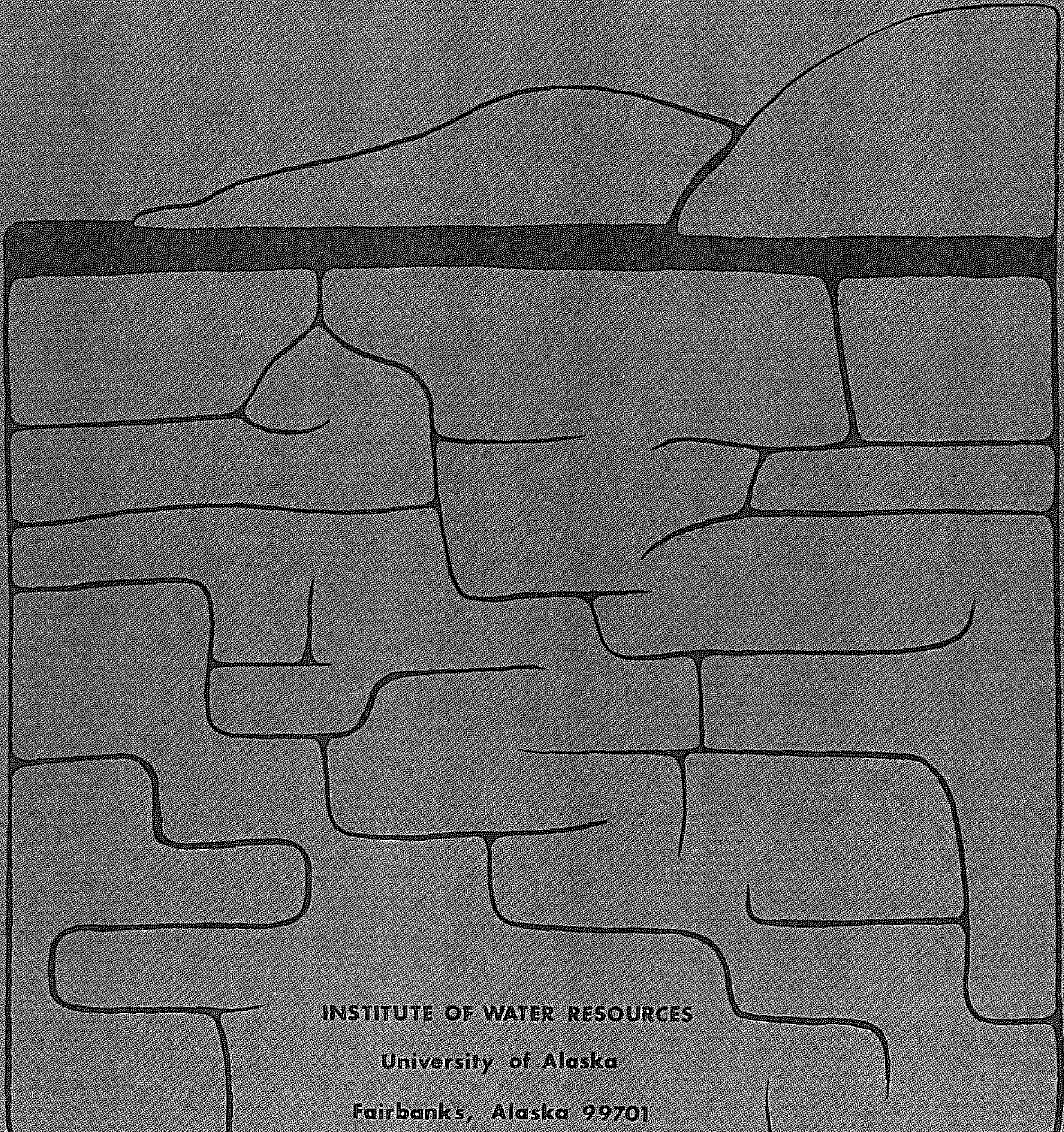
EFFECT OF RESERVOIR CLEARING ON WATER QUALITY IN THE ARCTIC AND SUBARCTIC



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EFFECTS OF RESERVOIR CLEARING ON WATER QUALITY IN THE ARCTIC AND SUBARCTIC

Completion Report
OWRR Project A-043-ALAS

Effects of reservoir clearing on water quality in teh arctic and subarctic
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Report No. IWR-58

January, 1975

ACKNOWLEDGMENTS

The work upon which this report is based was supported by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized by the Water Resources Research Act of 1964, Public Law 88-379, as amended. (Project A-043-ALAS).

The assistance of Mayo Murray in editing the report is greatfully acknowledged.

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INTRODUCTION

Reservoir construction for purposes of water supply in the Arctic and subarctic has been limited due to a relatively low water demand and a lack of conventional distribution systems. However, as development of natural resources and increased investment in northern communities take place, the need for installation of domestic water supplies will become a reality and flood control will be a more critical concern. With these developments, water retention facilities will become necessary in some locations.

At present, site preparation procedures for reservoirs in the Arctic and subarctic are based either on the practices in the warmer states or on economic constraints. A basis for making design decisions must be developed for Alaska's climate and topography. Considerable savings in water treatment cost might be realized if site preparation alternatives were carefully examined.

Reservoir sites in the Arctic and subarctic are frequently flat boggy areas surrounded by rolling terrain. Little is known about the effect the bog soils will have on water quality during long, cold periods. Many of the reservoirs will be quite shallow, causing the wetted soil area per unit water volume to be quite high.

Winter oxygen depletion due to chemical and biological action, restriction of atmospheric reaeration created by long periods of ice cover, and near-zero water inflows, are all of considerable concern in Alaska due to the long winters. Anaerobic conditions increase the ability of the water to reduce chemicals in the bottom mud and bring them into solution thus causing increases in undesirable constituents.

OBJECTIVES

The primary objective of this study was to evaluate sity preparation alternatives and their effects on the quality of water in Arctic and sub-arctic reservoirs. This objective was approached by a series of steps which were designed to develop a general understanding of the effects of leachings on water quality. These steps were

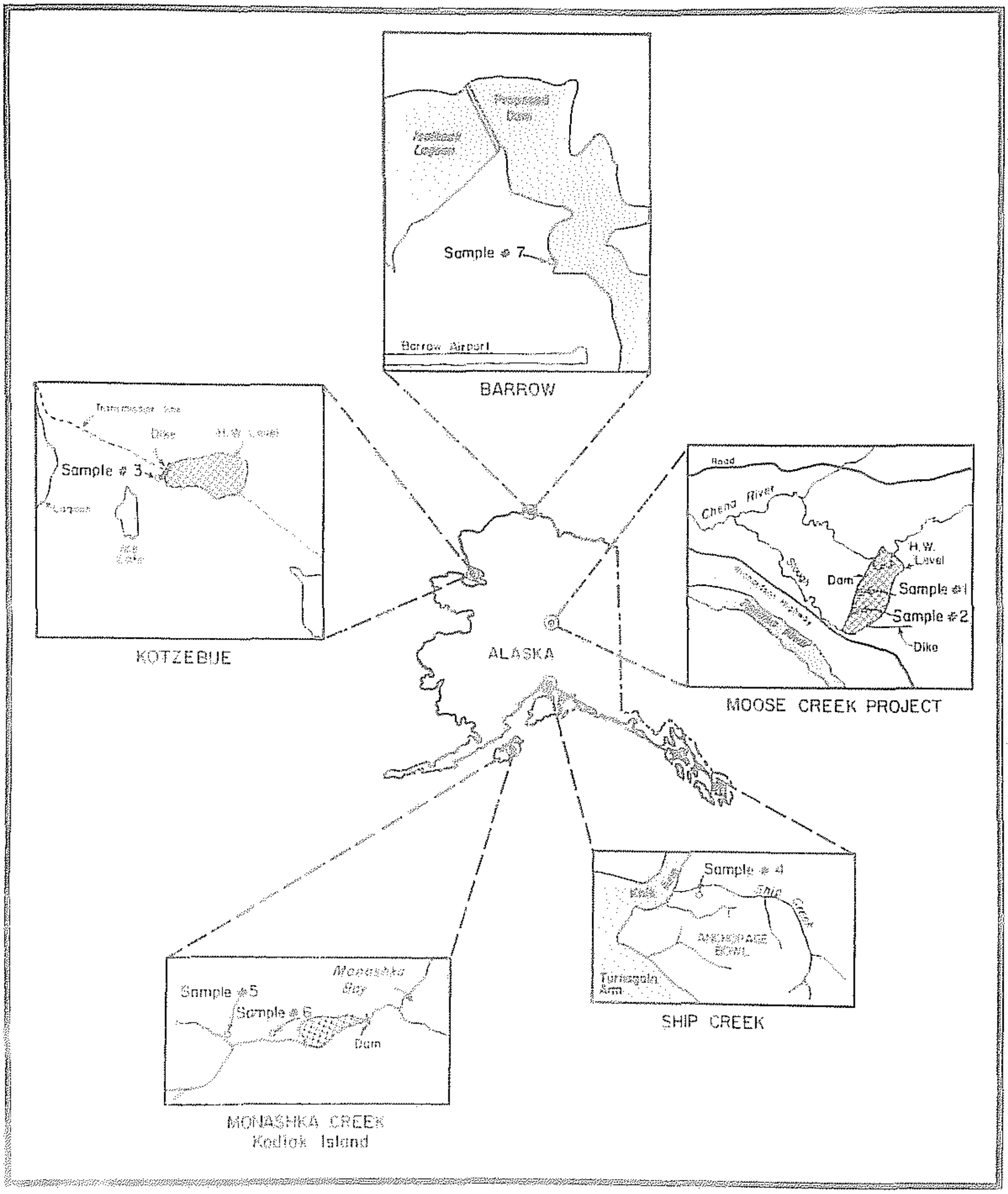
1) collection of soil samples from selected reservoir sites in Alaska
2) leaching of various layers of the samples under simulated, but accelerated reservoir conditions
3) determination of the changes in water quality due to leaching as a function of the soil sample depth.

A secondary objective was to develop a method of evaluating the economics of several clearing alternatives. This was done by comparing clearing costs with related water treatment costs to reach the same quality water.

SAMPLING AND LEACHING STUDIES

Undisturbed soil samples were collected from five reservoir sites around the state of Alaska as shown in the figure (see following page). At each soil sample site, samples 4 inches thick and 6 inches in diameter were removed from the soil profile at the surface and all points of obvious change in soil type. Three or four layers were sampled at each site. In the laboratory at the Institute of Water Resources, the samples were placed at the bottom of 6-inch diameter, 5-foot tall, PVC columns, sealed and filled with distilled water. A second set of soil samples was delivered to the U.S. Soil Conservation Service in Palmer, Alaska, for classification. Samples of this water were collected weekly for 6 weeks. Samples of 220 ml were removed from three ports, 0.5, 2.5 and 4.5 feet above the soil. After 4 weeks only the bottom ports were sampled. Temperature, electrical conductivity (E.C.), alkalinity, tannin/lignin, dissolved oxygen, and color were determined immediately and samples were stored frozen for subsequent nitrogen (NO_3 and NH_4^+), total organic carbon (TOC), iron, and manganese determinations. All analytical techniques were from Standard Methods (APHA, AWWA, WPCF, 1971).

The leaching rate in the laboratory columns was greater than that which may be expected in the reservoirs due to the higher temperatures maintained in the columns. The column temperatures were between 20 and 24°C, whereas reservoir temperatures will be 4°C or less during the period of ice cover. When the data is adjusted, the 1.75 month sample run time is approximately equal to 7 months in the reservoir, or the normal period of ice cover. Thus water quality at the end of the sample runs approximates that which will be found in the reservoir at the end of the period of ice cover.



Location of Sample Sites

DISCUSSION OF RESULTS

The five sample sites were located in greatly different regions of Alaska. The sites were selected to show these differences as well as the similarity of the problems encountered with reservoir site preparation. The results of each column study are summarized by sample site below.

MOOSE CREEK RESERVOIR, SAMPLE 1

The surface layer was all grass detritus with 20 percent volatile solids. The leaching study showed that this layer will cause a rapid onset of anaerobic conditions and dramatic increases in color, alkalinity, tannin/lignin, E.C. and TOC. This sample produces one of the most rapid changes observed.

The layer from 6 to 10 inches below the surface was an organic root mat with 31.5 percent volatile solids. It was fairly fine material. This layer caused much the same conditions as the surface layer only not quite as severe. Dissolved oxygen will be depleted but should not go to zero.

From 12 to 16 inches below the surface a very plastic grey brown silt was encounterd. Sieve analysis showed that 97 percent is "fine" material. Much improvement of reservoir water quality would result from removal of the material above this layer. Most constituents remained low except for nitrate which rose for two weeks then dropped off again.

The soil from 16 to 20 inches below the surface was similar to the soil directly above it except that the soil was even more plastic. It's effect on water quality was also similar. The pH dropped to 4.5 and remained there for the duration of the experiment.

MOOSE CREEK RESERVOIR, SAMPLE 2

The surface material was organic detritus below a Spruce-Birch forest with 46.4 percent organic matter. The water from the column containing this soil went anaerobic rapidly and reached high levels of alkalinity, E.C., tannin/lignin, TOC, NH_4^+, and color. The pH was from 4.5 to 5.0.

The material 6 to 10 inches below the surface was rusty and grey silt with only 1.6 percent organic matter. Sand amounted to 24 percent of the soil and 42 percent was fines. The water overlaying this soil was of good quality. Tannin/lignin and NO_3 rose initially but decreased by the end of the run.

From 12 to 16 inches below the surface, gravel and sand were encountered which contained very little organic matter. Sand constituted 26.1 percent of the soil and only 8.3 percent was fines. Excellent water quality resulted from inundating this soil.

KOTZEBUE RESERVOIR, SAMPLE 3

The top 4 inches of this sample contained tundra plants and their roots in an organic mat. The organic content was found to be 78.7 percent. The leaching column water went anaerobic rapidly and color, E.C., tannin/lignin, and TOC rose to high levels. The pH dropped to 4.5 so no alkalinity appeared.

The layer from 6 to 10 inches below the surface was an organic soil with 19.2 percent organic matter, and 85.6 percent fines. Oxygen did not go to zero in the water over this soil, but color and tannin/lignin still showed dramatic increases. The pH was at 4.5 for the duration of the experiment so there was no alkalinity.

The layer from 12 to 16 inches below the surface was also organic soil containing 32.4 percent organic matter with fines making up 88.7 percent of the sample.

Water quality derived from leaching this sample was quite similar to the layer above it, only the response was delayed. Color, TOC, and tannin/lignin rose to fairly high levels.

SHIP CREEK, SAMPLE 4

The top 3 inches contained roots and organic material in dark red-brown soil of which 53.3 percent was organic matter. This sample caused water to go anaerobic rapidly and created high to moderate rises of color, E.C., tannin/lignin, and NH_4^+. The pH dropped to 4.5 for 3 weeks then rose to over 5 as alkalinity became present.

The layer 3 to 7 inches below the surface was red-brown silt with grey areas. It was found to have a high organic content of 60 percent. Sand comprised 60 percent of the soil; and the other 40 percent was fines. Even with the highly organic soil, the overlaying water did not go anoxic. The water overlaying this soil remained very aerobic and E.C. and NO_3 were the only constituents to show much change. The pH was 4.5 or below during the experiment.

From 8 to 12 inches below the surface, a brown soil was encounterd with 39.9 percent organics. Sand comprised 26 percent of the soil and the remainder was fines. Good water quality resulted from inundating this soil. The pH was 4.5 and E.C. was the only constituent to show a rise.

At the 12- to 16-inch level a dark brown sand was encountered with 24.8 percent organic matter. Only 10 percent was fines, the rest being sand sized. Inundation of this soil resulted in very good water quality with only minor changes in constituents.

MONASHKA CREEK, SAMPLE 5

The surface layer at this site was a dark brown organic root mat with organic matter comprising 40.7 percent. Oxygen went to zero in one week. Electrical conductivity, NH_4^+, tannin/lignin, and alkalinity rose to high levels. Color rose to 10 and then stayed constant.

From 4 to 9 inches below the surface, a volcanic ash layer from the 1912 eruption near Mt. Katmai was encountered. It is a light red-brown sandy material with roots running through it. By sieve analysis, it was found to contain 64 percent fines and 36 percent sand-sized material. Only 1.3 percent organic matter was found. Good water quality resulted from leaching this material. Nitrate (NO_3) rose in the fourth week then fell to zero. The pH started low and rose to 4.7.

The next layer down was 9 to 13 inches below the surface and was an ash material similar to the previous layer. More of this layer was sand-sized material than the former with only 51 percent fines. The organic content was the same at 1.3 percent. Water quality was much the same.

Under the ash layer, we encountered an old organic soil from before the eruption. It was a dark brown silt, or clay material with 4.7 percent organics. Sieve analysis showed it to contain 68 percent fines. It has some potential for degrading reservoir water quality as TOC and NO_3 rose in the leaching column.

MONASHKA CREEK, SAMPLE 6

Near the surface, a dark brown organic root mat was encountered containing 63.9 percent organic matter. Leaching this sample caused a rapid decrease in oxgyen content but total depletion didn't occur until the fifth week. Moderate increases were observed in color, E.C., TOC, pH, and tannin/lignin. High increases were observed in alkalinity and ammonia.

At the 3- to 7-inch depth the ash layer noted at the previous sample site was found. The organic content was found to be 2.0 percent. The fines comprised 39 percent and sand 61 percent of the sample. As with the other leaching columns containing ash, good quality water resulted. None of the constituents rose to undesirable levels.

The lowest level to be leached at this stie was 8 to 13 inches from the surface and was ash material again. Less fines were found in this deeper layer comprising only 30 percent of the sample. Soil organic content and resulting water quality were essentially the same as in the previous layer.

The old organic soil was found below 13 inches.

BARROW, SAMPLE 7

The surface layer of this tundra soil was a black root mat with 12.4 percent organic matter. The leaching column water became almost anaerobic in two weeks and the dissolved oxygen remained at quite low levels for the rest of the time period. Color, E.C., and tannin/lignin showed moderate increases while alkalinity and TOC increased greatly. The nitrogen forms (NO_3 and NH_4^+) increased until the third to fifth week and then fell to low levels.

Below the root mat was a brown silt layer containing a few rocks and having an organic content of 2.6 percent; 29 percent was fine material; 57 percent was sand; and 14 percent was gravel. Better water quality was obtained by leaching this material but color, TOC, and tannin/lignin rose slightly. The pH rose to 6 by the end of the test run.

The last sample leached was a dark tan gravel mixed with fines from 14 to 18 inches below the surface. The organic content was 3.6 percent. The fines comprised 43 percent, the sand 49 percent and gravel 8 percent. This layer produced more color, E.C., alkalinity, TOC, and tannin/lignin than the layer above it. The permafrost directly beneath this layer probably had the effect of inhibiting drainage and thus effectively concentrating constituents at this layer.

ANALYSIS OF TREATMENT AND CLEARING COSTS

One of the primary objectives of this study was to present a simple and reliable method of examining the economics of various degrees of reservoir site clearing. The following assumptions are made in the analysis scheme:

1) The cost of water treatment after 10 years of reservoir operation will be the same for all degrees of clearing. The assumption was based on a number of studies which have shown that initial

differences in site treatment have an effect on water quality for 10 years or less. (Fair, Geyer, and Okun, 1966).

2) The costs of constructing dams, roads, transmission lines, etc., are independent of whether the reservoir is cleared or not and are therefore not considered.

The factors which are considered in the economic method are:

1) The cost of reservoir clearing for various depth alternatives. Obviously, no clearing at all is the cheapest and costs increase as depth of cut increases.

2) The initial capital cost of the water treatment plant as a function of how much clearing is done. This cost is usually highest for uncleared reservoirs and decreases if organic material is removed by clearing.

3) The annual water treatment plant operating cost as a function of how much clearing is done. Initially this cost will be high and decrease for approximately 10 years after which it will remain constant. (Fair, Geyer, and Okun, 1966).

Clearing costs can best be obtained from local contractors familiar with the terrain, but these estimates can vary greatly. Another source of such data is the Building Cost File or the Engineering News Record both of which publish such data. Adjustments have to be made to account for Alaska's remoteness and escalated prices. At the site, the area of land to be cleared must be determined and, if the terrain varies, different clearing costs may have to be applied to account for the variations. It would be advisable to apply different clearing criteria to different soil zones if the leaching studies show some zones to be more likely to contaminate the water.

The capital cost of water treatment plants is best obtained by a comparison of completed plants of similar size, process and location with those being considered. Leaching studies will provide a fair approximation of the water quality which can be expected from the new reservoir. A comparison with the applicable water quality standards will show the degree of treatment necessary to reach the standards. With this data, educated adjustments can be made as to the cost of the necessary treatment plant.

The operation cost of treatment plants can also be obtained from existing treatment plants. A treatment cost has to be determined for each of the predicted water qualities resulting from the clearing alternatives. Treatment costs decrease with time depending on the nature of material flowing into the reservoir. For example, if water with a high organic content flows into the reservoir, the water quality may degrade as this material decomposes. In the study, the quality of influent water was not determined at any of the sites.

For comparing alternatives it is only necessary to use the added operating cost of an alternative over the cheapest alternative because many of the basic units like the chlorination system and the building will cost the same no matter what degree of clearing is done.

Operating costs must be converted to present worth to facilitate cost comparisons.

RECOMMENDATIONS AND CONCLUSIONS

The following recommendations were derived by analyzing the water quality data. These recommendations are subject to change where economic variables of each case are considered. Other items such as slope stability and erosion control also warrant careful consideration.

Moose Creek Reservoir

The marsh-grass areas should be stripped to a depth of 1 foot. This stripping will result in significant improvement of water quality characteristics. On the higher and dryer areas, the upper 6 inches of material should be removed. Much less leaching occurs from the material below this depth.

Kotzebue Reservoir

Little improvement of water quality was obtained when deeper layers were leached, thus stripping is not recommended for this site as only slight improvement of water quality would result. The possibility exists that our sample was obtained from a disturbed site.

Ship Creek

A 3-inch depth of cut is recommended for stripping operations at this site. Remarkable improvement of water quality resulted from leaching material just 3 inches down. Good water quality will result from the impoundment on this site if the top 3 inches are removed.

Monashka Creek, Kodiak Is.

Surface material at this site will degrade water quality severely. The ash material had almost no effect on the quality constituents we observed, thus removal of all organic material above the ash is recommended. The effect of reservoir currents in scouring ash is unknown. Examination of ash scour is recommended before final clearing decisions are made.

Barrow Reservoir

Primarily because oxygen resources remained good when deeper layers were leached, removal of 4 to 6 inches of surface material is recommended. Moderate water quality degradation will still occur but aerobic conditions will remain, thus avoiding problems due to anaerobic conditions.

DISSEMINATION OF RESEARCH

A technical report and one journal article were developed from this project. A brief abstract of each is given below.

Laboratory Study of the Effects of Clearing Alaskan Reservoirs and Predictions of Resulting Water Quality

This report presents the detailed data of all laboratory tests conducted during the leaching study. All charts and graphs are presented. The method of sampling and analysis are included with photographs of selected reservoir sites and laboratory equipment. Information is included on how well total organic carbon, tannin/lignin and color correlate. More detailed discussion of the chemical data was presented. A method of economically comparing clearing alternatives was presented in detail as was an example of its use.

(Smith, D.W. and Justice, S.R. (1974). Institute of Water Resources Report University of Alaska, Fairbanks, Alaska. In press).

Clearing Alaskan Reservoirs and the Resulting Water Quality

This article contains a summary of the sampling and experimental methods used in the leaching experiments. Examples of the data are presented along with a discussion of the results. A method of economically comparing clearing alternatives and the results of this method on a sample reservoir were included. The summary and conclusions discussed the feasibility of doing studies of this type and their possible applications.

(Smith, D.W. and Justice, S.R. (1974). Institute of Water Resources, University of Alaska, Fairbanks, Alaska. In press).

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