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FACTORS AFFECTING WATER MANAGEMENT ON THE NORTH SLOPE OF ALASKA

Julian K. Greenwood
R. Sage Murphy

THE INSTITUTE OF WATER RESOURCES

in cooperation with

THE SEA GRANT PROGRAM

UNIVERSITY OF ALASKA
FAIRBANKS, ALASKA 99701

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Julian K. Greenwood
Graduate Research Assistant
Institute of Water Resources

and

R. Sage Murphy, Ph.D.
Director, Institute of Water Resources and
Professor of Environmental Engineering

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R. Sage Murphy, Director of the Institute
Robert F. Carlson, Assistant Director

David M. Hickok, Director of
Sea Grant Program

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ABSTRACT

The North Slope of Alaska is undergoing sudden development following the recent discovery of large oil and gas reserves in the area. The water resources of the region should be carefully managed both to ensure adequate supplies of usable water at reasonable cost, and to guard against excessive deterioration of water quality. The likely effects on the environment of man's activities are investigated and found to be poorly understood at the present time. Research priorities are suggested to supply rapid answers to questions of immediate importance. The applicability of a regional management concept to the North Slope waters is considered and the concept is recommended as part of a broad land and water planning philosophy which would emphasize regional control over state and federal control. The use of economic incentives rather than standards for the control of water quality is not recommended at the present time.

FACTORS AFFECTING WATER MANAGEMENT ON THE NORTH SLOPE OF ALASKA

Synopsis. Alaska's North Slope is the scene of a recent, very large oil discovery. Exploration and development of this potentially very profitable resource is radically altering a large area of previously untouched wilderness. The sum of ecological data in this area is extremely limited, though a number of studies are under way at present to catalog the species of flora and fauna on the tundra and in the larger lakes and rivers, and to attempt to describe some of the ecological relationships between organisms, and their adaptation to an undeniably harsh environment. The physical difficulty of maintaining year round sampling and observation posts and analytical laboratories in this distant area, and the extraordinarily high cost of doing so, emphasize the need for an efficient attitude towards research, and an identification of the major research needs of the immediate future.

This paper deals with the water bodies of the North Slope. It describes the state of knowledge about the physical, chemical and biological condition of arctic waters with the aim of answering some questions regarding the likely effects of man's activities in the area. It was found that very few categorical answers on this subject are possible until more data are available, but a synopsis of informed opinions from scientists, state officials, and oil company representatives familiar with the region is presented.

The relative difficulty of finding year round supplies of suitable water for man's use means that the availability of water should be an important parameter in any developmental planning. Man's water-related activities—particularly waste-disposal and gravel removal from stream beds—should be conducted in such a manner as to present minimal danger to aquatic life, and where ignorance about the effects of such operations is the rule rather than the exception, such activities should proceed with great caution, and under a defensive set of standards.

The unitization of the North Slope oil operation, and the lack of significant native population in the immediate area, make possible a regional approach to the development and management of the water resources by the combined oil companies under the watchful eye of the State. Whether or not it becomes possible to devise a very different organizational arrangement for water management than presently exists, it still seems advisable to mention some characteristics and advantages of regional management as used in other areas as part of a conceptual framework for management of the North Slope water.

The management of water quality has been discussed by many authors as an economic problem in which high quality water must justify its existence, or "pay its way" in competition with such "uses" as waste disposal. This purely economic approach to the problem is currently being challenged, especially with regard to the development of wild areas. Economists are faced with the need to evaluate preservation values in their terminology if their techniques of benefit-cost analysis are to represent current priorities. There are basic limitations which prevent the assignment of meaningful monetary values to wilderness, or wildlife. Any future water planning in the arctic wilderness will have to take this into account when the benefits and costs of a project are estimated.

GENERAL DESCRIPTION OF THE ARCTIC SLOPE

The area considered in this study is shown in the accompanying map. (Fig. 1.). It is bounded on the west by the Naval Petroleum Reserve No. 4 and the Colville River, and on the east by the Canning River and the Arctic Wildlife Range. Between the Brooks Range to the south, and the Arctic Ocean, the total area is some 26,000 square miles.

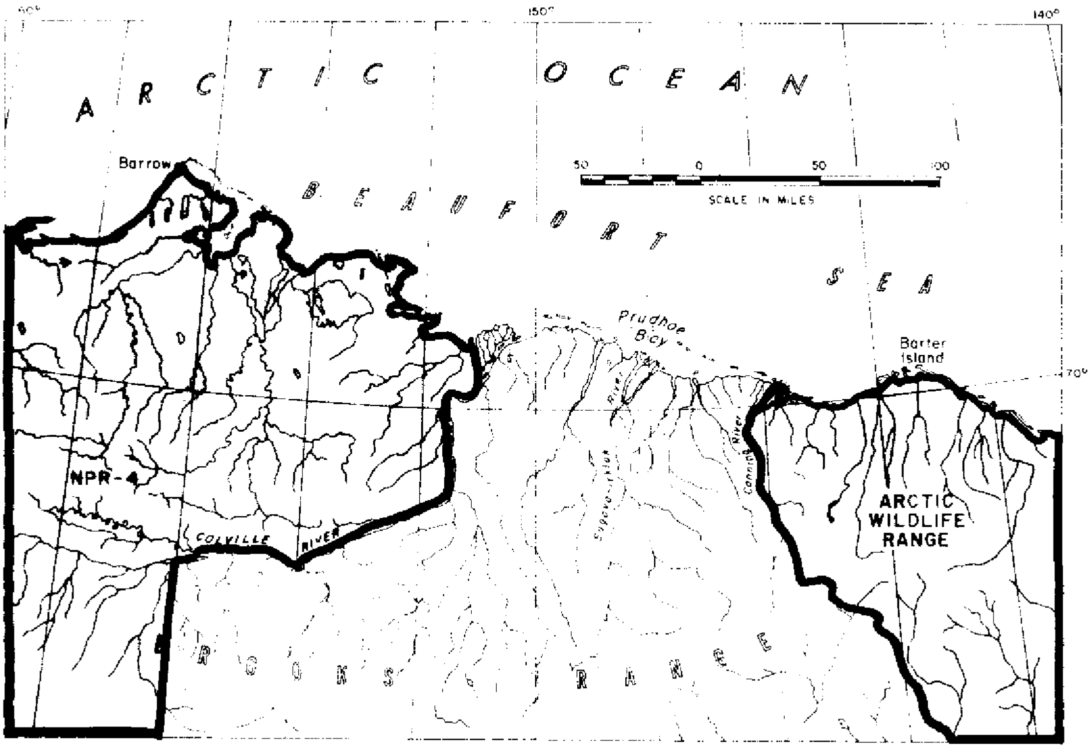

Fig. 1. Map of Study Area

Geologists have divided the Arctic Slope into three physiographic provinces[1] (Fig. 2). The Arctic Coastal Plain, bordering the sea and extending some fifty to one hundred miles inland, is a broad, level plain underlain everywhere with 1,000 to 2,000 feet of permafrost, and pockmarked with thousands of shallow lakes and swamps. The rivers east of the Colville cross the plain in broad braided channels and are building deltas. The active layer above the permafrost is generally ¼ to 4 feet deep. Perhaps the most notable features of the landscape other than the lakes and rivers are the pingos—occasional smooth mounds which can be up to 200 feet high,—and the network of ice-wedge polygons which cover much of the surface. Prudhoe Bay, the site of the first major oil strike announced in 1965, lies in this plain near the mouth of the Sagavanirktok River.

To the south of the Coastal Plain lie the arctic foothills, consisting of low linear mountains and rolling plateaus rising in altitude from 600 to 3,500 feet. The mountains of the Brooks Range rise abruptly out of the foothills to a height of 7,000 to 8,000 feet. Wide flat-floored glaciated valleys have been carved into these mountains, and at the heads of such valleys the main north-bound rivers start their journey to the sea.

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1. Clyde Wahrhaftig, **Physiographic Division of Alaska,** U.S. Geol. Survey Prof. Paper No. 482 (Washington: U.S. Government Printing Office, 1965).

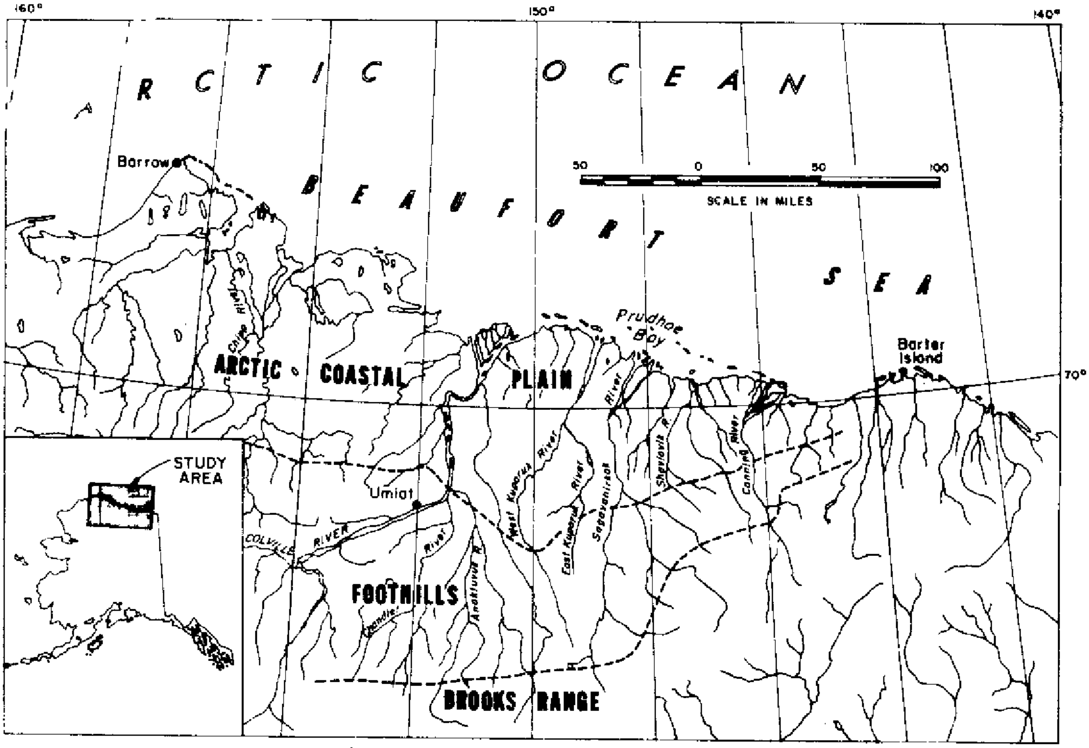

Fig. 2. Physiographic Divisions of the North Slope

WILDLIFE RESOURCES

The land north of the Brooks Range is true Arctic[2]; non-migratory organisms must survive exceptionally long, dark, and cold winters with monthly mean temperatures below freezing from October to June.[3] As a result the vegetation consists largely of lichens, sedges, grasses, and small hardy dwarf shrubs and conifers reaching only a few inches in height. The species diversity is exceptionally low.[4]

An excellent description of the mammalian populations and their importance to the local natives is to be found in the Federal Field Committee report "Alaska Natives and the Land"[5]. The

2. The Arctic is defined in various ways, depending largely on whether the writer is a climatologist, oceanographer, geologist, or biologist. The must useful definitions, in terms of their meaningfulness to man, are those based on climatic factors—though no single such definition has been agreed upon. A typical definition of arctic or tundra climate might be one in which the temperature for the warmest month is less than 10°C, and for the coldest month, below -3°C. Reference—**The Arctic Basin,** Coordinated by John E. Sater (Washington: The Arctic Institute of N. America, 1969) pp. 2,3,172.

3. For climatological details, see C. Hartman, and P. Johnson, **Environmental Atlas of Alaska,** Univ. of Alaska (College, Ak.: 1969).

4. L.A. Spetzman, **Vegetation of the Arctic Slope of Alaska,** U.S. Geol. Survey Prof. Paper No. 302-B (Washington: U.S. Government Printing Office, 1959).

5. Federal Field Committee for Developmental Planning in Alaska, **Alaska Natives and the Land,** A Report Prepared for the Senate Committee on Interior and Insular Affairs (Washington: U.S. Government Printing Office, Oct. 1968).

caribou are by far the most numerous of the large mammals, there being at least 360,000 caribou on the Arctic Slope in the summer months. More thinly distributed are the Barren Ground Grizzly Bear, together with wolves, wolverines, arctic foxes, and polar bears. A large population of Dall Sheep inhabit the Brooks Range.

Probably the best descriptions of the bird resources of the Arctic Slope are contained in recent reports by Dr. James Bartonek[6] and Bryan Sage[7], covering the regions of imminent oil-related development, and an earlier study by Kessel and Cade[8] on the Colville River. The last two reports give a good description of habitat types along with the results of reconnaissance surveys in the area. Dr. Bartonek's contains a thorough survey of previous bird studies on the Arctic Slope and points out some of the most significant threats to bird life offered by human activity in the area. He notes, among many other things, that there are large populations of birds, particularly eiders and oldsquaws, which summer in the narrow coastal and tidal regions, and that they are particularly susceptible to oil spillage.

Very little is known about the fish populations of the northern rivers, although there have been preliminary studies completed in the summers of 1969 and 1970 in the Colville River delta region by the Alaska Department of Fish and Game, (report in press) and the same department is gathering data at present (1971) in the Sagavanirktok River and its neighboring streams and tributaries. The Alaska Water Laboratory in College (Environmental Protection Agency—Water Quality Office) is also in the process of producing a report on their studies in the past year in the Sagavanirktok River and its tributaries, in which they hope to cast some light, not only on the fish populations, but also on their distribution and their relations to environmental conditions and food supply. Information from these studies represents an important first step in assessing the river and delta eco-systems of the Arctic, but much information about winter stocks and conditions is admittedly difficult to obtain, and remains to be gathered. Presently a certain amount of information on fish is available from those who take fish for subsistence use, but as there are no permanent Eskimo settlements between Barrow and Barter Island, this type of information is sparse in the Prudhoe region. "Bud" Helmericks has operated a small commercial fishery for many years in the Colville delta, where he finds whitefish, arctic char, and cisco in greatest numbers. Grayling exist in most arctic rivers, and lake trout in the larger mountain lakes. However, a recent report by Brooks et al.[9] rates the commercial potential of Arctic Slope fishery stocks as "quite limited."

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6. James C. Bartonek, **Arctic Slope and Trans-Alaska Pipeline Task Force Report: The Bird Resources of Alaska's Arctic Slope and Petroleum Development,** Typewritten Report on file at the Area Office, Alaska, Bureau of Sport Fisheries and Wildlife (Anchorage, Ak.: 1969).

7. Bryan L. Sage, **A Contribution of the Ornithology of the Atigun and Sagavanirktok Valleys, Northern Alaska,** unpublished report for the Alyeska Pipeline Service (Anchorage, Ak,:1971).

8. B. Kessel, and T.J. Cade, **Birds of the Colville River, Northern Alaska,** Univ. of Alaska Biol. Papers No. 2 (College, Ak.: 1958).

9. J.W. Brooks et al, **Environmental Influences of Oil and Gas Development in the Arctic Slope and Beaufort Sea,** U.S.D.I., Bureau of Sport Fisheries and Wildlife Resource Publication 96 (Washington, D.C.: 1971).

ANTICIPATED DEVELOPMENTS

The current large scale development at Prudhoe Bay began in January 1968 when the Atlantic Richfield Co. (ARCO) announced that its well, named Prudhoe Bay State No. 1, had flared "a substantial flow of gas" at 8,500 feet. Confirmation that this was a major find came within the next two months, and considerable exploration activity followed over the next year. On September 10, 1969 the State of Alaska held a sealed-bid lease sale for tracts near Prudhoe Bay which netted the State $900 million—the richest lease sale in history.

In the past two years the oil field has been developed as a unitized operation by 2 operators—B.P. Alaska Inc., and Atlantic Richfield Company. The participating area covers some 220,000 acres and will initially require some 150 wells to develop the field. Over 40 of these wells have been drilled to date, and access to the various drilling pads and camps has been achieved through the construction of almost 50 miles of gravel road. Comparison of the field layout map (Fig. 3) with the smaller scale maps of the Arctic Slope give one a good idea of the small percentage of the entire area which is affected by this planned development. It lies within perhaps 12 miles of the Arctic Ocean and stretches roughly 20 miles between the Kuparuk and Sagavanirktok Rivers in an East-West direction. However, leaseholdings extend considerably further afield, and exploratory activity is taking place over the entire coastal plain from the Colville River on the West to the Canning River on the East. For this reason any land or water management planning should concern itself with the whole area, and not merely that region of intensive development shown in Fig. 3.

The scale of development at Prudhoe Bay to date is further indicated by the tonnage of bulk supplies and heavy equipment which was brought in during the first construction phase in 1970. In that summer, a convoy of 70 barges, tugs, and special lighters brought in 187,000 tons of cargo. This year the sea lift was less than 10,000 tons[10]. Roughly 300 men are now employed at Prudhoe Bay, a figure in sharp contrast with the number of workers employed just a year ago.

According to Hickok[11] the maximum population of the entire Arctic Slope of Alaska in 1970 was about 5,900 persons, with 2,050 of those living in Barrow, and roughly 2,000 oil workers making up the bulk of the population. At the time of writing there is very little developmental activity near the Prudhoe Bay oil field because of the uncertain political situation. Under the assumption, however, that the barriers to oil and gas development in the Arctic will be at least partially lifted in the next year or two, there will be considerably increased drilling and production activity, and possibly the development of a township in the immediate region to accommodate the oil workers, service personnel, and a modest tourist industry. Hickok estimates a maximum population of Prudhoe Bay, at the height of future activity, of 4,000 people. In the same article he predicts a maximum future population for the entire Alaskan Arctic of some 15,000 persons, assuming offshore oil and gas development near Barrow, and also to the east, near the Canadian border. Umiat, Sagwon, and Anaktuvuk are also likely to grow, particularly during the construction of a pipeline, a road, and tele-communications with Interior Alaska. However, they will probably never be larger than a few hundred persons each, and will likely decline in importance once the construction phase is over.

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10. **Information, Prudhoe Bay Operations,** a publication of BP Alaska, Inc., (Anchorage, Ak.: July 1971). This pamphlet was the source of several details in this section.

11. David M. Hickok, **Developmental Trends in Arctic Alaska,** on file at Office of Sea Grant Programs, Univ. of Alaska, 108 E. 3rd (Anchorage, Ak.: July 1970).

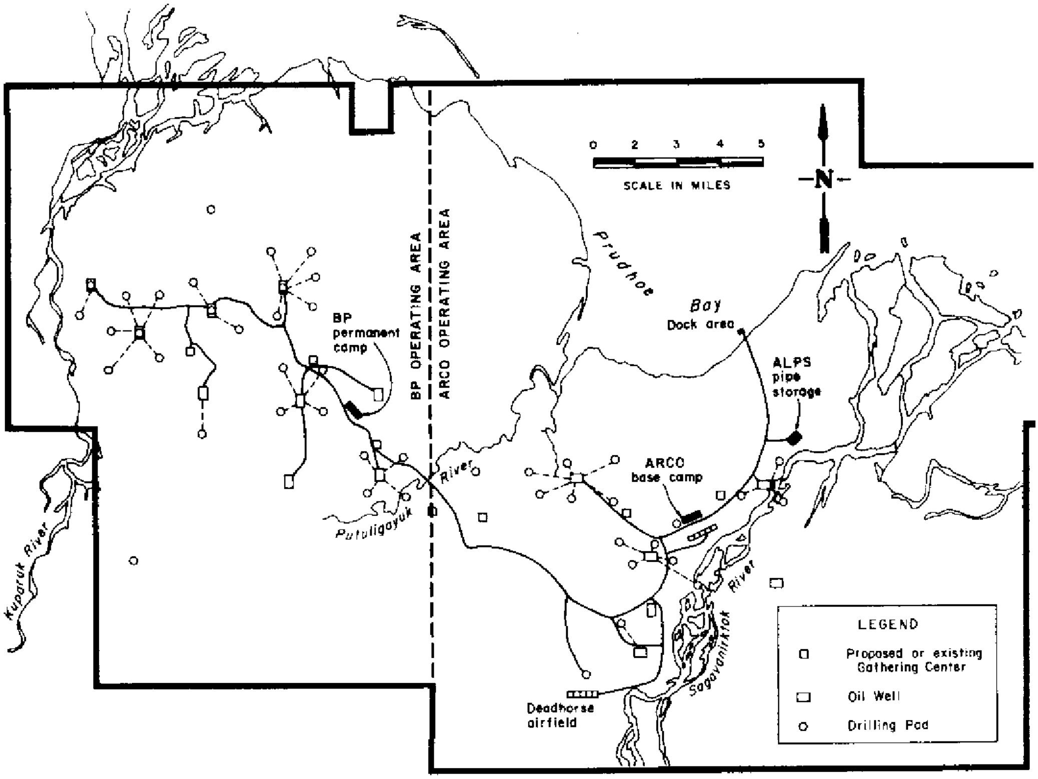

Fig. 3. Prudhoe Bay Oil Field Development

Brooks et al[12] also suggests that the Colville Delta may become the site of a permanent company camp as a major producing structure is located there. However, there is clearly not much point in speculating too much, since the eventual locations and sizes of camps will depend on future discovery patterns.

THE IMPACT OF MAN ON THE ARCTIC AQUATIC ECOSYSTEMS

Our knowledge about the arctic rivers, lakes, and estuaries is still at an infantile stage, as has been discussed above. Furthermore, our estimates of how man is likely to affect these water bodies, and the organisms which rely on them, is based largely on a conjectural extrapolation from experience elsewhere. And yet, what is known about the arctic waters indicates that conditions there are significantly different from conditions in the sub-arctic, and that extrapolation may not give the right answers, for this reason.

It is clear, for example, that environmental conditions in arctic rivers and lakes vary over extraordinarily wide ranges which would not be tolerable to many temperate species of fish, plants or insects. Without any assistance from man, the concentrations of dissolved oxygen in the water may fall, under the winter ice, to less than 1 mg/1, well below the accepted figure of 4 mg/l, considered critical for fish life in more temperate waters. The hydrology of arctic rivers is unique, in

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12. Brooks et al, **op. cit.** p. 10.

that there may be no flow in even the largest rivers, (such as the Colville River) throughout the winter[13]. An ice cover approximately 6 feet thick builds up on all surface water bodies, and though unfrozen water can still be found under the ice of deeper lakes or in deep pools in the river beds, flow essentially ceases to be measurable. The only year round measurements of stream and sediment load in an arctic river that have been published to date are the data of Arnborg et al. collected in 1962[14] (Fig. 4.).

This data was gathered on an area of the Colville River, and we can only suppose it to be typical of all the other rivers in this area. The figure also shows clearly that during the spring flooding, a period of 3 weeks starting just before "breakup," the waters carry an enormous suspended sediment load which is largely scoured from the river bed and the banks.

The significance of these environmental factors for organisms is clear. If they spend the entire year in the arctic streams, they must be able to survive very low dissolved oxygen levels for several months;[15] they must continue to metabolize, though slowly, at 0°C; they must survive high sediment loads in spring, and tremendous scouring of the riverbed. Some insects may be able to survive even though temporarily "frozen" into bottom-fast ice. Furthermore, if one hypothesizes that the conditions over large areas of the streams become unsuitable even for these cold-adapted organisms, then there must be considerable repopulation of these areas in spring when the ice moves out.[16]

The implication is that there will always be areas upstream of such "dead" reaches where conditions remain hospitable, where dissolved oxygen does not drop to intolerable levels, and where organisms survive in reasonable numbers. Research in the field will show the extent of such areas, and will give us some clues as to why they exist where they do. It may simply be a matter of the stored volume of unfrozen water under the ice and the concentration of oxygen-demanding organisms at that point. The possibility exists that some deeper reaches of rivers and deeper lakes are in year-round communication with ground water, though this has not been demonstrated, and it is hard to see why this fact should have any effect on the "hospitality" of such waters. Nevertheless it is mentioned as a possible factor.

These factors are food for some doubt about the seriousness of man's activities when he "pollutes" the streams with sediment during gravel mining operations or with domestic wastes and drilling muds from camps and drilling sites. It may be that by the use of judicious timing, the deleterious effects of man's activities will be minimal if they coincide with the devastating changes wrought by nature. If wastes were to be stored throughout the winter and flushed into the streams during the June floodings, or if gravel mining could be conducted during the period of high natural scouring and sediment carriage, then perhaps the damage would prove negligible.

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13. From the point of view of water bodies, ice conditions mark the duration of "winter", which on the Arctic Slope lasts from the beginning of October to the last week or so of May, a span of nearly 8 months.

14. L. Arnborg, H.J. Walker, and J. Peippo, "Suspended Load in the Colville River 1962," **Geografiska Annaler**, 49-A, 2-4 (1967).

15. Tests on certain non-migratory arctic char have demonstrated their ability to withstand D.O. levels below 1 mg/l. (Interview with George van Wyhe, Alaska Department of Fish and Game, Fairbanks, Ak., May 1971).

16. Evidence of repopulation of areas nearly devoid of insects in Interior Alaska rivers is emerging in current studies being carried out at the Institute of Water Resources, Univ. of Alaska. (Jim Clay—personal communication).

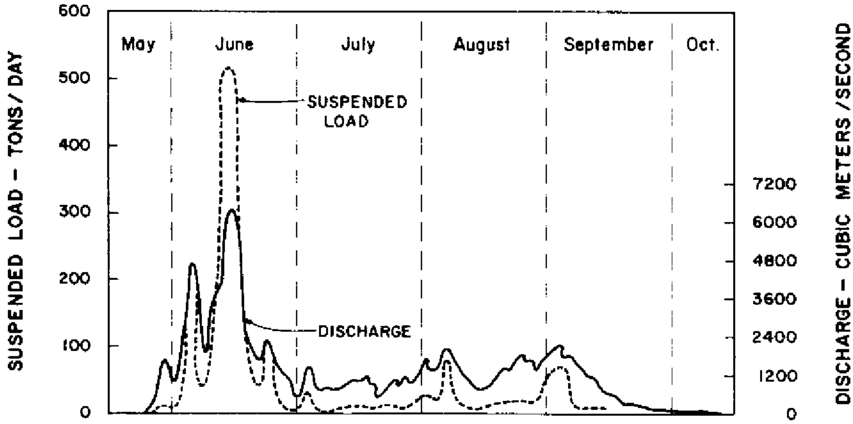

Fig. 4. Discharge and Suspended Load in the Colville River 1962
(Adapted from Arnborg and others, 1967)

One can illustrate this contention in an approximate fashion by employing some typical figures. Assume that a camp of 300 men is planning to store its sewage wastes in a holding pond for 11 months of the year, and discharge them into a major river only during the 30 days after the spring floods are well underway. If one further estimates the camp's water consumption at 80 gal/capita/day, and BOD (5 day, 20°C) of this waste to average 275 mg/l, then the following estimates are reasonable:

Camp daily discharge	–24,000 gal /day.
Storage for 11 months requires a holding pond volume of	–8.04 million gallons or 1.07 million cu ft

(This is equivalent to a pond 10 feet deep by roughly 330 feet square).

The pond will perform some reduction of dissolved BOD during the months of July and August, and will remove most of the settleable solids. However, it can be assumed for the purpose of this discussion that little or no biodegradation goes on for 9 months (275 days.). This is a questionable assumption but it will indicate a "worst case" situation.

Accumulation of BOD_5 over 9 months produces	–15,000 lbs. BOD_5
If this is discharged over a 30 day period then the daily discharge amounts to	–500 lbs BOD_5

The Colville River during the month of June flows at rates between 1,000 and 6,000 m^3/s (See Fig. 4). If the camp were situated near the mouth of the Colville and the waste discharge were evenly dispersed into this river in June the maximum BOD_5 concentration that could result would be only– .0026 mg/1.

Figures are not available on the discharge rates of other arctic rivers, but if one assumes the camp is located on a river of one-tenth the annual discharge of Colville, the maximum BOD_5 content of this river receiving the camp's wastes during the June floods would be– .026 mg/1.

These are low figures, and yet they are probably unreasonably high. The pond itself can be expected to produce a greater degree of waste stabilization over the year than has been assumed here. The health hazard indicated by the discharge of viable pathogens into the river seems small, due to the great dilution observed, and also to the action of the holding pond, which can be expected to destroy nearly all of these organisms prior to discharge. However, this condition would have to be shown to be true through some form of pilot testing if the river downstream is ever planned for water supply. Such calculations give one some confidence that this pattern of storage and spring disposal may prove an effective waste disposal mechanism in certain cases.

However, it is recognized that the key words here are "perhaps" and "may." There is insufficient information available as yet to justify a relaxation of operation standards on the North Slope. This philosophy of caution is well expressed in the guidelines for achieving state objectives in water quality, issued by the Branch of Environmental Health of the Alaska Department of Health and Welfare.[17] The section on sewage disposal begins, "It is the policy of the State to enhance the quality of State waters consistent with reasonable use." [emphasis added]. Yet sections which apply to North Slope waters seem to have been written to allow only the slightest use of these waters for wastes disposal.

> "9. Stabilization of organic wastes in rivers, ponds, or lakes, or in any waters of the State shall not be considered as adequate to be utilized as a principal waste treatment method in regions where daily air temperatures of 32°F or less occur on more than 200 days of the calendar year."
>
> "10. The assimilative capacity of cold regions waters of the State shall not be considered useful or available for dilution or treatment of wastes except these effluents from treatment plants providing a minimum of 90% removal of BOD, suspended solids, and free from toxic, deleterious, or objectionable materials."

The guidelines are extremely defensive, and appear to be based on the sometimes laudable theory that expensive caution is preferable to the possibility of more expensive mistakes, where ignorace about after effects is more the rule than the exception.

RESEARCH NEEDS

A feature common to all field research in the Arctic is its very high cost. This, combined with the comparatively recent nature of man's incursions into the Arctic on a large scale, has left us with very little data on which to base our decisions for the protection of environmental quality. And yet, as is mentioned above, our ignorance may in the longer run be costlier still; so research is definitely needed. However, in a siutation of this apparent urgency, research priorities may have to be set to yield some immediately useful answers to the operational questions that are troubling planners today.

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17. "Cold Regions Environmental Health Practices" Branch of Environmental Health, Alaska Department of Health and Welfare (1971) mimeographed.

It may be useful to spell out some of these questions in order to arrive at the high priority research needs:

1. What are the most important ways in which man's activities in the Arctic are likely to harm the environment; to what extent will these activities be harmful, and will the extent of harm be altered by the season during which the damage is done?
2. What are the alternative operational steps that can be taken to limit the deleterious impacts on the environment? (This implies consideration of the use of package waste treatment plants, for example, side by side with consideration of a storage and spring-disposal scheme.)
3. Is it uneconomical to insist on "maximum-security" operation for all types of activities on the North Slope? Can one justify a relaxation of operating standards for certain types of activities, or for certain areas which are less "critical" ecologically?

One or two research priorities seem to emerge from these questions. Stated broadly, the first is that ecological studies should be initially fairly large scale in purview, and should aim at establishing the most important areas for preservation. The results of these researches would be "Ecological Evaluation Maps" which could be very useful guides to planners who have to make the admittedly unwelcome choice of altering either one type of community or another for the disposal of wastes, or the construction of facilities.

A second research priority would be a pilot-sized field test of the overall effects on a stream of various levels and various patterns of waste disposal. This would involve choosing a small arctic stream near an existing or planned camp and "sacrificing" it, by releasing wastes into it in a controlled manner and observing the effect on the aquatic life. Disposal would also be suspended after a period to ascertain the rate of recovery. This test should provide a better understanding of the dangers inherent in waste disposal into arctic waters.

At present the only known attempt to answer the question of how heavily an arctic river could be polluted in winter and summer is a 1970 report from the Alaska Water Laboratory entitled "Assimilative Capacity of Arctic Rivers."[18] The conclusions drawn in this report are based partly on a laboratory study by Gordon[19] which demonstrated the presence of viable bacteria under the winter ice of the "Sag" River, and which showed that these bacteria would exert a significant demand even at 0°C, if provided with a substrate (such as domestic sewage). The indications are that winter disposal of sewage would totally deplete the already very low dissolved oxygen, and render that stretch of the stream unsuitable for most or all aquatic fauna. The authors concluded that the arctic rivers should not receive any biodegradeable wastes under such conditions. However, a laboratory study of this type cannot test its conclusions directly, or test alternative solutions (such as winter storage and spring disposal). Moreover, it has yet to be demonstrated that a localized destruction of the river fauna due to sewage disposal under the ice at one point would have serious consequences for the river as a whole. It may be that the spring flooding would bring a rapid recovery of the area. For these reasons, a pilot study seems indicated, aimed particularly at establishing rational requirements for small or short-term operation.

It should be noted in passing that there is currently a considerable amount of ecological research being undertaken in the Arctic, but that the research is being conducted by a number of different

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18. E.W. Schallock, E.W. Mueller, and R.C. Gordon, **Assimilative Capacity of Arctic Rivers,** Working Paper No. 7, Alaska Water Laboratory (College, Ak.: 1970).
19. R.C. Gordon, **Depletion of Oxygen by Microorganisms in Alaskan Rivers at Low Temperatures,** Working Paper No. 4, Alaska Water Laboratory (College, Ak.: 1970).

groups or individuals, and that perhaps not enough attempt has been made to establish uniform research priorities which could apply to all these groups, and which could govern future funding. It is realized that one walks on controversial ground when he suggests that "all" research in an area be guided by one set of priorities, or implies that "applied" research is necessarily of greater immediate value than so-called "pure" research which is not mission-oriented. Nevertheless development is proceeding apace in the Arctic, and a consensus on one or two research priorities would surely help to achieve some important results at minimum cost and with minimum delay.

The Tundra Biome division of the U.S. International Biological Program (IBP) is surely funding most of bio-environmental research on the North Slope, the bulk of their money coming from the National Science Foundation. Approximately 200 researchers were supported by Tundra Biome in 1971. Their research is guided by 3 broad objectives:

1. To develop a predictive understanding of wet arctic tundra ecosystems. (the dominant ecosystems on the Slope)

2. To obtain a data base from a variety of cold-dominated ecosystems for comparison, and for predictive modeling.

3. To bring environmental knowledge to bear on the problems of degradation, maintenance, and restoration of these ecosystems.[20]

Their activities are divided into 2 principal areas; one is comprehensive ecosystem research at an intensive site near Barrow, where they cooperate extensively with the Naval Arctic Research Laboratory for accommodation and logistics, and the other area covers comparative, Biome-wide investigations at other locations, notably Prudhoe Bay.

The Prudhoe Bay Unit, the organization of oil companies which is developing the area, supports an Evnironmental Subcommittee responsible for developing and implementing ecological research in the region. In 1970 they decided to spend their money largely sponsoring the Tundra Biome's general ecosystem modeling effort.

Both Tundra Biome and the Prudhoe Bay Environmental Subcommittee are endeavoring to coordinate their efforts with the various other research organizations working on the Arctic Slope. (Notable among these are various University of Alaska research Institutes, and the Battelle Memorial Research Institute). Nevertheless, although they may all cooperate with their research results, they are not necessarily all guided by similar research priorities. It is surprising, for example, in view of priorities which emerge in the next section of this report, that little effort has been donated to date to the study of how man alters or harms the arctic ecosystems.

It may be that this study—or the interactions between man and the environment—are of more immediate importance, in view of the threat presented to the environment, than is continued "base-line" study. If so, it should be receiving greater attention.

Certain obviously "local" priorities for research may well be different from the priorities apparent to world-wide organizations with long-term goals such as IBP. Therefore a local or regional management group should be responsible for setting priorities for the region, and coordinating the research funds flowing into the region.

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20. Jerry Brown, George C. West, **Tundra Biome Research in Alaska,** U.S. IBP—Tundra Biome Report No. 70-1, Box 345, Hanover, N.H. (Hanover: Nov. 1970).

Much of the above discussion has focused on the acute shortage of detailed knowledge on the nature and seriousness of man's impact on the arctic freshwater ecosystems. For this reason policies and standards are guided largely by informed opinion, as expressed by scientists with technical experience gained elsewhere, or by men with some personal experience of life in the Arctic. In view of this, a questionnaire was forwarded to some of the foremost scientists and administrators with knowledge of Arctic Alaska, requesting their opinions on a number of questions related to man's impact on the arctic aquatic environment. A resume of their replies follows.

QUESTIONNAIRE RESULTS

Preliminary. Questionnaires were sent out to some 30 scientists, state and federal officials, and other citizens presumed to have expert knowledge of conditions on the North Slope, with particular expertise in fields related to arctic ecology, or arctic health problems. Unfortunately there was not time to wait for all the replies to come in, with the result that this summary is based on 14 replies only. With this small a sample one cannot pretend to have a balanced "cross-section" of opinion, thus no attempt is made to give real statistical significance to the replies. Any "bias" apparent in the opinions surveyed can be partially attributed to the occupations and natural interests of the respondents. Nevertheless it is felt that the answers are revealing in that most informed points of view are represented, and that a number of important factors are mentioned.

Each question received between 8 and 12 answers; a point considered important by perhaps 3 or 4 people starts to look like a consensus. For this reason the number of answers representing a particular viewpoint are frequently mentioned, but in the large, this summary has been prepared in a qualitative manner.

Qu. 1. "In your opinion, what are the most important ways in which man is likely to harm the aquatic environment of the Arctic Slope? Please be as specific as possible, naming the season when the activity will be most serious, and describing the nature of the effect, as well as the activity itself."

Answers. The three most frequently mentioned dangers were the risks of oil spills, of inadequate sewage and other waste disposal, and of careless gravel removal practices. Of 12 respondents to this question, 9 specifically mentioned oil spillage as a problem of high priority. While most mentioned it just as one form of water pollution, 3 treated oil separately as the most important single issue. There was general agreement that waterfowl are the most endangered group, though two pointed out that oil may be toxic to aquatic organisms. It was noted that the arctic sea ice will tend to confine oil on the coastal waters. The most important potential sources of oil spills are (a) drilling activity and pumping tests, (b) "unnatural seeps" from barrels left on lake ice, or from improperly constructed sumps, (c) barge loading, tanker operation, and offshore drilling (affecting coastal waters), (d) pipeline problems, and the rupture of fuel storage tanks. One respondent noted that refined oil products are potentially more dangerous than crude. The critical period for all types of spillage is assumed to be the period of maximum biological productivity in the spring, and it was noted that winter dumping is usually simply a method of storing "pollution" until the spring.

Sewage disposal was mentioned by 8 people, though only 2 thought it the issue of highest priority. The effects on aquatic life were admitted to be not well known, although 2 thought that the winter season, when low dissolved oxygen levels prevail in surface waters, would be a critical period. The disease risk to man was thought to be the more cogent reason for good sanitary practice in the Arctic, rather than the risks to aquatic life. One person commented that the operations of greatest concern were not the large, "permanent" camps, which are in the public eye, and which can better afford good treatment facilities, but rather the small, temporary geophysical parties, or recreational sites, which would tend to be much less closely controlled.

Gravel removal was mentioned by 9, and thought most important by 3. Two biologists thought that the bottom biota of river beds were threatened by this activity, through suffocation. One wrote, "the lower reaches of all major rivers on the North Slope are important rearing grounds for young fish" which feed on these threatened species. A waterfowl specialist was more concerned about the erosion of lakes that can result from gravel removal, and the resulting reduction of good habitat. However another said, "there is no evidence that gravel removal from North Slope rivers has had any detrimental effects."

Because of the way the question was phrased, only two people mentioned possible beneficial effects that man may have on arctic waters. The warming and enrichment of arctic waters that could result from the disposal of non-toxic organic wastes into lakes and rivers were presented as possible ways of improving habitat for both fish and waterfowl. On land, the impoundments created by roads and camps raise possibilities of intensive waterfowl breeding.

Other harmful activities mentioned included the careless use of tracked vehicles, which may cause the erosion of lakes and streams, with the same kinds of undesirable effects noted under Gravel Removal.

Qu. 2. "Is it possible to suggest standards of activity or minimum standards of the common water quality parameters which would eliminate the problems you describe in Question 1? If so, can you specify these critical levels of quality or behaviour which should be enforced, if the impact of man is to be unimportant."

Answers. Answers to this question bore out the contention that no standards of water quality can be set, since there exists far too little knowledge of Northern Aquatic ecosystems. An official response from the Alaska Water Laboratory (Environmental Protection Agency—Water Quality Office) summed up the general feeling: "we haven't even begun to understand the arctic systems, therefore controls on activity or effluent standards will be required to protect the generally high quality of the existing aquatic environment." Most answers merely recommended the highest or most rigid standards practicable in each case. However there were a number of specific guidelines.

To protect against erosion and siltation, 2 suggested that some or all activity be carried out in winter only (November 1 to May 1 were suggested dates). This, it was observed, also removes nearly all the demand for gravel. However most felt that gravel mining will remain a major activity, but commented that it was possible, even "easy" to set standards of operation which could prevent damage to aquatic organisms through this activity. If heavy vehicles had to be used in the summer, then they should be prohibited near lakes or marshy ground to preclude drainage of these areas.

Everyone realized that oil spillage was a risk that could probably never be eliminated, but that the risk could be minimized. Practices recommended included the use of the highest standards in the construction, maintenance, and operation of oil-containing structures, including intelligent material specification, and insistence on operator training. Barge unloading and fuel storage facilities along the coast were points of special mention, one man recommending that the bladder storage tanks now in general use should be eliminated. Oil sumps were repeatedly considered sources of special concern, though views on how to deal with them varied. One man would discontinue their use, another would bar them in permeable soils, others would allow the practice if the construction of storage dykes meets the highest standards; disused sumps would be covered with a deep insulating layer where removal is not possible. Somewhat surprisingly, only one person offered the thought that the highest priority might be to provide prompt and effective clean-up technology for contingency use, while exercising the utmost care to avoid accidents.

All five who commented on sewage treatment standards insisted on the most complete treatment practicable. This meant secondary treatment or its equivalent for all wastes; references were made to the guidelines on this subject issued by the Alaska Division of Environmental Health, now in the Department of Environmental Conservation. However one person realized that for small, temporary camps such complete treatment was probably impractical, and almost unenforceable, and suggested rationing the use of an area as an alternative approach.

Qu. 3. "Are there any standards or requirements presently in force, with respect to waste disposal or other water related activity, which you feel could be removed or relaxed with negligible harm to the aquatic environment?"

Answers. Opinions varied among the respondents to this question. Five thought no relaxations were justified under any circumstances, and two others felt that this is advisable. However, another announced that data currently being gathered shows the need for higher standards, not lower standards, than have up to now been in force. In favor of partial relaxation of standards were 2 opinions advocating wider use of lagoons, both because of their relative simplicity for remote operation, and for their possible value under certain conditions as better breeding areas for waterfowl. One man felt that current solid waste disposal requirements were excessive, and that the lack of deterioration of such wastes in the Arctic was insufficient reason for barring careful burial as a disposal method. An oil company's view on oil handling equipment and standards was that a currently suggested revision to the Alaska Water Standards which would prohibit any discharge of oily wastes to arctic waters was too strong, in view of available equipment for handling of oils.

Qu. 4. "Is waste disposal a "legitimate" use of arctic streams and lakes? If you think not, please specify whether on scientific moral, or other grounds you make this judgement."

Answers. This question sparked a lot of reactions (12), over a wide range of opinion from 3 "Absolutely (definitely) not!" reactions, and 2 other more guarded no's, to 7 qualified yeses. The qualifications were concerned with the types of wastes to be discharged, or with the setting of suitable limits on such "use" of surface waters. Two men noted, as in their answers to previous questions, that sewage heat and nutrients might well be beneficial to the receiving waters, though other components of the waste flows would have to be prevented from reaching the effluent. One felt that the limits on such activity would have to be low, because the assimilative capacity of arctic waters was much smaller than that of more temperate waters.

Most of those who denied that waste disposal was a valid "use" claimed scientific support for their opinions. The slow rate of biodegradation of organics was the most commonly claimed reason, followed by other risks to aquatic biota, and risks to the health of man. One more practical response stated that it is an established policy of both Federal and State law not to allow waste disposal as a legitimate use of natural waters, and that the strength of public opinion behind this position is such as to outweigh any "scientific" evidence that might oppose this policy.

Qu. 5. "If waste disposal is a legitimate use, in your opinion, are there any water bodies in the oil region of the arctic slope that would be better applied to this use than others? Conversely, which streams or lakes should probably not be used for waste disposal? Why not?

Answers. There was general agreement that research can uncover particular water bodies that will be more suited to waste disposal than others, though two men preferred a different emphasis--that certain surface waters will be shown deserving of extraordinary protection. However there was less consensus of which water bodies should be zoned for which use. Three people mentioned the possibility of discharging wastes into small, landlocked, pothole lakes, though for different reasons. One merely felt this practice would be preferable to discharging the wastes anywhere else, though he said it would destroy waterfowl habitat, whereas another repeated his contention that the practice could be carried out in a manner that would improve the lake for those birds. The third envisaged using small so-called "dead" lakes in an intensive manner, after which they could be landfilled and planted.

Four people mentioned larger streams and lakes in this context. They felt that because of the danger to fish and other populations in these waters, they should not be used for waste disposal. (2 of them would allow the use of larger rivers for the disposal of secondary effluent only.)

Others pressed for more research before this question could be answered. One economist mentioned the need to establish for each water body the relative net benefits of not polluting the water versus those of doing so. He and 2 others asked for planning which could consider all possible future uses of the water before altering its quality by disposing of waste into it. Such uses might include future drinking water needs, scientific uses, recreational uses, and the presence of unusual natural environmental conditions, and rare biotic communities.

Qu. 6. "What are the major research needs to enable such questions as these to be categorically answered?"

Answers. Many of the major research needs presented in answer to this question were unavoidably linked together, and it was not always possible to separate them without some loss of information; bearing this in mind, they could be broken down as follows, in order of frequency of citation.

1. The development of better, cheaper, and more reliable waste treatment systems, and their testing in the field. (6 citations, of which 3 mentioned sewage lagoons specifically.)

2. The study of interactions between waste discharges of various kinds and the changes induced on the receiving waters. This includes both domestic and oily wastes, and the different effects of both short-term and long-term (chronic) discharges. (6 mentions, though they were clearly linked to research needs No. 1 and No. 3.)

3. Detailed limnological studies of the major water bodies, covering both macroscopic and microscopic biota. In this connection one person specifically wanted to study the productivity of these waters. Another would concentrate on the populations during the "critical" winter months, when dissolved oxygen is low. (5 citations.)

4. The study of natural environmental parameters such as hydrology, chemical and dissolved oxygen content, natural sediment loads, and rates of gravel replacement.

5. The rates of biodegradation of organics in arctic waters. This is related to No. 2. (1 mention.)

6. Various economic studies, ranging from the feasibility of various management practices, to the alternatives to any arctic development.

Qu. 7. "Do you feel that the same standards of operation regarding waste treatment and discharge should be required of all installations in the Arctic, no matter how temporary? If not, can you suggest what standards you would require of geophysical parties, or of drilling sites that are active for only 6 to 12 months, and how these standards could differ from those required at a "permanent" camp?

Answers. Considering the small sample asked, it was clear that no consensus emerged on this question. Of 9 replies, 5 expressed the belief that the same standards should be required of all operations, though some admit the methods used to achieve these standards would be dictated by the size of the waste flow. Four others felt that the standards could be varied, but they cautioned that the size of the camp was as important as its length of stay. Three people thought that the nature of the receiving body was at least as important a parameter as the type of camp, in choosing the standards to be applied.

THE WATER RESOURCES OF THE ARCTIC SLOPE

A WATER SHORTAGE?

Alaska, in most people's minds has a virtually endless water resource which is at present almost untapped. In overall quantity, this is perfectly true; Alaska's rivers produce an annual estimated runoff of some 800 million acre-feet, roughly a third of the total runoff of all watersheds in the United States. The Colville River drainage is estimated at 9 million acre-ft /yr and the drainage from Arctic Alaska river basins east and west of the Colville is another 20 million acre-feet annually (See Fig. 5).

In a sense the coastal plain is an arctic desert, since it receives very little precipitation. Annual figures vary from 2 inches per annum near the Arctic Ocean to 10 inches p.a. in the mountains. It remains characteristically "wet" in the summer because percolation into the ground is prevented by the permafrost, because the ground itself is extremely flat, discouraging rapid runoff, and because evaporation is low by comparison with warmer regions. Moreover, there are major variations both in quality and quantity of waters found locally around the state, and conditions in any one place alter enormously over the year. Hence the search for a suitable water supply, of year-round reliability can be very difficult.[21]

Permafrost markedly affects the distribution of water. Since it underlies virtually all the land area, it prevents subsurface drainage, and creates an artificially high "perched" water table on top of the frozen soil. Where this water table intersects the land surface, "wet-lands" result. Swampy "muskeg" vegetation covers most of the Arctic Coastal Plain and much of the foothills. This type of groundwater is generally very high in organic and iron content, and of course exists only seasonally. It cannot be used for community water supply.

Breaks in the permafrost do occur, but only under large, deep lakes (greater than 8 feet deep and more than perhaps 2,000 feet in diameter)[22], or under one or two of the largest streams such as the Colville River (Fig. 6). In the foothills, breaks in the permafrost may occur near the summits of low hills, and near a few perennial "hot" springs. These are the only areas where surface meltwater can sink below the permafrost, and conversely where "sub-permafrost" water can break through to recharge surface water bodies.

"Sub-permafrost" water is by far the largest source of year-round warm water, if it can be reached. It may, however, require an excessively deep well to reach it, and the problem of keeping the well free from ice has to be faced all year. Moreover, on the Arctic Coastal Plain most sub-permafrost water is extremely brackish, with salinities of 2,000 ppm common.[23] Coastal communities, such as Barrow, find that the groundwater salinity may be considerably higher, where sea water intrudes under the permafrost.

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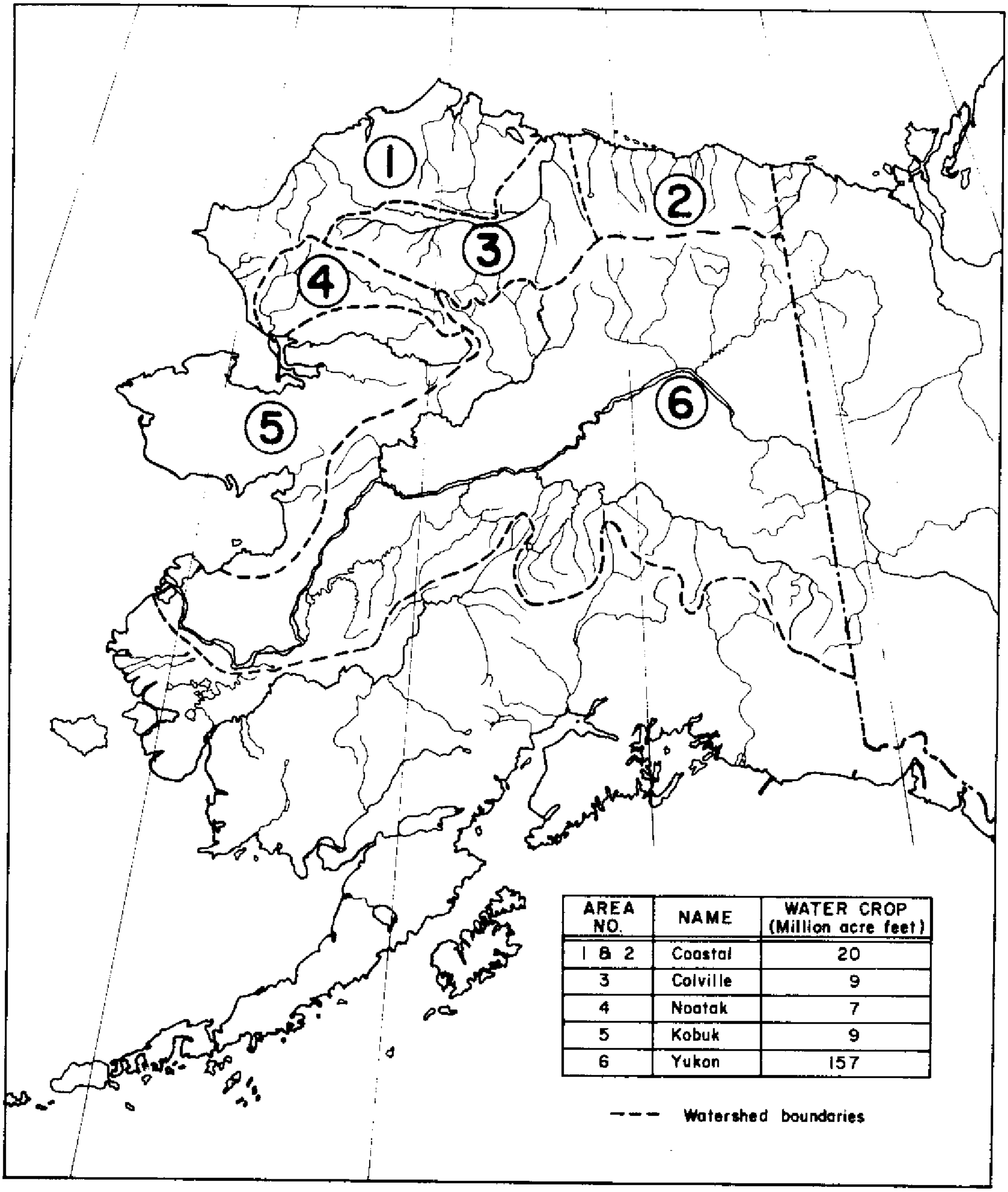
21. J.R. Williams, **Groundwater in the Permafrost Region of Alaska,** U.S. Geol. Survey Prof. Paper No. 696 (Washington: U.S. Government Printing Office, 1970).
22. David M. Hopkins, Thor Karlstrom et al, **Permafrost and Groundwater in Alaska,** U.S. Geol. Survey Prof. Paper No. 264-F (Washington: U.S. Government Printing Office, 1955).
23. It is theorized that this brackish water is inherited from one or more marine transgressions of the Pleistocene epoch. **Ibid.**



AREA NO.	NAME	WATER CROP (Million acre feet)
1 & 2	Coastal	20
3	Colville	9
4	Noatak	7
5	Kobuk	9
6	Yukon	157

Fig. 5. Northern Alaska Water Crop in Millions of Acre-Feet (From Johnson and Hartman, 1969)

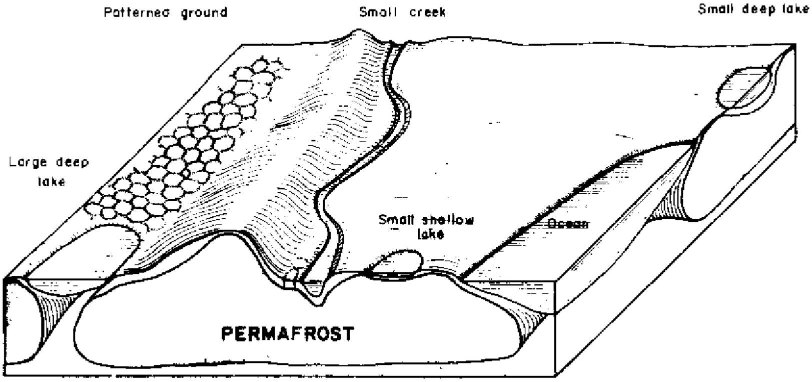


Fig. 6. Effect of Water Bodies on Permafrost in the Arctic Coastal Plain

In the foothills the problem of brackish water still occurs under the permafrost. Here the only reliable sources of groundwater are the few perennial springs. The largest of these is the Shublik Springs, which feed the Canning River, at a mean flow of 1,000 gpm. The Tulugak Springs in Anaktubuk Pass is of similar size.

Surface water supplies seem equally capricious. Since only the largest rivers and lakes maintain a substantial "thaw bowl" around them, only these large water bodies have reliable year-round water. Lakes less than 6 feet deep freeze solid each winter; and other lakes, only slightly larger, may remain unfrozen on the bottom, but this water will contain most of the concentrated impurities from the frozen upper layers and may become unsuitable in winter. Smaller rivers will similarly freeze solid, and even the largest rivers appear not to flow at all in winter. For a description of the flows in the Colville River in 1962 see Fig. 2.

Probably the best supply of year-round good quality water is to be found in alluvium near the large perennial rivers and lakes. The warming effect of surface water bodies on the permafrost is well described elsewhere.[24] (See Fig. 6, adapted from Lachenbruch et al, 1962). A "thaw bowl" exists in the alluvium around the water body. These thawed zones may be hundreds of feet deep, and may extend appreciably in the terraces to either side of the body. In general the storage available in such alluvial aquifers is greater under perennial rivers, which can continually

24. Lachenbruch et al, "Temperatures in Permafrost: Temperature—its Measurement and Control," **Science and Industry**, v. 3, 1 (1962) p. 791-803.

recharge them, than it is under lakes. Williams[25] estimated that in the Colville River valley yields from the alluvium under the river should be several hundred gallons/minutes, and that the quality should be high.

It is clear from the above discussion that in spite of the apparent abundance of water flowing over the Arctic Slope each year, suitable water supplies for human use are in fact available only at isolated points. This places a serious restriction on the size and location of planned communities. Only a few rivers are suitable for water supply, and these include the Colville River, the Sagavanirktok River where much of the oil development is taking place and the Kuparuk River. The main water source for the Prudhoe Bay establishment has been the Sagavanirktok River. However, this supply could easily be rendered unsuitable both by salt-water-intrusion during periods of lower flow, and by pollution from upstream camps. These facts emphasize the necessity for planning and close cooperation among communities and camps in the North. Thousands of lakes cover the coastal plain during the summer, but only a small fraction of these are large enough to become permanent water supplies. Water distribution systems have to be heated in the winter; for this reason it may be impractical to site camps and communities at any distance from their water supply. The practice for many isolated communities has long been to melt snow in the winter. This arrangement has serious limitations, as Alter[26] points out, in that the collection and melting of snow is expensive, and that the resulting water is subject to contamination by contact with animals and with human waste and refuse.

These problems must all be considered in any development plan for the Arctic. Indeed the job of planning for arctic development would be eased if a detailed inventory were prepared, mapping the major sources of potable water. This study would start by mapping all the known icings, open stream channels (indicating the presence of springs) and deep lakes. Further additions to the inventory would be gathered through the slower process of test drilling in the alluvium of rivers and lake beds.

WATER USE IN THE ARCTIC

Having discussed the availability of water on the Arctic Slope, we should note briefly the demands that are being placed on these limited supplies and the various systems which are being proposed for reducing these demands. Water on the Arctic Slope is reported to cost between $0.04 to $1.00 per gallon[27], with 35 cents a reasonable average, so there is a very real economic advantage to be gained from reducing the demand.

The quantity of water used is very much dependent on the nature of the supply and hence the size and permanence of the camp, but as a generalization the per capita demands will be low by comparison with usage in large cities. "Permanent" camps in the Arctic are averaging 84 gal /cap /day, and of this, probably 80% goes to uses such as washing, laundry, and toilet flushing for which water of drinking quality is really not necessary. The importance of this is that recycling systems, (which are not yet widely used), could exert a tremendous saving on the water bills. As an example, up to 25 gal /cap /day may be used for toilet flushing alone; this job can be completely taken over by recycled water which need receive only partial treatment to render it bacteriologically and aesthetically acceptable.

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25. J.R. Williams, **A Review of the Water Resources of the Umiat Area,** U.S. Geol. Survey Circular, No. 636 (Washington: U.S. Government Printing Office, 1970).
26. Amos T. Alter, **Water Supply in Cold Regions,** Cold Regions Science and Engineering Monograph III-C5a, Published by Cold Regions Research and Engineering Laboratory, Hanover, N.H. (Hanover: Jan. 1969).
27. S.E. Clark et al, "Alaskan Industry Experience in Arctic Sewage Treatment," Paper presented at 26th Ind. Waste Conference, Purdue Univ., Lafayette, Ind. (May 1971). Much of the information in this section was taken from this report.

Under pressure from the State, the waste treatment facilities in the Arctic have been considerably improved in the past two years. There are now 17 treatment plants using either biological methods or an equivalent physical or physical-chemical process, operating on the oil field or along the proposed pipeline route.[28] Eight of these plants are on the oilfield, most dealing with design populations of 50—75 people. All except two are extended aeration systems which discharge their wastes into tundra ponds. No arrangement is made for wasting sludge, though fortunately the sludge from an extended aeration unit in good working order should be relatively inert. The exceptions include one Physical-Chemical plant, and one experiment in recycling using a "pasteurization-incineration" process, in which culinary waste water, and shower and laundry wastes are heat treated and chlorinated before recirculating to the toilets. In view of the water cost, it is surprising that more systems of this kind have not been installed.

The camps along the pipeline route are in general larger, and the treatment units (again nearly all extended aeration plants) are designed for some 250 people each. Most of these camps discharge into the nearest river. One camp uses an aerated lagoon, and another has a Physical-Chemical unit of the same design as that mentioned above.

There are a number of inherent operating problems associated with these small isolated camps which mitigate against the effectiveness of a biological treatment plant. The most important are the wide variations in waste load which occur diurnally, and the high percentage of "down time" associated with seasonally occupied camps. It now appears that biological units cannot be expected to reach optimum operating conditions for the first two or three months of operation, by which time the usefulness of the site may have passed. This exorbitant start-up time could be reduced by an operator who really understood the process and who carefully seeded the plant initially, but such men are rare in the North. For reasons such as these, agency personnel are now recommending that strong consideration be given to Physical-Chemical processes for waste treatment, especially in temporary situations. These plants have yet to be properly tested in the North, but the indications are that they will work considerably more effectively. Furthermore they should begin to be effective immediately after they are put into use, they occupy very little space, and can be easily and cheaply housed. Operating costs are higher, because of chemical costs, and the need to dispose of large quantities of sludge, but at least one is paying for results.

Other new approaches that beg consideration for reducing the cost of water include the use of vacuum flush systems (which eliminate flush water), and the use of saunas to cut down the demand for showers. But in any discussion of treatment systems for the Far North, it is apparent that many approaches are feasible, though some are unconventional, and that the real task is to ensure that adequate treatment is carried out everywhere, no matter what system is used. Unfortunately, the biggest restriction on treatment efficiency is usually the lack of experienced and concerned personnel to manage these plants; and without good operation no system will be adequate. A good case can be made for making waste treatment of all the arctic facilities the responsibility of a single professional group which could recommend the best system for each type of camp, install all the units, advise on their operation and perform frequent service checks and analyses. These and other considerations are the subject of the next section.

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28. This may not represent a very high proportion of the sites occupied when one includes all the temporary exploratory camps, but it covers most of the larger sites.

A REGIONAL APPROACH TO ARCTIC WATER MANAGEMENT

There appears to be good reasons for a coordinated approach to arctic water resource and water quality management. Development is certainly taking place in the Arctic and will probably do so at an increased rate in the future.[29] Conflicts are already developing between the various demands placed on the surface waters of the area—from providing drinking water for man to providing habitat for ducks—and these conflicts must be resolved in an equitable manner. This paper advances the notion that, as has been proposed for other regions in the U.S.A., the management of the Arctic Slope water could best be carried out by an agency which represents regional interests, rather than by various State and Federal agencies, whose responsibilities in other spheres mitigate against effective, coordinated, and tailored-for-the-Arctic management of the North Slope, and its special problems.

The management needs cited in the text of this paper have been the following.

1. The desirability of choosing research priorities which emphasize the most immediate conflicts placed on the region by its sudden development; the coordination and distribution of research funds in line with these priorities.
2. The management of waste disposal systems throughout the region, including the design and provision of the equipment, the training of operators, and the organization of testing laboratories and services.
3. The need to plan future development within the limits set by the shortages of useable water and the various conflicting demands for water, including its "use" in the natural state, and its use or abuse as a vehicle for waste disposal.
4. The setting of standards, both of operation, and of waste or water quality, which reflect current knowledge of (or ignorance of) man's influence on the arctic environment; also the enforcement of these standards.

This paper will deal in some detail with the last two management needs, (planning for the future, and standards enforcement), both because these two functions will occupy a large proportion of management's time, and because they are activities which naturally receive more public attention than do the first two needs. In both cases comparisons can obviously be drawn with practice in other areas of the country, and questions are naturally raised about the applicability of some of these practices in the Arctic.

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29. Although the Prudhoe Bay oil field is likely to be the largest such deposit in the region under study, there is no doubt that further exploration will uncover further oil and gas fields of high potential profitability, and that pressure will in time be exerted to extract other minerals from the region. A fairly thorough discussion of the distribution of leasable minerals on the Arctic Slope is contained in "Alaska Natives and the Land" (**op. cit. pp. 405-411**) in which oil and gas potential is demonstrated throughout the region, considerable coal deposits are indicated in the foothills and along the Colville River, and substantial outcrops of oil shale, bituminous rock, and phosphate rocks are indicated. Furthermore, there is a possibility that some secondary industry (petrochemicals, for example), may develop on the Arctic Slope to make use of the ready supply of raw materials and the favorable backhaul situation. All such development is to an extent dependent on the supply of useable water, which, as has been pointed out, may be limited.

SETTING AND ENFORCING OPERATING STANDARDS IN THE ARCTIC

Comparison with the situation elsewhere reveals only that controversy reigns over the best methods or the best incentives to use to control man's waste discharges to the environment. A study of these various incentives was carried out, and is attached as Appendix 2, to this report. It was concluded that for most situations in the more temperate and more developed continental United States, regional management could effectively use a system of effluent charges to arrive at any desired level of waste control at a minimum cost to society. It was tempting to consider the application of this concept to the Arctic Slope, but there appear to be decisive reasons why it is not applicable, and why for the time being man's insults to the environment in the Arctic should continue to be controlled through standards, rather than through economic incentives of this type.

One hurdle to the introduction of effluent charges is the lack of a suitable unit of water quality to act as the basic charging unit. It is a widely recognized limitation of waste treatment theory that an adequate measure of "water quality" does not really exist. Specific chemical constituents can of course be quantitatively detected, and yet it remains impossible to compare two waters carrying rather different combinations of waste materials. The subterfuge we usually fall back on is to measure an effect of pollution which is common to a wide variety of pollutants—the reduction of dissolved oxygen which results from increased biological activity when bacterial substrates are released into water. The dissolved oxygen concentration (DO) measured either as an absolute number of mg/1, or as a percentage of saturation, then becomes an indirect measure of the "amount of pollution."

The concept can probably not be applied meaningfully in arctic streams, because of the extremely low DO levels which occur naturally at various times of the year, and because of the adaptation of aquatic organisms to these extreme conditions. The same criticism must be applied to the use of "suspended solids content" as a measure of another type of pollution. To be meaningful, the suspended solids content would have to be related to a "normal" suspended solids content at that time of year. It is doubtful whether any "normality" can be defined with the precision that would be required. Thus, unless research uncovers a "political parameter" which is really significant for arctic waters and a variety of wastes, no simple water quality levels can be defined.

Of course this reservation can be applied to the use of effluent standards as much as to effluent charges. The feeling is that as long as we remain ignorant of the seriousness and the downstream costs of waste disposal, the water quality levels will in any case be set in an arbitrary manner. There is therefore little justification administratively, and no economic justification for changing to an unfamiliar system of controls until the environmental parameters in the decision are better understood.

PLANNING FOR ARCTIC WATER RESOURCE DEVELOPMENT

Again, in searching for guidelines for arctic planners faced with foreseeing and resolving future water use conflicts, one can only look to experience elsewhere. In the conterminous states water conflicts are familiar, and the planning of major public works to relieve such conflicts now occupies the daily energies of many thousands of people. Such large scale public investments have necessitated some form of public control, with the result that water resource planners now operate within a number of strictures. Public planning methods were investigated, and the resulting comments are presented as Appendix 3, along with some thoughts on their applicability to the Arctic. Certain features of these methods are worth noting here:

(1) The development, (and frequent redevelopment), of "National Goals for Water Resource Planning." These are discussed at greater length in the Appendix, and it would be distracting to go into them in detail at this point.

(2) The development and refinement of various economic evaluation methods, primarily the technique known as Benefit-Cost Analysis, for choosing between alternatives. The connection between the analysis techniques and the planning goals is clear: no matter what technique of choosing projects is actually used, the choice must be made on the basis of some set of criteria, or objectives; however in an economic evaluation, those objectives which are purely economic in nature will be the only objectives given unambiguous weight. Any other criterion on which the choice is theoretically made will first have to be assessed in terms of a dollar value, and in very many areas this is extremely difficult. A prime example is the evaluation of "environmental quality" benefits and costs in monetary terms.

(3) The gradual awareness of a conflict between the even greater levels of development and the steady disappearance of wilderness, or under-developed land. There are undoubtedly many social reasons for this awareness which are beyond the scope of this paper, but one effect has been a demand for the inclusion of the benefits of wild land and wild rivers into Benefit-Cost Analyses in such a way that they can "compete" with development benefits. Needless to say this has proved a testing task, and it remains doubtful that methods can be developed which will enable planners to reduce such "extra-market" factors as "wilderness benefits" to tangible, monetary terms. In the meantime they are referred to as "intangible" or "incommensurable" values, and are relegated to a side-line position in the analysis of alternatives.

The situation on the North Slope of Alaska is different in a number of ways from the situation in the "lower 48" for which these water resources planning methods were largely derived. Therefore one can expect that traditional methods will have to be altered. The most obvious difference is the level of development. Alaska contains by far the largest percentage of true wilderness remaining in the United States, and thus it cannot be argued that wild lands are becoming scarce—in Alaska. However there are those who prefer to look at the national situation, and who argue that Alaskan wild lands and rivers should be preserved for their benefits to the entire nation; thus the conflict between development and wilderness still exists in Alaska. The planning goals for a truly wild area, such as the North Slope, should be somewhat different from those developed for use elsewhere. It is assumed, for example, that the environment cannot be enhanced by development, if the prime environmental goal is preservation of wilderness.

Most significant is the feeling that Benefit-Cost analysis in its usual form is of very limited applicability to the area. The reason is the intangibility of wilderness benefits in a region where these benefits may be the most important factors in the analysis. Arctic water management planners will have to take these differences into account, and will undoubtedly become pioneers in developing methods suitable for wild regions.

THE ORGANIZATION OF AN ARCTIC REGIONAL MANAGEMENT GROUP

There is a widespread feeling among environmentalists in this country that regional air and water management agencies should not include representatives of the major "polluters." The argument is that if they are represented, the effectiveness of the agency in carrying out its enforcement functions will be severely compromised. However the Arctic Slope is a rather special case, in that the resident population is extremely low, and is concentrated at sites far from the region of greatest development, at Prudhoe Bay. In the short term, resource extraction is likely to remain the only human activity over most of the region considered, and thus the principal industries must clearly be represented on any regional management board.

The difficulty with suggesting any particular institutional framework for an Arctic Slope water management agency is that such institutions are essentially political, and that the organizational details will reflect the political realities at the time of formulation. Unless one can predict these with some accuracy, it is perhaps a waste of time postulating an eventual institutional frame in anything more than broad outline form. This is no reason, however, to deny oneself the opportunity of airing some personal observations on the matter! The remarks that follow should, however, be read in this light, and not considered as logical extensions of any earlier material in the report.

The first observation is that although this paper has dealt with only water management problems, it seems obvious that water management is just one aspect of a much larger problem, that of the planned development of Arctic Alaska in all its economic and social aspects. Land management, the development of all subsurface resources, both on and offshore, and the future of the native residents of the region are all considerations which must ultimately be inseparable from the water quality and water resource planning which has been discussed here. If this is to be reflected politically, then a regional water management group would become just one aspect of a regional development agency which would represent local interests to a rather greater degree than most Americans presently envisage. In essence one is discussing a degree of autonomy for arctic residents in the planning of their future.

It cannot be denied that at present the Arctic Slope is managed in a "colonial" fashion (from the point of view of residents of the area) from Washington and Juneau. Resource extraction is carried out necessarily by "outside" concerns, largely for the benefit of users in the conterminous states. Development of the region as a place of permanent habitation where local residents can create their own economic base and manage their own interests is not apparently a major goal of Federal and State planning. Current policies, in fact, provide local residents, few though they are, with very little hope of even achieving true economic self-sufficiency.[30]

The move to establish an Arctic Slope Borough could well be an important step in the right direction. A satisfactory settlement of the Native Land Claims is undeniably another step Nevertheless the principle has yet to be widely recognized that a move toward regional autonomy in many spheres is desirable for the far North. Naturally the complexity of modern land and water management demands considerable expertise which cannot currently be found in the area, and this expertise must for some time be drawn from the various Federal and State agencies which currently have vested interests in these fields. Most of the land area of the Arctic (and of the rest of Alaska) is at present under direct Federal control, through such organizations as the Bureau of Land Management, the Department of Defense, and the National Park Service. In the area of water resources and water quality control, expertise is to be found in the U.S. Geological Survey, the Environmental Protection Agency, the Department of Health, Education and Welfare, and the Bureau of Sport Fisheries and Wildlife, on the Federal side; and the State of Alaska's interests in water management are expressed through the Department of Environmental Conservation, the Department of Fish and Game, and the Department of Health and Welfare.

Some or all of these agencies will have to be party to any changes which may take place in the future in the economic and environmental management of Alaska's Arctic. For a considerable period their representatives and the representatives of any development industries in the area will be members of the new Arctic management structure, in far more than just an advisory capacity. Nevertheless, in the long term the goal should be to encourage and enable the local population to take over the reins of arctic development, and in doing so to become a model for underdeveloped regions in other parts of North America and the world.

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30. People who doubt that the Arctic could ever become self-governing in this way should read Farley Mowat's recent book, **Sibir: My Discovery of Siberia** (Toronto: McClelland and Stewart, 1970) which contains many revealing observations on the extensive development of the Soviet Arctic which has followed the granting of considerable autonomy to the native peoples of Siberia. In its treatment of native populations, Americans have much to learn from the Russians.

SUMMARY AND CONCLUSIONS

In this paper it is proposed that the development of Alaska's North Slope oil provinces imposes a threat of uncertain dimensions to the wilderness character of the region, and that the best way to protect the water resources of the area would be to view the problem as a regional one, and to develop regional management procedures and philosophies governing all water related activity. Some of the factors which should affect water management of the region were discussed, including the rather limited state of knowledge of Far North ecosystems and the pressure of man on them, and the very difficult problem of analyzing and evaluating any future development plans with proper regard to the time value of the land in its wild state.

One has to conclude that no means exist, or are likely to exist, for evaluating wild ecosystems in a traditional economic framework. The conclusion is by itself rather unhelpful, since development in the Arctic is undoubtedly taking place, and the only course is to suggest the wisest way of directing and controlling such development. Wherever development will significantly alter the existing wild state, then the associated benefits and costs of that projected development would be subjected to the closest public scrutiny through the regional management board. It must be realized, however, that traditional methods of carrying out benefit-cost analysis are insufficient for dealing with such indefinable values as the preservation of "natural habitats," or of "wild areas," and that other methods of presentation of the benefits and "risks" (as they might be called), have to be found.

Evaluations of the benefits and costs (in economic terms) of any proposed project should surely be carried out, along side descriptions of the ecological significance and overall value of the area affected. But there need be no attempt to translate all such values into monetary units.

A first step in planning is the preparation, through guided research, of "ecological evaluation maps" of the entire region, as mentioned earlier in the paper. This concept, which was used by Tubbs and Blackwood[31] for a rather densely developed "country" area in Southern England, and again by McHarg[32] in a similar context, (though with an intriguingly flexible approach), has yet to be tried and proven on large and truly wild areas. The essence of the technique is that it achieves an ordering of natural surface features in terms of their values for wildlife habitat, and ecological importance. McHarg's approach is flexible in that it allows non-ecological values to be ordered in importance in the same way. Thus one could build up maps showing areas of greatest importance for recreation, or for aesthetic appeal, as well as for the maintenance of wildlife.

The usefulness of such maps to planners would be their ability to exercise a rational protection over certain areas in preference to others. Areas of lesser ecological importance would effectively be "zoned" for development, though the level of development and the standards of operation insisted upon clearly would still depend on the "importance" of that area in its wild state.

It has been pointed out frequently in this report that man's ignorance of such qualities as "ecological importance" of a lake or river or stretch of tundra may be much greater than his knowledge of those areas. However, the attempt can still be made to order these areas relative to one another. Ignorance can then be compensated for by the preservation of stiff operating standards and low development levels over most of the region. We envisage that only small areas of the arctic tundra would ever be "zoned" for any significant level of disturbance.

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31. C.R. Tubbs, and J.W. Blackwood, "Ecological Evaluation of Land for Planning Purposes," **Biological Conservation,** v. 3, 3 (1971).
32. Ian L. McHarg, **Design With Nature** (Garden City, N.Y.: Natural History Press, 1969) pp. 31-41.

The concept of regional management, then, is forwarded as an efficient means of controlling the development of the natural water resource of the Arctic Slope in a manner consistent with a true concern for the wilderness nature of that region. Under such a management scheme, research could be most effectively directed to obtain the most urgently needed information quickly. Standards of operation consistent with the type of operation and the significance of the affected area could be applied and enforced fairly over the entire North Slope region. Planning of future water resource developments would be carried out with a full understanding of the limited applicability in the Arctic of methods developed for more temperate regions. One concept of a regional management board which represented a variety of groups and agencies was presented.

APPENDIX 1

REGIONAL MANAGEMENT AND WATER RESOURCE ZONING IN CONTINENTAL U.S.A.

Numerous writers[33] in the field of water management have commented that effective control of water quality and quantity is impossible as long as the responsibility for water management is diffused among large numbers of agencies at all levels of government. Effectively this tends to prohibit regional planning in which individual schemes for local flood control or stream quality improvement can be set into a borad policy framework for an entire river basin or watershed. The advantages of regional planning lie in the fact that the "externalities" of a local project—those costs and benefits which do not accrue directly to the local agency planning the project—can be more explicitly accounted for in judging the worth of the project. A city discharging its wastes into a river will be unlikely to treat those wastes unless it is somehow forced to bear the "social" costs of the polluted water it forces on downstream users. Clearly a regional agency, representing both that city and other populations downstream is in a better position to judge alternative ways out of such a conflict. It can compare the cost of treatment of the city's wastes with the costs of non-treatment: the loss of downstream recreational opportunity, the cost of various pre-use treatment plants, and the like.

The regional agency is also in a position to use a wider range of alternatives to meet any problem. It can make use of economies of scale, in which two or more industries and population centers pool their wastes for treatment. It can consider possibilities which no one riparian dweller could force on others, such as the use of the stream for waste treatment, perhaps assisted by in-stream aeration and low-flow augmentation. Here the concept of zoning has been implicitly introduced.

Zoning, or stream classification, is simply the designation of certain streams or sections of streams within the region for particular application. In doing so, one implies the need for different quality standards for streams in different use zones. This contrasts with the philosophy behind most water quality policies in the U.S.A. which is the principle of uniform quality standards for all streams. A moment's thought reveals that for the region as a whole it is cheaper not to have to retain all streams at the highest level of water quality, defined as a quality suitable for drinking or maintenance of a sport fishery. If a higher level of pollution is permitted in some streams, then these streams are bearing some of the cost of waste treatment, and as long as they are not grossly overpolluted, they may be considered treatment devices in their own right, to be compared on a net-benefits basis with all the other alternatives for treatment of those wastes.

Around the world hundreds of different regional institutional arrangements are in operation. They stem from small watershed agencies involving a handful of municipalities, such as the Ontario Conservation Authorities, to powerful authorities representing large river basins and millions of people. The power and effectiveness of a regional agency is of course a function not only of the size of the region it represents, but also of the degree of sovereignty relinquished to it by its component municipalities. Many agencies are purely advisory; some may have authority to set river quality standards but no power or no money to enforce them. Certain regional agencies created by interstate compact have their effectiveness severely limited by the refusal of the state governments concerned to respect decisions that would be politically unpopular within the state.

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33. Particularly Allen V. Kneese. See for example his book, **Regional Water Quality Management**, (Baltimore: John Hopkins Press, 1964).

(The same type of non-cooperation is a familiar disease of the United Nations.) By definition, an effective regional agency which transcends political boundaries should be invested with real power to set regional goals for the water resource, to plan, construct and operate the facilities to meet these goals, and to levy the finances it needs to operate.

It must be said that agencies with this kind of power are rare in the world and nearly non-existent in the United States. Good examples of the type of agency suggested are the Genossenschaften in Germany, of which the Ruhr district Genossenschaften control particularly large populations and industrial concentrations.[34] The Ruhr is a vast industrial complex centered on coal and steel production. Its water problems have been acute for over a hundred years, in that the district is low-lying, often swampy land, with a small runoff, while the waste load on the rivers of the area, from domestic and industrial sources, is phenomenally high by comparison with American experience. One astonishing figure is that the mean low flow of the Ruhr River itself is only 0.8 of the mean waste discharge it is required to assimilate. And yet the Ruhr is used for recreation, and for municipal and industrial water supply, as well as for waste discharge. Clearly regional control of the water resource has long been the only solution, where so many competing water demands exist. Indeed the river basin authorities, or Genossenschaften, were set up as long ago as 1904. With this long history of regional water management behind them, the Germans should have much to teach Americans about the organizational design.

The Ruhr District experience has been ably described by a number of authors, and only a few points need to be mentioned here. One is the extent to which the stream classification has been taken. Of the three chief streams of the area (all tributaries of the Rhine), one, the Emscher, has been classified for use purely for waste treatment. In effect is is an open sewer. The stream has been concrete-lined, and a treatment plant taking the entire stream flow has been constructed at its mouth, just before it enters into the Rhine. The only quality objective in such a case is that the river remains aesthetically satisfactory.

The organization of the Ruhr District Genossenschaften varies, but the principle is worth outlining. They are semi-private corporations, similar to cooperatives, membership of which is made up of city and municipal governments as well as industries. Membership is compulsory, though the voting power held by any organization is proportional to the size of its financial contribution to the cooperative. This in turn is assessed on a dual basis—the size of the waste load the individual organization produces, and the extent of which that organization benefits from regional projects.

Again it should be noted that these Genossenschaften are effective agencies for water management, in that their powers are quite extensive. They have legal authority, not only to plan, construct, and operate facilities, but also to levy the charges that they need to stay in operation. The familiar difficulties associated with effluent standards—the problems of adequate inspection and enforcement—do not exist here, since the cooperative merely treats any waste presented to it, and charges the individual polluter accordingly. An industry has the option, of course, of reducing its effluent fee by improving its effluent, or by moving its location to a site where effective treatment can be achieved more cheaply. In this way an optimum response is achieved.

Marshall Goldman[35] has commented that there are political hurdles to be faced in trying to introduce the Genossenschaften concept into the U.S.A. He feels that people in America distrust

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34. Allen V. Kneese, "Water Quality Management by Regional Authorities in the Ruhr Area," **Controlling Pollution,** ed. Marshall I. Goldman (Englewood Cliffs, N.J.: Prentice-Hall, 1967) pp. 109-129.

35. Marshall I. Goldman, "Pollution: the Mess Around Us," **Controlling Pollution, ibid,** pp. 3-39.

economic controls, citing cases where they have not worked. Even Senator Muskie has denounced effluent charges as an anti-pollution incentive, calling them rather a "license to pollute." Furthermore, Americans are still more distrustful than the Europeans of centralized control in any form. As a result the difficulties of achieving cooperation among the many jurisdictions in a river drainage area can be acute, especially where the jurisdictions include more than one state government.

Nevertheless examples of regional planning are accumulating in the U.S.A., even if there is little progress towards really effective managing institutions to carry out the plans. The U.S. Public Health Service was authorized in 1912 under the Public Health Service Act to conduct investigations into pollution of navigable waters. They began with the Great Lakes, the Potomac River, and the Ohio River, yet 60 years later these areas are still polluted. They have since surveyed some twenty interstate waterways, yet improvement in quality in these areas has not happened. What is missing in every case is the regional authority that is powerful enough to overrule interstate differences and enforce the survey recommendations. Yet there remains in the United States substantial opposition to any such authorities which might undermine local self-determinism. The history of environmental legislation in this country is laced with examples of this type of resistance, with the result that legislation has been largely ineffective.[36]

One example of an interstate compact which on paper can issue enforcement orders and bring polluters to court is the Ohio River Valley Water Sanitation Commission, or ORSANCO, set up in 1948. It consists of 3 representatives from the Federal Government and 3 from each of 8 member states. However its enforcement powers had only been used six times up to 1966, and the cases concerned were never taken to court. Here again the individual states' commissioners appear to have retained too strong a veto power to allow ORSANCO real freedom of action. ORSANCO is effectively reduced to coordinating and implementing state programs.

Perhaps the most impressive of the interstate commissions is the Delaware River Basin Commission, formed in 1961. The representatives are the Governors of New York, New Jersey, Pennsylvania, and Delaware, with the Secretary of the Interior representing the Federal Government. The DRBC is unique in that it is responsible for all aspects of water resource development in the basin, not simply pollution control. It has adopted a comprehensive plan which includes provisions for water supply, pollution control, flood protection, and recreation. It has authority to construct treatment works and other development projects, and to enforce pollution control regulations. If it accomplishes its stated goals it will be an outstanding exception to the otherwise mixed performance of interstate organizations. It is worth noting that the DRBC, like other interstate compacts, has no industrial representation. This is in contrast with the Genossenschaften type of organization described earlier.

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36. J. Clarence Davies III, **The Politics of Pollution** (New York, N.Y.: Pegasus, 1970).

APPENDIX 2

ECONOMIC INCENTIVES FOR CONTROLLING POLLUTION: A REVIEW

One of many difficulties which arise in the attempt to control pollution is the inability of individuals to take an overall view, divorced from personal vested interests, and only broadly limited in space and time. There are fortunately a number of economists now writing articles and books which attempt this broader picture. Among many others one should particularly mention J.H. Dales,[37] A.V. Kneese,[38] and M.I. Goldman,[39] as it is from the writings of these people that most of the following ideas are drawn. The economist of course has his own "vested interest"—but it is probably an interest of which most segments of society would approve. This could be stated: "Given a particular set of objectives in any social problem, what are the cheapest alternatives for achieving these objectives?" Here the word "cheapest" is used in its most general sense; the aim is to minimize all costs, whether they be quantifiable and monetary, or non-quantifiable, and reflected in human unhappiness or disapproval.

In this kind of study, then, the economist is not concerned with choosing the objectives of society. That, presumably, remains the prerogative of the people, in a democracy. Nor is he concerned with engineering alternatives, except insofar as overall costs may be affected. Rather his attention is focused on the most desirable distributions of the direct financial expenses of the project society wishes carried out; and the desirable distribution is that which causes the overall costs to society to be minimized.

The "Pollution Problem", as Dales points out, is no different from any other social problem in this respect. Society is demanding a set of objectives—is this case cleaner water or cleaner air—and there are various political and economic ways of achieving these aims. Broadly speaking, the methods available to government are three: direct regulation, subsidization of "desirable" activities, or the assessment of charges or taxes on undesirable activity. The first alternative must rely on efficient policing and firm, prompt support from the legal branch of government, or on a high degree of popular cooperation, to be effective. The second and third methods are attempts to persuade individuals to conform through use of economic and market pressures.

Of the three alternatives, economic theory indicates that the latter methods, that of charging for antisocial activity, is likely to achieve the wished-for result most economically for society as a whole. Applying this pollution prevention, a system of "effluent fees" or "pollution taxes" is proposed as the most economical way of achieving a predetermined pollution reduction goal. In any particular case, however, there are likely to be a number of difficulties associated with the attempt to set up an effluent taxing scheme. Some of these will be technical difficulties, but others will be political. For reasons which will be explained, the idea often generates hostility among commercial interests. However many of their objectives might be softened by education and negotiation. In principle, the idea of effluent charges is sufficiently worthy to warrant considerable effort in finding an acceptable systems in a particular area.

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37. J.H. Dales, **Pollution, Property and Prices** (Toronto: Univ. of Toronto Press, 1968).
38. Kneese, "Water Quality Management by Regional Authorities in the Ruhr Area," **op. cit.**
39. Goldman, "Pollution: The Mess Around Us," **op. cit.**

J.H. Dales[40] in his book, "Pollution, Property, and Prices" considers a rather nice example of the various alternatives open to a governing body facing a particular social problem: It is worth quoting verbatim:

> "Suppose that we wanted to decrease the number of high-school drop-outs by, say, 90 percent. We could do so by paying prospective drop-outs whatever price would lead nine out of ten of them not to drop out; or by charging them a fee for the right to drop out that would result in only one out of ten prospects deciding to do so; or by passing a law forbidding drop-outs (but allowing kick-outs). The paying scheme would be very costly to the taxpayer in terms of money because every student worth his salt would think of dropping out in order to collect his payment for deciding not to! The law forbidding drop-outs would, I think, be worse; those who wanted to drop out badly enough would have to do enough damage or otherwise make enough of a nuisance of themselves to be kicked out. The taxpayer would have to pay for the damage, or for controlling the nuisance. Much more serious, however, would be the feelings of resentment at being forced to stay in school by those who would otherwise have dropped out, and even by those who would like to think they could drop out if they wanted to; the cost in terms of educational morale might be high. The charging scheme would cost practically nothing to administer; those who decided to drop out would actually be a small source of revenue to taxpayers; and there would probably be a lot less idle talk among students about dropping out than there is now—those who wanted to drop out badly enough would simply pay their exit fee and leave."

ELEMENTS OF AN EFFLUENT CHARGING SCHEME

1. THE TAXING AGENCY

Some of the resentments created whenever an effluent charging system is proposed can be traced to a suspicion that this is merely another source of government revenue, rather than a serious attempt to control pollution. These suspicions are hard to refute when the suggested tracing agency is the federal government, or even the state government. In these circumstances there may be no obvious connection between moneys collected as pollution taxes and moneys spent on water quality improvement. Ideally the "taxing" authority should be a regional water quality or conservation board on which the state and federal governments are represented only as equals with local interests, and whose direct responsibilities include the planning and construction of water improvement works. In this way it can be seen that moneys collected from "worst offenders" in a region support the lion's share of the cleanup effort for that same region. The greater degree of local control holds the added benefit of increased flexibility; a local agency is less likely to become tied to particular remedies, and is far better equipped to conceive large-scale treatment operations which would be beyond the scope of individual polluters.

2. THE TAXABLE UNIT OF POLLUTION

A difficult question arises whenever "pollution" has to be measured. Is there any meaningful unit of "pollution" which can be used to compare the effects of all the classes of pollutants a region is likely to face? The answer has to be "no," at present; there are a number of parameters presently in use—dissolved oxygen, BOD, chloride content, and many more—but they all are

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40. Dales, **op. cit.**

defective in that they each measure only one class of pollutant, or one type of effect on the waterway in question. And there exists such a variety of possible pollutants, exerting such a wide range of deleterious effects on streams, that a single unit of "pollution" is unlikely ever to materialize.

And yet such a unit of measurement seems to be the vital factor in an effluent charging scheme, since there is no other way that polluters can be equitably taxed. Various ideas which have been proposed or used are presented here for discussion, with no suggestion that these suggested units are superior to others which might be proposed.

There are two major ways in which pollutants cause damage to stream life. Either they are directly toxic to some or all living organisms in the water, or they encourage biological growth of one or more classes of organisms while ruining the environment for others. The prime example of this latter effect appears when a stream is dosed with nutrients which encourage the rapid growth of microorganisms, and result in very low dissolved oxygen levels. The environment becomes unsuitable for a great many forms of aquatic life, and in this situation we say the pollution has caused an "oxygen demand." Of the various ways of measuring the potential oxygen demand, the five day BOD has the perhaps dubious advantage of being the most widely used and understood; but there are other, chemical, methods which give a measure of oxygen demand that is much quicker to obtain and more reproducible. Nevertheless, the lb. BOD_5 is a possible unit of pollution.

In a sense, toxic materials can be given a BOD equivalence. If a material is toxic to the natural bacteria which tend of purify the stream, then the rate of treatment will be slowed. The effect would be the same as adding a greater amount of BOD. Hence from laboratory tests of "treatment" rates an equivalence table could be drawn up relating various toxic substances to an equivalent BOD. This system is the basis of the charging system used by the Ruhr Valley Water Conservation Agency, the Ruhrerband, in West Germany. Clearly its applicability is limited, in that the effect of certain industrial toxics on bacterial growth rates may not be the only undesirable effect. Specifically, phenols may combine with various products of chlorination to form chlorphenols—a class of compounds which tend to impart unpleasant tastes and odors to the water long before they reach a concentration which is dangerous biologically. Nevertheless, the pound or ton of equivalent BOD remains as feasible a unit as any other, and has been suggested by most commentators in this country, including Russell Train of the Council on Environmental Quality, as being the likely unit on which to assess effluent charges.

Perhaps a more direct way of measuring pollution is to test the concentration of a given pollutant which will have a given lethal effect on fish. A polluter can then be charged according to how much his effluent must be diluted in order that fish survive in it. It should be noted that this system could be used whether or not the river was to support fish; the unit is somewhat arbitrary anyway, and is basically being used as comparator for charging purposes. Again, a number of obvious criticisms can be raised against the equitability of this unit, but it is probably as meaningful as the pound equivalent BOD, and in fact is the basic taxing unit in the Emscher Basin, also in West German's Ruhr District.

The search for a better unit or combination of units for measuring pollution should be encouraged to continue. The lack of a suitable standard of measurement is a drawback no matter what scheme of regulation is proposed. It should not be used as an argument against effluent charging schemes.

THE MECHANISM OF ASSESSMENT AND CHARGING

Undoubtedly there are innumerable ways of organizing a successful effluent-charging scheme. The function of this section is merely to present one or two philosophies or approaches as food for thought.

In Germany's much quoted Ruhr District, the water conservation boards, or Genossenschaften, have memberships made up from the various industrial and municipal governing bodies in the district. Their financial contribution to this cooperative organization is then proportional to the amount that they benefit from the Genossenschaft's activities, both from the cleaner water supplied to them, and from the volume and strength of their effluents which they are permitted to discharge. In this sense it is truly an effluent-charging system, though in combination with other means of assessment. Critics, in this country, of effluent-taxing by the Federal Government have referred to the writings of Kneese[41] and others on the Genossenschaften and objected that there is no comparison with the systems being proposed in the U.S.A. Harold Lumb[42] has called the charging procedures in the Ruhr District "service charges"—comparable with home-owners' sewer service charges. But really he is obscuring the issue in semantics. There are no essential differences between effluent fees, effluent taxes, pollution charges, or service charges; the disagreements lie in who the money should be paid to, and do not represent attacks on the basic concept of effluent charging.

Dales suggests a system based closely on the market operations of a stock exchange. The conservancy board administering water for a region would issue a fixed number of "Pollution Rights," much as a corporation might issue bonds. Each Pollution Right would entitle the holder to discharge a fixed number of pollution units into the local water body. These "rights" could then be bought and sold, using the Board as the sole "broker," by any individual or group. The Board would ensure that the price for a pollution right could never drop below some minimum price, to be set by trial and error at a level comparable with the average cost to the individual of treating his effluents internally. By this means a maximum is set on the waste load the stream need ever carry. Increased demand would have the effect of raising the price of "Rights," and making it profitable for certain groups to set a certain number and treat the corresponding amount of waste. The idea is described in detail in Dales' book; it appears to have an appealing simplicity, and a degree of flexibility which could be achieved by raising or lowering the minimum price of a "Right," or by altering the total number of Rights in circulation—after a sufficient study period, and, probably, a public vote.

Whatever system is eventually tried in an area, people concerned both in government and industry should try to realize that the primary aim of an effluent-charging scheme is to achieve some predetermined water quality in the region; and that the increased revenue to the control agency is a secondary benefit, to be used wisely, to the direct benefit of the region. The unique nature of effluent-charging, as distinct from subsidization or direct regulation systems, is the factor on which men should concentrate.

IDENTIFIABLE EFFLUENTS

There are a number of situations for which effluent-charging would be impracticable to apply; these are conditions under which the source and strength of effluents are not readily identifi-

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41. Kneese, "Water Quality Management by Regional Authorities in the Ruhr Area," **op. cit.**

42. Harold C. Lumb, "Fallacies of a Pollution Tax," **Industrial Water Engineering,** v. 8, 4 (April 1971). This issue contains a number of articles by representatives of industry and the legal profession, on pollution control incentives.

able, and thus cannot be assessed. Under such a situation the control agency would be forced to use some combination of alternative incentives.

The most obvious example here is that of agricultural runoff, which may "pollute" water bodies with an excess of nutrients or with various artificial herbicides and insecticides, or with silt. There may be no question of the source of the pollution, but it may also be impossible to quantify and to charge for as "effluent." Under such a situation the undesirable agricultural practices can be attacked by one or more of the 3 classes of incentive. DDT, for example, is banned over wide areas of the U.S.A. (direct regulation). A tax could be imposed on fertilizers, or a higher price charged for irrigation water (taxing incentive). Thirdly, and from experience, most usually, good farming practices can be bought by government subsidy. The method or methods chosen here are more usually a reflection of political attitudes than of economic analysis.

A COMPARISON OF INCENTIVE SCHEMES

The discussion up to now has largely ignored the other two broad headings under which incentive schemes can be classified—subsidization of desirable activity, and direct regulation. A large part of the legislative activity in the United States' anti-pollution effort has been dedicated to schemes which involve various mixes of these two types of incentive. It is worth enumerating some suggestions which have been made and used, and classifying them under these headings.

1. DIRECT REGULATION: The work of the Senate Sub-Committee on Air and Water Pollution, under Senator Muskie, has been directed towards the nation-wide setting of standards for all interstate waters. This culminated in the Water Quality Act of 1965, the provisions of which are familiar to many people in the water resources field. This act required the States to prepare standards for their interstate waters which would satisfy the Secretary of the Interior. It also established the Water Pollution Control Administration to perform the essential duties of inspection, testing, and research which any regulation scheme must have. (EPA-WQO, as it is now entitled, also administers construction grants, as will be mentioned later.) It is clear that at present the Federal effort in pollution control is heavily reliant on direct regulation, even though it has tactfully passed much of the enforcement work to the States.

2. SUBSIDIZATION: Pollution control, particularly water pollution control, is an expensive proposition. The Senate Select Committee on National Water Resources has estimated it will cost $100 Billion before the year 2000 to preserve clean water in the U.S.A. No government, then, can enforce standards unless some means is found of financially assisting the individual polluters in cleaning up their wastes. Assistance takes various forms. The WQO spends 80% of their budget, or something over $1 Billion, on grants for the construction of waste treatment plants, and the states are strongly encouraged to invest a similar amount.[43] Various states have introduced tax incentives; these are usually either Tax Credits, based on a given percentage of pollution control facilities costs, or a rapid amortization allowance for such construction. A table showing the systems in effect in various states and a discussion of the costs involved are contained in an article by James Kussmann of the St. Regis Paper Co.[44]

43. Environmental Protection Agency—Water Quality Office. (EPA—WQO).

44. James E. Kussmann, "Fast Writeoffs Aren't Enough: We Need Tax Credits Too," **Industrial Water Engineering,** v. 8, 4 (April 1971).

However, all such systems of incentive can be broadly classified as subsidization in a general discussion of incentive philosophy. Subsidization must obviously be tied to a regulation scheme—a set of enforceable standards—or like the school children in an earlier example, industries and cities could blackmail the governments for financial aid.

SOME GENERAL COMMENTS

Before comparing these three types of incentive any further, we should note that there is a range of ways of applying any control system to a region or a nation. The limits of this range could be described as the "blanket" approach, and the "point-by-point" approach; and the economic efficiency of any incentive system may be vastly affected by the approach used.

In the "blanket" method, individual geographical, hydrologic, and local quality factors are ignored, and everyone is treated equally from the point of view of the administration. Perhaps every steel mill must meet the same effluent standards, or must pay the same toll per pound of BOD emitted regardless of the size of the local water body. Two facts are obvious here; such a system is relatively simple to administer, and yet there is a strong case for calling the scheme inequitous and inefficient. The effects of pollution do depend strongly on the stream being polluted, and thus there are bound to be instances where more treatment is being applied than is necessary from any scientific standpoint. The charge of economic inefficiency, then, is a reasonable one.

However the other extreme of a "point-by-point" treatment, no matter what incentive scheme is being proposed, will require an impossibly large and unweildy bureaucracy to administer it. If every individual polluter must apply to have his site inspected and tested before a discharge permit can be issued, then experience tells us the system would soon be overloaded.

But there is reason to believe that a "blanket" approach to effluent-charging can be reasonably efficient. The administration required for this type of system would be minimal. A testing service to assess the volume and strength of each waste for charging purposes is obviously needed, but once a permit is issued, there is little incentive for the discharger to break the agreement. In this way the need for a sizable enforcement service is avoided. A small office could handle the financial aspects of a "pollution rights" system, and any other services—such as engineering and design, or legal services, are unaffected by the organization of the incentive scheme.

It can then be further reasoned that the "blanket" approach to assessing charges would not result in inefficiency, so much as it would help to preserve diversity. If the control agency were to raise the effluent charges in a highly built-up and polluted area, the effect would be to force industry out of town, where charges remained low. The logical end of this reasoning is the somewhat unwelcome picture of a region without diversity, with all areas equally populated and evenly polluted. If one can also argue that a polluted river in one area makes its unpolluted neighbor progressively more valuable for recreation and wildlife values, then the charge of economic inefficiency dwindles.

INDUSTRY'S ATTITUDES TO ECONOMIC INCENTIVES

The prevailing attitude among corporation executives towards government's role in pollution control is that government should set standards (if they must) and provide subsidies. Effluent-charging schemes are widely opposed, both on the ground that they are really just revenue-gaining gambits; and also on the belief that effluent charges represent a "license to pollute," and what without standards there will be no clean streams left in America. The first argument has some substance; but it is possible to construct the taxing agency in such a fashion that the resistance on this count would crumble. The second argument is more difficult to deal with, because it is an emotional argument. But the critical factor in any effluent-charging scheme will be the cost of polluting. If the charges were to be set high enough, all of America's streams would be clean; but most of her industries would be forced to close down. Clearly a balance must, and can be found between the need to improve water quality and the need to preserve economic welfare.

Industrial spokesmen fear that effluent-charges will favor the big competitor—and the marginal concerns will be forced to close. There is no evidence that this will really happen to any great extent.

The point we all need to keep in mind is this: no matter what the system used, the cost of cleaning up the nation's rivers and lakes will be borne by all of the people, whether as consumers paying increased prices, or as taxpayers supporting expensive federal and state programs. This being so, the only important issue is to find the system which will have the desired effect at least-cost to the nation. Any other issue is economically irrelevant.

APPENDIX 3

BENEFIT-ANALYSIS, AND ITS RELEVANCE TO ARCTIC WATER PLANNING

The impending development of any wild area, and particularly of the North Slope and Brooks Range, which has caught the public imagination as America's "last great wilderness," poses difficult evaluation problems for planners. Whether or not the development involves public funds (which is usually the case in water resource projects), the wild area itself is an increasingly valuable public resource, and its use, in a natural state, can be considered part of the public's real income. Thus the value of this wild area to the nation must be estimated as conscientiously as possible before it can be determined whether a proposed development will represent a net gain or a net loss to the people.

Benefit-Cost Analysis, the official response that public moneys be spent responsibly, was introduced into the planning of water projects in 1936.[45] Ideally, Benefit-Cost Analysis would be carried out in roughly this fashion: (1) A series of alternative development plans, including (in theory) the alternative of no development, are chosen, and the tangible costs and benefits associated with the construction and operation of each plan are assessed. The assessment is best made in net-benefits terms, where the costs for each phase of the project are subtracted from the benefits that are expected to be created. "Benefits," of course, mean different things to different people, and in an attempt to avoid confusion and argument, the net benefits of a development have usually been evaluated according to some nationally announced set of water planning goals, or objectives, at least where federal funds have been substantially implicated. For many years the high priority national objective was to increase National Economic Efficiency, (or Gross National Product). Typical factors for which tangible, monetary, net benefits might be estimated would be reduced water treatment costs or waste treatment costs for area residents, increased sales of hydroelectricity, reduced probability of flood damage, and the like.

(2) The "optimum" level of development is then judged to be that level at which the marginal, or incremental net benefits of moving to the next development level is just equal to zero.

In fact Benefit-Cost Analysis has usually been developed in a rather different way, because a limitation of planning time or funds has prohibited consideration of a sufficient number of valid alternatives. Thus very often there has been no attempt to find an economically "optimum" level of development using the marginality principle described above. Rather a project would be approved simply on the criterion of whether the net benefits of the project were greater than zero, which is to say that the benefits accruing from the project were judged greater than the costs imposed on the nation.

But this form of economic analysis has come under critical fire ever since its introduction into public investment planning. The crux of the problem is that any economic analysis has the important effect of placing in the most influential positions those factors and values which can be evaluated in dollar terms. However, there exist a number of factors which should certainly influence planning, and yet which defy monetary evaluation. How does one attach a price to the experience of privacy, to the joy of fresh air, to one's appreciation of natural scenery? These are hard questions, yet perhaps not impossible. These are recreational values, and their value to

45. Flood Control Act 1936. (49 Stat. 1970).

society <u>for recreation alone</u> is probably not "priceless." There is a limit to what we will pay to preserve a scenic resource, or to enjoy a wilderness hike. It may be possible, then, to evaluate recreational worth in terms of consumer "willingness to pay," even though a meaningful market price for such goods does not exist.

This attempt to evaluate consumer "willingness to pay" has been the subject of some research in the last two decades, sparked off by Hotelling's pioneering work in 1949.[46] In essence each researcher chooses a recreational area to study, and gathers visitor statistics from each of various concentric zones around the site to estimate the demand. He then estimates how much each consumer is prepared to spend to use the site—either by polling the population or by assuming that some set of expenditures (e.g. travel costs) represents this "willingness to pay." The result is a price-demand curve, and an area under this curve is used to represent total moneys spent by consumers using the site. The result is at best a rough and ready estimate of the recreational value of the area.

However the mere possibility that such values may be estimated in dollar terms has produced considerable official interest in the possibility of transferring a wide spectrum of such "intangible" values into "tangible" values, and including them in economic evaluations. Certainly much of the criticism imposed on public benefit-cost planning has been based on the obvious inability of the planners to include in their analyses any estimates of the real worth of an undeveloped area, with the result that non-development has never been able to "compete," economically, with development. Furthermore, public investment planning has proved a rich field for political rivalries, with the emergence of numerous special interest agencies and lobbying organizations. Too often such values as recreation have been clumsily included into benefit-cost analyses in order to "justify" development decisions that had actually been made in response to political pressures.

The attempt to evaluate the "non-evaluable" in economic terms may be doing more harm than good in that a theoretical uncertainty exists in the value of many extra-market goods. Any attempt to assign a dollar value to certain classes of so-called "intangibles" underrates this uncertainty, and gives a false sense of reliability to the numbers produced.

GOALS OF WATER RESOURCE PLANNING

This concept is best enlarged by identifying various classes of planning objectives, including those which are now officially recognized in the new "multiple objective" approach to benefit-cost planning. In 1969 the Water Resources Council began producing a new series of guidelines for governmental agencies on planning water projects, popularly known as "Orange Books".[47] The first of these, "Principles of Water Resource Planning," defined four primary objectives as having equal weight. These were the preservation or enhancement of:

A. National Economic Development

B. The Quality of the Environment

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46. H. Hotelling. Letter quoted in "The Economics of Public Recreation: an Economic Study of the Monetary Evaluation of Recreation in the National Parks", National Park Serivce, U.S.D.I., Wash. D.C. (1949). For other examples, see also Clawson, M., **Methods for Estimating the Demand For and Value of Outdoor Recreation,** Resources for the Future, Wash. D.C., and Orlob, G.T., et al, **Wild Rivers, Methods for Evaluation** prepared for O.W.R.R. by Water Resources Engineers, Inc., Walnut Creek, Calif. (1970).

47. Water Resources Council, **"Principles for Planning Water and Land Resources,"** Special Task Force Report (Washington: U.S. Government Printing Office, June 1969).

C. Social Well-being (including redistribution of income, fuller employment, improvements to public health and national security, etc.)

D. Regional Development

It remains to be seen how effectively these four principal objectives can be integrated in any planning process that still relies to a large extent on Benefit-Cost Analysis, and hence of the "tangibility" or measurability of all the benefits and costs of projects. Government planning methods have always been prey to considerable criticism. Arguments are presented on two broad fronts. On the one hand economists such as Irving Fox[48] have set out to show that a number of valid economic principles are being misused under the terms of official procedures. Benefits of proposed projects are inflated by judicious adjustment of discount rates or discounting period, and by the addition of such considerations as "recreation" and "pollution abatement" entirely on the benefit side of the scales. Costs are often reduced in the same manner, with the result that proposed projects can hardly help showing a bias which accurately reflects the specialty of the agency designing the project, and the government grant structure.

On the other hand, critics argue that many of the objectives outlined in "Principles" cannot be evaluated in anything but a rather dubious manner. Freeman and Haveman[49] warn that the opportunities for overlapping and "double counting" of benefits or costs are widespread. It is only too tempting, for example, to include increased recreational opportunity under both the "Quality of the Environment" account and the "Social Well-Being" account. They also point out that it is illogical to calculate "regional benefits" only for the region in which the project takes place—a procedure which implies that the surrounding regions of the nation are less deserving!

All these objectives, however, still seem secondary to the rather decisive one that we still have no good methods for putting a price on most of these extra-market values. The objectives of "High Environmental Quality" for example, demands consideration of at least four factors, each of which would have to be evaluated at all proposed levels of development, including that of non-development: (1) Aesthetic value, (2) Recreational opportunity, (3) Public health and safety and, (4) Scientific value. The only one of these sub-objectives we even pretend to be able to estimate is the value of the recreational demand placed on the area. For the others we can only guess, and even then we will not know how to weigh each factor relative to the others.

To complicate matters further, there would seem to be a fifth factor affecting the environmental quality evaluations, a factor only lately emerging in the national pysche and hence on the political scene, but one that tends to place a high value on wild areas. This is a newfound concern for the future; a recognition that our actions today have a decisive effect on the future, and yet that we usually have only a vague idea of what that future effect will be. We see the emergence of an "Ecological Conscience" (to use Leopold's phrase),[50] a concern to preserve wilderness and wild areas for their own sake, and a pressure to comprehend all the interactions of complex ecosystems before we set out to alter them.

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48. Irving K. Fox, and Orris C. Herfindahl, "Efficiency in the Use of Natural Resources: Attainment of Efficiency in Satisfying Demands for Water Resources". **American Economic Review** (May 1964).

49. A.M. Freeman, and R.H. Haveman, "Benefit-Cost Analysis and Multiple Objectives: Current Issues in Water Resources Planning." **Water Resources Research,** 6. 6 (1970).

50. Aldo Leopold, **A Sand County Almanac** (Oxford: Oxford Univ. Press, 1969).

This "conscience" is born out of our fear for, and our uncertainty about, the future. It is this very recognition that wilderness areas have a real value to future generations which may render worthless any attempt to "evaluate" them in the present.

THE VALUE OF INTANGIBLES IN THE FUTURE

It is hard enough to put any value on a concept like "wilderness" in terms of our present-day use alone; yet this is not the value we should be looking for. Rather we should be concerned to find the maximum value that wilderness will have to mankind at any future time.

Any changes we plan to exert on our wilderness areas will probably be fairly permanent. We may destroy a wildlife habitat for a thousand years, or even hasten the extinction of a species. Examples of a wilderness returning to its natural state after a major disturbance by mankind are rather rare in the world, so if we are evaluating the alternative to change—maintenance of the status quo—in other words—we have rather a long period of time over which we must consider its potential value to mankind.

Now the "value to mankind" of an area of land at any point in time depends on the uses made of the land—and hence on the social behavior patterns and the technology of the period—as well as on the uniqueness, and the accessibility of the property. Any of these factors can change markedly over quite a short time period. As time passes and population and economic pressures increase, and as uses for land change, areas of previously untouched land tend to be gradually altered. Remaining wilderness regions may be discovered to be unique in terms of a new "use", or at least increasingly scarce because of the encroachment of man over similar areas elsewhere.

The "absolute" value of wilderness then, dependent as it must be on future technology, social behavior, populations, and political forces, could only be estimated if we could also predict accurately the state of all these factors at any future time. We patently cannot do this for more than a very few years ahead with any real hope of precision. Any model of these factors which we invent to predict future trends must be a model which extrapolates from past experience, and it must therefore assume no major departures from our present political and economic traditions. Perhaps we would consider such assumptions reasonably safe over 10, 20, or 30 years: can we be so sure about them over 50 or 100 years?

The "intangible" benefits which we associate with wilderness are different in kind, then, from the tangible benefits or costs of the traditional rivals to wilderness—human settlements and development projects. The difference lies in the need to evaluate wilderness benefits over a long time period—long with respect to the time scale of human societies.

The model used by a planner in predicting future use patterns of wilderness and future values to man of these areas will have to acknowledge the statistical uncertainty in its results. Perhaps the value obtained could be expressed as an "expected value" associated with a probability distribution with an ever-increasing variance with time. If so, it is doubtful that the predicted evaluation of future populations of a wilderness area could be shown to have any statistical reliability. Any effort to place a dollar value on such intangible assets does mankind a disservice by ignoring, or seeming to ignore, this major uncertainty.

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