochromis,* divers *Haplochromis* et *Barbus keisnerii.* Seules les trois premières espèces sont l'objet d'une véritable pêche et, des trois, *T. macrochir* est, commercialement parlant, la plus intéressante puisqu'elle représente plus de 90 % des captures. La seule espèce végétarienne présente, *T. metanopleura,* forme, suivant les statistiques de 0,5 à 3 % des captures. Si l'on peut ajouter foi aux statistiques, ce pourcentage a augmenté depuis 1951, époque où l'espèce ne figurait pas parmi les poissons capturés.

Chose étrange donc, dans ce lac marécageux, le poisson qui s'est multiplié le plus est planctonophage. Donc, les végétaux fixés ou flottants, qui représentent cependant la plus grande masse de nourriture potentielle, sont très mal utilisés par les poissons. La conclusion est évidente : la population actuelle de poissons n'est pas adaptée au milieu nouvellement créé.

L'augmentation du nombre des moustiques a été aussi spectaculaire que celle du tonnage des poissons capturés. Le long des berges, au lever et à la tombée du jour, en certains endroits même en plein midi, le passant est assailli de véritables nuées de moustiques piqueurs. Il s'agit essentiellement de *Culex* (*Taeniorhynchus*) *mansonoïdes* dont la larve vit dans les feutrages de racines de *Leersia* et d'*Oryza.* Les énormes prairies flottantes ou fixées favorisent par conséquent son existence. Chaque élévation du niveau du lac, qui fut suivie d'une extension des prairies lacustres, a été suivie d'une pullulation de ces insectes.

Il est vraisemblable que d'autres modifications de la faune se sont produites mais elles n'ont pas pu être notées.

C. — Chimie des eaux : L'eau de la Lufira, avant l'entrée dans le lac, possède une dureté totale de 16 °F environ et une conductibilité électrique de $460.10^{-6}$. Devant le barrage, la dureté est tombée à 11 °F et la conductibilité électrique aux environs de $400.16^{-6}$. Ces chiffres traduisent immédiatement l'influence de la masse des plantes sur la composition de l'eau. Cette influence se traduit encore mieux par les dosages d'$O_2$ et de $H_2S$. Ce n'est que dans le lit de la Lufira et dans les eaux relativement libres de l'ancien lac Tshangalele que la concentration en $O_2$ est un peu élevée et approche de la saturation. Dans les marécages et devant le barrage, elle tombe souvent à 1,5 ou 1 mg/litre. Près d'un îlot de plantes, on voit la tension d'$O_2$ diminuer encore. Au contact de l'îlot et sous lui, plus aucune trace d'oxygène n'est généralement discernable tandis qu'inversement la teneur en $H_2S$ croît jusqu'à 2 mg/litre contre les racines d'îlots flottants. Il en résulte que la plupart des organismes animaux et spécialement les poissons ne peuvent guère coloniser que les étroits chenaux et les zones libres de plantes. A certaines saisons, toute la cuvette du lac sent l'hydrogène sulfuré.

Une autre action de la décomposition des plantes se marque sur l'eau : celle-ci, bien que transparente, est absolument noire. Traitée par le permanganate de K, elle décolore celui-ci et en consomme par litre, une quantité équivalant à 5 ou 7 mg d'$O_2$. Lorsque les îlots flottants de graminées ont achevé leur cycle de végétation, les portions immergées sont couvertes de détritus organiques qui, en se diluant dans l'eau, lui donnent parfois sur des hectares une teinte terreuse.

La décomposition organique imprime donc un caractère fort spécial à ce milieu. Cependant, par suite probablement de l'apport continuel d'eau par la Lufira et ses affluents, le marécage ne se transforme pas en tourbière : ses eaux demeurent alcalines et possèdent toujours une dureté notable. En cela, le lac s'oppose à certains marécages contigus dont la végétation est beaucoup plus variée et l'eau légèrement acide.

On conçoit cependant que ce milieu fort spécial exige de la part des espèces animales des adaptations très particulières. Il n'est donc pas étonnant que toutes les espèces vivant dans l'ancien réseau hydrographique ne se soient pas multipliées de la même façon.

D. — Sédimentation : A son entrée dans la plaine inondée, la Lufira charrie énormément d'alluvions. La brusque variation du courant favorise le dépôt de ces matières d'aspect argileux. Ainsi se sont formées, jusque très loin dans le lac, deux banquettes dont le niveau affleure la cote maximum des eaux. Entre ces levées de terre, la rivière continue à couler jusqu'au centre de la plaine inondée. Mais, lorsque le niveau du lac est à son maximum, elle peut passer au-dessus de ces banquettes, les affouiller et se creuser de nouveaux trajets. D'année en année, la rivière change de place. Elle décrit des méandres qui se recoupent. A un endroit, quatre lits abandonnés existent côte à côte avec le lit actuel, aussi sinueux que les précédents d'ailleurs.

Au total, la partie amont du lac se remplit peu à peu par cette sédimentation d'origine étrangère. Derrière les banquettes ainsi créées, des étendues d'eau sont peu à peu séparées du lac proprement dit et soustraites à la réserve hydroélectrique. Lorsqu'en une saison sèche prononcée, le niveau des eaux est baissé pour entretenir la centrale, il reste, aux abords de l'entrée de la Lufira dans la plaine, des poches dont le niveau ne varie guère.

Une sédimentation d'origine biologique doit également exister, mais elle semble moins importante qu'on eût pu l'imaginer *a priori*. Les prairies flottantes se désagrègent en partie en surface et le produit de leur décomposition est entraîné par l'eau. Sur le fond, existent cependant plusieurs centimètres de débris organiques. Leur étude et celle de leur distribution sont à peine entamées et il est impossible d'apprécier leur épaisseur. Les dépôts organiques du fond sont d'ailleurs continuellement remaniés par la fermentation. Des bulles de méthane et d'acide carbonique se détachent sans cesse du fond. Fréquemment, des paquets de sédiments noirâtres, d'aspect spumeux par suite de l'abondance des gaz occlus, se soulèvent du fond et flottent à la surface de l'eau.

Telle est, rapidement esquissée, la situation actuelle d'un lac de barrage créé il y a une trentaine d'années dans une plaine katangaise. Les processus biologiques qui s'y sont installés n'étaient pas prévus par les constructeurs. Ils ont eu les conséquences suivantes :

1° Une augmentation formidable du rendement des pêcheries, bien que la population actuelle des poissons ne soit pas exactement celle qui convient au nouveau milieu. Ces pêcheries apportent aux populations autochtones une aisance remarquable qui provoque d'ailleurs une migration des populations vers la région du lac.

2° Une extension formidable des graminées et des roseaux dont les déchets agissent sur la composition de l'eau. Leur accumulation risque de créer un milieu impropre aux poissons et de tuer ainsi une richesse qui vient d'être créée.

3° Une exagération des dépôts de sédiments — tant autochtones qu'allogènes — qui combleront peut-être rapidement le lac.

4° Une altération des conditions d'hygiène indiquée par la pullulation des moustiques. Ceux-ci, il est vrai, appartiennent à une espèce qui ne transporte pas la malaria.

Actuellement, le lac représente une richesse à la fois pour l'industrie qui l'a créé et pour les populations riveraines. Il est probable que le rendement des pêcheries pourrait encore être augmenté par l'introduction dans le lac d'espèces appartenant à la faune des marais et spécialement d'espèces herbivores. D'autre part, l'extension exagérée des prairies lacustres risque d'altérer les caractères chimiques des eaux jusqu'à les rendre inhabitables pour la plupart des organismes animaux. A l'heure actuelle, il est impossible de prédire en combien de temps l'accumulation des alluvions et des dépôts organiques combleront le lac, mettant fin aux possibilités de pêche.

La source de richesse sous forme de protéines animales qui a été créée en même temps que le lac doit cependant être sauvegardée et si possible augmentée. Cela signifie une action sur la végétation lacustre et l'introduction de nouvelles espèces de poissons, adaptées à ce milieu. Une tentative semblable doit, pour être efficace, être guidée par une connaissance préalable du milieu et des processus qui s'y déroulent. Une équipe de travail, dépendant de l'Université de Liège, est en ce moment occupée à cette étude.

# THE EFFECTS OF WATER DIVERSIONS ON FISH

BY

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It is becoming apparent that most of the freshwater of the world eventually will be confined in reservoirs or will flow in diversion conduits. In areas of heavy precipitation and low population density this process will require a great many years, but in the more arid portions of the United States the ultimate development of water conservation is rapidly approaching. In the state of California the natural distribution of water does not fit the human needs. The areas of heaviest population are the areas of low precipitation. Conversely, in the sections of the state where water is abundant the need for this water is relatively slight. This situation exists in many other parts of the United States and in other parts of the world. As rapidly as possible this situation is being altered by storage and diversion.

Water can be diverted from a stream with or without a diversion dam. However, it is nearly impossible to divert large volumes of water without a dam of some type. Dams may be relatively low and useful only for diverting the water, or they may be constructed primarily for impounding water and secondarily for diversion. Whether there is a dam or not the water may be diverted by gravity or it may be pumped into the diversion conduit. The effects of dams and of pumps, per *se*, upon fish will be discussed elsewhere in this symposium. Let us assume that fish are entering the diversion conduit by some means. The point we are concerned with at this moment is the fate of these fish.

If we assume that the fish have entered the diversion conduit uninjured, the first consideration is whether the fish can be removed before they are killed or injured by some mechanical means or environmental change. Usually fish are in no immediate danger in the diversion but if the water is to be used directly for generating electricity, for cooling, or for some other industrial purpose, it may be impossible to save the fish once they have entered the diversion. In such cases it is necessary to screen the points of entrance. If, on the other hand, the point of water use is at some distance from the point of diversion the fate of the fish can be varied. Let us assume that the diverted water will have one of the following uses : *a*) industrial, *b*) domestic, *c*) irrigation. Industrial uses may be of a great many sorts and need not be listed. Similarly in those cases where the water is to be used for domestic purposes the fish must be removed or the loss will be very high. In some cases there will be a total loss of fish if the water is used for irrigation, in other cases a part of the water intended for irrigation is wasted and fish may return to safety. This is variable, but for the present let us assume that fish must be removed from diversion conduits before they reach the point of water use.

In the state of Montana there have been some valuable observations on the fate of fish which have entered farm irrigation ditches. It is pointed out by Clothier (1953) that trout, particularly brown and rainbow, will remain in the irrigation ditches until they are dewatered, or these fish may swim back up the ditches and re-enter the stream from which they came, if the flow in the ditch is partially reduced before being entirely shut off. It was also suggested in this study that resting places for trout be eliminated so that they would leave the ditch more readily when the flow was reduced. Also it was suggested that small reservoirs be constructed adjacent to such irrigation ditches when possible, and that the ditches be flushed into these reservoirs at intervals. The fish which escaped into these small reservoirs could then be caught by angling. This suggestion would seem to have wide application and might be considered as important a part of fish conservation as screens at the mouths of diversions. The State of California has proposed similar refuges for fish in a section of the San Joaquin river. In this case the river channel is to be reconstructed to permit a more rapid escape of flood water. This would destroy much of its value for fish life. Fish managers recommend that fish refuges of no less than three acres surface area be constructed at one-quarter mile intervals in this new river channel. The effectiveness of this conservation measure must be determined by test.

The more extensive irrigation systems, which conduct water many miles in large diversion canals may offer good opportunities for fishing in the canals themselves. Or the canals may empty into reservoirs from which water is drawn as needed. This situation is also a common one in domestic and industrial use systems. The canals may be reasonably well suited to fish and fish food organisms and can support considerable quantities of fish. However, they are rarely capable of supporting as large an amount of fish as normal streams because they are constructed for a rapid, unimpeded flow of water, and so the fish food environment is less desirable, and the hiding and resting places for fish are scarce. As a result fish tend to leave diversion conduits in search of a better environment. They may go back the way they entered or they may continue downstream. It is often impossible for fish to leave a conduit by the route they entered. Some mechanical obstruction is often present at the diversion point, or the water may have been pumped into the conduit. Thus they are commonly forced to remain in the ditch or continue downstream. In most cases the environment becomes less suitable as the distance from the point of diversion increases. Fish often continue great distances through water diversions and reach the end unharmed. In such cases the conduits are simply an artificial means for distributing fish over large areas and considerable distances. Thus the threadfin shad has been distributed over the semi-desert areas of southern California and Arizona. Kimsey (1957) has shown that following the introduction of this species into California in 1953 it was carried through one canal alone for approximately 300 miles. On this canal (Colorado River Aqueduct) there are five pumps which lift the water from one level gravity flow to another, and it was possible for shad to travel the entire route unharmed. Frequently this unintentional distribution of fish is harmless, or even beneficial as in the case of desirable forage species, but often the benefits are not balanced by the harm. The fisheries manager must be aware of this means of distribution and take precautions where necessary.

As more and more water is diverted into canals and reservoirs less remains in the natural stream channels. Thus we are substituting one type of fish habitat for another. The artificial habitat is usually less suitable for fish than the natural habitat but this is not always the case nor must we consider it inevitable. Frequently the reservoirs are highly productive of fish although these fish may not be of the same species which formerly occupied the area. There are many ways of improving reservoirs and their fish populations to make them more productive of food and recreation but the task of improving diversion canals for fish is a field of management rarely considered. It was mentioned that Clothier has suggested ways of caring for fish that have entered small irrigation ditches in Montana. This method of habitat improvement seems to have been overlooked or considered impracticable. Fish screens at the mouths of diversions are costly to construct and expensive to maintain. In some cases it would be advisable to let fish enter such canals and then develop ways of utilizing them in their new habitat. This thought seems to become even more reasonable as the size of the diversion increases. Very large screens not only become extremely expensive but all too often there is little water left in the natural stream channel below the point of diversion. Thus it sometimes happens that if we are to have fish at all they must be maintained in the canals and reservoirs. Admittedly this is often quite impossible. The diverted water may enter a tunnel, or pipe, or flume where they can scarcely live and from which they could not be removed by angling. In these cases it may be possible to construct enlargements of the conduits where fish will seek shelter and rest. Here there can be flushing valves and at intervals the concentrations of fish can be diverted back to the natural stream channel or to impoundments where they can live until captured. In large, open canals or ditches it should be possible to change their structure so that they can be fished in without danger. At present it is customary to construct canals with but one purpose in mind — to conduct water as rapidly and with as little friction as possible. This means that the sides and bottoms should be as nearly smooth as practicable. Under such conditions their value as fish habitat is greatly reduced and even if they harboured fish it would be difficult and unsafe to fish for them. Perhaps it would be possible to construct pools of considerable size at convenient points along large canals. With some study these could be designed to be attractive to fish and at the same time to offer little resistance to the flow of water. These basins for attracting and maintaining fish could be constructed with safety features and could be provided with public access. Fish descending such canals would tend to concentrate in such spots and remain there until fished out. It would appear that in some parts of the world this general approach may solve or tend to mitigate the harm of such diversions to fish life.

In parts of the United States, especially along the Pacific coast, a considerable proportion of the fish conservation work is directed toward saving as much of the natural stream flow as possible. At most points of diversion a fraction of the stream flow is released for fish and other aquatic organisms, but there is interminable litigation to save a part of each stream's flow for fish. Despite the sincere efforts of all fish conservation agencies a great many streams have been injured by water diversions. This drying up or partial drying up of streams is the greatest danger in water diversions. As a stream's flow is reduced the fish-carrying capacity of that stream is always or almost always reduced. It is true that the reduction in flow by diversion may improve conditions for angling in the larger, swifter rivers but this advantage is usually over-weighed by the reduction in the carrying capacity for fish. Not always do diversions cause a rise in the temperature of the remaining stream flow. It has been demonstrated in the Pit river of northern California that when the river flow was reduced the proportion of cool, subsurface water was increased and the harmful effetcs were thereby counterbalanced. However, the reduction in flow usually reduces the production of fish food organisms. This is due to several factors but the net result is that fish become less abundant. Frequently, too, the proportion of desirable fishes decreases and the proportion of undesirable fishes increases as stream flows are reduced.

In those streams which serve as nursery grounds for anadromous fish the diversion of water is usually more or less destructive. Many streams or sections of streams tributary to the Pacific coast of the United States have been completely ruined by diversions, as nursery waters for salmonid fishes. In part this is due to the dams, in part to the reservoirs which inundate the streams, and in part to the reduced stream flow. Many of the best salmon streams have been rendered useless to these fish by dams too high to be ascended or forming huge reservoirs which cannot be traversed safely by the young, downstream migrants. Many smaller tributary streams are dried or partially de-watered by irrigation and other diversions and the runs of salmonids greatly harmed.

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## Summary

Water diversions, of course, play an important part in fish and fisheries management throughout the world. The effects of diversions on fish are of two major types. When water is diverted the fish in the remaining portion of the stream are influenced. Usually the influence is harmful and much of the work of conservation agencies is directed toward preventing total destruction of stream flows.

The other problem created by water diversions can be summed up in the two questions : « How can fish be prevented from entering diversions ? » and « What can be done to conserve those fish which do enter the diversions ? ». Methods of screening or diverting fish away from the mouths of diversions will not be considered in this discussion, but we are concerned at this point with the fat of fish which have entered the conduits.

Let us summarize briefly the several things which may happen to fish that enter diversion conduits. They may be able to swim back out if they find the conditions disagreable, but usually the velocity is too great or there is some mechanical obstruction to the return passage. In some cases the conduit ends in an industrial plant, perhaps a hydro-electric or steam generating plant; perhaps a factory, or a domestic water-purification plant. In cases of this sort there may be mechanical screens intended to remove all unwanted debris. By-passes can be a part of such structures and under ideal conditions the major part of the fish are diverted back to the water from which they originally came. In opposition to such short diversions are those extending for many miles, perhaps hundreds of miles, through which fish can be carried without harm. Conditions in these conduits will vary with each situation, each will have its own set of problems. Some conduits may be pipes through which fish are quickly swept. Others are similar to natural streams and fish may grow and even reproduce in them. In all cases, however, these conduits will be de-watered at intervals, and even though conditions usually may be satisfactory, when the conduit is drained dry of water the fish will be killed unless they are flushed into a natural stream or into a reservoir built to conserve them. Insofar as fish are concerned the essential difference between a conduit and a natural stream (of poor grade) is that conduits are periodically drained dry or practically dry.

Conservation efforts must be directed towards salvaging fish before they are stranded in drying conduits or before they are carried to some lethal environment. Some methods of salvaging fish are discussed in this paper. Essentially the problem is to provide places for rest and shelter along a canal where fish will tend to congregate. Such structures should be required for all conduit systems where fish are abundant. When the canals themselves are de-watered the fish can be salvaged in these refuge areas. In some cases they may be flushed back to natural waters or they may be fished out of the refuges. The construction of these fish refuges should include safety features to prevent accidents to humans and should be provided with access routes for fishermen. The proper construction of such refuges will require study but as more and more freshwater is diverted into conduits and reservoirs more effort should be given to recreational uses of diverted waters.

In addition to the problems already mentioned, water conduits often distribute fish over large areas and into distant reservoirs, lakes and streams. Frequently this unintentional distribution of fishes is harmless or even beneficial but the manager must be aware of the possible introduction of highly undesirable species.

In conclusion it is evident that there are three broad problems raised by water diversions. First, the natural stream is reduced in flow by the diversion and this is often more or less harmful. Second, the aqueous environment of conduit systems is frequently harmful to fish, and devices are often nseded to prevent fish from being carried to their destruction. Third, diversions often serve to distribute fish over wide areas and this can create serious problems for the fisheries manager.

# OBSERVED CHANGES IN A RIVERS PHYSICAL CHARACTERISTICS UNDER SUBSTANTIAL REDUCTIONS IN FLOW DUE TO HYDRO-ELECTRIC DIVERSION

BY

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This paper deals with the physical changes which take place in a river — in its depth, water velocity, and area of submerged bottom — as the quantity of water flowing in the channel changes.

The investigation of these factors was carried out as part of a programme undertaken by the Pacific Gas and Electric Company of San Francisco. This company operates hydro-electric plants throughout northern California. At many of these, water is diverted by a dam from a river into a conduit which leads to a power house; between the diversion dam and the power house, where the water returns to the natural channel, the river is considerably reduced in flow. The question of how much water must be maintained for preservation of aquatic life in these sections of reduced flow is one which has troubled both the Company and the State of California's Department of Fish and Game for many years.

In late 1952 the Company, on its own initiative, proposed to undertake a programme aimed at providing factual data to aid in solving these problems. The State Department of Fish and Game cooperated actively in portions of the programme, but played only a consultative role in the work which is the subject of this paper. Data of the kind presented here have never been obtained before, and may never be again, since such work could only be carried on by an organization with large resources in men and equipment, and with sufficient interest in the problem to devote them to the task.

The rivers investigated were the Pit and the Feather in northern California, on both of which the Company planned new power plants. A sport fishery for rainbow trout was involved in both : how much water should be allotted to power, and how much to fish, in order to maintain both in healthy condition ?

One of the basic factors in fish life is food supply. One of the most important producers of trout food is the bottom — and in both the Pit and Feather, surface feeding of trout being rarely observed, bottom food is apparently more important than in some other trout streams. And one of the important factors in production of bottom food is obviously the amount of bottom area : the habitat of the organisms. The area of channel bottom covered by water varies as the volume of flow varies; a basic approach therefore would be to determine accurately this area at each stage of flow under consideration.

The method used was to survey a sufficient number of cross-sections of the channel to provide a sample from which a valid average could be derived for the part of the river under study. To eliminate human bias and to assure a true random sample, the interval between stations was arbitrarily chosen in advance, based upon the total number needed and the distance to be covered. Experienced survey crews with precision instruments measured the distances exactly, and were instructed that each station must be set up faithfully at the point reached and not shifted in one direction or the other to obtain a more easily surveyed section.

The most thorough of these studies was made on the Pit River, principal tributary of the Sacramento. The Pit has its source in lava formations which absorb the heavy winter rainfall and release it gradually throughout the year. It does not, therefore, have the extreme fluctuations of many California streams. Mean annual flow at the point under study was 2,636 cfs (cubic feet per second) over a 42-year period, with a maximum flood of 30,200 cfs in 1937, a year of extraordinarily heavy winter rains. Minimum natural flow in summer in normal years would probably be in the order of magnitude of 2,000 cfs, but the stream is regulated by reservoirs so that summer volume most of the time ranges from 3,000 to 3,500 cfs.

The new Pit 4 Power House is at elevation 2,080 feet, the diversion dam at 2,400; distance between them along the channel is about 7 ½ miles; gradient 8 feet per thousand. Most of the water is diverted out of the river into a 4-mile tunnel leading to the power house. The problem : how much water should be released into the natural channel between dam and power house for maintenance of fish life.

Studies were made at 50, 100, 150, 200 and 250 cfs. Volume was measured by a recording gauge below the dam, and was kept constant at the desired figure by automatically operated gates in the dam. The entire river bed from dam to power house was surveyed by a transit traverse, and stations were laid out at 1,000 foot intervals as measured along the centre line of the channel. At each station the cross-section of the river bottom was carefully profiled by instrument, and the elevation of the water surface in relation thereto measured for each rate of flow. The forty cross-sections thus obtained were plotted to a large scale on paper: the maximum depth, the wetted perimeter (the distance measured along the bottom.

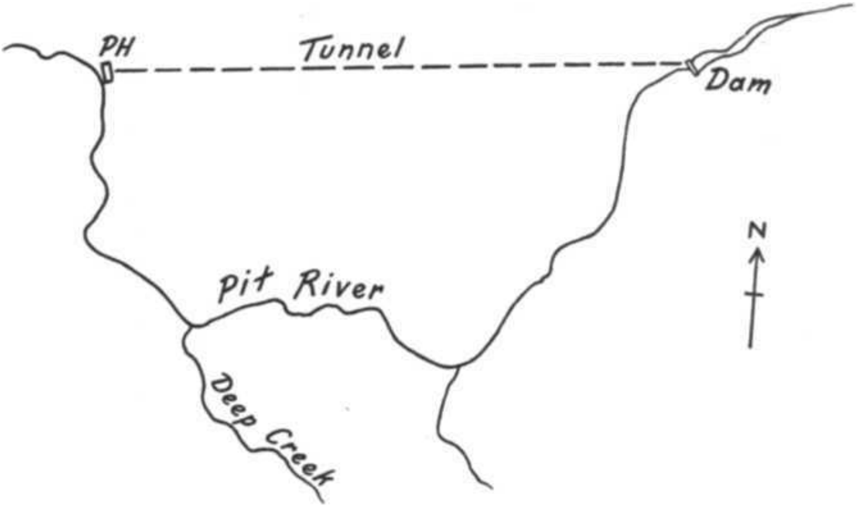


FIG. 1. — Sketch map. Pit River.

including the irregularities, from the water surface on one side to the water surface on the other), and the area of the cross-section were scaled from the drawing for each volume of release; and average water velocity through each cross-section was calculated from the

TABLE I.

**Means of 40 survey cross-sections at 1,000 ft. intervals, Pit 4 Dam to Pit 4 PH.**

| Volume of release at Pit 4 Dam | Wetted perimeter (feet) | | Max. depth (feet) | | Area (sq. ft.) | | Water velocity (ft. per sec.) | |
|---|---|---|---|---|---|---|---|---|
| | | % | | % | | % | | % |
| 250 cfs | 120.2 | 100 | 6.16 | 100 | 340.6 | 100 | 0.982 | 100 |
| 200 | 114.9 | 96 | 5.90 | 96 | 317.7 | 93 | 0.868 | 88 |
| 150 | 109.7 | 91 | 5.64 | 91 | 294.8 | 87 | 0.738 | 75 |
| 100 | 104.6 | 87 | 5.38 | 87 | 272.0 | 80 | 0.567 | 68 |
| 50 | 95.4 | 79 | 5.10 | 83 | 247.8 | 73 | 0.346 | 35 |

area so measured and the known volume of flow. The mean values of the 40 survey sections are shown in Table I. For those interested in the details, the values for each section are shown in Table II.

As a matter of interest, certain mean values which it was possible to obtain from the forty cross-sections for a volume of 3,500 cfs are shown below :

| Volume | Width | Max. depth | Area | Water velocity |
|---|---|---|---|---|
| 3,500 cfs | 160.1 ft. | 10.2 ft. | 876.0 sq. ft. | 4.23 ft. per sec. |

It will be noted that the tables do not give directly the values which were the prime objective of the study, that is, the total area of bottom covered by water at each rate of flow. However, the mean wetted perimeter is a direct function of this area : multiply the value of the mean wetted perimeter at any rate of flow by the total length under study — in this case 40,000 feet, Station 0 being at the dam, — and you have the total submerged area; e.g., 120,2×40,000 = 4,808,000 square feet of bottom covered by water at a rate of flow of 250 cfs. However, it is the relationships at various volumes of flow that are of interest rather than the absolute values, and since the wetted perimeter is an exact index of these relationships, this linear measure is used throughout as being easier to handle and to visualize than the large values in square feet.

The first important information to be derived from Table I is the fact that the wetted perimeter decreases much less rapidly than the volume of flow. Volume at 50 cfs is 20 per cent of volume at 250; but wetted perimeter at 50 cfs is 79 per cent of what it was at 250 cfs (Table I). Or to take another example, when volume of 200 cfs is reduced by 50 per cent to 100 cfs, wetted perimeter is reduced by only 9 percentage points. This means that the total submerged area at 100 cfs is over 90 per cent of what it was at 200 cfs; that the total habitat accessible to bottom organisms is over 90 per cent of what it was; and that, *other things being equal*, the total bottom population at 100 cfs would still be over 90 per cent of what it was at 200 cfs.

However, other things are not equal. Depth, which may be considered an index of shelter for fish, closely parallels wetted perimeter in its percentage reduction; and area of cross-section, an index of the total amount of space available for aquatic life, is probably not a limiting factor as volume varies over the range considered here.

TABLE II. — **Data obtained from cross-sections of 40 stations**

| St. | Wetted perimeter (ft.) | | | | | Area of section (sq. ft.) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 100 | 150 | 200 | 250 | 50 | 100 | 150 | 200 | 250 |
| | cfs | | | | | cfs | | | | |
| Y-1 | 32.5 | 35.0 | 37.5 | 40.0 | 42.5 | 77.0 | 89.3 | 101.5 | 113.7 | 126.0 |
| Y-2 | 70.0 | 75.5 | 81.0 | 86.5 | 92.0 | 46.0 | 76.8 | 107.6 | 138.3 | 169.0 |
| Y-3 | 108.0 | 112.5 | 116.1 | 119.5 | 122.4 | 205.0 | 238.8 | 272.6 | 306.3 | 340.0 |
| Y-4 | 107.0 | 113.0 | 119.0 | 124.0 | 129.0 | 341.0 | 373.0 | 405.0 | 437.0 | 464.0 |
| Y-5 | 83.0 | 88.9 | 93.0 | 97.0 | 101.0 | 130.0 | 158.8 | 187.6 | 216.4 | 245.0 |
| Y-6 | 75.0 | 80.0 | 85.0 | 90.0 | 95.0 | 120.0 | 143.8 | 167.6 | 191.4 | 215.0 |
| Y-7 | 73.0 | 76.5 | 80.0 | 86.0 | 90.0 | 153.0 | 169.3 | 185.6 | 202.0 | 218.0 |
| Y-8 | 90.0 | 92.0 | 95.0 | 98.0 | 100.0 | 325.0 | 341.8 | 358.6 | 375.4 | 392.0 |
| Y-9 | 57.0 | 58.7 | 60.4 | 62.2 | 64.0 | 312.0 | 326.3 | 341.6 | 356.4 | 371.0 |
| Y-10 | 103.0 | 109.0 | 115.0 | 122.0 | 138.0 | 291.0 | 318.0 | 345.0 | 372.0 | 339.0 |
| Y-11 | 106.0 | 163.0 | 166.0 | 169.0 | 172.0 | 482.0 | 504.8 | 527.6 | 556.5 | 573.0 |
| Y-12 | 127.5 | 128.75 | 130.0 | 131.75 | 132.5 | 597.0 | 603.3 | 609.6 | 615.8 | 622.0 |
| Y-13 | 107.0 | 109.0 | 111.0 | 113.0 | 115.0 | 547.0 | 576.0 | 604.0 | 632.0 | 660.0 |
| Y-14 | 82.0 | 102.0 | 112.0 | 122.0 | 132.0 | 106.4 | 126.6 | 146.8 | 167.0 | 187.2 |
| Y-15 | 102.0 | 104.0 | 106.0 | 108.0 | 110.0 | 478.5 | 503.7 | 528.4 | 554.1 | 587.3 |
| Y-16 | 83.0 | 93.0 | 98.0 | 103.0 | 107.0 | 174.0 | 197.8 | 221.6 | 245.4 | 269.0 |
| Y-17 | 157.0 | 163.0 | 167.0 | 171.0 | 175.0 | 243.8 | 276.6 | 309.4 | 342.2 | 374.8 |
| Y-18 | 108.0 | 123.0 | 132.0 | 141.0 | 150.0 | 114.1 | 152.8 | 190.4 | 228.0 | 265.6 |
| Y-19 | 86.0 | 88.0 | 90.0 | 92.0 | 94.0 | 550.0 | 574.3 | 598.5 | 662.7 | 646.9 |
| Y-20 | 82.0 | 85.25 | 88.50 | 91.75 | 95.0 | 93.8 | 113.0 | 132.0 | 151.0 | 170.0 |
| Y-21 | 93.0 | 95.25 | 97.5 | 99.75 | 102.0 | 338.2 | 363.0 | 389.0 | 414.6 | 440.2 |
| Y-22 | 88.5 | 89.86 | 91.24 | 92.62 | 94.0 | 312.0 | 327.0 | 342.0 | 357.0 | 372.0 |
| Y-23 | 152.0 | 157.0 | 162.0 | 167.0 | 172.0 | 697.0 | 727.0 | 752.0 | 778.0 | 804.0 |

**at 1,000 ft. intervals from Pit 4 Dam to Pit 4 Powerhouse.**

| Velocity (ft. per sec.) | | | | | Depth (ft.) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 100 | 150 | 200 | 250 | 50 | 100 | 150 | 200 | 250 |
| cfs | | | | | cfs | | | | |
| 0.65 | 1.12 | 1.48 | 1.76 | 1.98 | 3.40 | 3.85 | 4.25 | 4.60 | 4.95 |
| 1.09 | 1.30 | 1.39 | 1.45 | 1.48 | 1.92 | 2.37 | 2.59 | 2.89 | 3.18 |
| 0.24 | 0.42 | 0.55 | 0.65 | 0.74 | 3.10 | 3.55 | 3.88 | 4.20 | 4.50 |
| 0.15 | 0.27 | 0.37 | 0.46 | 0.54 | 5.65 | 5.95 | 6.23 | 6.50 | 6.85 |
| 0.38 | 0.63 | 0.80 | 0.92 | 1.02 | 3.70 | 4.07 | 4.37 | 4.66 | 4.95 |
| 0.42 | 0.70 | 0.89 | 1.04 | 1.16 | 2.65 | 3.00 | 3.29 | 3.57 | 3.85 |
| 0.33 | 0.59 | 0.81 | 0.99 | 1.14 | 3.10 | 3.40 | 3.60 | 3.80 | 4.00 |
| 0.15 | 0.29 | 0.42 | 0.53 | 0.64 | 6.15 | 6.34 | 6.53 | 6.72 | 6.90 |
| 0.16 | 0.31 | 0.44 | 0.56 | 0.67 | 10.10 | 10.42 | 10.73 | 11.04 | 11.35 |
| 0.17 | 0.31 | 0.43 | 0.54 | 0.81 | 10.20 | 10.45 | 10.70 | 10.95 | 11.20 |
| 0.10 | 0.20 | 0.28 | 0.36 | 0.44 | 4.40 | 4.65 | 4.85 | 4.90 | 5.05 |
| 0.08 | 0.16 | 0.25 | 0.32 | 0.40 | 10.35 | 10.55 | 10.72 | 10.89 | 11.05 |
| 0.09 | 0.15 | 0.23 | 0.30 | 0.38 | 8.40 | 8.69 | 8.92 | 9.14 | 9.35 |
| 0.47 | 0.79 | 1.02 | 1.20 | 1.34 | 2.80 | 3.09 | 3.34 | 3.57 | 3.80 |
| 0.10 | 0.20 | 0.28 | 0.36 | 0.43 | 12.95 | 12.42 | 12.73 | 13.03 | 13.35 |
| 0.29 | 0.51 | 0.68 | 0.81 | 0.93 | 3.60 | 3.80 | 4.00 | 4.20 | 4.40 |
| 0.21 | 0.36 | 0.48 | 0.58 | 0.67 | 4.10 | 4.36 | 4.59 | 4.82 | 5.05 |
| 0.44 | 0.65 | 0.79 | 0.88 | 0.94 | 4.25 | 4.62 | 4.93 | 5.24 | 5.55 |
| 0.09 | 0.17 | 0.25 | 0.32 | 0.39 | 12.60 | 13.00 | 13.30 | 13.60 | 13.90 |
| 0.53 | 0.88 | 1.14 | 1.32 | 1.47 | 2.70 | 3.00 | 3.29 | 3.57 | 3.85 |
| 0.15 | 0.28 | 0.39 | 0.48 | 0.57 | 7.04 | 7.33 | 7.62 | 7.91 | 8.20 |
| 0.16 | 0.31 | 0.44 | 0.56 | 0.67 | 5.80 | 6.15 | 6.50 | 6.90 | 7.30 |
| 0.07 | 0.14 | 0.20 | 0.27 | 0.31 | 14.60 | 15.60 | 16.60 | 17.60 | 18.60 |

TABLE II. — **Data obtained from cross-sections of 40 stations at**

| St. | Wetted perimeter (ft.) | | | | | Area of section (sq. ft.) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 100 | 150 | 200 | 250 | 50 | 100 | 150 | 200 | 250 |
| | cfs | | | | | cfs | | | | |
| Y-24 | 116.0 | 126.0 | 137.0 | 149.0 | 161.0 | 159.0 | 174.0 | 192.0 | 210.0 | 228.0 |
| Y-25 | 45.0 | 51.0 | 57.0 | 64.0 | 72.5 | 39.8 | 53.3 | 66.8 | 80.3 | 93.8 |
| Y-26 | 105.5 | 106.0 | 106.5 | 106.9 | 107.5 | 918.5 | 936.0 | 953.5 | 971.0 | 988.6 |
| Y-27 | 121.5 | 129.4 | 137.1 | 144.8 | 152.5 | 233.0 | 243.0 | 252.0 | 261.0 | 270.0 |
| Y-28 | 132.0 | 142.0 | 151.0 | 159.3 | 168.0 | 141.0 | 188.0 | 235.0 | 282.0 | 332.0 |
| Y-29 | 90.0 | 98.0 | 105.5 | 113.0 | 120.0 | 77.0 | 94.0 | 110.0 | 125.0 | 140.0 |
| Y-30 | 63.0 | 110.0 | 122.0 | 134.0 | 145.0 | 80.0 | 100.0 | 120.0 | 140.0 | 160.0 |
| Y-31 | 129.0 | 133.0 | 137.0 | 141.0 | 145.0 | 240.0 | 275.0 | 309.0 | 343.0 | 377.0 |
| Y-32 | 122.0 | 127.5 | 133.0 | 139.5 | 145.0 | 107.0 | 122.0 | 137.0 | 152.0 | 166.0 |
| Y-33 | 80.0 | 87.5 | 95.0 | 102.5 | 110.0 | 98.0 | 120.0 | 142.0 | 164.0 | 186.0 |
| Y-34 | 132.0 | 143.0 | 154.0 | 165.5 | 177.0 | 111.0 | 135.0 | 159.0 | 183.0 | 207.0 |
| Y-35 | 88.0 | 89.5 | 91.0 | 92.5 | 94.0 | 199.9 | 225.0 | 250.0 | 276.6 | 302.4 |
| Y-36 | 88.0 | 95.0 | 102.0 | 112.0 | 118.0 | 56.3 | 78.0 | 99.6 | 121.2 | 142.8 |
| Y-37 | 71.0 | 73.0 | 75.0 | 77.0 | 79.0 | 157.0 | 174.2 | 191.4 | 208.4 | 226.0 |
| Y-38 | 107.5 | 111.9 | 116.2 | 120.6 | 125.0 | 271.0 | 302.2 | 333.4 | 364.6 | 396.0 |
| Y-39 | 138.0 | 148.0 | 156.0 | 162.0 | 168.0 | 157.0 | 170.5 | 184.0 | 197.0 | 211.0 |
| Y-40 | 66.0 | 72.5 | 80.0 | 87.5 | 95.0 | 180.0 | 207.0 | 234.0 | 261.0 | 288.0 |
| Aver. | 95.4 | 104.6 | 109.7 | 114.9 | 120.2 | 247.8 | 272.0 | 294.8 | 317.7 | 340.6 |

But mean velocity of the water (Table I) shows a very much greater percentage reduction; it is in this factor that really striking and significant changes occur. Studies have been made on the relationship between bottom-dwelling organisms and water velocity (1). But a

(1) NEEDHAM, PAUL R. and ROBERT L. USINGER, *Variability in the macrofauna of a single riffle in Prosser Creek. California,* as *indicated by the Surbet sampler.* Hilgardia, Vol. 24, No. 14, pp. 383-409, April 1956.

**1,000 ft. intervals from Pit 4 Dam to Pit 4 Powerhouse (continued).**

| Velocity (ft. per sec.) | | | | | Depth (ft.) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 100 | 150 | 200 | 250 | 50 | 100 | 150 | 200 | 250 |
| cfs | | | | | cfs | | | | |
| 0.31 | 0.57 | 0.78 | 0.95 | 1.09 | 2.40 | 2.60 | 2.80 | 3.00 | 3.20 |
| 1.26 | 1.88 | 2.25 | 2.49 | 2.68 | 2.15 | 2.30 | 2.55 | 2.80 | 3.15 |
| 0.05 | 0.11 | 0.16 | 0.21 | 0.25 | 14.00 | 14.23 | 14.43 | 14.64 | 14.85 |
| 0.21 | 0.41 | 0.60 | 0.77 | 0.93 | 3.50 | 3.73 | 3.96 | 4.18 | 4.40 |
| 0.35 | 0.53 | 0.64 | 0.71 | 0.75 | 4.00 | 4.19 | 4.36 | 4.53 | 4.70 |
| 0.65 | 1.06 | 1.36 | 1.60 | 1.79 | 3.60 | 3.97 | 4.32 | 4.66 | 5.00 |
| 0.63 | 1.00 | 1.25 | 1.43 | 1.56 | 1.54 | 1.78 | 2.02 | 2.26 | 2.50 |
| 0.21 | 0.36 | 0.49 | 0.58 | 0.66 | 4.40 | 4.64 | 4.86 | 5.08 | 5.30 |
| 0.47 | 0.82 | 1.09 | 1.32 | 1.51 | 2.10 | 2.25 | 2.40 | 2.55 | 2.70 |
| 0.51 | 0.83 | 1.06 | 1.22 | 1.34 | 2.80 | 3.08 | 3.33 | 3.57 | 3.80 |
| 0.45 | 0.74 | 0.94 | 1.09 | 1.21 | 2.10 | 2.31 | 2.49 | 2.67 | 2.85 |
| 0.25 | 0.44 | 0.60 | 0.72 | 0.83 | 3.50 | 3.65 | 3.94 | 4.22 | 4.50 |
| 0.89 | 1.28 | 1.51 | 1.65 | 1.75 | 1.60 | 1.18 | 1.98 | 2.14 | 2.30 |
| 0.32 | 0.57 | 0.78 | 0.96 | 1.11 | 3.90 | 4.10 | 4.30 | 4.50 | 4.70 |
| 0.18 | 0.33 | 0.45 | 0.55 | 0.63 | 4.65 | 4.94 | 5.20 | 5.45 | 5.70 |
| 0.32 | 0.59 | 0.82 | 1.02 | 1.18 | 2.35 | 2.53 | 2.66 | 2.78 | 2.90 |
| 0.28 | 0.48 | 0.72 | 0.77 | 0.87 | 2.10 | 2.34 | 2.52 | 2.69 | 2.85 |
| 0.35 | 0.57 | 0.73 | 0.87 | 0.98 | 5.10 | 5.38 | 5.64 | 5.90 | 6.16 |

great deal is still unknown. Moreover, the figures we have here give at best only the average velocity through each cross-section. What actually happens is that the water velocity changes over every single point of the channel bottom; and about all we can say with certainty is that these changes undoubtedly affect the population of bottom-dwellers, not only quantitatively but qualitatively, and thus indirectly affect the fish populations. Also, in a mixed fish population such as we have here, including suckers (*Catostomus occidentalis*) in great numbers, hardheads (*Mylopharodon conocephalus,* a large Cyprinid) in abundance, and carp and other rough fish in addition to the rainbow trout, changes in velocity may affect the various species differently benefitting one and injuring another, and thus bringing about a redistribution of species, both in locality and in proportional numbers.

Another effect of change in water velocity, which was not a part of this particular study but which formed a most important part of the overall programme, is on water temperature, and thus indirectly on fish. When this channel carries 3,500 cfs the water traverses the distance from dam to power house in about three hours. With volume at 250 cfs, and mean velocity at approximately 1 foot per second (Table I), it takes eleven hours for the water to cover this distance, meaning that it is exposed to the sun during the full high-temperature period of each day — and this in a location where peak summer air temperatures reach 100 degrees Fahrenheit in the shade. The heating potential of the sun thus exerts a much greater effect at 250 cfs than at 3,500 cfs.

At this point we must mention a factor which, while it does not affect the overall situation as shown in the tables, must not be left out of the picture : the accretion, or inflow of water, into the channel between dam and power house. This, by stream gauging, was found to be approximately 50 cfs at the time of the study. The largest single increment was Deep Creek near Station Y-29 with 6 cfs; accumulated accretion just below the mouth of this tributary totalled about 35 cfs. Accretion remained constant, of course, at all volumes studied, but its proportional effect differed at different volumes, as can be visualized from the following figures :

| | cfs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | % | | % | | % | | % |
| Volume of release at Pit 4 Dam | 250 | 100 | 200 | 80 | 150 | 60 | 100 | 40 | 50 | 20 |
| Accretion between Dam and St. 40 | 50 | | 50 | | 50 | | 50 | | 50 | |
| Volume at St. 40 | 300 | 100 | 250 | 83 | 200 | 67 | 150 | 50 | 100 | 33 |

Theoretically, it would have been possible to adjust the volume of release so that the flow would have been the same at each station at time of measurement, but practically this was not possible and, in fact, was not desirable : this accretion is normal in this river, and the objective of the surveys was to show the normal changes in this river below the dam as the volumes of water released at the dam change.

Effect of the accretion on water temperature, while again not a direct part of this study, is so important that it deserves mention. Maximum water temperatures at the dam are close to 68 degrees Fahrenheit. Maximum temperatures of the tributary water were much below this : Deep Creek 55, and the springs and underground seepages which contributed much of the inflow probably less. Accretion water therefore had a cooling influence. And this cooling influence increased as the volume of flow decreased : at 200 cfs release at dam the cool inflowing water only added 25 per cent to the volume, whereas at 50 cfs the cool inflowing water added 100 per cent. And where a much greater increase in water temperature on its way down the channel at 50 cfs as contrasted to 200 cfs might have been expected, the influence of the inflowing cool water was such that there was no significant difference at the different rates of flow : maximum water temperature between dam and power house at 200 cfs was 71 degrees Fahrenheit, at 100 cfs 70, at 50 cfs 70 ½.

Similar surveys were carried out on the North Fork of the Feather River, a smaller, faster stream (gradient 12 feet per 1,100). Twenty-six survey stations were established at 500-foot intervals, and measurements made at controlled flows of 140, 200, 300 and 800 cfs. The figures for the means are shown in Table III.

TABLE III.

**Means of 26 survey cross-sections at 500 ft. intervals, North Fork Feather River, Gansner Bar to Queen Lily Camp ground.**

| Volume of flaw | Wetted perimeter (feet) | | Width (feet) | | Max. depth (feet) | | Area (sq. ft.) | | Water velocity (ft. per sec.) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | % | | % | | % | | % |
| 800 cfs | 87.9 | | 84.9 | | 4.5 | | 210.0 | | 4.07 | |
| 300 | 76.8 | 100 | 73.8 | 100 | 3.5 | 100 | 138.0 | 100 | 2.33 | 100 |
| 200 | 73.3 | 95 | 70.4 | 95 | 3.2 | 91 | 118.0 | 85 | 1.85 | 79 |
| 140 | 69.4 | 90 | 67.5 | 91 | 2.8 | 80 | 97.0 | 70 | 1.58 | 68 |

The flow of 800 cfs was included in the survey because it is not far from the estimated normal uncontrolled summer flow. Since it is outside of the range used on the Pit it is not of value for comparison with that river, and is therefore omitted from the percentage figures, which have been calculated for 300, 200 and 140 cfs. Comparing these with Table I, a striking similarity is seen between the percentage figures at proportional rates of flow, and it is probable that the picture would be much the same for many fast-flowing mountain streams. That it might be very different in flat, slow-moving rivers goes without saying.

## Summary

This study was part of an investigation carried out by the Pacific Gas and Electric Company in northern California aimed at providing factual data as an aid in determining the amount of water to be released at hydro-electric diversion dams for maintenance of aquatic life in the channel below the dam. In the Pit River, surveys were made at forty stations at 1,000-foot intervals between Pit 4 Dam (elevation 2,400 feet) and Pit 4 Power House (elevation 2,080 feet). Normal flow is 3,000 to 3,500 cfs (cubic feet per second); surveys were made at various rates of controlled flow from 50 to 250 cfs. From this sample of 40 cross-sections the following means were derived :

**Means of 40 survey cross-sections at 1,000 ft. intervals, Pit 4 Dam to Pit 4 PH.**

| Volume of release at Pit 4 Dam | Wetted perimeter (feet) | | Max. depth (feet) | | Area (sq. ft.) | | Water velocity (ft. per sec.) | |
|---|---|---|---|---|---|---|---|---|
| | | % | | % | | % | | % |
| 250 cfs | 120.2 | 100 | 6.16 | 100 | 340.6 | 100 | 0.982 | 100 |
| 200 | 114.9 | 96 | 5.90 | 96 | 317.7 | 93 | 0.868 | 88 |
| 150 | 109.7 | 91 | 5.64 | 91 | 294.8 | 87 | 0.738 | 75 |
| 100 | 104.6 | 87 | 5.38 | 87 | 272.0 | 80 | 0.567 | 68 |
| 50 | 95.4 | 79 | 5.10 | 83 | 247.8 | 73 | 0.346 | 35 |

On the Feather River, a smaller stream with a steeper gradient, surveys of this kind gave very similar results.

# DIVERSIONS, CANALS AND CONDUITS — THEIR ROLE IN INTRODUCING AQUATIC ORGANISMS INTO DRAINAGE BASINS WHERE THEY DID NOT RESIDE FORMERLY

BY

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In a review of the literature relative to the Suez and Panama canals, and various water diversions located in Europe and western North America, I have been impressed with the comparative lack of factual evidence concerning the part these diversions have in extending the ranges of animals and plants. It was especially evident that many of the Old World canals and other diversions have little tangible evidence to offer, because the changes that had occurred did so in the distant past and were poorly documented. I therefore have confined myself to some recently constructed canals that are located in the eastern United States and Canada, With these I have had personal experience, and am well acquainted with the literature concerning them. It is my belief that these canals have most of the fundamental problems relative to range extensions of aquatic organisms which water diversions have elsewhere throughout the world.

### Welland canal

The Great Lakes and their outlet, the St. Lawrence River, are situated in eastern North America, and form part of the international boundary between the United States and Canada. The St. Lawrence River, about 750 miles in length, drains into the Gulf of St. Lawrence and thence into the Atlantic Ocean.

Lake Ontario is the lowermost of the Great Lakes, and its overflow waters flow eastward into the St. Lawrence River. At its western end, Lake Ontario receives the overflow waters of Lake Erie and the remaining upper lakes, through the Niagara River. This river is approximately 25 miles in length, and contains the majestic Niagara Falls, which since early post-glacial times has prevented the upstream movements of many species of aquatic animals and possibly some aquatic plants.

In 1825 the Canadian Government began construction of the Welland Canal, completing it in 1829. This ship canal, about 25 miles in length and by-passing Niagara Falls, made possible the movement of aquatic forms from Lake Ontario into Lake Erie. Shortly after completion of the canal, Dr. Jared P. Kirtland and other ichthyologists of that period, predicted the early invasion into Lake Erie of fishes and the sea lamprey, believing that the barrier between the two lakes had been removed. However, it was not until 1856, 31 years after the completion of the canal, that the highly migratory American eel, *Anguilla rostrata* (LESUEUR), was recorded for Lake Erie waters, a species which KIRTLAND (1851, 78) considered to be absent from these waters prior to the building of the canal. GARLICK (1857, 126) in recording the capture of the eel in 1856, stated that it had « undoubtedly found its way from Lake Ontario [into Lake Erie waters by way of] the Welland Canal ». Obviously this species could not establish itself as a permanent, land-locked resident of the upper lakes because it spawns only in the Atlantic Ocean.

The alewife, *Pomotobus pseudoharengus* (WILSON), was known to be present in Lake Ontario since at least 1873 (MILLER, 1957, 97) but was considered to be absent above Niagara Falls. As late as 1929 HUBBS and BROWN (1929, 18) wrote : « It would be interesting to determine why the alewife, the marine form of which is strongly migratory, should not have passed through the Welland Canal to populate Lake Erie ». It was not until 1931, after a century had elapsed since the completion of the canal, that the first alewife was known to be present above the falls, DYMOND (1932, 32) reporting its capture in Lake Erie at a point approximately 50 miles west of the terminal of the canal. By 1932 occasional specimens were being taken by commercial fishermen in the eastern half of Lake Erie, in 1940 it was captured in the western end of the lake (TRAUTMAN, 1957, 180), after 1945 it was abundant throughout that lake.

The first capture of the alewife in the lakes above Lake Erie was in the Georgian Bay section of Lake Huron; it was taken there in 1933 (MACKAY, 1934, 97). Another was reported in 1935; this one was captured in the central portion of Lake Huron. VAN OOSTEN (1935, 195), in recording its capture, discussed the possibilities of its having been introduced accidentally by some state or federal agency or unknown individual, and suggests that the species entered Lake Huron from Lake Ontario by means of the 200-mile-long Trent Canal, instead of from Lake Erie through the 80-mile-long, large Detroit River. This river connects Lake Erie with Lake Huron. The Trent Canal, completed before 1933, was constructed by canalizing many lakes and streams and connecting them with canals. The completed canal extends from Lake Ontario to the southern tip of Georgian Bay. The distance from Lake Erie via the Detroit River to the points of capture of the alewives referred to above, is considerably shorter than is the distance from Lake Ontario to the points of capture via the Trent Canal. Other authorities, including HUBBS and LAGLER (1949, 34), MILLER (1957, 97) and Dr. J. A. DYMOND (personal communication of March 28, 1958) assume as I do that the alewife entered Lake Huron from Lake Erie. The species was first recorded in Lake Michigan in 1939, and in the remaining Lake Superior in 1954 (MILLER, 1957, 97). Land-locked alewives are of comparatively little value at present as human food, but under certain conditions become economically important as food for those fish species more highly valued as human food. Whether the alewife in the upper lakes becomes an asset or liability to human economy remains to be seen.

The parasitic sea lamprey, *Petromyzon marinus* LINNAEUS, ranges widely throughout the North Atlantic Ocean, ascending rivers as far south as southern Europe and the central United States. It is also land-locked in some waters of eastern North America. The species has long been present in Lake Ontario and the Niagara River below the falls. It was absent from the upper lakes above the falls, and as previously stated, early ichthyologists assumed that, after completion of the Welland Canal in 1829, this lamprey would quickly invade these lakes. Their assumption was based upon the facts that this parasite was a highly migratory and aggressive species, which not only attached itself to fishes, but also followed or attached itself to moving boats (ADAMS and HANKINSON, 1928, 238). This latter habit might be of material aid in transporting the lamprey through the canal. However, it was not until 1929, almost a century after the completion of the canal, that the first sea lamprey was recorded for Lake Erie waters (DYMOND, 1922, 60). The first factual evidence of individuals spawning in a Lake Erie tributary was obtained in 1935 (TRAUTMAN, 1957, 143).

The first sea lampreys were recorded for Lake Michigan in 1936, for Lake Huron in 1937, and for Lake Superior in 1946 (SHETTER, 1949, 163 and 171). The size of the Lake Erie population has remained small because of unfavourable environmental factors in the tributaries (TRAUTMAN, 1942, 211-223; 1957, 144), but in the upper lakes environmental conditions in the tributaries were highly favourable and as a consequence the species quickly became abundant.

From an economic point of view, the establishment of this parasitic lamprey in the upper lakes has been catastrophic. Events occurring in Lake Michigan will be cited as an example. For at least 100 years the Lake Trout, *Salvelinus namaycush* (WALBAUM), had been of prime commercial importance, and for many years previous to 1945 the catch from Lake Michigan had been in the neighbourhood of 6,000,000 pounds annually. In 1944 the catch was 6,498,000 pounds but after that year a drastic decline in poundage occurred; by 1955 the annual commercial catch had been reduced to 55 pounds (ESCHMEYER, 1957, 102-103), and the species appeared to be nearing extinction in the lake. Overwhelming evidence indicates that the Sea Lamprey was the causative factor for decrease in the trout population.

MOFFETT (1957) presents evidence that the lake trout and burbot, *Lota lota lacustris* (WALBAUM), were the first piscine members of the small, deep-water association of fishes in Lake Michigan to drastically decline in abundance; these large species are prime prey for the sea lamprey. The drastic decrease in the population size of these two species disrupted the biological balance of the lake, causing both the sea lamprey and the commercial fishermen to shift their efforts to the seven species of deep-water ciscoes (*Leucichthys* spp.), with the result that by 1955 the two ciscoes of largest size, the deepwater chub, *Leucichthys johannae* (WAGNER) and the bluefin, *Leucichthys nigripinnis* (GILL), had been almost eliminated. On the other hand, the bloater, *Leucichthys hoyi* (GILL), a ciscoe of quite small size, had increased greatly in commercial abundance because of increased population pressure, caused by the reduction in numbers of the larger-sized species, and because this small-sized species is relatively free from predation by the sea lamprey. As a result of this combination of factors, the commercial catch of the bloater increased 347 per cent.

It must be mentioned here that two native species of parasitic lampreys, both of moderately large size, the silver lamprey, *Ichthyomyzon unicuspis* (HUBBS and TRAUTMAN), and chestnut lamprey, *Ichthyomyzon castaneus* GIRARD, were present in the upper lakes long before the invasion of the sea lamprey (HUBBS and TRAUTMAN, 1937). Observations made prior to the advent of the sea lamprey indicated that there were no marked and obvious adverse effects upon the huge fish population, because of predation, or presence of, the native lampreys.

I have written in such detail, concerning the results of the sea lamprey invasion of the upper lakes, in order to emphasize what can happen when a species of aquatic animal extends its range into another basin, through means of canals or otherwise. It makes no difference whether the sea lamprey invaded the upper lakes by means of the canal, as we assume, or by some other method; the result would have been the same.

Assuming that the sea lamprey did enter the waters of the upper lakes through the canal, why did it not enter shortly after the completion of the canal instead of many years later ? Two possible reasons present themselves.

Lake Erie is more than 200 miles long and 50 miles wide, and has many tributary streams in which there are countless riffles. Many of these riffles are suitable for lamprey spawning and the development of their ammocoetes. Other riffles, however, are not suitable, usually because of the recent increase in the rate of siltation or other pollutants which have destroyed the spawning areas for adults or areas of development of the young, or because dams prevent upstream migration (TRAUTMAN, 1949). Before the sea lamprey can establish itself it is necessary for one or more pairs to meet on the same riffle when both sexes are in spawning condition, and since all individuals spawn only once before dying, each has only one chance in its lifetime. When we realize this, it becomes apparent that between the years 1829 and 1921 many lampreys, even many hundreds or thousands, could enter Lake Erie without a pair succeeding in spawning and/or the ammocoetes developing properly. Likewise, many individuals normally might be present in so vast a body of water as Lake Erie before a commercial fisherman could succeed in capturing one. After a fisherman had taken the first specimen, however, it was only a few years before the lamprey began to rapidly increase in numbers; this was particularly true in Lake Huron and Michigan.

Recently there has accumulated considerable evidence that, after a long period of relative stagnation as regards an increase in numbers or extension in range, some species of animals enter a phase of drastic change which results in a rapid population increase and/or the colonization of new territory. During this « aggressive » period some physical or other barriers are overcome which apparently were insurmountable previously. Such « aggressive » periods and their results have involved the serin finch, *Serinus canaria serinus* LINNAEUS, and the mountain wagtail, *Motacilla cinera* TUNSTALL, and have been well documented. In its expansive phase during the past century and part of this one, the mountain wagtail descended from the mountains and hills of central Europe, first to colonize the great plains of Germany and Denmark, then to continue onward to mountainous Scandinavia where the population increase was exceedingly rapid (MAYR, 1942, 238-239). Could not the sea lamprey have had such an « aggressive » phase recently ?

## Ohio canals

The State of Ohio is situated in the midlands of the United States, Part of its northern border bisects Lake Erie, and the northern one-third of this state lies within the Lake Erie, and therefore the Great Lakes, drainage. The southern border of Ohio is the Ohio River, and the southern two-thirds of the state is drained by that river. The Ohio River is the largest of the tributaries entering the Mississippi River from the east. A low divide separates the Lake Erie and Ohio River basins, extending across the northern half of Ohio in a northeast-southwest direction.

Upon several occasions over a great period of time, the State of Ohio has been partly overrun by continental glaciers, which have glaciated all except the southeastern third. At various times during the past 8,000 to 11,000 years since the disappearance of the last glacier, the Lake Erie and Ohio River basins have been connected at times by large glacial outlets. These outlets presumably have permitted fishes, other aquatic animals, and possibly some species of aquatic plants, to invade the glaciated Great Lakes basin (GREENE, 1935, 12-18). Studies of fossil pollens from bogs indicate that 5 major climatic periods have occurred since the last glaciation, and that during several of these periods the climate was warmer than it has been during the present period (DEEVEY, 1949). Present evidence indicates that during one or more of these warm periods, several species of fishes having essentially a southern distribution, extended their ranges farther northward into the Great Lakes basin than they extend today; the freshwater drum (*Aplodinotus grunniens* RAFINESQUE), is an example (HUBBS, 1940, 293-297). As late as 100 years ago there existed at periodic intervals, natural water connections across some lower portions of the divide, making possible the passage of some aquatic species from a headwater tributary in one basin to a tributary in the other. I have gone into considerable detail relative to these former connections in order to prove that the establishment of the canals, by connecting the two basins, did not destroy a barrier of long standing between them as many believe.

The construction of the two north-south canals across Ohio began in 1825, and upon completion a few years later, these two narrow ribbons of water united the two basins and made a continuous habitat across the state for some species of aquatic animals and plants. One canal, the Ohio and Erie, traversed the state through its central and northeastern portions (TRAUTMAN, 1940, 32-34); the other, the Miami and Erie canal, crossed western Ohio. These large canals contained many low-type locks, were 26 feet across at the bottom and only

4 feet in depth. Simultaneously with the building of the canals, several large reservoirs were constructed also; their function was to supply water for the canals. The four largest of these reservoirs had a combined total of 32,000 acres. They flooded very fertile land containing much land and aquatic vegetation and a few glacial pothole lakes (TRAUTMAN, 1949, 14); the latter containing a static-water fauna and flora whose habitat requirements were similar to those of the newly constructed canals and reservoirs. Because of the high fertility of the soil and water, the static-water fauna rapidly invaded its greatly expanded habitat, and within a few years this animal and plant association had become firmly established throughout the canals and reservoirs, and many fish species of great value as food had become abundant. A commercial fishery became established, reaching its greatest productivity between the years of 1850 and 1890, when thousands of barrels of choice food fishes were taken with nets annually from each of the larger reservoirs (TRAUTMAN, 1957, 21-22). After 1890 an ever-increasing deterioration of habitat and decreasing fertility became manifest, and the canals were abandoned or drained except for isolated sections. However, the amount of fishing for sport increased. As a result of these factors commercial fishing became curtailed by 1900; eventually such fishing was eliminated entirely. Today the reservoirs are of considerable economic importance as sport fishing areas and for recreational purposes.

There has been a diversity of opinion among ichthyologists relative to the part the Ohio canals have played in introducing aquatic animals from one basin into the other. It has been the general opinion until recently that what invasion did occur, involved species of essentially southern distribution that moved northward from the Ohio River basin into the Great Lakes basin. This theory is in keeping with the rather prevalent concept that there has been an almost continuous northward movement whenever possible into the lake basin since the retreat of the glacier. Some ichthyologists have been so insistent in their belief in a northern invasion into the lake basin through the canals, that they have made statements upon what appears to be insufficient evidence, as did JORDAN (1882, 873) who without the existence of preserved specimens stated that the skipjack herring, *Pomolobus chrysochloris* RAFINESQUE, actually « escaped through the canals into Lake Erie ». GREENE (1935, 24) suggested that the paddlefish, *Polyodon spathula* (WALBAUM), an inhabitant of the large rivers, probably had used the canals to invade Lake Erie instead of having utilized the former, large glacial outlets. KIRTLAND (1850, 1-2) appears to have been the first to suggest that the gizzardshad, *Dorosoma cepedianum* (LESUEUR), found its way into Lake Erie through the canals; present evidence indicates that this species had abundant opportunity to invade the lake basin before the canals were built (TRAUTMAN, 1957, 182-184). Recently MILLER (1957, 107) wrote that it was plausible to assume that the gizzardshad invaded the Lake Erie basin before the advent of the canals. Those advocates of a northward invasion through the canals may not have considered sufficiently the facts that there was an almost continuous connection between the two basins prior to the completion of the canals, and that the large, glacial outlets may have been a more favourable means of entering the lake basin for such deep- and lotic- water species as the paddlefish and skipjack, than were the static-water canals with their many locks.

Recent evidence indicates that several fish species, confined largely to northern Ohio when the canals were built, took advantage of the continuous southward extension of their habitats in the canals to penetrate into southern Ohio, and in some instances, to colonize small areas adjacent to the canals (TRAUTMAN. 1957, maps 107, 127, 131, 139).

To summarize : Completion in 1829 of the Welland Canal, by connecting lakes Ontario and Erie, destroyed a long-time barrier to invasion of the upper Great Lakes by aquatic animals and possibly aquatic plants. Presumably the eel, alewife and sea lamprey utilized the canal to invade the upper Great Lakes. The parasitic lamprey caused an upheaval in the fish association of the upper lakes with catastrophic results to the commercial fisheries in some of the lakes. The construction of the Ohio canals and their reservoirs resulted in a great increase in the amount of habitat for some of the desired food fishes which in turn resulted in a great increase in fish production, producing a major commercial, and later a sport, fishery. Early ichthyologists reported the northern invasion of several fish species from the Ohio River basin into the Lake Erie basin; such an invasion is questioned because of insufficient evidence. The southward extension of habitat in the canals enabled those fish species, inhabiting primarily northern Ohio, to penetrate into southern Ohio and in some instances to colonize small adjacent areas.

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## Summary

After reviewing some literature relative to various diversions throughout the world, it became evident that such diversions had many problems in common, that due to the antiquity of many Old World diversions it was impossible to evaluate accurately what had occurred, especially in the distant past, that many statements were based upon inconclusive evidence; therefore, this paper is restricted to some recently constructed canals in eastern North America with which the author has had considerable experience.

Completion of the Welland Canal in 1829 destroyed a long-time barrier between Lake Ontario and the remaining Great Lakes, making possible the invasion of aquatic organisms into the upper lakes. Invasions of the American eel, *Anguilla rostrata* (LESUEUR), alewife, *Pomolobus pseudo-harengus* (WILSON) and sea lamprey, *Petromyson marinus* LINNAEUS are discussed. The lamprey invasion and its present catastrophic effects upon fish populations and commercial fisheries is described in detail.

The Ohio canals, twice crossing the State of Ohio and connecting the Ohio river and Great Lakes basins did not destroy a long-time barrier between the two basins, because since early post-glacial times many glacial outlets have existed through which aquatic organisms, especially fishes, could have passed from the Ohio River basin into the completely glaciated Great Lakes basin. Small connections between low divides 'were still in existance when the canals were built. Evidence indicates that no marked invasion from the Ohio River basin into the Great Lakes basin occurred, despite statements of the contrary made by early ichthyologists. The canals, and their large, supporting reservoirs, because of increase in amount of habitat, produced an abundance of food fishes, and resulted in an early commercial fishery. The canals, through extension of suitable habitats, enabled some fish species which were largely confined to northern Ohio, to penetrate the southern third of the state. Later the canals were largely abandoned and deterioration of habitats and other changing conditions eliminated commercial fishing in the reservoirs. Today these reservoirs are important sport fishing areas.

# THE DECLINE OF THE FISH-STOCKS IN THE NETHERLANDS' SECTIONS OF THE RIVERS RHINE AND MEUSE

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In past ages the Dutch sections of the rivers Rhine and Meuse must have teemed with fish, such as salmon, sea-trout, sturgeon, Allis-shad, Twaite-shad, houting and eel. Though exact statistical data are not available we can safely deduce from a variety of descriptions that these rivers formerly provided a very flourishing fishing industry, which played an important part in the economy of the entire area and added materially to the prosperity of the country.

In our time the situation is very different; several of the species mentioned have completely disappeared and most of the others are of rare occurrence only. This serious decline in the size of the fish stocks of these rivers reached a disastrous character in the first half of this century. It went hand in hand with a loss in natural character of the rivers, as a consequence of the various measures taken during the rapid industrialization of Western Europe. Continuous improvement of the navigability of the rivers became a necessity; measures were also taken to ensure a better control of water drainage. At a later phase, hydro-electric plants were constructed higher up in the rivers. Regulation of the river-beds and construction of weirs brought about a complete change in the character of the rivers. In the first half of this century more and more weirs appeared in the upper sections of the river Rhine and in most of its tributaries; in the river Meuse weirs have been constructed almost as far as its estuary. These weirs did not actually reduce the area for migrating fish, but made it in many cases completely impossible for them to reach their natural spawning grounds.

Water pollution, a result of industrialization, has also contributed to the decline of fish stocks. Several spawning grounds in the tributaries became so badly polluted that they could no longer serve as such. Local pollution in the river Rhine was so serious that sensitive species such as salmon could not survive in the affected area, so that the reaches upstream of the pollution became virtually inaccessible to them.

It is not surprising that all this has led to a disastrous depletion of fish stocks. To illustrate the difficulties nowadays encountered by migrating fish and the influence the works of man have had on their stocks, we shall discuss the fate of two species passing the Netherlands on their way to the spawning grounds, both of which are of importance to the fishing industry. We have chosen an anadromous fish, the salmon, and a catadromous species, the eel.

### Salmon

The severe depletion of salmon stocks is clearly demonstrated in Table I in which we have brought together data on the numbers of salmon landed at public fish auctions in the Netherlands. Although the: figures in this table — especially those of landings in the last few years — are also influenced by the gradual disappearance of the salmon fishery, which was no longer remunerative after the serious decline in the stock, we may safely conclude that the salmon stocks in the river Rhine have been practically eliminated over a period of time.

In our opinion, inaccessibility or complete destruction of the spawning grounds represent by far the most important cause for the decline. This conclusion is corroborated by the very clear evidence that catches of specimens of a given year-class have tended to fluctuate considerably more in the years after 1920 than in the period before. We can explain this tendency by the fact that fluctuations in the size of salmon stocks have become more and more dependent on success or failure in breeding in the very few remaining spawning grounds, whereas in former years failure in one spawning area might have been compensated by success elsewhere, thus stabilizing the total salmon population in the river Rhine. The noteworthy revival of the salmon fishery in the year 1949 (Table I), 4½ years after the war-time destruction of the weir near Kembs, which greatly facilitated the migration of the salmon to the upper reaches of the Rhine, corroborates our view.

It is clear that the steady decline in salmon stocks has had its effects on the salmon fishery. In the 1930's very little was left of the flourishing industry which once gave work to countless fishermen. The figures presented in Table II illustrate this decline very clearly. In our time the Dutch salmon fishery has completely died out.

This disastrous decline of salmon stocks and the salmon fishery is not in our opinion primarily due to water pollution. Pollution is much less severe in the Meuse than in the Rhine. That the salmon stocks in the river Meuse have disappeared should be ascribed to the construction of weirs. In the Dutch section of the Meuse the first weirs were constructed in about the year 1925. It is true that fish-passes were built in these weirs, but these were apparently so inefficient that the number of salmon reaching the spawning grounds was almost negligible and completely insufficient for the conservation of the salmon population. The adult salmon moreover appeared to stay so long downstream of the almost impassable weirs that the fishermen could catch a much higher percentage of them than when the river still flowed freely. Both factors in combination led to a rapid decline of the salmon stock in the river and consequently to the disappearance of the salmon fishery in relatively few years. Though no separate data for salmon landings from the river Meuse are available we can present some figures on the size of the salmon fishing industry in this river, which indicate the hopelessness of the present situation (Table III). A separate salmon fishery no longer exists in this river.

It may safely be assumed that the same fatal combination of factors will follow construction of weirs in many of the tributaries of the river Rhine and that the gradual destruction of the salmon population of the tributaries will ultimately lead to the virtually complete disappearance of the salmon in the river itself.

**Eel**

In contrast with the case of salmon, the spawning grounds of the eel have not been affected by the works of man. None the less, the area in which the eel can grow has been seriously reduced through the building of weirs which have rendered large reaches of the river-basin inaccessible to the elvers. In addition, water pollution has contributed materially to the difficulties the elvers encounter during the migration upstream. As a result of all this, the total eel population in the river Rhine and its tributaries is considerably smaller nowadays than formerly, which means that smaller numbers of silver eels migrate downstream than before the large-scale construction of weirs.

There is yet another factor which has had a harmful influence on the fishery : the regulation and deepening of the river-bed to favour navigation, so that it has become more and more difficult to find shallow fishing grounds suitable for the usual eel fishing gear. Moreover, the great increase of navigation on the Rhine has made it increasingly difficult to fish in the middle of the river, where large eel catches can be made at a time of increased run-off, when many silver eels migrate to sea.

It is therefore not surprising that the eel fishery on the Rhine has declined considerably in recent years. This is reflected in the number of eel nets in use. Unfortunately we do not possess separate statistical data on the eels landed from the river Rhine. About 10 years ago some 95 to 100 eel fisheries operated in this river, whereas only 26 were still in regular operation in 1957.

While the decline of eel stocks in the Rhine should be at least partly ascribed to increased water pollution, this cannot be the reason in the case of the river Meuse where the stocks have also fallen sharply. Considering the low degree of pollution in the Meuse we must ascribe the depletion here almost exclusively to the construction of weirs, which block practically the whole river-basin for the ascending elvers. That the eel has not, however, been completely exterminated here can be accounted for by the presence of ship-locks at the weirs and to the behaviour-pattern of the elvers, which induces them to seek their way upstream through these locks, sometimes with successful results. The decline in the eel fishery is nevertheless noticeable from the fact that some 68 eel fisheries operated in the river Meuse in the year 1917, whereas the number had fallen to 28 in 1936, and only 15 in 1951. The falling off in the rents paid for fishing-water presents a similar picture. In 1926 — when the Dutch section of the Meuse contained only two completed weirs — 10 licences for the commercial fishery amounted to fl. 1,215, the figure having dropped to fl. 590 in 1951 (which is even more significant if we take into account the devaluation of the guilder in that period).

In the case of the Meuse, which in contrast to the Rhine is heavily weired in the Dutch section, the question has arisen as to whether it would be desirable to improve the already available fish passes, which do not appear to work efficiently enough to prevent the decline of fish stocks.

Conversion of fish passes is certainly possible in the Meuse weirs, and since the water levels on either side of these shipping weirs never differ by more than 4 metres, the costs of conversion will be fairly low. After careful study of the behaviour of ascending elvers at the weirs, we have found that it was possible to adapt the passes to meet their needs. This has resulted in the passage of weirs by millions of elvers, and it justifies the hope that the eel stocks in the river Meuse can be saved.

The success of this measure led to the question whether steps could be taken to facilitate the passage of other fish species too. Based on the results of observation of the behaviour of the migrating

TABLE I.

**Number of salmon landed at public fish auctions.**

1885 ± 100.000.

| | | | | |
|---|---|---|---|---|
| 1895 : 59,938 | 1915 : 29,439 | 1935 : 2,300 | 1947 : 233 | 1955 : 17 |
| 1896 : 57,846 | 1916 : 24,101 | 1936 : 2,868 | 1948 : 347 | 1956 : 2 |
| 1897 : 52,304 | 1917 : 28,346 | 1937 : 2,311 | 1949 : 900 | 1957 : 2 |
| 1898 : 56,578 | 1918 : 21,032 | 1948 : 1,920 | 1950 : 327 | |
| 1899 : 33,782 | 1919 : 14,559 | 1939 : 2,016 | 1951 : 94 | |

TABLE II.

**The size of the salmon fishery in the Dutch Section of the River Rhine.**

| Year | Small salmon seines | | Driftnet fishery | |
|---|---|---|---|---|
| | Number of companies | Number of fishermen | Number of companies | Number of fishermen |
| 1914 | 13 | 146 | 60 | 120 |
| 1915 | 12 | 114 | 60 | 120 |
| 1916 | 7 | 69 | 25 | 50 |
| 1928 | 13 | 140 | 70 | 140 |
| 1929 | 14 | 158 | 15 | 30 |
| 1930 | 8 | 123 | 10 | 20 |
| 1934 | — | — | — | — |
| 1935 | — | — | — | — |
| 1936 | — | — | — | — |

fish, a system could be developed which would make it possible for them to pass the obstructions without difficulty. It is true that these passes would be more expensive than those destined for eels, but in all probability they would pay and would at any rate be considerably cheaper than the maintenance of stocks in the various sections of the river by means of hatchery-reared fish. This latter practice would moreover encounter serious difficulties at the time of large-scale floods when the weirs are opened.

TABLE III.

**The size of the salmon fishery in the Dutch Section of the River Meuse.**

| Year | Large salmon seines | | Small salmon seines | | Driftnet fishery | |
|---|---|---|---|---|---|---|
| | Number of Companies | Number of fishermen | Number of companies | Number of fishermen | Number of companies | Number of fishermen |
| 1914 | 11 | 519 | 10 | 164 | 218 | 436 |
| 1915 | 10 | 429 | 11 | 160 | 235 | 470 |
| 1916 | 9 | 429 | 12 | 183 | 213 | 426 |
| 1928 | 3 | ? | 11 | 190 | 91 | 182 |
| 1929 | 3 | ? | 8 | 142 | 101 | 202 |
| 1930 | 2 | 160 | 7 | 122 | 69 | 138 |
| 1934 | — | — | 6 | 104 | 49 | 98 |
| 1935 | — | — | 3 | 50 | 56 | 112 |
| 1936 | — | — | 8 | 142 | 45 | 90 |

The conversion of fish passes is primarily intended for the migration of the common lowland fish species, such as cyprinids, pike, perch and pikeperch. In the Netherlands these species are of considerable importance to sport fishermen — it should be taken into account that this country counts some 50 registered sport fishermen per 1,000 inhabitants.

When plans for improvement of the fish passes have been realized at every weir on the Meuse, and if the old spawning grounds upstream remain unimpaired, we may even be able to reckon on a comeback of some anadromous migratory species such as, for instance, the sea trout and perhaps even the salmon.

# INFLUENCE DES OUVRAGES HYDRAULIQUES ET DES POLLUTIONS INDUSTRIELLES SUR LA FAUNE FLUVIALE DE L'APENNIN, DES MARCHES ET DE L'OMBRIE

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### Données générales.

Les rivières des Marches et de l'Ombrie se prêtent particulièrement bien à être étudiées par l'hydrobiologiste qui veut se rendre compte exactement des effets produits par les ouvrages hydrauliques et par la pollution des eaux courantes.

Il s'agit, en effet, de cours d'eau pour la plupart facilement accessibles et dans lesquels on peut trouver presque tous les types de déversements industriels et de barrages hydrauliques.

En outre, les rivières des Marches présentent la caractéristique d'avoir des cours brefs et parallèles, ce qui permet de confronter les données recueillies dans chaque rivière.

Enfin, le réseau fluvial de l'Ombrie présente un cas extrême de changement hydraulique et d'altération chimique dans une rivière qui, si elle avait été respectée par l'homme, aurait pu constituer un modèle de formation fluviale à régime hydrique naturellement équilibré. Mais on arrive à cet extrême par une gamme riche de formations intermédiaires se trouvant soit dans les Marches soit en Ombrie et qui font l'objet de recherches effectuées par notre laboratoire. Mais nous essayerons ici de tracer un tableau assez significatif des attaques supportées par la faune des cours d'eau de l'Ombrie et des Marches en raison des conditions altérées du milieu qui sont jusqu'à présent sous notre contrôle direct.

Mais pour cela, il est nécessaire d'indiquer certaines données géographiques, climatiques et hydrographiques.

### Caractères hydrologiques des systèmes fluviaux de l'Ombrie et des Marches.

L'arc que le crinal des Apennins trace vers l'Est (donc vers la mer Adriatique), détermine des conditions hydrographiques qui nous permettent de distinguer le système fluvial des Marches de celui de l'Ombrie de la façon suivante :

| *Rivières des Marches.* | *Rivières de l'Ombrie.* |
|---|---|
| Se jettent directement dans la mer. | Confluent vers un collecteur central (Tibre). |
| Ont des cours parallèles entre eux orientés vers l'Est. | Ont des cours convergents qui se ramifient vers l'Ouest ou vers le Sud. |
| N'ont que de médiocres affluents. | Ont des affluents importants. |
| Ont des débits semblables. | Quelques-unes ont un débit beaucoup plus important (Tibre-Nera). |
| Ont un profil rapide avec un dénivellement entre la source et l'embouchure d'environ 800 m. La plaine est peu étendue, les vallées le sont davantage. | Ont un profil rapide avec un dénivellement entre la source et le confluent de 600 m. La plaine est plus étendue, mais la vallée l'est moins. |
| Se divisent en trois zones :<br>1" *Appenninica* : ou du cours supérieur;<br>2° *Preappenninica* : ou du cours moyen;<br>3° *Subappenninica* : ou du secteur terminal du cours. | Ces zones ne sont pas bien reconnaissables. |
| Le secteur terminal (c'est-à-dire la zone de l'embouchure) est sujet à un climat moyen de 5°-6° en janvier et 25°-26° en juillet. | Le secteur terminal correspondant (dans la plaine) est sujet à une température atmosphérique de 4° en janvier, tandis que les conditions thermiques moyennes au mois de juillet sont de 21°-24°. |
| La précipitation annuelle de pluie est de 1.200-800 mm dans le cours supérieur et inférieure à 800 mm dans la section terminale. | La chute annuelle de pluie est de 1.200-800 mm sur toute la longueur du cours sauf dans des zones limitées et séparées entre elles qui reçoivent moins de 800 mm. |

Les bois et les plantations d'oliviers prédominent en Ombrie où ils couvrent 20 à 30 % de la superficie tandis que dans les Marches ils n'en occupent que 5 à 10 %. Mais il se rétablit dans les Marches une certaine proportion entre les terrains boisés et les terrains cultivés dont le pourcentage est toutefois plus élevé.

Les caractères lithologiques et pédologiques sont sensiblement identiques dans les deux régions. En effet, le sol de l'Ombrie et des Marches est généralement calcaire dans les zones plus élevées et arénacé-argileux dans les zones plus basses. Ainsi les étendues perméables et imperméables sont assez symétriques et les deux systèmes fluviaux présentent une certaine ressemblance.

Les deux régions sont soumises à un climat subméditerranéen avec des précipitations particulièrement abondantes dans les périodes équinoxiales. Le résultat est que le régime fluvial des Marches et de la plupart des cours d'eau de l'Ombrie est à peu près le même, avec de forts étiages en été et deux crues : la plus grande au printemps, la plus petite en automne.

Bien différent est le cas de la rivière Nera (ainsi que de son affluent le Velino) qui se jette dans le Tibre. En montagne le cours de ces deux affluents est régularisé par des réserves d'eau emmagasinée dans le réseau hypogé de calcaire Karstique si bien que les deux crues de l'automne et du printemps sont accompagnées d'une « morbida » (c'est-à-dire niveau normal) d'hiver et unies entre elles par un écoulement régulier, l'été. Le cours inférieur du Tibre après les confluents permet de rattacher le régime hydrique de l'Ombrie méridionale au régime fluvial du type de l'Apennin central. Mais nous verrons comment l'œuvre de l'homme a apporté des modifications au complexe fluvio-lacustre dans cette zone.

### Les ouvrages hydrauliques et leurs répercussions sur la vie rhéophile.

Par expression générale de « ouvrages hydrauliques » on entend les bassins hydroélectriques, les petits lacs agricoles, les digues de barrage, les canalisations, les conduites forcées, les galeries, les prises d'eau, les modifications apportées aux lits et tout ce que l'homme construit le long des cours d'eau en changeant leur cours originaire.

La situation hydraulique des régions que nous avons étudiée ici se caractérise par le manque d'eau, la perméabilité des lits et le faible débit de la plupart des rivières pour lesquelles même une installation peu importante est susceptible de faire sentir ses effets sur le courant de l'eau.

A l'exception de la rivière Nera, on peut dire en général que les bassins hydroélectriques prévalent dans les Marches et les petits lacs agricoles en Ombrie.

Quels sont donc les effets de ces ouvrages hydrauliques sur la vie dans la rivière ? Il est tout d'abord nécessaire d'indiquer les traits physionomiques fondamentaux de l'hydrobiologie régionale.

Les eaux claires, rapides et fraîches des cours d'eau de montagne sont principalement alimentées par des sources et coulent sur des fonds rocheux ou pierreux presque entièrement recouverts de houppes de mousse. Elles sont souvent surchargées d'oxygène (110-170 %), douées d'une bonne réserve alcaline, assez dures (25-35 degrés français).

C'est la région de la truite (*Salmo forio* et ssp. similaires) où la faunule du fond, abondante et variée, est surtout constituée par des sangsues de source (*Herpobdella*), hydracnides, gammarides et par une troupe de larves et nymphes d'insectes parmi lesquelles se distinguent les éphéméroptères (*Baetis*), les plécoptères (*Perla*), les trichoptères (*Rhyacophila*) et les diptères orthocladines (*Rheothanitarsus*); ces eaux conservent ainsi une population rhéophile, très spécialisée et extrêmement sensible à chaque altération de l'eau qu'elle soit de nature hydraulique ou d'ordre chimique.

Au fur et à mesure que la rivière descend vers la vallée, le lit s'élargit, les pierres rapetissent et se mêlent aux cailloux en se revêtant de conferves et de spyrogyres. Les eaux deviennent moins claires et plus hautes. Le taux d oxygène reste élevé; la dureté peut augmenter, mais la température de l'eau oscille entre des limites très étendues. Ce sont les eaux à barbeau (*Barbus plebeius*). La biocénose devient pius monotone, les plécoptères disparaissent ou diminuent, les éphéméroptères (*Ecdyonurus, Caenis*) et les trichoptères (*Hydropsyche, Hydroptilidae)* changent les diptères chironomides restent toujours nombreux mais sont accompagnés par les mélusines (*Simulium*), les mollusques sont rares. C'est une population moins exigeante, capable de supporter les eaux moins pures et plus troubles, les fonds plus variables et les changements hydrauliques plus fréquents.

Enfin, près de l'estuaire, les eaux deviennent troubles et paresseuses, le lit devient large et caillouteux, puis sablonneux et enfin limoneux. Les changements de température et du taux d'oxygène sont très grands, la réserve alcaline et la dureté changent sensiblement avec les crues et l'étiage. C'est la zone habitée par le chevaine (*Squalius cephalus*), par le gardon commun (*Leuciscus rutilus*) et par le rotengle (*Scardinius erythrophtalmus*). Les vers tubificides (*Tubifex*), les crustacés isopodes (*Asellus*), les diptères chironomides à larves rouges (*Chironomus* gr. *thummi*), les éphéméroptères cloéonides (*Cloeon*) et les trichoptères polycentropides (*Polycentropus*) sont caractéristiques de cette zone.

Toutes formes euribiontiques, très résistantes, peu sensibles aux déviations hydrauliques et capables de supporter les pollutions chimiques et des baisses considérables du taux d'oxygène.

Il nous est maintenant possible de faire un bilan concis des effets des ouvrages hydrauliques sur cette biocénose fluviale.

1° Plus les barrages sont rares, plus l'homogénéité de la composition de la faune réophile d'une rivière se conserve longtemps. Les barrages causent une fragmentation de la vie torrenticole et la disparition imprévue et définitive des limites qui, autrement, auraient progressivement diminué en nombre de la montagne à la vallée.

2° Si le barrage est total ou capable de transformer un secteur du lit en une nappe d'eau calme et profonde, les animaux rhéophiles disparaissent de l'endroit occupé par le lac et sont contraints à se réfugier dans le secteur qui se trouve en amont du bassin en colonisant aussi la partie initiale où les eaux s'écoulent encore sur le fond. L'étendue de cette biozonule est en fonction des variations de niveau au cours de l'année et elle est d'autant plus large que la pente du fonds est faible.

Le pourcentage de réduction des représentants réophiles est plus élevé dans les bassins à barrage total qui peut même provoquer leur disparition complète; si par contre le barrage est partiel ou assez bref et épisodique, les communautés lotiques émigrent provisoirement.

3° La réduction de la faunule des eaux courantes dans les rivières barrées par les bassins a été bien étudiée avec la méthode des pierres artificielles échelonnées le long du lit et dans ses différentes sections.

Avec ce procédé la diminution de la biocénose rhéophile causée par un barrage est caractérisée par : les vers anellides (*Herpobdella octoculata*), les acariens d'eau (*Hydrochnellae*), les crustacés amphipodes (*Echinogammarus pungens*), les stades aquatiques de certains insectes comme les plécoptères (*Perla)*, les éphéméroptères (*Ecdyonutus*), les trichoptères (*Rhyacophila vulgaris*) et les diptères (*Melusina*). Et par antithèse, le passage du milieu lotique à celui lentique du lac artificiel par la présence de vers anellides oligochètes (*Tubifex*), de crustacés isopodes (*Asellus aiquaticus*) et par des stades aquatiques des insectes diptères (*Chironomus*).

4° La disparition de la faunule rhéophile varie selon la cote altimétrique où le lit de la rivière est barré. Dans les bassins des hautes vallées des Apennins, la suspension de la vie torrenticole est toujours nette et catégorique; là où le lac commence, la faunule fluviale disparaît et là où se trouve la rivière, il n'y a aucun élément lentique. Ainsi le bassin hydroélectrique profond et articulé du Fiastrone (86 m de profondeur), situé dans le cours supérieur de la rivière Chienti (Marches), provoque une nette suspension du milieu lotique alticole qui ne se retrouve plus en aval. Au contraire, la nappe d'eau de Caccamo sensiblement moins profonde et tortueuse (20 m de profondeur), formée par la rivière Chienti barrée à une cote plus basse dans sa vallée principale ouverte et peu inclinée, est peuplée de nombreuses larves rhéophiles que l'on retrouve en aval de la digue, là où la rivière se reforme, ainsi que presque sur tout son parcours vers la mer.

5° Les bassins artificiels échelonnés le long de la rivière Chienti et du haut Tibre forment une production de phyto- et zooplancton qui va augmenter la faunule rhéophile qui vit en aval du barrage.

Cette euthrophisation est généralement accompagnée d'une population vigoureuse de larves d'insectes pêcheuses (*Polycentropus, Melusina,* Chironomides, *Ephemera*). Ainsi on retrouve, en petit, cette production du « caribo biologico » qui était déjà connu dans les affluents des grands lacs insubriques.

6° Un des phénomènes les plus intéressants pour les conditions de la vie dans un bassin artificiel est celui du dépôt de détritus transportés par la rivière. Il arrive que, lorsque le lit de la rivière s'enrichit, en aval du barrage, d'eaux courantes provenant de ce barrage ou de sources, ces eaux ne sont plus troubles et peuvent accueillir des animaux qui préfèrent la profondeur claire et les eaux limpides, comme *Rhyacophila, Melusina* et *Helmis.*

On constate fréquemment ces phénomènes dans les lacs du système hydrique des Marches. L'Ombrie, par contre, ne présente pas d'exemples dignes de remarque.

7° Pour les mêmes motifs que ceux indiqués ci-dessus, chaque barrage est la cause d'une parenthèse thermique plus ou moins tranchée le long du parcours d'une rivière. Les eaux superflues qui se déversent de la partie supérieure de la digue dans le lit inférieur n'ont pas toujours la même température que les eaux de la rivière. Souvent elles sont plus ou moins chaudes ou plus froides selon la saison et l'altitude. La faunule aquatique qui s'établit en aval des barrages se ressent de la différence thermique et accomplit le cycle biologique avec avance ou retard par rapport à la faunule située en amont.

8° Le phénomène devient très évident quand il s'agit de déversements d'eau qui proviennent des galeries creusées dans la montagne. Dans le lit de la rivière se déversent alors des quantités d'eau assez importantes qui, venant d'altitudes plus grandes et après avoir pris la température souterraine, causent, pendant l'été, un brutal refroidissement et, pendant l'hiver, un bienfaisant réchauffement du courant d'eau épigé, souvent transformé en simple ruisseau ou en mares isolées. On assiste dans ce cas à d'étranges et inattendues extinctions des faunules polysaprobes et, inversement, à des réapparitions singulières de faunules frigidicoles lesquelles, à la fin, doivent s'habituer à la saturation incomplète d'oxygène et à l'absence presque absolue de charges biologiques qui caractérisent les eaux qui ne sont pas tout à fait des eaux de montagne. Un exemple de ce genre nous est fourni par la rivière Nera qui traverse le centre même de Terni.

9° Mais le domaine des eaux courantes n'est pas toujours détruit ni effacé par la prédominance des eaux lacustres. En Ombrie même on peut citer le cas du déversement des eaux de la rivière Nera dans le lac de Piediluco à travers un canal souterrain de près de 40 km : ce déversement impose un changement profond de température, de la composition chimique et de la productivité biologique du secteur septentrional du petit lac se trouvant à l'ouverture. Le lac se refroidit fortement en été et se réchauffe en hiver; il se surcharge de sels minéraux et de détritus; il produit un riche benthos rhéophile et un peu de plancton. Il change donc sa physionomie et se transforme en une rivière profonde.

10° Les prises d'eaux canalisées, les écluses et les déviations modifient la faunule couranticole proportionnellement à la diminution de la vitesse d'écoulement. Dans les canaux découverts une population très homogène, formée de peu d'éléments spécialisés qui peuvent prendre grande vigueur et dominer tous les autres, cherche à s'installer.

Nous prenons pour exemple certains canaux de dérivation des rivières des Marches qui sont caractérisées par la *Lasiocephales basalis*. Ce type de modification peut être considéré comme le remaniement le plus circonscrit et le plus simple des lits fluviaux.

11° En Ombrie, au cours des dernières années, ont été créés les « lacs de colline » ou lacs agricoles. Il s'agit de petites nappes d'eau en surface, la plupart inférieure à un hectare, placées en terrains de colline argileux. Le résultat est toujours le même, qu'ils soient alimentés ou par les eaux pluviales seulement ou par des sources et de petits torrents : les petits lacs deviennent des sièges eutrophes de vie planctonique qui, en se déversant en aval en même temps que le trop-plein dans les périodes de forte pluviosité, alimente une riche, mais souvent occasionnelle, biocénose rhéophile.

L'augmentation numérique progressive de ces bassins qui se trouvent aussi dans les Marches, va changer le réseau capillaire du système d'irrigation des terrains cultivés et, en conséquence, la faunule rivicole qui se rapporte à ce réseau.

12° Tout ce que nous avons dit jusqu'ici à propos des effets produits par les travaux hydrauliques sur la faune des cours d'eau de l'Ombrie et des Marches, doit être considéré en fonction du régime hydrique des cours d'eau intéressés. En effet, ces conséquences sont d'autant plus évidentes que l'afflux des eaux dans l'impluvium est plus irrégulier.

Comme on a pu le voir, tous les cours d'eau des Marches ont des crues débordantes au printemps (mois de mars), des étiages extrêmes en été (mois d'août) suivis par d'autres crues en automne qui se prolongent pendant l'hiver.

Il s'ensuit que, de novembre à mars, en raison de 1 extension du phénomène sur toute la longueur du lit fluvial, le réseau hydrique des Marches tend à empêcher la fragmentation des faunes rhéophiles qui sont portées à se réunir.

Au contraire, à partir de juin jusqu'en septembre la fragmentation des côtes lotiques devient plus évidente dans les lits barrés par les bassins (Cesano, Esino, Potenza). La même remarque vaut pour les cours d'eau de l'Ombrie qui participent à un régime hydrique du type « Tosco-Marchigiano ». Nous pouvons mentionner par exemple l'étendue centrale du Tibre dont les modestes barrages à l'intérieur du lit fluvial exercent la fonction de producteurs de vie lentique en été et de vie lotique pendant les autres saisons.

Dans les cours d'eau de l'Ombrie méridionale, caractérisée au contraire par un régime du type « appenninico centrale » (la Nera et le Tibre après leur confluent) avec de modestes étiages estivaux et des crues modérées en automne et au printemps, on n'assiste pas — sauf quelques rares exceptions (Terni, Nera Papigno) — à d'évidents phénomènes de fragmentation du monde lotique, parce qu'il y a presque toujours dans le lit une masse d'eau courante capable de maintenir en vie les communautés torrenticoles.

13° Ce sont les poissons qui, notoirement, ressentent davantage les conséquences des ouvrages hydrauliques, soit à cause de l'action directe résultant des conditions modifiées de leur milieu, soit à cause de l'effet indirect résultant de la disparition et de la transformation de la faune alimentaire.

On peut dire que la situation ichtyque provoquée par les ouvrages hydrauliques n'est pas encore désespérée dans les Marches où les cours d'eau, dont la physionomie naturelle a peu changé, hébergent les espèces les plus connues et les plus répandues dans les eaux courantes. Même dans les cours d'eau peu modifiés de l'Ombrie (Haut-Tibre, Chiascio) le pêcheur peut encore obtenir des résultats assez satisfaisants.

Cependant, c'est précisément le secteur de l'Ombrie qui révèle les conditions les plus décourageantes pour la pêche alors que, vu son régime hydrique et l'abondance de ses eaux, il devrait fournir les majeures garanties de productivité en poisson.

Les nombreuses prises d'eau, les barrages, les bassins à niveau variable et surtout les pollutions industrielles dont on va dire quelques mots au cours de cette relation, ont transformé le cours supérieur de la Nera en un cours d'eau lamentablement dépeuplé.

Les bassins artificiels des Marches et les petits lacs des collines de l'Ombrie se trouvent à présent dans un état assez avancé d'exploitation piscicole, de sorte que l'on peut compter sur une production non négligeable de truites arc-en-ciel (*Salmo irideus*), de perches (*Perca fluviatilis*), de brochets (*Esox lucius*), de carpes (*Cyprinus carpio;* var. à miroirs et reines), de tanches (*Tinca tinca*) et d'anguilles (*Anguilla anguilla*). Cette faune remplace quelquefois avantageusement la population naturelle de truites de rivières (*Salmo fario*), de gardons, de chevaines, de rotengles, de barbeaux et de vairons que les barrages hydrauliques ont détruite dans l'étendue correspondante de rivière ou bien ont fragmentée en populations moins nombreuses et isolées.

Cependant les lacs naturels régularisés et les bassins artificiels du système de la Nera n'ont certainement pas favorisé la reconstitution — bien que limitée à la population lacustre — du patrimoine ichtyque qui a été détruit par les importantes altérations que l'industrie a apportées au lit de la rivière Nera. D'une part les ouvrages hydrauliques, nuisibles aux migrations et à la déposition des œufs à cause de leur mécanisme fonctionnel, et d autre part les pollutions chimiques ont déterminé le déclin piscicole de la rivière de l'Ombrie la plus importante et jadis la plus riche en poissons.

**Influence de la pollution industrielle sur la faune fluviale.**

Le développement donné à l'étude des effets des ouvrages hydrauliques sur la faune fluviale de l'Ombrie et des Marches, nous contraint à envisager ici seulement les conséquences de la pollution des eaux par les industries sur la faune.

Comme dans ce cas-ci la loi des dilutions intervient directement, il est clair que les rivières de moindre débit caractérisées par des étiages très considérables et qui ont des qualités et quantités égales de décharge industrielle, sont sujettes à une pollution plus grave.

Il est donc facile de prévoir que les cours d'eau des Marches et de l'Ombrie qui font partie d'un régime hydrique du type « Tosco-Marchigiano » seraient gravement menacés par l'industrie si celle-ci présentait un développement de quelque importance. Et il faut justement remarquer que, sauf queques exceptions (F. Esino à Iesi, F. Tronto à Ascoli), l'économie de l'Ombrie et des Marches dans les secteurs septentrional et central est bien plus de type agricole qu'industriel : aussi la destruction de la faune aquatique naturelle et des poissons est-elle le plus souvent restreinte à des secteurs limités du cours du fleuve. Puis, la nature calcaire des roches et donc les réserves alcalines des eaux tendent à neutraliser assez rapidement les effets destructeurs des pollutions.

Cela ne doit pas pourtant induire à un optimisme excessif car, en s'appuyant sur ce qu'on a dit plus haut, il est évident que des déversements même faibles suffiront à causer des dommages irréparables à la faune alimentaire des fleuves de mineur débit de l'Ombrie et des Marches et, en conséquence, au poisson.

C'est un fait curieux que le degré de pollution le plus élevé s'enregistre justement dans le système hydrique de plus grand et régulier débit, c'est-à-dire dans la rivière Nera.

Mais le phénomène trouve une explication immédiate dans l'intense développement industriel pris par la ville de Terni qui constitue aujourd'hui, le long de la rivière Nera, un des centres les plus remarquables qui comprennent plusieurs types d'industries.

Si la crise de la pollution des fleuves des Marches et de la plupart de ceux de l'Ombrie n'est pas encore ouverte parce que jusqu'à présent cette pollution est fragmentaire et compensée par une remarquable autodépuration, celle de la Nera par contre est ouverte et en plein développement parce que la rivière ne peut assurer sa propre défense en raison de la longueur du parcours pollué.

Entre tous les cours d'eau de la péninsule c'est certainement la Nera qui pose un des problèmes les plus graves et nous l'avons justement analysé en évaluant les altérations produites par les déversements sur la faune qui vit dans le fond de la rivière.

Une revue complète des ouvrages hydrauliques n'étant pas réalisable, il est pratiquement impossible de rédiger et tenir à jour une liste de tous les déversements industriels et des pollutions causées par les agglomérations qui se trouvent le long des fleuves de l'Ombrie et des Marches.

Nous nous bornerons donc à énoncer des jugements généraux sur les effets produits par les principaux types de déversements sur la vie aquatique macroscopique.

### 1. **Pollution causée par les agglomérations humaines.**

Compte tenu du débit du fleuve, la pollution est directement proportionnelle à l'importance de l'agglomération et inversement proportionnelle à la distance qui sépare l'agglomération du fleuve.

Les agglomérations tendent à eutrophiser les eaux, mais la biocénose fluviale change d'aspect et cède le pas aux représentants des eaux polluées et putrides, doués de faibles exigences respiratoires, d'une tolérance particulière à l'égard des gaz de la décomposition (*Tubifex, Chironomus plumosus*) et d'une facilité d'utilisation de l'acide sulfhydrique (*Leptomitus, Sphaerotilus*).

De semblables associations sont évidentes partout, mais celles du F. Tronto (Ascoli), du F. Nera (Terni) et du F. Esino (Iesi) sont particulièrement importantes.

2. **Décharges des usines à gaz.**

Elles sont toujours nuisibles à cause de la grande toxicité et de la permanence des déchets (résidus toxiques, hydrocarbures, produits ammoniacaux).

Elles causent une destruction considérable de la faune fluviale, destruction qui peut conduire à une complète abioticité du fond. Le recouvrement et l'autopurification du fleuve sont lents parce que la pollution progressive produit des phénomènes d'accumulation. Les larves des éphéméroptères et des trichoptères sont des tests très sensibles.

3. **Eaux de decharge des industries chimiques contenant du chlore, de l'ammoniaque, des anhydrides, des sulfates, des sulfures, des sulfucyanures, des phosphores, des chlorures, de la soude, des hypochlorites, de l'alcool methylique, des acides: sulfurique, nitrique, chlorhydrique, etc.**

Quand ces deversements sont abondants. ils sont capables de steriliser la vie des fleuves si l'on n'a pas recours a des bassins de decantation, filtration et neutralisation.

Quand les eaux du fleuve sont abondantes et bien mineralisees, on assiste a une auto-epuration par la formation de sels neutres inertes ou bien faiblement toxiques.

Si le courant est tres rapide et oblique par rapport aux rives, l'effet toxique peut se limiter a la couverture biologique d'un seul trait de lit, comme c'est le cas pour la Nera.

Tous les organismes aquatiques, exception faite des polysaprobes, sont extremement sensibles a ces pollutions.

4. **Decharges des industries metallurgiques.**

Elles contiennent une serie complexe de sels metalliques, acides libres et bases.

Particulierement toxiques, les acides libres (chlorhydrique, nitrique et sulfurique) et les bases (ammoniaque) produisent aussi des variations sensibles du pH en provoquant des destructions rapides et etendues dans la faune bentonique rheophile.

Sur de longs parcours, les cours d'eau qui, generalement, assument alors une coloration caracteristique, sont depeuplees a cause de ces deversements. On constate ce type de pollution le long de la Nera.

5. **Exploitation de mines et de carrières.**

Si le minéral est un métal pesant, la toxicité des débris se manifeste avec une lenteur plus marquée et dans certaines limites. S'il s'agit de carrières de pierre et de gravier, la pollution est de type principalement physique à cause des matières qui, en restant en suspension dans l'eau, la troublent et la minéralisent excessivement (Nera et Potenza).

Les larves des éphéméroptères et des plécoptères supportent des charges très fortes de débris minéraux et des duretés très élevées.

6. **Papeteries et industries du bois et de la cellulose.**

Les acides — principalement nitrique et sulfurique — les sels (chlorures de calcium) et les anhydrides (acide sulfurique) sont nuisibles à la population torrenticole, tandis que les résidus de paille, chiffons et cellulose eutrophisent le milieu et rendent plus épaisses les biocénoses du fond par l'apport d'éléments mésosaprobes.

Les résines, les pentosanes et les substances collantes forment des composés écumogènes à longue persistance si bien que l'écume et la couleur données aux eaux persistent sur plusieurs kilomètres.

C'est surtout la transparence insuffisante de l'eau qui est nuisible à la vie du fond, à cause du colmatage des branchies et des stigmates. Les poissons qui parviennent à survivre prennent une saveur tout à fait désagréable : c'est ce que l'on peut constater, par exemple, dans la Potenza (Castel Raimondo) et le Giano (Fabriano).

7. **Industries textiles et des fibres synthétiques. Linoléum. Blanchisseries. Teintureries.**

Les alcools, les anhydrides, les acides et les hydrates qui se trouvent dans ces déversements sont évidemment hostiles au développement de la faune potamique.

Les fibres naturelles jetées dans le cours d'eau sont charriées sur une longue traite et, s'engageant parmi les cailloux du fond, causent des fermentations en même temps qu'un développement de la faune saprobique et entraînent des inconvénients mécaniques et chimiques gênant la respiration en raison de la réduction du taux d'oxygène (Nera, Esino).

Les colorants peuvent être tolérés temporairement par la faune du fond à condition qu'ils soient de faible concentration (Nera, Potenza).

8. **Tanneries.**

Les acides organiques (A. tannique), les aluns, les hydrates et les chlorures que ces usines déversent dans les cours d'eau ne sont pas excessivement nocifs pour la vie du fond. Cela dépend de la quantité.

Souvent ils imprègnent les lamelles trachéo-bronchiales des larves des éphéméroptères (Potenza, Esino, Metauro, Foglia, Tronto).

9. **Sucreries.**

Les déversements appauvrissent les eaux en oxygène à cause des fermentations et provoquent de grandes mortalités. Mais souvent des résidus végétaux (betteraves) eutrophisent le milieu. Cette sorte de polution est manifeste dans les eaux de l'Esino et du Topino et entraîne une réduction numérique des espèces oligosaprobique et rivicole.

10. **Pressoirs et huileries. Industries des conserves alimentaires.**

Les charges des dissolvants (sulfure de carbone, alcools) détruisent la vie dans certains secteurs du cours d'eau. Les émulsionnants causent peu de dommage aux eaux dures. Les déchets organiques offrent un riche *pabulum* aux potamobiontes.

Enfin, si les eaux sont rapides, riches et bien oxygénées et si le fond de pierres est recouvert de végétation, nous pouvons assister à une augmentation de la densité de population, même si nous ne vérifions pas un virage du cénobe vers un type saprobique (Nera et Esino).

## CONCLUSION

Cette relation n'est que la première esquisse des conditions hydrauliques et de la pollution des cours d'eau de l'Ombrie et des Marches que nous avons pu examiner jusqu'ici. Elle nous permet toutefois de constater certains faits que l'on doit souligner à leur juste valeur.

Contrairement à ce que l'on pourrait s'attendre, les phénomènes les plus graves se vérifient dans la rivière qui a le plus fort débit et le régime hydrique le plus régulier : à savoir la Nera, le principal affluent du Tibre.

Ceci prouve que l'homme a modifié radicalement la portée et l'écoulement du cours d'eau en le transformant, au point de vue hydraulique, en un compromis fluvio-lacustre canalisé qui n'a plus rien de commun avec le cours naturel, et, au point de vue des déversements industriels, en un collecteur souillé par des résidus de toutes sortes. Ces deux aspects du problème sont évidemment interdépendants.

La crise hydraulique et chimique de la Nera est donc ouverte, tandis que tous les autres cours d'eau des Marches et de l'Ombrie (y compris le Tibre) examinés jusqu'ici peuvent encore être sauvés, étant donné le développement modéré de l'industrie dans ces deux régions contiguës du centre de l'Italie, mais ils restent exposés à des pollutions faciles et graves à cause de leur régime torrentiel.

Il faudra donc veiller attentivement à ce que la modeste borne de tolérance estivale des cours d'eau à régime hydrique du type « Tosco-Marchigiano » ne soit pas franchie par l'inévitable développement des usines et des établissements le long des cours d'eau. Ce contrôle pourra être réalisé au moyen d'une rigoureuse application des lois et des décrets qui protègent l'agriculture, la pisciculture et la santé. Il faudra pourtant ajouter à cette activité un rigoureux respect de la vie aquatique qui, tout en constituant une sûre ressource alimentaire pour la faune ichtyque, garantit sa fonction d'infaillible « test » diagnostique de la santé de tout cours d'eau.

**Résumé**

Les perspectives de modifications hydrauliques étendues et la menace d'une pollution industrielle des cours d'eau des Marches et de l'Ombrie (Italie) ont conduit l'Institut d'Hydrobiologie de l'Université de Pérouse à entreprendre une enquête sur l'état sanitaire actuel de ces cours d'eau.

La plus grande partie des rivières de l'Ombrie et des Marches ayant un régime torrentiel avec de longs étiages estivaux et des crues de printemps et d'automne, les effets de l'intervention de l'homme ne tarderaient pas à se manifester avec gravité pendant la saison chaude. La rivière Nera se trouve à présent très sérieusement altérée par suite du grand nombre de déversements industriels et de barrages hydrauliques bien qu'elle ait un débit plus important et que son régime soit plus régulier et mieux équilibré.

Enfin nous avons évalué les conditions sanitaires des cours d'eau de l'Ombrie et des Marches non seulement du point de vue de l'examen chimique mais aussi du point de vue de la résistance des représentants les plus significatifs de la faune fluviale et de la transformation des populations aquatiques dans les diverses zones de ces cours d'eau.

# DIE HYDROBIOLOGISCHEN AUSWIRKUNGEN DER GEWÄSSERVERBAUUNG

VON

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Die mit der Zunahme der Zivilisation sich ständig steigernde Inanspruchnahme der Gewässer für verschiedenste Zwecke führt zwangsweise dazu, der Wasserbeschaffenheit eine immer grösser werdende Bedeutung beizumessen. Die physikalischen, chemischen und biologischen Eigenschaften eines Wassers können aber vor allem durch die Gewässerverbauung entscheidend beeinflusst werden. Nachteilige Veränderungen der Gewässergüte im Hinblick auf die verschiedensten Wassernutzungen haben erkennen lassen, dass sie vielfach auf Fehlkonstruktionen des Wasserbauers zurückzuführen sind. Man wollte bei solchen Anlagen offensichtlich nur e i n e n bestimmten Zweck erreichen, ohne zu bedenken, welche Folgen diese oft schweren Eingriffe am Wasserkörper auf seine gütemässige Beschaffenheit nach sich ziehen können und welche mitunter grossen Beeinträchtigungen der Inanspruchnahme des Wassers daraus resultieren. Man hat zumeist nicht beachtet, dass das Gewässer als ein lebendiger Organismus angesehen werden muss, an dem « orthopädische » Eingriffe nur mit grosster Vorsicht vorgenommen werden dürfen, ansonsten sie zu kunktionellen Störungen durch biologische Schädigungen führen. Das Gewässer « erkrankt ». Aber nur ein gesunder wasserorganismus kann die ihm von der Natur bestimmte Aufgabe und die ihm vom Menschen zugemutete Leistung in optimaler Weise vollbringen. Es gibt kaum eine Sparte der Gewässernutzung, die nicht an der Beschaffenheit des wassers in irgend einer Form interessiert wäre, sei es die Gewinnung von Trinkund Brauchwasser, der Gemeingebrauch, die Fischerei, die Wasserkraftnutzung, die Schiffahrt oder die Abwasserbeseitigung. Der Wasserbau darf diesen Interessen nicht einseitig Rechnung tragen. Er muss trachten, möglichst für alle derzeitigen und künftig zu erwartenden Nutzungen am Gewässer, die sich am besten eignende biologische Basis zu finden und darauf seine Pläne aufzubauen. Das setzt aber hydrobiologische kenntnisse voraus, ohne diese die erforderlichen Wasserbaulichen Eingriffe zu Fehlschlägen führen müssen. Daher ist die Zusammenarbeit des Hydrotechnikers mit dem Hydrobiologen unbedingte Voraussetzung, die gewährleistet, dass optimale Umweltbedingungen und biologische Gesetze bei der technischen Ausführung gewahrt bleiben.

Grundsätzlich muss bei allen Wasserbauten getrachtet werden, die natürlichen Lebensbezirke in ihrer Vielseitigkeit möglichst zu erhalten. Jede Schmälerung führt zur unerwünschten Einseitigkeit und Verödung des Biotops. Die Wasserorganismen und ihre Lebensgemeinschaften (Biozoenosen) verlangen ganz bestimmte physikalische und chemische Verhältnisse, die, je nach Art, sehr verschieden sein können. Diese Ansprüche muss man kennen, wenn man eine bestimmte Besiedlung fördern will. Nicht jede Biozoenose ist aber erwünscht, sondern nur jene, die für die Art der gewünschten Gewässerbenutzung als optimal bezeichnet werden kann. In der Regel sind es jene Organismen, die an den Reinheitsgrad des Wassers höhere Anforderungen stellen und bei Gegenwart von Sauerstoff eine sehr arten- und mengenreiche Entwicklung zeigen. Je stärker diese ist, desto mehr und schneller können die Lebewesen ihre Funktion im Gewässer erfüllen. Sie besteht in erster Linie im Abbau organischer Reste menschlicher, tierischer und pflanzlicher Herkunft, den man als « biologische Selbstreinigung » bezeichnet. Dieser Vorgang ist, wie wohl verständlich, von allergrösster Bedeutung für die Gesunderhaltung der Menschen. Dennoch wurde und wird heute noch diese lebenswichtige Funktion der Wasserorganismen nicht oder zu wenig von den Wasserbauern beachtet. Eher erklärt man sich, dass den Kleinlebewesen die Aufgabe zufällt, als Nahrung für Fische zu dienen. Da jedoch unter den Organismen des Wassers den Fischen aus wirtschaftlichen und sportlichen Gründen, sowie als Leitformen bestimmter Gewässergütegrade eine bedeutende Rolle zukommt, so hat die Berücksichtigung auch dieses Umstandes grosse Berechtigung.

Im Folgenden sollen nunmehr kurz die einzelnen physikalischen, chemischen und biologischen Milieufaktoren einer Diskussion unterzogen werden, inwieweit sie allgemein für die Entwicklung der Wasserorganismen von Bedeutung sind.

Wichtig ist vor allem das Substrat, auf dem die Pflanzen und Tiere siedeln können. Ist dieses zu glatt, hat es keine Fugen und Hohlräume, so ist es praktisch unbelebt. Je grösser und rauher die Oberfläche, desto mehr Haft- und Wohnmöglichkeiten sind vorhanden. Betonflächen und glatt geschliffenes Geröll oder Sand sind daher sehr arm an Lebewesen, ebenso fugenloses Mauerwerk, reich hingegen gröberes, rauhes Gestein oder mit organischen Stoffen angereichertes Sediment.

Geschiebe- und mineralische Schwebstoffführung wirken sich auf die Besiedlung ungünstig aus. Eine gewachsene, von Schlamm, Sand und Geröll fast reine Sohle wird von den Organismen bevorzugt (Quellbäche). Sie ist reich an Pflanzengesellschaften und tierischer Besiedlung und soll daher durch Massnahmen des Gewässerbauers unbedingt angestrebt werden. Vor allem sind die Strömungen so einzurichten, dass das Wasser die Sohle nicht erodiert.

Da Trübungen durch Schwebstoffe zur Verminderung des Lichteinfalles führen, wirken sie auf Wasserpflanzen assimilationshemmend. Dies hat eine Verminderung der Urproduktion (Primärproduktion) zur Folge. Sperren wirken daher in diesem Sinne günstig, weil sie zur Absetzung der Schwebstoffe führen.

Gleichmässige Durchlichtung des Wassers ist aber biologisch ungünstig. Gewisse tierische Organismen (Plankton, Fische) bevorzugen eine bestimmten Helligkeitsgrad, wie er unter anderem durch Berg- oder Baumschatten hervorgerufen wird. Dieser verhindert auch eine zu starke Erwärmung.

Die Temperatur hat wohl den grössten Einfluss auf die biologischen Vorgänge im Gewässer. Es ist sehr schwer, allgemein einen optimalen Bereich anzugeben. Dieser wird je nach Belastung des Gewässer mit fäulnisfähiger Substanz und dem Nutzungszweck sehr verschieden liegen. Bekannt ist die rasche Mineralisation der organischen Stoffverbindungen bei höherer Temperatur. Da dieser Vorgang reduzierend auf dem im Wasser gelösten Sauerstoff wirkt, muss unter anderem die höchst zulässige Temperatur vom Angebot an Sauerstoff abhängen, ansonsten werden unerwünschte anaerobe Prozesse hervorgerufen. Höhere Temperatur bedingt aber auch eine Steigerung der Gewässerproduktivität. Letztere wird sich auf die Fischerei wieder günstig auswirken, soferne diese nicht kaltstenotherme Arten (Salmoniden) bevorzugt. Von anderen Nutzungszwecken sei hier ganz abgesehen. Der Gewässerbauer kann auf die Temperatur Einfluss nehmen durch entsprechende Wasserführung, Beschattung und Vertiefung.

Die Wassertiefe spielt aber nicht nur temperaturmässig eine Rolle. Im besonderen wirkt im tiefen Wasser das Licht auf das Wachstum der Organismen selektiv. Auch lieben verschiedene Entwicklungsstadien (z.B. Fische) eine bestimmte Tiefe (Kolke). Die Gewässer sollen daher abwechselnd seichte und tiefere Abschnitte aufweisen.

Was die chemischen Eigenschaften des Wassers betrifft, so kommt wohl dem Gehalt an Sauerstoff die allergrösste Bedeutung zu. Ihn zu regulieren, ist eine der ersten Pflichten des Wasserbauingenieurs. Dies ist durch jene Wasserführung erzielbar, die eine schnelle Anreicherung der Wasseroberfläche mit Luftsauerstoff, bzw. eine schnelle Zufuhr von sauerstoffreicheren Wassermassen bewirkt. Ausserdem kann man durch Verhinderung allzustarker Erwärmung den Sauerstoffverbrauch vermindern. Inwieweit diese oder jene Massnahme hierzu geeignet erscheint, wird vom bevorzugten Zweck der Wasserbenutzung, bzw. vom Ziel der Gewässerverbauung abhängen. Neuerdings sorgt man z.B. bei bestehenden Turbinenanlagen für eine gleichzeitige künstliche Belüftung ohne besonderen Kostenaufwand (Wagner 1958). Am besten ist es jedoch, ganz allgemein die Verunreinigung mit sauerstoffzehrenden Substanzen zu vermeiden. Sie können ansonsten Fäulnisprozesse hervorrufen mit der bekannten Entwicklung der auf Wasserorganismen sehr giftig wirkenden Gase Schwefelwasserstoff und Ammoniak. Eine völlige Verödung an höheren Organismen, d.h. eine Zerstörung des biologischen Gleichgewichtes, ist die Folge. Ausserdem macht sie der Fischerei ein Ende. Solche Fäulnisprozesse greifen aber auch die Bauelemente an. Es ist bekannt, dass $H_2S$ Stahl, Bronze, Beton und Holz zerstört und agressive Kohlensäure Eisen angreift. Ihre Entstehung müsste daher schon im Hinblick darauf verhindert werden.

Von den Wasserorganismen wurde bereits ihre vielseitige Funktion angedeutet. In hygienischer Hinsicht kommt wohl der mikrobiellen Entwicklung die allerhöchste Bedeutung zu. In erster Linie sind es die Bakterien, die im Verein mit anderen Organismen die Selbstreinigung bewirken. Sie benötigen aber nicht nur Nährstoffe, sondern, wie schon erwähnt, auch ein bewohnbares Substrat, wie z.B. die Abwasserpilze. Je mehr Möglichkeiten des Anheftens oder des Schutzes vor zu starker Strömung diesen Lebewesen gegeben wird, desto rascher ihre Vermehrung und desto schneller der biologische Abbau.

Gleichfalls soll den Reinwassertieren und -pflanzen die entsprechende Entwicklungsmöglichkeit gegeben werden. In dieser Hinsicht kommt den Pflanzenbewuchs eine hervorragende Rolle zu, gleich, ob es sich um einen Algenaufwuchs (Nahrung, Sauerstofflieferung) oder um die Ausbildung von höheren Pflanzengesellschaften handelt. Besonders zu bevorzugen sind die weichen Gelege der Unterwasserpflanzen. Sie sind sehr reich an Nährtieren und bieten gute Laichplätze, sowie Unterstände für Fische. Sie sind auch der Hochwasserabfuhr kein Hindernis. Für die Uferfestigung hingegen eignen sich wieder Schilf und Binsen.

Das biologische Ziel der Gewässerverbauung soll darin bestehen, eine arten- und mengenreiche Biozoenose, wie sie dem ß-mesosaproben Charakter entspricht, zu erreichen. Eine solche Lebensgemeinschaft ist im allgemeinen arm an Bakterien, Pilzen und Infusorien, aber reich an verschiedensten Arten von Kieselalgen, Grünalgen, höheren Unterwasserpflanzen, Insektenlarven, Mollusken und niederen Krebstieren, sowie an Fischen. Eine einseitige Lebensgemeinschaft, auch wenn sie noch so mengenreich ist (Egel, Schlammröhrenwürmer), ist unerwünscht. Sämtliche Lebensbezirke müssen biologisch gut gepuffert sein.

Nach diesen grundsätzlichen Besprechungen der Milieuverhältnisse und Biozoneosen im Gewässer sollen nunmehr die hydrobiologischen Auswirkungen der Gewässerverbauung des näheren erörtert werden.

**Korrektionen**

Uferbefestigungen, soweit sie aus Beton oder aus fugenlosem Mauerwerk bestehen, sind biologisch unerwünscht. Beton wirkt nicht nur im Aussehen furchtbar, sondern hat auch keine lange Lebensdauer. Auch die Fugenrillung ist nicht besser. Unterspülungen führen zur schnellen Zerstörung des Bauwerkes. Besser sind die Befestigungen mit Trockenmauern. Die Steine können in Beton eingebettet werden, müssen jedoch dann wasserseits in den Fugen Nährboden zur Ansiedlung von Pflanzen erhalten. Ansonsten wirken diese Bauwerke auf das Gewässer verödend mangels genügenden Ansiedlungsmöglichkeiten für Organismen und wegen ihrer Fischereischädlichkeit. Senkwalzen, Holzkonstruktionen unter Wasser und Bruchsteinvorwürfe sind jedenfalls Betonsicherungen vorzuziehen, da sie grosse Hohlräume und eine rauhe Oberfläche aufweisen. Sie bieten auch Jungfischen bei starker Strömung Schutz.

Das lebende Baumaterial, zumeist Erle, Eschen und Weiden, wirkt nicht nur durch das schnell wachsende und bindende Wurzelgeflecht sicherer als Beton und Stein, sondern ist auch vom biologischen Standpunkt aus zu begrüssen. Es schafft wechselnde Strömung und Tiefen, sowie natürliche Anhaftmöglichkeiten, Unterstände und Frassstätten für höhere und niedere Organismen. Eine Lebendverbauung im mittleren und höheren Uferbereich wirkt fördernd auf die Entwicklung von Insekten und bringt die erwünschte Beschattung. Oft genügt sie am angegriffenen Ufer. Da eine Bepflanzung billiger kommt als technische Bauwerke, soll sie schon auch aus Gründen der Erhaltung des Landschaftsschutzes erfolgen. Im allgemeinen rechnet man, dass die Lebendverbauung auch nur ein Zehntel der Baukosten beträgt, die bei Verwendung der teuersten Baustoffe — Bruchstein oder Beton — auflaufen. Ausserdem ist bei entsprechender Behandlung ihre Lebensdauer unbegrenzt. Sie hat weiter den Vorteil, dass sie als Energievernichter fungiert und keine Verklausungen verursacht. Wohl kann aber natürlicher Baumwuchs von Erlen, Eschen und Weiden zu natürlichen Buhnenbildungen und kleinen Kolken, die für die Fischerei sehr nützlich sind, führen, doch darf der Bewuchs nicht zu lückenhaft sein. In Österreich und Deutschland hat man auch z.B. an der Enns und an der Donau eine kombinierte Ufersicherung mit Steinen und darauf angesetztem Bewuchs mit Erfolg angewandt.

S o h l e n b e f e s t i g u n g e n durch Betonierung oder Pflasterung sind unbiologisch und sollen unterbleiben. Besser sind kleine Gefällsstufen zur Herabminderung der Strömungsgeschindigkeit, doch solle diese nicht mehr wie 30 bis 40 cm aufweisen. Bei Hochwasser sind sie aber bautechnisch wirkungslos. 75-80 cm Stufenhöhe wären für die Energiebrechung das Minimum. Bewährt haben sich auch Sohlgurten und der Bau von Niederwasserrinnen.

V e r t i e f u n g e n wirken sich in der Regel biologisch günstig aus. An diesen Stellen finden grössere Fische gute Aufenhaltsplätze, z.B. an den Kolken, Letztere können vom fischereilichen Standpunkt aus auch uferabseits liegen, z.B. bei gebogenen Sperren, Die Vertiefungen sollen aber nicht so weit gehen ,dass den Kieslaichern die Fortpflanzungsmöglichkeit genommen wird und einen unerwünschten Rückgang der weichen Unterwasserpflanzen zur Folge haben.

B e g r a d i g u n g e n führen zu einer Verminderung der Produktionsstätten und zumeist zu einer wesentlichen Veränderung der Gewässerströmung mit allen Folgen in hydrobiologischer Hinsicht (Aenderung der Biozoenosen). Auch der neuzeitliche Gewässerbau lehnt sie ab und bevorzugt gekrümmtes Flussgewässer.

B e t t v e r l e g u n g e n müssen nicht immer nachteilig sein, wenn bei ihnen die hydrobiologischen Grundgesetze gewahrt werden.

Viele Gewässerkorrektionen brachten bisher einen Rückgang der Fischerei, was als Zeichen des gestörten biologischen Haushaltes gewertet werden muss. Leitwerke und Buhnen haben Altwässer, kleine Bäche und seichte Uferpartien zur Gänze von Gewässern abgetrennt, die als Laichplätze, Wohn- und Frassstätten für Jungfische und als Hochwassereinstände fungierten. Besonders den weissfischartigen Vertretern der Fischwelt und den Hechten wurde dadurch ein wichtiger Lebensbereich entzogen. Diese ruhigen Bezirke wirken aber auch als Nieren der Gewässer. Hier konnten sich so manche Schmutzstoffe ausscheiden.

**Einbauten**

Sperren errichtet man im Wesentlichen zum Zwecke der Trinkwassergewinnung, der Wasserkraftnutzung, der Schiffahrtsverbesserung, der Hochwasserrückhaltung und der Gefällsbrechung.

Staue können sich besonders bei kleineren Gewässern wegen Vergrösserung ihrer Wasserfläche und -tiefe gut auswirken, wenn die Temperatur dadurch kein ungünstiges Ausmass erreicht. Im allgemeinen bilden sich im Stau erst nach längeren Zeiträumen stabile biologische Verhältnisse. Ob Staue produktionsbiologisch von Vorteil sind, hängt vor allem davon ab, ob sie wenig oder stark mit Schwebstoffen und Geschiebe belastet werden.

Im ersteren Falle kann eine Verbesserung des biologischen Haushaltes eintreten, nicht jedoch, wenn durch die vielen eingeschwemmten und abgelagerten Stoffe eine weitgehende Verarmung oder gar Sterilisation des Gewässerbodens durch Faulgase erfolgt.

Im allgemeinen wird bei Herabsetzung sehr starker Strömungsgeschwindigkeiten eine Anreicherung der Biozoenosen die Folge sein. Da sich aber dadurch auch andere Milieuverhältnisse, wie Temperatur, Trübung, Sauerstoff, Sedimentbildung, ändern, wechseln sie auch zumeist im fischereilicher Hinsicht ihren Charakter. Strömungsliebende Fische und Kieslaicher werden Fischen, die ruhigeres Wasser und höhere Wasserpflanzen bevorzugen, Platz machen. Aus einer Forellenregion kann eine Barbenregion, bzw. aus letzterer eine Brachsenregion werden. Die Zusammensetzung des Fischbestandes wird sehr von der Möglichkeit der Wanderung abhängen. Unterbindet man sie, dann gehen die Wanderfische rapid zurück, wie z.B. in den österreichischen Flüssen Salzach und Inn. Es muss in jedem Einzelfall, bzw. für jedes Gewässer, so dieses mehrere Staue erhalten soll, überlegt werden, ob Fischaufstiegsvorrichtungen eingebaut werden sollen oder ob die Kosten hiefür zur Erhöhung des Fischbesatzes heranzuziehen sind. Im Zweifelsfalle soll man den Einbau eines Fischpasses nach neuzeitlichen Erfahrungen vornehmen.

Starke Schwankungen des Stauspiegels wirken sich für die Fische zumeist dann ungünstig aus, wenn sie zur Laichzeit erfolgen oder wenn die Absenkungen schnell vor sich gehen. Kleine Aenderungen des Gewässerspiegels können zu erhöhten Eutrophierungen dadurch führen, dass Nährstoffe der überschwemmten Uferregion dem Wasser zugeführt werden. Selbstverständlich sind stärkere Absenkungen oder gar plötzliche Entleerungen von Stauhaltungen zumeist von katastrophalen Folgen für die Fischerei auch im Unterwasser begleitet und sind daher zu vermeiden.

Laufstaue sind Stauanlagen mit Umleitung des Wassers und damit nachfolgender Trockenlegung des Flussbettes unbedingt vorzuziehen. Im allgemeinen bewirken die Energieanlagen an Fliessgewässern, wenn es sich nicht gerade um Spitzenbedarfswerke handelt, eine gleichmässigere Wasserabfuhr, die auch für die biozoenotische Entwicklung und für die Fischerei günstig ist. Sie wirken als Hochwasserrückhaltbecken.

Anlagen zur Gefällsbrechung bestehen zumeist aus mehr oder weniger hohen Stufen. Sie können für die Fische unüberwindlich sein. Wo sie zahlreicher eingerichtet werden müssen, fehlen fast immer eigene Fischaufstiegsvorrichtungen. Um diesem Problem sowohl in wasserbaulicher als auch in fischereilicher Hinsicht beizukommen, hat man in Österreich begonnen, in Flüssen sogenannte « Blocksteinrampen » oder « Sohlrampen » nach Riedinger-Schauberger einzubauen. Sie bestehen aus räumlich gekrümmten, bis zur Hälfte ausbetonierten Blöcken von 1,20 m Höhe und 1 bis 2 Tonnen Gewicht. Die Kronenbreite beträgt 50 m, die Gefällshöhe 2-3 m, die Neigung 1 : 8. Sie sind, ausgezeichnete Energievernichter und kostenmässig von allen Gefällsstufen am billigsten, da sie ohne Wasserhaltung während des Baues gemauert werden und praktisch keine Instandhaltung erfordern. Derartige Rampen entsprechen weitgehendst auch den Wünschen der Fischerei, weil sie ein natürlicher Fischpass sind. Ausserdem bildet sich im Unterwasser ein langgezogener aber ungefährlicher Mittelkolk. Die untere Grenze der Anwendbarkeit liegt bei 15 m Flussbreite.

Aus dem bisher Gesagten ist zu folgern, dass die Aufgaben des Wasserbaues eng verbunden sind mit den Bestrebungen der Gewässerhygiene und der Wasserwirtschaft. Ein naturnaher Wasserbau dürfte allen Anforderungen am besten gerecht werden. Die Technik muss nicht naturfeindlich sein. Eine rechtzeitige Planung und Berücksichtigung der hydrobiologischen Entwicklungsgesetzte bei der Art der Verbauung und der Wahl der Baustoffe wird den besten Gewässerschutz ermöglichen.

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**Summary**

The physical, chemical and biological characteristics of water courses are greatly affected by construction works. Therefore, co-operation between engineers and hydrobiologists is essential to guarantee that optimum conditions with respect to these characteristics are maintained. Of fundamental importance here is the maintenance of some natural biotopes, and certain biocoenoses can even be improved by favourable changes in their biotopes.

A review is given of the importance of various physical, chemical and biological factors in the production of aquatic organisms and the changes brought about by different types of engineering works. The type of bottom most suitable for aquatic growth is described. The content of suspended mineral matter should be minimal to permit the optimal transparency necessary for the photosynthesis of plants. Temperature has a great effect on biological processes and must be in a certain relation to the oxygen consumption of the water. Of all the chemical characteristics of water, the oxygen content is most important. It is necessary in some cases to provide artificial aeration. The biological aim should be to attain a biocoenosis rich in species and numbers and to achieve the highest self-purification capacity as well as a high productivity of fish.

A review Is given of the materials and types of construction which will best benefit bodies of waters from a biological standpoint. As a substitute for the use of concrete, embankments may be strengthened through the use of loose stones and tree planting. Velocity of water may be decreased and bottoms improved through provision of small steps.

Barriers and dams cause considerable changes in water courses, and the results may or may not be favourable. For example, they decrease the rate of flow and thus may increase production. On the other hand, they may destroy the spawning grounds of many fish. Fluctuations of water level are usually unfavourable to fish populations. Fish migrations are usually blocked or greatly deterred. In Austrian rivers, natural fish passes have been constructed by using ramps composed of large stone blocks — the so-called Riedinger-Schauberger method.

Timely planning and adequate consideration of hydrobiological needs in choosing the type of construction and building materials is of the utmost importance.

# SOME INFLUENCES OF MULTI-PURPOSE WATER USAGE ON WATER QUALITY

BY

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This paper briefly presents some of the observations made on Columbia River Basin water quality in a study (1) conducted by the University of Washington for the U.S. Fish and Wildlife Service between 1954 and 1957. The purpose of the study was to ascertain changes in water quality that have taken place and the changes that may be expected to take place as a result of multi-purpose dam construction and the concomitant water uses therefrom. Special emphasis was placed on water quality in its relation to fish life.

The Columbia River Basin contains 259,000 square miles of which 39,700 square miles are in Canada. It lies in the northwest corner of the United States as shown in Figure 1. Between headwaters in British Columbia and the Pacific Ocean, the river is some 1,200 miles long, discharging an annual average of 160,000,000 acre-feet (220,000 cu. ft./sec.) of water to the Pacific Ocean. The headwaters of the Columbia River and those of its principal tributaries are in the mountains where the snow packs produce ground storage plus seasonal peak flows in the late spring of the year. About 4,500,000 acres of land are under irrigation in the arid central regions of the Columbia River and its principal tributary, the Snake River. The rapid fall of the river and its tributaries is utilized for some 200 hydro-electric power developments. Irrigated acreage is being steadily increased as is the number of multi-purpose and single-purpose dams.

### Water-quality changes in a river.

In a given river section, unaffected by man's activity, the quality of river water is subject to change by natural causes as it flows through this section. The magnitude of the change will vary with the length of the section, depth of flow, water quality and volume of tributary streams, shading afforded, elevation of the ground water table, turbulence, and it will vary with the physical and chemical characteristics of the ground over which the river flows. Water quality changes that usually take place in a river section are as follows :

1. Increase in dissolved mineral matter.
2. Increase in water temperature during the summer months.
3. Decrease in water temperature during the winter if a large impoundment exists above the stream section.
4. Decrease in hydrogen ion concentration (increase in pH) if the stream section contains alkaline soil.
5. Colour may be increased or reduced, depending upon the solar radiation received and on the nature of the surrounding soil.
6. Turbidity may be increased or reduced, depending upon the water velocity, the nature of the surrounding soil and the occurrence of rainfall.
7. Dissolved gases, such as carbon dioxide, will decrease in a river section unless entrained organic matter is undergoing rapid decomposition. Dissolved oxygen will increase toward saturation or remain in a saturated state unless rapid organic decomposition removes oxygen at a greater rate than it is replenished by reaeration.

The natural water quality in a river is subject to change from four man-made causes. They are:

1. Impoundment of water in artificial reservoirs behind dams.
2. Return flows from irrigation.
3. Introduction of domestic sewage and industrial wastes.
4. Soil erosion or vegetative cover changes from farming, logging, or construction activities.

**Impoundment of water.**

The effect of water impoundment on water quality depends upon the period of impoundment, water depth, air temperatures, character of reservoir bottom (whether highly organic or inorganic), on the physical and chemical quality of water entering the reservoir, wind action to provide circulatory currents, and on the point and depth of water withdrawal from the reservoir. A large, long and deep, stratified reservoir, with organic material on the reservoir bottom and water withdrawal from the hypolimnion, will discharge water that is low in dissolved oxygen, high in carbon dioxide and the products of decomposition, and it will discharge water that is relatively warm in the winter and cool in the summer. Impoundments will affect downstream water temperatures depending upon :

1. Volume of water impounded.
2. Average impounded water depth.
3. Surface area of impoundment.
4. Depth at which water is withdrawn.

5. Climatic conditions — wind and amount of sunlight.
6. Characteristics of upstream watershed.
7. Season of the year.
8. Ratio of length to width.
9. Ratio of width to depth as water surface falls during depletion period.

A large reservoir that is long and deep will usually discharge relatively warm water in the winter and relatively cool water in the summer, while a large, shallow reservoir will usually discharge warmer water in the summer.

Adverse water-quality factors in regard to fish life that may arise from water impoundment are : high water temperature; low dissolved oxygen; high or low hydrogen ion (pH) concentration; excessive carbon dioxide, ammonia and hydrogen sulphide from organic decompositions; siltation, and accumulation of trace elements that may be toxic to fish or their food supply, such as copper, lead, selenium, and zinc. Favourable water-quality effects that may arise from impoundment are : a decrease in the downstream water temperature in the warm season and an increase in the winter; increase in downstream flow during the normal low-flow period that will more effectively dilute pollutants and improve the habitat; reduction of scour during the flood season if a flood control structure is involved; and a reduction in stream turbidity.

**Return flows from irrigation.**

In the irrigation of land, it is necessary that the soil be well-drained so that the plant roots do not become water-sick and so that salts do not accumulate at the soil surface. A favourable salt balance is attained when the drainage water has a higher salt content than the imput water (2). Most irrigation projects are provided with drains or waste-ways which control the direction of ground water movement in the root zone by returning excess ground and irrigation water to a receiving stream. The amount of water required for irrigation varies from less than two to more than ten acre-feet of water applied per acre per year (3). Of this applied water, from 20 to 60 per cent may find its way back to the stream as return flow. These return-flow waters are more mineralized and have different physical properties from the input waters. Their return to a stream will produce marked water-quality changes if the quantity of return flow in relation to stream flow is significant. Some return flow can be expected throughout the year with the majority occurring at the height of the irrigation season.


FIG. 1. — Map of Columbia River Basin.

**Domestic sewage and industrial wastes.**

The quantity of wastes discharged to inland waters is continually increasing. Their content of polluting material is under surveillance by, and is in the process of being controlled by, water pollution control agencies. Uncontrolled discharge of these waste waters has, in many instances, caused serious impairment in water quality to the extent that fish life could not exist. It is to be expected that these waste waters will have an increased reduction in their deleterious effect on the receiving streams as waste treatment and other control processes become more common.

**Soil erosion.**

Poor land management practices, in the form of overgrazing or improper cultivation, together with logging, mining or construction activities that do not control soil erosion, frequently impart so much silt to a stream that all other forms of water-quality impairment become minor in comparison. A change in vegetation, such as from coniferous to deciduous trees, will usually result in an increase in the water colour and in the organic load carried by the stream.

**Influence of reservoirs on downstream water temperatures.**

Water temperature changes through reservoirs can be evaluated only if the temperature change that would occur in the absence of the reservoir is known. This normal temperature change in the absence of a reservoir can be determined approximately from a long history of temperature data obtained prior to reservoir construction or from comparison of temperature changes in the river stretch occupied by a reservoir with temperature changes in a similar stretch of the same or comparable rivers. Table 1 shows normal river water temperature changes in degrees Fahrenheit per 100 miles of river for eight river sections in the Columbia River Basin. These changes are very significant for the smaller streams during the spring and summer of the year. Table 2 lists observed average monthly water temperature changes from upstream to downstream of five reservoirs while Table 3 relates these changes to the volume, surface area and depth of the reservoirs. These tables indicate that each reservoir is different in its effect on downstream water temperatures and that this effect varies with the time of year. Reservoir drawdown in the late summer may change the reservoir's effect on downstream water temperatures from that of cooling to that of warming, as shown in Table 2 for Lake Roosevelt.

TABLE 1.

**Normal River Water Temperature Changes-°F. per 100 Miles.**

(Data from U.S. Fish & Wildlife Service and University of Washington.)

| River stretch | Miles | Time period | Flow × 1.000 c.f.s. | River characteristics (1) | Upstream water temperature | Downstream water temperature | Upstream air temperature | Downstream air temperature | Water temperature change °F per 100 mi. |
|---|---|---|---|---|---|---|---|---|---|
| *Wenatchee River* | | | | | | | | | |
| Plain — Cashmere | 27 | 1955-1956 Dec. | 2.07 | 1,5,7,9 | 33.7 | 33.1 | 20.5 | 24.8 | 2.22- |
| Id. | 27 | Feb. | 0.88 | 1,5,7,9 | 32.5 | 32.8 | 12.3 | 21.6 | 1.11 |
| Id. | 27 | Apr. | 5.95 | 1,4,7,9 | 39.2 | 42.0 | 47.2 | 54.2 | 10.30 |
| Id. | 27 | June | 13.55 | 1,4,7,9 | 45.3 | 46.7 | 55.2 | 63.0 | 5.20 |
| Id. | 27 | Aug. | 2.68 | 1,4,7,9 | 60.4 | 63.1 | 71.5 | 71.5 | 9.28 |
| Id. | 27 | Oct. | 1.82 | 1,4,7,9 | 47.4 | 47.7 | 43.9 | 49.8 | 1.11 |
| *Yakima River* | | | | | | | | | |
| Thorp — Selah | 53 | 1954 July | 4.28 | 1,4,8,9 | 58.3 | 61.7 | 64.7 | 66.6 | 6.40 |
| Id. | 53 | Aug. | 3.29 | 1,4,8,9 | 52.7 | 58.8 | 62.8 | 65.4 | 11.54 |
| Id. | 53 | Sept. | 2.85 | 1,4,8,9 | 51.7 | 55.8 | 57.3 | 59.5 | 7.70 |
| Union Gap — Enterprise | 96 | 1954-1955 July | 4.50 | 2,4,8 | 59.8 | 69.3 | 66.6 | 72.5 | 9.90 |
| Id. | 96 | Aug. | 1.48 | 2,4,8 | 61.2 | 70.0 | 65.4 | 69.2 | 9.20 |
| Id. | 96 | Sept. | 1.67 | 2,4,8 | 57.7 | 64.6 | 59.5 | 63.1 | 7.20 |
| Id. | 96 | Dec. | 2.22 | 2,5,8 | 35.0 | 35.5 | 31.5 | 36.1 | 0.50 |
| Id. | 96 | Mar. | 1.44 | 2,5,8 | 41.5 | 44.0 | 37.1 | 42.0 | 2.60 |
| Id. | 96 | May | 2.41 | 2,4,8 | 47.0 | 57.0 | 54.0 | 57.9 | 10.40 |
| *Columbia River* | | | | | | | | | |
| Elmer City — Rock Island | 140 | 1955 June | 448.00 | 3,4,10 | 52.4 | 53.3 | 65.8 | 67.3 | 0.64 |
| Id. | 140 | July | 404.00 | 3,4,10 | 55.3 | 56.8 | 68.7 | 69.3 | 1.07 |
| Id. | 140 | Aug. | 182.00 | 3,4,10 | 60.9 | 62.1 | 70.6 | 71.5 | 0.86 |
| Id. | 140 | Sept. | 113.00 | 3,4,10 | 61.3 | 61.3 | 62.7 | 63.5 | 0.00 |
| Id. | 140 | Oct. | 63.00 | 3,4,10 | 62.2 | 58.2 | 49.3 | 49.8 | 2.86- |

| River stretch | Miles | Time period | Flow × 1.000 c.f.s. | River characteristics ([1]) | Upstream water temperature | Downstream water temperature | Upstream air temperature | Downstream air temperature | Water temperature change °F per 100 mi. |
|---|---|---|---|---|---|---|---|---|---|
| Umatilla — Bonneville | 144 | 1954 Feb. | 127.00 | 3,5,10 | 39.9 | 39.7 | 40.7 | 40.5 | 0.14- |
| Id. | 144 | Apr. | 159.00 | 3,4,10 | 47.9 | 48.6 | 51.3 | 50.0 | 0.49 |
| | 144 | June | 504.00 | 3,4,10 | 55.4 | 56.5 | 64.6 | 58.6 | 0.77 |
| Id. | 144 | Aug. | 221.00 | 3,4,10 | 63.7 | 64.2 | 69.5 | 63.8 | 0.35 |
| | 144 | Oct. | 110.00 | 3,4,10 | 55.5 | 56.2 | 50.1 | 52.2 | 0.48 |
| Id. | 144 | Dec. | 103.00 | 3,5,10 | 43.9 | 42.1 | 33.1 | 38.1 | 1,25- |
| Bonneville — Cathlemet | 106 | 1954 July | 430.00 | 3,5 | 61.0 | 61.4 | 62.7 | 60.0 | 0.38 |
| Id. | 106 | Aug. | 230.00 | 3,5 | 64.2 | 63.8 | 63.8 | 60.9 | 0.38- |
| Id. | 106 | Sept. | 150.00 | 3,5 | 63.2 | 62.8 | 62.0 | 59.2 | 0.38- |
| *Snake River* | | | | | | | | | |
| Clarkston — Riparia | 71 | 1950 EarlyJune | 164.00 | 3,4,8 | 54.5 | 53.4 | 64.0 | 63.3 | 1.55- |
| Id. | 71 | Late Aug. | 27.00 | 3,4,8 | 65.9 | 66.4 | 73.4 | 70.8 | 0.70 |
| Riparia — Burbank | 66 | 1945 June | 111.00 | 3,4,8 | 61.7 | 60.4 | 60.9 | 66.6 | 1.97- |
| Id. | 66 | July | 36.00 | 3,4,8 | 74.2 | 72.8 | 71.3 | 75.4 | 2.13- |
| Id. | 66 | Aug. | 19.00 | 3,4,8 | 72.3 | 73.6 | 70.0 | 73.2 | 1.97 |
| Id. | 66 | Sept. | 20.00 | 3,4,8 | 61.5 | 64.9 | 57.5 | 62.1 | 5.17 |

([1]) 1. Turbulent with many rapids.
2. Few rapids.
3. Deep flowing.
4. Mostly sunny weather.
5. Partly cloudy weather.
6. Mostly overcast.
7. Upstream section of stretch mountainous.
8. Farming throughout stretch.
9. Some shading of stream.
10. Reservoir immediately upstream.

TABLE 2.

**Average Monthly Temperature Change in Water from Upstream to Downstream of Reservoirs.**

| Reservoir | Avg. vol. ac. ft. × 1.000 | Avg. surf. area acres | Avg. depth feet | Average monthly temperature change through reservoir | | | | | | | Theor. deten. at avg. flow, days |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mar. | May | June | July | Aug. | Sept. | Dec. | |
| Yale-Merwin, Lewis River | 747 | 7,340 | 140 | 1.6 | 3.0 | 5.1 | 1.4 | 0.8 | 3.1 | 4.0 | 83 |
| Grand Coulee Equalising | 951 | 24,500 | 52 | — | — | 7.0 | 7.5 | 5.9 | 2.0 | — | 140 |
| Roosevelt, Columbia River | 8,252 | 70,300 | 328 | — | — | 1.9- | 1.9- | 0.1- | 3.6 | — | 35 |
| Bonneville, Columbia River | 480 | 20,300 | 50 | 0.2 | — | 0.1- | 0.1- | 0.0 | 0.0 | 0.5- | 1 |
| McNary, Columbia River | 790 | 37,900 | 70 | 1.5- | 0.1- | 0.7- | 0.0 | 0.1 | 0.5 | 0.2- | 2 |

Plus sign indicates temperature rise in degrees F through reservoir; minus, temperature fall; — indicates no data. Data are for a two-year period. Values are not corrected for normal temperature changes shown in Tables 1.

Grand Coulee Dam, with its long and deep Lake Roosevelt, is the largest dam and water impoundment in the Columbia River Basin. Water temperatures have been kept by the Puget Sound Power and Light Co. since 1933 at their Rock Island Dam, 143 miles downstream from Grand Coulee Dam. These temperature data were used for pre- and post-Grand Coulee dam construction comparisons of water temperatures at Rock Island on the Columbia River. As the water temperature is a function of air temperature and flow rate in a given stream, a five-year period (1934-1938) prior to construction of Grand Coulee Dam and a five-year period after construction (1946-1950) were chosen when the air temperatures and flow were similar. Figure 2 is a plot of the average monthly water temperatures during these two, five-year periods. It indicates a warming effect from Lake Roosevelt of about seven degrees Fahrenheit maximum in the winter and a cooling effect of about three degrees maximum in the summer.

TABLE 3.

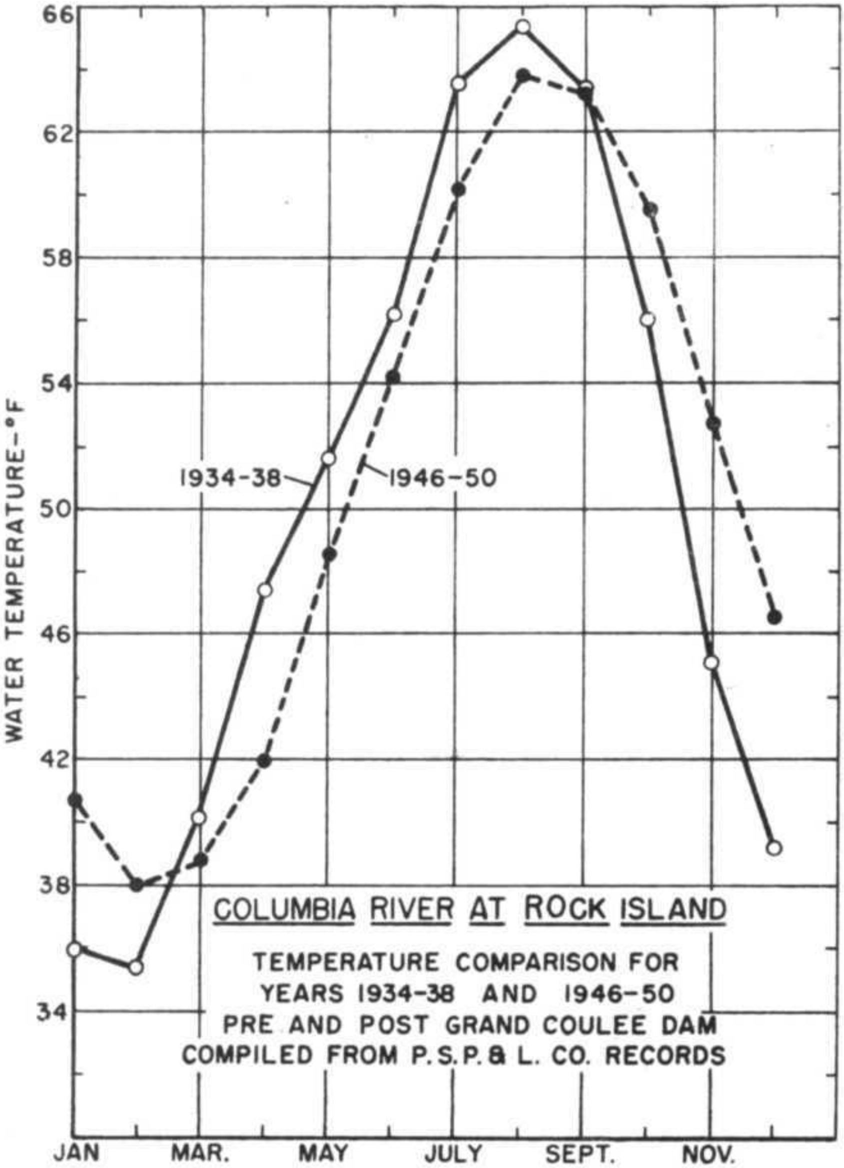
**Average Monthly Temperature Changes through Reservoirs.**
**Area, Volume, Depth Relationships; From Table** 2.

| | March | May | June | July | Aug. | Sept. | Dec. |
|---|---|---|---|---|---|---|---|
| *Yale-Merwin Reservoir (21 miles long).* | | | | | | | |
| Change in °F per : | | | | | | | |
| $10^6$ Acre Feet+ . . . . . . . | 2.10 | 4.00 | 6.80 | 1.90 | 1.10 | 4.10 | 5.40 |
| $10^4$ Acres Area . . . . . . | 2.20 | 4.10 | 6.90 | 1.90 | 1.10 | 4.20 | 5.50 |
| 100 Ft. Depth . . . . . . . | 1.10 | 2.10 | 3.60 | 1.00 | 0.60 | 2.20 | 2.90 |
| *Grand Coulee-Equalizing (27 miles long).* | | | | | | | |
| Change in °F per : | | | | | | | |
| $10^6$ Acre Feet+ . . . . . . . | — | — | 7.30 | 7.90 | 6.20 | 2.10 | — |
| $10^4$ Acres Area . . . . . . | — | — | 2.90 | 3.10 | 2.40 | 0.80 | — |
| 100 Ft. Depth . . . . . . . | — | — | 13.50 | 14.50 | 11.40 | 3.80 | — |
| *Roosevelt (150 miles long).* | | | | | | | |
| Change in °F per : | | | | | | | |
| $10^6$ Acre Feet+ . . . . . . . | — | — | 0.23- | 0.23- | 0.01- | 0.44 | — |
| $10^4$ Acres Area . . . . . . | — | — | 0.27- | 0.27- | 0.01- | 0.51 | — |
| 100 Ft. Depth . . . . . . . | — | — | 0.58- | 0.58- | 0.03- | 1.09 | — |
| *McNary [Corrected for Snake River Inflow] (61 miles long).* | | | | | | | |
| Change in °F per : | | | | | | | |
| $10^6$ Acre Feet+ . . . . . . . | 1.90 - | 0.13- | 0.89- | 0.00 | 0.13 | 0.63 | 0.25- |
| $10^4$ Acres Area . . . . . . | 0.40- | 0.03- | 0.18- | 0.00 | 0.03 | 0.13 | 0.05- |
| 100 Ft. Depth . . . . . . . | 2.10- | 0.14- | 1.00- | 0.00 | 0.14 | 0.72 | 0.29- |

Bonneville Dam is the farthest downstream dam on the Columbia River. There are 56 major dams upstream, 16 of which have been built since 1938, the year when the U.S. Corps of Engineers commenced taking multi-daily temperature readings of the River at Bonneville. Six additional dams are now under construction with seven more slated for construction in the near future. In 1938 there were about 3,731,000 acres of irrigated land upstream from Bonneville, increasing to about 4,500,000 acres by 1957 (4). These water temperature data at Bonneville were studied to see if there was any discernible overall effect on river water temperatures at Bonneville during this period of 1938-1957 as a result of increased impoundments and additional irrigation return flows. August, the month of maximum water temperatures (and high upstream irrigation return flows) was chosen for the comparison. The mean river flow during this 20-year period was 153,000 cu. ft./sec. in August, while the mean water temperature in August was 67.5 degrees Fahrenheit, varying from a monthly mean of 64.2 to 69.7 degrees F. River basin air temperatures for July and August from three representative areas in the Basin were averaged for each year and the mean for the 20-year period computed as 71.9 degrees F. Figure 3 is a plot of these flows, air temperatures and water temperatures. From this figure it can be observed that the water temperature is proportional to the air temperature and inversely proportional to the flow. Each yearly observed mean August water temperature was adjusted to what it might have been if the air temperature had been at the mean value of 71.9 degrees and if the flow had been at the mean value of 153,000 cu. ft./sec. For purposes of obtaining a comparative value, it was assumed that the water temperature varied directly with the air temperature and inversely as the square root of the flow. For example, in 1938 the average August flow was 140,900 cu. ft./sec, average basin July and August air temperature was 73.1 degrees F and the observed August water temperature was 68.1 degrees F.

$$\text{Adjusted water temp.} = 68.1 \times \frac{71.9}{73.1} \times \frac{\sqrt{140.9}}{\sqrt{153.0}} = 64.1 \text{ degrees F}$$

Figure 4 is a plot of these adjusted water temperatures versus the year of observation. While there is no true validity or significance in any single value, taken as a whole, they show a gradual rise in river water temperature during the month of August since 1938.



66
62
58
54
50
46
42
38
34
WATER TEMPERATURE - °F
1934-38
1946-50
COLUMBIA RIVER AT ROCK ISLAND
TEMPERATURE COMPARISON FOR
YEARS 1934-38 AND 1946-50
PRE AND POST GRAND COULEE DAM
COMPILED FROM P. S. P. & L. CO. RECORDS
JAN
MAR.
MAY
JULY
SEPT.
NOV.


FIG. 2.

**Yakima River irrigation and pollution effects.**

The Yakima River is the most highly developed and most highly utilized water source in the Columbia River Basin. Its waters irrigate 425,000 acres and receive the treated waste discharges from some 76,000 persons and from industries (mostly late summer food processing) having a population equivalent of 138,000 persons on an oxygen demand basis. The irrigated portion of the Valley is semi-arid, receiving an average irrigation application of about 4.5 acre-feet per acre per season.

In the typical irrigation year of 1954, an average of 0.921 acre-feet per acre per month was applied during the peak irrigation months of July and August, requiring a total river flow of 6,580 cu. ft./sec. During this two-month period, the total river flow available for irrigation was 5,100 cu. ft./sec, leaving an excess of 1,400 c.f.s. of diverted flow over river flow originally available for irrigation. This extra water that is used comes from irrigation return flows upstream from the point of diversion. During the late summer, there are times when nearly the entire river flow is diverted near Parker (about the centre of the irrigated area), yet at Kiona, about 70 miles downstream, the river flow (with no natural tributaries at this time of year) will be around 2,000 c.f.s. This 2,000 c.f.s. consists largely of irrigation return flows. These return flows continue into the river bed from ground water depletion after the irrigation season has ended in September, and they continue until the commencement of the next irrigation season in April. Maximum return flows are in May when irrigation diversions are high, air temperatures relatively low and consumptive use is low. Return flows drop to around 1,500 c.f.s. in July and August when air temperature are high and consumptive use is greatest.

In 1910-1911, Walton Van Winkle of the U.S. Geological Survey made a comprehensive water-quality study in the Columbia River Basin (5). A comparison of his data with those obtained by the U.S. Geological Survey in 1953-1954 will tend to indicate the changes in water quality that have been caused by man's activities in the river basin since 1911. Between 1911 and 1954, the basin irrigated acreage increased by 240,000 acres or about 130 per cent and the population, including industrial waste biochemical oxygen demand equivalents, increased by 216,000 persons, or 340 per cent.

A study of water-quality data in the lower Yakima River at Kiona indicates that, as for example in the water year 1953-1954, April is the month having the lowest individual constituent concentrations.

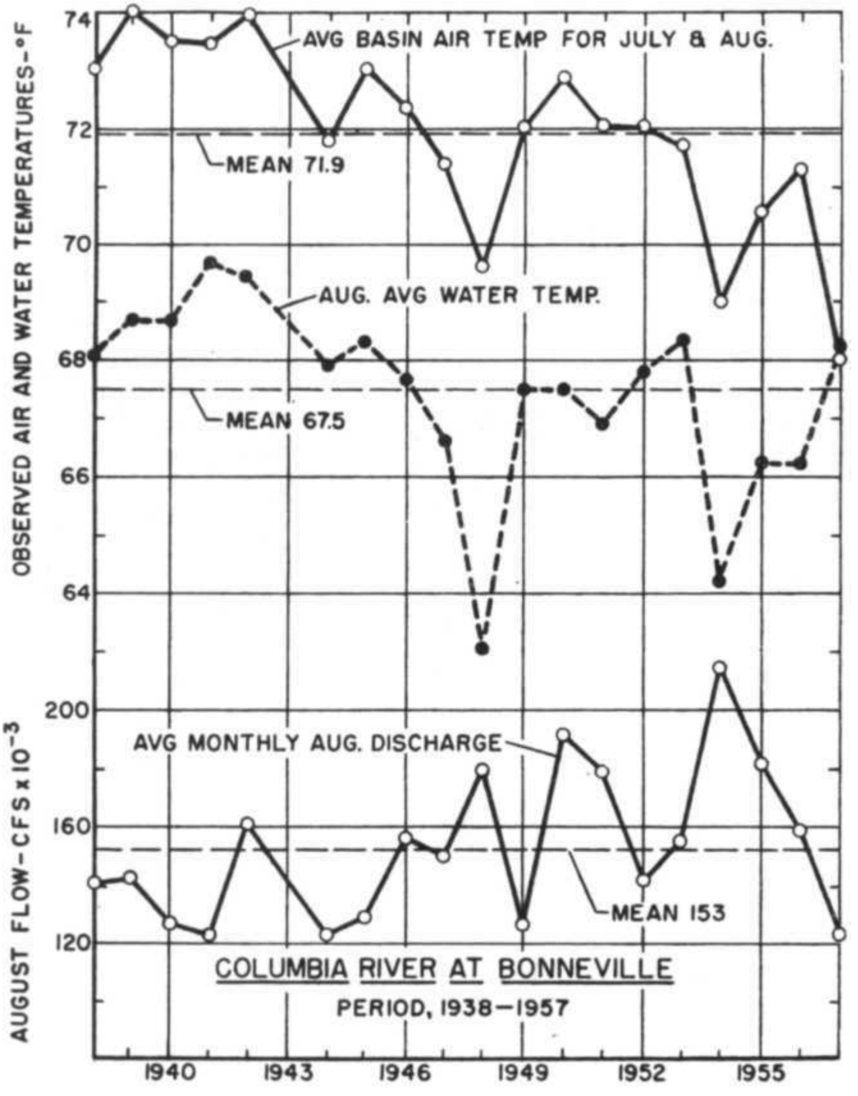

OBSERVED AIR AND WATER TEMPERATURES-°F
AUGUST FLOW-CFS x 10^-3
AVG BASIN AIR TEMP FOR JULY & AUG.
MEAN 71.9
AUG. AVG WATER TEMP.
MEAN 67.5
AVG MONTHLY AUG. DISCHARGE
MEAN 153
COLUMBIA RIVER AT BONNEVILLE
PERIOD, 1938–1957
74
72
70
68
66
64
200
160
120
1940
1943
1946
1949
1952
1955

FIG. 3.

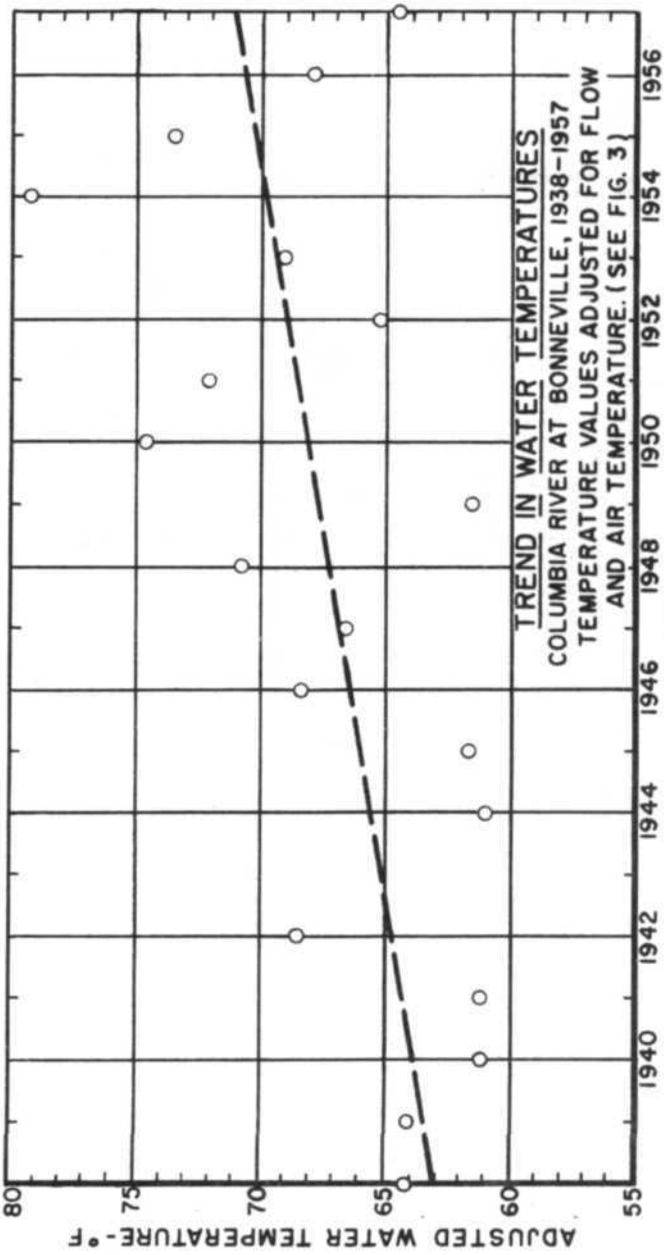

TREND IN WATER TEMPERATURES
COLUMBIA RIVER AT BONNEVILLE, 1938–1957
TEMPERATURE VALUES ADJUSTED FOR FLOW
AND AIR TEMPERATURE. (SEE FIG. 3)
YEAR
ADJUSTED WATER TEMPERATURE - °F
1940
1942
1944
1946
1948
1950
1952
1954
1956
55
60
65
70
75
80

FIG. 4.

The average monthly flow at Kiona in April, when the irrigation season commences, is about the same as in the preceding months of January, February and March, and it is less than in the succeeding

TABLE 4.

**Comparison of Water Quality, Lower Yakima River (1).**

| Constituent | April (2) 1953-1954 | September (2) 1953-1954 Unadjusted | September (1) 1953-1954 Adjusted to April Flow | September (2) 1910-1911 Unadjusted | September (1) 1910-1911 Adjusted to Sept. 1954 Flow | Constituent Increase 1910-1954 (September) |
|---|---|---|---|---|---|---|
| Flow × $10^3$ | 4.87 | 2.51 | — | 0.43 | — | — |
| Total alk. | 71 | 135 | 70 | 110 | 19 | 116 |
| Total hard. | 60 | 113 | 58 | 122 | 21 | 92 |
| Sulphate | 7.5 | 18 | 9.3 | 53 | 9 | 9 |
| Diss. solids | 114 | 211 | 109 | 245 | 42 | 169 |
| Ca + Mg | 20.6 | 38.6 | 19.9 | 41 | 7.0 | 31.6 |
| Na + K | 12.0 | 25.1 | 12.9 | 30 | 5.1 | 30 |
| Silica | 18 | 35 | 18 | 23 | 4 | 31 |
| Chlorides | 3.5 | 6.4 | 3.3 | 14 | 2.4 | 4.0 |
| Nitrate | 1.3 | 1.9 | 1.0 | 0.17 | 0.03 | 1.87 |

(1) Adjusted values consider dilution effect from difference in flows. See discussion.

(2) Monthly weighted-average values in p.p.m. (Individual values during a month, multiplied by the flow, summed, and divided by the sum of the flows at the time of observation.)

months of May, June and July. If it is assumed that the water quality constituents in April are representative of those that would be present in the absence of large, direct return flows and summertime food processing, a comparison can be made between these April values and the high constituent values that are found in September by adjusting the values inversely proportional to the flows. Table 4 shows the comparison of the April and September 1953-1954 constituent values unadjusted and adjusted for the differences in flow in April and September. When the September values are adjusted (inversely

TABLE 5.

**Yakima River, Change in Constituents from Above to Below Irrigated and Populated Areas U.S.G.S. Weighted-Average Values in p.p.m. 1953-1954 (1).**

| Constituent | CleElum (3) | Kiona (2) | Per cent increase |
|---|---|---|---|
| Flow, c.f.s | 1,943 | 4,269 | 120 |
| Silica ($Si\ O_2$) | 7.7 | 23 | 200 |
| Iron (Fe) | 0.03 | 0.02 | -33 |
| Calcium (Ca) | 5.7 | 18 | 215 |
| Magnesium (Mg) | 1.6 | 6.4 | 300 |
| Sodium (Na) | 2.1 | 12 | 470 |
| Potassium (K) | 0.7 | 2.4 | 240 |
| Bicarbonate ($H\ CO_3$) | 29 | 100 | 245 |
| Sulphate ($S\ O_4$) | 1.4 | 10 | 615 |
| Chloride (Cl) | 1.1 | 4.1 | 270 |
| Fluoride (F) | 0.1 | 0.2 | 100 |
| Nitrate ($N\ O_3$) | 0.6 | 1.7 | 185 |
| Dissolved solids | 39 | 129 | 230 |
| Hardness ($CaCO_3$) | 21 | 71 | 240 |
| Conductance (umhos) at 25° C | 53.4 | 193 | 265 |

(1) Weighted according to flow.
(2) Kiona is 142 river miles downstream from CleElum.
(3) CleElum is in foothills of Cascade Mountains.

proportional) by a dilution factor of 1.94 for the difference in flows, it will be noted that the water quality (or total content of impurities) is about the same in April as it is in September. From a study of the flows and quality values in the other months, it is evident that the quantity of impurities (on a weight basis) discharged by the

Yakima River to the Columbia River is about the same each month of the year.

If the 1910-1911 water-quality data for the Yakima River (Table 4) in September are adjusted for the differences in flow between 1910-1911 and 1953-1954, a rough comparison can be made of the change in water quality due to an increased irrigated acreage of 240,000 acres and an added total population equivalent of 216,000 persons between these time periods. Table 4 shows this comparison in the last column. From an actual weight basis then, the irrigation of an additional 240,000 acres and the addition of a population equivalent of 216,000 persons between 1910 and 1954 has resulted in the following approximate percentage increases in constituents : alkalinity, 610; hardness, 435; sulphate, 100; dissolved solids, 400; calcium plus magnesium, 450; sodium plus potassium, 390; silica, 775; chlorides, 165; and nitrates, 6,000 per cent. These are very large increases and are representative only of a change in the maximum yearly constituent values in September for the years compared.

Table 5 shows the change in Yakima River water quality, during the water year of 1953-1954, as it flowed from the foothills at CleElum, through the irrigated and populated areas to Kiona, a distance of 142 river miles. The river at CleElum is fed from snow packs and from three large storage reservoirs. All constituent values increased by at least 100 per cent with the exception of iron, which decreased. This decrease is probably due to precipitation of iron as the water pH increases down river. During an average water year, it was found from University data that at CleElum, the pH would vary from 7.0-8.4, the temperature from 32-67 °F, and the carbonate alkalinity as $CaCO_3$ from 0 to a trace. At downstream Kiona, the pH varied from, 7.3-8.9, the temperature from 32-77 °F, and the carbonate alkalinity from 0-30 p.p.m. as $CaCO_3$.

**Prediction of future water quality.**

The quality of water in a river unaffected by man's activities ia related to the size of the watershed, the amount of river discharge, climatological conditions and the nature of the soil and rock formations. The larger the watershed for a given rate of flow, the greater will be the amount of mineral matter taken into solution. Conversely, the greater the rate of flow for a given watershed area, the less will be the amount of matter taken into solution. The solvent effect of the water is dependent upon the water temperature, water pH or carbon dioxide content, and on the solubility of the soil and rock formation in the watershed. Dissolved material is usually greatest in a water draining an area of fine-textured, alkaline soil. Normally, the dissolved constituent values in a given stream are present in an inverse ratio to stream discharge. Colour and turbidity are usually present in somewhat of a direct ratio to stream discharge, increasing particularly after a heavy rainstorm.

Man has altered this natural water quality by the construction of reservoirs, return of spent irrigation waters, discharge of domestic sewage and by the discharge of industrial wastes. In a given watershed, a very detailed analysis and study would be necessary to separate the effect of each of these man-made changes on the river water quality constituents. In general, reservoirs have their principal effect on water quality by reducing turbidity and by changing the downstream water temperatures. They may slightly increase or decrease the dissolved constituents but do not produce (in the Columbia River Basin) any marked effect therein except, if the reservoir is large, to even out the normal changes in constituents with changes in stream discharge.

Since the marked changes in water quality are then caused by irrigation and pollutants, a prediction of future water quality will necessitate the relating of these factors to stream flow and watershed area for a given drainage basin.

**Watershed usage factors.**

To combine these stream water quality variables, a factor has been devised which will be called the « Watershed Usage Factor ». This factor, with components therein in units $\times\ 10^{-3}$, is equal to (population is for watershed plus industrial waste equivalent on an oxvgen demand basis) :

$$\frac{\text{Population} \times \text{Irrigated Acreage in Acres}}{\text{Discharge in c.f.s.} \times \text{Watershed area in aq. mi.}}$$

Table 6 represents a computation of these factors for the Yakima River at CleElum and Kiona, and for the Columbia River near Bonneville, Oregon. Factors are shown for 1910, 1950, and the predicted factors for the year 2000. Table 7 shows the yearly weighted-average constituent values for these locations in 1910-1912, 1952-1956, ond the predicted values for the year 2000. Predictions were made on the broad assumption that a constituent change between 1956 and the year 2000 would be proportional to the changes in usage factors and constituent values between 1912 and 1956, as shown in the sample

TABLE 6.

**Watershed Usage Factors for Water Quality Prediction**

| River and location | Watershed area Sq. Mi. | 1910 | | | |
|---|---|---|---|---|---|
| | | c.f.s.([2]) | Total pop. | Irrig. acres | Usage factor |
| Yakima-CleElum ...... | 0.5 | 2.37 | 5.3 | 1- | 4 |
| Yakima-Kiona ........ | 5.6 | 5.70 | 63 | 184 | 362 |
| Columbia-Dalles ...... | 237 | 183 | 936 | 2,273 | 49 |

| River and location | Watershed area Sq. Mi. | 1950 | | | |
|---|---|---|---|---|---|
| | | c.f.s.([2]) | Total pop. | Irrig. acres | Usage factor |
| Yakima-CleElum ...... | 0.5 | 1.94 | 3.4 | 1 | 4 |
| Yakima-Kiona ........ | 5.6 | 4.27 | 279 | 424 | 4,930 |
| Columbia-Dalles ...... | 237 | 179 | 3,529 | 4,010 | 334 |

| River and location | Watershed area Sq. Mi. | Future year 2000 | | | |
|---|---|---|---|---|---|
| | | c.f.s.([2]) | Total pop. | Irrig. acres | Usage factor |
| Yakima-CleElum ...... | 0.5 | 1.96 | 6 | 1- | 6 |
| Yakima-Kiona ........ | 5.6 | 5.65 | 508 | 534 | 8,560 |
| Columbia-Dalles ...... | 237 | 195 | 6,456 | 7,284 | 1,017 |

([1]) Values $\times$ $10^3$ except for usage factor.
([2]) Mean Annual Flow for period of record.

calculation on Table 7. These predictions are gross approximations and one cannot definitely say that past changes in water quality will necessarily be reflected in like future changes.

TABLE 7.

**Past and Estimated Future Water Quality Characteristics (1).**
Yearly weighted-average values in p.p.m.
Computed from usage factors in Table 6.

| Constituent | Yakima River at CleElum | | | Yakima River at Kioma | | | Columbia River at Dalles | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1910-1912 | 1952-1956 | Future | 1910-1912 | 1952-1956 | Future | 1910-1912 | 1952-1956 | Future |
| Alkalinity . . . . . . | 23 | 24 | 25 | 53 | 82 | 105 | 48 | 73 | 133 |
| Hardness . . . . . . | 25 | 21 | 25 | 53 | 71 | 85 | 55 | 77 | 130 |
| Diss. solids . . . . . . | 47 | 39 | 47 | 102 | 129 | 150 | 88 | 116 | 183 |
| Sulphate+ . . . . . . | 5.9 | 1.4 | 5.9 | 13 | 10 | 13 | 10 | 17 | 34 |
| Ca + Mg . . . . . . | 8.4 | 7.3 | 8.4 | 17.7 | 24.4 | 30 | 19.9 | 26.9 | 44 |
| Na + K . . . . . . . | 3.7 | 3.0 | 3.7 | 9.9 | 14.6 | 18 | 7.9 | 10.9 | 18 |
| Iron . . . . . . . . . | 0.02 | 0.03 | 0.03 | 0.14 | 0.02 | 0.14 | 0.10 | 0.05 | 0.10 |
| Chlorides . . . . . . | 1.5 | 1.1 | 1.5 | 2.7 | 4.1 | 5.2 | 2.5 | 3.8 | 7 |
| Nitrate+ . . . . . . . . | 0.32 | 0.6 | 0.9 | 0.23 | 1.7 | 2.9 | 0.39 | 0.7 | 1.5 |
| Silica . . . . . . . . . | 10.4 | 7.7 | 10.4 | 18 | 23 | 27 | 13 | 10 | 13 |

(1) Future year 2000 is based on anticipated industrial, population and irrigation growth with control exercised over all waste discharges.

**Sample Calculation. Yakima River at Kiona.**

Change in usage factor, 1910-1956 = 4,568; 1956-Future = 3,630.
Alkalinity change = 29 p.p.m. as $CaCO_3$ between 1910-1956.

$$\frac{4568}{29} = \frac{3630}{\times}; \quad \times = 23$$

Future estimated alkalinity = 82 + 23 = 105.

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## Summary

A brief resume has been presented on portions of a water quality study that was made in the Columbia River Basin by the University of Washington for the U.S. Fish and Wildlife Service. Water quality constituents evaluated (only a portion of those determined are shown herein) were those that might relate to the productivity of the River Basin fishery. The natural Basin water quality has experienced a significant change in the past 45 years through the construction of multi-purpose and single-purpose dams. After these dams were built, water was available for agriculture, industrial and domestic consumption. It is the spent waters from these sonsumptive uses, more than the dams themselves, that have produced this water-quality change. From the standpoint of the fishery, the seemingly most important component of water quality at this time is that of temperature. Water temperatures in the central Columbia and in the lower Snake and Yakima Rivers are high during the summer. Dissolved constituents have shown a marked rise during the past 45 yars but have not risen to the extent that the fishery is endangered, according to data, presently available. Dissolved oxygen values are high throughout the Basin, with the exception of the lower Willamette River. With the usage of more complex organic and inorganic compounds in the home and in industry, it can be expected that present criteria for water-quality evaluation will have to be expanded in the future.

# THE INFLUENCE OF SEWAGES ON FISHERIES

BY

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Sewages may harm fish by :

(1) Toxic influence;
(2) Oxygen depletion;
(3) Shift of biological balance and
(4) Storage of taste-influencing substances in fish flesh.

### 1. — The influence of sewage toxics on fish.

By toxics we mean chemico-physically effective substances which are foreign to the body by their nature and concentration, and cause disturbances of function in the living organism. Generally, toxics are understood to be compounds, of which even small quantities have a noxious effect. Only insoluble matter is absolutely non-toxic.

According to the way the toxics attack, we differentiate between local and resorptive toxic effects.

#### a) Local toxic effects (caustic effects in the broadest sense).

The toxics of this group destroy the respiratory epithelium of the gills and the skin, so that the fish will die of suffocation and an accumulation of carbon dioxide (carbonic acid) in its body. If the respiratory epithelium is damaged, oxygen deficiency and an accumulation of carbon dioxide in the body of the fish will result in increased respiratory frequency and depth. The oxygen intake will go down, despite increased respiratory frequency; the respiratory intensity cannot be maintained and the fish will finally die. A local toxic effect is often characterized by an intensive muciparous process in the body of the fish. If the gills are more severely corroded, the fish will die even if transferred into fresh water. Local toxic effects are caused by many heavy metal salts, acids, alkalies and chlorine.

#### b) Resorptive toxic effects.

The toxics of this group cause toxic reactions after having been absorbed by the blood. The symptoms will show when the toxic, at its point of attack in the body, has reached the degree of concentration necessary to provoke a reaction.

Depending on the part initially affected, we differentiate blood toxics, nerve toxics, protoplasmatic toxics, etc. In many cases, however, the toxic effect is of a complex nature. The ability to recover is very strongly pronounced in some cases of resorptive poisoning, i.e. it is occasionally possible (as in the case of cyanogen poisoning) to save the fish shortly before death by placing it in fresh water.

Absorption of toxics can take place :

(1) Through gills and skin. In this case, it is mainly the gills which act as the port of entry, while the skin is of secondary importance.

(2) Through stomach and intestinal canal. Only a few toxics are absorbed this way.

**The process of poisoning of fish.**

We can differentiate between a chronic and an acute toxic effect. We use the term « acute toxication » if the symptoms of poisoning present a uniformly harmful picture clearly connected with the applied toxic, no matter at what time these typical symptoms of poisoning occur. In the case of chronic toxication, however, fish are weakened to such an extent that they will easily succumb from disease and unfavourable environmental conditions, or else their growth or powers of reproduction will be inhibited although the fish themselves will not die.

The most important factor in determining the toxic effect of a substance is the definition of standard phases regarding the symptoms of poisoning. The poisoning process can be divided into two phases :

*a*) The latent phase, during which the fish is still able to recover if it is removed from the poisoned solution and placed in fresh water.

*b*) The lethal phase which covers the period during which the fish is actually still alive but there no longer exists any possibility for its recovery.

In the course of the whole poisoning process (including both the latent and the lethal phase), one can note certain periods marked by a characteristic behaviour of the affected fish, such as the reaction period, the manifestation period, lethal period and the expectation of life.

Despite many variations we can, as a rule, distinguish the following consecutive phases in the course of poisoning :

(1) Initial disturbance;

(2) Decrease or increase of irritability (excessive irritation or paralysis);

(3) Disturbed equilibrium, reeling, convulsions;

(4) Disturbed coordination of motion, loss of equilibrium;

(5) Agony (death struggle);

(6) Rigor mortis.

The toxicity of a compound can be influenced locally by ecological factors; on the other hand, the extent of toxicity is determined by the fish itself, according to its species, size, condition, etc.

Two groups of environmental factors may influence the toxic effect of a substance :

(1) Factors which directly influence the physiological action of a toxic, e.g. change of gill-permeability or the reaction velocity at the points of attack of the toxic substance;

(2) Factors which affect the toxic substance itself, by changing its concentration or its chemico-physical properties. These factors indirectly change the degree of noxiousness of toxic river pollution.

In practice, however, it is very often impossible to draw a clear distinction between the two types of ecological factors. Important ecological factors are : temperature, oxygen-capacity, carbon dioxide and mineral contents, substances with a synergic or antagonistic effect, stream velocity and stream flow, as well as light.

Frequent requests are made to detect analytically the toxics in the cadaver of a poisoned fish or to determine the pathologic-anatomical symptoms of the poisoning that has taken place. This is possible in very few cases and only when fish which have recently died of poisoning are available for examination.

### 2. — **The effect of oxygen deficiency on fish.**

The oxygen capacity of water is influenced by :

*a*) Physical conditions for oxygen intake, such as velocity of flow and temperature;

*b*) Production of oxygen by aquatic plants and algae;

*c*) Oxygen consumption by aquatic plants, algae and aquatic fauna;

*d*) Oxygen consumption by bacterial processes.

The injurious effect of oxygen depletion caused by domestic sewages and some industrial effluents often shows only quite a distance downstream from the outfall. Unlike the damage caused by organic sewage, the effects of toxic sewage show, as a rule, immediately at the outfall of the sewage into the receiving water and will gradually lose some of their force by dilution or chemical detoxification.

In practice, mortality of fish results from oxygen deficiency in the receiving water in the great majority of cases.

The injurious effect of domestic sewage is mainly due to its consumption of oxygen in the receiving water. Some trade and industrial effluents affect the receiving water only by their oxygen-depleting properties (e.g. the effluents of potato starch factories, flax retting plants, sulphate pulp factories, wood-sugar producing industries).

Oil skins can, in addition to their toxic effect, separate the water from the atmosphere and prevent the re-aeration of the water. Also an intensive growth of water blooms can, to a great extent, separate the water from the air. In the case of more extensive growth of algae blooms there will be oxygen deficiency, especially in the early morning hours, which can result in fish mortality.

In summer, mortality is often caused by the combined effect of high water temperatures, causing a more rapid process of oxygen depletion, and a suddenly decreasing barometric pressure by which the gases absorbed by the sludge are liberated.

Flushes of oxygen-depleting sewages, causing a sudden oxygen deficiency in the receiving water, have a particularly harmful effect on fish, since they can only gradually get accustomed to oxygen-deficient water.

It is of great importance to fish survival that they should have recourse to lower oxygen concentrations.

In case of oxygen deficiency, an increase of respiratory frequency and depth takes place; the fish become nervous. In this case, many species swim to the surface of the water and snap up air bubbles together with the water, which turn over oxygen to the surrounding water, or they use only the oxygenated water layer directly below the surface (emergency respiration). The shortness of breath caused by oxygen deficiency can be overcome shortly before death by placing the fish into water containing oxygen.

According to the oxygen demand of freshwater fish, the following sequence of growing insensibility can be established : Trout — whitefish — barbel — burbot — pike — carp — tench — goldfish — eel. Trout grow best in water with an oxygen capacity of 10-11 mg/l.

4 mg/1 already cause emergency respiration. Carp show respiratory difficulties at an oxygen content of 4 mg/1 but carp as well as tench are still viable at a minimum oxygen capacity of 0.7-0.9 mg/1.

Oxygen deficiency can also inhibit the growth of spawn.

### 3. — **Shift of biological balance.**

The biological balance of the water can be affected by sewage toxics as well as by oxygen-depleting substances and this can impair living conditions for the fish by :

(1) The formation of a deserted zone;
(2) The mass development of certain groups of organisms;
(3) The formation of a zone of annihilation.

Deserted zones originate when certain fish-food fauna are harmed by sewage effects, so that the food becomes insufficient for the original fish population and the fish are obliged to migrate from the area. These deserted zones can have an unfavourable effect by destroying the spawn-plants (potamogeton), as the progeny is jeopardized by the loss of the spawning grounds.

One-sided over-saturation of the water (over-manuring) with organic putrescible matter can result in a mass development of organisms (e.g. waterblooms or Sphaerotilus-growth) which can have the following injurious effects :

*a*) clogging the gills;
*b*) secretion of metabolic products which have a toxic effect on the fish;
*c*) clogging of fishing nets;
*d*) deposition of dying organisms in storage capacities (digested sludge).

### 4. — **Storage of taste-influencing matter in fish.**

There are a number of substances in sewage which infiltrate the flesh of the living fish through skin and gills and, though more rarely, through the stomach and intestinal canal. These substances are deposited particularly in parts rich in fat and make the flesh unpalatable. Most of these tainting substances are absorbed by the body of the fish in a very short time, often in only a few hours. The disagreable taste can, however, be eliminated by keeping the fish in clean water for some days or weeks. In all cases of substances so far discovered to be taste-influencing, fat- resp. lipoidsoluble compounds are involved; therefore fish rich in fat, such as eel and salmon, will be more easily tainted than those poor in fat. Regarding industrial effluents — especially those from coking and gas plants, oil refineries, sulphate pulp factories, Buna-producing plants and factories producing explosives, all of which contain phenol — all of these have an adverse influence on taste.

But it is not only artificial causes (sewages) which affect the taste of fish; natural causes also (such as the growth of waterblooms) can have this effect.

To sum up, it can be stated that it is technically possible to remove both toxic substances and organically putrescible matter from sewages by means that are financially feasible. Fish mortality is therefore a sign of a misplanned water economy. By proper control of the water courses, not only those substances with a toxic effect on fish but also organically putrescible matter can be collected in adequate sewage plants and brought to an economic use.

The above statements are, in an abridged form, quoted from the author's Manual of Fresh Water and Sewage Biology published by the Oldenbourg Verlag in Munich. Volume I of this manual was published in 1951. Volume II will be published in the course of the year 1958. The chapter on the toxicology of sewage, in volume II, has been prepared by the author in cooperation with H. A. STAMMER.

# EFFECTS AND CONTROL OF STREAM POLLUTION

BY

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Since his beginning man has been closely associated with water courses. Streams have been his highways, the source of his drinking water and much of his food, and a place for his recreation and sports. Streams are an intimate part of his culture, his legends, and his history. As man became as we say « more civilized » he congregated in villages along streams and used them for the disposal of his wastes. As he increased in numbers and developed new skills, his ability to pollute the streams also increased until it has attained its present high level of effectiveness.

In pre-sanitation times refuse was thrown directly into the nearest stream where it was rapidly removed from sight by the stream flow. As towns sprang up at strategic locations along the rivers and grew into cities, modern methods of sanitation were adopted where wastes were collected by sewers and discharged some distance downstream. This pooling of wastes underground and their discharge in an out-of-the-way place below the city allowed a more impersonal and pious attitude to be assumed in regard to this method of disposal. However, as the amount of wastes increased and they travelled farther downstream one man's wastes became another man's drink. More recently due to population growth and the manyfold increase in industry the undesirability of discharging wastes into and taking drinking water from the same pipe has been forcibly demonstrated. New manufacturing processes have resulted in many new and complex wastes, many of which are toxic unless highly diluted. Petrochemical wastes, pesticides, and wastes from production of new synthetic organic materials bear little resemblance to « old-style » sewage wastes. Toxic materials and those not subject to natural stream purification are becoming an increasing problem in the utilization of water resources. As man's activities have become more complex, they have had an ever-increasing influence on the aquatic environment, resulting in changes so great that the public is finally beginning to realize that water resources are not inexhaustible; that water is not a cheap commodity but a necessity of life worth whatever they have to pay for it; and that water supplies must be protected and wisely used for the greatest good of the greatest number, if the total supply of fresh water is to meet the needs of future generations.

**The Pollution Problem.**

It should be realized that the discharge of sewage and industrial wastes to our streams is only one cause of their decline. The activities of man on the watersheds have been responsible in many areas for a whole succession of undesirable stream conditions. Some of these damaging activities are clean cutting, burning, overgrazing, unwise agricultural practices, drainage, and road construction (1) (2) (3) (4) (5). These practices have increased surface run-off and erosion, decreased soil seepage, lowered the water table, reduced or eliminated spring flow; they have made streams intermittent or greatly reduced low-water flows; they have increased the frequency and severity of floods, the extent of low-water periods, and the turbidity and silt load; and they have covered productive bottom areas or filled stream channels with eroded materials (6).

It must be realized also that management of water and land or soil resources are interdependent entities. Without good land management we cannot have good water management. Unwise use and misuse of vegetative cover and soil resources are the cause of many unfavourable conditions in our streams. A large portion of our water resource problems can be solved only by improved watershed management. Remedies applied to a stream itself give only temporary results because they treat the effect and not the cause which has its source out on the watershed (7).

A study of stream habitats indicates that stream pollution is not due solely to sewage and industrial wastes. Silt and eroded materials, hot water, and radioactive materials can also act as pollutants. Organic wastes, when added in small quantities, serve to enrich the stream and bring about an increase in the number and growth rate of the fishes (8). Under such conditions, therefore, these wastes cannot be considered pollutants. Pollution depends not on the mere addition of a material but on its character, the amount added, the characteristics of the receiving water and the stream, and the extent of environmental changes produced. In its broadest sense, water pollution may be defined as the addition of any material to a stream in such amounts that a beneficial use is interfered with, lessened, or destroyed. While a small amount of organic materials may fertilize a stream and be beneficial, utilization of larger amounts by the stream biota may result in depletion of dissolved oxygen and killing of fish or production of nuisance growths or conditions. Such results constitute pollution. Pollution is, therefore, dependent on quantity and degree of change, and in simplest terms may be defined as « too much ».

### Classification of Pollutants.

It is customary to classify pollutants according to their source, for example, as domestic and industrial wastes. For a more thorough understanding of the problem, it is believed best to classify them according to their effects on the stream, its biota, and its various beneficial uses. All pollutants and wastes may be placed under one or more of the following headings : 1. inert suspended or settleable materials; 2. dissolved substances, especially those which are toxic; 3. putrescible materials; 4. wastes of a significant heat content; 5. wastes containing pathogenic organisms, contaminants, or materials which produce undesirable tastes or odours and 6. radioactive wastes. The main beneficial uses of our water resources are for domestic, industrial, and agricultural supplies for recreational, aquacultural, and navigational uses, and for power generation and waste disposal.

### Effects of Pollutants on Beneficial Uses.

Human consumption ranks first among all the beneficial uses of water. Domestic water supplies must be palatable and safe, and chemically acceptable for use in and about the home.

Water is used by industry for cooling, as wash water to remove insoluble materials such as soil particles, iron scale, fly ash, etc; to remove unwanted soluble materials and chemicals; and to aid in chemical processes. Generally speaking, water for industrial purposes should be available at all times in adequate volume; it should be cool and clear and low in dissolved salts, especially those which may interfere with a process. When used for food processing and similar uses, it should be free of contamination.

The principal agricultural uses of stream water are for irrigation and stock watering. These uses require a water which is safe from the standpoint of pathogenic organisms and parasites and which does not contain dissolved materials in concentrations which are toxic to plants or animals. For production of crops of aquatic organisms (aquaculture) water must have a suitable temperature and pH range, contain sufficient dissolved oxygen at all times, must not contain concentrations of dissolved material which are toxic under conditions of continuous exposure and must be free of settleable solids and turbidity which limit benthic populations and plankton growth.

Fishing in many fresh waters and over wide areas of the seas is both a recreation and an industry. In North America, the raising of trout for food and minnows for bait is growing in importance. Pond culture, including farm ponds for recreation and food and pay-fishing lakes, is on the increase. In Europe, carp have been raised for the market for many years while in southeast Asia several species are pond-reared for food. While many of the commercial marine fishes are taken in the open waters, oysters, clams, lobsters, scallops, crabs, and shrimp are associated with estuarine and shore waters and are more subject to the various effects of pollution — silting, turbidity, oxygen depletion, excessive growths of nuisance organisms, toxic materials, and other unfavourable environmental conditions.

Navigation, power production, and waste disposal all require a continuous adequate supply of water. Excessive amounts of acids are harmful to ships and turbines.

Population increase, urbanization, better roads, and transportation are resulting in a constantly increasing use of water areas for recreation. Since the value of such areas is directly related to demand and inversely proportional to the supply, the destruction of such areas by economic encroachment and pollution will cause remaining suitable areas to increase greatly in value. The aesthetic value alone for such areas is immense. Picnickers, campers, or those just going for an outing, generally prefer to be near water; hence the value of clean, attractive recreational water areas is considerable. Last year (1957) in America, the national forests, parks, and wildlife refuges had 119,000,000 visitors (9). Many additional millions visited state and county parks, the Great Lakes, and the sea coasts. Almost 85,000,000 visited Corps of Engineers Reservoirs in 1957, and it is expected the number will reach 180,000,000 by 1966.

During the past few years boating has increased severalfold. In many reservoir, lake, river, and coastal areas there are now thousands of boats where formerly they were numbered in tens. Swimming, water skiing, and other aquatic sports are constantly growing in popularity. Fishing is the most important water sport and the most popular form of recreation in the United States. In 1957, there were more than 19 million licensed fishermen (10) and perhaps some 25 million fishermen over-all. Fishermen and hunters spent some 3 billion dollars in 1955. Recreation is big business and an important industry. It ranks high among all industries in many of the states and is of outstanding importance in some.

The preservation and perpetuation of sport fishing are dependent, as is the commercial fishery, on the maintenance of a suitable environment for the fishes. Required water quality characteristics are about the same as those listed for aquacultural uses. For general recreational uses water should be clear, free of floating solids, odours, and contamination, and they should provide an environment conducive to the survival, growth, reproduction, and well-being of aquatic life.

Pollutants may affect the beneficial uses of water resources in a variety of ways. Suspended materials can produce turbidities which decrease aesthetic value, reduce light penetration, and thus photosynthesis and productivity. They can fill reservoirs and lakes, choke streams, or blanket stream bottoms with resultant destruction of pools, cover, and spawning areas. The deposition of sand, mud, or silt over gravel, rubble, or boulder bottoms largely eliminates or severely curtails production of the larger macroinvertebrates, invaluable as fish food. Clear water is also desired for domestic, industrial, and agricultural uses.

Dissolved solids leached from soil or contained in industrial wastes may make a water supply unsuitable or undesirable for domestic, industrial, or agricultural uses. Tolerable levels of some dissolved substances are quite low for certain industrial processes, for example, chlorides in water used in the production of stainless steel. The drinking water standards of the United States Public Health Service state that total chlorides should not exceed 250 p.p.m. While many aquatic organisms can live in waters having a wide range of dissolved solids, there are definite limits which must not be exceeded if they are to thrive. If the salts in solution are physiologically balanced they may have little adverse effect on aquatic life until they reach concentrations which exert an osmotic effect (11). This concentration varies with different organisms. If the dissolved salts are not in physiological balance some of them may exert a toxic effect at a concentration which is considerably lower than that tolerated under « balanced conditions. The salts of heavy metals are generally toxic to aquatic life, some being lethal at very low concentrations. The insecticides, some synthetic organics, and cyanides are also very toxic.

While putrescible wastes usually produce unsightly conditions, their major effect is the reduction of D.O. which, if sufficient, may produce nuisance conditions. Their excessive fertilizing effect often results in nuisance growths which can be detrimental to water supplies, clog fishermen's nets, and smother fish food organisms (1).

The effects of the discharge of hot waters to a stream depend upon the extent of the resulting rise in temperature of the receiving stream and the peak temperature attained. A sudden rise of 10° F. in stream temperature can have widespread effects. It can cause some species to disappear to be replaced by other species; it can change the food chain and the dominant species; it can increase or decrease productivity; and it may serve as a block to the migration of certain species. Depending on the temperature levels reached, temperature changes can be favourable, unfavourable, or even lethal for aquatic life (11). They can also adversely influence domestic and industrial water uses.

Wastes from human populations may be damaging to water uses because of pathogenic organisms which they may contain. Such contamination may severely limit recreational uses and create problems in the provision of a safe water supply. Materials which produce undesirable odours or tastes in water may have as their source industrial wastes or living or dead organisms. Such materials present difficult problems to water works operators. The tainting of fish flesh by materials absorbed from the water also constitutes a serious problem. Even a few fish having a disagreeable smell or taste will destroy the market for all fish from that area. With industrial development, tainting of fish flesh is becoming more widespread and important.

It is to be expected that the atomic energy industry will experience rapid development and expansion. Wastes from this industry and the corollary uses of radioactive materials will, therefore, have increasing effects on water resources and water uses. In evaluating this phase of the water pollution problem all of the various modes of contact with the total environment must be considered. It has been shown that certain plants and animals concentrate radioactive materials to levels many times that in their environment. For example, algae may concentrate certain radio-isotopes to 200,000 times that in the surrounding water. It has been stated (13) that if fish lived in waters containing radiophosphorus at maximum permissible levels for drinking water, their flesh would be unsafe for human consumption.

## Pollution Control

Effective control of water pollution is a complicated and difficult problem. It requires first of all a public awareness of the problem, an understanding of the necessity for multiple water uses, a knowledge of the factors limiting such uses, and a desire to take remedial action. The abatement and control of pollution also requires a unified and cooperative approach to the problem by groups or agencies responsible for water resource development; the establishment and maintenance of water quality criteria for the various beneficial uses, and decisions as to which uses shall be given precedence. Finally, definite and detailed knowledge of the quality requirement for each beneficial water use is basic to the whole problem.

The public has come to regard discharge of waste materials to a water course as the customary method of disposal. Industrial and other wastes are usually contained in wash waters or they are water solutions of the materials used in the industrial processes. To prohibit all waste discharge to streams is practically impossible and in fact, at our present state of knowledge, would be economically unfeasible. Therefore, the present problem is to keep the concentration of wastes in receiving waters below those levels which are known to be detrimental to the beneficial uses of that water. Stream standards or water quality criteria preserve the chosen beneficial uses by specifying the upper allowable limits of concentration for various wastes or waste components discharged to the stream. These stream standards can be attained by means of effluent standards which must be sufficiently flexible to meet problems as they arise in the watershed.

The allowable concentration of specific materials in any water will, of course, depend on the favoured beneficial uses, the quality of the receiving water, and the location or point of use in reference to the waste outfalls. It is apparent that water for navigation, power production, cooling, or certain industrial uses can contain materials in concentrations which cannot be tolerated in water for domestic use or fish production. The character of the receiving water is a major factor in determining the amount of waste which can be added safely and the resulting toxicity to aquatic life. For instance, an alkaline stream can neutralize a greater quantity of acid waste than a stream which is neutral or slightly acid, and the opposite is true for an alkaline waste. A stream may contain materials synergistic or antagonistic to added wastes and the pH of its water may greatly influence the toxicity of added materials, Water quality criteria cannot be applied generally over extensive areas but must be tailored to fit specific situations.

Various water quality criteria have been proposed and some have been widely accepted. Criteria for drinking water are outstanding in this regard. Criteria for agricultural uses have been concerned mainly with irrigation. Industry in general appears apathetic toward the use of criteria for its water supplies. It is believed that some criteria will be essential in the future in order to provide adequate industrial supplies. There is, however, widespread demand for water quality criteria for the protection of aquatic life, especially the sport and commercial fisheries. This phase of the subject will, therefore, be discussed in greater detail.

Objectives of water quality criteria for aquatic life are restoration and maintenance of those environmental conditions conducive to and essential for the survival, growth, reproduction, and well-being of fish of economic or recreational importance, and of those organisms which serve as their food. These criteria must, therefore, be based on the environmental requirements of the organisms to be protected. Much remains to be learned and considerable research must be carried out before the environmental requirements, minimum lethal levels, and maximum harmless levels under conditions of continuous exposure, are definitely known. However, considerable data are already at hand which can be utilized effectively in meeting present problems. It is believed desirable to make use of the present knowledge to improve pollutional situations while additional data are being secured.

As previously mentioned, a widespread pollution problem affecting aquatic life is turbidity and settleable solids due to land erosion and the discharge of wastes containing suspended materials. This problem has increased in North America during the past century. It is difficult to control since it involves widespread operations and many people who work independently of each other. Further, criteria applicable for one stream may not be totally applicable in another. Fishes and their food organisms which have evolved and developed in muddy streams with silt or mud bottoms can withstand greater quantities of these materials than can fishes accustomed to clear water and gravel, rubble, and boulder bottoms. Criteria for turbidity and settleable solids will, therefore, vary according to the fish and the type of stream to be protected. In gravel-rubble-bottom streams, even small amounts of sand or silt reduce the supply of macroinvertebrates because they fill the spaces between the stones and reduce the area for attachment; whereas in a sand-mud-bottom stream small additional amounts have little effect. Turbidity is more harmful to those fish which feed by sight than to those which feed indiscriminately. Criteria for turbidity and settleable solids must therefore be set for each particular area, basin, or stream if they are to be realistic. Turbidity criteria may be set on the basis of the penetration of a certain percentage of incident light to a given depth, for example, it might be stated that 4 per cent of incident light must reach a depth of 6 feet.

Criteria for temperature, dissolved oxygen, and pH can be expressed in fairly definite terms for warm and cold-water fish populations over extensive areas. For a well-rounded warm-water fish population, it has been suggested that water temperatures should not exceed 93° F. at any time or place and that D.O. levels should not fall below 5.0 p.p.m. for more than 8 hours in any 24-hour period, and at no time should the D.O. go below 3 p.p.m. (11). The same recommendation is made for coarse fishes except for a minimum D.O. level of 2 p.p.m.

Fish have tolerated pH levels between 5 and 9 and higher without apparent harm. However, they seem to do better between values of 6.5 and 8.2. While pH in itself does not appear to have much affect within the above range, it does affect the toxicity of many materials, the action of $CO_2$, and the ability of the fish to take up oxygen from the water.

Cold water fishes, especially members of the family Salmonidae, do best in clear, cold streams. Numerous studies have shown that, in general, streams having maximum temperatures in the range of 60 to 68° F. provide the best trout fishing. While trout live in streams reaching much higher peak temperatures, it has been found that streams with temperatures habitually in excess of 70° F. usually have large populations of minnows and suckers or other coarse fishes which seriously limit trout reproduction. While members of the Salmonidae can live for extended periods in waters containing 4 to 5 p.p.m. of dissolved oxygen, higher concentrations are needed at some life history stages and growth may be better at higher levels. According to present knowledge it appears that 6 p.p.m. of D.O. is the minimum required for successful completion of the life history and good production of the cold water species.

The toxicity to fishes of many materials is greatly influenced by the quality characteristics of the receiving water. Among these factors are temperature, D.O., pH, hardness, total alkalinity, $CO_2$, and dissolved materials which may exercise an antagonistic or synergistic effect. In general, metals are more toxic in soft water and at low pH; ammonia is more toxic as high pH. Such materials as the nickel cyanide complex become rapidly more toxic as the pH is lowered, while copper and zinc act synergistically and become more toxic when they are together (14).

For these reasons general numerical criteria cannot be set for most complex wastes. Bio-assays using dilution water from the receiving stream, are necessary to determine the toxicity of a particular waste in a particular stream. Safe dilution ratios for that waste can then be expressed numerically.

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**Summary**


It is customary for man to dump his wastes into streams. Since water is a universal cleansing agent and many wastes are water solutions, it is to be expected that wastes will continue to be discharged into streams and will be impossible to eliminate totally from water courses. Abatement should be directed toward maintaining waste concentrations below levels harmful to the beneficial uses of the

streams. Water resources are not only valuable but essential to continued existence. The principle of multiple use must be given more than lip service and must be earnestly applied if water supplies are to meet increasing demands. The discharge of sewage and industrial wastes into streams is not the sole cause for the declining value of our aquatic resources. Misuse of watersheds is an outstanding cause. Water and land resources are interdependent entities and good land management is a prerequisite for good water management.

Water quality criteria must be established and enforced if the favoured beneficial uses of our watres are to be preserved. These criteria or standards must be based on knowledge of the minimum requirements essential for the protection of each beneficial use. Cooperation among the various agencies concerned with water resources and water uses is vital if supplies are to be protected and the most beneficial uses given preference in the setting of criteria. All uses must be recognized and the greatest good to the largest number over the longest time should be the determining factor in a decision on the highest uses of any aquatic resource. Aesthetic and recreational uses have great economic value and are increasing in importance. Increasing interest in aquatic sports demands increasing concern for these water uses. While water quality criteria are largely undeveloped for some uses, considerable progress has been made in the setting up of criteria for aquatic life. A knowledge of the environmental requirements of the species to be protected is basic to the establishment of such criteria. While much remains to be learned, the data now at hand can be used effectively to meet existing problems.

# LES REPERCUSSIONS DE L'EMPLOI DES DESHERBANTS CHIMIQUES SUR LA FAUNE AQUATIQUE

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## I. — INTRODUCTION

Actuellement, les ingénieurs auxquels incombe l'entretien des cours d'eau, rivières, canaux d'irrigation, réservoirs d'eau de consommation, etc., et les pisciculteurs qui désirent conserver leurs étangs en un état convenable à la croissance et à la reproduction des poissons recourent de plus en plus à l'emploi du désherbage chimique. De cette façon les ingénieurs empêchent la dégradation des berges, libèrent les voies d'eau obstruées par une végétation trop dense. Les pisciculteurs détruisent les plantes envahissantes impropres au développement normal des alevins d'élevage. D'autre part, les entomologistes envisagent parfois la destruction de la flore aquatique pour mieux lutter contre les larves de moustiques ou de simulies. Mais on est en droit de se demander si ces opérations qui mettent en œuvre des produits chimiques, plus ou moins toxiques, ne peuvent pas éventuellement compromettre la santé publique ou avoir sur la faune aquatique spontanée, des incidences plus ou moins graves. C'est pourquoi il nous a semblé utile, dans le cadre du point « d » du thème I consacré entre autres « aux résultats de la conservation du sol et de l'eau sur les ressources aquatiques naturelles », de présenter l'état de nos connaissances actuelles sur le problème de la lutte chimique contre les plantes aquatiques et sur les incidences que cette opération peut entraîner.

## II. — RÔLE DES PLANTES AQUATIQUES

En premier lieu, il faut souligner que les plantes aquatiques, qu'elles soient plancton, algues filamenteuses, plantes de berges ou plantes flottantes, sont loin d'être inutiles lorsque leur développement est en équilibre avec la surface et le volume d'eau environnant. Hotchkiss (1939) a énuméré les principaux rôles que jouent les plantes dans l'économie du cours d'eau ou de l'eau stagnante. Ces rôles sont loin d'être négligeables. En effet, les plantes aquatiques :

— assurent la production d'oxygène indispensable à la vie des animaux pourvus de branchies et tout particulièrement des poissons,

— favorisent le développement de toute une faune dont les poissons font leur nourriture,
— procurent un ombrage pour les poissons et pour les œufs, ceux-ci étant très sensibles à la lumière du jour, comme l'a montré récemment Thomot (1958),
— forment pour les alevins des refuges indispensables pour les préserver des poissons carnivores,
— clarifient l'eau en facilitant la précipitation des matières colloïdales en suspension.

D'autre part, nombreuses sont ces plantes qui par leur port, leur feuillage ou leurs fleurs, sont d'un effet décoratif indiscutable et qu'il est souhaitable de ménager.

La destruction rapide des plantes aquatiques peut donc amener, par leur seule disparition, des perturbations considérables dans le milieu. De plus, leur destruction par nécrose lente entraîne une fermentation intense qui, à elle seule, peut causer la mort de nombreux poissons et batraciens.

Le désherbage chimique des eaux mettant en œuvre l'emploi de produits chimiques plus ou moins toxiques, doit être précédé d'une connaissance approfondie des produits eux-mêmes et de leur technique d'emploi.

## III. — LES DÉSHERBANTS

Les principaux produits chimiques pouvant être utilisés pour détruire les plantes aquatiques constituent actuellement une gamme très importante, dont la liste sera donnée ci-dessous :

A. — *Composés minéraux :*

1. Sulfate de cuivre.
2. Arsenite de sodium.
3. Sulfamate d'ammonium.
4. Borax.
5. Permanganate de potassium.

B. — *Huiles minérales.*

C. — *Composés organiques de synthèse :*

1. Esters du 2,4-D ou acide 2,4 dichlorophénoxyacétique.
2. 2,M-4, C-P-A ou acide 2-méthyl-4-chlorophénoxyacétique.
3. 2,4,5-T ou acide 2,4,5 trichlorophénoxyacétique.
4. Aminotriazole ou 3-amino-l-H-l-2-4 triazole.
5. Monuron ou N-(4 chlorophényl) N'-N' diméthylurée.

6. Dalapon ou 2,2-dichloropropionate de sodium.
7. Acide trichloroacétique.
8. Delrad ou acétate de déhydroabiéthylamine.

La toxicité de ces divers produits pour la faune aquatique sera examinée ci-dessous.

### A. — **Composés minéraux.**

Deux composés minéraux désherbants, le sulfate de cuivre (Moyle, 1949, Documents Phelps Dodge Refining Corp.) et l'arsenite de sodium, sont actifs contre le plancton végétal, les algues filamenteuses et les plantes submergées. Le sulfamate d'ammonium agit surtout sur des plantes dont une partie des organes végétatifs est émergée. Les autres produits sont peu employés.

#### 1. Sulfate de cuivre.

Ce produit est actif à :

0,1-0,5 ppm (1) contre *Microcystis* sp.;
0,1-1 ppm contre *Anabaena* sp., *Spirogyra* sp.;
0,33 ppm contre *Hydrodictyon* sp.;
0,5 ppm contre *Chara* sp.

Il se trouve que ces doses sont assez proches des doses dangereuses pour *Huro salmoides* et pour quelques autres espèces de poissons et que, de ce fait, les marges de sécurité sont assez faibles. Ces faibles marges peuvent expliquer les résultats contradictoires qui ont été observés dans la pratique. Par exemple, Thorpes (1942) note que dans un étang traité régulièrement pendant 16 ans au sulfate de cuivre, la raréfaction du poisson était évidente. En revanche, Moyle (1949) constate que dans les lacs traités depuis 26 ans avec ce produit, la pêche est meilleure que dans des lacs non traités de la même région.

Mackenthun et Cooley (1952) précisent que l'accumulation du cuivre dans les vases des étangs ne présente pas de danger pour les poissons.

#### 2. **Arsénite de sodium.**

Ce composé, assez largement utilisé (Reed, 1956), est considéré également comme ne présentant pas une marge de sécurité bien

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(1) Les doses exprimées en « ppm » sont calculées sur un volume d'eau ayant 30 cm d'épaisseur. Par exemple, un épandage de 3 kg de matière active par hectare donne pour une couche d'eau de 30 cm, une dose de 1 ppm.

grande. En effet, les doses nécessaires pour détruire les plantes immergées exprimées en $AS_2O_3$, sont les suivantes :

2 ppm contre *Ceratophyllum, Potamogeton* sp.;
4 ppm contre *Oedogonium* sp., *Pithophora* sp., *Hydrodictyon* sp., *Najas* sp., *Elodea canadensis, Myriophyllum heterophyllum, Utncularia gibba, Myriophyllum* sp.

On admet en général avec Mackenthun (1950), que des doses de 10 ppm et plus sont nécessaires pour tuer les poissons. Mais il a été démontré que des doses plus faibles pouvaient ralentir le développement de certaines espèces. Par exemple, d'après l'Alabama Department Conservancy (1955), 4 ppm de $AS_2O_3$ réduisent la production de *Lepomis macrochirus* de 30 % et 8 ppm de 65 %. Lawrence écrit : « La moyenne de production d'un étang en *Lepomis macrochirus* était de 16,8 % plus faible après deux applications à 4 ppm en 1955 et une application en 1956 que dans les étangs non traités. Les perches américaines, à la suite de ces mêmes traitements, avaient une croissance ralentie. Ce phénomène n'est peut-être pas dû à l'action directe de l'arsénite de sodium sur les poissons. L'arsénite peut agir indirectement en empoisonnant une partie des animaux leur servant de nourriture ».

Les observations de Surber et Meehean (1931) semblent confirmer cette hypothèse. En effet, si les Odonates, Libellules, Gerris survivent à des doses de 10,5 à 21 ppm de $AS_2O_3$, les Éphémères et de nombreux amphipodes sont tués pour des doses de 2,5 à 4 ppm.

Les effets de l'arsénite de sodium sont fugaces. Lawrence a dosé le $AS_2O_3$ après épandage. Un traitement effectué à raison de 4 ppm permet de retrouver, 24 heures plus tard, 3 ppm de $AS_2O_3$ sur une profondeur de 75 cm. Dès le lendemain, sur 3,6 m on ne retrouve plus que 0,3 à 0,8 ppm.

3. **Sulfamate d'ammonium.**

Ce produit est actif sur de nombreuses plantes émergées à la dose de 5 ppm : *Lotus, Nuphar, Carex* sp., *Typha latifolia, Sagittaria sagittifolia, Lemna minor.*

La non-toxicité du sulfamate d'ammonium, dans les conditions normales d'application, a été constatée sur les poissons et les grenouilles par Bauman (1947). A 10 ppm, Surber (1948) a constaté également la non-toxicité de ce composé sur les poissons.

Les deux produits suivants semblent d'un emploi encore plus délicat bien que l'on ne possède pas sur eux de renseignements bien complets sur leur toxicité.

4. **Le borax.**

D'après Lawrence (1958), le borax est susceptible, à la dose de 12 ppm, de détruire les *Pithophora* et à 350-650 ppm, les *Najas, Elodea, Potamogeton.* Mais ces dernières doses sont dangereuses pour les Daphnies, aliments très appréciés des poissons. En effet, d'après Anderson (1946), pour immobiliser ces crustacés, 240 ppm suffisent.

5. **Le permanganate de potassium.**

Ce produit est actif à la dose de 20 ppm sur les *Ceratophyllum* et *Pomatogeton,* mais au-dessus de 5 ppm, le permanganate de potassium est dangereux pour les poissons.

B. — **Huiles minérales et solvants aromatiques.**

Ces produits s'utilisent à des doses assez élevées contre les plant immergées (Craft, 1949). Par exemple:

150 à 300 ppm pour le Benoclor 3 C;
600 à 1 400 ppm pour le Solvant Naphta.

D'après plusieurs auteurs (Hilliard, 1952; Seale et Coll., 1952) des composés voisins sont toxiques pour des doses de 250 à 350 ppm et même moins, pour de nombreux poissons, les mollusques, les écrevisses, le plancton.

Le diesel fuel à faible dose, parfois employé seul ou pour dissoudre *d* autre composés désherbants, communique un goût très désagréable susceptible de durer pendant les 4 à 6 semaines qui suivent l'application.

C. — **Composés organiques de synthèse.**

La plupart des produits organiques qui seront cités ci-dessous ne sont valables que pour assurer la destruction des plantes émergées, des plantes de berge et des plantes flottantes. Les principaux sont des esters du 2,4-D, le 2,4,5-T, l'aminotriazole, le Monuron, le Dalapon, l'acide trichloroacétique. Seul le Delrad est strictement algicide.

1. **Esters du 2,4-D.**

D'après Harrison et Rees (1946), la dose léthale 50 en acide 2,4-D est de 2 000 ppm pour les *Cyprinodontidae* et *Ameiurus nebulosus* et de 1 000 ppm pour *Eupomotis gibbosus.* La dose léthale 0 serait 1 500 ppm pour les *Cyprinodontidae* et 500 ppm pour les deux autres espèces.

Les esters du 2,4-D, l'ester butylique et l'ester isopropylique sont plus toxiques que le sel de sodium. Il faut souligner, néanmoins, que les esters s'emploient à des doses plus faibles que le sel de sodium ou l'acide.

En effet, d'après King et Penfound (1946) la dose dangereuse de 2,4-D-Na pour les poissons est de 100 ppm et Cope (1946) a montré que les individus jeunes de *Salmo gairdneri* supportaient 112 ppm sans dommages. Lhoste et Roth (1946) ont montré que le développement des têtards de *Rana temporaria* n'était pas affecté pour des doses de 100 ppm.

En revanche, Snow (1948) a montré que l'ester butylique du 2,4-D tuait 40 % des alevins de *Lepomis macrochirus* pour des doses de 1 ppm. A la dose de 5 ppm, une mortalité totale était obtenue. A la dose de 10 ppm, l'ester isopropylique, selon Geagen (1954), est toxique pour ces mêmes alevins. Ces deux esters doivent être utilisés comme désherbants aux doses suivantes :

0,05 ppm contre *Eichhornnia crassipes;*
0,25 ppm contre *Sagittaria sagittifolia, Polygonum* sp.;
0,5 ppm contre *Nymphaea alba, Nuphar lutea, Hydrocotyle vulgaris, Carex* sp., *Typha* sp., *Scirpus lacustris, Polygonum* sp., *Lemna* sp.;
10 ppm contre *Najas, Elodea, Potamogeton.*

Donc, si l'on fait abstraction de ces trois dernières espèces, on constate qu'il existe une marge de sécurité importante entre les doses nécessaires pour détruire les plantes aquatiques et les doses dangereuses pour les poissons. Néanmoins, il ne faut pas oublier que Zischkale (1952) fait remarquer que les esters du 2,4-D et l'ester isopropylique en particulier, peut déterminer des pertes importantes chez les animaux inférieurs servant de nourriture aux poissons. En effet, ce composé, selon cet auteur, à :

0,1 à 0,4 ppm tue 25 % des crustacés;
0,4 à 2 ppm tue 25 % des insectes;
2,4 à 3,3 ppm tue 25 % des mollusques.

D'autre part, le 2,4-D et ses dérivés peuvent contenir sous la forme d'impuretés, des dichlorophénols et de l'orthomonochlorophénol qui, selon Bandt (1940), peut provoquer une altération organoleptique de la chair des poissons.

2. **2-M-4-C-P-A.**

Ce composé, assez voisin du 2,4-D, fut beaucoup moins bien étudié que ce dernier produit en ce qui concerne son action sur les plantes aquatiques. La raison en est certainement que son action désherbante sur ces plantes est moins grande que celle du 2,4-D. Sa toxicité pour les animaux serait, au contraire, plus élevée. Hillard (1952) considère que le sel de sodium du 2-M-4-C-P-A aux doses de 35 à 75 ppm, serait dangereux pour les poissons.

3. **2,4,5-T.**

Le 2,4,5-T est très actif sur de nombreuses plantes. Il s'emploie à des doses plus faibles que le 2,4-D sur les plantes aquatiques et de berges comme le montrent les chiffres suivants. Il s'utilise en effet à :

0,3 ppm contre Carex sp., *Sagittaria* sp., *Typha* sp., *Scirpus* sp., *Polygonus* sp.;

0,5 ppm contre *Nymphaea* sp., *Lotus* sp., *Nuphar* sp., *Hydrocotyle* sp., *Lemna* sp.;

3 ppm contre *Ceratophyllum;*

10 ppm contre *Elodea, Potamogeton.*

A 5 ppm une mortalité totale des *Lepomis macrochirus* a été observée. En conséquence, il est donc souhaitabe d'éviter l'emploi du 2,4,5-T contre les *Ceratophyllum, Elodea* et *Potamogeton.*

4. **L'aminotriazole.**

Ce produit est actif sur certaines plantes, à des doses faibles. On l'emploie, en effet, à :

0,6 ppm contre *Sagitaria* sp., *Typha* sp.;

1,2 ppm contre *Nymphaea.*

C'est un des désherbants les moins toxiques pour la faune aquatique. La dose léthale 50 est pour *Lepomis macrochirus* de 10 000 ppm. La dose léthale 0 est de 1 470 ppm.

5. **Le Monuron.**

Le Monuron détruit à la dose de 10 ppm le *Potamogeton* sp. et *Eichhornia crassipes.*

Ce produit est assez toxique. Aux doses de 4,6 à 15,4 ppm on observe une certaine mortalité chez *Huro salmoides, Lepomis macrochirus.* De plus, les individus de cette dernière espèce ne fraient plus. En aquarium, à 20 ppm, les jeunes *Notemigonus crysoleucas crysoleucas* sont intoxiqués.

### 6. **Le Dalapon.**

Il existe une large marge de sécurité entre les doses désherbantes et les doses toxiques pour les poissons. En effet, le dalapon s'utilise à :

0,6 ppm contre *Sagittaria* sp., *Polygonum* sp.;
1,2 ppm contre *Typha* sp.

Il a été démontré, d'autre part, que l'« Emerald Shiner » résistait à une dose de 3 000 ppm de Dalapon-Na. C'est seulement à la dose de 5 000 ppm que tous les poissons étaient empoisonnés.

### 7. **Acide trichloroacétique.**

Sous la forme de sel de sodium, cet acide peut être utilisé à 10 ppm pour détruire *Najas* et *Potamogeton.*

Peu toxique, ce composé, selon Geagen (1953), n'est pas dangereux à la dose de 102 ppm pour les alevins de *Huro salmoïdes* et à la dose de 56 ppm pour les « white crappis » selon Hillard (1952).

### 8. **Delrad ou acétate de déhydroabiéthylamine.**

C'est le seul composé organique qui, actuellement, possède des propriétés spécifiquement algicides. En effet, à la dose de 0,3 ppm le Delrad détruit *Microcystis, Anabaena, Spirogyra. Oedogonium,* A la dose de 0,5 ppm, *Pithophora, Hydrodictyon* sont attaqués (Lawrence, 1958).

Mais dès la dose de 0,7 ppm, les poissons rouges, les jeunes individus de *Huro salmoides*, les brêmes, sont intoxiqués (Lawrence, 1954 et Mackenthun, 1955). A 1 %, ce produit peut provoquer une destruction importante de diverses espèces de poissons (Eipper et Brumsted).

## IV. — DISCUSSION

Lawrence (1958) a pu fixer les doses de désherbants qui ne sont pas dangereuses dans les conditions normales d'utilisation. Cet auteur a comparé les doses en général supportées par les poissons et les doses léthales médianes pour le rat blanc. La plupart des renseignements fournis par Lawrence son trésumés dans le tableau I.

Il ressort de ce tableau qu'il n'y a pas un rapport constant entre les doses non toxiques pour les poissons et les doses léthales 50 pour les rats. Par exemple, le Monuron peu toxique pour les rats qui supportent 3.500 mg/kg (DL 50), est dangereux pour les poissons à moins de 1,2 ppm dans l'eau.

TABLEAU **I. — Doses supportées par les poissons exprimées en ppm et DL 50 pour le rat, traduites en mg/kg** (d'après Lawrence, 1958).

| Produits | Concentrations sans danger pour les poissons (en ppm) | DL 50 pour le rat (en mg/kg) |
|---|---|---|
| Sulfate de cuivre | 0,5 à 2 | 300 |
| Esters du 2,4-D | 3 à 5 | 500 (pour l'acide) |
| Arsenite de Na | 18 | 13 |
| Acide trichloroacétique | 50 | 3.370 |
| 2, 4, 5-T | 3 | 300 |
| Aminotriazole | 1.470 | 14.700 à 25.000 |
| Sulfamate d'ammonium | 10 | 3.900 |
| Baron | 5 | 1.000 à 3.500 |
| Dalapon | 3.000 | 5.590 à 8.120 |
| Delrad | 0,5 | 850 |
| Silvex | 3 | 650 |
| Borax | 130 à 200 | 5.330 |
| Monuron (CMU) | 1,2 | 3.500 |
| 2-M-C-MA (acide) | 35 | 28 (DL 100) |
| Permanganate de potassium | 3 à 5 | 500 |

## CONCLUSION

Pour détruire la flore dans des canaux non peuplés et dont les eaux sont très diluées avant d'être utilisées, tous les désherbants peuvent être employés et, en particulier, les huiles minérales. S'il s'agit d'eaux dans lesquelles vivent des poissons, il faudra proscrire l'emploi de certains composés tels que les esters du 2,4-D, du 2,4,5-T ou l'acide trichloroacétique pour détruire les plantes immergées. Ces mêmes produits, au contraire, seront recommandés pour éliminer les plantes plus ou moins partiellement émergées. Ils nécessitent en effet des doses infiniment plus faibles pour intoxiquer les plantes à feuilles aériennes que pour intoxiquer les algues.

On peut conclure avec Stickel et Springer que « ... peu d'herbicides sont très toxiques pour les poissons... » et que lorsque ces produits sont appliqués avec soin les risques d'intoxication sont très faibles.

Si cet aspect de l'emploi des désherbants chimiques et de son incidence sur la faune ichtyologique peut être considéré comme partiellement résolu, il ne faudrait pas pour autant en conclure que tous les problèmes relatifs aux désherbages des étendues d'eau soient clarifiés. Par exemple, on possède encore actuellement peu de renseignements sur l'action ovicide des désherbants et on recommandera, par prudence, d'éviter de traiter au moment de la ponte.

Enfin, en ce qui concerne les eaux d'irrigations et de consommation, une réglementation sévère doit être établie afin qu'en aucun cas ces eaux ne puissent contenir des traces de produits désherbants, traces nocives soit pour les cultures et la flore spontanée, soit pour l'homme et les animaux à sang chaud.

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# THE INFLUENCE OF DRAINAGE WORK AND RECLAMATION ON STOCKS IN DANISH ESTUARINE WATERS

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## INTRODUCTION

During the last twenty years or so a large number of projects of land reclamation, covering a total of about 70,000 hectares of Danish territorial waters, have been planned. These projects are mainly intended to make available new agricultural land to replace land which is gradually being withdrawn for the construction of roads, urban areas, military drillgrounds, etc. (about 2,000 hectares a year), but they are also intended as occupational measures in those parts of the country where unemployment problems exist.

The inner Danish waters on the whole are shallow, and about 144,200 hectares have a depth of less than 2 metres. As only the shallow waters are of interest for reclamation projects, the 70,000 hectares proposed for these projects will involve the reduction by almost half of the total shallow area mentioned above. The fry of several of the species of fish which economically play an important part in the Danish fishing industry (flounder, plaice, eel) spend part of their lives in shallow water; therefore it is obvious that the drainage of these areas suitable for their growth will involve a severe loss to the fishing industry.

It is understandable, therefore, that the fishermen have made strong protests against the plans for reclamation and demanded a fishery-biological investigation into the shallow marine areas, so that the agricultural and piscicultural values could be weighed against one another. Such research is now being carried out in each of the territorial waters intended for draining.

The reclamation plans involve a total of about 90 fjords and bays or creeks, a large number of which have an estuarine character. As the shallow estuaries, which frequently have only a narrow connection with the sea, are particularly easily and cheaply drained, these are at the top of the list for draining and have therefore been the special object of the preliminary fishery-biological investigations which were started in 1954.

The salinity in the estuaries is rather fluctuating, but nearly always below 20 per thousand, which severely limits the number of fauna species. The depth is on the whole very low, most often less than one metre and the fish fauna therefore mainly consists of fry.

### The production of the estuaries.

In order to get an accurate impression of the value of the estuaries for the fishing industry it was decided to examine the existing reclamation projects on four different planes :

1. A quantitative investigation of the micro-flora, especially diatoms, with production determinations of photosynthesis as well as of the growth and amount of the higher plants.

2. A quantitative examination of the fauna attached to bottom and vegetation and which serves as food for, or competes with, the fish fauna.

3. An attempt at determining the number of fish, the possibilities of growth and other biological conditions of the various species of fish.

4. On the basis of statistical information from the fisheries, to arrive at a figure for the value to the fishing industry of the area investigated and to compare this with a similar figure obtained as a total result of the first three items of the investigation.

#### Plant production.

The higher plants (*Zostera, Ruppia,* algae) seem to be only of indirect importance to the fauna, as no fish and very few members of the invertebrate fauna consume higher plants. The indirect importance of this vegetation is :

1. the surface of the bottom of the sea is increased by the surface area of the plants so that there is space for more animals bound to a substratum and for sessile diatoms;

2. the plants serve as protection to fry and a large population of rapidly reproducing crustaceans (*Gammarus, Idothea*), which constitute important food for the fish fauna.

In contrast to the higher plants the lower ones (especially the diatoms) form an important link in the direct food chain. The diatoms form brown coatings on the bottom of the sea, where they are consumed by the deposit feeders, and they grow on the higher plants, where they are rasped off by gastropods and crustaceans.

The number of individuals of the free-living diatoms vary from about 100,000 to a few millions per square centimetre of the bottom surface; of less importance are various flagellates and green and blue-green algae.

Through assimilation experiments an estimate has been made of the quantity of organic matter produced by the micro-organisms. A gradually standardized experimental methodology has made it possible for the results from various localities to be compared.

Productivity is strictly determined by seasons and localities; it is therefore necessary to make a considerable number of assimilation experiments in each area, and preferably every month, in order to obtain a fairly reliable average result. The potential productive power of the microscopic bottom vegetation is indicated by the number of milligrams of carbon assimilated per day per square centimetre.

Steemann Nielsen's method for measuring the intensity of photosynthesis by means of radio-active carbon is used in the case of diatoms.

Experiments have shown that the production of plankton plays a rather minor role in the shallow estuaries, but some plankton organisms are continually conveyed to these areas by the water exchange caused by the tides.

**Fish food**

The amount of fish food is estimated in the classical way, by quantitative bottom samples taken with the Petersen bottom sampler. In order also to make a quantitative survey of the micro-fauna (*Ostracoda, Copepoda, Nematoda, Oligochæta*) small bottom samples are taken with a core sampler, and the samples are sorted under the microscope.

Examinations of the stomach contents in the fry of the species of fish occurring in the estuaries show that the micro-fauna plays an extremely important part.

On the basis of the quantitative bottom samples it is possible to estimate the amount of fish food, i.e. standing crop, in the estuaries. The following table shows the fresh weight of bottom animals in a typical Danish estuary.

| | gr. per sq. m. |
|---|---|
| Class I. — Fish food (worms, crustaceans) . . . . . . . . . . . . . . . . . . . | 45 |
| (the micro-fauna) . . . . . . . . . . . . . . . . . . . . . | 5 |
| Class If. — Fish food (gastropods : *Hydrobia, Littorina saxatilis*) ... | 37 |
| Almost or completely valueless bottom animals (lamellibranchs : *Mya, Cardium*) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | 100 |
| Total . . . . . . . . . | 187 |

On the basis of the information available as to the growth, number of annual generations, etc., of the various species it can be estimated that the annual net production of first-class fish food amounts to 185 grams per square metre per year. Assuming that the whole of this production is converted into fish flesh at a rate of conversion of 5 : 1 we shall get the theoretically maximum annual production of fish, which is 37 grams per square metre, corresponding to 370 kilograms per hectare.

It would be interesting to compare the production of fish food in the estuaries with conditions in the open sea. There, however, fish have some keen competitors for food among the invertebrates (e.g. echinoderms) and it would therefore be impossible to make a reasonable calculation of conditions in the open sea. In the Danish estuaries fish have very few competitors for food among the invertebrates (crabs, shrimps).

In the fish food estimate quoted above the amount consumed by these competitors has not been deducted. This fact, however, is more or less compensated for, as a few pelagic animals (*Mysis*) are not included, although they are in fact of some importance as fish food.

The estimated annual production of fish flesh per hectare corresponds to the production in ponds where no feed is given.

Fish fauna.

It is rather difficult to determine the magnitude of the total fish stock. By a combination of various methods of marking and by experiments with trawls for young fish the following average density figures for the various species have been obtained :

| | Number per ha | Weight in kilos per ha |
|---|---|---|
| Gobies, sticklebacks . . . . . . . . . . . . . . . . . . . . . | 30,000 | 55 |
| Pipe-fish (*Syngnathus*) . . . . . . . . . . . . . . . . . . . . . | 15,000 | 30 |
| Flounder (*Pleuronectes flesus*) . . . . . . . . . . . . . . . | 2,500 | 21 |
| Eel . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | 400 | 20 |
| Eelpout (*Zoarces viviparus*) . . . . . . . . . . . . . . . | 400 | 10 |
| Total . . . . . . . . | 48,300 | 136 |

Besides the species mentioned above, cod, young herring, plaice, and sea trout occasionally occur, but in such small quantity that they are of no value from an economic point of view. An essential reason why trout are not common is presumably the increasing pollution of the streams, which spreads to the estuaries.

The total annual production of fish flesh amounts to about 400 kilograms per hectare, calculated on the basis of studies of the growth rate of the species and the mortality rate (which, incidentally, is very low in the estuaries). This figure agrees well with the production figure estimated on the basis of the amount of fish food. The fisheries, however, profit from only a modest part of this production, as 250 kilograms per hectare are economically valueless, while the remaining 150 kilograms represent young fish, which in winter emigrate to the open sea. It is estimated that the fisheries make a profit from at most 30 per cent of the emigrating fish, which further reduces the actual yield to 45 kilograms per hectare annually.

The Danish saltwater fisheries fetch 175-200 million Danish kroner (= about £ 10,000,000). Of these proceeds the plaice fisheries fetch 30-40 per cent, and these fisheries will not be affected by a possible drainage of the Danish estuaries, as the species does not occur in such waters.

The eel fisheries, which fetch about 10 per cent, are mainly based on silver eels immigrating from the Baltic. A large amount of eel fry, however, spends some of the summer months in the Danish estuaries, which offer excellent conditions of growth and protection from predation by fish, and the eel fisheries therefore will suffer a certain loss if these areas are reclaimed. The value of the annual fisheries for flounder amounts to 4-5 million Danish kroner (= about £ 250,000) for the whole country, an amount which will inevitably be lost through reclamation.

As stated above, pollution is the main cause of the decrease of trout fishing. Even though strict regulations have gradually been introduced which demand the purification of sewage, etc., an alarming number of the Danish streams are polluted. Even though much work is being done to purify sewage, we shall presumably have to face the fact that a process of general eutrophication of freshwater cannot be stopped in a densely populated country.

### The estuarine resources judged from other points of view.

A large number of Danish estuaries are preserved as sanctuaries for the many sea birds which pass through Denmark during the migration season. The shallow protected areas with their rich growths of reeds are of the greatest importance for the preservation of wild birds, especially in a country which, like Denmark, is almost completely cultivated. From the point of view of science and the preservation of natural amenities it is therefore to be regretted if the estuaries are lost.

With the intensive method of cultivation used by Danish agriculture, it is certain that the estuaries, if reclaimed, will give a higher economic yield than they do at present. The initial expenditure, however, will be so great that the necessary investment would return a considerably better interest if it were used for the improvement of the agricultural land already existing. An essential reason for this is the comparatively poor quality of the soil in the estuaries as seen from an agricultural point of view.

There is a possibility of improving the utilization of the estuaries by the fishing industry by establishing brackish-water pond farming, based partly on the food naturally present, partly on feeding. Experiments of this type have been started, but it is still too early to make any statement on the results.

# METHODS OF MINIMIZING THE DELETERIOUS EFFECTS OF WATER- AND LAND-USE PRACTICES ON AQUATIC RESOURCES

BY

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BACKGROUND PAPER

## 1. — INTRODUCTION

The primary purposes of this paper are to : (1) review the practical techniques that — applied to environment or stocks — may prevent, alleviate or capitalize on the consequences of environmental changes induced by water- and land-use practices; and, (2) to present suggestions as to how the acceptance of these measures can be achieved in the face of conflicting objectives.

The major effects of water- and land-use practices or works on the aquatic environment and its stocks have been related in other papers presented at this session [Theme I (*d*) ] of the Symposium, and we shall not treat of them in detail. Furthermore, there is no attempt — nor could one be made in this brief paper — to discuss the larger aspects of the relation of water- and land-use or conservation to the preservation and wise use of aquatic resources. It is obvious that aquatic organisms are dependent upon their habitat which, in turn, is dependent upon the interactions of many factors concerned with the hydrological cycle. Questions of watershed management and « the problem of co-ordinating the use and development of a river, to achieve the maximum net benefits to the economy and the amenities... » are treated in other sessions [Theme I (*b*)] of this Symposium, and the answers to that centrally posed problem can be understood to constitute both supplements and complements to this more severely limited review.

Although our ultimate interest is in the effects produced in the fish stocks, our primary practical task is to counter or profit by the effects produced in the environment and thus to preserve and, in some cases, enlarge the stocks. Some of the effects on environment constitute major changes; some are minor. Some may be harmful when they are produced in one drainage and yet when produced in another may leave its stocks quite unaffected or even benefitted. Again, some of these effects on environment may have a permanent influence on the stocks while others may have only temporary influence. Moreover, an influence exerted by some effects produced in the environment is not necessarily proportional to the duration of the phenomenon producing the effect, but rather the relation of the change in the environment with the vital features of the life-history of the stock is of most importance. Finally, some consequences to stocks of environmental changes are quite irremediable; others can be effectively offset.

It should be obvious, therefore, that one cannot construct a simple table showing, for each type of water- or land-use practice, the kind of environmental change it produces and then a measure or technique that will prevent or minimize the effects produced in the fish stocks. Nevertheless, the measures that can be taken (in the interests of the stocks) fall into a limited number of categories of practical action. Each of these has, generally, a relation with at least two, and often more, characteristics of the stocks. And, any of these practical measures may be considered in two ways : either with regard to the immediate physical operation involved — such as providing a way of access to migrating fish; or with regard to the characteristics of the stocks (their numbers, reproduction, etc.) which the measure aims to protect.

## 2. — BIOLOGICAL OBJECTIVES

We begin with an examination of these « biological objectives » by itemizing the different characteristics of the stocks, the ways in which they may be interfered with or exploited and indicating which of the practical measures may be applied to minimize undesirable changes or maximize desirable ones.

### 2.1 Reproduction and recruitment.

Perhaps the greatest attention has been paid to the problems of maintaining the reproductive activities of anadromous species; this is probably because the interruption of spawning migrations is the most easily observable consequence of these works. Although other aspects may be of equal importance, it is convenient to consider this one first.

2.11 Denial of access to spawning ground. — The fish may be denied access to the kind of situation in which they spawn; where this is brought about by the building of dams or other structures, means must be taken to allow passage across the obstruction (see 3.1). Other obstructions to passage to spawning areas must also be considered; e.g., those created by a fall in water level which exposes natural barriers (see 3.2).

2.12 Destruction of spawning sites. — In some instances it may prove possible to create alternative spawning sites within the natural situation; in others it may be found that potentially suitable sites can be opened up (see 3.8).

2.13 High mortality among juvenile stages. — Where such mortality is due to chemical or physical changes in the water within a dam it may sometimes be possible to take direct remedial measures (see 3.3). Where such changes take place in the flow below the dam special control of outflow may solve the problem (see 3.2). Sometimes changes in the fauna, resulting from the artificial junction of two river systems, may intensify predation on young stages of desired species; such a situation calls for special measures of predator control (see 3.5).

2.14 Reproduction or recruitment too low. — If one or more of the above situations should prevail and restorative measures of the kinds to be described should be unsuccessful, it may prove necessary to substitute artificial measures such as fish stocking (see 3.8). Measures of this kind may also be applicable in situations where species that have been introduced to fill some unoccupied ecological niche are slow in building up a sufficient reproductive potential.

2.2 **Growth.**

Here we are concerned with the efficient use of the whole range of food materials available within each system. Changes produced in the system by water- or land-use schemes may alter the magnitude and character of the supply of basic nutritive substances available for plant growth; if there should be reduction, measures may be necessary to restore the supply; if there should be increase, steps may be necessary to ensure that the resultant increase in flora takes place in desirable species of plants, and not in weeds. Furthermore, where there is increase in the flora steps may be necessary to ensure a favorable and efficient expansion of the fauna through all the links of the food chains. Often undesirable changes take place in such systems before appropriate measures can be taken and the program then must consist of restorative measures followed in some cases by measures to reconstruct and develop the ecosystem.

2.21 Reduction in food supply. — Changes in physical and/or chemical characteristics of the water of the system, or secondary changes induced in other elements of the biota (increase in predators, reduction in prey) may lead to a reduction in the quantity of the organisms fed on by the desired species. Sometimes an attempt may be made to restore the original habitat and its biota (see 3.3, 3.6, and 3.7), or it may be necessary to introduce new organisms able to thrive in the changed situation.

2.22 Denial of access to feeding grounds. — One of the consequences of the erection of barriers (such as dams) is that they may prevent access to normal feeding grounds. The measures described in 3.1 are appropriate.

2.23 Expanded habitat and/or increased biota.— Reference is made here to situations, such as in new impoundments of water, where a great increase in water area and volume may nevertheless give no increase of fish production because the endemic species are not adapted to the environment offered and thus cannot use the food available; or, in other circumstances, where the newly created zones (especially the mid-waters) do not become populated by food organisms appropriate to the endemic food species. In such cases there is necessary a detailed ecological analysis of the system and the adoption of various measures such as those discussed in 3.9.

2.24 Changes of physiological consequence. — The changes produced in the environments may have serious physiological consequences, inimicable to nutrition of the desired species; temperature may be changed to lie outside the optimum limits, although not to lethal limits; trace element concentrations may be changed; accessory dissolved organic substances may also be changed in concentration; dissolved gases and pH may also be changed. Any of these may have the effect of retarding growth of the desired species and making them less efficient in using available food supply.

2.3 **Mortality.**

Assuming that under the changed conditions presented the desired species are able to reproduce and grow, there still may be factors in the environment that increase mortality to a degree that will lead over a number of years to reduction or even extinction of the stocks.

2.31 Losses from changes in the hydrological regime. — Increases in rate of flow may be physically harmful to the fish; conversely, diminished flow may expose the fish to many hazards, such as the lethal effects of high temperature in shallow pools. Rescue operations to meet such situations are discussed in 3.3 and 3.4 — the latter dealing especially with the hazards in diversions and irrigation systems; alternatively, in some situations it may be appropriate to use screens or barriers to prevent the entry of the fish into hazardous water courses.

2.32 Damage from structures. — Physical damage may be caused to fish in passing over dams or through races and turbines. Carriage of fish past such hazards is discussed in 3.1; or, again, screens and other devices may be used to prevent the fish reaching these structures, but if movement past them is necessary, the problem of transport remains.

2.33 Increased predation and competition. — This may follow from disturbance of the original equilibrium of the system, or by allowing access to the system through connecting channels, for undesirable species. Measures for control of such organisms are discussed in 3.5.

### 2.4 **Composition and structure of the biota.**

The greater part of the foregoing discussion is based on a presumption that it is desirable to maintain the biota that existed in the system before measures were taken for water- and land-use. This may in fact be an erroneous presumption if we accept the general principle that the objective is to ensure the existence in the water body of an ecosystem that makes the fullest possible use of the characteristics of the body of water. Thus, if the ecosystem is found to be defective with regard to any of the above characteristics of the desired stocks, the correct approach is not merely to seek ways of patching up the system in order to restore it to the form it is thought to have had prior to the changes made, but to consider the entire system objectively to ascertain whether in fact drastic changes would not be desirable.

Of course, the biologist is here confronted with the serious problem that there may be great difficulty in trying to separate effects induced by environmental changes from defects inherent in the original ecosystem. He may have to make a strong effort of will to prevent himself from looking only for ways of restoring that original system, especially if policy makers should be inclined to insist on providing solely for those measures that might make good the damage done by their intervention.

### 3. — THE PRACTICAL TECHNIQUES

As a preliminary to this discussion of specific methods to offset the ill-effects of specific types of water- and land-use, let us first consider that : « It is rarely necessary ... to make an out-and-out objection to a proposed water-development scheme, or a part thereof, because of immediate and irremediable detrimental effects on fish life » (Miles and Job, 1955). To be realistic, one might better say that in most instances it is *useless* to make such out-and-out objections unless one can prove conclusively that the value of the fisheries greatly exceeds the other values to be created or promoted by the project.

Furthermore, if there is to be any use of water or land by man, then it is, of course, impossible to preserve the « natural state ». If, for example, a dam is to be built, then it will obviously drown out and convert a portion of the area above it into a new type of habitat with the magnitude of the change largely dependent upon the type of dam and its operation. Therefore, one can hardly minimize the extent of this habitat change — which brings about an accompanying change in the fauna and flora — unless one minimizes the effectiveness of the dam itself.

In some situations it does appear that the value of the original type of habitat and original type of fishery may outweigh any other considerations, and if one is to have both habitat and stocks unchanged then one must do without the dam. This is a controversial matter, well illustrated by the various disputes — important fisheries have not always been involved — within countries such as Japan, Switzerland and the United States concerning the construction of dams in National Park or wilderness areas.

However, in most cases land- or water-use will come, and it is usually better to try to work with the other users or consumers of water — exploring every possibility of alleviation of damage — and to determine the measures that should be taken well in advance of the construction period or while they may still be incorporated into the overall plan.

It is appropriate at this point to re-emphasize that the whole of this work should be guided by the principle that the objective is to secure an integral and efficient use of the resources of the bodies of water affected. Thus, it is an eminently « practical technique » (and perhaps we should have listed it as one) to have a complete ecological description of each situation and a careful appraisal of all elements of the system. If this is done, ways may be found not only to preserve the habitat and life of existing desirable stocks, but also of filling many niches that were previously unoccupied or have been created by the changes introduced.

Public interest in the effect of water-development projects on fish has — at least in the northern regions of the world — centered largely on the effect of dams on the migration of anadromous fishes, especially the salmonids (1).

(Attention has also been devoted to other groups, such as alewives, eels, shad, smelt and sturgeon in northern areas, and to catfishes, cyprinids, eels and mullet in southern areas.) We shall begin by an examination of what has been done or can be done to alleviate their ill-effects.

### 3.1 Minimizing the effect of dams or other manmade structures as physical barriers or deterrents to upstream or downstream movement.

#### 3.11 Passing upstream migrants.

(i) *Fishways.* — There are several ways of allowing fish to pass over dams by their own efforts, ranging from devices such as a simple notch cut in the crest of a weir to the several types of fishways in which fish swim up a simple chute or sluice; or « climb » up through a series of stepped pools separated by low weirs or connected by submerged orifices; negotiate their way through the more complex Denil-type in which closely spaced baffles in series in a chute slow the bottom currents; or swim up through a series of pools in which the velocity of the water is retarded by slots and baffles. Choice of the type to be selected involves consideration of engineering problems, economics and the biology of the species. For example, the type of dam may dictate the type of structure; the cost increase may be disproportionate to the height of a dam, and therefore it may not pay to transport a very small run of fish over a very high dam. Again, a fishway that is suitable for and readily accessible to one species of fish may be quite unsuitable for another. Pacific salmon (*Oncorhynchus*) will negotiate several types of fishways; striped bass (*Roccus saxatilis*) rarely use any of the existing types.

Although fishways may be able to function for a considerable period without much attention, all fishways require periodic inspection and repair and may require a continual adjustment of flow.

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(1) This has, in fact, received so much attention that it has often diverted interest from other problems concerned with dams that are of equal or even greater importance. For example, expensive fishways have sometimes been constructed in lieu of water release. (One of the authors recalls seeing a dam equipped with an excellent fishway but with a total release into the main river channel of only one-quarter of a cubic foot per second.) See also the account of the history of fishways in the development of Brazilian water resources (Charlier, 1957).

(ii) *Fish locks.* — These are essentially similar to navigation locks. Fish are attracted into the lock chamber by outflowing water and are prevented from leaving by a trap device. A lower gate is then closed and the chamber fills with water admitted through the floor. When the lock fills the fish swim out through an upper gate at a higher level.

(iii) *Fish lifts* or *elevators.* — The above methods permit the fish to proceed by on its own effort. A fish lift consists of a tank or hopper which fish enter and which is then hoisted mechanically to the stream above the dam where the fish are released. It may be noted that in addition to the facilities that actually enable the fish to ascend past the dam, it may be necessary to provide a « collection system » or channel which directs the fish to the fish-passing facility.

(iv) *Other means of transport over dams.* — Methods such as the above have been impracticable in some cases either because of mechanical difficulties or the exhorbitant expense of construction or difficulties of collecting fish. (Shasta Dam on the Sacramento River and Grand Coulee Dam on the Columbia River are examples.) In some such cases the fish may be trapped and then transported by tank trucks to release points above the dam, or even to other streams. Failing in such schemes to pass the dam, entirely different attempts to offset the termination of a migration route — and consequent reduction of stock — may be tried. (See 3.8 below.)

Although many fishways and other devices for guiding and passing fish over, through or around dams have been successful the mere fact that a fishway has been installed is no guarantee that the run will be preserved. It must be carefully designed, known to work, carefully maintained and always viewed with doubt rather than with optimism. Whatever method of ensuring upstream passage is used, it is imperative that the closest working relations be maintained between the fisheries biologists and the engineers and that a careful procedural plan be followed. (See Clay, 1955, for an example of such procedure.)

It must also be emphasized that even if the fish succeed in getting over a dam — injuries, delay to their normal upstream movement, or additional energy demands during the passage may still prevent fish from reaching their spawning grounds or may reduce their reproductive performance. Again, on a river containing a series of dams — even when the facilities for passage are good — the tax at each passage may be such that the numbers eventually arriving at the spawning ground may be below the minimum required for successful reproduction. According to Hourston *et al.* (1955, p. 443), « An economical and satisfactory method of passing a large run of fish over a high dam has not yet been devised. »

(v) *Some special cases.* — There are also special problems such as the passage of fish through tidal gates on estuaries or the transferences of fish from one aquatic medium into another that demand methods quite different from those described above. See, for example, Deelder's paper in this Symposium, which describes an ingenious method of allowing elvers to pass from the sea into inland waters.

Man-made structures such as culverts under roads may also require attention. Modifications of their position or gradient, the installation of baffles and the clearing of the stream above them constitute some of the methods whereby migration through them is facilitated. See McKinley and Webb (1956).

(vi) *Removal of barriers.* — The actual removal of abandoned dams or ones that no longer serve a useful purpose is also an effective tool of management and one that may re-open many miles of stream to migrant fish. See, for example, the reports by Handley and Coots (1953) and Wendler and Deschamps (1955).

3.12 Passing downstream migrants. — Until comparatively recently, concentration on the problem of getting upstream migrants over dams has distracted attention from the equally important problem of ensuring the safety and free passage of downstream migrants, both young and adult, through and around dams. Low dams with ample overflow may not present a problem. However, the numerous high dams and large impoundments of today present some formidable problems, especially with the anadromous salmons and trouts.

First of all, the creation of an area of water (the reservoir) above the dam lacking in strong directional currents may confuse and retard the downstream movements of young fish which may be directed largely by response to currents. Such delays may result in increased mortality of the fish or in their failure to leave the reservoir and their falling into a « residual status ». This latter effect may be of benefit to man if the fish can be caught or if they reproduce successfully. However, reproduction of such residuals (the coho, *Oncorhynchus kisutch*, for example) may not be successful, and they may compete with the truly migratory fish stocks. Changes in water temperature, the absence of suitable foods and increased predator populations in the reservoir are other factors that may seriously affect this downstream migration.

The authors are not aware of any devices that will speed up or ensure the downstream migration of young or adult fish through long areas of lacustrine waters. However, consideration might be given to trapping them near the head of the reservoir and transporting them by truck or barge to below the dam ([1]).

Of more immediate practical interest is the problem of getting the fish over the dam itself. Here the questions are of two sorts : (1) how to protect the downstream migrants from passing over or entering structures that will endanger them, and (2) how to direct them over or into structures that will permit them to pass with safety.

Generally speaking, most young fishes migrate near the surface and will select a surface exit, such as a spillway, if one exists. If the fall over the spillway is high, if the velocity of the spill is rapid, if the surface of the spillway is rough, and if a suitable basal pool is not present — then the descent in this way may be very dangerous.

The ill-effect of some of these adverse factors can be minimized during the designing period. For example, during the construction of the Cleveland Dam on the Capilano River, British Columbia, a « ski-jump » type of spillway was substituted for the original one. It was believed that the fall from this type might be cushioned and that mortality would not be as high as had to be expected without this innovation (Hourston *et al*, 1955). Investigations at several dams have shown distressingly high spillway mortalities. Where it is believed that this is an important factor, attention should be given to preventing escape (and consequent destruction) in this way. Screens might be used, but in most cases their installation on a large spillway is not physically practicable nor possible economically.

The same type of problem may also arise when fish strive to leave through diversion channels which lead them into the danger of stranding or through outlets which take them through valves or turbines where they may come to harm as through changes in pressure or by striking the runners. (The screening of such structures is discussed in section 3.4.)

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([1]) Ellis (1956) has described experiments with the transport of hatchery fish that may cast light on the matter, and the California Department of Fish and Game has just completed an experiment in trucking and boating salmon fingerlings the length of the Sacramento River to take them past diversions and areas of water pollution.

It must be realized, however, that the same type of channel that may in some cases lead a fish to harm may in other situations be the only means whereby downstream migrants can leave the reservoir.

Thus, just as a spillway may be the best means of permitting downstream migration, a diversion tunnel, penstock or other orifice may have to be utilized. In fact, some turbines of great size and low pressure may be satisfactory as a path of escape. (See, for example, Monten, 1955.) Other means of escape may be provided either through fishways themselves or through a separate set of bypasses, and experimental flumes have been used at at least one installation.

But even where existing or potential exits appear to be satisfactory the fish themselves may be unable to find or use them. For example, although chinook salmon (*Oncorhynchus tshawytscha*) may sound to a depth of 65 feet to seek an exit, other species such as *O. kisutch* will delay their migration until they find a surface exit (Anon., 1954, p. 16). Many experiments have been and are being tried to « direct » fish to use safe (or safer) exits, or at least to reach areas of safety or collecting areas from which they might later be removed [1]. Among the methods that have been tried are : artificial currents, artificial lights of various intensities and wave lengths and either constant or intermittent, shaded areas, hanging and oscillating curtains of chain or cable, veils or walls of air bubbles, chemicals producing odors or color, air and water vibrations, louvers, and various electric shocking devices. (See, for example, Andrew et al, 1955; Fields, 1957; Brett and Alderdice, 1958.)

Research aimed at finding means of ensuring adequate downstream migration has been imaginative, painstaking and promising, and some of the problems have been minimized. In 1952, various fisheries agencies joined with the U.S. Army Corps of Engineers in what is said to be the « largest coordinated interagency fisheries research program ever undertaken in an effort to resolve problems deriving from environmental water-use conflicts » (Anon., 1957?). Several reports on the progress of the work have been issued, but as late as February 1957 the Sport Fishing Institute (Stroud and Seaman, 1957, p. 100) felt that « There is no proven device for passing downstream migrants at high dams ».

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(1) As used by Brett (1953), « directing » with respect to fish may consist of : attracting, guiding, scaring or inducing.

### 3.2 Minimizing the ill-effects of changes in the magnitude and chronology of flows below dams.

When a dam is erected and operated for purposes such as irrigation, the production of hydro-electric power or flood control, the consequent changes in volume of flow below the dam may produce changes in the aquatic stocks since they may :

(i) Reduce or increase the space available to them;

(ii) Reduce or increase the size of spawning and nursery grounds or withhold access to them. (For example, the actual stream channel may be reduced, or overflows into beels, billabongs, oxbows, etc. be reduced.);

(iii) Reduce or increase the food-producing zones or change their components;

(iv) Produce changes in water velocity;

(v) Produce changes in water temperature;

(vi) Produce changes in water chemistry;

(vii) Produce changes in water turbidity;

(viii) Change the capacity of the stream for self-purification.

When it appears that such changes will be adverse, then consideration should be given to altering the original plans for operation so as to minimize their ill-effect. Whether or not this can be done is dependent largely upon economic considerations or how much compromise is possible between the interests of, say, power and those of fisheries, recreation and aesthetics. In some instances, the project itself may be of such a borderline nature that — to be economical — it may be necessary to squeeze every drop of water out of a stream; in other instances — probably most — some degree of compromise is possible, and at times it may even be possible to plan the project so that the net effect will be beneficial to all users. It is most important to realize that the cumulative effect of many small diversions of water — each appearing to be of minor significance — may eventually prove very serious.

With respect to any recommendations that may be made with regard to ensuring flows that are adequate in amount, duration, and quality, it is imperative that the fisheries biologist have a full understanding of the structures contemplated and their operation — and be informed of these facts well in advance of construction and not after the design has been fixed.

Furthermore, if the provision of adequate flows by modification of releases from the dam under study appears to be impossible, then consideration should be given to the ensurance of such flows by water regulation at other points, either upstream or downstream, or by providing releases from other basins through diversion.

If adoption of the recommendations for the satisfactory flows, or at least partly satisfactory ones, cannot be achieved, and the stocks are endangered, some measures of alleviation or substitution can still be prosecuted. For example, if barriers to migration are exposed by deficient flows, these may be removed. Or, fish that are stranded by low flows may be salvaged by netting or providing exit channels. If concentrated in areas of low flow where they are so easily captured that the population may be destroyed — they might be given sanctuary during the vulnerable periods. These are general statements, and the value of either of these substitution procedures is often questionable. (See also section 3.8.)

3.21 F l o w. — The most compelling requirement is simply that water be released from the dam, but the requirements must be specific, and — in the interests of the fishery — entire patterns of flow should be recommended. Thus, with reference to releases one might have to consider : minimum allowable, maximum allowable, desirable mean (if appropriate), seasonal such as summer and winter flows, diurnal patterns, holiday patterns, etc. It is also generally desirable to seek a modification of operating schedules that would cause sudden harmful flushings of the stream bed or sudden diminishments of flow that may also have harmful consequences. Although constant flows are sometimes recommended, the pattern approach is probably the ideal to strive for. For example, it might be of benefit to increase the flows at certain times so as to attract fish upstream. (See Hayes, 1953.) Or, it may be possible to use low flows at one time of year if compensated by increased flows which would create additional spawning area during another period.

It should be mentioned that the actual determinations of basic flows or schedules as have been suggested above are not easy to make and may require prolonged study. Different levels affect the width of a stream, its depth, its velocity, its temperature, etc., and all of these variables affect production. However, very little basic research has been done on the matter of determining the requirements for maximum production of aquatic stocks at various levels of flow. It must honestly be said that many of the recommendations made by fisheries agencies for minimum flows below dams are not based on very exact evidence. It may also be said, however, that this is not the fault of the present-day fishery worker. He is working in an applied field where but few basic principles have been determined, and — when confronted by the necessity of making such recommendations — is usually pressed for time and without opportunity to make the type of investigations that are desirable. His recommendations may sometimes fall into the category of an « informed guess », but they are still both necessary and generally better informed than any others would be.

It must also be said that the integration of the recommendations of the fishery workers with those of the other users of the water may be a most difficult accomplishment, and as with all types of multiple use — compromise is necessary.

3.22 Temperature. — Aside from such changes in water temperature as may result from increased or decreased volume of flow, the temperature of a stream below a dam is determined by factors such as the point of release from the dam, the time of year that water is released, the area of the impoundment, etc. Thus, if it is desirable to have warm water, surface spill should be provided; for cold water, low-level discharge should be utilized. Furthermore, consideration should be given to the natural temperature regime; the maintenance or approximation of such a cycle may be necessary to ensure the timing or survival of a run or to ensure reproduction of a resident stock.

In some situations, drastic temperature changes in the water below a dam may require the introduction of species of fish or other aquatic organisms that will be adaptable to the new conditions.

3.23 Water quality. — There are numerous instances of reservoir discharges of dissolved toxic gases or water with low oxygen or heavy silt content. Such discharges, especially when accompanied by pollution and high temperatures, have caused decided injury to stocks. Some such discharges are from new dams containing material creating high oxygen-demand, and the situation soon remedies itself. However, adequate clearing of the reservoir might have prevented even temporary injury. Discharges of this kind may occur when a dam is drained for repairs and — given a warning of the possibility of damage — some steps may be taken to prevent it.

In most instances, regulation of the time of discharge and source of the water discharged can aid in minimizing the ill-effects.

Where the discharge of unsuitable water is of a duration that prolongs the effect, other measures may be attempted. For example, Dendy and Stroud (1949) have suggested that a reaeration plant below a dam discharging oxygen-deficient water might make the physical environment in downstream reservoirs suitable for fish with high oxygen-demands.

It is not believed that changes in the magnitude or chronology of flows brought about by impoundment have usually caused lasting changes in the chemistry of the stream below that are harmful to aquatic organisms. The reverse, in fact, has been true in some instances ([1]). However, only long-range studies — such as are now being conducted on the Columbia River — will enable this point to be fully ascertained. Obviously, water diverted from a stream used for irrigation or industry and later discharged into the stream with changed quality may affect aquatic life — sometimes adversely.

### 3.3 **Minimizing the ill-effects on aquatic resources above a dam due to changes in depth or fluctuation in water level.**

The harmful effects of water fluctuation on the aquatic resources above a dam can be summarized as follows :

(i) May result in the stranding of fishes;

(ii) May result in destruction and lower production of rooted aquatic plants (that function as cover and as a habitat for food organisms);

(iii) May result in destruction and lower production of bottom food animals with consequent destruction or in some cases dwarfing of stocks;

(iv) May affect the success of spawning by uncovering nests or former spawning areas, or by covering them with too much water;

(v) May affect migration up tributary streams by exposing natural barriers at low water;

(vi) May produce changes in habits inimicable to the stocks.

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([1]) See, for example, Dill (1944) on the beneficial changes to aquatic fauna in the lower Colorado River following the erection of Hoover (Boulder) Dam which stabilized the composition of the water and reduced its alkalinity and total dissolved solids.

Rarely, if ever, can this fluctuation be eliminated since the primary purpose of most reservoirs demands that the water level in them should rise and fall. However, its potential ill-effects can often be diminished especially if the matter is considered during the planning stages of the project and steps taken to stabilize the levels during periods critical to fish.

Some dams are operated under a plan by which they may be completely drained in order to provide storage space for expected flood water or to provide emergency supplies during times of drought. For such dams the reservation of at least a « minimum pool » may ensure the survival of a nucleus of fish to repopulate the reservoir when it fills again.

It may also be possible to construct smaller secondary or sill dams across the mouths of bays or tributaries where water can be held at a constant level despite fluctuations in level in the main impoundment. The success of some such sub-impoundments has been limited, and there may be a tendency for them to function primarily as producers of undesirable stocks.

Cuerrier (1954) has investigated a Canadian lake where a decided difference in water level was created through the addition of a dam, with a subsequent change in the population of lake trout (*Salvelinus namaycush*), namely, the decrease in the number of large individuals and a slow growth in the numerous young ones. He concluded that the small trout were separated from their food requirements — largely through the increase in depth. The remedy he proposed was the introduction of a bottom-feeding forage species not present in the lake, to substitute for the species on which the trout had formerly subsisted but which, he believed, had not been able to adjust to the new environment.

In the event that uncontrolled fluctuations — either in the reservoir or in the lower stream — result in the stranding of fish, rescue or salvage measures may be undertaken; i.e., fish may be netted out and transported to safe waters. This is often difficult and expensive; the results may not be worth the effort.

On the credit side, controlled fluctuations such as the reduction of water levels immediately following the egg deposition by unwanted species may permit the control of these fish. Conversely, flooding the margins during the spawning season may be of benefit to some species. Further attention should undoubtedly also be given to the possibility of increasing the productivity of reservoirs by the inundation of marginal vegetated areas — both planted and unplanted.

3.4 **Prevention of fish loss in diversions or conduits (penstocks, pumps, canals, tunnels, etc.) from streams or reservoirs.**

Heavy losses may occur among fish — especially anadromous ones — that find their way into diversions, and it is often desirable to protect them by the installation of fish screens or other devices ([1]).

Although many types of mechanical devices have been invented, comparatively few of them have proved satisfactory. The choice among them is dictated by such considerations as : the size and shape of the aperture to be screened, the volume and velocity of flow, the amount and type of debris that will enter, the species of fish, their age and size, and whether they are upstream or downstream migrants. It is also dictated largely by the costs of installation and the costs and possibilities of keeping the screen in good operating order. Mechanical screens fall into several classes :

(i) Simple stationary panel screens of wire mesh or hardware cloth;

(ii) Simple parallel bar screens requiring manual cleaning, or self-cleaning bar screens fitted with wipers driven by paddle wheels;

(iii) Rotary-drum screens consisting of a drum covered with wire mesh and rotated by paddle wheels (or a motor) so that it cleans itsef of debris;

A variation of the rotary type developed by John (1954), and not in common use, consists of a series of circular discs mounted concentrically on an axle.

(iv) Belt-type travelling screen which consists of a series of mesh frames that run as a belt and are washed as they emerge from the water surface.

(v) The perforated plate screen, newer than any of the above, consists of a sloping metal plate with circular openings through which the water passes. A wiper bar travels up and down the plate removing debris.

(vi) Louver system which «... consists of a fence-like series of vertical steel slats. Each louver slat is set at right angles to the direction of stream flow. The louver system is placed diagonally across the canal. Fish, upon approaching the louvers, tend to avoid them and are swept downstream by the current. At the downstream

(1) Of lesser importance but worth consideration is the possibility of damage to upstream migrants which attempt to enter the draft tubes of power plants and find their way into the turbines. Studies of swimming capacities of the fish may enable one to determine whether protection is necessary.

end, the louver system terminates in a by-pass which the fish enter and follow into a pond or a channel leading downstream. » (Bates and Vinsonhaler, 1957, pp. 42-43.)

There are numerous variations of these basic types. For further descriptions see Wales *et al* (1950), Leitritz (1952) and the authors mentioned above.

Each location demands individual study and, as with fishways, the mere provision of screens is never enough. Screens situated on a diversion at some distance from the headworks must be provided with bypasses so that the fish can return to the stream, and neglect of this feature was a common fault in many early installations. Furthermore, mechanical screens require constant maintenance which is expensive and time-consuming.

The possibility of using electrical screens has excited attention and continues to do so, especially because they will allow the passage of debris and, therefore, are not subject to the clogging that is the bane of mechanical installations. Electric fish screens have been studied in Europe at least since 1912 (Meyer-Waarden, 1957) and in the United States since 1917 (Holmes, 1948), but their success is still limited.

In recent years considerable experimentation has been done with various type of deflectors, including electrical ones, or methods whereby the fish is repelled from entering diversions or attracted elsewhere. In general, the experiments on guiding or repelling described under section 3.12 apply here. It might appear that some of these methods might afford — in the end — a far simpler method of preventing fish from entering diversions than the cumbersome and expensive mechanical screens which, so far, still appear to provide the best method in general use.

There are some situations where it may be preferable to allow the fish to enter a diversion if they can be removed at a later time or at a lower point and returned to the stream channel or to another body of water such as a reservoir. This might be accomplished through flushing or pumping, or, as Clothier (1953, 1954) has shown may be possible for some trout in irrigation ditches, by reducing the flow in which case the fish may swim back into the stream. In other cases the diversion channel itself might be so improved that it becomes a satisfactory habitat for the entering fish.

Salvage (fish rescue) when a diversion is drained may be practised, but the expense is often not commensurate with the results.

In many of the more tropical areas where irrigation is practised it is virtually impossible to screen the canals through which many millions of fish eggs and fry enter the fields. If the inflow of water can be kept constant and is returnable to the streams, losses may be mitigated. In paddy-field culture it is, of course, advantageous for the fish to enter the fields to grow and be harvested as a crop.

### 3.5 Prevention of harmful introductions through diversions of aquatic organisms into drainage basins where they did not formerly reside.

The diversion of one drainage into another or the creation of an artificial waterway between drainages offers an opportunity for the sudden transference of a rather large assemblage of organisms to a new environment where its increase may have serious effects upon the resident fauna.

Furthermore, the introduction of even one species — and even if a long time ensues before it establishes itself — may be a very serious matter. One of the best known examples of such a dangerous introduction is the invasion of the Great Lakes above Niagara Falls by the parasitic sea lamprey (*Petromyzon marinus*) following the construction of the Welland Canal. Almost one hundred years (1829-1921) elapsed after passage became possible before the lamprey was recorded above the Falls, but as it gained foothold its effect became disastrous — causing the collapse of the lake trout fisheries in Lakes Huron and Michigan. In an effort to control the lamprey, a system of electro-mechanical barriers has been installed on spawning tributaries, and thousands of chemicals have been tested to find those toxic to larval lampreys and relatively harmless to other fish (Applegate and Moffett, 1955).

This is, of course, control after the introduction has been accomplished. Prevention of such introductions is most difficult with any of our present methods — especially if the connecting channel between waterways is one of gravity flow. It is almost impossible to screen out eggs or fry, and even if turbines or pumps intervene, the passage of at least some fish through them is well known. Lindsey (1957) in discussing the possible effects of water diversion on fish distribution in British Columbia has suggested that turbines might be modified specifically to kill fish, including their eggs. Research on this matter might turn up several other ways to kill unwanted entering fishes.

It is also possible (as he suggests) to eliminate unwanted fishes from a stream above its diversion point by the use of chemicals. This might be desirable for one drainage but perhaps not for the diverted one in that its fauna might be quite appropriate for it.

It is fast becoming a practice in North America to eliminate entire stocks of « undesirable » fish in streams by the use of chemicals —

later replacing them with « desirable » stocks. It may be especially valuable when a reservoir is to be constructed on a stream since it enables one to select the species of fish which will repopulate the waters.

### 3.6 Reducing the ill-effects of drainage, dredging, modification of stream courses and banks, and similar practices.

The extensive drainage of water or wet-land areas especially as a landgaining measure or as a method for improving cultivated soils, or for flood control has often effectively removed the feeding-, spawning- and nursery-grounds for riverine fishes as well as the habitat of those which dwell permanently in such areas.

Obviously, the competing claims of say, agriculturists, and fisheries (as well as wildlife) interests should be balanced. We cannot treat here of those conflicting claims in which the arguments and ill feelings on the subject are numerous and in which local and national politics, policies and economics are large considerations in determining the extent and type of drainage to be practised. We can say that land or water drainage schemes should be studied without bias, with an eye for the future, and with the full realization that such profound changes in the ecology of the land may well destroy far more than is produced. In any case, sometimes only a little thought will enable measures to be taken that will protect and may serve to increase the aquatic resources in the area.

It may, furthermore, be noted that there have been few attempts to estimate the relative potential returns of fishing from an inland-water area under a controlled system of management and exploitation and the results that might be obtained from the same area if drained and cultivated. One such study for a water area has been carried on for several years in Egypt with the co-operation of F.A.O. Technical Assistance experts, and more such projects might ensure better decisions with regard to the value of such drainage schemes.

A host of other types of land- and water-use and development may have a severe impact on aquatic resources. Among these may be listed : the flood control projects that alter the channels of streams — often turning them into raceways without holding places for aquatic organisms; the dredging of spawning beds to remove gravel; excessive removals of useful aquatic vegetation that impedes the flow of streams; the deposition of spoil; the lowering of natural lake levels to provide a water supply; the clogging of channels with the debris from lumbering, etc.

Where the damage has already occurred and is easily recognizable, a considerable part of the damage can often be undone. For example, log and debris jams left in streams by lumbering operations can be cleared out — even if with considerable effort and expense — to restore both habitat and migration routes. Similarly, denuded areas along stream courses can in time be replanted with vegetation; spoil can be removed; etc.

Or, the ill-effects of certain harmful practices — dredging for example — can be minimized by timing operational schedules so that the work is carried out during periods when fish requirements are at a minimum.

Better yet is the prevention of specifically harmful practices — often to be achieved by compromise or by joint planning. As an example, see the description by Voight (1958) of how a highway department accepted a proposal to include low flow channels as a standard specification for contractors on bridge and highway construction projects on fishing streams.

Over and above all is the necessity of using good soil-conservation, forestry and land-utilization methods that will conserve water, and will prevent watershed erosion. A voluminous literature exists on the effects of cultivation, overgrazing, logging and deforestation, burning of vegetation, the construction of highways and railroads, mining operations, and other activities of man that affect aquatic environments and hence their stocks. Good land use is generally good water use.

### 3.7 The prevention and control of water pollution.

The general effects of water pollution on aquatic stocks are well known, as are the general methods of preventing pollution or alleviating its harmful effects. As with most of the other measures suggested, one of the best ways to ensure pollution control is for the conservation or fishery agency to work with the industries and cities responsible for the pollution in aiding them to work out methods of prevention and disposal. Among these are: treatment of the effluent before release; discharge only during certain periods (as when the river flow is high and/or temperatures are low) when the harmful effects will be minimized; land disposal as by evaporation or burning; re-use of industrial waters; location of plants according to the type of waste produced; and re-design of industrial processes to reduce the quantity or improve the quality of the effluent. Other papers in this Symposium discuss the matter at some length.

It will suffice here to say that emphasis must be placed upon preservation and improvement of the aquatic habitat and that it is often in the slow degradation of the physical and biological environment that water pollution has its most serious effect. Rapid destruction of fish or mass mortalities are spectacular, but since in many cases this loss may be restored through natural reproduction, migration or artificial stocking, the ultimate effects of the destructive process go unrecognized. Consequently, the active entry of the biologist (in addition to the engineer and chemist) into the field of pollution research and control that has been evidenced in recent years is a noteworthy trend.

Another recent development that can promise much is the establishment of regional pollution control bodies such as the River Boards in England which deal with the functions of land drainage, freshwater fisheries and the prevention of pollution as well as water conservation within a given catchment area or group of catchment areas. Or, as is the case with certain bodies in the United States, their function may be concerned only with pollution (1). Cognizance of the value of such bodies was taken in the recent study prepared for the Economic Commission for Europe which recommended the establishment of such boards for both national and international rivers (2).

Along with the older forms of pollution (industrial waste, sewage, etc.) must be considered the growing use of insecticides, pesticides and herbicides. Some of the work with such toxins has been largely uncontrolled and when used by single-purpose minded individuals or agencies has been extremely harmful to aquatic stocks. It is undeniable that mosquito control (as by the use of dieldrin) or the control of *Simulium*, the vector of *Onchocerca*, (as by DDT) may be beneficial to man. However, such chemicals should be used cautiously and never without the knowledge of the agencies responsible for the maintenance of aquatic resources. Furthermore, account should be taken of the fact that various pests may develop resistant strains to the pesticides and that the latter's quick results should not allow neglect of a more fundamental type of control — modification of the environment — that may produce far more and more permanent results.

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(1) It should not be assumed that all such bodies do function effectively or in the best interests of the public — especially if (as may occur) there is an unproportionate representation of waste discharge interests.

(2) « A study of Water Pollution Control Problems in Europe », paper E/ECE/311, 26 February 1958, prepared by its Executive Secretary in co-operation with the secretariats of the World Health Organization and the Food and Agriculture Organization.

### 3.8 **Substitution of artificial methods as a replacement for reduced natural propagation.**

In situations where the habitat has been so reduced or changed that the natural stock has declined, or — in the case of migratory fishes — where it has proved impracticable to permit the fish to pass a barrier, various substitution methods may be tried.

Fish stocking. — The artificial propagation of fish is a practice that has been linked with inland fisheries for such a long time and so closely that in many countries the term « fish culture » in the sense of stocking fish has been held to be almost synonymous with fish management. This concept is, of course, an erroneous one since fish stocking is but one of many practices used to sustain and increase the resource. Artificial propagation is a valuable tool but cannot be thought of as an adequate substitute for a self-propagating natural resource.

It was originally assumed that any measure that reduced early mortality would be of benefit, and for many years no adequate investigations were made to determine the actual value of such activities. When thorough investigations were made *it* gradually became clear that much of the effort had been wasted.

Many of the early hatcheries that raised only fry or fingerlings, often under poor conditions and with poor methods of culture, transport and planting, contributed little to the restoration of the original stocks, and rises and falls in the fish populations were usually largely independent of hatchery operations. The accumulation of this knowledge has gradually resulted in the cessation of much of the earlier type of wasteful stocking (1).

While it is impossible to generalize — especially on a world-wide basis — it would appear that, as long as good spawning, feeding and rearing conditions prevail, attempts to substitute artificial for natural propagation are largely wasted. This applies especially to warm-water fishes such as those which dwell naturally in many lakes and streams affected by water-development projects or those which come to dwell in the reservoirs resulting from such projects.

With respect to salmonids, however, improved methods of culture including careful selection of stocks and the rearing of fish to larger size make it possible to obtain much higher yields than were possible

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(1) Unfortunately, the same type of stocking still continues in many parts of the world — not only in areas where no investigation has been done but even in areas where the evidence against such practices appears to be conclusive.

a few years ago. Coupled with these have been the practices based on the « pasture » theory that since the stream can « graze » only as many fish as food is available for — the fish should be raised to migrant age or size and liberated at a time when the demands they need make upon the stream for their nutriment will be commensurate with the supply. The control of disease, better nutrition and better methods of handling the fish both in the hatcheries and rearing ponds and during their transport, have all contributed to a better survival of hatchery stock and consequent increased return to the fishery.

The use of such stock is twofold — it may be used to maintain a fishery in waters adversely affected by environmental changes (where there has been a loss of spawning grounds, for example) or as an aid to restoration of the stock in waters that have been rehabilitated (as by erection of a fishway, for example).

In recent years Sweden has come more and more to depend upon the rearing and stocking of smolts to replace the natural reproduction of Atlantic salmon (*Salmo salar*) which have been barred from their spawning sites by power dams; and water-development projects in increasing number in the western United States have incorporated the construction of hatchery and rearing facilities into their plans. The construction of hatcheries and rearing facilities is expensive, and the costs of rearing and stocking the fish are great, but can be justified if careful studies prove that the returns attained are commensurate with the costs.

Artificial spawning areas. — Allied to the methods of propagating fish by the familiar sequence of hatching eggs and rearing the fry to larger size under decidedly artificial conditions (hatcheries, rearing ponds, etc.) are methods whereby artificial spawning areas are provided either in natural streams or lakes or in other areas, such as simulated streams to which water is supplied. Such methods have been the subject of investigation and trial as a means of replacing or augmenting stocks affected by water-development schemes.

One such type described by Hourston and MacKinnon (1957) provided conditions similar to a natural stream bed by diverting water over an artificial gravel bed within a controlled flow channel alongside the original river channel where the flow was sharply reduced due to power diversion : Pacific salmon which were made to enter the channel spawned there, and the first results were encouraging.

Another type of experiment is that of the International Pacific Salmon Fisheries Commission which utilizes a bed of gravel into which water is introduced by means of a diffusion system consisting of a grid of plastic pipes at the bottom of the bed ([1]).

Creation of new spawning grounds by the provision of bottom materials in artificial lakes and other areas which will not be uncovered by falling waters has also been attempted.

Transfer of runs. — With respect to anadromous fish for which no methods of passing a dam have been practicable, attempts may be made to transfer the run to other streams — sometimes by improving these by the release of more water. While this has been practised rather extensively in the Pacific Northwest it must be noted that many attempts to transfer runs have failed. With regard to salmonid stocks, careful attention should be given to attempts to duplicate migration distance and reproductive environment for both the donor and recipient streams (Anon., 1957).

### 3.9 The improvement of habitat in new waterways; and impoundments and the management of their stocks.

Although land- and water-developments often result in a loss of habitat they may also increase the water areas. Singling out only two of many examples, one may note that the projects of TVA increased the water area of the Tennessee River system from about 114,000 acres to almost 600,000 acres (Anon., 1950), and that the network of canals and irrigation channels in India has a total length of about 70,000 miles (Chopra, 1951). Whether or not such increases in water area also result in an increase in suitable habitat for aquatic organisms depends largely upon the type of impoundments or canals that are created and their operation.

Some reservoirs provide excellent habitat for fish. Others, subject to frequent drawdowns (sometimes total) may actually provide little habitat, and this not of a sustained nature, and statistics showing their maximum capacities or areas may be quite misleading as an index of their biological capacity. Section 3.3, above, has discussed some of the measures that may be taken to minimize the poor effects of water fluctuation on habitat in reservoirs and to utilize its potentialities for better yield.

Almost any of the other methods that are useful for the improvement of habitat in natural lakes can also be used in artificial waters. Among these are : the provision of cover or shelter; provision of spawning facilities; introduction of food organisms including forage

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(1) Personal communication from Loyd A. Royal, 3 January 1957.

fish; retarding wave action; and the control of excess aquatic weeds. Many methods and devices have been suggested, and many have been tried. (See, for example, the detailed descriptions in the — now somewhat dated — handbook on lake improvement by Hubbs and Eschmeyer, 1938). There are, however, few thorough studies of the value of lake and reservoir habitat improvement, and attention in recent years has shifted more to manipulations of the fish population rather than wholesale lake improvement of a rather artificial nature.

Again, as with so much of fishery management, attention to problems such as the provision of basic fertility and control of watershed erosion may promise far more than the installation of largely untested habitat improvement devices.

As with reservoirs, some canals may increase the fishing water decidedly; others may have only portions that constitute actual or potential habitat. Canals may be poor fishing waters because of the following : a velocity of the water too high to afford good resting places for fish; an unsuitable type of bottom (concrete, for example); sections consisting of covered conduit, tunnel or siphon; steep-sided banks; congestion with weeds; frequent drying. Any modifications of the above that will permit more natural conditions and still allow the canal to function for its major purpose (irrigation, navigation, etc.) will help the fishery.

With respect to both reservoirs and canals it may be advisable in some instances to introduce species which can utilize the new habitat better than can the native ones.

Given potential habitat in new waters and given a suitable assemblage of fish, one should then strive to utilize to best advantage the stocks that are provided. It is well beyond the limits of this review to discuss the complicated subjects of fishery theory and management, but obviously the populations should be utilized according to a scientific management plan. Attention is, therefore, directed in passing to a few principles often disregarded in the management of new waters and thereby not permitting as full a utilization of the resource — whether diminished or not — as might be possible.

First of all, it is in the public interest that new waters be open to fishing unless their use for this purpose interferes unduly with their primary use or is inimicable to public safety. Steep-sided, fast-running canals are sometimes closed because of the danger from drowning. Reservoirs for domestic water supply are sometimes closed because of presumed danger to public health. In most situations it should be entirely possible to allow fishing provided a few simple precautions are taken. With respect to the use of water-supply impoundments, there is a growing realization that their isolation is unnecessary in view of modern methods of water treatment, and continued efforts should be made to see that these waters have multiple use.

Secondly, fish populations should be handled as a crop and harvested. It is generally best to commence fishing a new reservoir rather soon. Populations usually build up quickly, and it is foolish to close the reservoir to fishing for a long period of time with a hope that one can stockpile the resources. (One of the authors recently visited a reservoir in North Africa which had been closed to fishing for twenty years after it first filled. The fish population was quite wasted during this period.)

Third, provision for increased fishing intensity, which — especially for fast-growing stocks — is often one of the best means of management, can be afforded through minimizing restrictions on fishing (longer seasons, larger catch limits, etc.) or by creating better means of access to unexploited areas.

Fourth, even where sport fishing is the predominant concern (as is usually the case in North American reservoirs) the simultaneous use of commercial fishing in some waters may not only afford an abundant harvest of the resource, but aid to regulate populations and improve the catch for the angler. Many conflicts in these two spheres still need to be resolved.

Fifth, the creation of fish-catching areas prior to impoundment can make later exploitation of stocks much easier. Some of the brush piles originally designed as fish « shelters » have been found to function as good fish « attracters » and with respect to certain sport fish — have value in concentrating under-utilized stocks so that they can be captured.

With respect to commercial fishing, failure to clear reservoir sites has often made it very difficult to use any type of bottom gear for catching food fish. In Indian reservoirs such as the Poondi, in Madras, and the Krishnarajasagar, in Mysore, during years of extraordinary drought whole villages and the spires of ancient temples emerge as the lake level falls. This has been a most aggravating problem and although modifications of traditional gear have been helpful, the problem has not yet been solved. Recognizing such difficulties, Morocco now has a program for clearing off vegetation at low water and bulldozing out flat shoals so that seines can be used.

Meyer-Waarden (1957) has suggested the use of electrical frightening equipment to drive fish into bays or catching areas where they can be caught, and the use of other guiding equipment is contemplated.

Sixth, the control of undesirable fishes (those that compete with or exert population pressures on desirable food or game fishes) is a frequent tool of management — largely achieved today with the use of either total or selective chemical treatment, but also by trapping or netting out of the unwanted species.

In addition to the use of new reservoirs to produce wild stocks of fish, decided advances have been made in utilizing them to produce cultivated fish. In Israel, seasonal irrigation reservoirs are used extensively to raise carp, employing methods quite similar to those used in standard fish-pond culture; i.e. they are stocked with fry; the water is fertilized; the fish are fed artificially and harvested by draining. The use of these reservoirs for two such purposes reduces costs and the irrigation water is enriched. See Yashouv (1955).

The use of farm ponds for irrigation, stock-watering and sport fishing is another example of multiple-use of new water.

## 4. — POLICY, THE PROBLEM OF RECONCILING CONFLICTING OBJECTIVES

In summarizing the methods that may be used to minimize the ill effects and exploit the potentialities of established or projected water- and land-use or development upon aquatic resources, it may be noted that they fall into several general classes :

(i) Methods whereby the ill effects can be alleviated by modifying the construction of the structures and appurtenances themselves. For example, a fishway may be built around a dam or a screen may be placed in an irrigation canal.

(ii) Methods by which the changed habitat can be restored or improved.

(iii) Methods by which there is a compensation in kind for the use of water needed for aquatic production. For example, if the flow of a stream is to be diverted with consequent damage to fish stocks below, the effect might be offset by the storage of flood flows that can be released during needed periods.

There may even be a replacement in kind by the development of lesser producing waters through allocation of excess or stored flows to basins apart from the affected stream or to sections of these streams that are not receiving sufficient water; e.g., areas of low flow below other dams.

(iv) Methods in which there is a substitution intended to make good some part of the resource system destroyed by the scheme. For example, a hatchery may be constructed to offset the loss of spawning grounds.

(v) The above methods involve compromise, and there are probably few cases where the natural aquatic resource is so important that no compromise should be tolerated — in time. However, there are situations — and highly important ones — where there are *at present* no known means of saving the resource if the water development is to be created and where the resource may be totally and irretrievably destroyed.

In such cases it may be that plans for such water development should be shelved until there has been time for research to provide a satisfactory solution. (Dr. Arthur D. Hasler, in fact, has suggested to the U.S. Congress that a moratorium should be declared on dam building on certain important salmon streams (Stroud and Seaman, 1957, p. 47). This is a temporary expedient, but it may be considered as a « method ».

(vi) One may perhaps lump a good many other « methods » into the great complex of good soil and water-conservation practices that begin at the head of the watersheds and extend to the sea. Acceptance of such practices will come largely from public education and the development of governmental conscience but may also be encouraged by the incentive motive. For example, «… tax laws that will allow a landowner to deduct the money he spends for soil, water and land erosion prevention conservation projects for income tax purposes... » (Hudoba, 1955, p. 341) may serve to bring about good practices that altruism alone will not produce (1).

One could continue with an elaboration of the specific methods that have been used or could be used or could be imagined in order to prevent the loss of aquatic environments and aquatic stocks through

(1) This incentive motive can obviously be used almost anywhere for the furtherance and protection of fisheries. For example, a municipality may open up a reservoir to fishing if it can be demonstrated to it that a managed fishery can constitute a new source of income. A power company may provide access roads or landings at its reservoirs for the furtherance of its public relations. And, as a final example, we quote from Pehrson (1958, p. 458) who in giving an account of the disposal of sulphite wastes through evaporation and combustion says : « Even if water pollution has been the incentive for the inclusion of waste liquor evaporation on the expansion programme, it may be said that all plants have been calculated to produce a good return on invested capital and thus contribute to lower the production costs of pulp. »

inimicable land- or water-use. However, this paper is a bare review of the subject and even as a review must be permitted to have lacunae.

There are, of course, many instances where water development has been largely beneficial to aquatic resources. The Tennessee Valley Authority (T.V.A.) dams, for example, through a happy combination of circumstances have brought about a greater production of fish in their reservoirs than existed in the original streams. Similarly, the extensive acreage of artificial impoundments constructed in Oklahoma have created conditions conducive to a far greater production than known before, and the net effect to the fisherman and the States's economy has been very profitable. (See Thompson, 1955.) ([1]). However, the fact that we do possess a variety of methods for alleviating some damage and the fact that some water- or land-use not specifically designed for the furtherance of fisheries has indeed resulted in improvement for them, should not mask the equally important fact that the value of aquatic habitat and aquatic stocks as economic, nutritive, recreational and aesthetic resources is generally overlooked — and this, throughout the world ([2]).

An increased public interest in these resources and their furtherance is indispensable. However, neither interest alone, nor sentiment alone — as for the preservation of the natural state, nor more talks or more papers merely viewing with alarm or pleading for a hearing — will achieve sound or long-lasting results. Let us consider rather that their furtherance may best come from steps such as the following :

(i) Public recognition that the production of aquatic resources — whether they be utilized as food or as a recreational asset — is a primary beneficial use of water fully as important as other traditional consumptive water uses.

(ii) Realization of the importance of aquatic resources should be reflected in sound guiding policies and legislation which will safeguard the use of water for fisheries and ensure that protection and enhancement of aquatic resources are legitimate purposes of public multiple-use water-development projects.

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([1]) It must be said, of course, that to those interested in the preservation of natural conditions or natural faunal assemblages such works of man have often destroyed the original nature of such assemblages.

([2]) Typical of this neglect are the statements frequently made concerning the multiple use of water but omitting all mention of the use of water to produce aquatic crops. For example, in a review of the recent World Power Conference at Belgrade, 1957, Robinson (1958, p. 1503) says: « Any discussion of water resources involves the question of the most economic division of these resources between the conflicting requirements of power production, irrigation, transport and municipal supply ».

(iii) Economic evaluation of aquatic resources which is essential tor comparison with the other costs and benefits of water development. With respect to commercial fisheries the monetary value of a threatened stock can often be assessed, and the number of studies to show the economic value of sport-fishing stocks is growing. As examples among these may be listed the national survey of fishing and hunting in the United States made for the Fish and Wildlife Service (Anon., 1956.1) and that of Wallace (1956) for the State of Washington. Such surveys take no account of the so-called intangible values of sport fishing as a recreation, which are, of course, neither to be denied nor minimized.

(iv) Broader concepts of water-resource planning on the regional, national and international levels, with provision for considering the ecological consequences.

(v) Fisheries biologists must take a more active part in water- and land-use planning and development to assure consideration of fisheries in engineering plans. An encouraging trend in this field is the employment of biologists by water development and engineering agencies.

(vi) Intensification of research which will lead to alleviatory measures which will protect and further threatened waters and aquatic stocks.

It should be completely obvious that even though we possess a good many « tools » or a good many methods whereby natural aquatic resources can be protected, or where some degree of substitution can be achieved, that we are still lagging in the investigation necessary to improve methods and to devise new ones. Such investigation is of two types : applied research on methods themselves; basic research.

From applied research we may learn how to lift fish over a particular dam or how to divert downstream migrants. But from basic research — which may have nothing to do with water-development problems — we may learn the principles that can later be applied to these pressing problems. Many of these problems seem to lie in the field of fish behavior and physiology. Research on muscle fatigue, or the exhaustion of stored fat, for example, may lead to knowledge that will aid in getting upstream migrants past dams. See especially the discussion by Brett (1957).

With reference to both types of investigation (although particularly with respect to applied work) greater reliance is being placed on teams. Kerr (1953) describes the organization of such a team, composed of engineers and biologists, for the study of a single project to prevent the loss of fish entering a steam plant. As might be expected, the history of the project progressed through several stages : «… fish rescue methods taken as an expediency, an attempt for a quick solution to the problem and [then] a decision to embark on a long-range practical research program ». Of larger scope and on a grander scale is the present research on experimental studies of methods for the control of movement of downstream salmonid migrants, whose workers are described by Fields (1957, p. 10) as « An interdisciplinary research team composed of biochemists, biologists, electrical and hydraulic engineers, mathematicians, physiologists, and psychologists... investigating these problems, with the cooperation of various state, national, and international fisheries organizations. » ([1]).

Both applied and basic research are slow and laborious. There may be instances where it is best to stay the rapid changes in the natural environment of aquatic organisms until the work is done.

An estimate (Anon., 1956.2) has been made that the world's population (now 2.6 billion) may increase to about 6.5 billion in 100 years with a consequent increase in demands for power. According to Greig (1958) on a United Nations' estimate of the annual rate of increase of power consumption, the year 2000 would see a three-fold increase on the present demand for power. While it may be expected that nuclear energy will largely meet these demands, all present indications are that hydro-electric power will also be expanded to its fullest development. There are demands for more water for irrigation, for navigation, for domestic supply and for industry. Some of these uses are consumptive — some non-consumptive. All of them require changes in the water courses and changes in the land.

Any change that will stay the consumption of water or augment its supply for the above uses, or any changes that may eliminate the need for one of these uses (the substitution of nuclear power for hydro-electric power) will serve — in the long run — to increase the amount of water available for aquatic resources. Heed should then be taken of developments — actual, promised or surmised — that may offset the demands upon our existing waters containing aquatic stocks. Among these can be mentioned : increases in the

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([1]) Attention is also called to « The Investigation of Fish-Power Problems », a symposium edited by P. A. LARKIN, *H. R. MacMillan Lectures in Fisheries*, University of British Columbia, Vancouver, 1958, 111 p., received too late to be used in writing this review.

amount of new water available through artificial rain-making; savings in water consumption or application as through more efficient methods of water transport and irrigation or the re-cycling of water in industry or the use of sewage water through reclamation; conversion of saline water to fresh through demineralization; prolongation of the life of present reservoirs through control of silt; retardation of evaporation in reservoirs as through the use of cetyl alcohol; the recharging of aquifers; substitution of forms of power other than hydro-electric (solar and nuclear power); etc.

With such developments on their way, it is urged that high consideration be given to the water requirements for aquatic resources and their values — economic, nutritive, recreational and aesthetic — and that we rush not headlong into environmental changes that may be irreversible.

Seventeen years ago, Aldo Leopold (1941) said :

« Mechanized man, having rebuilt the landscape, is now rebuilding the waters. The sober citizen who would never submit his watch or his motor to amateur tamperings freely submits his lakes to drainings, fillings, dredgings, pollutions, stabilizations, mosquito control, algae control, swimmer's itch control, and the planting of any fish able to swim. So also with rivers. We constrict them with levees and dams, and then flush them with dredgings, channelizations and floods and silt of bad farming.

« The willingness of the public to accept and pay for these contradictory tamperings with the natural order arises, I think, from at least three fallacies in thought. First, each of these tamperings is regarded as a separate project because it is carried out by a separate bureau or profession, and as expertly executed because its proponents are trained, each in his own narrow field. The public does not know that bureaus and professions may cancel one another, and that expertness may cancel understanding. Second, any constructed mechanism is assumed to be superior to a natural one. Steel and concrete have wrought much good, therefore anything built with them must be good. Third, we perceive organic behavior only in those organisms which we have built. We know that engines and governments are organisms; that tampering with a part may affect the whole. We do not yet know that this is true of soils and water.

« Thus men too wise to tolerate hasty tinkering with our political constitution accept without a qualm the most radical amendment to our biotic constitution. »

To this we should like to add a last statement by Sears (1958) :

« Our future security may depend less upon priority in exploring outer space than upon our wisdom in managing the space in which we live. »

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# ANADROMOUS FISH CONSERVATION IN A SWEDISH SALMON RIVER

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The Baltic stock of Atlantic salmon is mainly dependent on the smolt output from the Swedish rivers. The ever-increasing demand for energy in Sweden, for the time being largely satisfied by hydro-electric power, constitutes a serious menace to the undisturbed life of the rivers. Salmon conservation in Sweden is, therefore, a centre of interest for conservationists, fishery biologists, power engineers, and even the public and press.

This paper will give an illustration of how the problems are dealt with in a particular river.

### The river and its fish.

The river Indalsälven in the middle of Sweden comprises a catchment area of 26,700 $km^2$ (8.5 per cent lakes) and is the fifth largest Swedish river system. It empties into the Baltic with a mean water flow of 440 $m^3/s$, and a mean high-water flow in early summe; of 1,600 $m^3/s$. The water is of oligotrophic character, pH just below 7, and resistance about 20,000-25,000 $Ohms/cm^3$ in summer. The river is ice-covered from about December-April; water temperature rises in summer to a monthly mean of about 15°C in July-August.

Until recently the river was accessible to anadromous fish for a distance of 80 km from the mouth, where a power station blocked further progress. This stretch of the river comprised no lakes, received very few, and mostly small, tributaries and had a mean fall of 0.45 m/km. The bottom consisted of gravel and stones in the rapid flowing parts, and was sandy elsewhere, the former type of bottom with an estimated extension of some 4,000,000 $m^2$.

Fish species inhabiting this area were, in estimated order of abundance,

Bullhead, *Coitus gobio* L.
Minnow, *Phoxinus aphya* L.
Grayling, *Thymallus thymallus* L.
Salmon (parr), *Salmo salar* L.

Sea trout (parr), *S. trutta* L.
Lamprey (ammocoetes), *Petromyzon fluviatilis* L.
Dace, *Leuciscus leuciscus* L.
Whitefish (fry), *Coregonus lavaretus L.*

Perch, *Perca fluviatilis L.*
Pike, *Esox lucius* L.
Roach, *Leuciscus tutilus* L.
Eel, *Anguilla anguilla* (L.).
Sticklebacks, *Gasterosteus aculeatus* L. and G. *pungitius* L.

Only the first group comprises true stream fishes, anadromous or stationary. The four anadromous species proper live and feed in the river only as young : the salmon and sea trout as parr for two to three years before leaving for the sea in June, the ammocoetes for some years and the whitefish as fry for a few weeks at most after hatching, just after the breaking of the ice. In their migration to spawning areas the salmon and sea trout ascend the river in summer, whitefish and lamprey in autumn. The sea trout runs also in late summer and autumn, mostly as immature fish. All species seem to stay in the river during the winter and descend again in the spring in a spent condition, salmon and sea trout in a bad state, but surviving to a certain extent, the lamprey in a dying condition.

**The fishing industry.**

Commercially important are salmon, sea trout, and whitefish. Old catch records and, from about the turn of the century, regular catch statistics from this river and other Swedish rivers reveal heavy catch fluctuations; these reflect fluctuations in the stock, not fully understood, composed of long-term primary fluctuations and shorter secondary variations. As a provisional indication of the mean level of the populations the following annual river catch figures are given.

| | Tons | Ind. |
|---|---|---|
| Salmon | 35 | 3,900 |
| Sea trout | 3.5 | 1,500 |
| Whitefish | 15 | 37,500 |

The river fishery, which is in the hands of the riparian owners, is carried out by means of seine netting, the season being closed on September 1st for salmon, October 1st for sea trout and whitefish. The populations are further exploited by professional fishing on the coast and, in the case of salmon, in the Baltic Sea.

## The dam and damage.

In 1951 the construction was begun of a new power plant in the lower reaches of the river with a dam 10 kilometres from the mouth, below all the spawning places for salmon and sea trout. The spawning run was impeded as from the summer of 1954, but the upstream water level was not raised until the autumn of 1955 when the spawning areas were flooded for 50 kilometres from the plant. (The remaining short upstream stretch of the river will soon be impounded.)

As a result of the building of the dam and the impoundment, the river fishery was spoiled (except for the lowest 10 kilometres) and spawning was made impossible for all the three species under consideration, likewise the growth of the young of salmon and sea trout.

## The conservation programme.

As compensation for the damage done to the river fishery and in order to conserve the commercially important fish populations, an extensive programme has been adopted. This involves : (1) compensating river fishermen, according to the regulations in the Swedish « Water Law », either in cash or, in part, with electric power, and (2) substituting artificially reared fry or young fish for such fry (whitefish) and young or smolt (salmon, seatrout) estimated to have previously left the river under natural conditions, in order to maintain at their previous level the sea phase of the species' existence and the sea and coast fishery.

The execution of the conservation programme has involved :

1. a decision as to the phase of existence of fry or young of the species to be released, as well as to the time of year and place best suited for the success of the operation;

2. an estimate of the right quantity to be released;

3. the elaboration and application of the most economic rearing technique to provide healthy fish for stocking;

4. timing to replacement of natural by artificial reproduction so as to avoid a gap in the process.

### 1. Type of conservation.

The general criticism recently directed against the widespread release of fish fry and young in natural waters is certainly valid, but it is not applicable to cases where the artificially reared material is liberated as a substitute for natural fry and young and in such places and at such times as to fill the ecological niche left empty by the latter's disappearance. The truth of this argument has been proved in the case of salmon by the very successful releases of salmon reared to smolt size in Sweden by the Migratory Fish Committee under the direction of Dr. B. Carlin. The overall returns from sea and river for the later, properly executed experiments exceed 10 per cent. Investigations are being carried out, involving 325,000 fish tagged and released up to and including 1957. This research is intended to determine the importance of origin, rearing methods, size, and condition of the fish, time and place of release and so forth. At present, it is considered best to release salmon and sea trout in June as far upstream in the home river as possible — but below the dams — and at a size of not less than 12-14 centimetres; whitefish as newly hatched fry about May 1st or as fingerlings in September (after one summer in drainable ponds without artificial feeding).

2. **Stocking quantities.**

Exact data concerning relative quantities at different stages of the fish species in question under natural conditions are more or less non-existent. It is reasonable to assume a higher mortality occurring among the species at their earliest phases of life in the river. For salmon our rough estimates show averages of 80 per cent survival from eggs to the alevin stage, 2 per cent to the smolt stage, and about 0.05 per cent at first spawning migration when 50-70 per cent of the running fish have been caught in the river at the former commercial fishing. This gives a ratio of smolt : river-caught salmon of about 100 : 1 which, applied to the average number of salmon caught, gives the average number of smolts necessary for maintaining stock at the same level as previously permitted this exploitation in the river. The destruction of the old river fishery as well as the heavily increased exploitation of feeding fish in the Baltic make any testing of these figures impracticable. They are used for the first provisional estimate of the number of smolt to be released; subsequent adaptation to actual needs will be carried out by means of comprehensive tagging projects in line with the laggings supervised by the Migratory Fish Committee mentioned above.

The principles given above involve for the river Indalsalven an average annual smolt descent of 300,000 to 400,000 produced in an area of 4,000,000 square metres.

For sea trout and whitefish the data are still more scanty.

The conservation programme now in operation for the river Indalsalven involves 390.000 salmon smolt, 40,000 sea trout smolt and 25,000,000 whitefish fry.

3. **Production of fish for stocking.**

The activities of the Swedish Migratory Fish Committee have largely been devoted to developing a technique for rearing salmon smolt. Most of the work has been done at the Hölle Salmon Labo-

Appendix 1.

**Example of rearing programme.**

| Stage | Unit | Mort. per cent | Year 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Males | kg | | 100 | 100 | | | |
| Females | kg | | 500 | 500 | | | |
| Eggs | 1,000 | | 525 | 525 | | | |
| | | 20 | | | | | |
| Fry | 1,000 | | | 420 | 420 | | |
| | | 50 | | | | | |
| 1 summer | 1,000 | | | 210 | 210 | | |
| | | 25 | | | | | |
| 1 year | 1,000 | | | | 160 | 160 | |
| | | 20 | | | | | |
| 2 summers | 1,000 | | | | 130 | 130 | |
| | | 10 | | | | | |
| 2 years | 1,000 | | | | | *60* + 56 | *60*+56 |
| | | 20 | | | | | |
| 3 summers | 1,000 | | | | | 45 | 45 |
| | | 10 | | | | | |
| 3 years | 1,000 | | | | | | *40* |
| Smolt, total | 1,000 | | | | | | 100 |

The security margin of this programme is fairly wide.

ratory under the direction of Dr. Carlin. It can now be safely stated that artificial rearing of salmon to smoli size is possible on a large scale and produces fish which, tagged and released, bring in excellent return figures (up to and exceeding 10 per cent), with a survival rate that is probably scarcely inferior to that of natural smolts, and already materially contributing to the catches, in spite of the comparatively small extent of the operation so far. The annual artificial smolt production in Sweden now amounts to about 300,000 of which more than 20 per cent have been tagged; by 1965, the size of production will be in the order of 2,000,000.

The smolt production by means of artificial feeding in crowded conditions has to take into account fish diseases of various kinds. The central organization will soon have a pathology branch at the disposal of rearing stations and the rearing programme will be worked out with a good margin of safety. Appendix 1 gives an example of a rearing programme.

No further details of the rearing procedure will be given in this connection. Progress reports (typewritten) from the Migratory Fish Committee contain the preliminary results and final reports are awaited.

The hatching and pond rearing of whitefish follows the old procedures long since adopted for this species.

The production of smolt and fry for the river Indalsalven is carried out at Bergeforsens's salmon fishery and rearing station close to the power plant situated nearest to the river mouth. It will not be in full operation until 1960, and it will not be until 1962 that the Indalsälven stocks of commercially important anadromous fish will consist exclusively, or almost so, of fish reared artificially.

4. **The taking-over plan.**

Appendix 2 is a simplified plan, highly schematic, for the taking over of the former natural fish production in the river by Bergeforsens's salmon-rearing station. No comment seems necessary.

It is true that experiments have not yet provided evidence of the possibility to maintain large stocks of anadromous fish unimpaired by the complete incapacitation of the whole home rivers. However, in the light of Swedish activities in recent years in this field, there seems to be no reason to doubt a final success for these conservation schemes, forced into operation by the social and industrial need for energy.

| Stage | Unit | 1953 | 1954 | 1955 |
|---|---|---|---|---|
| Male salmon | 1 | 1,900 | Spawning run impeded, fish transported past dam 20 | |
| Female salmon | 1 | 2,000 | | |
| Eggs | mill. | 20 | | |
| Fry | mill. | 16 | 16 | 16 |
| 1 summer old | mill. | 1.6 | 1.6 | 1.6 |
| Yearlings | mill. | 1.4 | 1.4 | 1.4 |
| 2 summers old | mill. | 0.7 | 0.7 | 0.7 |
| 2 years old | 1,000 | *130*+470 | *130*+470 | *130*+470 |
| 3 summers old | 1,000 | 280 | 280 | 280 |
| 3 years old | 1,000 | *260* | *260* | *260* |
| Smolt, total natural production | 1,000 | 390 | 390 | 390 |
| Calculated mortality in turbines, 5 p.c. | 1,000 | — | — | — |
| Smolt, remaining natural production | 1,000 | 390 | 390 | 390 |
| Need for stocking | 1,000 | — | — | — |
| Smolt, total pr )duction | 1,000 | 390 | 390 | 390 |

**production in river Indalsalven in Sweden.** (Simplified plan.)

| 1956 | 1957 | 1958 | 1959 | 1960 |
|---|---|---|---|---|
| Power plant in operation, impoundment spoiling 2/3 of spawning and growth areas | | | | New plant, total spoilage |
| 0.5 (*) | | | | |
| 1.4 | 0.44 | | | |
| 0.7 | 0.22 | | | |
| *130*+470 | *130*+470 | *40*+150 | | |
| 280 | 200 | 85 | | |
| *260* | *260* | *260* | *80* | |
| 390 | 390 | 300 | 80 | — |
| 20 | 20 | 15 | 4 | — |
| 370 | 370 | 285 | 76 | — |
| 20 | 20 | 105 | 314 | 390 |
| 390 | 390 | 390 | 390 | 390 |

(*) 1-summer-old parr liberated from rearing station.

# MODERN FISH PASSES IN THE NETHERLANDS

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## INTRODUCTION

Until the twenties of this century a huge number of fish populated the river Meuse or used it as a route to their spawning grounds. Among these, salmon, sea-trout and eel were the most valuable species, giving rise to a fishery of considerable economic importance.

For navigation purposes, seven weirs of the overflow type were built in the Dutch part of the Meuse in about 1930. With regard to the fish population it was then decided that fish passes should be constructed simultaneously with the weirs. At that time only salmon was considered a really important species and the passes were therefore designed with the intention of facilitating only this species' migration.

Passes of the « Denil » and « pool » type were therefore constructed in conjunction with the weirs. Contrary to expectation, however, the salmon did not succeed in making use of these passes. This finally led to a complete annihilation of the salmon population and to a serious diminution in the stock of eels and other species (which were able to avoid complete annihilation because some fish managed to pass the weirs by using ship locks). This disaster is the more to be regretted as the Meuse is virtually the only unpolluted river in the Netherlands and is biologically eminently suited for a profitable fishery.

Repeated complaints from anglers and from professional fishermen ultimately led to the decision that the fish pass problem should be reconsidered, but this time from the biological point of view. It was now considered desirable to develop a pass suited not only to salmon migration but also to that of other species occurring in the river Meuse.

### Considerations

In our opinion two factors are of extreme importance to the satisfactory working of a fish pass : (1) the location of the entrance; (2) the type of pass.

1. The present passes in the river Meuse have their entrance alongside the weirs, their discharge directed parallel to the flow of the river. This is an unsuitable feature, since the subdivision of a river into a narrow stream flowing alongside a broader one in exactly the same direction will not lead to any essential change in the general current pattern that is liable to be perceived by the migrating fish. We hold, on the contrary, that for efficient functioning, the final path to be followed by the water in a fish pass should form a right angle to the direction in which the river flows and should be situated just downstream of the point where the turmoil of the water falling over the weir finishes.

Fish migrating upstream will be alerted by the turmoil, hesitate downstream, and will thus have a fair chance to detect the water quietly flowing out of the fish pass in a completely different direction.

2. Apart from our insistence that even the tiniest fish should be able to make use of a fish pass, we are convinced that it is a considerable advantage even for the more powerful migrants, such as salmon, that their passage through weirs be made as easy as possible. Any serious obstacle may affect the condition of the fish and may lead to a diminished migration-urge. If a given type of pass can be used by the fish only by means of considerable expenditure of effort, a series of such passes may have the cumulative effect of forming an unsurmountable barrier, especially for those migrants with the weakest migration-urge. From this point of view, theories that a series of fish passes in some rivers bring about a segregation of salmon sexes can be plausibly explained, as the sexes differ in migration-urge.

Furthermore, it should not be assumed that the whole stock assembled in front of a weir will be in a position to proceed upstream merely because some migrants have been seen to make good use of the fish pass. There is always the possibility that only the strongest specimens do in fact succeed and this may lead to a serious reduction of the number of fish reaching the spawning grounds.

It was therefore decided to construct fish passes in such a way as to avoid the necessity for fish to surmount the difference in water level by their own effort. Instead they would be lifted to the higher level, and it seemed most convenient that this should be done by the water itself. For this reason, the ship-lock system was chosen — the principles of which are well known — operating by electricity.

One of the Meuse fish passes (that at the weir at Lith) has already been converted into a fish lock, despite considerable costs. Underwater observations made in a specially designed room revealed that all the fish species inhabiting the river — down to the three-spined stickleback — even the tiniest specimens were able to make successful use of the pass, and obviously without exertion.

The enormous advantage of the lock system is that, in contrast to the commonly used « pool » type pass, the height of the weir (i.e. the difference in water level on either side of the weir) no longer affects the fish. The truth of this statement has been demonstrated in practice by the construction of a 20-metre high fish pass of the lock system at the hydro-electric weir on the river Liffey at Leixlip near Dublin. It has been stated (1) that the automatically operated lock functions here in a most efficient way for all fish species. Here too the fish are lifted by the water itself, which avoids the need for them to exert much effort themselves.

Up till now we have discussed the biological aspect of the fish lock, but apart from its suitability from this point of view, it also has certain technical advantages. These are well worth considering, at least when the weir in question has not yet been constructed. Most of the weirs are planned as part of a hydro-electric scheme, which requires as great a difference in water level as possible. Should the levels on either side of the weir be connected by a « pool » type fish pass, then the pass necessarily has to extend for a considerable length along the bank of the river and has to be constructed a great distance beyond the weir itself. This will involve considerable costs.

A fish lock on the contrary can be built in the weir itself, as a sort of tube, running parallel to the slanting downstream side of the weir. The space required can be left free in the concrete mass. The construction will not, therefore, involve heavy costs. Moreover it has been ascertained that a fish lock spills considerably less water than a « pool » type pass would do under the same conditions. From a hydro-electrical point of view this is an important feature.

### Short description of the hydraulic fish lock on the Meuse at Lith

This particular fish pass can be considered as a narrow canal with a slanting bottom. Part of the canal functions as a lock, this section being enclosed between hatches at its upper and lower end, which can move up and down. In the lock itself a concrete block has been built with the aim of reducing the volume of the lock, so that it will fill quicker when in use. This block has a slanting downstream side so

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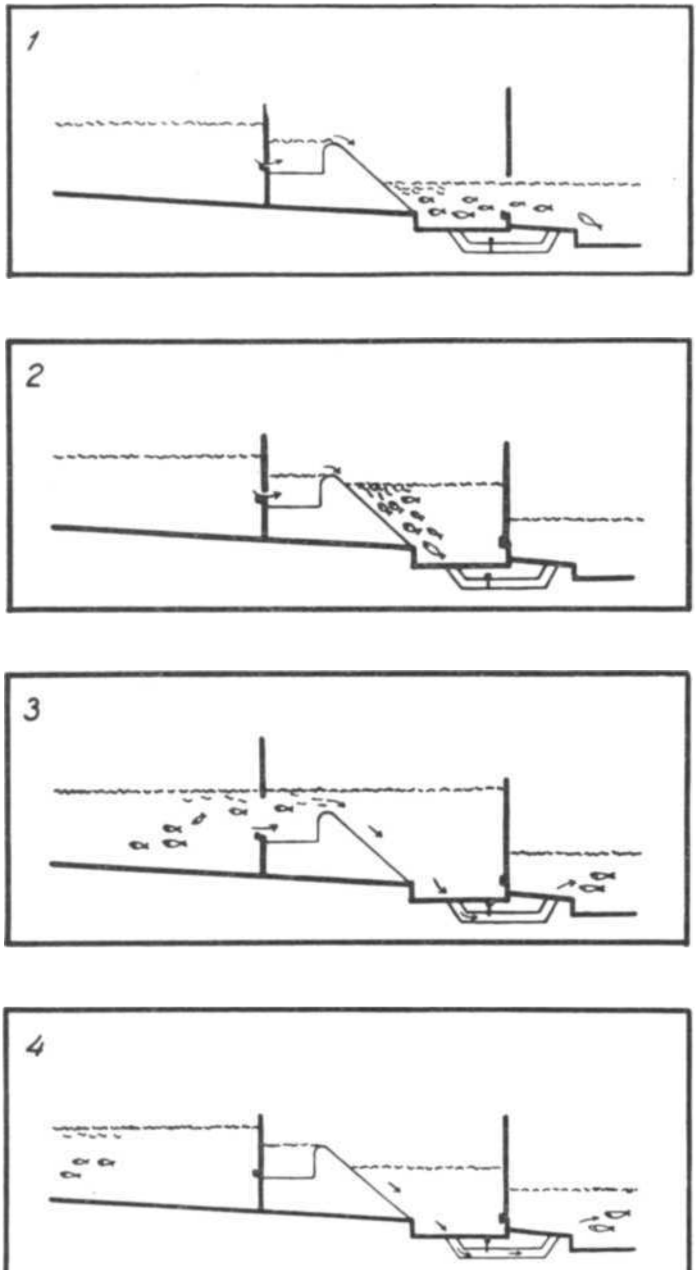
(1) Cf. : The hydraulic fish lift at Leixlip (*Bull. of the Inst. of Civil Engineers of Ireland,* April 1951, p. 61).


1
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3
4

that water flowing over the top rushes down : in fact a sort of spillway is created. It has appeared that water flowing down obliquely in this way greatly attracts migratory fish, although it is not known why this should be so. Perhaps a special kind of turbulence is created which the fish prefer. In the first stage of the operation the lower hatch is opened and the upper hatch is manipulated in such a way that a small amount of water rushes into the lock (Fig. 1). By this procedure fish are strongly attracted to enter the lock and to assemble at the foot of the block mentioned above. Then the lower hatch can be closed, so that no water can leave the lock, which leads to its gradual filling (fig. 2). When the water level in the lock is equal to that of the river upstream of the weir, the upper hatch is fully opened. At this stage no fish will leave the lock as there is no flow to guide them. Some water is therefore discharged at the bottom end of the lock and is immediately replaced by water flowing in at the upper end (Fig. 3). As soon as this flow occurs, the fish will begin to move upstream and consequently leave the lock. When there are no more fish left behind in the lock the upper hatch is brought right down so that the lock will be emptied by the continuous discharge at the bottom end (Fig. 4). Finally when the water in the lock has reached the downstream level the lower hatch may be opened again, after which the whole procedure can be repeated.

As the difference in water levels at both sides of the weir at Lith is fairly small — about 4 metres — it was possible to design the fish-pass as a sort of open canal. With greater differences in water level it is advisable to use a tube-shaped canal. Such a tube is no obstacle to migrating fish, as has been demonstrated by the Leixlip fish lock.


**Summary**

In the Dutch river Meuse an inefficient fish pass of the « pool » type has been converted into a fish lock which has operated with great success. Fish which enter this lock are carried upwards by a rising water level without being forced to exert any considerable labour themselves. It has been pointed out that fish locks may not, biologically, be highly efficient, but that their construction offers certain technical and financial advantages. Moreover, as far as one can see, fish locks can be used over any differences in water level.

We therefore strongly recommend the discarding of inefficient types of passes and the construction in future of fish locks only.

# CONSERVATION OF ELVER MIGRATION ROUTES INTO THE INLAND WATER SYSTEM OF THE NETHERLANDS

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In response to regular demands to keep the inland waters of the low-lying parts of the Netherlands as fresh as possible, more and more dams, locks and sluices are being built to separate the sea from the inland water-system. Hence elvers encounter steadily increasing difficulties in their efforts to reach the inland waters from the sea and at some places it is virtually impossible for them to cross these barriers.

With the aim of preserving the most important migration routes it was decided to investigate the possibility of facilitating the inward elver migration, especially at the Afsluitdijk, which bars the IJsselmeer from the sea. In this respect it may be stated that the most obvious solution of this problem — the construction of so-called elver ladders — is practically impossible, because such ladders would be too easily destroyed by heavy waves pounding on the dam during spells of bad weather.

In the first years following 1932 — the year during which the Zuyder Sea was dammed off from the North Sea and was renamed IJsselmeer — it was decided to open the sluices in the Afsluitdijk in the elver season at the time when the sea level was at the same height as that of the IJsselmeer. By this procedure elvers were given sufficient opportunity to pass the sluices and subsequently to migrate into the lake. The great drawback was that, in addition to the elvers, considerable quantities of sea water also entered the lake. For even when fresh water passed the sluices on the way to the sea, saline water seeped into the IJsselmeer along the bottom.

As the salinity of the lake decreased, which was of considerable advantage for the agricultural areas around the IJsselmeer, this inward flow of sea water could no longer be allowed. Therefore a new elver-passing procedure was introduced in the year 1938, based on the results of several years' study of elver behaviour.

The new method consisted of the alternate opening and closing of the two hatches of the sluices. First the seaward hatches were lifted, so that elvers were able to enter the sluices and congregate there near the inner hatches. This worked especially well during the periods when fresh water leaked in through the sides of the inner hatches. Next the seaward hatches were closed and the inner ones opened, thus enabling the elvers to enter the fresh lake. After some time the inner hatches were closed again and the outer ones opened, and so on. In fact the elvers were handled like a ship in a lock. This whole sequence was repeated six times per night throughout the elver season, and up to 1957 inclusive the method met with considerable success. The great drawback was, however, that appreciable quantities of sea water still flowed into the IJsselmeer — some 10,000,000 cubic metres per season.

In an effort to eliminate this drawback a renewed study of elver behaviour was begun. This revealed that elvers are quite willing to migrate against a freshwater flow along the sea bottom, and not exclusively in the surface layers as was hitherto presumed. On the basis of this information, a new procedure will be put in operation from 1958 onwards; during low tide the hatches of the sluices will be raised a few centimetres only, so that a continuous flow of freshwater will pass the hatches on its way to the sea along the bottom of the sluices.

Extensive and large-scale aquarium experiments have revealed that in such a situation elvers will be attracted by the fresh water and will assemble in front of the hatches. As soon as the velocity of the freshwater flow diminishes sufficiently — owing to the rise of the sea level at flood tide — all elvers will make for the fresh water of the IJsselmeer. As soon as the sea level is equal to that of the lake the hatches will be closed, thus preventing the salt water from flowing into the lake. By this procedure the elvers will easily reach the lake without a simultaneous inflitration of considerable quantities of sea water.

Aquarium tests have also revealed that elvers are not the only fish species to react in this way to a flow of fresh water. Flounder and smelt, the latter forming a very important stable food for eel, pike-perch and perch abounding in the IJsselmeer, show the same type of behaviour. It is therefore assumed that adoption of the new procedure described above will offer these species a chance to enter the lake, which they have previously lacked.

# FISHERY PROBLEMS CREATED BY WATER UTILIZATION PROJECTS IN SCOTLAND AND EAST AFRICA

BY

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All over the world water resources are being utilized for power, irrigation and water supplies, and such developments are taking place rapidly in the two countries which form the subject of this paper.

Such waters are often the *milieu* of very large commercial fisheries, whose destruction would result in severe economic loss, and whose preservation is usually essential. The necessity to extract the maximum working efficiency from the water is not always compatible with the optimum use of that water by the fish themselves, and arrangements which have to be made to suit fish and fisheries in the same water must involve some loss of efficiency in the utilization of that water for other purposes. So conflict inevitably exists, which must be resolved by a compromise which is often suitable to neither interest concerned, since it is very seldom that the whole flow of a river, for example, is available for both fish and power or irrigation.

Engineering projects utilizing water may be anything from small diversion weirs for irrigation or water supplies to vast hydro-electric dams supplying hundreds of megawatts of power. Except where static and large bodies of water can be used in pump schemes for such purposes (which in themselves may create fishery problems if they involve loss of water, although hydro-power pump schemes use the same water over and over again) — in most cases water usage schemes involve partial or complete obstruction and diversion of flowing water, with consequent alterations of head and flow.

Fish whose life history and biology are static — non-migratory — such as the cichlids in East Africa, are often not much affected by such alterations unless storage reservoirs are made too deep, and a thermocline effect prohibits or markedly restricts the area available for such bottom-spawning fish. But commercially exploited fish of this kind are uncommon, and large commercial fisheries are usually based on fish having a migratory biology such as eels, sturgeon and salmonid fishes in Palearctic and Nearctic regions, and in the Ethiopian region, eels, cyprinids and siluroids.

Providing spawning facilities are not affected, in conditions where the water flow is controlled the problem is in essence to allow fish to pass up and down obstructions, perhaps in reduced flow, avoiding blind alleys, in absolutely normal numbers comparable to those before control. This is much more difficult than it first appears, for in the great majority of instances the normality of a river has not been known before artificial alteration occurred, and can only be inferred from an analysis of catch rates from existing fisheries. One of the main difficulties is that any detrimental effects on fish stocks are usually long-term. Because of life spans of freshwater fishes extending perhaps over several years for each generation, and the presence of several generations of fish in the river at any one time, it may take years before a true decline is apparent. Furthermore, in assessing the effects of artificial alteration of flow, normal population fluctuations must be allowed for, of which all too little is yet known in most instances. A decrease occurring in fish stocks after alteration may in fact be due to natural causes far removed from the immediate environment of the river, and only long-term investigations of both normality and abnormality will provide the factual evidence required. Usually the pressure of development is such that all too little time is available to relate one to the other.

Though it has occurred in a very few instances, it is not often that water alteration for other uses will increase a stock of migratory fish already existing in a river; there are however numerous examples of engineering works which have been specifically undertaken to increase such fish stocks — often most successfully — such as construction of fish passes in previously impassable areas.

The problems which arise may be illustrated by two examples, that of salmon fisheries in Scotland, which are being affected by hydro-power development, and that of river fisheries in Kenya which may be affected by irrigation projects. I have been personally concerned with both, and in each case the problems posed are of a contrasting nature because of the different methods of water usage involved, and the differing biologies of the fish concerned.

For power purposes in Scotland, water is stored in specially constructed dams across rivers in order to stabilize the flow and effect conservation of potential power. Such dams in turn produce a working head for turbines, of anything from perhaps thirty to several hundred feet. Part or all of the stored water is then passed continuously or intermittently through a turbine to generate electricity.

Usually, but not always, the water driving the turbine is returnable to the main river below the dam, either at the dam itself in the case of a low-head station, or much farther downstream in the case of a high-head station. Occasionally however it may be diverted through a tunnel from the dam and used in another watershed altogether. Whenever possible the same water is used over and over again at serially placed dams; thus there may be not one, but several, obstructions to be passed by migrating fish.

Such alterations of natural conditions impinge on the life cycle of the Atlantic salmon at many points. Firstly, the adult fish travelling upstream in all months of the year, may have to move in the reduced « compensation flow » required below each dam for varying distances, instead of in a naturally fluctuating flow. Very often the dam is built at the top of natural falls in order to utilize the maximum height available, and the compensation flow over such falls may be insufficient to allow fish to ascend easily. Thus either a further pass, operative on low flows, must be made at these falls, or else the fish encouraged to travel in « freshets », which are a periodic release of an agreed amount of stored water from the dam for a fixed period of time. An allowance for such release is usually granted to the local fishery authorities to use how and when they decide, but the quantity of water per annum for such use is fixed. The effect of such freshets is not really known. Stored water, released from the bottom of a dam, cannot be similar in composition to flood water which normally stimulates salmon to move; it may be colder, or de-oxygenated, and the increased flow alone is perhaps not sufficient to induce movement. Often the reduced compensation flow over a river bed in hot summers may reach temperatures almost lethal to fish, and which are certainly conducive to sporadic outbreaks of enzootic furunculosis. Compensation flow is not always a constant quantity in different rivers, nor even in the same river; in some cases winter compensation flow, or turbine discharge, is less than that agreed upon for summer, and this even lower flow may expose spawning fish or redds in the river bed below a dam.

If salmon must pass a dam in which is incorporated a low-head station whose working is intermittent, the fish reaching the foot of the dam may be subjected to flows varying from flood level when the turbine is on load to almost dry weather conditions when off load, all within a period of perhaps a few hours. At a high-head station, the major flow which is presumed to be attractive to fish may be perhaps several miles downstream where the turbine tail-race discharges, and not at the dam foot itself. In some cases, it is insisted by local authorities that the fish must be screened from entering such tail races since they might be killed in the draft tubes. The installation of such screens inevitably causes a loss of head and thus efficiency of the station.

Having reached the dam itself, the fish must be passed up to the reservoir above, up some sort of pass which the fish must be able to find easily and surmount readily; thus the design, and particularly the siting, of such passes is most important. Denil and vertical baffle passes are not used in Scotland. Early installations were of the traditional overfall weir type, but these have been superseded by the submerged orifice and pool type, and later still by the Borland fish-lock. The latter is an essentially simple idea using the principles of an ordinary ship-lock on a canal, and it can be incorporated singly or in stepped series as an integral part of the dam wall. The first two types are continuous in action, and fish travel up in their own time, but expend energy in so doing; in the Borland, the action is intermittent, often automatically cycled, and fish must be in position to be lifted hydraulically when the lower pressure gate is closed on each cycle, but they expend little energy themselves in reaching the higher point of release into the reservoir above. With such passes as the Borland, fish will occasionally refuse to pass out into the reservoir when lifted, in spite of the counter-draw provided by a by-pass valve, and must be dropped again for the next lift, but this is not common. Also, fish will not necessarily remain poised in the lower entrance pool till the next lift commences, and it is possible that the efficiency for such up-going fish could be improved by installing some simple form of non-return entrance immediately above the lower pressure gate to prevent such droppers-out. This need not necessarily be a conventional V-entrance. In general however the efficiency of the Borland for ascending fish is high.

It is customary to site the downstream entrance to such passes in the vicinity of the tail race discharge at a low-head station, in an area where maximal attraction is supposed to exist; but nevertheless ascending fish tend to seek the furthest point upstream which they can reach, and pass entrances could be sited accordingly. Remarkably little is known about the effects of greater or lesser flow in attracting adult salmon, though a maximum flow is possible which will discourage them from entering a area; turbulence must also play a part.

Any pass for ascending fish must take into consideration the magnitude of the salmon runs; though little is yet known on this feature, it is probably fortunate for Scotland that runs do not reach the size of say, the sockeye run in the Fraser River in Canada, where it has been estimated that fish run at the rate of 750,000 per day. No mechanical lift could cope with such numbers, and a constant flow pass must be of great volume to pass this number of fish up.

If there is any delay in ascending a dam, perhaps due to diversion of the fish or faulty siting of a pass, there will be delay in reaching the upper spawning grounds, and hence exhaustion of the fish reserves; salmon do not feed in freshwater, and their stored fats appear finely balanced from the time of entry into a river to spawning. Or, if fish are delayed too much, the spawning grounds may be reached too late, when ice-bound, or subject to winter floods before completion of redds; or else the fish may try and spawn in unsuitable areas.

In several Scottish rivers, the traditional spawning beds have been drowned by raising of the water level at the dam, and thus rendered unusable or unsuitable; or, if not completely drowned, markedly reduced in extent, thus leading to overcutting of redds and disturbance of previously laid eggs. In such cases, hatchery propagation has been resorted to, either by sowing of green eggs, eyed eggs, unfed fry or reared smolts in whatever suitable water is left. No certain information is yet available as to the efficiency or economics of any of these methods in the few rivers thus treated, for the practice has not been in operation long enough yet.

The methods of operation of dams and power stations is of some considerable importance. In some reservoirs the water level fluctuates a very great deal, and there may or may not be a complete turnover of stored water in a very short time; and in others the water level is held very stable with little turnover. Similarly the river level below a dam fluctuates to varying degrees depending on the type of station and method of operation. The effect of such fluctuating water levels on fish themselves, or indirectly on the food available for the resident young stages, is not known.

The descent of spawned fish — kelts — takes place in two waves, possibly dependent on water temperature. Evidence suggests that on two watersheds, affected by hydro-power developments, at least a proportion of kelts descend later in the year than formerly, for reasons at present not clear. It is not evident at present that such delay induces any greater mortality among kelts, but since only some 5 per cent of kelts survive in east coast rivers to spawn in later years, there are conflicting opinions as to whether preservation and total descent of kelts is important or not.

Evidence is also accumulating that fry and parr tend to show a drift downstream, particularly in autumn months, but the final migratory stage of smolts descends in huge shoals from approximately April onwards, depending on distance from the sea.

All descending fish, either smolts or kelts, can descend dams in only three ways — either through the turbines, through passes, or in spills. A Committee, appointed by the Secretary of State for Scotland, has recently issued a report on this subject, based on a fact-finding enquiry (*The Passage of Smolts and Kelts through Fish*

*Passes*, Scottish Home Dept., H. M. Stationary Office, London, 1957). In connection with turbine passage, they have stated that on the limited evidence available the number of smolts injured in passing through turbines up to a head of 106 ft. is probably negligible. It is customary to pass smolts through turbines at low-head stations, but there is still considerable anxiety on this point, and as with most aspects of salmon biology in relation to power construction, considerably more research is still required on this point before definite conclusions can be reached. Further experiments are planned, and clearly much depends on working conditions, the actual type of turbine employed (Kaplan for instance have wider-set runner blades than the Francis type, and the chances of mechanical damage must be different in both), and the method in which shoals enter the intakes, whether in small numbers or in crowded lots; and any possible long-delayed effects due to the sudden release of pressure on the downstream side of runner blades.

At most high-head stations, turbine intakes are screened from smolt entry, since it is assumed that smolts will be killed in passage through turbines at such. Scottish smolt screens are made of vertical mesh, covering several hundred square feet at tunnel intakes, the mesh being 1 inch horizontal by % inch vertical, which is enough to prevent a fish of about 5 inches long swimming through vertically. Mesh smaller than this leads to a loss of power. These screens are normally installed in double rows to facilitate cleaning, but this is still a problem and no better method than hand-cleaning has yet been devised. Since even this mesh causes a loss of power, it has been usual to place these fine screens in position from about March to August only, replacing them with coarser screens of vertical barring in the winter months. This practice takes no account of the growing evidence of downstream movement of fry and parr in fairly large numbers particularly in autumn. Both of these young stages could in any case pass easily through the smaller mesh, and it may be that heavy losses of young fish occur undetected each year in such situations. The Report mentioned above expresses the view that the Committee were generally satisfied with the smolt-screening arrangements now in use.

The choice of mesh for such screens is however a compromise, based on tests, between the necessity to retain or prevent penetration of the maximum number of smolts and the necessity to present minimum impedance to water flow. But smolt size at migration is not a fixed quantity; it varies from river to river, depending on environment and age at migration, and tends to decrease northwards. Quite apart from small smolts, or the younger stages mentioned above, even an average sized smolt can quite easily penetrate the mesh in use by turning on its side — a habit not infrequently observed in salmonid fishes, and evidence is certainly available that smolts do in fact penetrate such screens for they have been observed behind them at tunnel intakes.

It seems therefore that losses are inevitable; but there is no evidence of the magnitude of such losses and such should be obtained as soon as possible. What losses can be sustained by a stock yearly without long-term detriment to the future are a matter for conjecture only, for information on the dynamics of Atlantic salmon populations is extremely scanty.

It is known however that even with the present mesh, the placing of such screens is vitally important, and they must be installed at such a distance from the tunnel intake that water velocity through them does not exceed one foot per second. The small fish cannot resist velocities greater than this, and they become held on the screens, as has happened already with one installation in Scotland; where the fault is now being rectified. For the same reason, the closest attention must be paid to keeping the screens clean, because excessive clogging of the mesh will also lead to excessive velocities through clear parts of the screens and some head loss.

A review of the literature shows that possibly more attention has been paid to screening than almost any other aspects. Many other types have been tried elsewhere, such as lights, rows of bubbles, lines of moving chains and various electric « fences »; but none of these have proved more than about 90 per cent efficient, which is not considered enough. A recent American idea of passing the intake water through rows of vertical louvers, which induce small turbulent eddies by the angle at which they are set, through which small fish will not apparently pass, is promising.

I consider personally that trials should be made on the use of horizontal screening, using the « Wolf-trap » grid principle, the water to the turbine passing over a suitably spaced grid which separates the fish from water passing down through the bars, the fish themselves then being passed down a much smaller channel into a normal pass. Even with spacing as wide as half an inch, such horizontal grids are highly efficient for small parr-size fish, and this system would have two advantages. First, that the fish would pass out of the dam in a very much greater volume of water than the conventional pass allows and might therefore travel more readily; and second, that a horizontal screen is much more easily cleaned than a vertical screen underwater. Such a design would necessitate tunnel intakes being in the form of a long spillway adjustable for fluctuating reservoir levels, rather than an underwater entrance, in order to reduce the total depth of water passing over the screen, all of which require fish-filtration; and it might necessitate some loss of working head. These difficulties should not be insurmountable. Some evidence has been obtained that even coarse six-inch vertical barring screens placed for trash collection at tunnel intakes exert some deterrent effect on travelling smolts, and entrances to passes should not be situated behind such.

So far, there is no known way of efficiently directing fish to the right path, as opposed to merely discouraging them from taking the wrong path. If fish are to be passed down a fish pass, then the type, and particularly the siting of the entrance to such a pass is of the greatest importance, perhaps even more so than siting the lower entrance to the pass for ascending fish.

In this connection, the downstream migration of young fish is very different to the upstream migration of their parents. In the latter case, single large fish actively seek a way up and through obstacles. In the former, in the Atlantic salmon at least, downgoing fish consist mainly of large shoals of apparently passively drifting fish, with little impulsion or direction to their movements except that of the current and perhaps light direction and intensity. Shoals vary in size, and in the size of their individual fish depending on the location in the river (another factor of some importance to the size of mesh used in screens, since the optimum size for the lower reaches of a river may be too large for the upper reaches). Descending fish tend to travel tail first, and smolts are very timid; leading fish scared by an obstacle will transmit their alarm to the whole shoal.

Observations of such shoals indicate an apparent dislike for deep water, and a tendency to congregate in the shallowest, furthest downstream corner above a dam; they tend to keep a remarkably even distance away from vertical faces, screens and narrow passages, and travel more readily down a gradually accelerating slope than over a sharp vertical fall. They show little response to a major current flow as at tunnel intakes, and in fact often avoid such unless drawn physically by it; and they show a marked preference for travelling when the light intensity is low, as at dusk. These are all observations of experience, which can be confirmed at any dam in the migration season; but there are little or no scientific data available to indicate factors which really influence smolt behaviour.

In most Scottish dams, the pass entrance on the upstream face of the dam is usually only a few feet wide, overshot as in a Borland, or underwater as in a pool pass, and is situated either in the centre of a crescent dam or to one side, but always near the main tunnel intake. This is based on the assumption that the draw from turbine operation will persuade the fish shoals to enter the adjacent pass. The passes themselves seldom utilize more than about 12 cusecs, the remainder of the water being used for main or compensation turbines.

The observations of migrating shoals would however indicate that the pass entrance would be more favourably sited at the furthest downstream corner of a dam, irrespective of where the intake is situated; that it should have the widest possible entrance, and a shallow gradually accelerating fall over its sill as in a grid trap; and that it should be situated where the water is shallowest above a dam (with regard to its furthest downstream aspect), or else above a sloping wall and not a deep vertical face which creates reverse currents. All these features would accord with behaviour indications as known, and would apply to either a separate pass entrance or a combined intake-pass entrance as suggested above. They would of course involve difficulties with dams which fluctuate markedly in level, but again these should not be insurmountable. They could be incorporated in a Borland pass without interfering in any way with its efficiency as an ascending pass.

Because of the conflicting and scanty evidence on the efficiency of existing passes, further experimentation is obviously necessary.

If smolts are held up for any reason, they may suffer from delayed mortality before they reach the sea, for they appear to be in a state of physiological imbalance preparatory to entering salt water, and these changes are progressive even if held in fresh water. Certainly handling of them can be dangerous.

In some instances, it has been proposed that smolts be passed over dams in spills. Such spills, when due to rainfall, are often of great volume and are not necessarily controllable at the right time when the fish are moving. Water spilling down a dam face often reaches terminal velocity and risk of mechanical abrasion to the fish is great, together with damage when they fall at the foot of the dam. Conclusions of the effect of spilling fish thus are not clear-cut. In some cases in Canada the dam face is glazed to minimize risk from abrasion, and fish reaching the foot are dispersed upwards in the spray from a ski-jump to minimize risk from concussion. Smolts certainly slide down the chute of a normal Borland in the « fishing » position (lower gate open) without apparent harm, but even this small area could with advantage be glazed. A fish remaining in water in such a chute is clearly less subject to damage than a fish which leaves and then re-enters the water if the volume is insufficient or too finely dispersed. The effect of spilling larger fish such as kelts, or the damage which results to kelts as a result of accidental turbine passage, is not known.

Some of the Scottish power schemes introduce a more subtle danger to salmon because of their homing tendencies, the mechanism of which is not at all clear, but has been supposed to be due to detection of physical and chemical differences in the water. There are installations where the water is led by tunnel from one dam and discharged through an entirely different watershed, the water then becoming mixed to a greater or less extent. It is an obvious possibility that fish approaching the watersheds either from the sea or at tributary junctions may become confused as to which path to take, and thus straying and perhaps unsuccessful breeding may result therefrom; but the magnitude of such straying is not known. Furthermore, it is known that salmon prefer to spawn in the somewhat more acid rivers, and if an alkaline river is led to discharge into an acid river or *vice versa*, the chemical characteristics of the water must be altered and fish may find conditions no longer suitable for spawning.

Such inter-watershed tunnels may also facilitate the spread of predatory fish such as pike and perch into waters in which they did not previously occur, and present screening methods would be ineffective in preventing this. If smolts are delayed for any reason at a dam, opportunities for predation by pike and trout increase enormously.

Very few of the schemes at present constructed have been in operation long enough to enable records to be taken of the effectiveness of measures designed to overcome all these difficulties. Some of the difficulties, such as inter-watershed mixing of waters, are ignored; others have measures applied on an *ad hoc* basis whose efficiency is in doubt; some are undoubtedly successful. But behind all this lies a great ignorance of what normality was, or should be, in all rivers affected at present by power development, and with increasing utilization of water the urgency of such basic study is clearly apparent.

Turning to East African problems, irrigation projects already constructed, or proposed, are at present potentially more dangerous than power concerns, but there is perhaps an even greater lack of basic knowledge about the fish themselves.

For irrigation purposes, water is also stored to stabilize flow and effect dry-season storage; this storage may also produce a small head for gravity schemes. Part or all of the water is than spread over fields, and may, or may not be, returnable to the main river.

In Kenya Colony, two principal areas are concerned. The rivers of Nyanza Province which flow westwards into Lake Victoria support fisheries producing up to 2,000 tons of fish per year. The rivers of the Tana and Athi watersheds flowing eastwards to the Indian Ocean are as yet relatively undeveloped, but have an estimated potential at least as great as that of Nyanza. Large-scale irrigation projects for crop cultivation are being undertaken in both these areas, and a few small power projects for hydro-electricity are also under way.

Entirely different types of fish are involved in these areas to the salmon previously discussed. In the eastern area, eels are of considerable importance, the principal species *Anguilla nebulosa labiata* being typically catadromous as is the European eel. With the propensity shown by elvers and adults for ascending and descending places almost impossible to other fish, it is unlikely that power or irrigation projects will markedly affect the stocks, nor would any homing instinct be involved, since rivers must be recruited from the general body of elvers approaching the East African coast without reference to their parents' river of growth. Certainly however, at power stations such as that proposed on the Tana River at Seven Forks, some form of floodwater pass will be required, and the turbine intakes will require screening, for African adult eels are long and heavy and probably would not survive turbine passage. The stock of eels from the Tana watershed must contribute an appreciable portion of the total spawning stock reaching the Indian Ocean each year from Africa.

Various species of Cyprinid fish form the bulk of commercial catches in both areas. One, *Barbus,* is similar to salmon in some respects. They are anadromous, and as far as investigations have shown, the adults ascend rivers to spawn in rain floods; they spawn in rocky areas of rivers, and their progeny descend as fry or small fingerlings a few weeks or months later. Whether or not they exhibit a homing instinct is not known, nor is the extent of their river migrations; evidence available suggests this latter may be many miles. The adult migration is not prolonged over the year as in salmon, but takes place in two main waves in each twice-yearly flood season; runs may be of great magnitude involving many thousands of fish over a short period of a few weeks.

Various species of *Labeo,* in both eastern and western rivers, approach *Barbus* in their commercial importance. They are similarly anadromous, and floodwater spawners, ascending in great numbers over short periods. Unlike *Barbus,* however, they do not spawn in main river channels, but in flooded side swamps, their progeny descending again in only a few days as eggs or fry. Their spawning seasons are coincident with those of *Barbus,* but again the extent of their travels is not known; distances are probably a good deal less than for *Barbus.*

Various siluroids such as *Clarias* species are also anadromous floodwater spawners somewhat similar to *Labeo,* and are of commercial importance; but the cichlids are, as far as is known, relatively static.

Such river fish therefore pose somewhat different problems to salmon, though of the same complexity and magnitude. The ascending adults are subject to the same difficulty induced by reduced flow and lack of floodwater stimuli to migration, at least in areas where total storage is effected, though storage is seldom complete in the important flood seasons. Passes over obstructions must be provided for them; they cannot leap to the same extent as do salmon, and even quite low weirs of only a few feet in height may prove impassable.

It would appear at present virtually impossible to screen furrows in irrigated areas from minute eggs and fry of a few millimetres in size, and therefore in irrigation schemes in important fishery areas, it is of the utmost importance that the system of irrigation employed be continuous at least over the known spawning seasons, and all water be made returnable to the main river flow. Otherwise, loss of eggs and fry will be enormous when the fields dry, enough perhaps to destroy a complete stock for several years.

It is also obvious that erection of levees and flood control works on river banks will lead to a great diminution of previously natural spawning areas for *Labeo* and the *Clarias* species of fish; but by contrast if such fish are permitted to ascend weirs and enter the main and lateral irrigation canals, the presence of many hundreds of acres of flooded paddies will make available vast new spawning areas, and may thus increase total stocks greatly, provided the essential requirement of return of all irrigation water to main channels is fulfilled. There will however inevitably be losses of fish in areas under dry-foot crops and intermittent irrigation, so that water crops such as rice are an essential safeguard for the fisheries if maintained under continuous flow during egg and fry descent.

In such irrigated areas, other methods of fishery exploitation become possible. While we are not impressed with the possibilities of simultaneous cultivation of rice and fish in the same field, results obtained so far from the utilization of fish as a rotational crop to rice in fallow paddies have been very encouraging, and the shallow water culture of cichlids offers many biological advantages.

At present, however, methods required for schistosomiasis control are in complete conflict with fishery utilization of irrigation schemes, and this must be resolved in some way.

On the sociological side, artificial control of water flow introduces further difficulties. Indigenous fishing methods, while primitive in some respects, may nevertheless be complex in social structure, and are often extremely efficient. Thus, for example, the canalization of main rivers and the necessity to exert flood control will conflict with traditional fishing methods such as the communally owned cross-river fences with trap baskets commonly used in Nyanza, which usually cause backing-up of the water and flooding to some degree. These difficulties are not insurmountable, for experiments are now in progress to design highly efficient horizontal grid traps which offer minimum impedance to river flow, and other fishing methods such as drifting river gill-nets are also most effective. Adoption of such methods would clearly be required, but realization of their advantages is only a matter of time. The provision of passes over weirs also offers interesting possibilities for complete control over fishing effort — always a desirable feature, since escapement can be regulated.

It is evident from some of the proposals already made in Kenya for water utilization, that many of these will have a detrimental effect on existing or potential fisheries. Some will be beneficial, but efficient safeguards will be required. Fortunately, most of the water utilization schemes already in being are in areas where fisheries are of little importance, and serve as useful experimental pilot schemes. The main fishing areas are not yet affected to any extent, so that unlike the situation with salmon fisheries in Scotland, time, although short enough, is still on our side. The small research effort available is being actively directed to discovering the basic features of the biology of the fish concerned, and the characteristics of normality, before any alterations are imposed.

**Summary**

This paper deals with problems affecting Atlantic salmon stocks in Scotland, arising from hydro-electric power development of rivers, and secondly with those affecting commercial river fisheries in Kenya Colony arising from irrigation projects.

In the former case it is emphasized that basic knowledge concerning the normal dynamics of salmon population is very scanty, so that the effects of alteration of their river environment cannot yet be truly assessed; and there is at the same time a similar lack of knowledge concerning the biology of the river stages which would have been most useful in designing and operating such power constructions to mutual advantage. The urgency of development has outrun the fundamental research necessary.

In East Africa, major irrigation projects affecting commercial fisheries are still only in the proposal or early construction stages, so that research is being actively pursued to determine the features of normality, which will safeguard

the fisheries before it is too late. Entirely different types of migratory fish are involved, whose biology and behaviour so far as known will necessitate different arrangements to those required for salmon.

Certain principles are however basic to both, such as design and siting of efficient fish passes and screens, and major differences will lie in the actual method of utilization of the water in each case.

A brief review is given of problems arising with salmon in relation to the actual design of power installations as regards ascent and descent of fish, and also in relation to methods of station operation as they effect the migrating fish. Provisions made to ensure adequate ascent of adult fish are generally more satisfactory than those for the young descending stages, which still require a good deal of experimentation, and are equally important. Some suggestions are offered for improving such facilities based on observations already made. The efficiency of methods for artificially maintaining stock cannot yet be assessed, but have been applied in relatively few instances.

As far as irrigation projects are concerned, while satisfactory passes and screens are required, the main requirements will be to operate the schemes so as to suit the spawning habits of the fish concerned, and continuous, as opposed to intermittent, irrigation is essential, as is the culture of water crops such as rice. Irrigation of areas given over entirely to dry-foot crops will inevitably damage fisheries. Considerable attention will also to be paid to the alterations which will be required in existing indigenous fishing methods, which at present may conflict with flood control. The institution of irrigation may however to some extent increase the total fishery potential if properly managed.

# THE INFLUENCE OF DRAINAGE WORKS, LEVEES, DYKES, DREDGING, ETC. ON THE AQUATIC ENVIRONMENT AND STOCKS

BY

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## INTRODUCTION

In making an assessment of the effects of drainage works on the conservation of fisheries and land use, the complexity of the problems encountered is measured by the number of variable factors that must be considered. The results of any treatment will vary with climate — the amount of rainfall, its intensity and duration; with topography — the effect of surface relief and rate of run-off; with the amount and type of soil and vegetation and type of land use generally, both past and present.

The present survey is based chiefly on observations made in the rather humid climate of Scotland, mainly in connexion with the special conditions necessary for the maintenance of salmonid stocks whose requirements are usually adequately provided for in natural streams and rivers. It will be shown below, however, that if the basic needs of a salmon and trout population can be met in streams and drainage channels, the modifications made to attain this end, by conserving soil and water, will undoubtedly benefit many other kinds of wild life and may indeed prove of some value to agriculture and other consumers of water.

### The effect on the environment and stocks.

The increasing number of extensive drainage operations in various districts of Scotland, chiefly for the purpose of modification of soils for agricultural use and for flood control on the lower levels, has caused anxiety on the part of fishery proprietors and other interested parties who are concerned about the deterioration of fishing value which often results from such operations.

Investigation of some of the areas treated for drainage purposes has shown that while certain streams have been affected very adversely, many are undoubtedly improved by such works. The ameliorations (and of course the converse) have however been purely coincidental. It has so happened that, while the methods employed by drainage engineers have been similar in all the areas visited, their effects on the fisheries have been very different due to variations in local conditions.

The results to the fauna of the present system of drainage will be discussed first. Briefly the purpose of this system' is to remove surplus water from the surrounding land as quickly as possible by hurrying excess rainfall to the sea. To achieve this object the channels have been excavated to a depth determined by the general topographic features of the land and the new bed graded uniformly. The excavated material is deposited on the banks to form generally unbroken embankments on each side of the river, thus virtually increasing further the depth of the channel.

As a result, on even the gentlest slopes, pools are eliminated and, with the increased rate of discharge, the water over the river bed is in constant movement at all levels, and at the higher water levels the whole surface of the substratum itself moves due to the widespread scouring effect. Owing to the uniform configuration of the new watercourse, silt is also in constant motion. This condition is inimical to aquatic plant and animal life, the former being smothered and the latter denied their natural food and shelter. As all stones and gravels are embedded in silt, no resting places are available for many forms of insect and other life on which the growth of trout and young salmon depends. In addition, the most serious effect is caused by the destruction of the spawning beds of those fish which depend on clean and stable gravels for their reproduction. Owing to the absence of natural shelter the fish and other fauna are particularly vulnerable to all kinds of predators and those that survive have to withstand a constant current on a substratum that provides no resting place.

On steeper slopes the detrimental effect is more pronounced. The linear and symmetrical channel adopted by the drainage engineer is designed, as already mentioned, for speedy removal of surface water — the excess rainfall that cannot quickly infiltrate through the soil of the surrounding land. As the erosive power of a stream is related to the forces of gravity and velocity that determine its load-carrying capacity, the accelerated rate of run-off results in continuous degradation of the stream bed. Such drainage channels are initially characterized by great fluctuations in the amount of water they carry and during drought conditions may cease entirely to flow. In effect these channels resemble streams cutting back into hitherto ungullied land and the high rate of erosion is only retarded when the bed reaches the level of permanent ground water and pool formation takes place. In the absence of further interference the water course becomes relatively stable and may again be colonized by a normal aquatic fauna. This process however may take many years to complete and in the interval the water is practically sterile.

In regions of less frequent rainfall than Scotland the damage due to loss of material through erosion is less serious than the resultant lowering of the water table which leads to excessive drainage and damage to vegetation through drought (ROBINSON, 1949). Nevertheless some streams in Scotland have, in recent years, shown an increased tendency towards stagnation and in some cases have stopped flowing altogether during relatively short periods of drought. In the absence of any evidence of a decreasing annual rainfall the cause is presumably due, at least partly, to the increasing drainage operations which intensify the effects of drought (WISLER and BRATER, 1949).

In areas of flat or concave relief the scouring effect is reduced or non-existent as the bed of the channel approaches base level. In such areas, in direct contrast to the condition on slopes, aggradation occurs which also limits or prohibits the reproduction of salmonids owing to the continuous and widespread deposition of alluvium. While this more gently flowing water is less destructive to food organisms, etc., and the fish fauna finds a more restful environment, continuous aggradation compels periodic dredging of the channel to prevent reversion to the original state and the results to the fauna are catastrophic.

A similar chain of events caused by artificial dams may also be mentioned here. When a river valley or depression is flooded the flow becomes retarded in the lower reaches of the affluent streams and in sections affected by dams, by the impounded waters backing up the channels. As a direct result of the deceleration of the current, deposition and. aggradation occur and dredging becomes necessary to prevent flooding over the banks. The spawning beds which are normally situated on the alluvial deposits on the lower courses are first of all drowned, then by dredging removed.

After a period of repeated dredging resulting in the formation of artificial levees or dykes by depositions of the dredged material to heighten the existing banks, the necessity for further dredging as a flood control measure may be minimized for a number of years at least. Even with some aggradation the heightened banks may effectively contain flood waters. The building up by the stream, however, of a platform of alluvium above the normal level of the substratum carries its own threat to the aquatic fauna due to its great permeability. During periods of less frequent rainfall the channel may become dry with reference to surface flow while normal and otherwise adequate amounts of water are passing through the gravels as underflow.

In some basins, however, where the land drained for agricultural purposes has been mainly swamp or bog the previously existing streams, owing to their sluggish and muddy nature, have not provided suitable environments for salmonid fishes. As a result of typical drainage operations, streams have been made to flow from bogs and silted channels — streams which have since proved attractive to salmon and trout which had previously ignored the channels owing to their stagnant character. It has been shown that conditions of stagnation in a stream or factors that caused the current to be dispersed or reversed as it entered a reservoir inhibited the spawning runs of trout (STUART, 1957). Unfortunately the rejuvenated channels suffer from the same defects in respect to fish stocks and agriculture in that they will continue to act as excessive drains during dry weather and, in addition, while the running water provides an incentive for migratory fish to enter them, they make no provision for their reproduction.

It is important to realize and accept that drainage channels have become, for various good reasons, a necessary adjunct of agriculture and flood control, but as considerations of land use and management are outside the present scope of this paper, only the importance of their design will be emphasized here.

As a first step towards the alleviation of the deleterious effects of the present system of drainage, it is useful to summarize the physical characteristics of artificial and natural channels as they affect the aquatic fauna :

| *Artificial Channel* | *Natural Channel* |
|---|---|
| 1. The water course is straight, symmetrical and smoothed. The effective slope is increased by reduction of bed and bank friction due to the elimination of rock sills, gravel banks, etc. and therefore increases the velocity of the water and thus allows a given discharge to pass at a lower surface elevation. | The natural slope diminishes gradually from the source in steps with alternating pool and riffle formation. The bed is longitudinally asymmetrical and the capacity of the channel increases in a downstream direction. At bends and inflexions there is also a transverse asymmetry. |
| 2. Continuous tractional or bed-load movement of fine particles at all levels and of coarser materials at higher | With alternate decelerations and accelerations in a pool and riffle sequence, grading of the products of erosion |

levels. Rapid degradation on slopes and aggradation on flats. Absence of pools.

takes place with deposition of gravels at the ends of pools and a « pavement » of larger stones below rapids. Stability of conformation of bed, with erosion and deposition balanced.

3. Excessive drainage during drought with lowering of the level of the water table thus reducing ground water reserves. The lowering of the water table may decrease low water flow with danger of dessication to the fauna. Permits rapid fluctuations in the water table with possible adverse effects on soils (RUSSELL, 1950).

The storage capacity of the channel maintains some reserves during drought. In certain areas the stream may act as an irrigating channel instead of a drain, thus maintaining the level of the water table or reducing an excessive rate of decline or fluctuation.

Consideration of the above-listed attributes leads inevitably to the conclusion that the chief fault inherent in the present system is the absence of pools, which, by their decelerating effect on the velocity of the water, retard erosion and provide reserves of water in times of scarcity. This has been recognised for a long time and the provision of small dams or weirs at intervals along the water course has been suggested as a remedy (I.U.P.N., 1954). While initially at any rate such dams provide immediate alleviation, unless they are soundly constructed they are costly in maintenance and renewal. If of solid construction they will impound a great deal of the silt load and the bed load at the upstream face which in the free-flowing river would be carried forward (LEOPOLD and MADDOCK, 1954; GORRIE, 1954).

Such obstructions at the ends of pools with their accumulations of mud and silt render the pools unsuitable for the spawning of salmonids which require clean, unconsolidated gravel for nest building, incubation of ova and development of larvae (HOBBS, 1937; STUART, 1953*a*). Permeable dams of solid construction have similar, though less severe, effects but require an uneconomic expenditure of labour for cleaning purposes. Both types produce a flood hazard by their inflexibility and each is a serious impediment to upstream and downstream migration of fishes.

As the aim is to return the channel to a more natural configuration with its self-cleaning regimen the solution is undoubtedly to be found in the hydraulic conditions that establish the equilibrium of « stable » river beds. Restoration of a system of pools is the first step, but we have seen that the insertion of dams and weirs does not result in either stability or clean gravels. Examination of a natural pool produces evidence of strong scouring of the head of the pool due to the convergent and accelerated flow from the pool above. Relative rate of scour is a function of the rate of jet velocity to fall (or « settling », « sinking ») velocity of the granular components of the bed. If the components are non-uniform, the scour hole becomes paved with coarser material, thus increasing the effective fall velocity, which results in a reduction of the rate of scour (LEHAVSKY, 1955). Eventually only the larger stones are left at the bottom of the scour hole and further scouring is minimal. The finer materials have now been deposited farther downstream and for a given flow will be graded according to their fall velocities as the velocity of the current becomes reduced. The flow in natural or artificial channels however is seldom uniform and as a result banks are formed composed of an assortment of gravel sizes which eventually become stabilized at a distance from the initial scour hole which depends on the varying velocities of the current and the width of the channel.

This stability under widely fluctuating velocities is typical of the gravel banks favoured by salmon and trout for their reproductive needs and is founded on mechanical as well as hydraulic conditions. « 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 » (LELIAVSKY, 1954). During heavy floods, however, some of this material is carried farther downstream but is replaced by similar materials from upstream.

Recent research has shown that the choice of such accumulations of gravel by spawning salmonids [and also by minnows (*Phoxinus phoxinus* L.)] is conditioned by the presence of definite downward currents through these gravels which are also necessary for the adequate aeration of ova and alevins (STUART, 1953 *b*). It can also be demonstrated that these currents, always at right angles to the surface of the gravel, irrespective of its gradient, are due to the hydraulic head resulting from the difference in level of successive pools and become very much reduced in flood when the levels of the pools become nearly uniform and cease completely when the levels coincide. This phenomenon further accounts for their remarkable stability. These banks therefore define the lower limits of a pool, providing shelter stones, suitable gravels for reproduction and clean and well aerated water.

Depending on the size and type of granular material composing the bed the gradient at the end of the pool varies from around 5° to 10°, sloping from the middle of the pool to the apex of the mound, then dropping to the succeeding pool with a gradient of approximately 20° to 30°. Under ideal conditions the whole formation closely resembles that of a desert sand dune. During the season of full flow these mounds retard the passage of the water but slightly, while the gravel on the surface is constantly renewed by the normal process of gradual erosion. During protracted periods of low water levels, however, the shallow water over the gravels favours growths of algae and diatoms which by gradually blocking the interstices in the gravel and filtering out fine silt and mud, check the downward flow and maintain the levels of the pools. Such conditions also favour the proliferation of food animals for the fry remaining in the pools. Only under extreme conditions does the flow over the apex of the mound stop. Before the stagnation point is reached, however, the fish fauna finds unrestricted access to more congenial environment downstream and observations have indicated that even the smallest fry are seldom trapped by receding water levels in such pools. On the other hand it has been observed that even under optimal conditions of water flow a pool terminated by a dam or similar obstruction seriously hinders the normal downstream migrations of juvenile and adult salmonids and many fry and yearlings were lost when the pools eventually dried out (STUART, unpublished).

In the natural pool, with the return of higher water levels, the first effect of the increasing velocity of the water is a progressive cleansing action on the elevated gravel banks at the ends of the pools. LELIAVSKY (1955), discussing the silt-carrying capacity of irrigation canals, shows that this effect depends on the width to depth ratio — the greater the width as compared to the depth the greater is the force lifting the particle. In the spawning streams this cleansing may be completed by the nest-building fish whose activities often coincide with the first heavy rains. At the commencement of spawning the upturned gravel of the first redds is conspicuous against the darker coloured growths covering the rest of the bank. After the end of spawning and with floods or freshets in succession the gravel bank is once more clean and permeable to the water (STUART, 1953 *a*).

### Methods of alleviation of deleterious effects.

Experiments at present being conducted show that it is perfectly feasible to atain this self-regulating system in artificial channels even when the necessary gravels have to be imported at the beginning. In one stream the water was diverted into an entirely new channel, cut through cultivated land, for flood control reasons, and a sinusoidal instead of straight water course was adopted. Gravel brought from elsewhere was placed in the channel to form pools and although this work was only completed within a few days of the spawning runs, the gravel was utilized immediately by the fish. The channel successfully controlled the flood water and the result to the trout population was increased space for reproduction. It is also of interest to note that although some erosion took place during the first winter in the soft earth of which the banks were composed, the bed of the stream remained clean and the gravel banks increased in extent with the increment of small stones from the eroded soil.

A further experiment at present in operation in a low-level, highly aggraded stream bed which, owing to widespread silting, eventually caused the water to be diverted through broken banks into a bog, has shown that large-scale modifications for drainage purposes using mechanical means for digging need not entail an added expense when the stream bed is reconstructed according to the principles outlined above. Pool formation with gravel banks suitable for spawning salmonids was attained merely by leaving some gravel from the dredging at intervals calculated empirically along the stream bed. In effect some working time was saved by leaving the mound where it accumulated instead of transporting it to the banks with the bulk of the spoil. At the time of writing, three months since the operation was completed, a succession of heavy winter floods has dispersed the heaps of assorted stones and gravel according to the hydraulic and mechanical principles noted in the natural stream. While the gravel banks must await the spawning runs of the autumn to confirm their acceptance by the trout stock, physical tests at present indicate that the known requirements are fulfilled and the results of earlier experiments give no reason to doubt that this is so. The winter floods have been safely contained in the new channel and maximum flow has been uninterrupted. At normal levels and below at any given stage the amount of water in the channel is of the order of two to three times greater than before, chiefly contained in deep basins formed near the head of each pool and extending towards the middle.

Finally a further but unforeseen advantage to wild life in general and small livestock in particular has become apparent. While any water course carrying a flood is a death trap to many small animals that become entrained, the typical drainage channel constitutes a continual hazard at almost all levels due to its unchanging velocity between banks and its uniform depth. The modified channel on the other hand, at normal levels, offers frequent opportunities of foothold and shallow fords on the gravel slopes at the ends of the pools.

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**Summary**

This paper deals primarily with the consequences to salmonid stocks, their food supplies, shelter, access to and from spawning grounds, following upon drainage activities, etc. Both beneficial and deleterious effects of drainage works are examined and compared with conditions obtained in natural systems. The possibility of combining the desirable features of both systems with a view to conservation and improvement of stocks in artificial channels is discussed and suggestions are made and experiments described which endeavour to achieve this result without interference with, but possibly with benefit to, other legitimate uses of land and water.

# THE OKANAGAN RIVER FLOOD CONTROL PROJECT

BY

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**The Okanagan Salmon Run.**

The Okanagan River is a tributary of the Columbia River which has a large part of its drainage area in Canada. The anadromous fish utilizing the Okanagan River are sockeye or blueback salmon (*Oncorhynchus nerka*) which are exploited by a United States commercial fishery in the lower Columbia, and proceed up river to spawn entirely within Canada.

While salmon have been observed in the Okanagan system over the past 50 years, dam construction, irrigation projects, and other water use projects appeared to have taken their toll, so that by 1939 the run had been reduced to a low level. The construction of Grand Coulee Dam on the Columbia River at this time shut off sockeye migration to spawning areas in the Upper Columbia River above the confluence of the Okanagan River. A transplantation program was implemented by the U.S. Government, and one of the areas selected to receive the transplants was the Okanagan. Adults and fingerling sockeye were planted over the period 1939 to 1943, and since that time the run has developed to a point where the Okanagan is a major contributor to the production of this species in the Columbia River. As an indication of its size in recent years, the average spawning population over the period 1951 to 1953 was 35,000 fish.

The sockeye salmon pass through the commercial fishery in the lower reaches of the Columbia during June and July each year, the Okanagan portion proceeding upstream to Osoyoos Lake where they stay until the spawning period approaches. Spawning takes place in September and October in the 15 miles of the Okanagan River upstream from Osoyoos Lake. The eggs incubate and hatch through the winter and the fry emerge from the gravel and migrate downstream into Osoyoos Lake in March and April. Like other Pacific sockeye salmon they remain in the lake a year before migrating seaward, and return to their home spawning grounds as mature adults in their fourth year.

A considerable amount of data was gathered on the more important environmental conditions affecting salmon in the Okanagan River prior to construction of the flood control project. Besides determining the exact times of migration described generally above, records of temperature and discharge were obtained, and the depth and velocity of water and grading of gravel were determined for the most densely used spawning areas. From these observations it was possible to foresee any changes in environmental conditions which could be detrimental to the fishery, and to predict with some assurance the optimum conditions for production of salmon.

**The Okanagan Flood Control Project.**

Recurring floods around Okanagan Lake and along the river made consideration of a flood control project inevitable. A serious flood in 1942 precipitated formation of a Board of Engineers to study the problem, and a report was produced by this Board in 1946 recommending measures for flood control. While prevention of floods in towns and farms bordering Okanagan Lake and River was the main purpose of the study, incidental benefits were expected to include improvement to navigation on Okanagan Lake, and better regulation for irrigation downstream of the lake. In addition, many acres of marshland would be reclaimed.

The flood control works recommended included new storage dams at the outlets of Okanagan Lake and Shaka Lake, a smaller lake below Okanagan Lake. These dams were both above the upstream limit of salmon migration. A new diversion dam serving a large irrigation project was also necessary, but would be located at the site of an existing diversion dam which formed the upstream limit of salmon migration. From this point downstream to Osoyoos Lake 15 miles below, it was recommended that the channel be straightened and rebuilt to have a much larger discharge capacity. To provide the larger capacity in a shortened channel, it was considered necessary to pave some 2 miles with native stone, and provide 13 low weirs or drop structures each 3 feet high, in the remaining 13 miles of the channel for erosion control. This work would cover the entire 15-mile area utilized by sockeye salmon for spawning.

**Changes in Environment for Sockeye.**

The storage dams and other features of the project not directly affecting the fishery were commenced in 1952. In the meantime, steps were taken to assess the effects of the balance of the project on the fishery and to recommend measures to avoid any detrimental effects which might become apparent.

A joint study was made by biologists and engineers of the U.S. Fish and Wildlife Service, the Washington State Department of Fisheries and the Department of Fisheries of Canada. The results of this study were incorporated in a report completed in 1954 ([1]), which included certain recommendations for protection of the fishery.

With the physical data on spawning ground requirements at hand, the assessment of critical changes in the environment was comparatively straightforward. It was readily stated that the proposed paving would eliminate a large percentage of the best spawning area. Test borings had been taken on the remainder of the new channel, and from these it was possible to determine that gravel sizes and grading while usable would not conform to the best natural spawning gravel. Velocities and depths in the new channel could be predicted, and it was determined that these would provide some spawning area although it would be below optimum. The 13 drop structures, with a proposed head of three feet each, were known to be beyond the capacity of Pacific Salmon for ready ascent.

**Solutions to Critical Changes.**

While this assessment was comparatively straightforward, the solution to the critical problems posed required much further detailed study. The main problem appeared to be the loss of the most productive spawning area if the proposed section of channel were paved. One solution examined was the possibility of substitution of artificial spawning areas adjacent to the flood channel. Another possible solution was to substitute for the proposed paved section a system of rock fill dykes on each bank of the existing channel. A cost study indicated that the rock fill dykes would actually be cheaper than paving the channel. On the other hand the construction of artificial spawning areas would require additional excavation, gravel screening, and expensive headworks in addition to the cost of paving. The dykes were therefore decided on, and this course of action permitted the largest portion of the spawning areas containing the best conditions to be left in its natural state. While a saving in capital cost of the flood control project also resulted, it was generally conceded that this advantage would be at least partly offset by higher annual maintenance costs.

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([1]) The Salmon Problems Associated with the Proposed Flood Control Project on the Okanagan River in British Columbia, Canada. (Mimeographed report, unpublished.)

In the balance of the channel containing the 13 drop structures, it was considered that while conditions would not be optimum, they would be adequate to provide for the smaller portion of the spawning which normally occurred in this reach. The drop structures themselves, however, required intensive engineering study in a hydraulics laboratory to produce a design which would ensure ready ascent by the salmon.

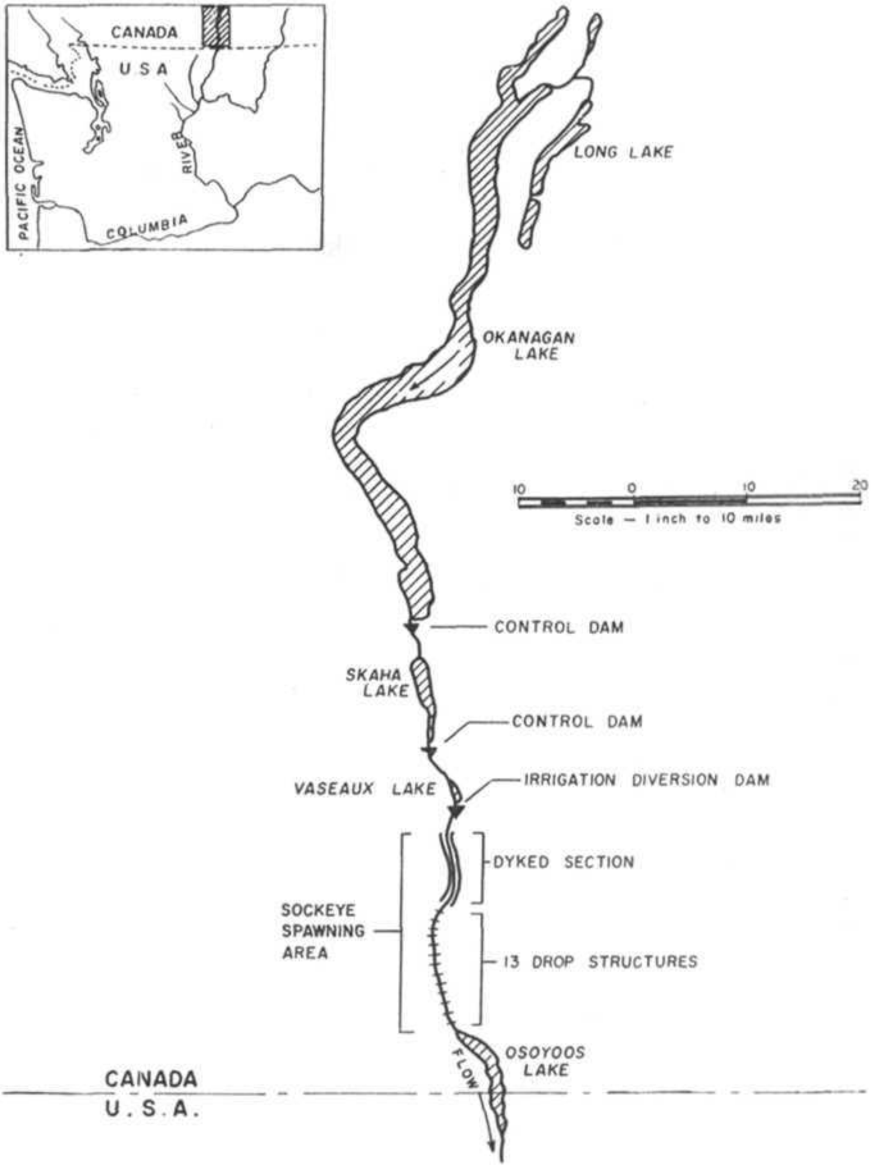
Since fishways at each of the 13 drop structures would be expensive and would present a continuing maintenance problem, it was decided to search for a design that would permit passage over the structure itself. The proposed structures were modelled in the Hydraulics Laboratory at the University of British Columbia, and drastic changes were made immediately in the hydraulic design in the interests of stability. The structure had been originally designed as a free overfall in the stream bed of three feet. It was found early in the model work that this design would produce velocities too high to prevent channel erosion. Other designs were then tested, and a multiple notched breast wall was finally selected. This design had the advantages of guaranteeing a three-foot hydraulic head at all river stages, and requiring bed and bank protection only in the immediate vicinity of the structure.

Further experiments were then made to find suitable facilities for fish passage. After testing several alternatives, the method selected was the addition of two simple weirs in the stilling basin below the notched breast wall, which would break the total drop into three even increments of one foot each at the average river flow during salmon migration. It was not expected that these increments would vary enough over the range of flows expected during migration to prevent ready ascent by salmon. The total effect then was to provide a fishway the full width of the river, with the advantage that ascending salmon could pass upstream at any point across the river and would not be delayed by searching for a narrow fish entrance.

It was considered that with these changes to the drop structures, and substitution of dykes for paving in the upper section, the sockeye salmon populations could be maintained at least at a level comparable to that prior to construction of the project.

**Operation of the Project.**

One can readily understand that the operation of a flood control project, if not carefully planned, can impose changes in environmental conditions which can be critical to anadromous fish. It has been the writer's experience that this applies generally to all water use




Plan of the Okanagan River System
showing flood control works and salmon spawning areas.

projects including hydroelectric schemes, and even to some low volume consumer schemes such as for domestic water supply.

The Okanagan Flood Control Project was brought into operation gradually as the various parts were completed. Some operating experience was gained prior to its completion this year. However, it is now obvious that careful assessment of all factors affecting the runoff in any particular year or series of years, must be made to ensure best operation of the project not only for flood control, but for the other interests involved including irrigation, navigation, and fisheries. The mechanics of setting up a method of study and control which would be satisfactory to these varying interests are now receiving consideration. Flow prediction from snow surveys, river discharge, and groundwater data has become a complex science in itself, but advances in this field have resulted in increased ability to regulate the discharge of selected watersheds intelligently. While conflicts may develop between some of the interests noted, it is felt at present that both flood control and fisheries are reasonably compatible on the Okanagan River, and that the environment of the sockeye salmon can be well maintained while accomplishing the main purpose of the project.

**Summary**

The Okanagan River Flood Control Project is an example of achievement of desired measures of flood control without harm to anadromous fish utilizing the river. Flood control was achieved by construction of storage dams in the headwaters, channel improvements in the lower reaches, and use of so-called « drop structures » for dissipation of energy in the improved channel. The natural environment of the anadromous fish utilizing the river was protected and possibly will be improved by designing the project to maintain the required original physical conditions during the spawning and incubation periods, and by providing ready access over the drop structures to the spawning areas above.

# EFFETS DU BARRAGE DE MARKALA SUR LES MIGRATIONS DE POISSONS DANS LE MOYEN-NIGER

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(Soudan français)

Le Moyen-Niger est un fleuve à régime tropical soudanien présentant une crue annuelle régulière et une grande différence de débit entre l'unique saison des pluies et la saison sèche. Dans le territoire du Soudan français, il traverse une vaste région sans relief, dite zone d'inondation au delta central, où il déborde son lit et inonde chaque année environ 17.000 km$^2$. Dans cette région, où la pêche est très importante, on constate que la croissance des poissons est totalement arrêtée durant les basses eaux et qu'elle est au contraire rapide durant les hautes eaux grâce à l'abondance et à la richesse relative des ressources alimentaires que procure l'inondation. La reproduction débute en fin de saison sèche et se poursuit tant que les eaux montent. A la décrue, jeunes et adultes qui s'étaient dispersés dans toute l'étendue de la zone inondée, sont obligés de retourner dans le lit mineur du fleuve. Beaucoup d'espèces entreprennent alors des migrations longitudinales anadromes qui les mènent vers des eaux à moindre densité de population où elles peuvent subsister jusqu'à la crue suivante. De telles migrations n'ont donc rien à voir avec la reproduction; elles sont déclenchées et entretenues par des stimuli d'ordre externe liés à la diminution progressive et régulière du volume d'eau disponible. Depuis des temps immémoriaux, les pêcheurs indigènes, installés tout le long du Niger, attendent qu'à la décrue les poissons migrateurs passent en bancs ou qu'ils se concentrent en certains points du lit mineur, pour les capturer plus facilement.

Il est donc évident qu'un barrage comme celui de Markala qui a été construit sur le Moyen-Niger un peu en amont de la zone d'inondation (6°05' W et 13°42' N) devait perturber considérablement les migrations de poissons et par contre-coup le rendement de la pêche en amont, sans pour autant menacer aucune espèce puisque les zones de frayères se trouvent en aval. Précisons que l'ouvrage en question est un pont-barrage à hausses mobiles de 813 m de long; il est destiné à maintenir le plan d'eau amont à une cote voisine de celle des hautes eaux, afin de pouvoir irriguer par gravité une vaste dépression située au N-E. Cette région, dite delta mort, était autrefois parcourue par un réseau de bras du Niger qui n'étaient plus alimentés naturellement, leurs entrées ayant été colmatées par un bouchon alluvionnaire de sable et d'argile. Le fonctionnement du barrage peut être schématisé ainsi : aux hautes eaux, les hausses mobiles sont baissées et il n'y a pratiquement aucune dénivellation entre l'amont et l'aval. A la décrue, au fur et à mesure que le débit diminue, un nombre croissant de hausses sont relevées et la dénivellation entre les plans d'eau amont et aval s'accentue; elle atteint environ 6 m en fin de saison sèche. Toutes les hausses sont alors relevées et le faible débit d'étiage est évacué sous forme de lame déversante ou de fuites entre les hausses. A la montée des eaux, les hausses sont progressivement abaissées.

Dès le stade des études préliminaires, la construction d'une passe à poissons avait été décidée. Mais, par suite de retards dans les travaux dus à la guerre, la passe ne devait pas entrer en fonctionnement avant 1946 alors que dès 1941 les effets du barrage en cours de construction se faisaient sentir. A la décrue, on notait d'énormes accumulations de poissons migrateurs bloqués dans leur remontée et séjournant juste en aval de l'ouvrage. Pour éviter la destruction de ces migrateurs, un arrêté local était pris interdisant la pêche, sauf celle dite « à la ligne flottante » durant toute l'année dans une zone s'étendant à 1 km en amont et 1 km en aval du barrage. Corrélativement la campagne de pêche en amont s'avérait catastrophique. Un rapport administratif signale que sur le marché de Ségou, ville assez importante située à une quarantaine de kilomètres du barrage, la vente des gros poissons durant le mois de mars 1942 était tombée à 5 par semaine, alors que les années précédentes à la même époque elle était de 250 par jour. Le ravitaillement de la population qui avait toujours été grosse consommatrice de poissons était sérieusement compromise. L'année suivante, la situation demeure aussi grave; nous lisons dans un rapport daté de janvier 1943 : « En amont du barrage le Niger reste vide de poissons. Les (pêcheurs professionnels) Somono vendent leurs pirogues, abandonnent leurs filets... La vie de nombreux villages est menacée. La population de Ségou tant européenne qu'indigène souffre du manque de poissons. C'est toute une branche importante de l'activité du Cercle qui est atteinte ».

On pensait que la mise en service de la passe à poissons, qui eut lieu en 1946, allait promptement remédier à cette situation. En effet le projet avait été étudié par les meilleurs spécialistes de l'époque et un soin particulier avait été apporté à sa réalisation. Il s'agit d'une passe à courant continu, repliée sur elle-même et formée de deux chenaux parallèles et accolés de 4 m de large, avec un bassin de repos au point de rebroussement. L'entrée s'ouvre juste au bas du barrage, dans l'eau blanche créée par une cascatelle. Le plafond de la passe présente une pente longitudinale de 7 % et une pente transversale de 10 %; il est muni de chevrons pour réduire la vitesse du courant aux environs de 1,50 m/s. Enfin, à la partie supérieure, le plafond est formé de dalles amovibles qui peuvent être déposées et remises en place de façon que la passe fonctionne avec un débit constant pour toutes les cotes de retenue. Les poissons migrateurs, parmi lesquels *Alestes leuciscus, Alestes nurse, Hydrocyon btevis, Hydrocyon forskali, Labeo senegalensis...* pour ne citer que les espèces les plus fréquentes et les plus importantes au point de vue économique, peuvent remonter le chenal sans difficulté. Cependant, il était facile de constater que la passe, avec ses 4 m de large, ne pouvait livrer passage aux énormes bancs de poissons qui, à certaines périodes de l'année, s'étalaient sur toute la largeur du fleuve. Au bout d'un certain temps, après avoir tourné en rond, buté contre le bas du barrage ou vainement sauté dans la lame déversante, les individus qui n'avaient pu rentrer dans la passe parce que celle-ci était constamment encombrée, finissaient par redescendre le courant et disparaître. Par ailleurs, en arrivant dans le bief amont, les migrateurs se trouvaient brusquement placés dans un milieu à niveau constant et à densité de population incomparablement plus faible que ceux dont ils provenaient. N'étant plus de ce fait soumis aux stimuli externes liés à la surpopulation et auxquels nous avons fait allusion plus haut, il est probable qu'ils s'arrêtaient dans la retenue d'eau juste en amont du barrage plutôt qu'ils ne continuaient à remonter le courant. En définitive, et bien qu'un nombre important de poissons franchissent la passe, le résultat en ce qui concerne le rendement de la pêche fut extrêmement décevant : aucune amélioration sensible ne fut constatée dans toute la partie du fleuve en amont de Markala.

Des études furent entreprises sur les moyens d'augmenter au maximum le nombre de poissons qui franchissaient le barrage. Le chenal de la passe qui avait une largeur de 4 m fut divisé longitudinalement en deux; une moitié a conservé les caractéristiques primitives, c'est-à-dire une pente longitudinale de 7 % et une pente transversale de 10 %, qui conviennent parfaitement aux migrateurs de taille importante et bons nageurs comme les *Hydrocyon*, les *Labeo* et les grands *Alestes.* Dans l'autre moitié, la pente longitudinale fut réduite à 4,6 % et des amortisseurs de tôle ont été disposés de façon à rendre la vitesse du courant aussi faible que possible, pour les petits *Alestes.* En même temps, une écluse à Poissons fut installée sur l'une des piles du pont; le fonctionnement en est automatique et réglé par une horloge. Le résultat de ces améliorations ne fut pas celui que l'on escomptait. L'augmentation, cependant notable, du nombre des poissons arrivant dans le bief supérieur n'étant suivie d'aucun relèvement vraiment sensible dans le rendement de la pêche en amont du barrage.

Il faut donc reconnaître que des dispositifs tels que des passes ou écluses à poissons, du type de ceux qui ont fait preuve de leur efficacité dans les pays tempérés, se sont révélés sans intérêt pratique dans le cas du barrage de Markala, le problème à résoudre étant de nature particulière; en effet, à Markala, il ne s'agissait pas de permettre à des géniteurs poussés par l'instinct de reproduction de franchir un barrage pour continuer leur migration anadrome jusqu'aux frayères, mais de faire passer rapidement des bancs de poissons, en quête d'espace vital, tout en maintenant dans le bief amont des facteurs suffisants pour entretenir le mouvement migratoire; une solution pratique à ce dernier problème reste à trouver.

Le barrage de Markala a donc profondément et, semble-t-il, définitivement modifié le régime des migrations de décrue dans le Niger Moyen. Il constitue maintenant une ligne de séparation nette entre deux régions bien distinctes tant au point de vue biologique qu'économique. En aval, on observe toujours des migrations de décrue importantes et le rendement de la pêche en saison sèche y est très *élevé*. En amont, aucune migration comparable ne se produit plus et le rendement de la pêche reste faible, même aux plus basses eaux. Jusqu'à Siguiri, à 500 km environ en amont de Markala, les pêcheurs locaux prétendent avoir remarqué une diminution sensible du stock de poissons exploitable depuis la mise en service du barrage; mais c'est pour la région située immédiatement en amont et plus particulièrement celle où le relèvement de la cote d'étiage s'est fait sentir, que les perturbations socio-économiques ont été les plus profondes. Ne pouvant plus compter sur un rendement rémunérateur en saison sèche, les pêcheurs professionnels ont pris l'habitude de partir chaque année pour une campagne de pêche vers l'aval, allant parfois à de grandes distances, jusque dans le haut de la boucle du Niger. Ils contribuent ainsi à l'exploitation d'eaux qui étaient et sont probablement encore insuffisamment pêchées par les populations locales; par ailleurs, le transport du poisson frais par camionnette est maintenant de pratique courante; toute quantité pêchée juste en aval du barrage et ne pouvant être vendue sur place trouve un écoulement facile et rémunérateur sur le marché de Ségou ou dans les villages situés en bordure de la route. L'interdiction de pêche 1 km en amont et 1 km en aval du barrage est en voie d'être sinon supprimée, du moins assouplie. Une enquête avait *révélé* que des poissons carnivores de grande taille, en particulier des *Clarotes laticeps*, profitaient de la tranquillité procurée par l'interdiction de pêche pour se rassembler à l'entrée de la passe; ils en bloquaient l'entrée et avalaient au passage les migrateurs qui se présentaient; un arrêté local publié en 1955 prévoit que « l'Administration des Eaux et Forêts pourra organiser des pêches à proximité des passes à poissons avec le concours des pêcheurs volontaires munis de leurs engins pour la destruction des espèces carnassières gênant la remontée des espèces migratrices. Les pêcheurs ayant prêté leur concours et le matériel auront droit selon la coutume aux deux tiers du produit de la pêche ». Faute de personnel pour organiser et contrôler ces sortes de battues, le texte précédent ne fut pratiquement suivi d'aucun effet, mais l'idée a fait son chemin. Actuellement, l'Assemblée territoriale discute un texte qui permettrait d'exploiter rationnellement les poissons qui pullulent sans intérêt ni profit d'aucune sorte dans la zone où la pêche a été interdite de part et d'autre du barrage.

**Résumé**

Le barrage de Markala, construit sur le Moyen-Niger en amont de la zone d'inondation constitue un obstacle aux migrations de décrue. Il a de ce fait profondément modifié le rendement de la pêche en amont, et causé de graves perturbations à l'organisation socio-économique du pays. Une passe et une écluse à poissons se sont révélées solutions sans efficacité pratique. Après onze années d'observations et d'études, on envisage maintenant d'exploiter au mieux les rassemblements de poissons qui existent de part et d'autre du barrage, mais surtout en aval, alors que, au début, on avait jugé prudent de les protéger par une interdiction totale de pêche.

# UTILIZING THE NATURAL RESOURCES OF LAKE VICTORIA FOR THE BENEFIT OF BOTH FISHERIES AND AGRICULTURE

BY

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A shortage of sulphates in solution is a factor affecting the productivity of Lake Victoria. This was discovered by growing cultures of algae in known amounts of lake water to which were added solutions containing all but one of the essential plant nutrients and then observing the growth made in these various media (1). The usual method for determining chemical deficiencies by observing the reduction of chemical substances in solution and relating them to the growth of the plankton is not applicable in Lake Victoria, because under the tropical conditions obtaining, seasonal fluctuations in the plankton are slight and because throughout the year the amount of sulphate in the lake water is too small to be readily detectable by chemical means.

As sulphates are present in most waters of the world in quite high concentrations, the discovery that they were a limiting factor in Lake Victoria was a matter of considerable interest.

A study of the records made by water analysts in different areas of Africa revealed that in many African lakes and streams sulphates are present in only very small amounts (2); the writer suggested that this might indicate that sulphates were in short supply in the soils through which these streams drain. Several agricultural departments in East Africa have since found that many soils in Uganda, Kenya and Tanganyika contain only a little sulphate; apart from references to this in current annual reports, their results have not yet been published. It seems moreover that in some cases where fertilizer trials with ammonium sulphate and superphosphates have led to increased production of crops, part of the increased yield has been due to the sulphate contained in these fertilizers. Applications of gypsum in the Kitale area of Kenya have led to increased yields, particularly of leguminous plants used for fodder. Although all these investigations are only in an early stage, there are clear indications that many African soils contain too little sulphate for maximum production.

As far as the work of the East African Fisheries Research Organization was concerned it was obviously of great importance to investigate the sulphur cycle in Lake Victoria. [Some interesting work was done on the secretion of sulphuric acid by molluscs (3), but this lies outside the scope of this paper.] Analyses showed that the streams flowing into the lake contained little or no dissolved sulphate and that very little is contained in the rain falling on the lake. It was found, however, that the bottom deposits (4) contain very considerable amounts of sulphur, both in the form of sulphates and as organically combined sulphur. Only a little is present in the form of sulphides. Values for total sulphur as high as sixteen thousand parts per million (dry weight) were recorded and values of eight thousand parts per million were of common occurrence in the mud deposits in sheltered bays.

Further analyses of these mud deposits showed that they contained very little inorganic matter and much that might be described as inorganic was in fact composed of diatom, frustules. These frustules are, it seems, responsible for the high values for sulphate contained in the mud, as they have the capacity to adsorb sulphates and prevent their reduction to sulphides.

Over ninety per cent of the sulphur contained in the mud deposits is, however, organically combined. We thus find that sulphur is strangely distributed within the lake, with the water overlying the mud containing less than one part per million, while the mud itself contains many thousands of parts per million.

A peculiar feature of these deposits is that they do not decompose, or if they do, they do so extremely slowly. Either *in situ* or if brought into the laboratory and kept either aerobically or anaerobically they show little tendency to decompose or breakdown in any way. However, this mud, if dried and rewetted or if boiled, produces a very fertile medium in which bacteria grow profusely; aqueous extracts derived from this mud can be used to grow a variety of micro-organisms and cultures of algae. Microscopical examination of these deposits show that they contain enormous numbers of minute, immobile encapsulated organisms, related, it seems, to certain primitive forms of blue-green algae or to *Nocardra*-like organisms. Herein lies a probable explanation for the fact that these highly organic deposits do not decompose in the way one might expect.

These deposits are composed in the first place of precipitated plankton, plant detritus and excreta of fish and other animals. Evidently this material provides conditions that are extremely favourable to the growth of these encapsulated organisms. They become dominant in the mud and seem to prevent in some way the growth of other micro-organisms while they themselves appear to be resistant to the normal processes of decay. It is of interest to record that these minute organisms are not readily visible until the deposits have been well shaken with glass beads. In the natural state they bind the other organic material into small aggregates composed of detritus, algal cells, etc.

Another property of the mud which was discovered on analysis is its very high nitrogen content; later it was found that most of this nitrogen is in the form of protein, and values for protein as high as twenty per cent have been recorded (5).

Spectrographical analyses (6) of these deposits have shown that they contain in considerable amounts all the trace elements required by both plants and animals as well as the usual mineral requirements.

As can be seen from the above brief account, the bottom deposits of Lake Victoria, which are of great extent and depth particularly in the sheltered coastal areas, contain vast quantities of organic matter, rich in plant nutrients. They contain large quantities of organically combined sulphur, which is a known deficiency in the lake water and which is a suspected deficiency in many African soils. The problem that awaits solution is how best these deposits can be utilized for the benefit of both fisheries and agriculture.

Before outlining any major development projects it may be as well to consider first the effect of man's activities on the natural biological cycle as it occurs in the lake.

In the early part of the century modern fishing gear was introduced, notably gill nets. These nets when first set in the lake caught very large numbers of fish, particularly so with regard to the two species of *Tilapia* endemic to the lake, *T. esculenta* and *T. variabilis.* These fish are still the most important element in the commercial fishery. Though reliable records were not kept, it is certain that the lake supported in those earlier days populations of *Tilapia* vastly more numerous than at present. The abundance of large *Tilapia,* of a size to be caught in five inch gill nets, indicated that there were accumulated stocks belonging to many year groups.

The more numerous of the two species of *Tilapia* is *T. esculenta;* both are herbivorous and feed mainly on the Phytoplankton. They thus, as converters of plant material into animal material, play a very important rôle in the general economy of the lake. It follows that a reduction in the numbers of these fish will mean that less phytoplankton is consumed and more will be lost by precipitation to the bottom of the lake where, as shown above, it becomes unavailable and is not even liable to decomposition in a way that would restore the nutrient status of the water. There is no doubt that the general fertility of this lake depends on the maintenance of large stocks of these herbivorous fish. Unfortunately intensive gill net fishing over the past fifty years has greatly depleted the stocks of *Tilapia.*

Investigations carried out by E.A.F.R.O. indicate that there is still an abundance of Phytoplankton which could support vastly greater numbers of *Tilapia* than occur at present. Studies on the life history of these fish indicate that the most important factor limiting their numbers is a shortage of suitable spawning sites. These fish require a firm sub-stratum, in-shore and in moderately sheltered water, where they can make nests in which the eggs are spawned and fertilized. After fertilization the eggs are carried in the mouth of the female and « brooded » for about three weeks by which time the fry have completely resorbed their yolk sacs. The brooding females retire to sheltered waters on the fringe of water-lily swamps, where the fry are eventually abandoned. Subsequently these fry migrate away from the margins of the lake and feed on the plankton in the more open waters of these sheltered bays. They do not, until much older, move far from where they were spawned.

The shortage of suitable spawning sites arises from the fact that much of the littoral region is overgrown with papyrus swamps. The water in these swamps is without oxygen and is unsuitable for fish without accessory airbreathing organs. These papyrus swamps frequently extend some distance into the lake over several feet of water, floating at the surface as a dense mass of vegetation. Beyond the fringe of the papyrus the bottom is composed of soft mud, thus the *Tilapia* in such regions can find few suitable areas on which to make their nests.

As an immediate expedient to overcome the present shortage of fish, it has been recommended that a vigorous policy of restocking should be adopted. *Tilapia* can be reared quite easily in shallow ponds. If these ponds are managed solely as breeding ponds, and not as ponds for growing fish to edible size, great numbers of fry can be reared annually and liberated to grow to full size in the lake. Some pilot experiments have already been carried out along these lines. In these experiments *T. zillii,* which were bred from a few individuals taken from Lake Albert, were used because it was thought that these fish, which eat higher plants, would not interfere with the two endemic plankton-feeding species and furthermore it was thought that they might have a beneficial effect by reducing the amount of littoral vegetation. The results of these experiments have been encouraging and fry, which have been introduced, have grown to commercial size in just over two years. *T. zillii* appears to grow rather faster than either *T. esculenta* or *T, variabilis.* However, a good case can be made out for the restocking of the lake with fry of *T. esculenta* as well.

Restocking can only be considered as a partial solution to the problem of increasing the numbers of fish in Lake Victoria; a more adequate solution would seem to lie in a policy of swamp clearance and reclamation. Papyrus swamps should be cleared in places where they are not too extensive and where such clearance would uncover areas suitable for nest building by *Tilapia.* Furthermore, a coast line cleared of excessive vegetation would certainly provide better conditions for the young fry. Part of the cost of swamp clearance might be recovered by making compost of the papyrus and some of the other aquatic plants and grasses might be converted into silage for cattle.

A distinction should be drawn between a policy of swamp clearance, as outlined above, and a policy of swamp reclamation. There are many places, particularly on the north coast of Lake Victoria, where former shallow enclosed bays have become entirely choked with vegetation composed partly of papyrus and partly of swamp grasses. Such areas, which are already in the process of becoming dry land, might be reclaimed quite easily by pumping on to them fertile lake mud with the aim of converting them into productive market gardens. This might be done economically where there is a high demand for food in areas close to townships. Fertile water draining into the lake from these reclaimed and cultivated areas should lead to an increase in plankton production and so to an increased production of fish. This type of swamp reclamation would have the added advantage of eliminating places where mosquitoes can breed and so lead to a reduction in the incidence of malaria.

Looking rather further afield for ways of utilizing the bottom deposits of Lake Victoria, it seems that it may be worthwhile to pump this mud from the bottom of the lake, dry it and use it elsewhere as an agricultural fertilizer. Some preliminary trials have shown that good results may follow the application of this mud to infertile soils, but it has yet to be determined whether this can be done on a commercial basis.

Some rather ambitious trials have been made to see whether lake mud could be used as a food for pigs. The high protein content of the mud suggested that this might be feasible; in this connection it is perhaps worth recording that significant quantities of vitamin $B_{12}$ are contained in the mud (5). Pigs tolerated up to twenty per cent of their food in the form of mud. Over the period of the experiment, which was from shortly after weaning till they went to the bacon factory, approximately ten per cent of their normal rations were withdrawn and made up with mud. Five out of the six pigs used in this experiment were classed by the factory as grade « A ». Their growth rate was, however, slightly slower than normal. This experiment cannot be considered as adequately controlled, but it did show that there is some possibility of using this mud as a food.

Very carefully controlled feeding experiments were carried out on rats; in this case it was found that these animals could make no use of the protein contained in the mud. As explained above, most of this protein is probably contained in the very small encapsulated « blue-green algae », which comprise the main living constituents of the mud. These have a very resistant cell wall which appears to defy digestion by most animals. Future research may find a way to process this mud so as to make the protein more available.

In this short article, it has not been possible to do more than outline briefly a number of possibilities, it is hoped, however, that future research and the application of this research may lead to the planning of a programme of development that will make good use of the natural resources of Lake Victoria.

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## Summary


The question of a sulphur deficiency in the waters and soils of Africa is discussed and suggestions for using the fertile deposits from the bottom of Lake Victoria for the benefit of both fisheries and agriculture are put forward.

Reference is made to the importance of maintaining adequate stocks of *Tilapia* in Lake Victoria, in order that the basic fertility of the lake be kept at a high level. Restocking with fry is recommended as an immediate expedient to overcome the present shortage of fish, and swamp clearance is advocated in order to increase the extent of areas on which *Tilapia* can spawn.

In the Lake Victoria basin the interests of agriculture and fisheries are closely linked and development policies can be formulated to benefit both these industries.

# THE INFLUENCE OF SOIL AND WATER CONSERVATION ON NATURAL AQUATIC RESOURCES

BY

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**Summary**

The object of this paper was to examine and elaborate, with reference to selected catchment areas, the general principles which had emerged from the background papers for Theme Id.

The main example was the river Nile of which the catchment is shared by eight countries. From a scientific viewpoint this is one of the best-known rivers of the world with records of flow, unfortunately not continuous, dating from the early civilizations of Egypt. A quantity of modern information is now available through the activities of organizations such as the Physical Department of Egypt, the Irrigation Department of the Sudan, the Hydrological Survey of Uganda, the East African Fisheries Research Organisation, the Game and Fisheries Department of Uganda, the Hydrobiological Unit of University College Khartoum, the Jonglei Investigation Team and the Fisheries Section of the Game Department in Sudan.

The accidents of geological history, including the formation of rift valleys, the pluvial and inter-pluvial periods, river capture and erosion, have achieved in the Nile system a remarkable amount of natural water conservation. For instance there are the vast natural reservoirs of Lakes Victoria, Edward and George, Albert, Tsana, which help to control the river's flow. This water control, coupled with natural soil erosion of prodigious dimensions in Ethiopia, made possible the ancient and modern civilizations of Egypt and the Sudan. It has also led, through varying degrees of isolation, to the evolution of aquatic fauna, especially fishes, which are of great interest to evolutionary biologists and are fundamental to the proper use of the aquatic resources.

Most scientists who have been concerned with the conservation and use of the Nile's water resources are in broad agreement with a master-plan for improving on the natural system of water-storage and water-flow in different parts of the river system, in the interests of all inhabitants of the countries concerned. The various measures

are, however, still being debated actively on the political level and there may be long delays before final decisions are reached. The influences on aquatic and related natural resources of those works already completed (Owen Falls Dam, Jebel Aulia Dam, Sennar Dam, Aswan Dam) and of those which may be undertaken in future [Lake Kioga Barrage, Lake Albert Dam, Lake Tsana Barrage, Blue Nile (Roseires) Dam, Aswan High Dam] were examined, as also were the increased and reduced amount of soil erosion in different parts of the catchment, consequent on the activities of mankind in exploiting or conserving the soil and vegetation. On the whole, the conservation of Nile waters increases the potential of the aquatic resources. In this connection, however, it is important to distinguish between the quantity and the quality of water which may be held in storage or released down the river, as influencing biological productivity. Such influences extend, in the case of big rivers, into the sea; the progressive reduction in the Nile's effect in fertilizing parts of the Eastern Mediterranean is a case in point.

Other catchment areas were compared with the Nile. The Volta river project in Ghana and the Kariba Gorge hydro-electric scheme in Rhodesia will create lakes on the rivers Volta and Zambezi respectively which in size and biological potential will be comparable with the Great Lakes of East Africa, but they will be situated in parts of the continents which are conspicious for the absence of standing water. Both these projects provide opportunity for the development of substantial aquatic resources through wise scientific management, but at the same time they will involve other biological changes, including risks to health, which need to be woven into a new ecological pattern.

Nearer at home, on the much smaller scale of catchment areas in the British Isles, where until recently water has been thought of as abundant in supply, many new projects are having pronounced biological influence. Often the situation is dominated by water pollution, the prevention or cure of which presents problems so intense that they can be tackled only on the scale of pilot areas. In one case, that of Milford Haven in South Wales, where major industrial developments are to take place in an estuary and a catchment of pure water, it is hoped that arrangements can be made to demonstrate that, by applying the resources of modern knowledge, industrial development and the purity of water are not incompatible.

# POLLUTION CONTROL AND WATER CONSERVATION

BY

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There is no need for me here to discuss the use of water nor its importance to mankind. Over large areas of the world they have been subjects of fundamental importance ever since human settlement began, and it is only in countries like Great Britain where rainfall is abundant that we have been accustomed to regard ample water supplies as the normal state of affairs and are now inclined to be a little surprised when we have to plan the use of water so as to avoid difficulties owing to water shortage. To many people the problems which are so novel to us are a mere commonplace of everyday existence.

My subject is one aspect of the problem of the loss of water; I almost said waste but that would be too harsh a term, for water which is unavoidably lost cannot be said to be wasted.

Of course, the total amount of water in and on the earth, in the seas and in the atmosphere is approximately constant. Very little is being made, for there is no sizeable source of hydrogen to serve that purpose and very little is being permanently destroyed as water. It may be vaporized or frozen, it may penetrate into inaccessible strata deep down in the earth, it may be incorporated into organic tissue or used in chemical syntheses. Yet steam condenses, ice melts, water in the earth emerges as springs somewhere, organic matter decays to carbon dioxide, nitrogen and water, and many chemical processes produce water as a by-product. But however satisfactory and stable the overall position may be, the distribution of water in time and in space leaves much to be desired. Too much here and too little there, too little now, too much in three months' time are conditions painfully familiar to us all and the problem is to have enough, but not too much, in the right place, at the right time.

It is as well to remind ourselves at the outset that all water originates in precipitation from clouds as rain or snow and sometimes hail.

As it falls, water is, of course, most useful for the irrigation of growing crops but its usefulness is very much increased when it has reached the surface of the ground and has collected into lakes, rivers, ponds, permeable underground strata, or even manufactured reservoirs like the cisterns at Aden and Gibraltar or the peasant's water butt.

When the water has been conveniently collected whether by nature or man then it begins to be used and some of it to be lost. All over the world much is lost by evaporation; the loss is greatest in hot, arid areas and where water is used for irrigation it is much increased, not only by evaporation from the increased surface area of the water, but by the transpiration of the irrigated crops. Water is also lost by seepage, though I cannot quote a case where this is a serious problem. I have no doubt though that were my knowledge more complete I should know of cases where rivers disappear underground and the water does not reappear as useful springs to be of practical benefit to the inhabitants of that region.

The third source of loss and the real subject of this paper is where in the course of domestic or industrial use substances are added to the water which make it unsuitable for further use and it is discarded in that state. This is the problem of water pollution.

I am therefore proposing to consider how we can avoid the waste of water by spoiling its quality so that it can only be used once. It would be as well, however, first to realize that not all contaminants make water unserviceable for all purposes. Water containing organic wastes may be very satisfactory for irrigation; fish are reared in China in waters which by European standards would be regarded as seriously polluted, and effluents from sewage disposal works are commonly used for cooling purposes at electricity generating stations. Nevertheless it is generally true that clean water is more useful than polluted water for the reasons set out below.

In a recent paper, Hynes (1) divided waste waters into four groups, and though, as he remarks, they are fairly ill defined, they can conveniently be used to indicate the type of problem to which they give rise in the subsequent use of water :

1. poisons such as metals, salts, acids, alkalies, and phenolic wastes;

2. inert suspended matter such as wood pulp, coal washings and china clay wastes;

3. organic residues such as sewage, effluents from the food processing industries, slaughterhouse drainage and some types of organic chemical residues, like waste from gas works;

4. hot water from condensing plants; the biggest source in this class is from electricity generating stations, but hot water is produced in many industries where the processes used include evaporation under reduced pressure.

There is also nowadays the problem of radioactive wastes but that is a new and specialized field which has so far been dealt with by the responsible authorities deciding on medical advice what is the permissible level of radioactivity in the water and then limiting discharges so that that figure is not exceeded. This method in itself gives rise to other difficult problems to be dealt with — for example, how are wastes not to be allowed to be discharged — but the whole subject is too complex to be further dealt with here.

The discharge of poisons will very probably make the receiving river unsuitable as a source of water supply; the water will be unsuitable for irrigation, for the poisons may destroy crops and will probably destroy the river, at least for a time, as a fishery valuable either for the production of food or for recreation.

It is said that in Wales the discharge of lead and zinc salts from mine workings led to the loss of agricultural land. The metals poisoned the vegetation growing on the banks of the stream and when the plants had died the soil became more subject to erosion. Acids will corrode underwater structures of metal and concrete.

The discharge of inert substances will probably not make the water unsuitable for irrigation nor will it necessarily make it unusable as a water supply, though treatment of the raw water to make it potable may be much more expensive, but it will almost certainly reduce the value of the river for fishery purposes by the blanketing effect of the sedimenting material on the flora and fauna of the river bed. There are often, too, very powerful objections on aesthetic grounds to black, brown, white or grey rivers, and these objections are not lightly to be disregarded.

Organic wastes are the commonest form of pollution and have probably received far more investigation than any others. They are susceptible to bacterial attack and decomposition and in this process oxygen is used up and the receiving stream becomes deoxygenated or even anaerobic. Fish and other organisms may die of asphyxiation, the water will probably develop tastes and odours which make it difficult to use as a source of water supply, apart from its bacterial contamination, and if it becomes anaerobic it may well become a public nuisance owing to the stench arising from it. On the other hand such waters are not necessarily unsuitable for irrigation, and indeed the material they carry may well have some manurial value.

The discharge of waste heat, of course, makes the water unsuitable for immediate re-use as cooling water. In one generating station in Great Britain it happens that tidal conditions sometimes result in water flowing direct from the outflow to the intake and the temperature has on more than one occasion built up to 40 °C. Heated water may be biologically harmful owing to the direct effect of temperature, and it is also liable to be deoxygenated, partly because of the decreasing solubility of oxygen as the temperature rises, and partly also because the rate of decomposition of organic matter is increased and the rate of consumption of oxygen rises rapidly.

The question which faces all industrialized countries is : how are these effects to be prevented ? One facile solution that is still proposed from time to time is that the discharge of all effluents should be prohibited. Though it is true that some wastes could be, and are indeed, evaporated — for example, still liquor from the manufacture of whisky — such a general solution is entirely impracticable. For one thing evaporation means that the water is lost even more effectively than if it had been discharged in an impure condition. Secondly, evaporation is economically only practical where the waste liquid is strong, and most effluents are very weak solutions.

Allied to the suggestion is one that was seriously considered about a century ago in Great Britain, that all wastes should be conveyed in pipes to the sea. Even in Great Britain where it is said that no part of the country is more than 60 miles from the sea, that remedy is of extremely limited application, and it would, of course, be even more inapplicable to Central Europe. The main reason is that the quantity of water is often as important as its quality. Water is still extensively used to develop power, and a permanent diversion from the watershed of all that has been used by industry would be a very serious loss. Further it is well known that rivers to which effluents are discharged can become re-purified, and this useful property would be lost.

So the problem must be tackled in other ways. One extremely profitable method is water economy so that the amount used is kept to a minimum, and another is that water should be re-used as often as possible in the same industry. These methods make less demand on the supply of raw water and probably result in the production of a manageable amount of effluent. This is the situation in the beet sugar industry in Great Britain and is why some electricity generating stations are equipped with cooling towers so that water once used in the condensers is cooled and used again.

Nevertheless when all measures such as these have been taken, there still remain vast quantities of waste waters which can and should be purified to a greater or less extent before they are discharged, and indeed during the last century many investigations have been undertaken with the object of enabling waste waters to be disposed of without prejudicing the health, well-being or economy of those who live below the point of discharge.

It would be impossible in a short paper of this kind to specify how effluents should be purified. In general it may be said that with organic materials arrangements are made so that some proportion of the oxidation which will be required to purify them takes place before they are discharged to the river. Two well-known ways of doing this are by means of percolating filters, and the activated sludge process. Inert material can, of course, be removed by physical means and it sometimes happens that the purification of the effluent results in an economy in raw material, as, for example, has been observed in the paper-making industry. Poisonous materials have to be got rid of by biological or chemical agents, and it is surprising how successfully some methods have been used in most unpromising circumstances. For those who wish to go further in this subject I recommend the reports of the Water Pollution Research Board of Great Britain (2) and of the Centre Beige d'Etude et de Documentation des Eaux in Belgium (3).

In Great Britain the problem we are now facing is not in most cases how to purify an effluent but a quantitative assessment of what degree of purification is necessary. It is a question of economics. Purification is an expensive process and the greater the degree of purification the more steeply the cost rises. We are now trying to find out what is the capacity of our rivers to absorb waste waters without damage to their use for water supply, fisheries, agriculture and industry.

It is also necessary that there should be administrative and legislative arrangements so that water users are encouraged or even compelled to take the best available methods to avoid the discharge of polluting effluents, and it is a great advantage if arrangements are sufficiently flexible to allow of the rapid application of new advances in the techniques of water purification. In Great Britain we are fortunate that new laws designed « for maintaining or restoring the wholesomeness of the rivers and other inland or coastal waters » were passed in 1951 and that over the greater part of the country the administration of these laws is the responsibility of River Boards which have jurisdiction over a whole catchment area or a group of catchment areas. The system seems to be working well and though progress in restoring the wholesomeness of some of our waters is not so rapid as we could wish, the reasons are primarily economic and not technical or administrative.

I hope I have not given you the impression that the pollution problem is solved; it is not, but we are making progress, and the point I want to emphasize is that the pollution of water is a process of waste, and that the cure of pollution is a conservation measure of increasing importance in the world of to-day.

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# RECOMMANDATIONS DE LA REUNION TECHNIQUE

## adoptées par l'Assemblée Générale

Thème I*d* : *Les résultats de la conservation du sol et de l'eau sur les ressources aquatiques naturelles (depuis les bassins de réception jusqu'aux estuaires y compris).*

L'Assemblée,

— considérant l'influence que les activités et les exigences humaines croissantes exercent sur les milieux aquatiques, ces activités se manifestant parfois de manière favorable mais aussi souvent nuisible;

— reconnaissant que dans de nombreux cas concernant l'utilisation des ressources, des conflits d'intérêts pourraient provoquer une dégradation des ressources naturelles;

— la preuve étant néanmoins acquise que des dommages inutiles ont été causés comportant de sérieuses conséquences dans les domaines économique, scientifique, esthétique et dans ceux de la nutrition et des loisirs du public;

Recommande :

Que tous les projets affectant, à travers le monde, directement ou indirectement, les milieux aquatiques soient intégrés dès leur stade initial d'élaboration, dans un programme d'investigation qui viserait à assurer la préservation des espèces et des communautés aquatiques ainsi que l'amélioration des ressources vivantes.

## RECOMMENDATIONS OF THE TECHNICAL MEETING

### adopted by the General Assembly

Theme I*d* : *The influence* of *soil and water conservation on natural aquatic resources (from headwaters to, and including, estuaries).*

The Assembly,

— considering that aquatic environments are influenced by man's increasing activities and needs, in some cases favourably but often in harmful ways;
— and while recognizing that conflict of interests among several resource-uses may necessitate impairment of aquatic environments;
— as there is nevertheless evidence that needless damage has been done with consequent serious losses, economic, nutritive, recreational, scientific and aesthetic;

Recommends :

That all projects throughout the world affecting aquatic environments, either directly or indirectly should, at the planning stage, be integrated with a programme of investigation that would secure the preservation of aquatic species and communities and improvement of living resources.

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