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ENVIRONMENTAL CONSEQUENCES OF WATER RESOURCES DEVELOPMENT WITH SPECIAL EMPHASIS ON FLOOD CONTROL, IRRIGATION AND DRAINAGE**

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ABSTRACT

The need to consider the environmental and sociological factors in the water resources planning process is emphasized and the problems of dealing with them are discussed. Despite these problems, it is suggested that since society and culture are considerably influenced by these factors, traditional economic and technologic analyses solely are not sufficient for proper water resources planning and decision-making.

The effects of flood control, irrigation and drainage developments, in Canada on environmental quality are outlined. Flood damage to urban communities located within the flood plain has been controlled by structural measures rather than by enforcement of zoning restrictions. The combined environmental effects of a flood control dam, for example, are complex and relatively unpredictable by ecologists. The environmental problems created by a Canadian dam are cited. Irrigation in the semiarid region of western Canada is on slowly permeable soils that hold a potential for environmental damage through waterlogging and salinization. However, research and experience show that the short growing season and the 7 months of drainage during the fall and winter have prevented damage to the soil environment under existing management practices. The limited surface water quality measurements made to date indicate that irrigation projects

* Effets écologiques de l'exploitation des ressources hydrauliques avec un accent particulier sur la lutte contre les inondations, l'irrigation et le drainage.

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do not contribute excessive quantities of nitrate nitrogen, phosphorus, soluble salts and organic matter, but expanded studies are planned to obtain more reliable estimates of pollution. Conclusive evidence of the beneficial effects of drainage on the soil environment for crop and animal production is presented, but reliable quantitative estimates of the pollutants contributed to drainage waters from agricultural land use activities have not been established. The limited small plot study results and a comprehensive field study plan to monitor such pollutants are described.

RESUME ET CONCLUSIONS

Historiquement, l'expansion du Canada a suivi le cours des fleuves et des rivières. Ces cours d'eau étaient des voies de transport importantes, et la population s'est regroupée le long de leurs rives. Des études récentes ont montré que les inondations sont un problème dans plus de 200 agglomérations situées en basses plaines. Dans la plupart des cas les inondations ont causé des dégâts minimes, mais parfois aussi, il s'agit de désastres importants. Entre autres, la cure de la Frazer en 1948, a causé des dégâts s'élevant à 22 millions de dollars; en 1950, celle de la Rivière Rouge, 25 millions et les inondations en Ontario en 1954, causées par la tornade Hazel, 25 millions. Entre 1948 et 1970, les dégâts directement attribués aux inondations et l'aide aux sinistrés se sont élevés en moyenne à 5 millions par année au Canada.

Ce n'est que récemment que des études de régulation des cours d'eau ont tenu compte des effets des mesures de lutte contre less inondations. De telles études sont essentielles à la prévision des effets d'ordre social, écologique et mésologique de pareils projets. De plus, des études subséquentes sont essentielles à l'établissement des coûts réels d'ordre social et mésologique pour prendre le recul nécessaire permettant de juger de l'exactitude des prévisions. Peu d'études semblables ont été entreprises au Canada ou ailleurs. De ces quelques études, il ressort que la construction d'ouvrages contre les inondations, entraînant des coûts corollaires d'ordre écologique et mésologique, a été nettement préférée aux mesures indirectes comme l'isolement des champs d'inondation, qui ont des effets écologiques moins grands. La raison de cette anomalie et l'expérience canadienne des effets bénéfiques et contraires sur le milieu des diverses mesures de lutte contre l'inondation, font l'objet de la présente étude.

La plus grande partie des travaux d'irrigation au Canada s'est faite dans des régions semi-arides de l'Ouest où certains sols sont irrigués depuis près de 60 ans. Selon les normes actuelles, la plupart de ces terrains seraient classés comme peu drainables et de peu d'intérêt pour l'irrigation. Bien qu'environ 10 pour cent de ces sols soient devenus salins, l'apport bénéfique de l'irrigation pour l'agriculture des Prairies l'emporte sur les obstacles rencontrés.

L'infiltration de l'eau des canaux, qui s'est produite peu après le début de l'irrigation, a rendu les terres salines et sursaturées en eau. Les efforts de récupération des sols salins par drainage n'ont pas été un succès. La présence de moraine glaciaire peu perméable à faible profondeur exigerait un faible espacement des drains, ce qui est économiquement irréalisable. Les études d'irrigation et de drainage exécutées depuis 20 ans montrent que certains problèmes qu'elles soulèvent n'ont pas de solutions faciles. Toutefois, la courte période de croissance et les sept mois de drainage d'automne et d'hiver ont permis une bonne irrigation dans les conditions actuelles d'exploitation. Depuis quelques années, l'agriculture de l'Ouest canadien est devenue plus intensive grâce à une augmentation du nombre de terres irriguées. Heureusement, cette augmentation s'est accompagnée d'une multiplication marquée des systèmes d'irrigation par aspersion, rendant ce type d'irrigation plus efficace que les méthodes d'irrigation superficielle. Toutefois, le danger de sursaturer le sol demeure et les efforts doivent porter sur la prévention plutôt que sur la récupération de sols salins.

Le drainage des sols agricoles à faible capacité de drainage naturel a été mis en pratique dans les régions humides du Canada au cours des dernières décennies. Sans réseaux de collecteurs-fossés principaux, on ne pourrait produire aucune culture, même à faible rendement, sur plusieurs de ces sols. Le travail supplémentaire de drainage effectué dans les exploitations a permis de produire une vaste gamme de cultures vivrières importantes. Ainsi, le drainage a un effet extrêmement bénéfique sur l'écologie des sols.

Par contre, les réseaux de drainage assurent des voies d'accès facile aux agents polluants agricoles et autres qui peuvent être écologiquement nuisibles aux sources d'eau. Des études récentes ont soulevé des questions en ce qui concerne l'importance de la pollution par le drainage, provenant de sources naturelles ou de la production de cultures et de l'élevage. L'examen des principes fondamentaux de l'agriculture permet d'identifier des types et des sources probables de pollution agricole. Toutefois, il n'existe pas pour l'instant assez de données expérimentales sur la qualité de l'eau pour déterminer l'importance réelle de la pollution agricole provenant de sources connues, pas plus qu'il n'existe de connaissances adéquates sur le sort des polluants dans les différentes parties du milieu aquatique. Une étude approfondie du bassin du réseau inférieur des Grands lacs porte sur la planifiction et l'état des travaux d'identification des sources de la pollution causée par le drainage des terres.

INTRODUCTION

Appreciation of the importance of the environmental consequences of water resources planning and management is of comparatively recent origin. This is not surprising as in the past, the decisions to develop water resource systems were primarily based on economic and technologic feasibilities. However, during the past decade it has become increasingly obvious to water resource planners and decision-makers in Canada, as elsewhere, that this simplistic procedure is no longer adequate. Rising public concern indicates the need for in-depth studies to evaluate the environmental and sociological consequences of proposed water development projects and of existing water management practices. Studies of proposed projects can be justified since planning is for people and thus should improve their quality of life. One can argue that water resource decisions ought to be based primarily on environmental and social consequences, and that the success or failure of a resource development should be judged by its techno-economic excellence and on its impact on people. It is the people who use and misuse the water and who, as consumers and taxpayers, pay for the development and conservation costs (4). Thus, planners need to ask searching questions about the developments, not only in terms of the usual benefit-cost ratios or cost-effectiveness but also in terms of how the lives and attitudes of people may be affected, and how it may effect the environment and ecology.

This paper emphasizes the need to consider, and the problems of dealing with, environmental factors in the water resources planning process. Background on the evolution of existing water resources developments is given, and the known effects and some planned studies of unknown effects of flood control, irrigation and drainage developments on environmental quality are outlined.

THE PLANNING PROCESS AND ENVIRONMENTAL CONSIDERATION

The fundamental goal for planning of water resource developments, in common with other natural resource developments, should be the enhancement of the general welfare of the nation's people. Achievement of this objective would necessitate the determination of the goals of a nation as a whole, as well as their relative priorities. One would then have to further decide how water resource development and management can best help achieve these goals, what should be the water resource development objectives, and what policies should be formulated in attempting to achieve these objectives.

Broadly speaking, national objectives can be divided into two categories: economic and social-political. These two categories, however, are closely interrelated. The economic objectives, in general, provide criteria for resource allocation and investment planning whereas social-political objectives provide the environment within which planning has to proceed. The national economic objectives include economic growth (increase in Gross National Product, increase in per capita income, favorable balance of trade and foreign exchange position), proper income distribution (among various social groups or among different sectors of the economy), and full employment. The social-political objectives include personal freedom, equality of opportunity, reduction of human strife, justice and improvement of the environment.

These goals, however, are not specific enough to be of great use to the water resource planners, and as such the use of fundamental objectives, against which major policy questions of water resource development and management can be tested, may lead to an intangible wilderness. Thus, currently, planners translate these goals into a set of specific economic criteria which give rise to a multi-part objective function that is then maximized for economic efficiency. The use of economic criteria is a matter of expediency, as they are tangible and quantifiable, in contradistinction to social-political elements which are, in general, intangible and non-quantifiable. Generally, the objective function is multi-dimensional, and the goals are not mutually exclusive; they are in fact, often conflicting. Thus, it is not possible to have the best of all the goals, and priorities need to be assigned.

The next most important step is that of decision-making. The roots of the current approach to public decision-making are micro-economics, welfare economics, and quantitative decision theory. The methods available are cost-effectiveness analysis, operations research and systems analysis and program budgeting. The planners do not make the final decision, nor do they pass legislative actions. In fact, water resource planning, project authorization, and its funding are all essentially political processes. The planners do, however, point out the cost-effectiveness of various alternative courses of action as well as their social and technical feasibilities. This information helps the policy-makers arrive at responsible decisions. Decision-making, to a great extent, is an economic process where every decision may be considered as an allocation of resource between alternatives ([3,5]). Oftentimes, the planners are handicapped by the absence of clearcut directives from policy-makers about objectives and planning criteria, and the process is further complicated by the consideration of intangible and indirect values in which society is interested, but which have never been adequately defined.

Even though benefit-cost analyses have been an integral part of resource planning for some time, social and environmental assessments have only played a secondary role in the formal planning process. The reasons are many. At the present state-of-the-art, there is a lack of general methodology to identify and evaluate the potential social and environmental consequences of water development, and there is no common unit of measurement as in economics (i.e., dollars). Data are lacking, and whatever data are available are often rough estimates. Hence, social and environmental changes due to water developments tend to be qualitative rather than quantitative. Besides, the existing machinery for making socio-environmental decisions is inadequate, and few explicit criteria are available by which the decisions made can be judged or evaluated. Hines ([11]) suggests another reason :

> ...agencies planning highways or dams are compelled to adopt a single-purpose approach, generally ignoring other considerations except when they are forced upon them by an aroused public. For the agency to do otherwise—for example, to admit the economic and aesthetic loss that results from the destruction of wilderness—is to weaken the case for the agency's projects, to reduce the number of projects that can be undertaken by the agency.

In spite of these difficulties, it is possible for the planner to minimize the possible adverse effects, even though the adverse consequences can be forecast only in general terms.

It is suggested that techno-economic analyses are not enough for proper decision-making. Most technological designs are based on the explicit or implicit assumption that they are closed systems which can be "fully described by the technological inner constraints and marked by clear boundaries decoupling the systems from other parts of the environment" ([10]). On the other hand, dollar values frequently tend to unfairly dominate the economic analyses ([12]). Rickover ([16]) suggests that :

> Cost effectiveness suffers from a philosophical weakness. It holds that one factor—the economic—is fundamental, and that all other factors—the social, cultural and political—are derivative. This is a fallacy known to students of philosophy as the fallacy of reductionism;

> it reduces the complexity of reality to one of its elements, and offers that one is sufficient reason for the whole.

Since society and culture are considerably influenced by the environmental conditions, environmental forecasting should play a major role in any water resource development decision-making process.

BACKGROUND TO WATER RESOURCES DEVELOPMENTS

FLOOD CONTROL

Canada's development has historically followed river courses. In the early years, the rivers provided major transportation routes and hence communities sprang up along their banks. In recent years, the transportation role has diminished but the advantage to be derived from the level flood plain adjacent to rivers and streams has continued to attract community development.

The action of man building within the flood plain has resulted in the inevitable—a series of damaging floods. In the early days, a flood brought discomfort but the magnitude of property damage was not large by present standards. However, over the years, with rising standards of living and increasing concentration of population in urban areas, flood damages have rapidly increased.

Total flood costs of $22 million following the Fraser River Flood of 1948, $25 million for the Red River Flood of 1950 and almost $25 million as a result of Hurrican Hazel in Ontario in 1954 are the larger outlays for major floods in Canada. Over the period from 1948 to 1970, immediate flood damage and disaster assistance throughout Canada have totalled in excess of $100 million of which some $40 million was met by federal contributions in the form of ad hoc assistance. Averaged over the period, flood damages amounted to about $5 million per annum of which the Federal Government paid out slightly less than $2 million per annum. In addition indirect losses, such as loss of income, are experienced in affected communities. Adding to these the losses resulting from minor floods, the combined total is indeed substantial. Various levels of government—municipal, provincial and federal—have constructed and are continuing to construct a number of flood protection works costing in excess of $100 million.

IRRIGATION

Although the Prairie Provinces in Western Canada are blessed with thousands of acres of fertile soil, some parts of Southern Alberta and Saskatchewan often suffer from insufficient rainfall. The annual precipitation averages 35 to 41 cm, of which approximately 20 cm occurs during the growing season. Captain John Palliser, who surveyed the western plains from 1857 to 1860, delineated this area and stated, "This district, although there are fertile spots through its extent, can never be of much advantage to us as a possession." The heartsick farmers who had settled in the area were painfully reminded of this during the periods of drought that occurred in the first half of the present century.

New farming techniques introduced during the past 40 years have improved the agricultural output considerably. However, control of moisture through irrigation was considered by many as the only way to bring stability of production to the area. A frost-free period of 120 to 140 days, combined with long hours of sunshine, favored irrigation development and enabled the growing of such crops as potatoes, sugar beets, and maize, which could not be grown under dryland conditions.

Many of the early irrigation projects were initiated by private corporations during the early part of this century. For instance, the railway companies attempted to capitalize on their land grants by starting irrigation projects. They succeeded in increasing business for the railways by bringing in more settlers. However, farmers were soon faced with the management of these projects. Throughout the ensuing years, it became clear that any irrigation district that had to meet its own capital costs as well as the costs of operation was almost certainly doomed to failure. Therefore, governments (federal as well as provincial) have now come to accept the fact that farmers cannot be expected to carry the capital costs of irrigation development and maintenance without government support.

DRAINAGE

Although drainage is practiced to some degree in all provinces of Canada, the majority of work is done in the more humid regions which include the coastal valleys of British Columbia and the eastern half of Canada between Manitoba and Newfoundland. Historically, the need for the construction of drainage works for food production was recognized by the early settlers, and the general pattern of drainage development in Canada has followed the pattern of settlement.

The first drainage improvements were made almost 400 years ago in areas adjacent to the Bay of Fundy on the eastern coast of Canada ([1]). The Acadian colonists built mud dykes to reclaim many hundreds of hectares of fertile marshland that are subject to tide water flooding. These and subsequent settlers raised beef cattle on the marshlands and adjacent uplands for export to Europe until about 1900 when a British embargo against Canadian live cattle stopped this industry. However, cattle were gradually replaced by hay production which was quite profitable until about 1920 when hay prices commenced to decline reaching their lowest price in 1938. These declining prices were accompanied by declining maintenance of drainage works and dykes. Only emergency work was carried out until 1948 when the Maritime Marshland and Rehabilitation Administration was formed and a major reclamation program was initiated. Today, about 32,300 hectares of marshahland are drained, protected from the tides, and receive benefit from this program.

As settlement progressed westward, agricultural development was slow and disorderly due to the large areas of wet land encountered. By the latter part of 1800, provincial governments in eastern Canada recognized that drainage would increase the agricultural productivity and value of these lands, and public funds commenced and continue to be used to finance the construction of outlet ditches. At the same time, most provincial policies have also encouraged the subsurface drainage of poorly drained soils on individual farms by providing (a) financial assistance through low interest loans and sometimes direct subsidies, (b) engineering assistance to plan systems, produce literature on the benefits of drainage, and conduct drainage extension, advisory and field demonstration programs, and (c) in some provinces, providing government-owned drainage machinery to construct drainage works.

Hence in Canada, government policies toward drainage provide individual farmers with various forms of incentive and encouragement to invest in drainage improvements that will increase their agricultural productivity and financial returns from farming. Drainage improvements are still required and although progress has been made, it has been variable. Economic and weather conditions are the two main factors that affect the variaibility in drainage construction and its maintenance.

FLOOD CONTROL AND THE ENVIRONMENT

Floods and flood threats are a recurring problem in Canada; it has been estimated that floods pose a menace in over 200 communities. While in most cases floods have been temporary, and have resulted in relatively minor damages, major disasters (Toronto, 1954; Winnipeg, 1950; and Vancouver, 1948) have occurred. Widespread physical damage, especially when coupled with threat to or loss of life, places pressure on the federal government for involvement in the emergency and compensation phases, and in providing financial assistance toward the construction of permanent control works.

Due to the economic advantages it offers, the flood plain has seen extensive public and private development which historically has turned relatively local flood situations into regional or national disasters. Moreover, the level of public and private investment on Canadian flood plains continues upward. There is an "imitation effect" whereby one development prepared to accept the flood risk, leads to others which are not. Protective dykes, upstream storages, and even emergency aid and compensation by senior governments serve only to encourage further investment, raising potential flood damages, and leading to requests for high levels of protection. Moreover, as the memory of past floods recedes, there is a tendency to ignore maintenance requirements for local permanent control works, to develop areas outside control works, and to accent other purposes for upstream storage.

By any standards, the costs to repair damage caused by floods and to build control works to prevent future flooding are enormous. Yet these costs could have been significantly lower if all possible alternatives were considered and proper flood plain management practices had been adopted. However, unfortunately, most of the flood control measures have been structural, and the zoning approach has not been very successful, since it has not been forcefully enforced.

Thus, to a great extent, environmental problems associated with flood control in Canada are those of water control structures. These control structures are generally planned carefully and extensively, but this planning proceeds from the perspective of the planners in which individual social consequences are not anticipated. Thus, the aggregate of the many individual and unanticipated effects may often lead to results that are completely unexpected by the planners. Environmental damages arising from flood control structures are many and they have far reaching effects. Their interactions are so complex and so little understood that ecologists and environmentalists cannot predict them with any degree of certainty. Our current knowledge of the ecology of man-made lakes leaves much to be desired, and unless planning precedes construction by 5 to 10 years, many things will go wrong and several unpredictable and unforeseen situations will develop. Because of the lack of sound evidence, environmentalists and ecologists find it impossible to influence engineers, economists and politicians against certain developments or of the necessity of incorporating remedial measures. The environmental implications of a flood control dam are shown diagramatically in Figure 1.

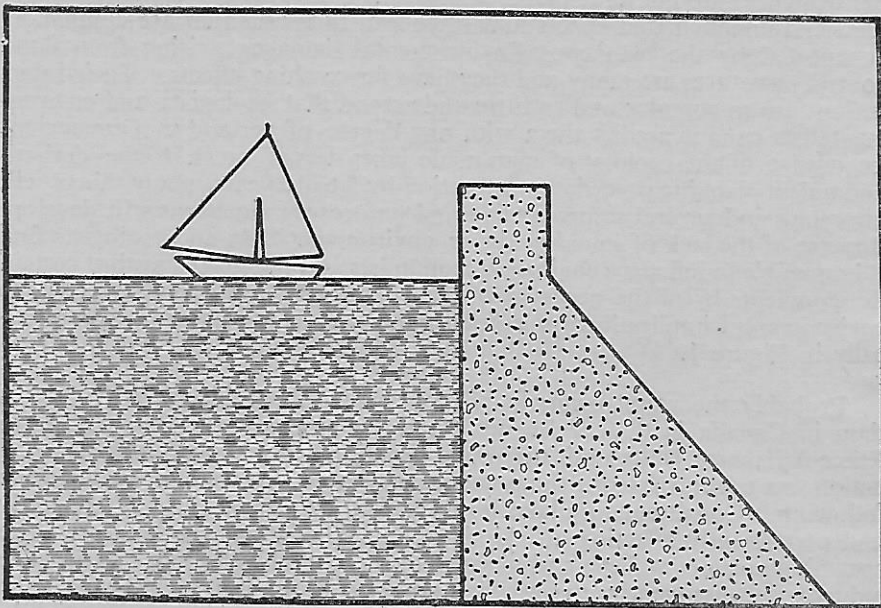
Probably the worst example of environmental problems created by a dam in Canada is that of Bennet Dam. It changed the life-style in the Peace-Athabasca Delta until the whole situation was reviewed and remedial action was taken. Among the potential problems that were created are the following. Consistent low lake levels had a high probability of adversely and permanently affecting all kinds of fish populations in the area. The spawning areas of walleye and pickerel in the eastern Athabasca basin were reduced. Consequently, the growing commercial fishing industry on Lake Athabasca, currently estimated at $100,000 per year with a potential in Alberta for $1.5 million, was in jeopardy. With the loss of sport fishing, the recreational potential of the area was obviously diminished. The muskrat population was disappearing, and it had substantially reduced the income of the local inhabitants, in some cases to zero. Loss of marshy habitat and an increase of willow habitat would have reduced water flow production. The moose population would probably have decreased in the long run since their food sources would have gradually disappeared. All these unfortunate side effects had seriously affected the people who lived in that area—primarily Treaty Indians and Metis. The social as well as the economic dislocation was considerable, and review of individual cases suggested that severe hardships were being experienced by many. Admittedly, it is not possible to put a dollar value on the environmental and social costs involved, but they were considerable and serious.

IRRIGATION AND THE ENVIRONMENT

WATERLOGGING AND SALINIZATION

Although the semiarid regions of Western Canada have a shorter growing season and lower evapotranspiration than many arid regions of the world, problems of waterlogging and salinization under irrigation are similar.

One of the major problems in the irrigation districts of Western Canada is the very slowly permeable glacial till soil (ground moraine) that occurs at depths of 60 to 180 cm. These saline glacial till subsoils have an apparent density of 1.6 to 1.7 g/cm^2 and a hydraulic conductivity of less than 0.2 cm/hour. According to modern appraisal standards, most of the land now under irrigation would be classified as poorly drainable and marginal for irrigation.



Physical System

Hydrologic System
Water Quantity
- Level
- Discharge
- Velocity
- Groundwater
- Losses

Water Quality
- Sediments
- Nutrients
- Turbidity
- Salinity
- Temperature stratification

Atmospheric System
Evaporation
Micro-climate

Crustal System
Geology (soil, mineral content, structure)
Earthquake

Biological System

Aquatic Ecosystem
Benthos
Aufwuchs
Zooplankton
Phytoplankton
Fish and Aquatic Vertebrates
Plants
Disease Vectors

Terrestrial Ecosystem
Submerged Land and Vegetation
Drawdown Zone
Zone Above High Water Level
Failure Impacts
Loss of Animal Habitat
Food Chain Repercussions

Human System

Production System
Agriculture
Fishing and Hunting
Recreation
Energy
Transportation
Manufacturing

Social System
Anthropological Effects
Political Implications
Social Costs

FIGURE 1: Environmental implications of a flood control dam

Some of the land has now been under irrigation for about 60 years and, although some soils have become saline, the benefits of irrigation for agriculture on the prairies far outweigh the various problems associated with irrigation. An estimated 10 per cent of the irrigated land is now saline. Most of this waterlogging and salinization was caused by seepage from the laterals and occurred soon after irrigation was started.

Efforts to reclaim saline soils by drainage have not been very successful because the presence of glacial till at shallow depths requires close tile drain spacings, which are not economically feasible. Some experiments with tile drains 60 m apart and 1.5 m deep showed that the water-table recession was not appreciably greater than where tile drains were not used. With tile drains installed above the glacial till (80 cm deep), saline soils could be successfully reclaimed but, when grass was grown on the site, the surface soil became saline in one season. Thus it seems that water tables at 80 cm or shallower will not sustain irrigated agriculture on the Canadian prairies.

In one typical irrigation system, the average annual water-table depth during the past 20 years was 165 cm. The depth fluctuated considerably during the growing period. For example, after irrigation, the water table rose to within 10 cm of the surface and then slowly receded at a rate of about 9 cm/day until it leveled off at 120 cm. Below this depth, downward movement of the water table became very slow. The initial high rate at which the water table receded was mainly due to water uptake by the plants whereas the low rate was mainly the result of slow downward drainage.

During the fall and winter period, water tables normally drop about 70 cm but this drop is caused by upward translocation of water to the frozen surface as well as by downward drainage. Measurements indicate that up to 2.5 cm of water move upward, but this generally does not penetrate into the upper 30 cm of the soil. An increase in water content in the upper portion of the profile is mainly due to snowmelt in the spring. Thus it seems that, although downward movement is slow, the 7-month period without irrigation allows sufficient drainage to prevent waterlogging during the growing season.

In recent years, agriculture in western Canada has been intensified and more water is applied to the land. Fortunately this has been accompanied by a tremendous increase in sprinkler systems, which enable more efficient irrigation than by surface methods.

Experience on the Canadian prairies shows that the problems resulting from irrigation cannot be solved easily but that the short growing season and the 7 months of drainage during the fall and winter have permitted successful irrigation under present management practices. However, the danger of waterlogging is ever present and mjor efforts must be directed toward the prevention rather than the reclamation of saline soils.

EFFECTS OF IRRIGATION ON ENVIRONMENTAL QUALITY

Recently, the effect of irrigation and subsequent subsurface drainage on the quality of river water has become a major concern to irrigation specialists. In many arid regions, the salt load of the water returning to the rivers from irrigation projects has caused deterioration of the river water to an extent that was not anticipated when irrigation projects were started.

Two reasons for this development are low irrigation efficiency on the farm and the tendency of farmers to overirrigate to satisfy leaching requirements. As was mentioned before, land levelling, as well as the trend toward more sprinkling, has improved the irrigation efficiency in Canadian irrigation projects.

The leaching requirement and possible overirrigation to keep the root zone salt-free have probably caused a considerably greater return of salts to the rivers than was necessary. Recent studies by Bernstein and Francois ([2]) indicate that sustained crop growth is possible with a much lower leaching requirement than that originally recommended. If the leaching requirement is reduced, salts accumulate and/or precipitate below the root zone; the salt load entering the river systems by way of subsurface drainage is thereby reduced.

Thus far, most studies on water quality in Western Canadian irrigation projects have been focused on surface flow. Results of periodic samplings from the rivers, supply ditches, and spillways showed that irrigation projects did not make measurable contributions to the salinity of the river systems.

Sommerfeldt([17]) reported that the pollution from nitrate nitrogen, phosphorus, soluble salts, and organic matter was not excessive nor was there a deficiency of oxygen at the times and locations sampled. His studies showed that contributions from industry and cities far exceeded those from irrigation. Graveland([9]) did not detect any apparent increase in dissolved salt concentrations in the Oldman River. He measured the outflow of subsurface drains in one project and concluded that the increase in salts in the river water from this source was less than 1 per cent. Ground water from the irrigated area also enters the river system but the extent of the contribution from this source is not known at present. Studies are now underway to obtain reliable estimates which is a difficult and costly process.

DRAINAGE AND THE ENVIRONMENT

DRAINAGE EFFECTS ON ENVIRONMENTAL QUALITY

The natural process of land drainage is one of the vital processes required to produce a suitable quality of environment for the existence of life on land. This fact must be emphasized at the outset, because without drainage, there would be no natural environment as it is known today. Therefore, drainage is necessary. However, not all land is naturally well drained. Where poorly drained areas contain deep fertile soils suitable for the production of crops and animals that are necessary for man's survival, the practice of artificial drainage improves environmental quality for these purposes.

Many years of field observations and research in humid areas of Canada have shown the beneficial affects of drainage on the soil environment and the resulting improvements in crop production, and in the many facets of overall farm management. In the early 1900's these benefits were reported in extension publications in the form of testimonials from farmers who had drained parts of their farms and compared the results with undrained fields (7, 8, 14). In some cases, the beneficial yield increases due to drainage were phenomonal and were likely due to the extremely poor general state of drainage that existed. Subsequent research, mainly in Ontario, contributed to the present fundamental knowledge of the several biological, physical and chemical reactions brought about by improved drainage. These facts are now well documented in textbooks today.

Land drainage, including agricultural drainage, has been placed under scrutiny recently by people concerned with environmental quality in Canada. The process of drainage itself can hardly be accused of degrading environmental quality as witnessed above, but the contributions of pollutants from some man-made surface drainage improvements, from different land use development sources, and from natural sources have been questioned.

Drainage systems do provide convenient pathways for the transport of pollutants arising from various land use developments, and it is mainly the consequences of land use developments as they affect water quality, that are of concern. These sources are referred to as "diffuse sources" as compared to readily identifiable "point sources", such as sewage outfalls.

In a number of areas in Canada, regulatory agencies have measured and reported the quantities of such pollutants as Bio-chemical Oxygen Demand, Total Solids, Suspended Solids, turbidity, *pH*, nitrogen, phosphorus and bacteria that are contributed to receiving waters by point sources. However, very few hard facts based on field monitoring studies under Canadian conditions are available to identify the types and quantities of pollution by land drainage from such diffuse sources as agriculture, forestry, urban and industrial land development, recreational and park land development, utility and transportation systems and natural sources. It is precisely the lack of this knowledge that the International Joint Commission (I.J.C.) was requested in the 1972 Canada-United States Great Lakes Water Quality Agreement to enquire into and report to the two governments on the question of boundary water pollution by land drainage from these sources.

The following discussion is confined to the agricultural effects on drainage water quality. It shows the limited extent of present knowledge and outlines the expanded research program underway to identify agriculture's role in the pollution of drainage water.

STUDIES OF AGRICULTURAL DRAINAGE QUALITY

In 1961, the first Canadian field plot study relating the losses of plant nutrients in tile drainage effluents from three cropping systems (continuous corn, continuous bluegrass, and a four-year rotation of corn-oats-alfalfa-alfalfa) under non-fertilized and fertilized treatments, commenced at the Research Station, Harrow, Ontario. Results from the first seven years have been reported by Bolton et la (6), and they showed that the highest losses of N, P and K occurred with corn and the lowest with bluegrass sod. Additions of N-P-K increased average losses almost 100 per cent but even with fertilizer the average N loss, mostly as NO_3, was only about 8 kg/ha/year, P loss was 0.19 kg/ha/year, and K loss was 2.22 kg/ha/year. Nitrate nitrogen concentrations under fertilized corn and fertilized second-year alfalfa did exceed the commonly recognized upper limit of 10 ppm by health authorities which suggests that attention should be given to nitrogen use for intensive corn production grown in rotation with alfalfa. Other observations from this study were that nutrient concentrations tended to be lowest in the spring, and that the amount of drainage water passing through the soil was the predominant factor influencing nutrient losses.

This study is continuing and was expanded in 1972 by the installation of 20 additional tile drained plots of similar size, 12.2 m wide by 76.2 m long. On the new plots, continuous corn is grown to study the effect of two drain depths, two drain materials (clay tile and plastic tubing) and four rates of fertilizer on nutrient losses in tile drainage water.

Another major field study dealing with the contributions of N and P to drainage water from fertilized agricultural land was initiated in 1972 in south-western Ontario by the University of Guelph. The 12 drainage systems being studied range from 3 to 100 ha and have pumped outlets. All sites are intensively cropped; four are on muck soils, four are on clay or clay loam, and four are on sandy soils. Definite conclusions from this study have not been released.

Field studies to evaluate the effect of high density animal production operations on drainage water quality have been initiated recently in most provinces in Canada, but since they have not been in operation very long, it is premature to report the results. The potential sources of pollution from animal operations are mainly from feedlot runoff, manure storages, and land application of manure. The main pathways for pollutants from these sources that are of immediate concern are by direct surface drainage or by downward movement to subsurface drains.

In the humid regions of Canada, feedlot and manure storage runoff is being monitored in Ontario by the Engineering Research Service, Agriculture Canada, Ottawa, and by the School of Engineering, University of Guelph. In Quebec, a similar monitoring program is being conducted by Macdonald College of McGill University, Ste. Anne de Bellevue. The consequences of land application of manure is being studied on small plots or small watersheds by the University of British Columbia, Vancouver, the University of Manitoba, Winnipeg, the University of Guelph, Ontario, Agriculture Canada, Ottawa, Ontario, Macdonald College, Quebec, and the Nova Scotia Department of Agriculture and Marketting, Truro. These studies cover a reasonably broad range of climatic conditions in the humid regions of Canada.

The occurrence of pesticides in surface water supplies from land drainage has been summarized for Ontario by C.R. Harris and J.R.W. Miles in 1973 in an unpublished report of the "Agriculture Canada Task Force for Implementation of the Great Lakes Water Quality Program". These authors extracted data from numerous studies done in Ontario, and concluded that: (*a*) DDT and to a lesser extent dieldrin are the only two insecticide residues prevalent in Lakes Huron, Erie and Ontario; (*b*) recreational use of organochlorine insecticides for biting fly control has been the major source of insecticidal contamination of the Great Lakes; and (*c*) knowledge is grossly lacking of the persistence, fate, mobility, and environmental impact of herbicides, fungicides, and nematocides.

The plot studies referred to above are useful to compare the effect of one agricultural practice with another, but they do not yield information on the ultimate fate of pollutants in the receiving waters. Some irregular water quality monitoring has been done at fixed stations along watercourses that receive water from a variety of sources([15]). Although the concentrations of pollutants were measured, simultaneous flow rates at many stations were not; hence, the total of pollutants passing such stations cannot be determined. Furthermore, there are only a limited number of situations where the measurements are complete and where the monitoring stations are suitably located to differentiate reliably between the types and quantities of pollution by land drainage from the different diffuse sources.

The comprehensive IJC study of the Lower Great Lakes Basin water quality has been planned to attempt to differentiate between the various pollution sources and quantify them([13]). The agricultural drainage studies that will commence in 1974 are co-ordinated with the drainage studies of other land uses to utilize field resources and staff as efficiently as possible.

The techniques used to plan the agricultural phase of this IJC study are not unique but they do illustrate how existing information was studied and used to select agricultural watersheds that will likely represent a typical agricultural land use and allow some extrapolation of results to other similar watersheds.

The first stage in planning was to compile existing data for the Basin to identify "agricultural regions". An agricultural region was defined as an area of similar soils in the same climatic zone upon which an identifiable agricultural land use or combination of land uses exists. Soil groups reflect the potential of a soil to transfer a pollutant from the soil surface to a water system (surface water or ground water or both). Soil texture, depth, slope and drainage class were taken into account. Climatic zones were differentiated on the basis of snowfall, rainfall, runoff, degree-days and length of growing season. Livestock and crop types and combinations thereof were used to identify an agricultural land use and 1971 Statistics Canada data were used to locate areas of various livestock and crop intensity.

From the integration of these data by maps and map overlays, five distinct agricultural regions were identified. Within each of these areas, detailed inspections from airphotos of small watersheds (2.5 to 25 km^2) were made to determine the precise land use. Comparisons between a number of small watersheds were made, and the watershed that had the least amount of non-agricultural land use and included the typical agricultural activity of the region was selected for study. Twenty such watersheds will be monitored on a preliminary basis during the first part of 1974. Analyses of these preliminary data will be made later in 1974 and between 6 and 8 watersheds will be selected for continuous measurement of water quantity and quality. If results deem it necessary, sub-watersheds may be instrumented to obtain additional detailed information. Water samples will be examined for microbiological, physical, inorganic and organic pollutants.

SUMMARY AND CONCLUSIONS

Historically, Canada's development has followed river courses. Rivers provided major transportation routes, and communities developed along the river banks. Current studies indicate that floods are a recurring problem in over 200 communities located in flood plains. In most cases, floods have caused minor damages but major disasters include the Fraser River flood of 1948 ($22 million damage), Red River flood of 1950 ($ 25 million damage), and Ontario floods of 1954 due to Hurricane Hazel ($25 million damage). Between 1948 and 1970, immediate flood damage and disaster assistance throughout Canada averaged about $5 million per year.

Until recently, river planning studies have seldom dealt with the effects of flood control developments. Such studies are essential to forecast possible social, ecological and environmental costs of the proposed development. In addition, post-studies are necessary to determine the actual social and environmental costs for feed-back to decide the accuracy of the forecasts. Not many such post-studies have been made in Canada or elsewhere. From the few studies made, it seems that structural methods of flood control, with their possible attendant ecological and environmental costs, have been widely preferred to indirect measures, such as flood plain zoning, that have much less environmental cost. The reason for this anomaly, and the Canadian experience related to both beneficial and adverse effects of various flood control measures on the environment, are considered.

The majority of Canadian irrigation has been practised in the semiarid regions of the West where some of the land has been irrigated for about 60 years. According to modern standards, most of this land would be classified as poorly drainable and considered as marginal for irrigation. Although an estimated 10 per cent of these soils have become saline, the benefits of irrigation for agriculture on the prairies far outweigh the various problems encountered.

Most of the waterlogging and salinization was caused by seepage from canals and occurred soon after irrigation was started. Efforts to reclaim saline soils by drainage have not been very successful. The presence of glacial till with low permeability at shallow depths requires close tile drain spacings, which are not economically feasible. The irrigation and drainage studies conducted over the past 20 years show that some problems resulting from irrigation cannot be solved easily. However the short growing season and the 7 months of drainage during the fall and winter have permitted successful irrigation under present management practices. In recent years, agriculture in Western Canada has been intensified resulting in an increase of irrigated land. Fortunately this has been accompanied by a large increase in sprinkler systems, which enables more efficient irrigation than by surface methods. However, the danger of waterlogging is ever present and efforts must be directed toward the prevention rather than the reclamation of saline soils.

Drainage of agricultural soils with naturally poor drainage has been practised in humid regions of Canada for the past several decades. Without an outlet ditch system, either no crop or a very low yielding crop could be produced on many of these soils; the additional drainage work on individual farms has allowed a wide variety of important food crops to be produced. Therefore, in terms of crop production, drainage has an extremely beneficial effect on the soil environment.

On the other hand, drainage systems provide convenient pathways for the transport of agricultural and other pollutants that can be environmentally detrimental to water supplies. Recent studies have raised questions regarding the magnitude of pollution by drainage from natural sources and from crop and animal husbandry operations. From fundamental agricultural principles, possible types and sources of agricultural pollution are understood. However, there are not at present sufficient water quality results from field studies to identify absolute quantities of agricultural pollution from existing sources, nor is there adequate knowledge of their ultimate fate in various parts of the water environment. A comprehensive basin study of the Lower Great Lakes System is outlined to show the planning and progress toward the identification of existing water pollution by land drainage.

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