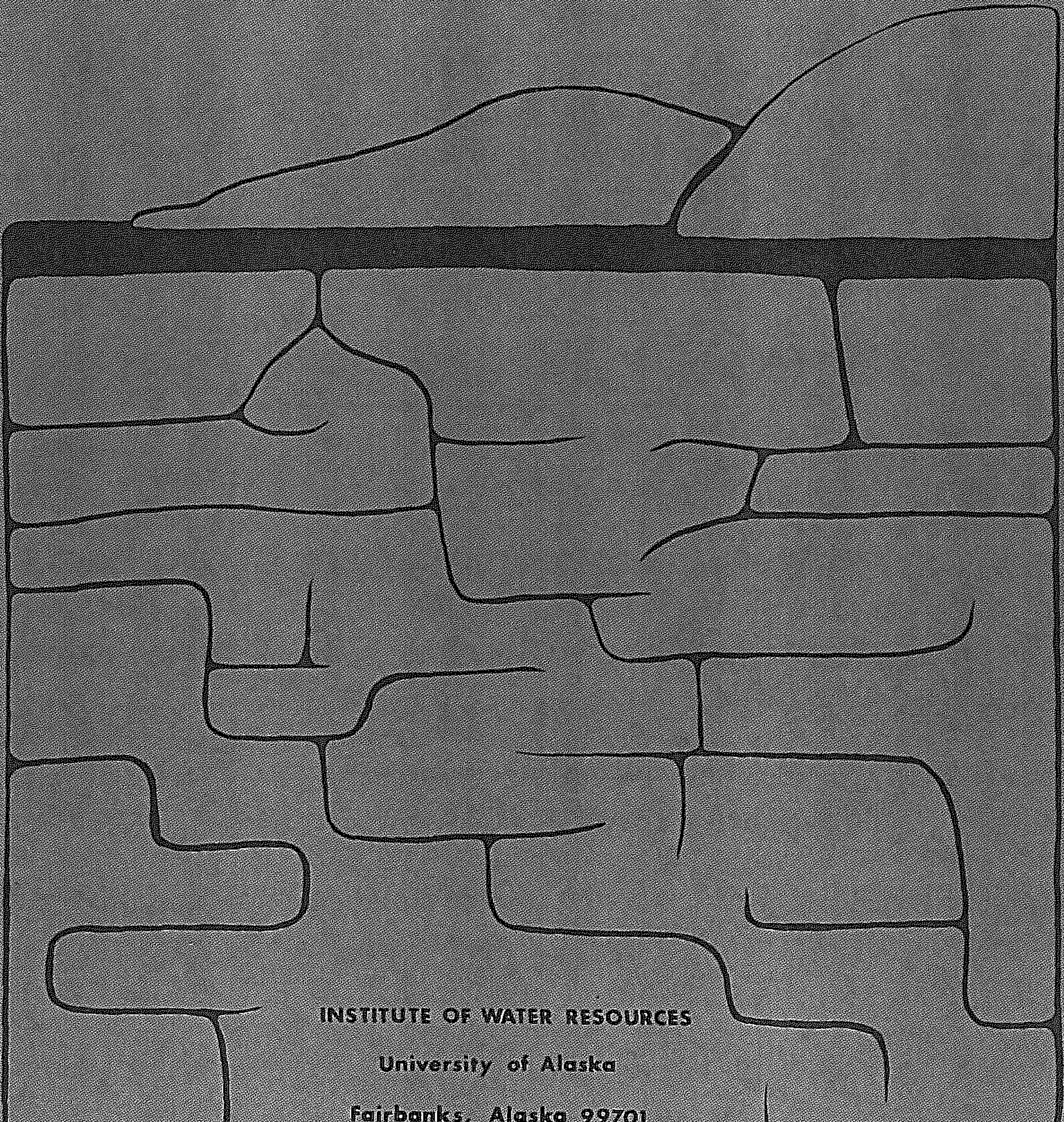
SUPRAPERMAFROST WATER



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SUPRAPERMAFROST WATER

COMPLETION REPORT

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Suprapermafrost Water: Completion report
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INTRODUCTION

This is the final completion report for a two-year project which began 1 July 1972. The original completion date was extended to 31 December 1974 to allow an additional summer's data collection effort should it be required. Although additional data is always of some value, it is apparent that additional data will not contribute materially toward fulfilling the objectives of the project. Accordingly, the final completion report is submitted within the time frame of the original proposal.

At the time this study was formulated it was believed that a hydrology-oriented objective was of paramount importance although it was recognized that certain other engineering applications would be served by the research. It is now clear that the greatest priority area for studying subsurface water in Alaska is in the area of engineering applications, *i.e.* large-scale structures. Also, it is equally clear that the primary area of study needed is near-surface groundwater (*i.e.* suprapermafrost water).

Within the next decade or so, Alaska will certainly see significant growth in her resource extraction industry. The long-debated hot oil trans-Alaska pipeline is now underway. Intensive studies are now being conducted toward moving the vast gas reserves of the Arctic to market. Energy shortages in the US may stimulate development of Alaska's vast coal reserves. The present state of long distance electrical power transmission technology coupled with energy shortages in the US may stimulate the development of Alaska's hydroelectric potential.

Paralleling these developments, actual or potential, will be a need to develop surface transportation facilities (roads and pipelines) across Alaska's great expanse of wilderness. Concomitant with the construction of these structures will be a need to safeguard and protect the environment. The cost of such projects will be billions of dollars. Alaska must construct thousands of miles of new roadway over the next decade or so to link up remote villages, to provide access to mineral and resources-rich areas, and to provide access to Alaska's wilderness. These highways will traverse many miles of terrain where thaw consolidation, heaving, and icing conditions will entail costly maintenance and failure problems.

The construction of reservoir impoundments in Alaska within the next decade is a real probability. Virtually nothing is known about the effects of such impoundments on permafrost soils in Alaska. Problems associated with embankment dams, usually the most economical type of dam to construct, may result because of underlying permafrost.

The health and well-being of many rural peoples on the Arctic Slope would be considerably improved if reliable underground utilities could be constructed in ice-rich soils. Presently, water supply and sanitation is a major health and economic problem in such areas. High maintenance cost of distribution and collection systems due to heaving and thaw consolidation of underlying soils is the main deterrent.

Increased wood fibre needs, coupled with improved transportation, will probably result in major forest-harvesting in permafrost areas in interior Alaska. Such activities coupled with United States Forest Service and Bureau of Land Management management practices will have a marked influence on the hydrology. Unproductive stunted-spruce areas may be burned to upgrade the forest. The resulting changes in the soil moisture thermal regime of such areas will profoundly influence the hydrology.

A good deal of work is yet required in the area of hydrological studies related to snowmelt, flood flow, and stream-aquifer interaction. Additional understanding is necessary to determine how the soil zone influences these processes. For example, information on infiltration of snowmelt into frozen ground is essential to the development of sound flood prediction methods.

OBJECTIVES

The objective of this research proposal was to extend our quantitative knowledge of the soil water regime of permafrost soils as it is related to hydrological analysis. Specifically the objectives were to:

1) develop additional understanding of the seasonal storage and movement of water in the suprapermafrost layer;

2) develop a quantitative mathematical description of the storage and movement of water in the suprapermafrost layer following the onset of spring thaw;

3) investigate possible quantitative differences in this process depending on the nature of the soils; *i.e.* the possible differences between arctic tundra, subarctic muskeg, or temperate alpine soils.

RESEARCH RESULTS

The research consisted of three related components: (1) field work on *in situ* soils, (2) experimental laboratory work to develop knowledge under controlled conditions, and (3) theoretical work based on the known theory of porous media flow. Field work received the most emphasis during the course of the project because it soon became apparent that the most productive expenditures of funds would be achieved by work on *in situ* soils. Laboratory work was curtailed in comparison to the level originally conceived of in the project proposal because it became obvious that the processes being considered were so complex and unknown that meaningful laboratory research in the context of this project could not be accomplished. Theoretical work was carried out in parallel with the other phases of the work. The technical details of the results of this project are reported in four technical journal articles (accepted by OWRR as partial completion reports for this project).

Hydrologic Regime of Alaska Soils

Objectives 1 and 3 were accomplished primarily by an extensive program of field observations on different soil-vegetative-topographic systems in interior and arctic Alaska. Measurement of soil water pore pressures and soil temperatures *in situ* together with laboratory determination of soil moisture parameters permitted an evaluation of the hydrologic regime of important soil systems in Alaska.

Two facets complicate the understanding of soil moisture movement in arctic soils. First, isothermal conditions are seldom found and, second, during a good percentage of the year, near-surface soils are frozen. Considerable work by others has been done to understand thermal gradients that exist in these soils; however, this data was never collected for the purpose of assessing soil moisture behavior. A major emphasis of this project was to develop data that would permit an assessment of the role of moisture transport in arctic soils.

Considerable variations exist in soil temperature profiles at different sites because of slope, aspect, vegetation and snow cover. Research identified several important terrain-vegetative systems. Stunted-spruce forests underlain by shallow permafrost are poorly drained and waterlogged during the summer. Low evapotranspiration results and such areas may have a profound influence on stream flow quantity and quality. There are vast areas of such low-productive forest in interior Alaska. Lowland tussock areas underlain by shallow permafrost are also poorly drained and waterlogged during the summer. These regions have a marginal influence on stream flow except to limit flow to the streams. However, vast regions of tussock-thermokarst topography exist in Alaska and must be crossed by many transportation routes. Significant areas of upland deciduous forest exist in Alaska; however, these soils are usually well drained and dry, providing the most productive plant canopies. Finally, vast areas of treeless tundra exist north of the Brooks Range. These soils, underlain by ice-rich permafrost, are often waterlogged.

Research indicates that the most dynamic and perhaps most important soil water behavior occurs during the winter. There is evidence that a significant amount of water is lost to the atmosphere. Evidence also suggests that an appreciable amount of heat may be convected by moisture migration. Additionally, there is good evidence that quantities of snowmelt may infiltrate for certain soil types. Research indicated that, in most instances, water is driven by hydraulic gradients produced by freezing part of the soil profile.

Laboratory Experimentation

The laboratory research phase of the project deviated substantially from the work originally proposed. There are two reasons for this. First, it became clear that the most productive expenditures of resources and time would be in observations on *in situ* soil systems. Accordingly, field work was emphasized over other phases of the work. Second, research of the available literature relating to experimental work indicated that little work had been undertaken in the context of the objectives of this project. Most research reported in the literature pertained to freezing processes or were limited, disciplinary studies of little value in a hydrologic modeling effort. The processes of soil moisture and heat transport in freezing and thawing soils are extremely complex, and during the early phases of the project, it was unclear as to what type of experiments should be undertaken. It was therefore decided to postpone laboratory work until more field experience was gained.

However, limited laboratory research was conducted to perfect a means of determining ice-pore-water structure of frozen soil. By means of a specially constructed saw, frozen soil cores were cut into very thin sections. These sections were examined by means of a microscope and polarazing light to photograph and observe ice crystal structure within soil pores. Research was primarily confined to technique development in order to perfect a method for better understanding the manner in which moisture in soil freezes.

Mathematical Modeling

Objective 2 was accomplished by using a published two-dimensional program to model summer moisture states adjacent to a stream. This modeling effort indicated that the stream bank area immediately adjacent to the stream is the primary recharge area to the stream, supporting base flow. In general, this modeling also indicated that, in most instances related to hydrologic application, one-dimensional modeling is sufficient. Accordingly, a one-dimensional coupled heat and moisture transport model was developed for freezing and thawing soils.

There are numerous models which predict the thermal behavior of soils undergoing phase change. The admitted weakness of these models is that they do not consider moisture movement. Such movement may have a profound effect on thermal soil regimes over the long run. This is particularly true of the soils of interior Alaska. These soils are at or near 0°C for significant periods of the year and ice-rich permafrost may or may not be present in a given area as a result of a complex interaction between numerous factors.

The most important result to come out of the modeling effort is the conclusion that such modeling, when applied on a regional basis, is of little applied value unless means are perfected for determining accurately: (1) the hydraulic conductivity parameter for freezing soils, (2) the ice-water ratio function, and (3) boundary conditions at the soil surface for both moisture and thermal states.

These unknowns can be determined by carefully constructed laboratory experiments and field plot experiments. The most difficult unknown will be the determination of hydraulic conductivity in frozen soil. To be applicable on a regional scale, hydraulic conductivity functions must be developed by relating hydraulic conductivity to soil, moisture state, and temperature. An equally important problem to deal with will be the soil surface boundary condition for the heat and moisture state equations. To be usful on a regional scale, means must be developed for relating these boundary conditions to available data such as soil, vegetation, and meteorological conditions.

DISSEMINATION OF RESEARCH RESULTS

During the course of this project one paper was presented at a national scientific conference, four scientific journal articles were submitted for publication, and data and findings were supplied to several agencies. An additional manuscript is in preparation and will be submitted to a scientific journal. These are summarized below:

Why Study Subsurface Water in Alaska?

Abstract: Ground water in Alaska, although the subject of several recent descriptive reviews, is generally unexplored and undeveloped. More important than these considerations, however, a physical understanding of ground water as a continuous linkage in the hydrological cycle is not adequately understood. A quantitative understanding of subsurface water in cold regions, particularly those regions of "extreme" cold, is complicated by permafrost and freezing and thawing of an active layer between the ground surface and the permafrost table. It is here that important hydrological linkage between surface and subsurface waters takes place, road and other embankments are constructed, structures such as pipelines and dwellings are placed, plants draw their nutrients and water, and small streams and lakes receive their baseflow. A two-year project to measure soil water pore pressures and temperatures in several locations in Alaska has shed new light on soil water and thermal processes. A mathematical model, together with laboratory measurements of soil water parameters of subarctic and arctic soils, has resulted in a better understanding of coupled moisture and thermal processes involved in freezing and thawing soil systems. [Guymon, G. L., 1973, Invited paper presented at Symposium on Soil-Water Problems of Cold Regions, AGU National Fall Meeting 1973, San Francisco, California, Abstract published in *EOS*, 54(11), 1973.]

Soil Moisture-Vegetation-Temperature Relationships in Central Alaska

Abstract: Measurements of soil moisture and soil temperature were made during the summer of 1972 at four locations in the Goldstream Valley near Fairbanks, Alaska. Two sites were under aspen-birch forest, one in stunted black spruce forest and one in cleared grassland. These field results and observations of conditions in central Alaska led to the development of a model showing the interrelationships among drainage vegetative cover, and the thermal regime of the mineral soil. In addition the subsystems comprising the thermal regime system have been identified. [Luthin, J. N. and G. L. Guymon, Soil moisture-vegetation-temperature relationships in central Alaska, *Journal of Hydrology*, (in press), 1974.]

Soil Moisture-Temperature Relationships for a Subarctic Alaska Lowland

Abstract: Measurements of annual pore water pressures and temperatures in a well-drained lowland suprapermafrost soil indicate a complex sequence of events with the most dynamic and significant behavior occuring in the winter months. A water table promotes warmer winter soils and results in appreciable upward migration of water which also convects appreciable heat. Estimates of spring snowmelt infiltration into these soils and a lowland tussock soil underlain by shallow permafrost suggest significant downward movement of water. Vertical water movement in the soil profiles during the summer months is negligible, the well-drained soil being unsaturated and the tussock soil being waterlogged. The absence of a water table during the winter promotes complete freezing of the soil, drying it and causing low pore water pressures and hydraulic conductivity. The significance of these interpretations to the development of general purpose numerical models is discussed. [Guymon, G. L., Soil moisture-temperature relationship for a subarctic Alaska lowland, submitted to *Water Resources Research* for possible publication, 1974.]

A Coupled Heat and Moisture Transport Model for Arctic Soils

Abstract: The thermal and moisture regimes of arctic and subarctic soils act in parallel in a complex manner and must be considered together. The problem of moisture movement and storage in these soils is complicated by water undergoing a phase change during freezing and thawing and by the presence of ice-rich permafrost. A one-dimensional model of these processes is developed and is based on an equivalent quasi-linear variational functional for the Richard's equation and the heat conduction equation including convective components. The variational functional is solved by a finite-element analog. Convergence and stability are investigated and it is concluded that the numerical procedure is convergent and stable in general. [Guymon G. L. and J. N. Luthin, A coupled heat and moisture transport model for arctic soils, *Water Resources Research,* (in press), 1974.]

Summer Soil Moisture-Temperature Relationships for Arctic Tundra, Barrow, Alaska

Abstract: Measurements of soil moisture and temperature were made during the summer of 1973 at three sites in an arctic tundra region underlain by shallow ice-rich permafrost near Barrow, Alaska. These sites represent a range of internal soil profile and topographic drainage conditions. In addition to obtaining data *in situ*, soil samples were collected and evaluated in the laboratory to establish soil water transport and storage parameters. Interpretation of the data suggests that significant snowmelt infiltration may occur in poorly drained soils. Heat convected by vertical moisture migration is significant during periods of appreciable soil moisture movement. [Guymon, G. L., Summer soil moisture-temperature relationships for arctic tundra, Barrow, Alaska, submitted to *Arctic and Alpine Research* for possible publication, 1974.]

Techniques for Thin-Sectioning Frozen Soil Cores

Abstract: A new technique for cutting thin sections from frozen ground and permafrost with a wire saw is described. The optimum operating parameters for temperature, cutting force, wire size, wire tension and lubrication are given. The method of preparation of thin sections for photography under a microscope is described and several examples of photographs of thin sections of frozen ground and permafrost are shown. As a result of these techniques, it is now possible to study the structure of ice lenses in frozen ground and permafrost. In addition, the structure of ice in concrete and in frozen rocks which has a bearing on engineering and geological problems (e.g. curing of concrete in cold weather, weathering of rocks) can now be determined. [Osterkamp, T. E., Techniques for cutting thin sections from frozen ground and permafrost, Manuscript in preparation, 1974.]

TRAINING

An advanced degree thesis was not prepared as part of this project because of the difficulty in recruiting a qualified student interested in cold regions soil problems. However, four advanced degree candidates worked on the project and received beneficial training.

COLLABORATION

Dr. J. N. Luthin, Chairman, Department of Water Science and Engineering, University of California (Davis) actively collaborated with the principal investigator in carrying out the objectives of the proposal.

A limited amount of collaboration was possible with CRREL; however, because of limitations imposed by distance and the remoteness of Alaska, the degree of collaboration originally hoped for was not possible. CRREL assisted in the field research at Barrow by providing facilities (through Office of Naval Research authorization).

During the later phases of the project, collaboration with Japanese scientists of the Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan was made possible by means of a supplemental travel grant through the National Science Foundation.

Dr. T. E. Osterkamp of the Geophysical Institute, University of Alaska, conducted laboratory experiments on thin-sectioning frozen soil cores.