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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

"DESIGN CONSIDERATIONS FOR SAMPLING PROGRAMS IN REMOTE AREAS"

U. S. ENVIRONMENTAL PROTECTION AGENCY
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# DESIGN CONSIDERATIONS FOR SAMPLING PROGRAMS IN REMOTE AREAS

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# PREFACE

Field work in the Arctic is in some respects, as much an art as a science. Each investigator develops his own set of procedures and designs apparatus to meet his scientific objectives. Frequently the innovation of one person has the potential for being of value to another investigator conducting field work. Such innovations are often taken for granted despite their ingenuity and are not passed on to other workers.

This paper is by no means a complete discussion of innovations in Arctic field work. However, it is a start toward compiling and communicating techniques which have been used successfully.

Readers are encouraged to direct comments on the subject to the authors so that the information herein may be continually upgraded. Specific information on techniques and apparatus are especially welcome and will hopefully be incorporated into future editions.

## ABSTRACT

Water quality field studies in the Arctic rapidly reveal flaws in logistic schemes and equipment reliability because of severe constraints placed on all components by the environment. Since these studies generally require collection of samples in areas remote from central laboratory facilities, the time lag between sampling and analysis necessitates the inclusion of field analyses in the sampling scheme where the analytes may exhibit rapid change. The selected scheme includes components of sampling, field processing, shipping and laboratory analysis which are dependent on both the time and mode of transportation as well as the requirements for analytical reliability. Decisions regarding analytical specification are dependent upon the resources of the investigator, although in a more immediate sense are a function of the working environment and available field instrumentation.

Investigations conducted in the Arctic frequently involve component failure problems exaggerated by the extreme conditions encountered. Beyond local interest, this experience has implications for the planning of all field projects in that lack of component reliability becomes apparent more rapidly and perhaps with more severe consequences under these conditions. Out of this experience, equipment and procedures have been innovated which allow more reliable sampling specification.

Additional development and design is necessary to bring component reliability up to the state-of-the-art. Unit data cost and statistical reliability can be optimized through critical path analysis. Equipment reliability can be greatly improved through the application of environmental simulation techniques such as those developed for space program

instrumentation. Research on analyte concentration for improved transportability and preservation could achieve a reduction in statistical and logistical restraints.

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# INTRODUCTION

Recent emphasis on natural resources and the environment has taken the scientist and engineer from their traditional roles and imposed the task of cooperative studies in locations far from the laboratory or desk. This has required interrelation of a type not experienced by these professions in their more traditional, strictly defined roles. Therefore, it becomes critical that participants have an awareness and appreciation for the objectives and techniques of other disciplines as well as for problems inherent in interdisciplinary studies. This becomes most evident in planning and executing field data acquisition where the physical environment imposes additional constraints.

The difficulty of field operations grows rapidly as distance is increased from central facilities, particularly where geography imposes its own set of limitations (Figure 1). Nowhere is this more apparent than in the vast cold regions of Alaska (Figure 2) and Canada. Alaska has about 20% of the U. S. land mass (Figure 3), 66% of its coastline, approximately 40% of its freshwater, and is characterized by several distinct climatic/geographic areas (Figure 4). The population of only 300,000 is predominantly concentrated in a few cities which has resulted in a road system less extensive than found in many smaller states. Thus, sampling programs in northern regions have been conducted in remote areas.

The additional stress of an extreme environment has placed a critical burden on the ability to function in a scientifically reliable and cost-effective manner. Any weak point in a field operation, whether in planning or in equipment specification and performance, will generally become apparent and may cause failure in meeting project objectives. Field

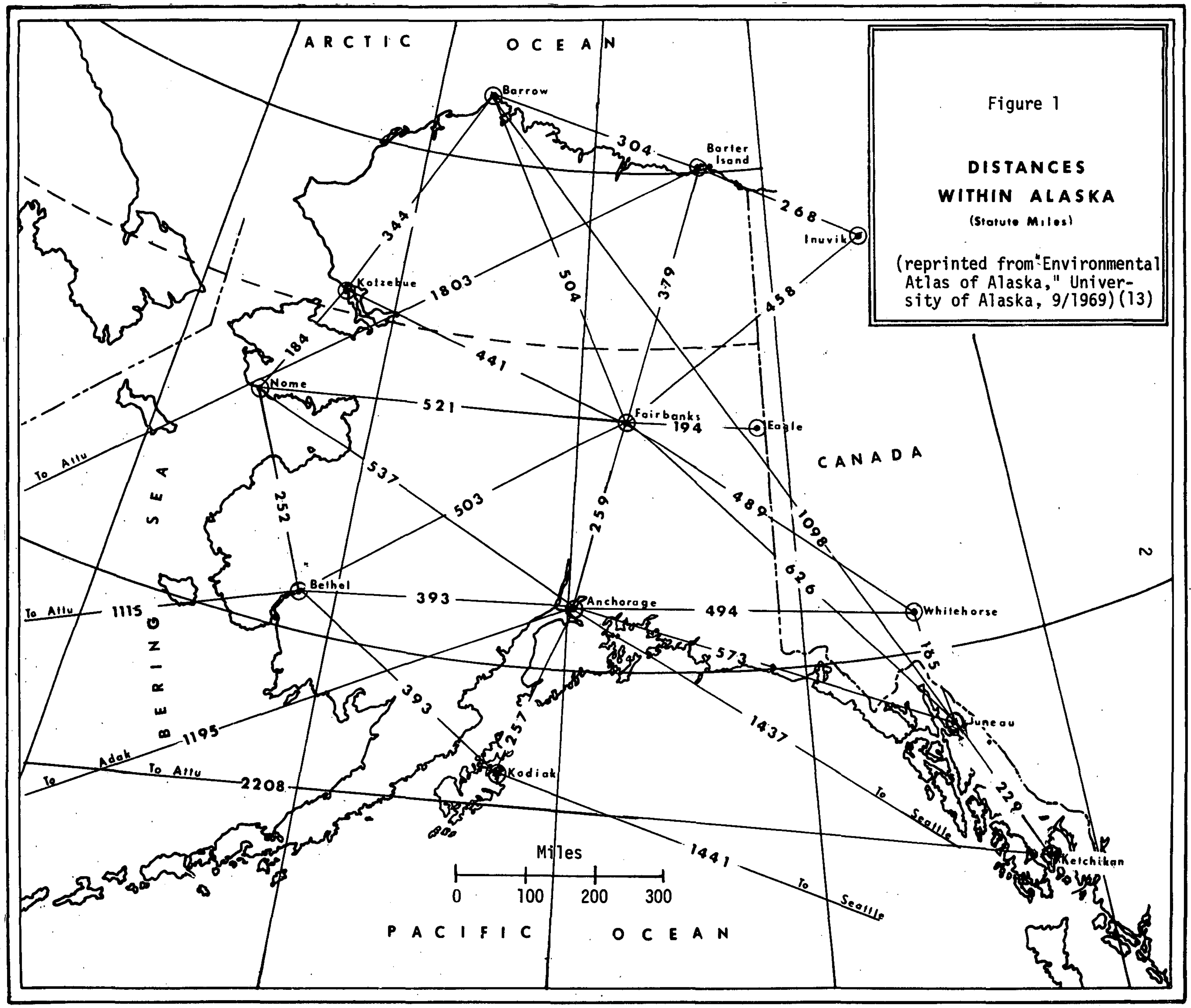


Figure 1

**DISTANCES WITHIN ALASKA**

(Statute Miles)

(reprinted from "Environmental Atlas of Alaska," University of Alaska, 9/1969) (13)

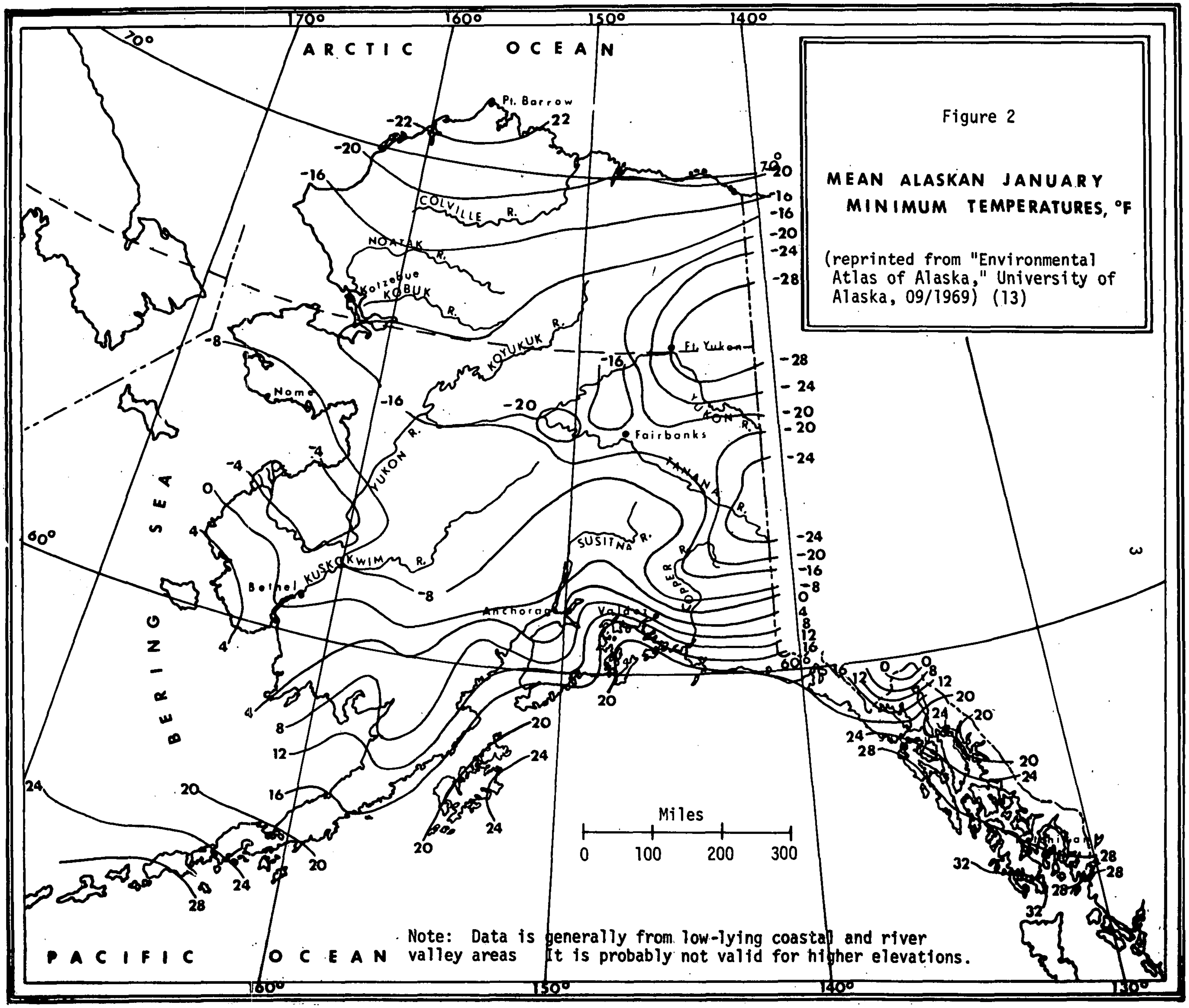


Figure 2

**MEAN ALASKAN JANUARY MINIMUM TEMPERATURES, °F**

(reprinted from "Environmental Atlas of Alaska," University of Alaska, 09/1969) (13)

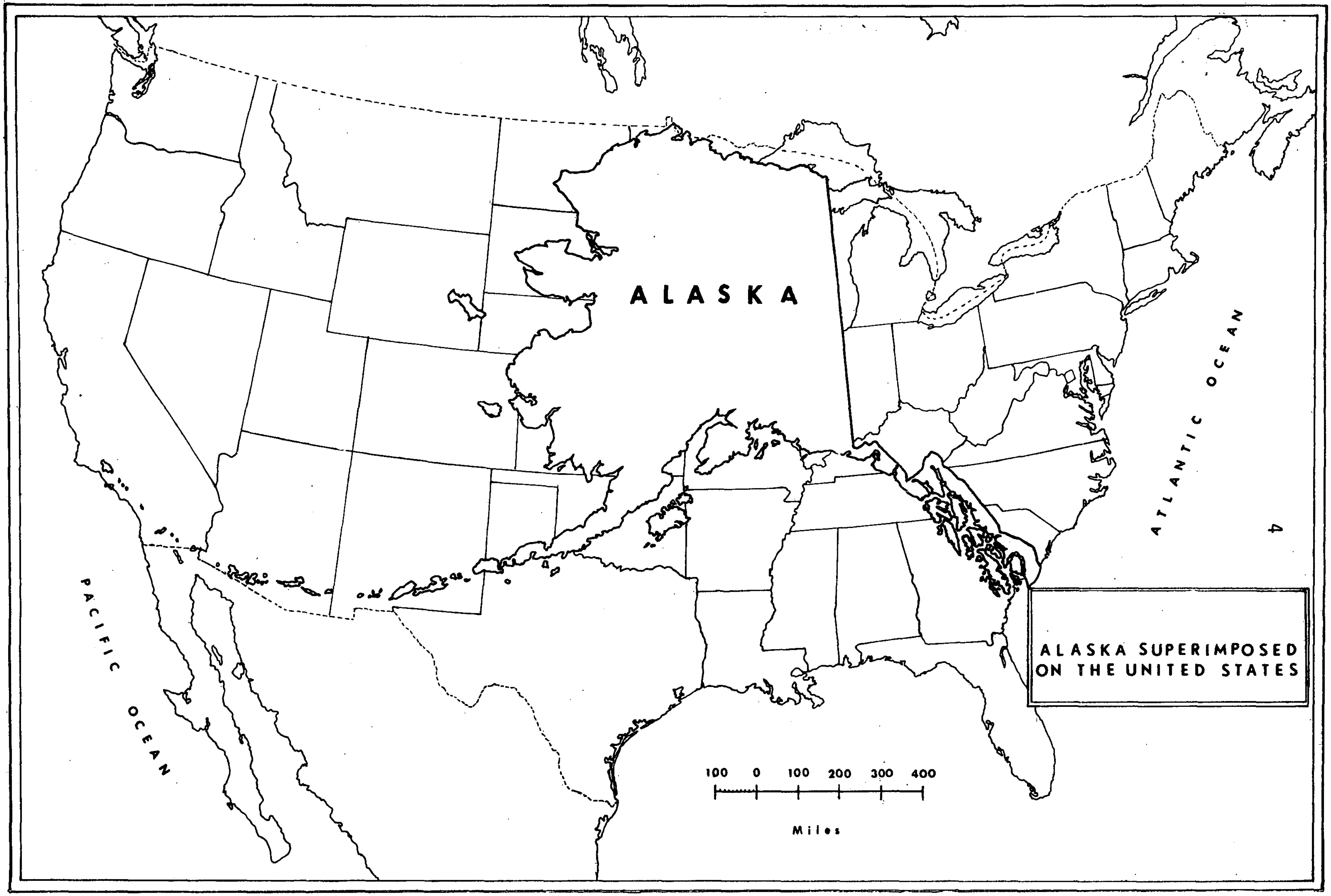


Figure 3. State of Alaska Superimposed on the Contiguous United States at same scale. (Reprinted from "Environmental Atlas of Alaska," University of Alaska, 09/1969) (13)

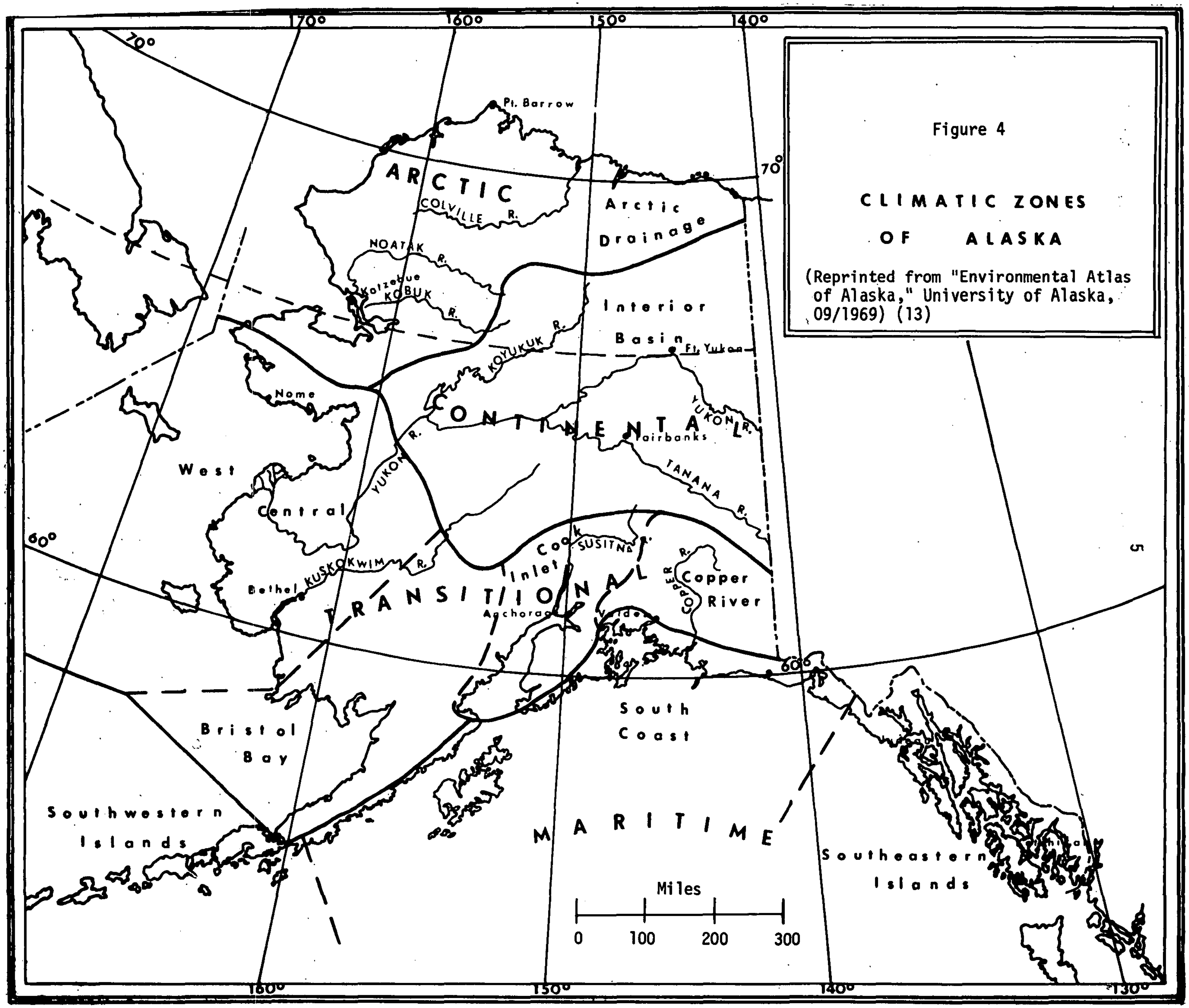


Figure 4

CLIMATIC ZONES OF ALASKA

(Reprinted from "Environmental Atlas of Alaska," University of Alaska, 09/1969) (13)

experience under extreme conditions has resulted in observations on support system performance, requirements for effective project management, and cost-benefit evaluation.

## EQUIPMENT RELIABILITY AND USE

A key consideration in the design of field sampling programs in remote areas is the capability of instrument and equipment systems to withstand being transported to field laboratory locations and/or to sample stations, and the ability to function properly under severe environmental conditions. This is a particular challenge in the Arctic where cold and high winds combine with remoteness to place great stress on equipment.

Each sampling program plan must specify the precision and accuracy criteria for the information desired. These criteria will dictate whether complex electronic instrumentation will be required or whether simple field methods can be used. This, in turn, will indicate which parameters must be determined on site, the sample volume necessary for analysis, and the means and necessity of sample preservation. Recent developments in field analysis techniques provide the project designer with a number of alternatives for sample collection and analysis. These factors not only permit the designer to construct a system which will generate data meeting his project requirements, but should also minimize program cost and the number of on-site manipulations required.

As field analytical and sampling systems become more complex, the need for reliable energy sources to power these systems becomes greater. Although simple field techniques may require only manual manipulation, more sophisticated instrumental analysis and sampling techniques require sources of electrical and/or mechanical energy. The capability of such energy sources to function adequately is essential if data are to be gathered in severely stressed environments. Currently available commercial power sources must be kept at warm temperatures to operate reliably.

Dry-cell batteries become inoperative at temperatures below approximately -20°C, and the lead-acid storage battery generally unuseable below -40°C. Portable power generation systems can be used in arctic climates if they are operated continuously. Diesel-powered generators are used in field stations, but require special arctic fuels, with a pour point of -57°C, rather than the more common -20°C pour point. For continuous monitoring systems requiring low power, thermoelectric generators can be used. The propane fuel commonly used in these systems must, however, be stored above -40°C or it will not vaporize.

Electrical generation systems of the small size commonly used in field applications may not provide the frequency and voltage stability required to operate sensitive electronic instruments, especially if heavy variable loads are also present on the same circuits. Rechargeable battery powered instruments are superior in this regard, as they can be operated on the battery phase, and can be recharged with unstable power. The battery also provides some "back-up" in the event of a generator failure. For monitoring purposes, circuitry can be developed to separate the power-critical elements, powering them with batteries, while the less critical pumps, heaters, etc., can be powered by a generator. Intermittent charging periods can be used to maintain the batteries.

The amount of field manipulation required to operate apparatus in harsh environments must be minimized. Instrumentation requiring calibration, such as pH meters and dissolved oxygen analyzers should be designed to retain calibration for an extended period. In an artic climate, the operator must limit the external exposure of himself and his instruments. This would include minimizing the time spent on activities not directly related to sample collection and field analysis.

Instruments must also be designed for optimal manipulation of controls. Control knobs and switches must be shaped and positioned so that they can be easily used while the operator is wearing gloves. Potentiometers should have easily operated locking devices attached so that vibration and accidental movement cannot change critical settings. Meters should be designed so that they can be read in the low light levels found in the north during winter months, not be affected by static electricity, and be free from condensation.

In many cases, commercially available instruments and equipment may be easily modified to improve their usability in arctic field situations. Standard potentiometers used for calibration can be replaced with ten-turn "Helipots" which have a convenient locking feature and a positive position indicator. Instruments may be made somewhat waterproof by the addition of gaskets and use of sealants; dessicant packages can be added to prevent condensation. Plug-in circuit boards, which have a tendency to vibrate loose in transit, should have screw tabs attached so that they are firmly seated in their sockets.

All equipment should be designed for minimum operational maintenance. Although solid-state circuitry is extremely reliable in this regard, other elements of the measuring systems are frequently poorly designed. In addition most solid state circuitry requires sophisticated electronic test equipment for even minor repairs. As these repairs are not readily done in the field, the field scientist must often carry redundant sets of equipment. This is true of many other devices, including ice augers, tools, pumps, etc. In addition, at least twice the amount of supplies normally used for supporting sample collection and analysis should be provided. Items like batteries, electrodes, chemicals, chart paper etc., must be in sufficient supply to guard against uncertainties. In the Arctic, the investigator is frequently at the end of the traditional "line of supply" and cannot rely on local sources for spare parts or materials necessary to support the operation.

Figure 5 shows a standard commercially available ice auger that has been modified for rapid and positive field assembly and addition of flights. The square coupling design simplifies assembly, and strengthens the joint which can also be more easily cleaned of ice. The cutting tip has also been redesigned for rapid removal, as it dulls very rapidly in silty or sandy ice, or when it inadvertently strikes the stream bottom. This apparatus is successfully used to temperatures of -50°C, but an ether spray is often required to start the gasoline engine at subzero temperatures.

The ability of instruments and equipment to operate well at low temperatures is not only a function of physical design of the system and its circuitry, but also the materials of construction. Today, as synthetic plastics replace metals and natural rubber as construction materials, the capability of field instrumentation to withstand rigorous field use is lessening. This is particularly true when instruments, associated external wiring, and probes are exposed to extremely cold temperatures. Conventional plastic insulated wire not only becomes inflexible, but also may become quite brittle at low ambient operating temperatures. The development of criteria for evaluating flexibility and brittleness is not well defined, as they depend not only on the material itself, but also on the cross-sectional area, configuration and application. In the absence of these

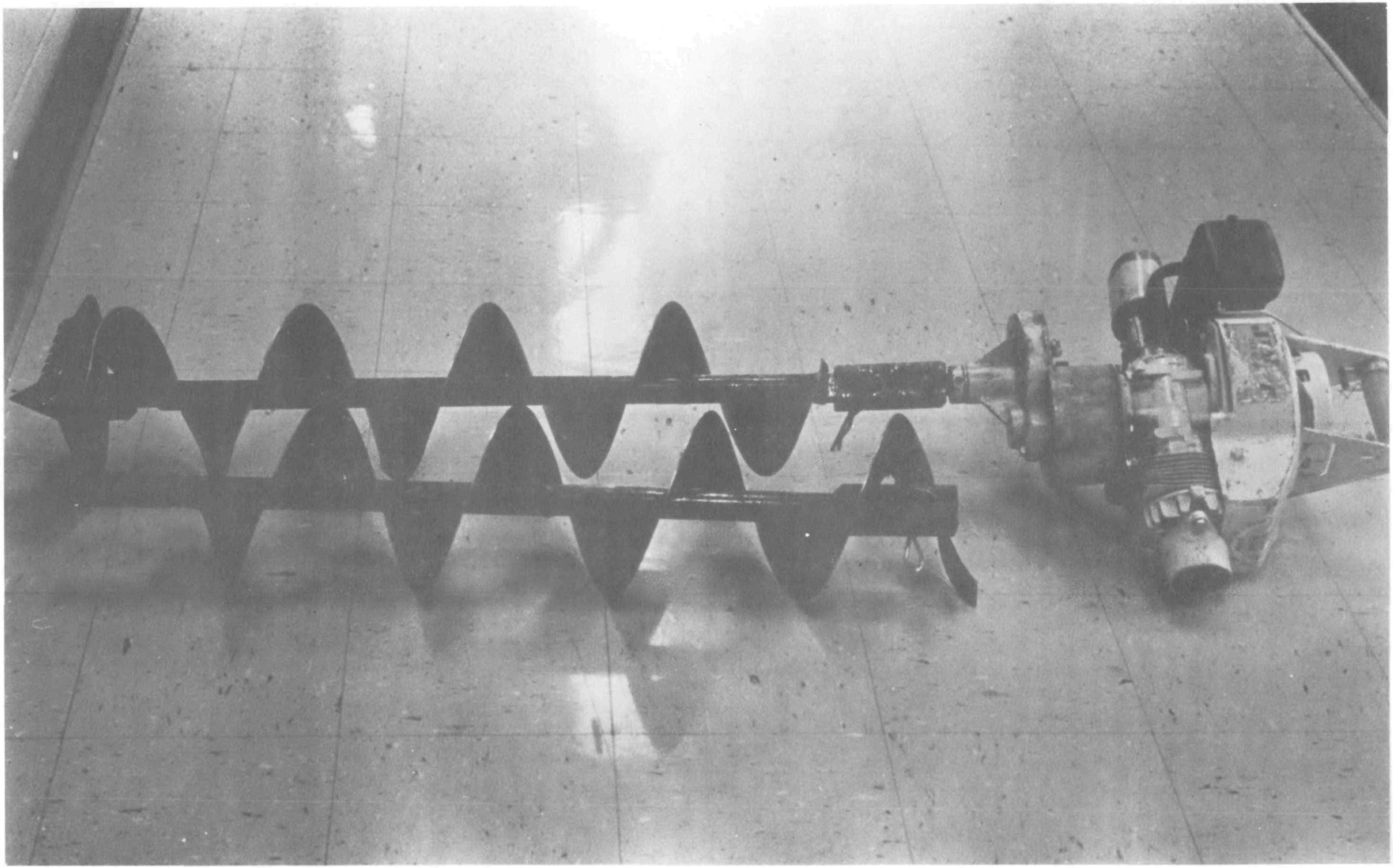

Figure 5. Commercially available ice auger showing modifications to enable rapid field assembly.

criteria, the tendency is to select the best material available, a practice which can be unnecessarily costly. Manufacturers, on the other hand, attempt to minimize costs to meet competition, and frequently provide equipment inadequate to meet severe arctic conditions. The small market potential of those who use equipment in cold climates is not likely to result in design and materials for instruments useful for work in the arctic at a low cost. Until readily available synthetic materials have been developed which meet the criteria of use in harsh environments, we will continue to have instrument failure.

Metals are frequently the preferred construction material because of ruggedness. However, their high rate of heat transfer often makes them unusable for field equipment. Metal sampling devices become ice-coverd almost instantly in use, rendering them inoperative. Differential expansion and contraction, coupled with vibration in transit and use, may loosen fasteners such as pins, bolts and screws. Plastic samplers fare somewhat better, but have the disadvantage that they cannot be unfrozen by direct application of high heat, and thaw very slowly because of their low heat transfer coefficient. Sampling devices must have the simplest possible field assembly and operation. At times, some sacrifice of accuracy must be made in sampler design in order to collect a sample at all. Figure 6 shows a simple sampling device developed for collection of samples below ice cover. We are currently modifying this device so that the sample container is sealed sterile when it enters the water, and can be resealed before it is removed. Although a simple system, it has proven successful, particularly in collection of samples for bacteriological examination.

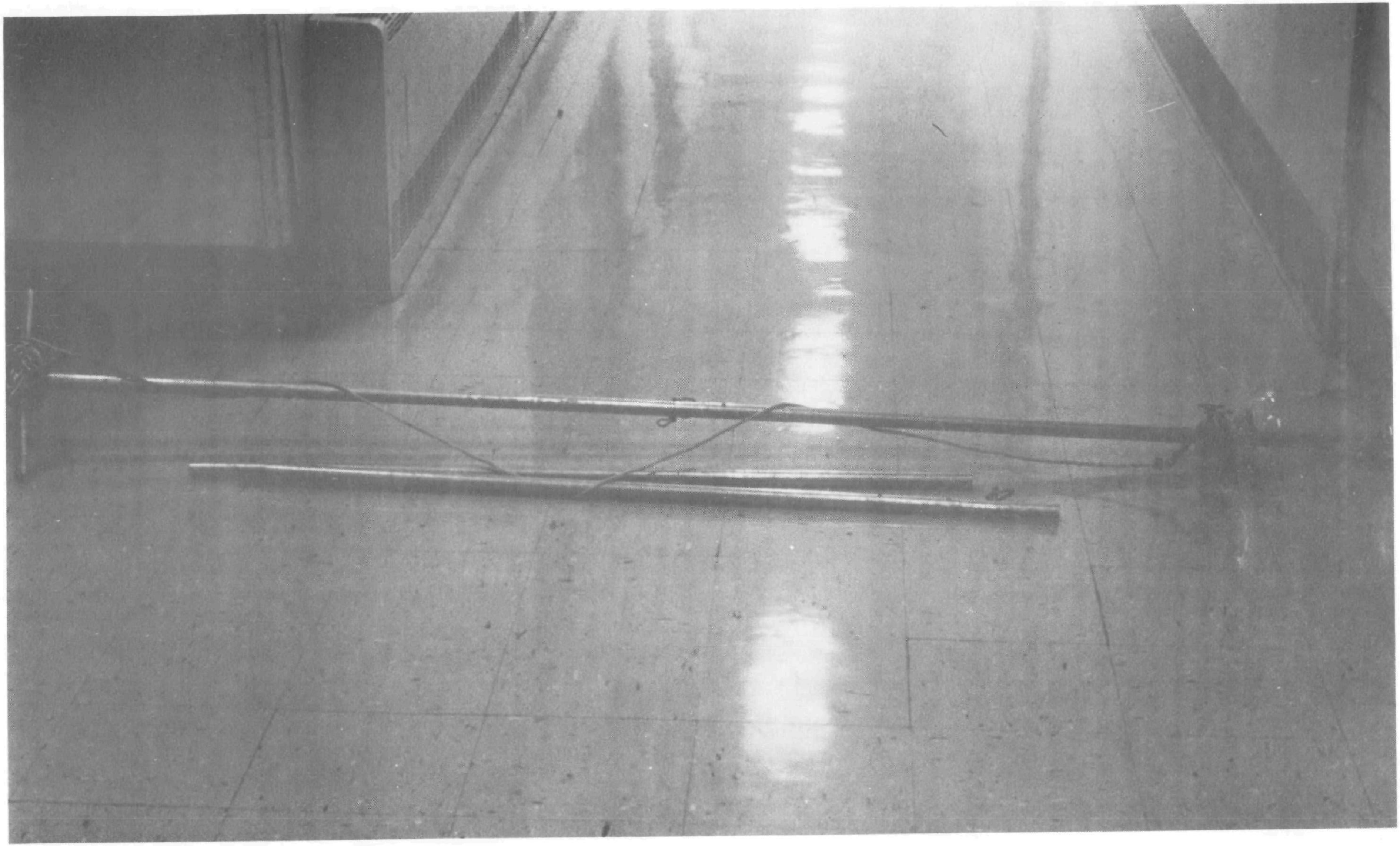

Figure 6. Sampling device used to collect water samples under ice cover.

The transport of equipment and instruments to field labs and sample sites requires particular care in planning and design. Material must be securely packed to avoid damage in transit, yet must also be easily and quickly unpacked and repacked, and arranged conveniently for the user. We have designed and experimented with a series of shipping containers for equipment and supplies, particularly those required for analyses which must be performed in the field. Figure 7 shows a container which holds all of the equipment necessary for the examination of samples for bacteria by the membrane filter technique at a field laboratory, not including supplies and incubators. Styrofoam is used as the packing material, cut out for each individual item. This also provides some thermal insulation.

The cost of field operations in remote areas can be extremely high, particularly in the arctic winter. Collection of a single sample, and its field analysis, has cost as much as $600. To justify this high cost, the quality of the sample collection and field analysis must be as high as possible. Through a combination of adequately designed field equipment, efficient field procedures, and proper sample preservation, field data quality should approach that gathered under less severe conditions.

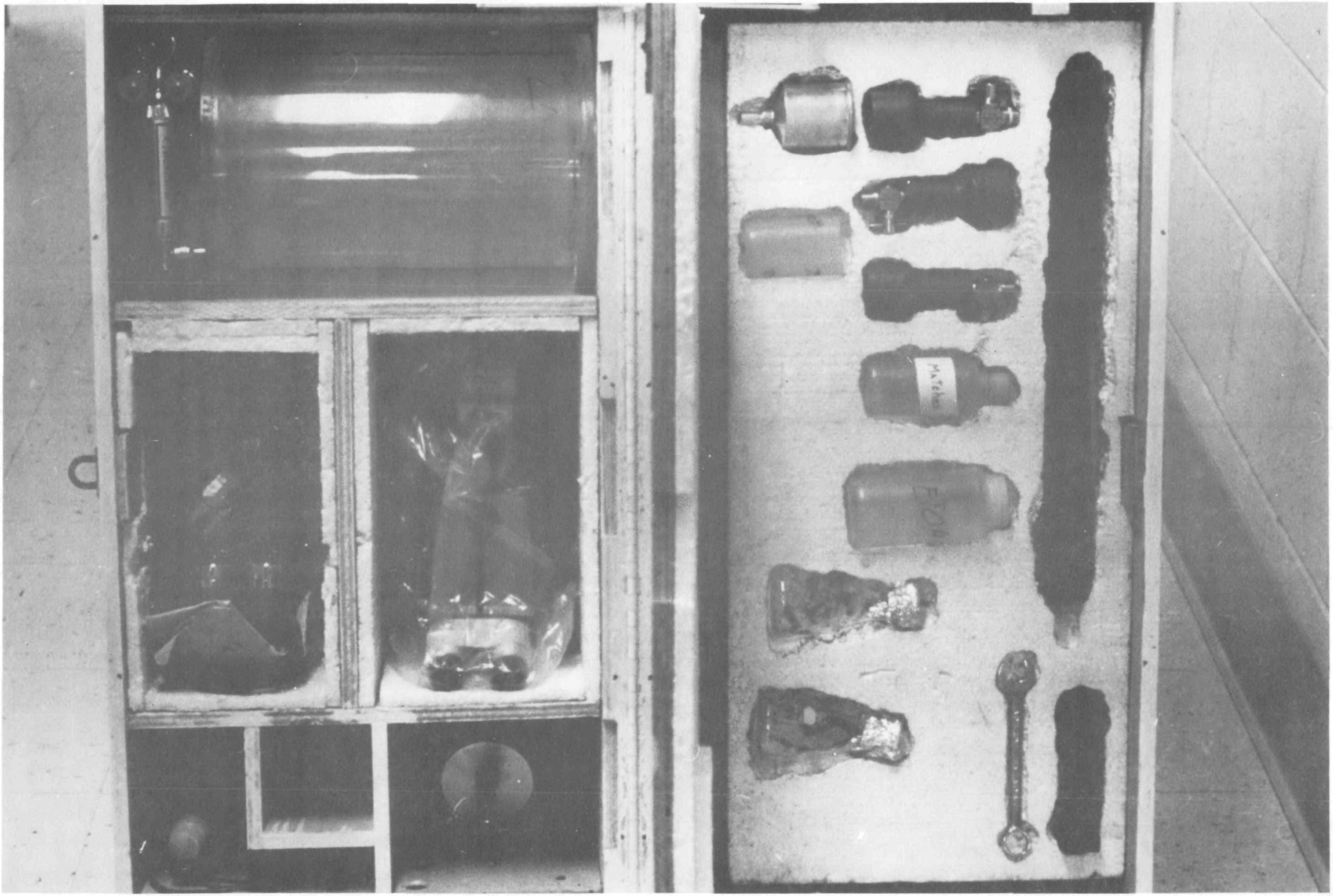

Figure 7. Container for storage and shipment of equipment for microbiological examination of water.

## LOGISTICS

Selection of transportation modes for a particular remote area sampling program is a critical consideration. Accessibility of the geographical area in which the sampling will be conducted, season of the year and expected weather conditions, operating costs, number of sample stations which must be visited each day, time required on station, distance between stations, sample preservation methods, load restrictions (space and weight), and time limitations between sampling and laboratory processing are among the factors which must be considered. Two over-riding considerations, regardless of transportation type, are: that adequate survival gear for the operating conditions must be carried at all times and that field crews consist of no less than two persons. In addition a two-way radio should be carried if possible.

Highway vehicles, including the various types of mobile laboratories, have only limited usefulness in remote area sampling. Among the main factors restricting their usefulness in Alaska and much of Canada are: that the limited road system permits access to only a small portion of the geographical area under the best conditions, poor road quality often necessitates very low travel speed in many areas, many roads are closed during winter months, and access to rivers along the road system is severely limited.

Road transportation would be useful for indepth study at a single station or series of stations on a particular river which has road accessibility and short travel time between stations. Highway vehicles can also be used along the road system as tow vehicles for moving snow machines, all-terrain vehicles and boats to a launching point.

The recreational snow machine, prevalent throughout the northern United States and Canada, is a useful vehicle in remote area winter sampling programs under some circumstances. These vehicles are easily and rapidly loaded, transported and off-loaded, and have fairly high travel speed. They can be an asset when a station or series of stations fairly close to the road system must be visited regularly with bulky or heavy sampling equipment.

Most models of these machines are fairly reliable, but all are subject to mechanical break-down in the field and require continuous preventive maintenance. A few basic considerations when selecting such a unit are: maximum flotation on snow, ability to carry two persons and pull a sled with the necessary field gear, availability of repair parts, and ease of field repairs. A typical unit is the Alpine Ski-Doo with sled and field gear (Figure 8).

The range limitation of snow machine travel is dependent on several variables. When traveling with one machine a basic consideration is to travel no further than the field crew would be willing to or capable of walking. When two machines travel together the range can be extended. However, for most sampling programs it would be an impractical utilization of time to make extended trips. Other operating range variables all relate to travel time. Travel speed is affected by the condition of the trail, the load being transported, and the effect of equivalent chill temperature on the field crew. The ambient air temperature not only affects the field crew but is a primary consideration in sample preservation. There is generally no heated area available during snow machine operations so keeping samples from freezing becomes a significant problem, and in effect becomes a limitation on operating range.

Figure 8. Snow machine with field equipment used for sampling freshwaters in winter.

Tracked all-terrain vehicles are available in sizes and capabilities from small recreational units to the large heavy duty construction rigs. These specialty vehicles have a definite place in some remote area sampling programs and selection of a vehicle must be based on the needs of a particular program. They can be used year-round, are capable of negotiating unfavorable terrain, can cross small rivers, carry a large pay-load and may be enclosed so that the field crew and samples are protected. Their travel speed is low which increases the time required to obtain and return samples to the laboratory for processing. The Thiokol Imp (Figure 9), which is about in the middle of the available size range, is typical of this mode of transportation. The figure shows a sampling device being lowered into a lake using a boom and winch. The major application of this particular vehicle has been to carry personnel and supplies to a field laboratory site located in a watershed set aside for research use.

Snow machine and trailer systems can be easily developed to carry necessary field equipment and portable shelters for use during sampling and other field operations. Figure 10 shows a snow machine set up to pull two sled-trailers. The center sled is designed to be the base for a tent-shelter, supported by aluminum poles fitted into sockets on the sled (Figure 11). Figure 12 shows the tent set up over the supports and sled. Inside this minimal shelter, which covers the sampling hole through the ice, field operations can be performed in relative comfort. A small heater can also be used in severe weather.

All-terrain vehicles or snow machines can both be used under many similar types of winter sampling situations. The snow machine has the

Figure 9. Tracked all-terrain vehicle in use for collecting samples from an ice-covered lake.

Figure 10. Snow machine towing two trailers with field equipment for sampling lakes in winter.

Figure 11. Aluminum supports attached to center sled for tent over sampling area. Note storage of sampling equipment inside sled.



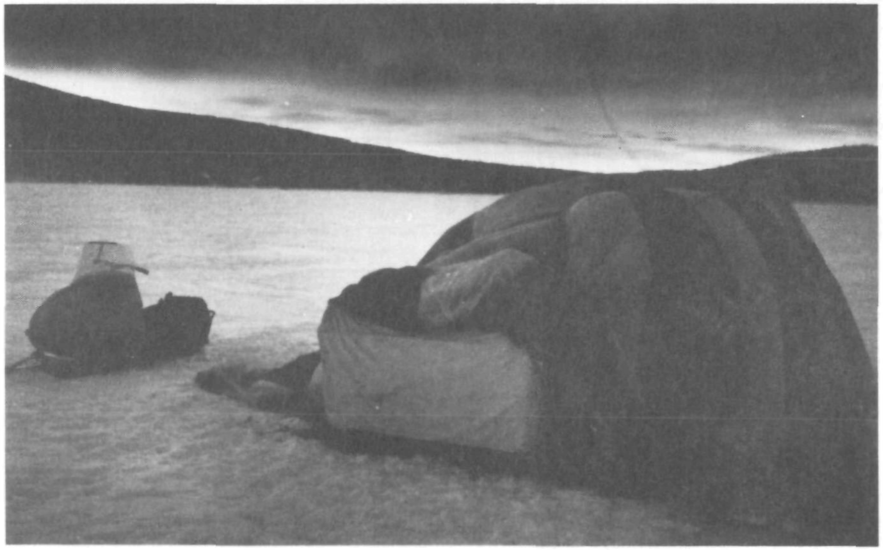

Figure 12. Parachute covers sled and supports, providing shelter for sampling through hole in lake ice.

advantage of lower initial and operating cost, smaller size and weight, and higher travel speed under most circumstances.

Boats are widely used in lake and river sampling programs, so little need be added except for the adaptations which are used in some remote area sampling programs. There are several inflatable boats available on the market which are designed for use with outboard engines up to 50 horsepower. The compact packaging and light weight of these boats make them excellent for transporting to remote sample sites in small aircraft. The length of time required to prepare the boat for use and to repackage it may limit the usefulness depending on time limitations. However, they have excellent application for such work as measuring river discharge or lake sampling in remote areas.

The most commonly used boat for remote area travel in Alaska is the flat bottom river boat (Figure 13). These have excellent carrying capacity and 20 to 28 foot models are generally used. Outboard engines of more than 100 horsepower are occassionally used but the 40 to 60 horsepower engines are more common. A back-up unit, usually in the 18 to 35 horsepower range, is always carried with these craft. The engine, with either a propeller or jet unit, is mounted on a lift rather than directly on the transom which permits raising the engine for travel through shallow water. Because rivers may be braided and contain submerged sand or gravel bars, these boats must be operated by a highly skilled person. Speeds in excess of 35 miles per hour are possible on a sustained basis but are limited by operator skill, equivalent chill temperature, river conditions, and weather. These craft are the summer equivalent of the snow machine and provide a relatively inexpensive and fairly rapid means of conducting a sampling program on otherwise inaccessible rivers.

Figure 13. Flat bottom boat with engine lift for use on shallow rivers.

It is apparent that most of the types of surface transportation are adequate for some remote area sampling programs. However, they are all essentially dependent on the area being relatively close to a usable road system. Considering the conditions prevalent in Alaska and much of Canada, aircraft generally provide the most satisfactory means of transportation. This is particularly true when the sampling program is to be conducted in areas far removed from a road system. It is also the case along the road system wherever several widely separated stations must be visited in a short time period, or even in visiting one station if extended surface travel time is required to reach that station.

Both fixed wing aircraft and helicopters are used for remote area sampling programs. Circumstances such as season, weather conditions, and geography of the sample area must be considered when selecting the aircraft type. The size of the aircraft can be selected within limits; therefore space and weight requirements must be predetermined. It may be necessary to make some compromise either in number or size of samples in order to stay within the capabilities of the aircraft. Although aircraft cabin heaters are excellent when flying, rapid cooling is experienced after the aircraft has landed at a sample station. Thus, sample preservation becomes a problem unless adequate measures are taken to prevent freezing.

Aircraft charter is expensive and may run into several hundred dollars per hour. Any cost data presented here is the current price in the Fairbanks, Alaska, area and is only indicative of what might be expected elsewhere. The procedure of contracting with the lowest bidder may otherwise provide satisfactory results but is often poor economy in obtaining charter aircraft. Only firms which have well-maintained aircraft and can provide pilots qualified for the type of operation being undertaken should be hired. The charge for most charters is by the flying hour regardless of the number of days involved. When the aircraft is required for an entire day there is usually a minimum charge for flying time (four hours in most cases), and there is often a lower rate charged for standby time while at a sample station. Thus, written contractual agreements, to ensure that the desired services are provided, should be made as necessary.

Large fixed wing aircraft are often used to stage materials, equipment, and personnel into a remote airfield if a field laboratory is to be established. Occasionally, regularly scheduled commercial flights can be utilized, but it is often necessary to charter. When such items as aviation fuel must be staged, charter is the only way it can be handled. However, this may be the most economical means of putting the sampling program in the field.

Small single engine, fixed wing aircraft are much less expensive to charter than helicopters of similar capabilities. These aircraft are, however, limited to use during winter sampling programs because the ice cover is usually the only available landing strip at the sample sites. They are generally equipped with wheel-ski combinations which permit operation on snow, ice, or from a cleared runway. The Cessna model 180 or 185 (Figure 14) has a charter rate of $70.00/hr., and is widely used for this type of operation. The model 185 is the same size as the 180 but has a larger engine, permitting a heavier load to be carried and a shorter take-off distance. If the landing area at the sample station is very short, a STOL (Short Take Off and Landing) aircraft of similar capabilities

Figure 14. Small, single engined aircraft used in sampling on ice-covered rivers.

can be obtained for $75.00/hr. Larger standard or STOL aircraft are available if needed to carry the field gear and sample load, but cost per hour and required landing strip length both increase rapidly.

Helicopters are probably the most versatile means of transportation in remote areas. Although they have a shorter range than an equivalent sized fixed wing aircraft, they can be used year-round, require a very short landing space and can be used for a variety of tasks. The smallest (Figure 15) carry three persons including the pilot and cost $150.00/hr. All field gear and samples are carried in baskets outside the cabin which makes the samples very vulnerable to environmental factors. Therefore, this particular type should not be considered for winter operations when samples cannot be allowed to freeze.

The most useful size of helicopter for water quality sampling is shown in Figure 16. This unit can carry four persons other than the pilot and charters for $225.00 to $245.00/hr., depending on the model. All samples can be carried internally and preservation problems are about the same as with the fixed wing aircraft.

The next two figures demonstrate the versatility of the helicopter for field operations. It can be used to lay and retrieve gill nets in remote lakes as shown in Figure 17. This eliminates the need to carry an inflatable boat with the resultant time loss in setting up the boat for use and repackaging for travel. If the services of a large unit can be obtained, it can reduce the time and effort in moving heavy objects such as the trailer laboratory shown in Figure 18. This field laboratory was placed by helicopter in a research watershed and serves as the operations base for studies being conducted there.

Figure 15. Small helicopter with external equipment storage racks.

Figure 16. Turbine powered helicopter with internal equipment storage compartments.

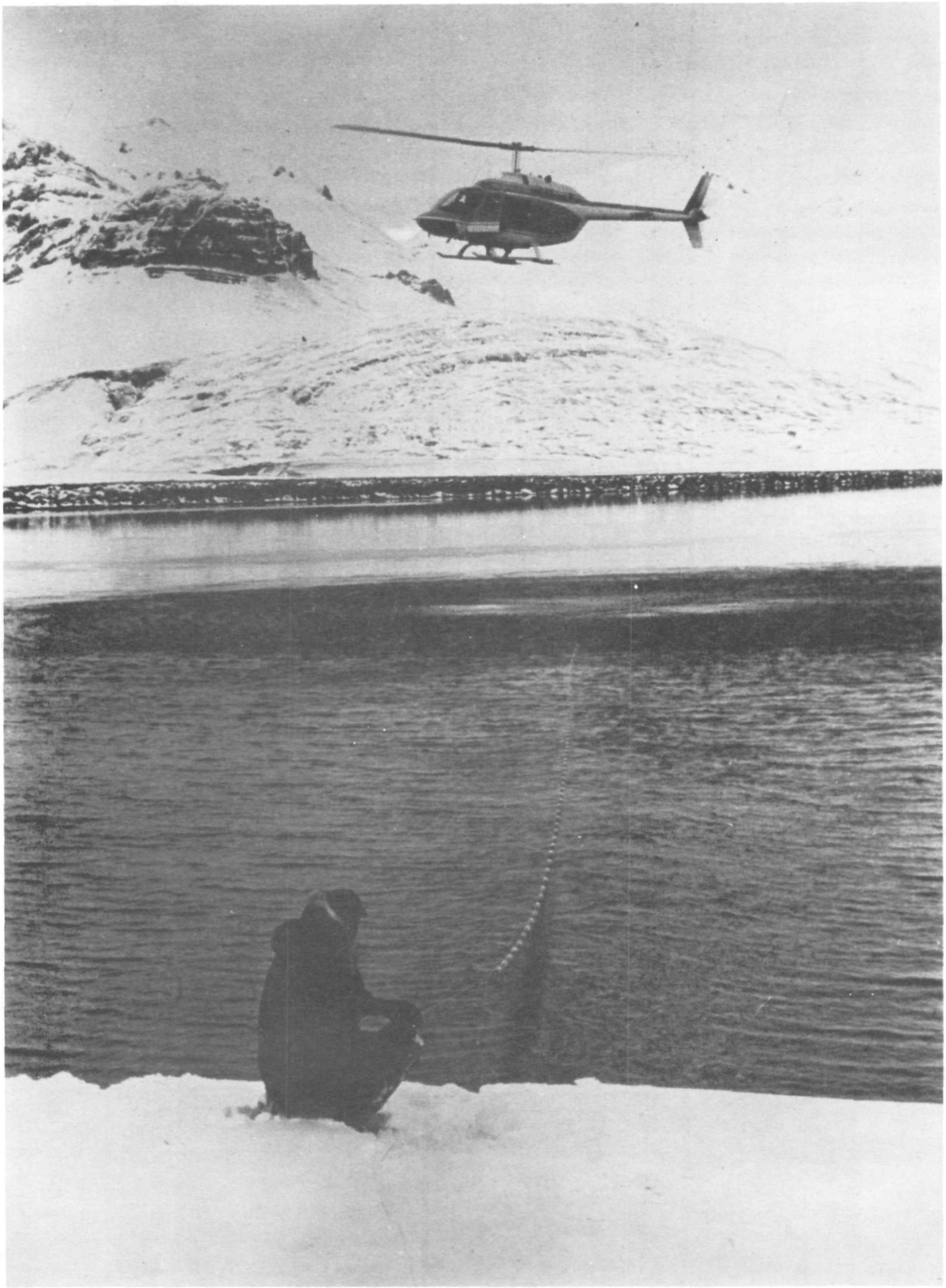

Figure 17. Helicopter laying experimental gill net for sampling lake fishes.

Figure 18. Trailer laboratory being transported by U.S. Army Chinook helicopter to field site.

A point which must be considered in all aircraft operations is the effect of weather, particularly fog or snow conditions which may limit visibility. Although helicopters can operate under somewhat lower visibility than fixed wing aircraft, they too are grounded under severe circumstances. Such weather problems are more often encountered in remote areas because accurate weather forecasts are usually totally lacking. Thus, a crew in the field can be weathered out of part of the study area and find it necessary to alter the day's sample program, or be forced to turn back entirely. Since time in the field will usually be lost because of weather, extra time must be included in the program schedule. Changes to the original sampling program made in the field make two-way communications valuable for other than emergency use because it permits the personnel at the base laboratory to be informed of the situation without delay.

# HUMAN PERFORMANCE

Perhaps the single most important factor in designing a sampling program is the performance expected from the field crew. Long working days are generally the rule and, when combined with severe environmental conditions encountered in the field, varying degrees of stress result which may impair human performance. The severity of the environmental conditions, along with the physical and mental state of individuals in the crew, determine the total effect of the stress. Remote area conditions accentuate any problems which may arise and basic survival must be a prime consideration. Thus, the need for a field crew of no less than two persons carrying adequate survival gear can not be overemphasized.

Field crew performance during summer sampling programs in remote areas would be expected to be little different than that found in other locations. The irritation caused by mosquitoes and/or black flies is well known to most persons involved in field operations. The severity of this irritation in Alaska and much of Canada can be such, however, that it may impair an individuals ability to obtain samples and data at a particular station. This problem is reasonably overcome by using a good insect repellent or mosquito netting.

The effect of cold on field crew performance is also not exclusively a remote area problem. However, sampling programs in a large portion of northern North America are conducted in remote areas under conditions of continuous extreme cold not encountered elsewhere. The effect becomes a consideration in field crew performance when the equivalent chill temperature (combination of wind velocity and ambient air temperature) begins to cause discomfort. The overall discomfort can be minimized by proper utilization of protective clothing. This makes it necessary that the field crew understand the potential hazards and what constitutes adequate protective clothing for the conditions. Even when properly clothed, the potential dangers of frostbite must not be underrated. The information presented in Figure 19, adapted from a U. S. Air Force publication (2), indicates that the danger of freezing exposed flesh becomes an increasingly significant factor as the equivalent chill temperature decreases below -20°F (-28°C).

The equivalent chill temperature below which field work should be suspended is difficult to ascertain. If the field crew is protected from adverse environmental conditions while traveling between sample stations, the coldest acceptable working conditions become a function of exposure time at any station and the length of time during which work without hand protection is required. If the samples can be collected in five to ten minutes with little or no hand exposure, an equivalent chill temperature of -100°F (-73.3°C) is often tolerable. This, of course, is also dependent on the ambient air temperature because the actual temperature is what affects sample preservation and impairs vehicle and equipment operation.

Medical research indicates that humans do become acclimatized to cold after prolonged exposure (3,4,5). However, field crews conducting the type of operations discussed in this presentation are generally exposed only intermittently to cold and, therefore, do not have the opportunity to become acclimatized (4). Cold has been shown to be a stress factor even in acclimatized individuals (6), and becomes a significant factor during intermittent exposure because of fatigue, loss of efficiency, and impairment of manual dexterity (7). Although attention

| WIND SPEED MPH | COOLING POWER OF WIND EXPRESSED AS "EQUIVALENT CHILL TEMPERATURE" | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TEMPERATURE (°F) | | | | | | | | | | | | | | | | | | | | |
| CALM | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 5 | 0 | -5 | -10 | -15 | -20 | -25 | -30 | -35 | -40 | -45 | -50 | -55 | -60 |
| | EQUIVALENT CHILL TEMPERATURE | | | | | | | | | | | | | | | | | | | | |
| 5 | 35 | 30 | 25 | 20 | 15 | 10 | 5 | 0 | -5 | -10 | -15 | -20 | -25 | -30 | -35 | -40 | -45 | -50 | -55 | -65 | -70 |
| 10 | 30 | 20 | 15 | 10 | 5 | 0 | -10 | -15 | -20 | -25 | -35 | -40 | -45 | -50 | -60 | -65 | -70 | -75 | -80 | -90 | -95 |
| 15 | 25 | 15 | 10 | 0 | -5 | -10 | -20 | -25 | -30 | -40 | -45 | -50 | -60 | -65 | -70 | -80 | -85 | -90 | -100 | -105 | -110 |
| 20 | 20 | 10 | 5 | 0 | -10 | -15 | -25 | -30 | -35 | -45 | -50 | -60 | -65 | -75 | -80 | -85 | -95 | -100 | -110 | -115 | -120 |
| 25 | 15 | 10 | 0 | -5 | -15 | -20 | -30 | -35 | -45 | -50 | -60 | -65 | -75 | -80 | -90 | -95 | -105 | -110 | -120 | -125 | -135 |
| 30 | 10 | 5 | 0 | -10 | -20 | -25 | -30 | -40 | -50 | -55 | -65 | -70 | -80 | -85 | -95 | -100 | -110 | -115 | -125 | -130 | -140 |
| 35 | 10 | 5 | -5 | -10 | -20 | -30 | -35 | -40 | -50 | -60 | -65 | -75 | -80 | -90 | -100 | -105 | -115 | -120 | -130 | -135 | -145 |
| 40 | 10 | 0 | -5 | -15 | -20 | -30 | -35 | -45 | -55 | -60 | -70 | -75 | -85 | -95 | -100 | -110 | -115 | -125 | -130 | -140 | -150 |
| WINDS ABOVE 40 HAVE LITTLE ADDITIONAL EFFECT | LITTLE DANGER | | | | | INCREASING DANGER (Flesh may freeze within 1 min.) | | | | | | GREAT DANGER (Flesh may freeze within 30 seconds) | | | | | | | | | |
| | DANGER OF FREEZING EXPOSED FLESH FOR PROPERLY CLOTHED PERSONS | | | | | | | | | | | | | | | | | | | | |

Figure 19. Chill factor chart relates equivalent chill temperature to wind speed and air temperature.

to detail is not necessarily diminished (6), sample quality can suffer progressively throughout a day in the field if the conditions are sufficiently extreme. This occurs if the field crew becomes more interested in minimizing exposure time than in observing proper sampling procedures.

Water sampling programs add the dimension of being wet to other cold exposure problems. This ranges from the remote possibility of going through the ice to the chronic problem of wet feet, legs, and hands. The operation of cutting a hole in the ice (Figure 20) always results in wet hands, and sometimes wet legs and feet, as the auger is pulled from the completed hole. The water beneath the ice is often under pressure, causing overflow on the ice surface around the hole. Kneeling to obtain the water samples (Figure 21) compounds the wet leg problem. Figure 21 also shows shoulder length rubber gloves used to submerge sample containers in the water and short rubber gloves used to handle the ice auger and other wet materials. It is often necessary to do manipulations without gloves (Figure 22); this must be minimized as handling wet containers increases the cooling rate and the resultant frostbite danger.


Figure 20. Cutting hole in ice with gasoline powered ice auger results in wet hands and clothing.

Figure 21. Kneeling to obtain water samples often causes wet clothing and subsequent chilling. Note use of rubber gloves to collect samples.

Figure 22. It is often necessary to perform field manipulations without gloves in cold weather.

## SAMPLING PROGRAM DESIGN

In the preceding discussion, we have considered criteria necessary to select components for a field operation. It is also essential to consider the process of planning and conducting the study in which these criteria will be applied.

Certainly all projects involve planning, which ranges from listing required equipment and activities to setting up a flow chart and developing a complete activity schedule. Although this is important for field operations in general, it is absolutely critical in remote regions. Obviously a sampling program in New Jersey is not subject to the same constraints as one on Alaska's North Slope. A project component failure in New Jersey could probably be remedied in a few hours, or a day at worst. Similar failure due to lack of planning on the North Slope could be disastrous in comparison, not only in terms of failure to meet scheduled objectives, but also in terms of cost, and very possibly, field personnel safety.

Water resource studies may include: chemists, biologists, engineers, resource specialists and technicians. In addition, administrators, data processors, editors, and other non-field personnel may be involved. It is difficult to conceive that a single person could adequately integrate the performance of such an interdisciplinary team. The key to successful implementation of a field project is coordinated planning by all disciplines involved. This includes not only the field personnel but also those in laboratory support, administration, and data-processing roles.

Communication and coordination among the various disciplines involved in a field project is critical from the very onset, when objectives, criteria, and constraints can be fully discussed in terms of individual needs. Several alternate plans and subplans should be developed in this early phase, and the best selected.

This planning process is common in large-scale operations. Expeditions in polar regions have been conducted for decades by governments, scientific groups and more recently, industry, where extensive logistical resources were available for support (8). Such an operation may involve support from military forces and other large agencies. However, we are concerned with planning for a group of, perhaps, not more than a dozen persons where professionals must be involved in disciplines outside their field, and must function as planner, stevedore, laborer, equipment operator and, possibly, cook or medic.

The planning process should begin by evaluating various planning techniques in order to select one which will best achieve the desired results. The most common planning technique is the bar chart (Figure 23). These diagrams are valuable since they display project activities on a time scale. This can include preparatory operations such as equipment checking and packing, vehicle maintenance or purchasing, or the allocation of budget items. As progress is made on a task, this can be indicated by marks or pins on the bar. The technique is simple, rapid, inexpensive, and may be entirely adequate for some purposes. However, a major drawback is that it fails to indicate the interrelationship of tasks and it is difficult to adjust time assignments for critical tasks. Also, if a large number of small tasks are represented the chart quickly becomes unmanageable.

A more sophisticated technique utilizing networks to display planning functions is termed the Critical Path Method (CPM). A variation of this

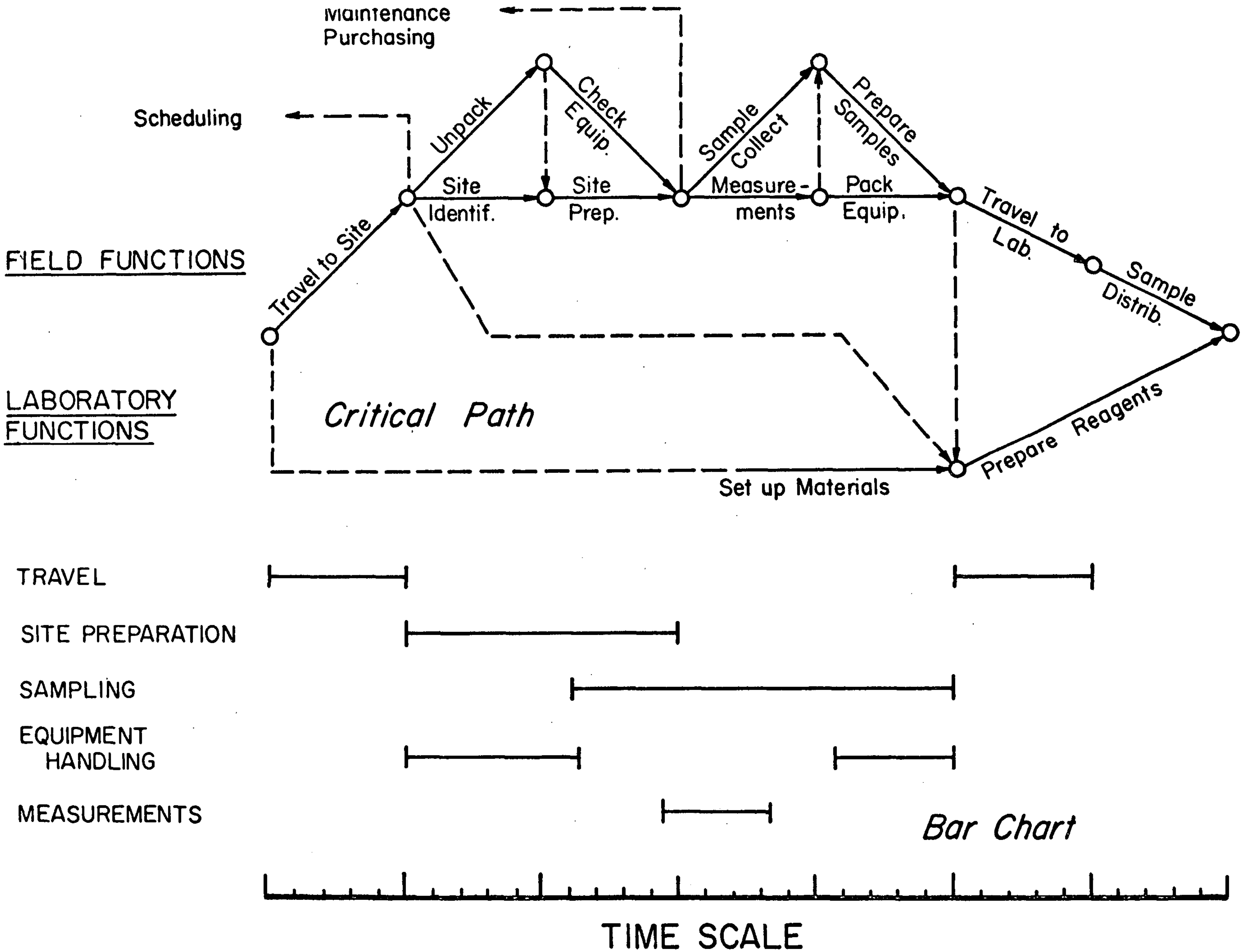


Figure 23. Bar Chart and Critical Path method "graph" as used in planning a simple field program.

is the Program Evaluation and Review technique (PERT). Such a scheme may be viewed as an application of the traditional flow chart commonly used in qualitative chemical analysis or taxonomic classification. The formal CPM and PERT procedures were developed for large construction projects, such as buildings or commercial aircraft. These procedures can, however, be used in planning less complex projects since they involve coordination of various skills to produce the most efficient attainment of objectives.

The basic Critical Path Method (Figure 23) utilizes a two dimensional graph where lines represent activities, and points of intersection or nodes represent status of the project. Dependencies, such as required communication between activities, can be shown by dotted lines. A completed network may show several separate paths which converge at some point of readiness. Each path will require a different time allocation such that the most time consuming path, the critical path, dictates the completion time for that set of activities. Determining the critical path clarifies which activities are most important in terms of scheduling, and allows estimation of the slack time, or float, in the non-critical paths. From this the most efficient utilization of personnel can be achieved. It can be seen that the functional detail of the network allows inclusion of many small tasks while maintaining a logical, sequential representation.

The network is valuable in the field since alternatives have been programmed for contingencies. Interruption of a sampling run because of inclement weather or mechanical breakdown would require re-scheduling of laboratory analyses, replacement of a broken part, or other appropriate responses which should have been planned in advance.

Advanced techniques are available which allow for resource allocation, corrections for failure probability, and budget control (9). Since the network may be written as a matrix, it can be analyzed by digital computer. Frequent updating of the program for time or budget expenditures and changes in activity time estimation provides a management system which is always current. However, the expense of maintaining a computerized management system is generally beyond the budget limitations of small field projects.

# DIRECTIONS FOR DEVELOPMENT

Components for field operations must generally be adapted to the natural conditions if the project is to be successful. Where they have been specifically designed for operation in remote areas, they may be adequate or easily adapted. In other cases, components such as surface vehicles and aircraft are limited in the extent to which they can be modified.

Human performance can be improved through research in apparel designed for specific climatic conditions. Corporations working in the Arctic as well as the U. S. Armed Forces are developing garments which have superior insulating and freedom-of-movement properties. There is generally an extended lag time between design of garments for military use and availability to the general public. This lag time could be shortened through technology transfer from the military to the garment industry.

The capability to perform physical-chemical measurements is a fundamental concern in field operations and, in remote areas, takes on greater importance because of laboratory unavailability. There is clearly a lack of instrument packages for which state-of-the-art materials and concepts have been used.

Size and weight are major factors in instrument transportation. Units are commonly packaged in cast-aluminum cases which are bulky, heavy, and readily conduct heat. Perhaps the best illustration of the state-of-the-art in miniaturization is a comparison of two electronic calculators representing a span of about 5 years in design (Figure 24). As a point of comparison the older unit, which in order of magnitude is larger and heavier, performs five functions as compared with approximately 40 in the


Figure 24. Two electronic calculators representing the state-of-the-art in 1968 (rear) and 1973 (front). Not only is the earlier model much larger but also cost four times as much as the later model, for far fewer functions.

smaller unit. Application of integrated circuitry and liquid crystal displays to field instruments would allow production of a pocket-sized unit, such as a pH meter. Extending the concept of miniaturization further, it should be possible to transfer technology from the biomedical engineering field. Sensors play an increasingly important role in in situ analysis of physiological systems (10), and have been designed to meet stringent criteria such as small size, inertness, ruggedness, and low power consumption. Integration of existing electronic and sensor technologies would allow the design of a single unit having the capabilities to measure pH, dissolved oxygen, electrical conductivity, and specific ions. A digital multi-meter recently marketed by Hewlett-Packard has applied such concepts, resulting in a unit which meets the needs of field personnel in electronics.

The preservation of samples for future analysis at a central facility has long been a concern to environmental scientists. Methods such as filtration, freezing, and the use of toxins have the advantage of speed and simplicity. However, the validity of trace component analysis on preserved samples is always open to question. Techniques for proceeding with color development to a point where an analyte is in a stable form for transport to the laboratory have been described (11). These methods may have only limited field application under adverse environmental conditions. Another area having possible application is the development of separation techniques. Forensic analysis has successfully utilized resin loaded papers for quantitative sampling of drug metabolites in urine. Resins and other ion exchangers as well as fixative reagents should be further examined for sampling and preservation under field conditions (12).

Component failure in the field could be reduced by the application of environmental testing to ascertain performance under a range of conditions. Such testing has been applied in the aero-space industry to produce systems nearly fail-safe under extremes of temperature, pressure, vibration and other physical stresses. The lack of uniform design standards is so serious that investigators must often learn of instrument performance only through costly experience. Standards should be developed for field equipment and instrument evaluation with societies and agencies concerned with the environmental sciences forming a study committee to begin the development of an evaluation program.

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