FMFRP 0-55

Desert Water Supply

U.S. Marine Corps

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DEPARTMENT OF THE NAVY
Headquarters United States Marine Corps
Washington, DC 20380-0001

5 November 1990

FOREWORD

1. PURPOSE

Fleet Marine Force Reference Publication (FMFRP) 0-55, Desert Water Supply, describes the problems with supplying water to a force operating in a desert.

2. BACKGROUND

a. Desert operations have much in common with operations in the other parts of the world. The unique aspects of desert operations stem primarily from deserts' heat and lack of moisture. While these two factors have significant consequences, most of the doctrine, tactics, techniques, and procedures used in operations in other parts of the world apply to desert operations. The challenge of desert operations is to adapt to a new environment.

b. FMFRP 0-55 was originally published by the Naval Civil Engineering Laboratory in 1982 as a technical note. In August 1990, Desert Water Supply was republished as OH 0-55.

3. SUPERSESSION

Operational Handbook 0-55 Desert Water Supply; however, the texts of FMFRP 0-55 and OH 0-55 are identical and OH 0-55 will continue to be used until the stock is exhausted.

4. RECOMMENDATIONS

This manual will not be modified. However, comments about the manual are welcomed and will be used in revising other manuals on desert warfare. Submit comments to --

Commanding General
Marine Corps Combat Development Command (WF12)
Quantico, VA 22134-5001

5. RECOMMENDATIONS

This manual will not be revised. However, comments on the manual are welcomed and will be used in revising other manuals on desert warfare. Submit comments to --

Commanding General
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6. CERTIFICATION

Reviewed and approved this date.

BY DIRECTION OF THE COMMANDANT OF THE MARINE CORPS

M. P. Caulfield

M. P. CAULFIELD
Major General, U.S. Marine Corps
Deputy Commander for Warfighting
Marine Corps Combat Development Command
Quantico, Virginia

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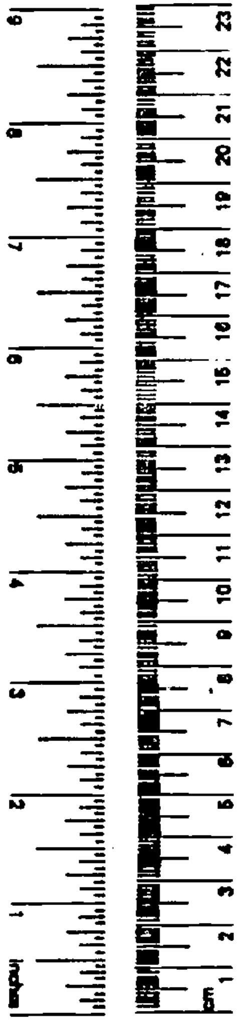
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

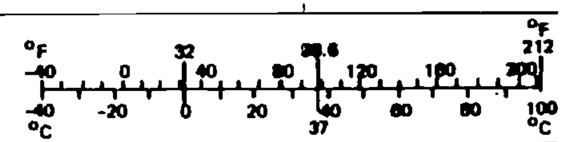
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

Operational Need

The Marine Corps role requires the capability of rapid deployment, mobility, and maneuverability for strike force operation. Deployment to desert regions will require the additional logistic burden for water self-sufficiency since most desert areas will not have adequate water resources readily available for exploitation to support combat forces. A complete capability for water self-sufficiency, with all of the problems and constraints unique to desert operations, does not currently exist in the Marine Corps structure.

Background

The Marine Corps is currently and has traditionally been a rapidly deployable, infantry-based assault force capable of functioning either independently or in conjunction with other forces. Operations have historically been in geographical areas with adequate water resources to meet assault force requirements for both potable and nonpotable use. Therefore existing water supply equipment inventories have been based on the assumption that adequate water resources will be available in the operational area and can be exploited. The potential for deployment to arid regions, and specifically to one of several politically sensitive desert regions of the world requires the addition of new capabilities to the Marine Corps force structure and equipment inventory. The Marine Corps is currently procuring Army-developed equipment to address a portion of the immediate requirement. Even with this new equipment, deficiencies will exist in water supply capabilities in the near term, and the next generation of water supply equipment for the year 1990 to 2000 timeframe remains to be defined and developed.

The Naval Civil Engineering Laboratory under the Advanced Base Mobility Program has been tasked to identify the equipment and procedural capabilities that will be required for water supply in support of Marine Corps tactical operations in desert areas.

Objectives

The objectives of this task are to define the water supply requirements and constraints facing the Marine Corps in desert tactical operations, and to identify technological alternatives for providing new capabilities in the mid and long term.

Approach

In concept the Marine Corps assault force structure is tailored to suit mission specific requirements. The basic infantry structure can be reinforced with additional air, mechanized, or other elements as appropriate to the mission. High level commanders have substantial flexibility to adjust force structure and tactical concepts to suit a variety of factors including objectives, geography, logistics, and political situations. The high degree of potential variation in force structure complicates any overview of logistic support requirements. Therefore, the approach used in this assessment is to use several potential mission and force structure scenarios representing a realistic range of operations to determine the following:

- Quantification of the requirements for water acquisition, treatment, and distribution.
- Assessment of current capabilities and identification of required new capabilities.
- Identification of technological alternatives for the period through the year 2000.

Marine Corps tactical commanders are pragmatic planners who must by necessity adjust deployment tactics and time phasing to accommodate the constraints of existing capabilities. Since one objective of this assessment is to identify requirements for new or additional capabilities in water supply, the scenarios used presume the tactical operations are not constrained by limited capabilities in either water quantity or water supply logistics. Restated, the tactical scenarios are not adjusted to water constraints, but conversely the water requirements are to be determined from the tactical scenarios.

GEOGRAPHIC AND CLIMATIC CONSIDERATIONS

The Desert Environment

In general terms a desert is characterized by very low precipitation, lack of surface water, and a lack of shallow ground water. Contrary to the common misconception, all deserts are not hot and are certainly not sandy. Flora will be xeric or nonexistent, and fauna will be uniquely adapted to desert life. A detailed description of geographical and climatological factors in various parts of the world is presented in Appendix A.

Military Considerations

Several desert areas of the world have significant military importance due to either their strategic location or their natural resources. If national interests dictate the deployment of a Marine Corps force to a desert region of the world, the structure, equipment, procedures, and logistic support for the force must be consistent with the climatological constraints of the area to insure military capability and effectiveness.

Human factors, or the ability of the personnel to function effectively in the specific region, is of major concern. Dehydration casualties, which will primarily be heat casualties in the desert, place a major burden on medical, transportation, and logistic resources. Since this type of casualty is avoidable with appropriate training and water discipline, the development and institution of sound doctrine is essential. Such doctrine will impact significantly on water supply planning. Human factors considerations are presented in a subsequent section of this report.

In most prior deployments, Marine Corps forces have been capable of partial or complete self-sufficiency with regard to water supply. Organic water treatment equipment has been used to establish water points at local surface sources, or civilian sector systems were tapped to meet water needs. In practically all foreseeable desert scenarios, existing potable water sources will be either inadequate or nonexistent. The options available to the assault force will, therefore, be limited to importation of water, desalination of seawater, or development of new supply sources. It is apparent that the equipment, skills and logistic support required for water supply in desert operations will necessitate some changes in the Marine Corps force structure. Equipment considerations are discussed in subsequent sections of this report.

Trends in Geographic and Climatic Data Collection

Water support technology for the detection of subsurface hydrology in a generalized synopsis can best be described by the following water resource analysis approach. Currently heavy emphasis is placed by most desert hydrographers on satellite image analysis; specifically Landsat. The large areal coverage provided by Landsat imagery and imagery computer enhancements enables precise location of geologic features, such as fractures, faults, and scarps. This data is further correlated with higher resolution aerial photography and historic data. The satellite data analysis is then examined in conjunction with regional climatic projections with rainfall estimates superimposed for specific areas. Finally a systems approach is applied to coordinate the overview data with existing data on vegetation, existing wells, seeps and oases, drainage patterns, and local geology. Utilizing ADP equipment, multifactor analysis can then be processed to project geographic locations of highest subsurface water resource potential.

The Army is presently pursuing multiple research and production programs in attempts to provide water resource information of the Persian Gulf areas. For an excellent review of these programs the reader is referred to "Report of the Defense Science Board Task Force on Water Support to U.S. Forces in an Arid Environment," July 1981, Office of Undersecretary of Defense for Research and Engineering, Washington, D.C. 20301 (SECRET:NOFORN).

The Engineering Topographic Laboratory, Fort Belvoir, Va., is the prime organization for terrain analysis in the Army and plays a critical role in their approach to the desert water problem of combat troops.

Also prime in the desert hydrology area is the Army's Waterways Experiment Station in Vicksburg, Miss., which is currently producing the water resource maps 1:125,000 of the Middle East for the Rapid Deployment Joint Task Force (RDJTF).

Field level technology, which the Army is pursuing for subsurface desert hydrology detection, is based on the following five methods.

1. Loop/loop electromagnetic (magnetic field fluctuations)
2. Electric self-potential (DC electric resistance)
3. Seismic refraction (sonic)
4. Seismic reflection (sonic)
5. Ground penetration radar (electromagnetic waves)

The previous items were included to provide the reviewer with a basic outline of current desert hydrologic military programs. Marine Corps resources to date require that most desert water resource operations in combat must rely on Army performances. This indicates a decided dependence on Army priorities to fit Marine Corps needs. It should be noted, however, that the potential does exist within the Marine Corps, provided that current research programs are congruently aligned, to have a minimum sustaining capability to locate critical desert combat required water resources. Requisite for this self-sufficiency function is a coordinated effort within the Marine Corps of intelligence functions, engineering and reconnaissance functions, and logistic support functions. A paradigm has been provided for this coordination by the Army, albeit in a large scale and/or high cost support manner.

WATER USE CONSIDERATIONS

Human Factors

Current military equipment is highly sophisticated, and modern warfare requires high mobility, massive firepower, and the movement of large quantities of materiel. Nonetheless, the basic combat element is still the individual infantryman, and his ability to survive and function will determine the success of any mission. Desert operations present unique problems for both men and machinery. Presumably mechanical problems can can be overcome by appropriate engineering design, but problems facing the Marine in a desert environment relate to basic human physiological phenomena which cannot be contravened by training or improvement of physical condition. The value of training and physical conditioning for desert operations lies in preparing the soldier to recognize and successfully provide for his physiological requirements.

The Israeli Defense Forces (IDF) have developed a highly successful heat doctrine for desert operations as was demonstrated during the 1967 war with Egypt. The Israeli forces experienced minimal heat casualties, while the Egyptians suffered 20,000 casualties from heatstroke, representing approximately 50% of the total Egyptian war casualties. The physiological principles identified by the IDF are briefly:

(1) The amount of heat accumulation in the human body depends on the amount of physical activity and climatic conditions.

(2) In hot surroundings, sweating is the main body mechanism to dissipate heat.

(3) Following the loss of sweat, fluids must be consumed to replace the loss of body fluid.

(4) If the loss of body fluid by sweating is not replaced, dehydration will follow which will hamper subsequent heat dissipation and lead to heatstroke.

(5) The soldier will not realize when he is dehydrated. Therefore, it is forbidden to rely on thirst for determining fluid consumption. Regular and timely consumption of adequate fluids by individual soldiers is the responsibility of the commanding officer.

(6) Excessive high climatic temperature and continuous exercise can cause an excessive rise in body temperature, even while sweating and drinking fluids. Adequate and recurrent rest periods are mandatory to prevent a continuous rise in body temperature.

Drinking Water Requirements

The value of the IDF doctrine is in establishing the necessity for discipline and training essential for forced rest periods and consumption of liquids in excess of quantities dictated by natural thirst. The IDF specifies consumption requirements at one liter per hour (1.1 quarts per hour) during periods of strenuous physical activity, and 11 to 18 liters per day (2.9 to 4.8 gallons per day) during desert operations.

The Soviet Union, suppliers and advisors to the Egyptian military during the 1967 and 1973 wars, learned valuable lessons (costly to the Egyptians) that prompted significant changes in Soviet military water doctrine. Pre-1970 doctrine was based on the erroneous assumption that water deprivation would "toughen up" personnel, and 2.5 to 3.5 liters per day (2.6 to 3.7 quarts per day) per man was adequate. In the mid-1970's the Soviets changed their basic doctrine to 10 liters per day (10.5 quarts per day), and 8 liters per day (8.4 quarts per day) during an attack or march.

The Israeli and Soviet doctrines can be considered upper and lower bounds for water consumption by modern forces in desert operations. Employing these daily consumption factors in a graphical presentation of drinking water requirements versus force size will produce a supply requirement range for any size forces as shown in Figure 1. The Water Advisory Board to the United States Rapid Deployment Joint Task Force (RDJTF) is currently using a planning factor of 4 gallons of drinking water per person per day for desert operations. A plot using this factor is also shown in Figure 1. Note that no water uses other than drinking requirements are accounted for in the Figure 1 values. Non-drinking water requirements are discussed in a subsequent section of this report.

WATER SUPPLY SOURCES

Discussion of Alternatives

In geographic regions with extensive surface water resources, the tactical commander is likely to establish several decentralized water points in proximity to the various deployed elements of his force. In a desert theater, readily accessible water resources will be limited or nonexistent. Individual water supply sources, therefore, take on much greater importance, and may even be critical to conduct the mission. In general terms, water supply alternatives will fall into the following categories:

- Importation of water
- Exploitation of existing sources
- Development of new resources

Each water supply alternative has definite advantages and disadvantages and must be considered in relation to the time frame of a specific mission, the degree of autonomy required of the assault force, and the logistics and manpower burden associated with erection and operation of the water supply systems. It is entirely possible that the best solution may not be a single method, but a combination of various alternatives used either simultaneously or in a time-phased sequence.

Importation of Water

The importation of potable water into a theater of operations can be accomplished with systems comparable to those used for delivering fuel. Bulk liquid tankers carrying water can tie up at mooring locations and discharge through either floating or bottom-laid hose or pipelines. The installation of appropriate offloading systems would be provided by NMCB forces, and the Marine Corps responsibility would begin at the high-water line. Presumably any imported water would be potable, offering the advantage of requiring no treatment beyond disinfection. An inherent disadvantage would be the potential for enemy interdiction or delays in deliveries due to adverse sea conditions.

Current and Programmed Importation Capability. As an interim measure to provide bulk water transport for JRDTF, the Department of Defense contracted with the Zapata Corporation to preposition the Zapata Patriot at Diego Garcia. The Zapata Patriot, a 9 million gallon tanker, can carry in excess of 6 million gallons of potable water and offload from any of several separate holds. The use of a large volume tanker will require either an equivalent large volume of storage ashore to receive the offloaded water or the long-term mooring of the tanker where it can serve as a floating reservoir. The turnaround time for the tanker to refill at some friendly location and return to the AOA must also be factored into the operational scenario.

A new class of military prepositioned ship is currently in the acquisition cycle. The ship, designated the TAK(X), will be capable of carrying cargo, bulk POL, and bulk water. The 81,250 gallons of water carried on the ship can be offloaded with two shipboard pumps rated at

300 gal/min each. The TAK(X) is currently scheduled to carry 10,000 feet of 6-inch buoyant fuel hose which may or may not be suitable for dedicated potable water use. An additional capability incorporated into the TAK(X) package is the ability to distill 20,000 gallons of seawater per day, providing an additional potable water resource.

Offloading of imported water will presumably be via floating hose. Although there are no programmed buys for floating hose for potable water use, suitable hoses are currently in the Navy inventory. Floating fuel hose, NSN 2C 3835-01-065-4938, procured from Elastofab Company of Oak Ridge, New Jersey under contract DLA-700-78-C-8245 does comply with potable water requirements as stated in CFR Sec 177,2600 (rubber articles intended for repeated food use). Elastofab provided two 6-inch systems of 10,000 feet each under their contract. At the present time one system is located at CBC Gulfport, Miss., and one is located at CBC, Port Hueneme, Calif. Neither system has been used to transfer fuel and could be dedicated for water use. Note that no other systems in inventory are known to be suitable for potable water use, and no approved methods are known for sanitizing a hose system subsequent to its use with fuel products.

Technology Transfer Potential. Extensive capability currently exists for the importation of bulk fuel into a theater of operations and new systems are currently under development. Several of the systems may be adaptable to bulk water handling with minor modifications to allow for the higher specific gravity of water and to insure compatibility of construction materials with health requirements. Although existing systems may provide proper mechanical function, components such as gaskets, O-rings, and hose linings must be changed to comply with water requirements.

Floating fuel lines were previously discussed. At the present time, the NCBs also have, in inventory, steel piping systems which are designed to be assembled on the beach and towed to a mooring location offshore. The pipeline, which lies on the bottom, is used for POL transfer from a mooring buoy. A current research project at NCEL is exploring the potential of replacing this system with fiberglass reinforced plastic (FRP) pipe. If successful, the FRP material will weigh less, be easier to implace, and be directly adaptable to bulk water transfer.

Mooring equipment is currently in inventory, and a substantially improved single-point mooring buoy is currently under development at NCEL. The new buoy system will have all weather capability and two 8-inch pipeline connections for POL transfer. A 4-inch or 6-inch water line could be added to the buoy for both fuel and water offloading by the TAK(X) class ships or other vessels.

Capabilities currently exist for towing bulk fuel containers into a theater of operation. Barges are readily available, and a floating cylindrical rubber tank called the "Dracone" has been tested for Navy use. The Dracone has a capacity of 120,000 gallons, and could be moored offshore as a floating reservoir.

New Concepts in Water Importation. Any net producer of water in the Fleet can be used to augment water supply to the Marine forces. Vessels with nuclear propulsion systems are net producers of water since they generate distilled water in quantities greater than shipboard use requirements. Excess purified water, normally ported overboard, can be pumped ashore from a mooring location. In the case of submarines, it is conceptually feasible to remain submerged while a diver connects a water discharge hose to a water buoy, offload, disconnect, and depart without being observed at the surface.

In addition, existing barges can be cleaned and coated for use as water carriers, or new barges can be fabricated for this purpose in any desired size at nominal cost. Barges can then be anchored on station as floating reservoirs.

Exploitation of Existing Sources

Any source of water that can be treated adequately for human consumption, and is available in sufficient quantity to either partially or fully meet the assault force requirements must be considered for exploitation. Equipment either in inventory or in procurement at this time will provide the capabilities for filtration, disinfection, and demineralization. Therefore, seawater, brackish water, or highly mineralized waters are as acceptable as existing potable water sources.

Existing Potable Sources. In inhabited but undeveloped desert areas hand-dug wells of less than 100 feet in depth have historically been used for water supply. This type of well intersects shallow ground water aquifers which will generally be of limited production potential, and may even be seasonal. Water is generally highly mineralized, and may be biologically contaminated by human and animal wastes. The major problem associated with exploiting these resources is that the limited water production potential will be diverted away from the local inhabitants, and their survival may be threatened. The use of existing hand-dug wells may provide occasional supplementation to other supply sources, but does not appear to be a viable major source of supply.

Modern cased wells have been constructed in many desert regions of the world in recent years. In most cases these wells are very deep, occasionally reaching 3,000 feet, and are capable of producing substantial quantities of excellent quality water. In some cases new wells tap flowing acquifers, but occasionally tap water lenses that may have existed for thousands of years. Modern wells are likely to have sufficient excess capacity to provide for the local populace and significantly augment water supplies for an assault force. All known existing modern wells will, therefore, become important tactical objectives.

Major population centers in desert regions have extensive water supply systems which may consist of wells plus seawater desalination. Wherever available these resources should be accessed. Their vulnerability to sabotage or direct attack is apparent, so an existing water system may require substantial security measures for continued survival.

Seawater. In most foreseeable military roles the Marine Corps will enter a theater of operations from the sea and will establish logistics bases in close proximity to the coastline. Therefore desalination of seawater appears to be a viable and consistently available alternative for obtaining potable water. Desalination technologies have been used successfully in both civilian and military fixed installations. A method for obtaining a debris- and sediment-free feedwater source will significantly enhance desalination system function and reliability. Therefore, intake equipment or beach well equipment is highly desirable as ancillary support equipment for use of seawater as a supply source.

Current and Programmed Capabilities for Existing Sources. Current and programmed capabilities for accessing existing shallow well water, existing well water, and seawater is generally limited to a selection of pumps in the range of 50 gallons per minute with suction lift capabilities of approximately 15 feet. The current inventory well kit does contain a well pump with a capability of 60 to 100 gallons per minute at a 250-foot pump bowl setting.

Technology Transfer Potential. Well pumps to meet any requirement are available off the shelf in the private sector, as are a wide variety of water pumps for moderate suction lifts. The reliability of shaft seals on submersible pumps has been improved substantially in the last decade. Submersible pumps would be suitable for shallow or deep well application; their use would eliminate the suction lift limitations of ground level pumps or the requirement for shafting between ground level drivers and turbine well pump bowls at the water level.

Intake structures and small self-jetting well points for beach well use are commercially available in a variety of screen mesh sizes. It is possible to proceed to procurement without extensive development tests, based on industry experience and practices.

Development of New Sources

In a desert environment the development of new water sources is essentially limited to drilling wells. The expertise and equipment for rotary drilling of modern gravel envelope wells is currently in the Marine Corps inventory. A trained crew can drill at a rate of 200 feet to 600 feet per day, completing a deep well in approximately 5 days. Unfortunately, fairly extensive data concerning the geology and underground strata of an area is essential to insure a high degree of success at accessing underground water.

Current and Programmed Capabilities for New Sources. The well drilling rigs currently in the Marine Corps inventory are combination rotary/downhole hammer drills capable of drilling to a 1,200- to 1,500-foot depth. Well completion kits on hand, however, are limited to setting an 8-inch casing down to 800 feet. Deep well pumps in inventory are only capable of pumping 100 gal/min from a water level of 250 feet. As required, personnel are rotated through the Well Drilling School at NCBC, Port Hueneme, Calif., to maintain skill levels. Additional well drilling capabilities reside in the NMCB forces.

The Army's Waterways Experiment Station and the Defense Mapping Agency are currently developing a geological data base for groundwater, presumably incorporating test boring data, existing well logs, and satellite photo imagery. Ultimately it is hoped their work will cover all potential operational areas for Fleet Marine Forces, however, coordination will be required to insure this.

Technology Transfer Potential. Down-hole hammer drill equipment currently available on the commercial market can drive drill stem and well casing at the same time, eliminating the requirement for drilling muds and chemicals. Productivity is substantially higher, ranging from 600 to 1,200 feet per day depending on formations and bore size.

WATER TREATMENT

Water Quality Requirements

The Army Surgeon General has established field standards for potable water quality which address major physical and chemical properties. An extract of these standards are presented in Table 1. Bacteriological pollutants are presumed to be destroyed by standard field disinfection methods. These standards address potability criteria which will presumably guard against adverse health effects, but do not address palatability aspects of a potential water supply. In a desert environment personnel will drink adequate amounts of water to satiate thirst, but not sufficient quantities to replenish lost body fluids. Since dehydration threatens to be the largest single source of manpower loss in desert operations, the palatability of the water supply takes on new significance. Color, turbidity, taste, odor, and temperature are aesthetic parameters that will influence palatability and, therefore, the quantities of water consumed. The ability of a treatment scheme to address these parameters, possibly excluding temperature, must be considered in a desert environment. Temperature control may more logically be addressed in other portions of the water supply system.

Tactical Considerations

Tactical operations may require a variety of unit sizes and geographical distribution for the various elements of an assault force. Ideally equipment of the appropriate size and type could be provided to each element of the force, but in practical terms this would require a massive equipment inventory to accommodate any and all possible combinations of personnel. Obviously compromises must be made in equipment selection to minimize the logistic requirements while maintaining an acceptable level of utility over a reasonable range of requirements. In terms of water treatment equipment, appropriate sizes appear to be:

- High capacity for logistics base and battalion level water points (greater than 400 gal/hr).
- Low capacity for company level use in independent operations (50 to 100 gal/hr).

Transportability will also be a significant factor for company-sized equipment. Ideally the hardware for small units should be transportable by 5-ton truck or utility trailer. The consideration of treatment versus resupply for company level and smaller units must be made on an individual case basis after considering water availability, mission, etc.

Treatment Technology

Current and Programmed Water Treatment Capability. The Marine Corps currently has, in inventory, 1,500 gal/hr "Erdlator" water treatment units which remove suspended materials by chemical flocculation and sedimentation. These units are scheduled for replacement by a new reverse osmosis water purification unit (ROWPU). The ROWPU, developed by the Army Mobility Equipment Research and Development Command (MERADCOM), is rated at 600 gal/hr. ROWPU units are currently in procurement.

Reverse osmosis is a demineralizing process wherein salts are retained on one side of a semi-permeable membrane, while salt-free water is permitted to pass through the membrane. When the ROWPU is used to demineralize brackish water with a total mineral content of approximately 3,000 milligrams/liter, demineralized water (permeate) production is approximately 600 gal/hr and the concentrated waste brine stream (concentrated) will be 1,000 to 1,400 gallons per hour. Membrane flux, or the rate at which water passes through the membrane, is influenced by salt content of the feed stream. On seawater a permeate stream of approximately 450 gallons per hour will be produced, and the waste brine stream will be about 800 gallons per hour. Membrane flux is improved at higher water temperatures, essentially doubling between 50°F and 90°F. Membranes will fail at temperatures above 120°F, creating potential problems and reducing membrane life in hot desert operation or on geothermal waters which are not uncommon in many desert regions.

The 600 gal/hr ROWPU package currently in procurement includes filtration equipment which will remove suspended material from the feed water stream. In addition to enhancing the quality of the water, the filters protect the reverse osmosis membranes, which are subject to fouling and blinding. The filter system may be used alone to treat waters that are already potable with respect to mineral content.

Water treatment equipment in the 50 to 100 gal/hr size suitable for use by company level or smaller unit use is neither in inventory nor planned for procurement.

Technology Transfer Potential. Large scale reverse osmosis water demineralization equipment is available commercially at the present time. MERADCOM is currently adapting a commercial unit that is rated at 2,000 gal/hr for possible military use. Tentative packaging plans call for three ISO configured 8-foot by 8-foot by 20-foot container, one of which will house the RO unit while the remaining two are required for ancillary and supporting equipment.

Small capacity reverse osmosis units are available commercially from several sources. A particularly promising line of small units is marketed by Seagold Industries, Ltd. Their product, called the "Water Lever," has a special pump head that recovers energy from the pressurized waste brine stream, reducing the total input energy required for operation. The WL-1000 model is driven by a 3/4 hp motor and will produce up to 1,000 gallons of potable water per day. This is adequate to meet drinking requirements of a 250-man unit.

New Concepts in Water Treatment. With the exception of solar distillation, new concepts and research appear to be concentrated on areas that do not offer any promise for military application. Work is being done, however, on pretreatment systems for reverse osmosis treatment and on operational methods for enhancing reverse osmosis function.

A separate NCEL project investigating flow surging for cleaning reverse osmosis membranes shows great promise for simplifying ROWPU operations and extending membrane operational cycles. Bag filtration systems are also being investigated for potential augmentation or replacement of the bulky and heavy multi-media ROWPU pretreatment filter system. Additional possibilities exist for developing energy recovery devices for the waste concentrate stream on ROWPU systems, reducing total energy input requirements.

WATER STORAGE

Tactical Considerations

The selection of appropriate water storage equipment may be influenced or even dictated by other components or requirements of the water supply and distribution system. Batch importation of potable water, possibly in delivery volumes of 4 to 6 million gallons, would require either very large tanks and reservoirs or literally dozens of containers in the 50,000 gallon capacity range. On the opposite end of the spectrum, batch resupply of small independent units would suggest the use of containers in the 500 gallon size range, serving the dual function of distribution and storage. Tactical considerations in system selection would be concealment, cover and the potential for enemy interdiction. Large storage systems are vulnerable, while small systems as a trade-off are more labor intensive and require substantial redundancy. No single hardware item will satisfy all situations, and trade-off considerations must be weighed to minimize the variety and types of systems to maintain in inventory. All systems, regardless of size, should be transportable and capable of rapid erection.

Large Volume Storage

For purposes of discussion the term "large volume" is taken to mean 20,000 gallons or more in a single container. Large volume storage could be used in the logistics base complex, airfield, beach area, or as far forward as battalion support areas.

Current and Programmed Large Volume Storage Capability. Naval Mobile Construction Battalion forces that support the Marine Corps currently have in inventory field-erectable bolted steel tanks with a capacity of 126,000 gallons. Each tank weighs 28,000 pounds and requires over 1,000 manhours to erect, making it a less than desirable item for rapid deployment. At the present time it is the only container in the Navy/Marine Corps system with a capacity over 100,000 gallons.

The Marine Corps has programmed funds for FY 1982 procurement of 13 rubber bladder tanks with a 50,000 gallon capacity and 18 tanks with a 20,000 gallon capacity. Combined capacity for all 31 tanks will be approximately 1 million gallons. Tank farm hardware for the bladder tanks is also scheduled for procurement. Bladder tank technology is a direct transfer from the bulk fuel system currently used DOD-wide.

Technology Transfer Potential. The Dracone, a cylindrical rubber fuel tank of 100,000-gallon plus capacity has been in use in the United States and the Mediterranean area for several years. The Dracone, which floats in seawater, is towed behind a small vessel and can be anchored at a use location. A Dracone was tested at NCEL for suitability as a storage tank ashore, and found to be quite serviceable with appropriate berms to preclude rolling. The Dracone can be fabricated with a rubber formulation suitable for potable water, and can be used as either floating storage offshore or as storage ashore.

Plastic linings for direct placement in earthen basins are in common use in both the public and private sector in the United States. Inexpensive containment lagoons or reservoirs can be rapidly and inexpensively constructed after minimal grading and earthwork, and size and shape considerations are not critical since fabric is cut and joints are cemented on site. A basin of 60 feet by 55 feet by 5-foot depth will accommodate 100,000 gallons of storage. Once in place, however, the lining material is non-retrievable. Floating or fixed covers can be used with lined reservoirs. Coverings must be used in tactical applications to protect the water supply against wind blown contaminants and possible chemical or biological attack. Rigid wall sections for membrane liner sections are also commercially available or can be field designed and fabricated. Complete wall section/liner packages are available from several sources, including ModuTank, Inc. of Long Island City, New York.

Several rigid tank concepts have been developed in recent years, most of which are intended for permanent installations. Two concepts may have military applications. Plank Tank, Ltd., of Santa Barbara, Calif., is marketing a stave-type tank with fiberglassed foam tongue-in-groove and gasketed staves. Capacities range up to 31,000 gallons. The finished surface can be colored to provide appropriate camouflage, and the construction materials will provide excellent insulation properties to reduce solar heating. A second possibility is the West German Aluminum tank which offers the characteristics of easy erection and very low maintenance. The 119,000 gallon tank has aluminum sides and top, and a rubber bottom. A 10-man crew can assemble the tank in 6 hours.

Secondary Storage

For purposes of discussion, secondary storage is taken to mean single container water storage volumes between 1,000 gallons and 20,000 gallons. Secondary storage could be used to establish forward area water points and intermediate storage or surge capacity in extended systems. For operations involving smaller force structures, containers in this size range would logically serve as primary storage since large volume storage capacity would be unnecessary.

Current and Programmed Secondary Storage Capability. The Marine Corps currently has in inventory and is using the 3,000-gallon wood stave supported black rubberized fabric tank. This open-top tank has been highly serviceable and versatile over the years and will probably remain in inventory for the foreseeable future. Although it has a rubberized fabric cover, airborne contaminants can enter the tank under high wind conditions.

The Marine Corps is currently procuring 20,000 gallon bladder-type water tanks similar to those used in the bulk fuel system. The 18 tanks under procurement can be used to augment large volume tank farm storage or to provide intermediate or secondary storage capabilities.

Technology Transfer Potential. Several European manufacturers market a small tank similar in configuration to the wood stave supported 3,000 gallon tank currently used by the Marine Corps. A British manufactured tank uses an inflatable collar that automatically raises the tank sides as the tank is filled. MERADCOM is currently testing one version of this tank. Discussions with MERADCOM personnel indicate that the concept is sound, however, quality control of seam construction in manufacture will have significant impacts on serviceability.

A Norwegian design, the "NBC-Sanator," offers great promise for Marine Corps field use. The 1,500 gallon rubberized fabric tank has no rigid supports, yet is stable on flat or sloped ground due to its pear-shaped design. The NBC-Sanator can also be placed in the bed of a 2-1/2-ton truck for expedient water resupply. Weight when empty is 70 pounds.

Bladder tanks similar to the 20,000 gallon and 50,000 gallon versions currently in procurement have been fabricated for industry in a wide array of shapes and sizes. Bladder tanks can be provided in 3,000, 5,000, or 10,000 gallon versions if military requirements dictate. One version used in private industry, available in the 3,000 to 5,000 gallon range, is configured to fit a flat bed trailer when full. When empty the bladder tank can be rolled up and tied down at one end of the trailer. This permits dual function use of the trailer as a tanker and cargo hauler.

Small Volume Storage

Tanks and devices with capacities less than 1,000 gallons are more conveniently classified as containers, and in field operations would be used for distribution of water and temporary storage at the user location. Small volume containers will be addressed under the appropriate sections on water distribution.

WATER DISTRIBUTION

Tactical Considerations

The probability of limited water storage or supplemental water sources in forward areas suggests that combat forces will be highly dependent for their survival on an adequate and uninterrupted resupply of water from support areas in the rear. The characteristics of the distribution system and its individual components must, therefore, include:

- Transportability or deployability by organic motor transport or rotary-wing elements not exclusively dedicated to water resupply
- Limited susceptibility to interdiction by unfriendly forces
- Limited susceptibility to sabotage or unintentional contamination

Individual components must, therefore, be sufficiently flexible for use in varying applications, be readily deployable by organic personnel and equipment, and be either secure or capable of protection from damage or contamination.

Portable Containers

Small volume storage, as defined previously for the purpose of this discussion, includes containers of less than 1,000 gallon capacity. Using organic equipment, all containers in this category can be considered portable, ranging in size from 1,000 gallons to 1 quart.

Current and Programmed Capability. The Marine Corps currently has in inventory the following types of water containers:

400-gallon water trailers
30-gallon lister bags
5-gallon water cans
1- and 2-quart canteens

The water trailers, commonly called the water buffalo, exist in several versions. Earlier versions are either steel or insulated double wall fiberglass construction, while new items are insulated double-walled stainless steel. Tests by the Army indicate that both types of insulated water buffaloes are excellent for maintaining cool water in hot climates, but of course, will do equally well for keeping hot water hot.

Lister bags are constructed of a canvas fabric that weeps, providing some degree of evaporative cooling at the bag surface. The bags tend to lose 5 percent to 30 percent of their contents through weeping, and are not highly effective at cooling due to the low surface area to volume ratio.

The 5-gallon water cans and the various canteens are for individual or squad use. Current versions are not insulated, and will permit rapid warming of their contents in hot weather. Insulation covers, developed by the Army, are programmed for procurement by the Marine Corps.

Current Marine Corps plans include the procurement of several forward area water point supply systems(FAWPSS) similar to those developed by the Army. The system is a direct transfer of current POL system technology.

New Concepts in Portable Containers. The Naval Civil Engineering Laboratory, under a Marine Corps funded POL project, is developing an 800-gallon container system. The rectangular containers are called "SIXCON Modules" because 6 of the containers can be joined to make up an 8-foot by 8-foot by 20-foot ISO configured single unit. Ancillary equipment is also being developed for the water versions of the module, such as manifolds for water spreading for construction, filling of canteens, etc.

Hoses and Pumps

Hose systems for transporting water over long distances present unique problems. They are subject to damage by wheeled or tracked vehicles of friendly forces, susceptible to damage by shrapnel from incoming rounds, and can be sabotaged or diverted by unfriendly forces or the civilian population. In terms of sabotage, interruption of the supply may present a lesser hazard than contamination of the water supply with an incapacitating agent or toxic substance. Nonetheless, hose and pump systems may be ideally suited for bulk transfer of water in secure support areas. For example, demineralization of seawater with multiple ROWPU units at the beach area may be dictated, but bulk storage at a battalion support area or airstrip some distance away may best suit resupply efforts.

Current and Programmed Capability. A limited capability for hose-line transfer currently exists in the Marine Corps inventory as the TAM B26000 and B2610 Water Distribution Equipment. The systems, limited to a few hundred feet of hose and three 55 gpm pumps, are used in conjunction with the Erdlator water treatment units which are scheduled for phase out. The Army is currently developing a tactical water distribution system (TWDS), and is programming procurement of seven systems. Each TWDS will contain pumps and approximately 10 miles of hose. The Marine Corps has no plans to procure new hose or pipeline systems at the present time.

Technology Transfer Potential. Several equipment items for fuel handling and transfer are currently being developed for the Marine Corps at NCEL, all of which can be directly adapted to water distribution.

A hose reel system currently being tested can deploy up to 1,200 feet of 6-inch hose from the back of a moving vehicle. If hose sections longer than the standard 50 feet are used, or smaller diameter hose is substituted, additional footage can be stowed on the reel.

Long hose runs, perhaps up to several miles, will necessitate line pressure boosts at intermediate locations. NCEL is currently developing and testing an automatic control system for the Marine Corps 600-gpm fuel transfer pump that will throttle the pump speed to maintain desired line pressure. A second project involves retrofitting the pump driver with a turbocharger to increase maximum output to 800 gpm.

TEMPERATURE CONTROL

Tactical Considerations

Human factors relating to water consumption in a desert environment were discussed earlier in the report. Due to human palatability preferences, personnel will generally not drink enough water to offset dehydration when the water temperature exceeds approximately 85°F. Dehydration reduces personnel efficiency. The net result will be loss of military effectiveness and possibly substantial heat casualties. Therefore, to avoid adverse impacts on personnel and maintain their physiological requirements for hydration, a drinking water supply should be provided at a temperature below 85°F, and preferably close to the 65°F range.

Ground temperature in hot desert regions can easily reach 130°F at mid-day, creating significant problems for all equipment and stored materials. In a tactical setting the basic requirements for a water supply system will be to provide passive methods for controlling heat buildup in bulk storage, perhaps active methods for cooling water for delivery to the individual user, and finally passive measures for the individual to keep his own water supply from rewarming prior to consumption.

Passive Measures

By employing appropriate devices or operational procedures, it is feasible to control the rate of transfer of heat into stored water. Such devices or procedures are passive in the sense that they require no external input of energy, but rely solely upon the characteristics of certain materials and natural phenomena. Assuming a diurnal temperature variation in hot desert areas, such devices or operational procedures may even be capable of increasing the nighttime transfer of heat out of stored water that was absorbed by the water during daylight hours. Passive measures include insulation, radiation and convection control, and evaporative cooling.

The insulated water trailers currently in inventory incorporate a passive temperature control measure. In addition, 6,500 insulated covers for 5-gallon water cans are currently in procurement. It should be noted that insulated containers will keep hot water hot as well as maintain cool water.

Active Cooling

Direct solar or solar-induced heating is a natural phenomenon that can be overcome by the use of an active device such as a refrigeration unit. Active devices will consume energy and probably require maintenance and logistic support. The most common refrigeration devices are either vapor compression or absorption cycle systems. Absorption cycle systems offer the ultimate simplicity, however, their bulk and low efficiency minimize their appeal for tactical equipment application. Therefore, vapor compression systems are the most common in the private sector and offer the greatest appeal for military application.

Current and Programmed Capability. At the present time the Marine Corps does not have any equipment specifically designed for cooling water. There is, however, a programmed procurement for 83 units designated as the "400-gallon cooling units." This item was developed for Army and sized to mount on the tongue of a 400-gallon water trailer. When operated as a single pass cooler, the amount of cooling will be a function of the initial water temperature and the withdrawal rate. At a 7 gpm withdrawal rate, the cooler will drop the water temperature 12°F. If the withdrawal rate is relatively constant at two-thirds of a gallon per minute over a 10-hour day, 400 gallons can be cooled from an initial 120°F to a 60°F delivery temperature. This translates to a withdrawal rate of less than 1 gpm. If operated in a recirculation mode the unit can gradually cool the contents of the water trailer.

Technology Transfer Potential. Refrigeration systems are commercially available in practically any desired size or configuration. Large single pass units can be adapted to chill water as it is transferred from bulk storage into insulated distribution containers such as the 400-gallon water trailer. (The new stainless steel water trailer has excellent insulation that will maintain temperatures effectively. In a recent Army test conducted in a 120°F environmental chamber, water at 50°F increased only 10°F to 60°F over a 23-hour period!)

New Concepts in Passive Measures. Few, if any, passive measures can truly be considered new in an absolute sense, but may certainly be new in the context of military application. Some of the applications discussed in this section have been conceived at NCEL, while some have been provided by others either through various discussion groups and publications.

High ground temperatures in the desert, reaching up to 130°F, do not penetrate to any appreciable depth. An operational procedure that may be of benefit for placement of water storage bladder tanks is to excavate a depression of approximately 30 to 36 inches to expose the tank surface to cooler subgrade temperatures which are frequently in the 70°F plus or minus range. Of course the upper structure of the tank will be exposed to solar radiation, and must be protected by some other means.

In coastal areas where ocean temperatures are moderate, water storage tanks may be placed directly in the shallows permitting seawater to maintain storage temperatures. (In some areas of the world intertidal water temperatures are suprisingly high, negating the potential for this operational procedure.)

Metallized polyester film, a spinoff from space technology, has proven to be a significant breakthrough for control of radiated heat. If combined in a layered configuration with a material that provides for control of heat conduction, an excellent insulating device can be produced for desert application. This concept, using air as the conduction limiter, can be configured similar to a low pressure air mattress. With minimal storage volume and weight, the device can be inflated in the field and draped over water storage bladders to significantly reduce solar heating. An artists concept of the device is shown in Figure 2.

A significant problem at the consumer level is reheating of chilled water in the canteen prior to actual consumption. The 60°F water held in the currently issued plastic canteen will warm to 85°F in about 1 hour in a 120°F environment. Preliminary tests on standard issued 1-quart canteens which were jacketed with 1-inch of low density polyurethane foam indicated that the temperature rise from 60°F to 85°F could easily be extended to more than 8 hours. A prototype insulated canteen, currently under evaluation at NCEL, is shown in Figure 3. Preliminary test results are presented in Appendix B.

Night sky radiation, also known as north body radiation, is a natural phenomenon in which objects at the earth surface radiate heat outward toward space during the hours of darkness. On clear, wind-free nights sufficient heat may be radiated to actually cause freezing even though ambient air temperature may be as high as 50°F. The phenomenon is well known to citrus growers, who are forced to counteract potential freezing of fruit crops by using orchard heaters or wind machines. On clear dark nights the sky appears as a black body at -70°F. The warm citrus fruit naturally radiates heat unless it is warmed by convection or breezes at ambient temperatures. Ancient peoples in the Middle East, Persia, and India used this natural phenomenon to produce ice on clear desert nights, and the technique was used as recently as the 1930s in Iran. NCEL has been exploring night sky radiation as a long-term alternative for cooling stored water. Initial efforts employing solar water heater panels were promising, but certainly not conclusive. Results will be reported at a later date under separate cover.

OPERATIONAL SCENARIOS AND FORCE STRUCTURES

Basis for Water Supply Requirements

The Marine Corps, as a rapidly deployable force, may be required to respond to a wide variety of mission types. The mission profile will be used by senior commanders to structure the required force, which in turn will dictate the logistic support requirements. Considerations such as deployment methods, mission duration, force structure, and configuration will impact on water supply volume and logistic techniques. It cannot be assumed that a single supply concept will be ideal for all contingencies. To facilitate an overview four, different types of missions were selected to permit relative comparisons between water supply concepts and technologies. In this manner it may be possible to identify technologies offering the widest range of capability. The mission profiles selected are:

a. Seize and hold a developed objective such as an airfield, port, logistics complex, or administrative center.

b. Amphibious assault and conventional infantry advance inland.

c. Helicopter-borne rapid strike assault on an objective up to 50 miles away.

d. Mobile-mechanized assault from a base camp to a distant objective with minimal resistance enroute.

For each of the four types of missions the forces are assumed to be either withdrawn or linked to other forces at the end of the mission time period.

Scenario A: Seize and hold a developed objective. Assault operations are to seize and hold a developed objective such as an airfield-logistic complex, port, or administrative center including control of the surrounding perimeter and any key defensive points within 5 to 10 miles of the objective. Defense will be essentially static, and command and control will be exercised from a base complex which may or may not use developed facilities at the objective. The assault force will consist of 1 conventional Marine Amphibious Brigade (MAB) of 12,674 men. The notional organization is shown in Table 2. Duration is assumed to be 120 days.

Scenario B: Projection of assault forces inland. Operations will include an amphibious landing, establishment of a logistics base, and projections of forces inland to control terrain up to a distance of 20 miles. The assault force will consist of one 12,674-man MAB deployed as shown in Table 3. Duration is assumed to be 120 days.

Scenario C: Helicopter borne rapid strike force. The requirement is envisioned as a short duration (15-day maximum) move-in, accomplish the mission, and move-out operation that will be conducted by selected elements from a MAB. The 992-man force structure, consisting of one infantry battalion reinforced with personnel from other MAB components is shown in Table 4.

Scenario D: Mechanized assault. Assault on an objective up to 250 miles from a MAB base camp, assuming little or no resistance enroute, will create a long and vulnerable logistic train. The force of 1,716 men, consisting of a reinforced battalion landing team, is shown in Table 5. Duration of the operation is assumed to be not more than 30 days.

Extrapolation of Water Use Factors

The recent formation of the Joint Rapid Deployment Task Force (JRDTF) necessitated a substantial amount of water planning and the estimation of water use requirements by the armed services. This information was subsequently compiled by the Army Logistics Center, Fort Lee, Va., for use in various planning functions. The water consumption planning factors produced by the Logistics Center, which are shown in Table 6, represent the force average in gallons per man per day.

Although the bottom line value of 20 gal/man/day in Table 6 may be realistic for an entire operational area, the distribution of water requirements within the area will vary substantially. Using the values from Table 6, men at the forward edge of the battle area (FEBA) will require water for drinking (4.0 gal), personal hygiene (2.7 gal) and vehicles (0.3 gal) for a total of 7.0 gal/man/day. The various other uses totalling 13 gal/man/day which support these men will all be located in rear or intermediate locations. Quantification of how much water must be delivered when and to what location within the operational area is critical to equipment selection and logistic system planning.

Time Phasing of Water Demand. The projection of an assault force of substantial size into an objective area and the establishment of various logistic support systems is a time-phased operation. For a MAB size force an assumed landing time of 5 days is not unrealistic, although additional time will be required to consolidate the area. In terms of water supply, adequate water must be carried with the assault forces to meet requirements pending the establishment of a water logistics system. Typically an assault force can be expected to carry a 3- to 5-day subsistence level quantity of water. This automatically defines the time frame in which a water logistics system must be established for resupply. For several of the study scenarios an existing land or sea base is assumed, and the water logistics problem is one of supplying an assault element deployed from the base.

The time-phased buildup of forces estimated for the assault phase of each of the four study scenarios are shown in Figures 4 through 7. The lower half of these figures show the time-phased water demand based on the types of assault elements involved and the appropriate water use planning factors.

Geographic Distribution of Water Demand. In an established logistics base the service support elements of the assault force will have an operational system for importing or producing water plus some form of bulk storage to maintain the water supply. Actual use points will be geographically distributed from rear areas such as airfield operations to forward combat elements. Distribution operations must be tailored to provide appropriate water quantities to the specific use locations. Hypothetical graphic representations of the four study scenarios during the follow-on phase of operations showing daily water requirements are presented in Figures 8 through 11. The figures depict overly simplified operational areas that would, in reality, be influenced by terrain, unfriendly forces, and many other factors.

Required Operational Capabilities

Each of the four defined scenarios represents a unique military mission, however, similar requirements and functions exist for providing a water supply. Water supply functions may be grouped as follows:

- Acquisition: obtain an adequate supply source
- Treatment: insure potability of the water
- Storage: maintain a ready supply
- Distribution: deliver to the required use points

An interdependence exists between these functions, and selection of a specific alternative will impact on other system components. For example, a batch acquisition system such as a large water tanker may influence the selection of treatment type and will certainly influence needed storage capacity. The assessment of required capabilities must, therefore, precede the consideration of specific technologies and alternatives.

It is assumed that acquisition and treatment capability must exceed daily requirements by 50% to cover contingencies and enemy interdiction, and the supply must be treatable by disinfection, filtration, and/or demineralization. A 3-day storage capacity is required, and the distribution system must be capable of water delivery on a daily basis. Specific requirements and characteristics for each of the study scenarios are presented in Table 7, and are based on information developed in previous sections.

The requirements for the four water supply functions of Scenarios A and B are essentially identical, indicating that suitable hardware could be used to support either mission. Equipment for Scenario C, the heliborne assault, must be lightweight, portable, and quickly deployable. Although the requirements for Scenario D, the mechanized assault, are similar, a greater degree of flexibility is required in terms of transportation and deployment.

Required Water Acquisition Capabilities. Realistically assuming that freshwater streams and lakes will not be available for supply sources, the alternatives open to the assault force will be importation, demineralization of seawater, and possibly tapping of groundwater. It is probable that a combination of all three would be used in actual operations in a time-phased sequence to avoid major logistic burdens. Table 8 assumes the worst case situation of a single acquisition route. Scenarios C and D have not been included in Table 8 since they consist of a relatively small force involved in a short duration operation where either resupply with water distribution equipment or exploitation of existing sources would logically be used.

Required Water Treatment Capabilities. Water treatment will include filtration, disinfection, and possibly demineralization. Requirements for the various scenarios are presented in Table 9. Scenarios A and B represent major water treatment demands while Scenarios C and D represent relatively small scale exploitation of existing sources which may or may not be augmented by resupply from rear support areas.

Required Water Storage Capabilities. Water storage capabilities include all bulk storage equipment with the exception of small volume portable components logically addressed in water distribution considerations. Requirements for the various scenarios are presented in Table 10.

Required Water Distribution Capabilities. Water distribution equipment may include transportable containers and hose or hasty pipeline systems. Requirements for the various scenarios and presented in Table 11.

SUMMARY AND RECOMMENDATIONS

The data presented in Tables 7 through 11 identify areas where shortfalls in capabilities exist relative to the study scenarios. Specific recommendations for action in these areas are presented in Table 12. The most serious deficiencies appear to be in the areas of water acquisition, well drilling, and temperature control of bulk water storage. Therefore, a substantial amount of near-term effort should be devoted to ameliorating the impacts of these deficiencies.

Water Acquisition. Capabilities required for the Fleet Marine Forces cover two technological areas: intelligence on high probability locations for obtaining groundwater in the operational area prior to entry; and groundwater detection capability after entry. The first area involves the development of a groundwater data based for selected geographic regions of interest. Although substantial assistance can be obtained from other agencies, the development and maintenance of an appropriate information network structure for storage and retrieval of data will remain a Marine Corps intelligence function. The second area, groundwater detection capabilities, is currently being explored by selected Army agencies. It is, therefore, in the best interests of the Marine Corps to closely monitor Army efforts and to provide support when promising technologies are identified that will complement the Marine Corps capability.

Well Drilling. The Marine Corps currently needs well drilling equipment that incorporates as many of the following capabilities as possible:

- High drilling rate in a variety of formations
- Operable with limited training
- High mobility on unimproved roads or cross-country
- Transportable by ship, aircraft, and landing craft

Specific criteria must be defined in a required operation capability document (ROC), however, the adaption of modern commercial technology to a military chassis appears to be highly feasible.

Temperature Control. Water stored above ground in hot desert areas may reach temperatures of 120°F during the day, exceeding the capability of available water chilling units to cool adequate volumes. The use of passive insulation devices for temperature protection will limit heat buildup in stored water, significantly reducing the load on water chillers and their associated fuel consumption. Passive devices in the form of easily deployed or erected insulators should be evaluated for Marine Corps use.

Table 1. Field Water Quality Standards

Constituents	Short Term (Less Than 7 Days)	Long Term (More Than 7 Days)
Physical:		
Color		50 Units
Turbidity	Reasonably Clear	5 Units
Chemical:		
Arsenic	2 mg/l	0.2 mg/l
Chloride		600 mg/l
Cyanide	20 mg/l	2 mg/l
Magnesium		150 mg/l
Sulfate (SO_4)		400 mg/l
Total Dissolved Solids		1500 mg/l

Table 2. Notional Force Structure
Scenario A: Fixed Objective

Airfield-Logistics Base		
MAB Hdqtrs		652
Air Group		4,101
MQ	405	
Fixed Wing Sqdrn (2)	1,314	
Rotary Wing Sqdrn (4)	1,229	
Support Units	1,153	
Infantry Regiment		1,808
Hdq. Co.	164	
1 Battalion	1,109	
Artillery	317	
Armor	44	
Recon	15	
Amph. Assault	129	
Combat Eng.	30	
SSG		2,726
Hdg. Co.	581	
Supply Co.	470	
Maint. Co.	375	
Med/Dent. Co.	170	
Eng. Co.	65	
Truck Co.	250	
Fuel Co.	200	
Land. Spt. Co.	15	
NMCB	600	
	Subtotal	9,287

Deployed Within the Objective Area		
Infantry Regiment		2,901
2 Battalions	2,218	
Artillery	351	
Armor	66	
Recon.	100	
Amph. Assault	100	
Combat Eng.	100	
SSG		486
Eng. Co.	65	
Bridge Ptn.	43	
Truck Co.	71	
Bulk Fuel Co.	104	
Land. Spt. Co.	53	
NMCB	150	
	Subtotal	3,387
	Force Total	12,674

Table 3. Notional Force Structure
Scenario B: Amphibious
and Conventional Advance

Airfield-Logistics Base			Deployed to Forward Areas		
MAB Hdqrts		652	Infantry Regiment		4,709
Air Group		4,101	Hdq. Co.	164	
Hq.	405		3 Battalion	3,327	
Fixed Wing Sqdrns (2)	1,314		Artillery	668	
Rotary Wing Sqdrns (4)	1,229		Armor	110	
Support Units	1,153		Amph. Assault	229	
			Combat Eng.	130	
SSG		2,769	SSG Elements		443
Hdq. Co.	581		Engineer Co.	65	
Supply Co.	470		Bridge Ptn.	43	
Maint. Co.	375		Truck Co.	150	
Med/Dent. Co.	170		Land. Spt. Co.	35	
Eng. Co.	65		NMCB	150	
Truck Co.	171				
Fuel Co.	304				
Land. Spt. Co.	33				
NMCB	600				
	Subtotal	7,522		Subtotal	5,152
				Force Total	12,674

Table 4. Notional Force Structure
Scenario C: Rapid Strike
Airmobile Assault

Deployed to the Objective Area	
Infantry Battalion (Helo element)	900
Reconnaissance Det.	25
Combat Engineer Platoon	36
Landing Support Det.	31
Force Total	992

Table 5. Notional Force Structure
Scenario D: Mechanized Assault

Deployed to the Objective Area	
Infantry Battalion	1,109
Art. Battery	117
Reconnaissance Det.	25
Amph. Assault Det.	200
Combat Eng. Det.	72
2 Tank Platoons	44
Landing Spt. Det.	31
Bridge Platoon	43
Service Support Det.	75
Force Total	1,716

Table 6. Water Use Planning Factors

	Gal/Man/Day
- Drinking*	4.0
- Hygiene*	
Personal	2.7
Centralized	1.3
- Food Preparation*	3.0
- Vehicles	0.3
- Medical*	
Hospitals	1.0
Heat Treatment	1.0
- Graves Registration*	0.2
- Laundry	2.0
- Construction	1.5
- Aircraft	0.2
Total (1 & 2)	17.2
Factors for Loss	
- Waste/Evaporation (10% of Total)	1.7
Total	18.9

*Recommended joint planning factor: 20 G/M/D

Table 7. Required Operational Capabilities
Desert Water Supply Systems

Functions	Scenario "A"	Scenario "B"	Scenario "C"	Scenario "D"
Acquisition	· 340,000 gal/day · Organic or Navy Support · Ship Transportable · Deployable in 72 Hrs	· 375,000 gal/day · Organic or Other DOD Support · Ship Transportable · Deployable in 72 Hrs	· 10,700 gal/day · Organic · CH-53E · Deployable in 24 Hrs	· 33,000 gal/day · Organic · Truck Transportable · Deployable in 72 Hrs
Treatment	· 340,000 gal/day · Organic · Ship Transportable · Deployable in 24 Hrs	· 375,000 gal/day · Organic · Ship Transportable · Deployable in 24 Hrs	· 10,700 gal/day · Organic · CH-53E Transportable · Deployable in 24 Hrs	· 33,000 gal/day · Organic · Truck Transportable · Deployable in 24 Hrs
Storage	· 680,000 gallons · Organic · Ship Transportable · Deployable in 24 Hrs · Temperature Control	· 750,000 gallons · Organic · Ship Transportable · Deployable in 24 Hrs · Temperature Control	· 21,500 gallons · Organic · CH-53E Transportable · Deployable in 24 Hrs · Temperature Control	· 66,500 gallons · Organic · Truck Transportable · Deployable in 24 Hrs · Temperature Control
Distribution	· 226,500 gal/day · Organic · Truck Transportable · Deployable in 24 Hrs · Cooling & Temp Control	· 248,500 gal/day · Organic · Truck Transportable · Deployable in 24 Hrs · Cooling & Temp Control	· 7,100 gal/day · Organic · Helo Transportable · Deployable Immediately · Cooling & Temp Control	· 22,100 gal/day · Organic · Truck Transportable · Deployable in 24 Hrs · Cooling & Temp Control

Table 8. Water Acquisition Requirements

	Scenario "A"	Scenario "B"
Importation by Tanker		
Volume required/3 days	680,000 gallons	750,000 gallons
Programmed ships	TAK-X	TAK-X
Quantity required[a]	12	13
Transfer hose programmed	None	None
Transfer hose required (min)	10,000 feet	10,000 feet
Alternative vessels	barges	barges
Seawater Demineralization		
Volume required/day[b]	340,000 gallons	375,000 gallons
Programmed equipment	ROWPU	ROWPU
Quantity required	28	42
Intake or beach wells programmed	None	None
Intake or beach wells required	38	42
Groundwater Acquisition		
Sub-surface water detection equipment/data base programmed	None	None
High speed well drilling[c] equipment programmed	None	None
High speed well drilling rigs required	4	4
Deep well development kits, including pumps, programmed	None	None
Well development kits required[d]	4	5

[a] Assumes 6 day turnaround for resupply
[b] Assumes 450 gal/hr, 20 hrs/day
[c] Beyond current capability
[d] Based on 75 gal/min pumps at 800 ft bowl setting

Table 9. Water Treatment Requirements

	Scenario "A"	Scenario "B"	Scenario "C"	Scenario "D"
Daily requirement	340,000 gallons	375,000 gallons	10,700 gallons	33,000 gallons
Programmed equipment	ROWPU[a]	ROWPU[a]	None	ROWPU[a]
Quantity required[b]	29	32	undefined	3

[a]Includes filtration, demineralization and disinfection
[b]Assumes 600 gal/hr, 20 hrs/day

Table 10. Water Storage Requirements

	Scenario "A"	Scenario "B"	Scenario "C"	Scenario "D"
Volume required, 3 days	680,000 gallons	750,000 gallons	21,500 gallons	66,500 gallons
Programmed equipment for primary storage[a]	50K gal pillow tank	50K gal pillow tank	3K gal stove tank	20K gal pillow tank
Quantity required	14	15	7	4
Temperature protection programmed	None	None	None	None
Temperature protection kits required[b]	14	15	7	4

[a]Small secondary storage at water points assumed.

[b]Temperature control kits would also be required at secondary storage points, not included in quantity estimates.

Table 11. Water Distribution Requirements

	Scenario "A"	Scenario "B"	Scenario "C"	Scenario "D"
Daily volume	226,500 gallons	248,500 gallons	7,100 gallons	22,100 gallons
Large bulk transfer programmed	5,000 gal truck	5,000 gal truck	N/A	5,000 gal truck
Quantity required[a]	23	25	N/A	3
Small bulk transfer programmed	400 gal trailer or 500 gal FAWPSS or six-con module	400 gal trailer or 500 gal FAWPSS or six-con module	400 gal trailer or 500 gal FAWPSS or six-con module	400 gal trailer or 500 gal FAWPSS or six-con module
Water cooling programmed	"400 gal chiller"	"400 gal chiller"	"400 gal chiller"	"400 gal chiller"
Coolers required[b]	283	311	9	28
Quantity required[c]	283	311	9	28
Hose/reel systems programmed	None	None	N/A	None
Hose/reel systems required	40	40	N/A	40
Transfer pumps programmed	None	None	N/A	None
Transfer pumps required[d]	20	20		20

[a]Assumes 2 round trips/day per truck
[b]Assumes 1:1 ratio with small bulk transfer equipment
[c]Assumes 4 reels/mile, 10 mile transfer capability
[d]Assumes 1 pump/2 mile interval

Table 12. Recommendations for Additional Water Supply Capability

Capability	Requirement	Recommendation
<u>Water Acquisition</u>		
Transfer Hose	Floating hoseline of water compatible rubber for offloading moored vessels	Evaluate for procurement current water compatible floating fuel hose systems
<u>Seawater Demineralization</u>		
Beach intake wells	Intake device to exclude sand, debris, and sediment from ROWPUT feedwater	Procure off the shelf self-jetting well points
<u>Groundwater Acquisition</u>		
Data base	Data base on tappable groundwater resources in potential deployment areas	Develop and maintain a groundwater resource data base
Detection capability	Rapid techniques and methods for identifying high probabilities of accessible groundwater	Coordinate with Army efforts and explore independently promising technologies not within the Army program
High speed well drilling equipment	High speed, low skill requirement percussion/rotary drills to simultaneously drive drill pipe and casing, packaged for ship or military airlift	Develop militarized version of commercial equipment packaged for sealift or airlift deployment.
Deepwell development kits	Well casing, turbine pumps and piping for bowl settings up to 1,200 ft depth	Procure commercially available equipment
<u>Water Treatment</u>		
Small treatment unit	Lightweight, compact treatment equipment suitable for helo deployment of small forces	Development low skill requirement compact unit capable of providing 1,000 to 2,500 gallons/day output

continued

Table 12. Continued

Capability	Requirement	Recommendation
Water Storage		
Temperature Protection	Devices and procedures to reduce solar heating in bulk water storage	Develop insulation or solar protection devices and procedures for rapid erection in desert deployments
Water Distribution		
Hose/reel system	Rapidly deployable and retrievable hose laying system for bulk transfer of water in rear support areas	Adapt bulk fuel hose/reel technology currently under development to water transfer requirements
Mid-size water cooler	Water cooler with a capacity of 10 to 25 gallons per minute for use in staging and support areas	Develop appropriately sized unit
Temperature protection	Devices and procedures to reduce solar heating in small storage containers such as FAWPSS 500 gallon units	Develop suitable devices and procedures capable of rapid erection and retrieval

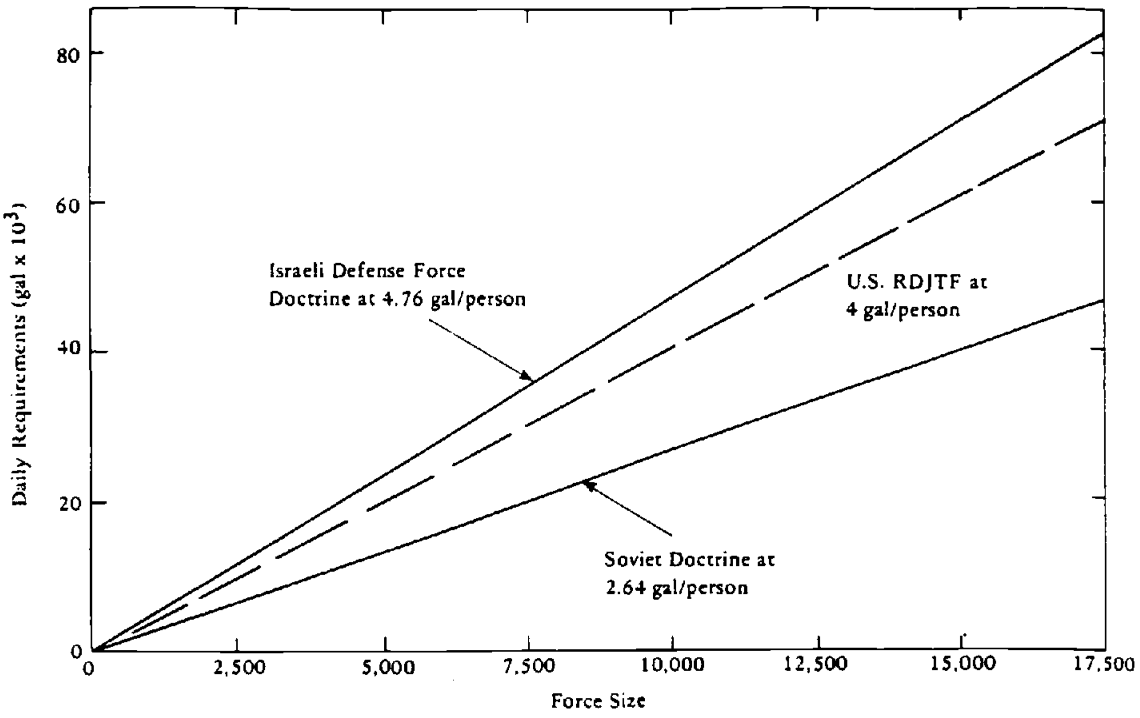


Figure 1. Drinking water supply requirements for desert forces.

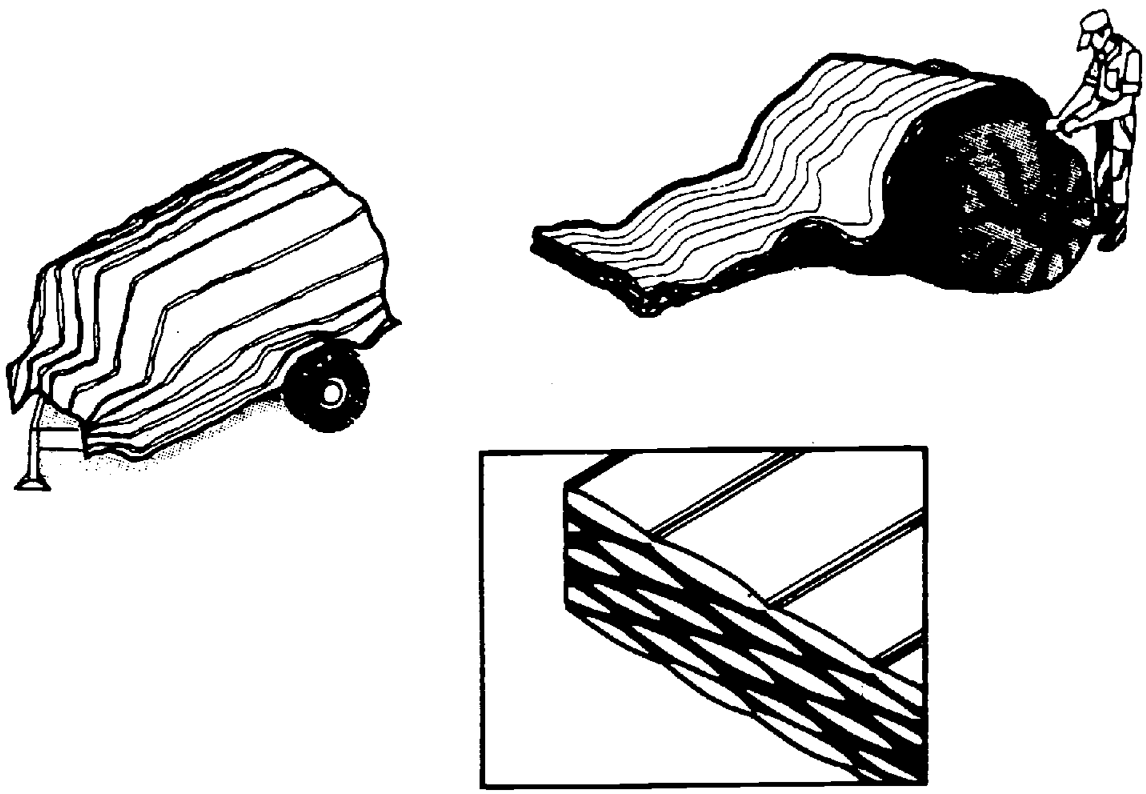
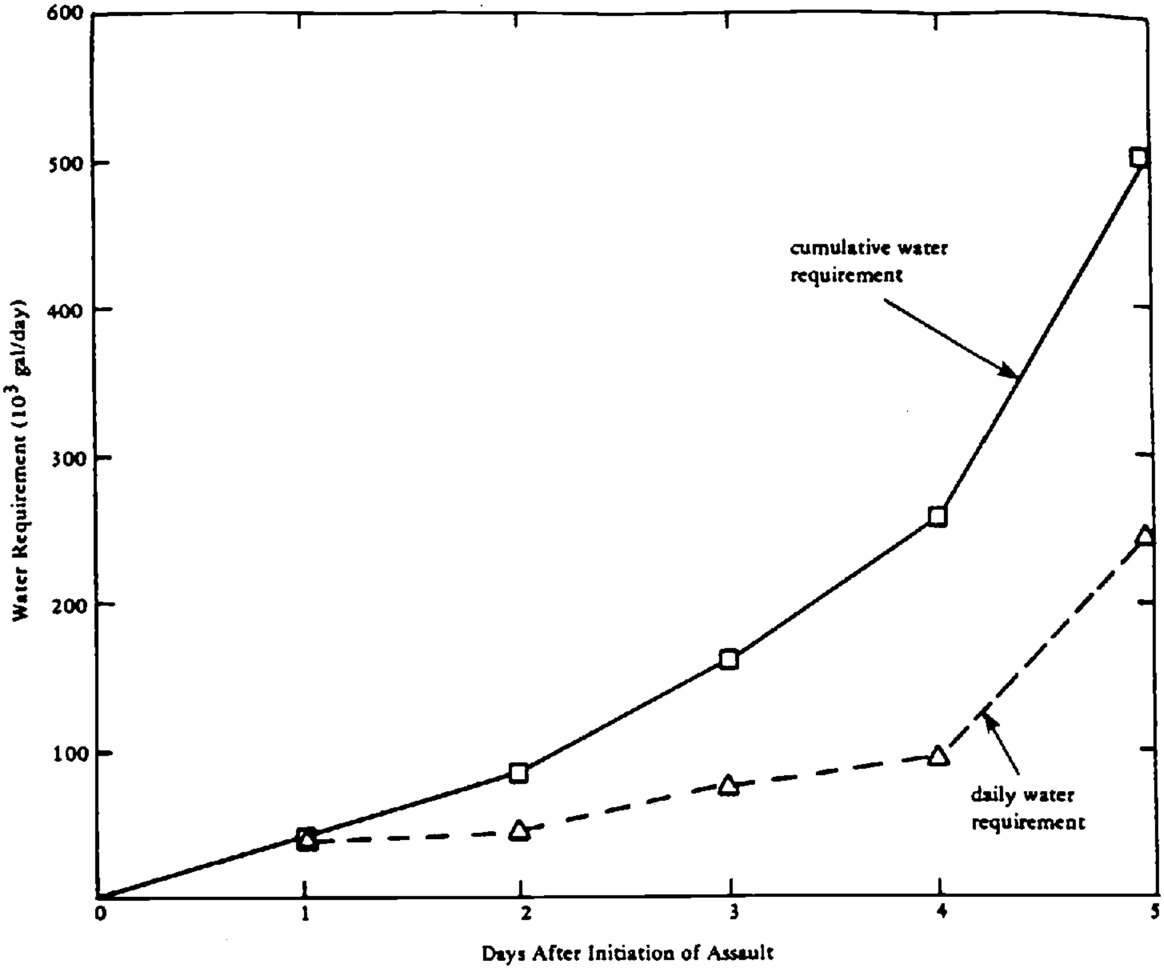


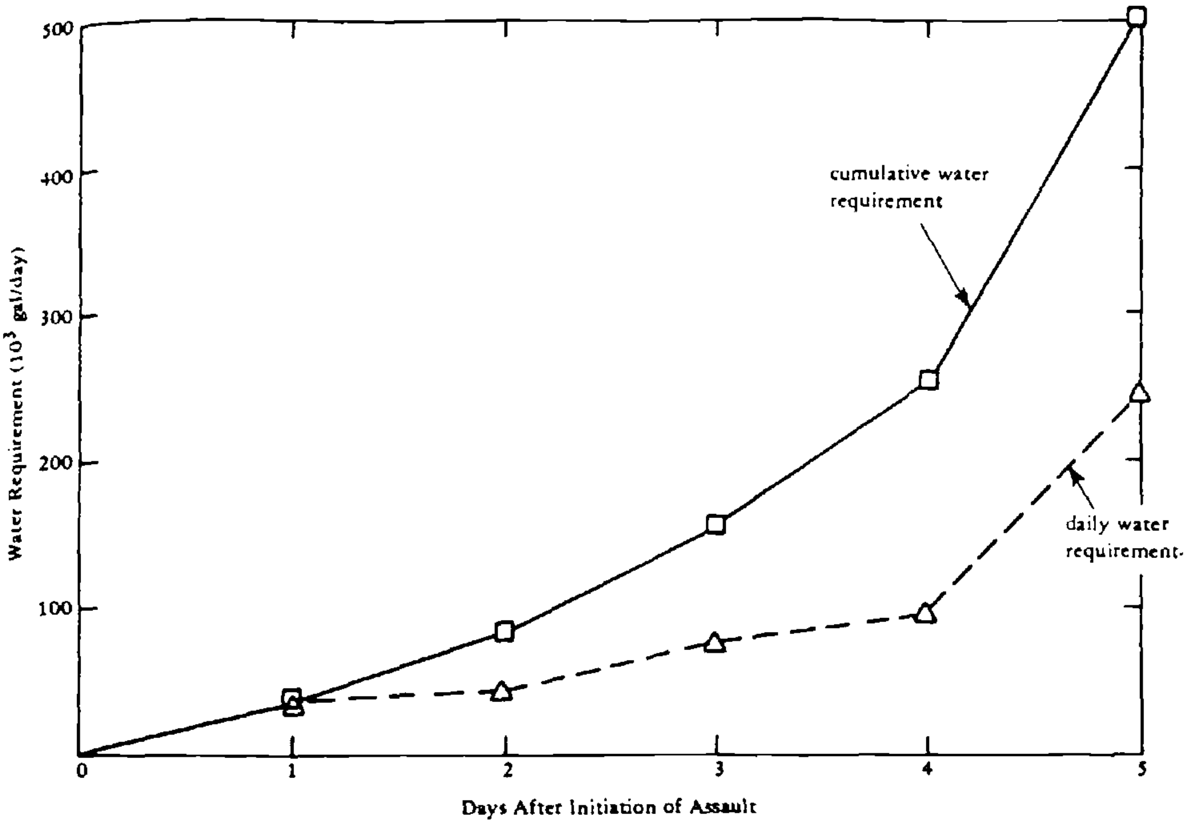
Figure 2. Insulation concept for keeping stored water cool.

Figure 3. Prototype desert canteen.



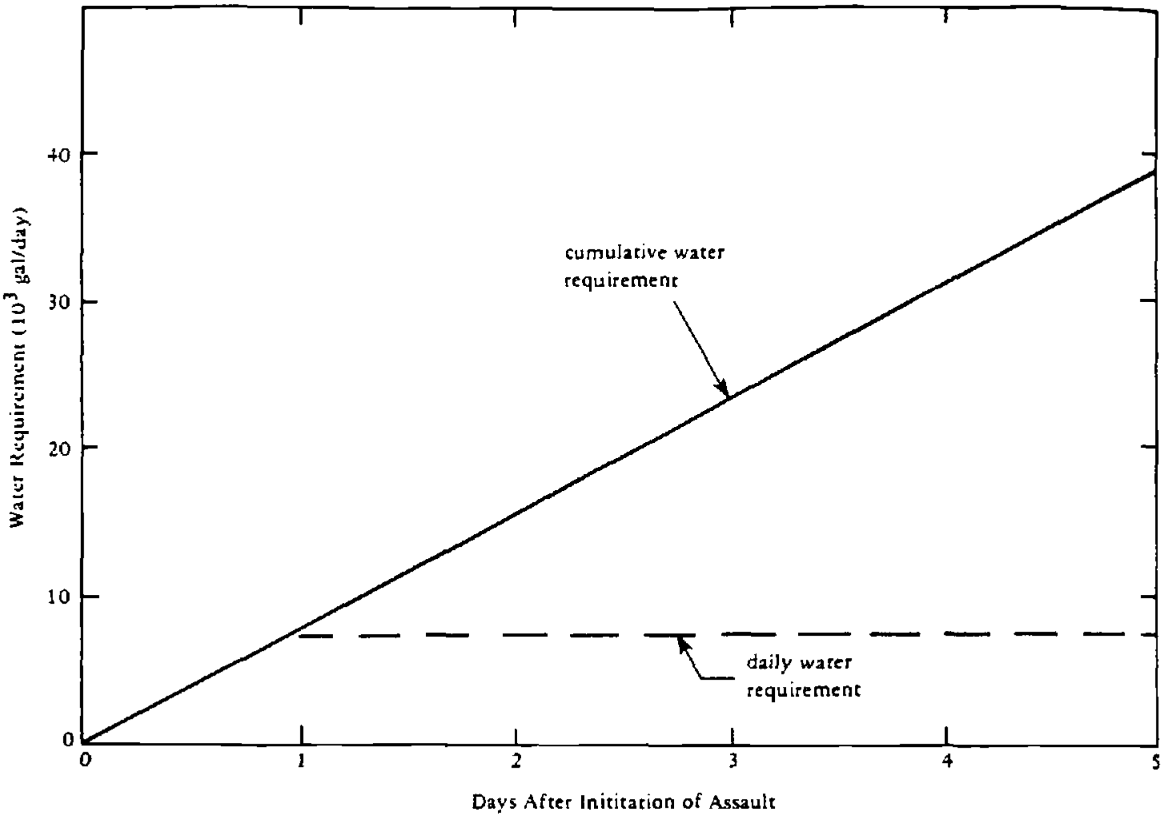
Day	Landing Elements	Personnel	Water Uses Added
1	Infantry, artillery, combat support units	4,350	Drinking, pers hygiene, heat treatment, vehicles
2	Armor, artillery, bulk fuel	531	
3	Truck, fuel, air support, medical, engineering	2,669	Hospital
4	Rotary wind sqdn (4) SSG HQ	1,810	Aircraft
5	Fixed wind sqdn (2), maint, NMCB	3,314	Bath, mess, laundry, construction, Graves Reg
	Total	12,674	

Figure 4. Assault phase water requirements, scenario A.



Day	Landing Elements	Personnel	Water Uses Added
1	Infantry, armor, combat support units	4,109	Drinking, pers hygiene, heat treatment, vehicles
2	Artillery	668	--
3	Medical, fuel co., truck co., air spt, engineering	2,773	Hospital
4	Rotary wing sqdn (4) SSG HQ	1,810	Aircraft
5	Fixed wing sqdn (2), supply maint, NMCB	3,314	Bath, mess, laundry, construction, Graves Reg
	Total	12,674	

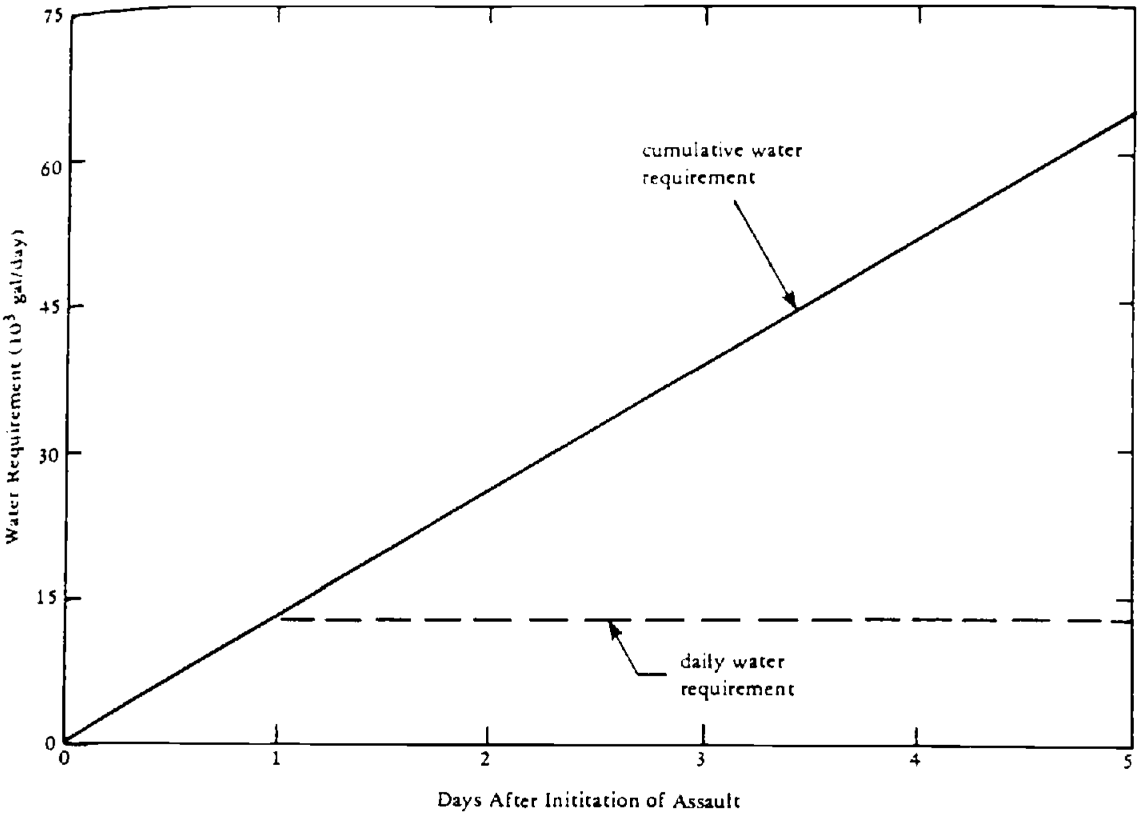
Figure 5. Assault phase water requirements, scenario B.



Day	Assault Elements	Personnel	Water Uses Added
1	Infantry, Recon, combat engr, land spt	992	Drinking, pers hygiene, heat treatment
2	No additional personnel		–
3	No additional personnel		–
4	No additional personnel		–
5	No additional personnel		–
	Total	992	

Note: Services such as hospital, etc., are assumed to be at rear base areas, and personnel are evacuated for service.

Figure 6. Assault phase water requirements, scenario C.



Day	Assault Elements	Personnel	Water Uses Added
1	Infantry, artillery, recon, armor, combat support elements	1,716	Drinking, pers hygiene, vehicles, heat treatment
2	No additional personnel		–
3	No additional personnel		–
4	No additional personnel		–
5	No additional personnel		–
	Total	1,716	

Note: Services such as hospital, etc., are assumed to be at rear base areas, and personnel are evacuated for service.

Figure 7. Assault phase water requirements, scenario D.

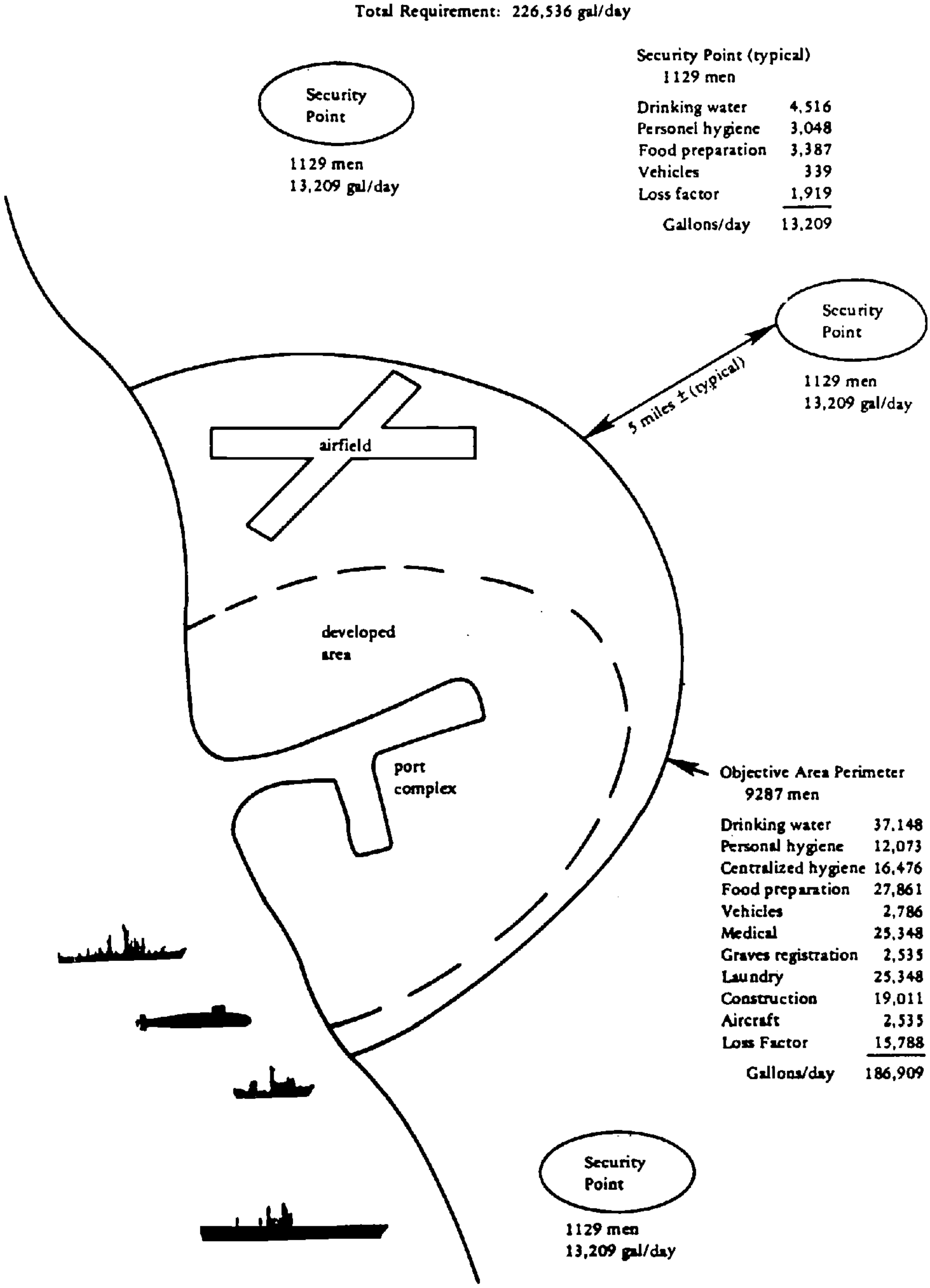
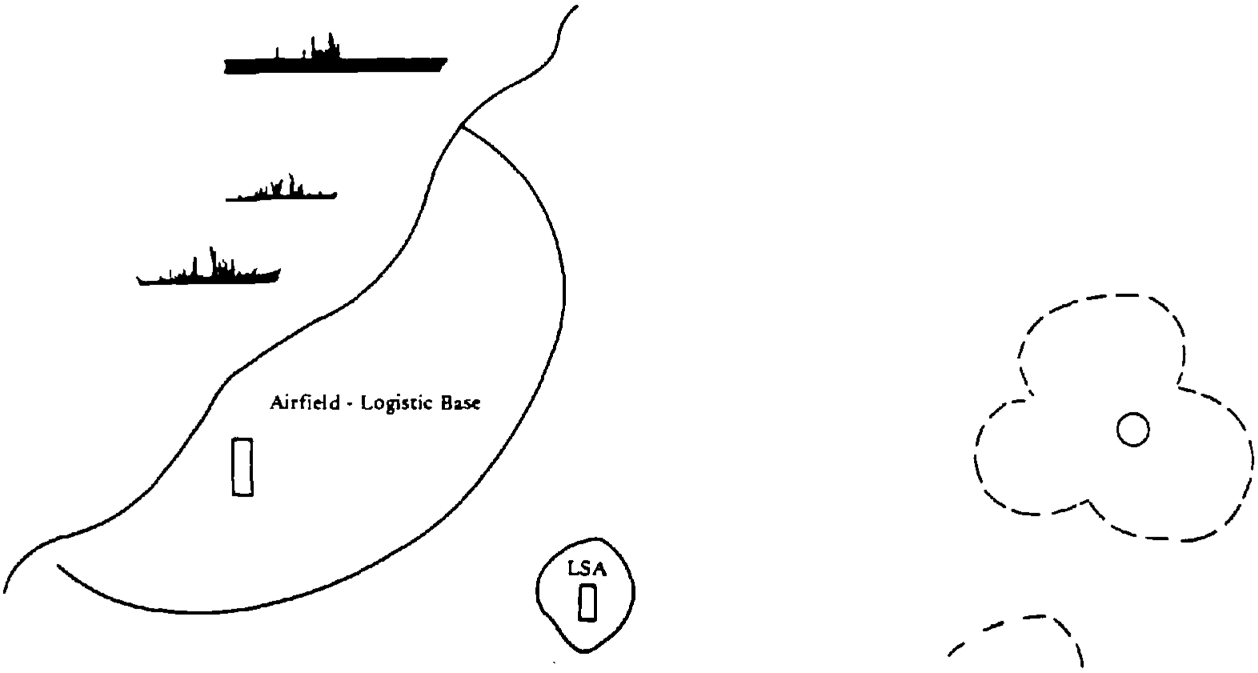
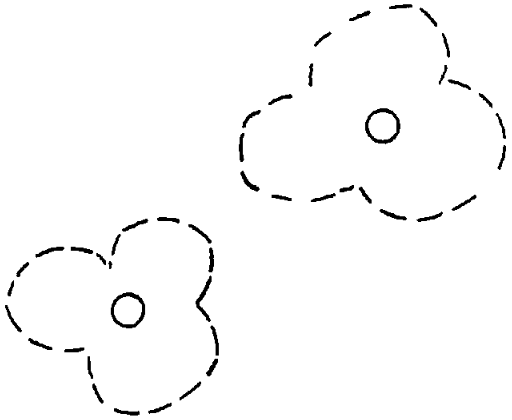


Figure 8. Scenario A: fixed developed objective.





Stationary Elements
Airfield - Logistic Base
7522 men

Drinking water	30,088
Personel hygiene	20,309
Centralized hygiene	16,476
Food preparation	38,022
Vehicles	2,256
Medical	20,196
Graves registration	2,535
Laundry	25,348
Construction	19,011
Aircraft	2,535
Loss Factor	24,749
Gallons/day	201,525

Moving Elements
5152 men

Drinking water	20,608
Personel hygiene	13,910
Vehicles	1,546
Medical	5,152
Loss factor	5,770
Gallons/day	46,986

Figure 9. Scenario B: amphibious assault and conventional advance.

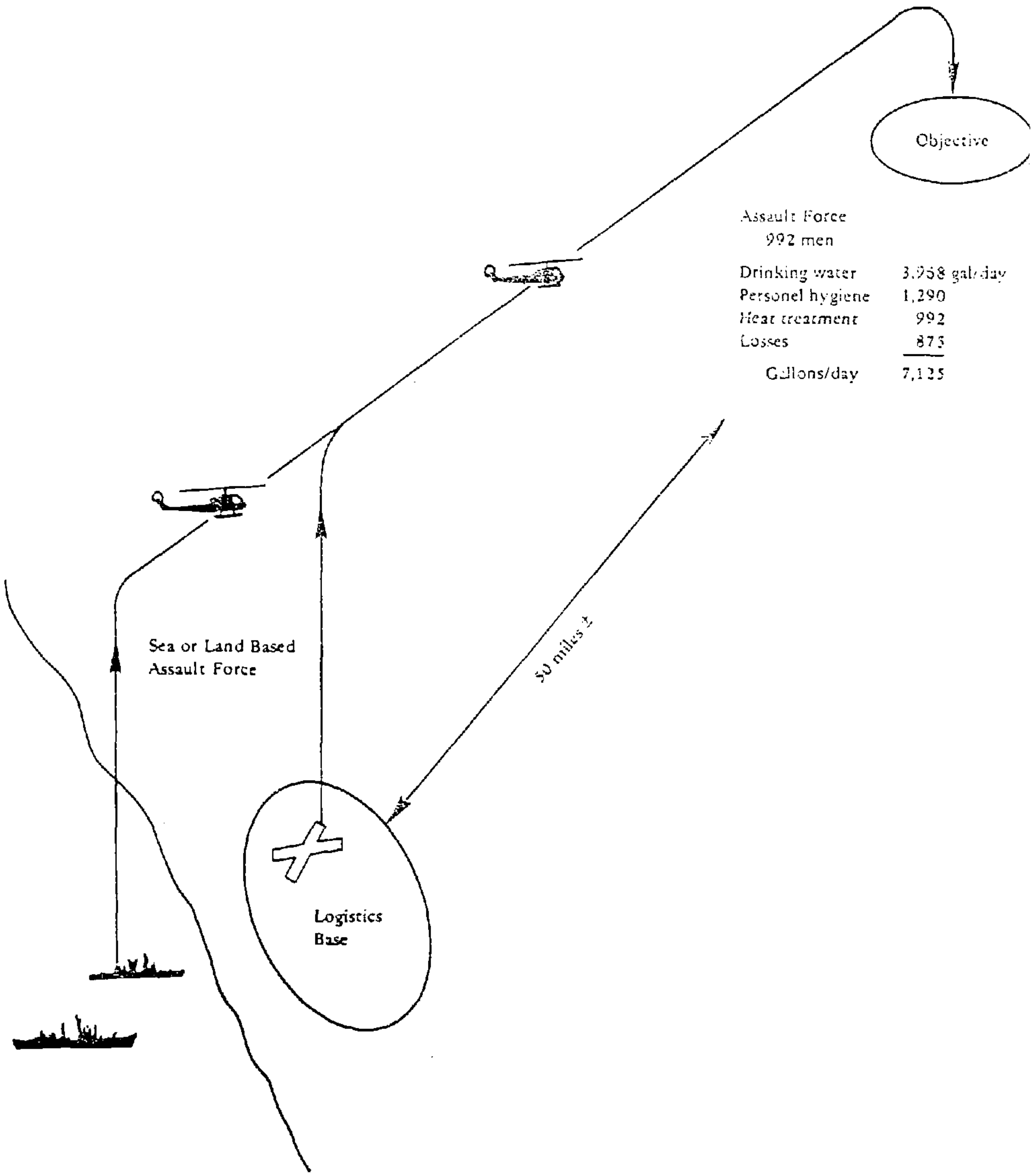


Figure 10. Scenario C: rapid strike airmobile assault.

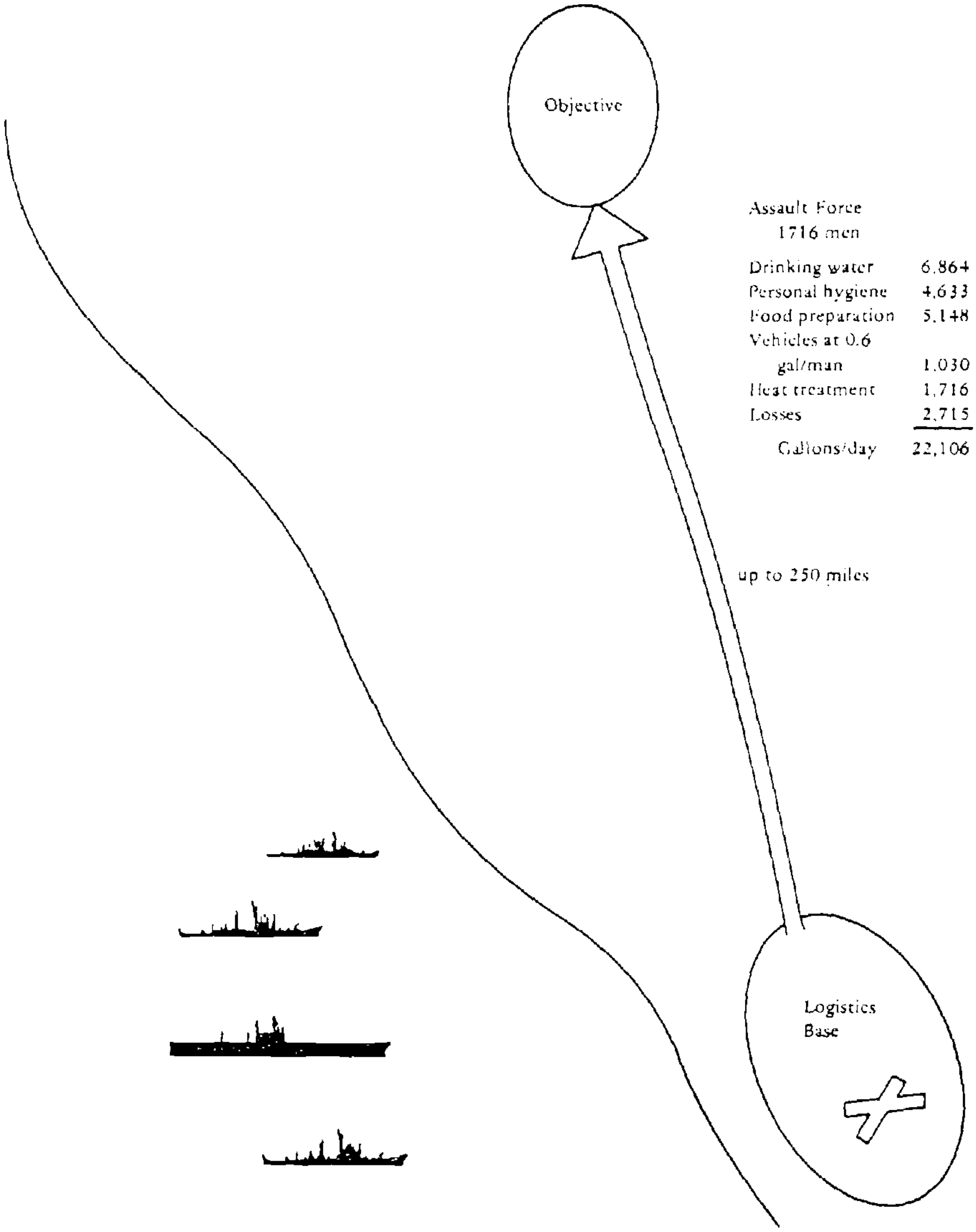


Figure 11. Scenario D: mechanized assault force.

Appendix A

DESERT WATER SUPPLY: GEOGRAPHICAL AND CLIMATOLOGICAL CONSIDERATIONS

ACKNOWLEDGMENT

This Appendix draws on material developed by the Office of Arid Lands Studies of the University of Arizona, Tucson, Arizona, under contract to the U.S. Army. This study appears as Reference A-1 at the end of this Appendix. Other sources used were the U.S. Army Natick Laboratories' Technical Report 69-38-ES (Ref A-2), U.S. Army Field Manual FM 90-3 (Desert Operations, Ref A-3), and Reviews of Research on Arid Zone Hydrology published by UNESCO (Ref A-4).

by

Leslie Karr
Tim Foresman

CONTENTS

I. DESERT DEFINITION

There are many distinctive environmental traits that distinguish the dry lands of Earth, but the essential trait, and the one upon which all others depend, is the lack of precipitation. Just how little precipitation places an area in the desert category is not self-evident. It has been stated that the essential feature of a dry climate is that the potential evaporation from the soil surface and from the vegetation should exceed the average annual precipitation.

It is known that temperature is a climatic factor that affects rate of evaporation most strongly, and as temperature observations are widely available, some sort of ratio involving precipitation and temperature is most useful in expressing the aridity of an area. A system was developed that uses an index based upon the adequacy of precipitation in relation to the hypothetical evapotranspiration of natural vegetation. Where the precipitation analyzed month by month is just adequate to supply all the water that would be needed for maximum evaporation and transpiration in the course of a year, the moisture index would be 0. Climates with an index between 0 and -20 are considered subhumid, between -20 and -40 semiarid, and below -40 arid. It should be noted that within deserts there are many degrees of dryness; such terms as "arid," "desert," semi-arid," semidesert," "absolute desert," "total desert," and "extreme desert" are used in many ways by many authorities. We may define the true or extreme desert as one in which a given locality has recorded at least 12 consecutive months without rainfall, and in which there is not a regular seasonal rhythm of rainfall.

Temperatures vary according to latitude and season, from over 136°F (57.8°C) in Mexico and Libya to the bitter cold of winter in the Gobi in East Asia. In some deserts, day to night temperature fluctuations can exceed 70°F (21°C).

Desert terrain varies considerably from place to place, the sole common denominator being lack of water with its consequent environmental effects, such as little if any prominent vegetation. There are three types of deserts: mountain, rocky plateau, and sandy or dune deserts.

Mountain deserts are characterized by scattered ranges or areas of barren hills or mountains, separated by dry, flat basins. High ground may rise gradually or abruptly from flat areas to a height of several thousand feet above sea level. Most of the infrequent rainfall occurs on high ground and runs off rapidly in the form of flash floods, eroding deep gullies and ravines and depositing sand and gravel around the edges of the basins. Water rapidly evaporates, leaving the land as barren as before, although there may be short-lived vegetation. If sufficient water enters the basin to compensate for the rate of evaporation, shallow lakes may develop, such as the Great Salt Lake in Utah or the Dead Sea; most of these have a high salt content.

Rocky plateau deserts have relatively slight relief interspersed by extensive flat areas with quantities of solid or broken rock at or near the surface. They may be cut or dry, steep-walled eroded valleys, known as wadis in the Middle East and arroyos or canyons in the United States and Mexico. The narrower of these valleys can be extremely dangerous to men and materiel due to flash flooding after rains, although their flat bottoms may be superficially attractive as assembly areas. The Golan Heights is an example of rocky plateau desert.

Sandy or dune deserts are extensive flat areas covered with sand or gravel, the product of ancient deposits or modern wind erosion. "Flat" is relative in this case, as some areas may contain sand dunes that are over 1,000 feet (305 m) high and 10 to 15 miles (16 to 24 km) long; trafficability in such terrain will depend on windward/leeward gradients of the dunes and texture of sand. Other areas, however, may be totally flat for distances of 3,000 meters (9,843 feet) and beyond. Examples of this type of desert include the ergs of the Sahara, the Empty Quarter of the Arabian Desert, areas of California and New Mexico, and the Kalahari in South Africa.

II. DESERT GEOGRAPHIC DESCRIPTIONS

The locations of the following desert areas are indicated in Figures A-1 through A-7. In general, the dry climates of the continents occur in five great provinces separated from one another by oceans or by wet equatorial zones. The bulk of the desert lies between 15° and 35° latitude (in both the northern and southern hemispheres), and extends to 55°N latitude in some cases. Of these five provinces, the North Africa-Eurasia province is larger than all the remaining dry areas of the world combined. It includes the world's largest desert, the Sahara.

Sahara

The Sahara extends from the Atlantic coast of Africa to the Red Sea (Figure A-1). It measures more than 3,000 miles (4,827 km) from east to west and 800 to 1,200 miles (1,287 to 1,931 km) from north to south. Its northern boundary starts near the Wadi Dra on the Atlantic Coast near Goulimine, follows eastward along the Saharan Fault to Erfoud, Figuig, and Biskra, and there dips southward to the Gulf of Gabes. The southern boundary, which generally follows the 16th parallel (north), is not as well defined, being a broad transitional area between desert and semidesert. The total area of the Sahara is between 3,000,000 and 3,500,000 square miles (7,770,008 and 9,065,009 sq km).

The Sahara is not only the largest desert on Earth, but it also includes some of the hottest and driest areas and the greatest expanses of sand. The Great Tanezrouft has an annual precipitation of less than 1 inch (25.4 mm) and may experience several years without appreciable precipitation. The highest temperature recorded anywhere is 136.4°F (58°C) in the shade at El Azizia in Libya. Libya also has the most extensive sand desert in the Sahara, covering an area of about 750 by 300 miles (1,207 by 483 km).

The Sahara has a Mediterranean climate in the north and a tropical climate in the south. The Mediterranean climate, with an emphasis on winter precipitation, is the predominant influence extending from Spanish Sahara through Morocco, Algeria, Tunisia, Libya, and Egypt. The central portion of this area is extremely dry and hot. The northern portion has cool-to-warm winters and warm-to-hot summers.

The southern Sahara falls in the intertropical convergence zone. Countries containing tropical desert portions of the Sahara are Cameroon, Chad, Mali, Mauritania, Niger, Nigeria, Sudan, and Upper Volta. This area has warm winters, hot summers, and predominantly irregular and scanty summer rainfall.

The Sahara embraces a variety of landscapes, including mountain massifs, great flat areas of stone and gravel, and huge expanses of sand. Geologically it is a series of elevated areas and closed basins.

The elevated areas include the foothills of the Atlas on the north, the great Ahaggar (Hoggar) massif in southern Algeria, and the 11,000-foot (3,353-m) Tibesti massif in northern Chad, as well as lesser plateaus and mountain ranges. The elevated plateaus or hamadas are often very extensive. Outwash material from them eroded by wind into rocky desert pavement is the source of regs (stony desert plains), which often cover large areas. Extensive sand dune areas, called ergs, have formed from wind-blown sand. The largest of these ergs, located in the Libyan desert, embraces an expanse of sand as large as France. Second in size is the Grand Erg Occidental in Algeria.

Somali-Chalbi

In East Africa lie the hot lowlands of the Somali-Chalbi, which bear certain affinities to much of the southern part of the Arabian Peninsula. Delineations of the Somali-Chalbi (Figure A-1) vary according to scientists. One has extended the desert climate classification in a narrow band along the African shores of the Red Sea and Gulf of Aden and, in a slightly wider band, southward along the east coast bordering the Indian Ocean to just south of the equator, with an extension inland near the southern extremity. Another includes an area along the coast of the Red Sea extending northward to approximately 12°N latitude. The western boundary of his arid area starts at the coast at approximately 40°E and extends southward, bearing slightly to the east, to a point at approximately 10°N, then eastward nearly to Cape Guardafui, then in a southwesterly direction, following along the western boundary of Somali and extending into Kenya to the south. An arid area is also shown surrounding Lake Rudolf.

The Somali-Chalbi area, like the southern Sahara, is under the intertropical convergence influence, but the low rainfall is related to orography, thermal low pressure, and coastal upwelling. The (light) precipitation season varies from winter or no seasonality in the north of the area to summer in the south, with a lack of definite seasonality in between. The climate is generally hot with little temperature variation from winter to summer.

Within this same province lies a series of other hot deserts and semiarid areas that continue eastward through the Arabian Peninsula, along the Persian Gulf, to Pakistan and India.

Arabian Desert

The Arabian Desert (Figure A-2) includes the nations of the Arabian Peninsula and Jordan, Iraq, Israel, Syria, and a small part of Iran. Roughly a rectangle, its longer axis extends from southeast to northwest through the Arabian Peninsula to the Mediterranean Sea. It includes the Syrian, Saudi, Aden, and Tihama deserts, and the very dry Rub' al Khali.

The Arabian desert area has been classified in slightly differing ways. One authority has classified most of the area either E (extremely arid) or A (arid) except for high elevations in the southwest of the Arabian Peninsula, a small area bordering the Gulf of Oman, the northernmost part of Iraq, and the northern two-thirds of Syria. The second authority shows the area varying from "sub-desert" to "true desert."

The southern portion of the Arabian Desert is much like the Sahara, with a small area of extreme aridity along the southwest coast of the Arabian Peninsula and a larger area in the southeast. Practically all of the peninsula is arid or extremely arid. A Mediterranean influence and winter precipitation govern in the northern third; scanty rainfall occurs any season of the year in the southern half. The southern portion is hot in all seasons; moving northward, the winters gradually change to milder, but without much, if any, relief from summer heat.

The western corner of this desert is characterized by a coastal plain and a mountainous belt with elevations up to 3,600 feet (1,097 m) dropping off on the east side to deep valleys, which are bordered on the east by plateau country. There are sand dunes along the sea coast, but most of the area has a cover of desert soils.

The Arabian Peninsula has a basement of crystalline rocks that reaches an altitude of more than 9,300 feet (2,835 m) in the western highlands. It is overlaid in places with sedimentary rocks and by great sand desert areas, including the great An Nafud (Nefud) in the north and the Rub' al Khali in the south-central area.

Sand dunes of the erg type occur in a broad arc extending from southern Jordan through northeastern and eastern Saudi Arabia to the vast expanse of the Rub' al Khali. Stony and gravelly plains cut by wadis, along with barren and rocky desert mountains, form another arc beginning in western Iraq and curving through Jordan, the Negev in Israel, Sinai, western Saudi Arabia, Yemen, and South Arabia.

The Thar

The Thar (Figures A-2 and A-3), sometimes called the Indian Desert, includes the arid portions of western India and eastern West Pakistan. Some authors identify the area eastward to the Aravalli Range and southward into Sind as arid. There is some question, however, as to how much of this area is naturally arid and how much of its arid appearance has resulted from the activities of man.

The Thar is in a transition zone between major wind belts. Mid-latitude cyclones produce moderate amounts of winter precipitation in the northern and western portions, while the eastern portion receives its rainfall from the monsoon circulation that dominates the subcontinent in summer. The monsoon movement of moist air terminates in western India, resulting in a small and irregular rainfall in the Thar. Summers are hot and winters warm throughout the area.

The entire desert consists of level to gently sloping plains broken by some dunes and low barren hills. For the Thar as a whole, interspersed sandy and medium- and fine-textured surface materials are dominant. Sand dunes occur within the Thar Desert area of the Indus plain and more widely outside the plain.

Iranian Desert

To the north lie the milder cool-winter dry areas of the Mediterranean coast and Iran. The Iranian Desert (Figure A-2), which includes parts of Iran, Afghanistan, and Pakistan (the Baluchistan area), is one of the smallest desert areas and one of the least known. It has been classified as arid with cool winters, winter precipitation, and warm-to-hot summers. It includes five major units: the Dasht-e-Kavir in the northwest, the Kavir-i-Namak in the north, the Dasht-e-Lut in the southwest, the Dasht-i-Naomid in the east, and the Dasht-i-Margo in the southeast.

The Iranian Desert has primarily a Mediterranean type climate with winter rainfall produced by cyclonic storm systems. The winters are cool and the summers hot.

Central Asia: The Turkestan Desert

Farther northward and eastward lie the vast deserts and steppes of the U.S.S.R., China, and Mongolia, with subfreezing winters and warm or hot summers.

The Turkestan Desert (Figure A-2) lies in the U.S.S.R. between 36° and 48°N and between 50° and 83°E. It is bounded on the west by the Caspian Sea, on the south by the mountains bordering Iran and Afghanistan, on the east by the mountains bordering Sinkiang, and on the north by the Kirgiz Step'. The region is an immense undrained basin with parts below sea level. Very young dry land areas are encountered, formed as a result of drying up of lake basins and the drop in the level of the Caspian Sea. The average precipitation varies from 3 to 8 inches (76-203 mm), falling in winter or spring, leaving the summer months without precipitation. Except in the far north, the Turkestan Desert has a Mediterranean type of moisture distribution but with colder winters than in typical Mediterranean climates. Throughout the area winters are mostly cold and the summers hot or very hot. The temperature range is great: summer high temperatures reach 115°F (46°C), and winter low temperatures may drop to -40°F (-40°C).

Elevations within the basin vary from 85 feet below sea level near the Caspian Sea to about 1,200 feet (3,660 m) toward the eastern boundary. The Turkestan Desert includes extensive sand dunes, alluvial plains, fine-textured depressions or river terraces, and floodplains. Two large rivers, the Amu-Dar'ya and Syr-Dar'ya, rise in the high mountains southeast of the Kyzyl-Kum and flow northwestward into the Aral Sea. The Ili River rises in the Ala-Tan Mountains and flows into Lake Balkhash.

Central Asia: The Takla-Makan and Gobi Group

Desert and semidesert comprise the most extensive natural region of China, more than 1.75 million square kilometers (675,675 square miles), extending to the middle course of the Hwang Ho (Yellow River) in the east (Figure A-3). The Gobi, largest desert in Asia, lies in Outer Mongolia (Mongolian Peoples' Republic) and mainland China's Inner Mongolian Autonomous Region. The deserts of Outer Mongolia change gradually, going northward into desert steppes and then into steppes. To the southwest of the Gobi lies the Takla-Makan; between them and south of the Gobi lie other desert areas, including notably the Bei Shan (Peishan, Beichan) Tsaidam, Ala Shan (Ala-Chan), and Ordos.

The desert areas of Asia represent diverse conditions. The mean elevations are: Dzungaria, 150 to 600 meters (492 to 1,968 feet); Takla-Makan, 700 to 1,400 meters (2,296 to 4,593 feet); Bei Shan (Beichan), 1,000 to 2,000 meters (3,281 to 6,562 feet); Ala Shan, 800 to 1,600 meters (2,625 to 5,250 feet); Ordos, 1,100 to 1,400 meters (3,609 to 4,593 feet); and Tsaidam, 2,700 to 3,100 meters (8,859 to 10,171 feet).

Rocky and pebbly deserts predominate in this part of the world, in contrast to the Turkestan Desert. In general, the area lacks external drainage and receives very little rainfall; mean annual precipitation seldom exceeds 100 mm (4 in) and may be below 50 mm (2 in). The driest parts are eastern Kashgaria, Bei Shan, and Tsaidam. In the Turfan and Hami depressions, both below sea level, the summers are hotter than in the tropics and the frost-free season is 240 days; elsewhere the vegetation must contend with extremely low winter temperatures. January means are from -6°C to -19°C (21°F to 2°F) and warm summers with July averages of 24°C to 26°C (75°F to 79°F).

Takla-Makan. The Takla-Makan (Figure A-3), in common with other Central Asian deserts, owes its dry climate to the high mountains and great distance separating it from moisture sources. The Tibetan plateau, 2,000 miles (3,218 km) in length and with an average elevation of 12,000 feet (3,658 meters), forms an effective barrier to moisture moving northward from the Indian Ocean. It is an area of hot summers and cold winters with no particular seasonality for the scanty precipitation. A large portion of the Takla-Makan is extremely arid. The remainder of the area is arid as far as can be determined from available records. The southward-moving, shifting sands occupy much of the central part of the Takla-Makan.

Gobi. The Gobi is a repeating sequence of mountains, gravelly and stony footslopes, plains, and gentle slopes and depressions, giving a mountain-and-basin landscape with some basins up to 5 to 20 miles (8 to 32 km) across. Sand dunes are extensive in some parts of the Gobi and may be found nearly anywhere on the plains; they are not nearly as extensive, however, as within the Takla-Makan.

Kalahari-Namib

The South African dry province consists chiefly of the narrow elongated coastal desert of the Namib, and the Karroo and Kalahari and steppe uplands.

The Namib extends 1,750 miles (2,816 km) from Luanda (8° 45'S) in Angola to St. Helena Bay (32° 45'S) in the Republic of South Africa (Figure A-4). The extreme desert extends from about 18° to 29°S latitude, or less than half the total length of the desert; its width from the coastline to the Great Western Escarpment is about 100 miles (161 km) at most places. The Namib receives an average of less than 2 inches (51 mm) of rainfall but benefits from sea fog and dew, and in some areas it supports a scanty vegetation. Extreme desert conditions are found along the west coast and semiarid conditions inland toward the escarpment. In the northern and central portions, it is bordered by the grasslands and thornbush country of the plateau. In the south, it merges eastward into the Kalahari and Karroo.

The Kalahari, in popular concept, occupies Botswana and eastern South West Africa, from the Okavango River in the north to the northern border of South Africa in the south. The northern part, however, has neither the climate nor the vegetation of true desert; referred to locally as "thirstland" and lacking surface water because of deep layers of subsurface sand, it supports a year-round stand of trees and grass following the December-to-March rains.

From 22°S latitude southward to the Orange River, however, the Kalahari is more truly desert, receiving only little and unreliable rainfall in the summer, and supporting scattered small trees, bushes, and, in occasional wet years, summer grasses. South of the Orange River, the Karroo subdesert receives both summer and winter rains, and the wooded grassland gives way to scattered low succulent shrubs.

The Kalahari-Namib desert of southern Africa lies in a transition zone with a tropical storm pattern on its equatorward margins and winter cyclonic precipitation on its poleward borders.

The Namib varies from extreme desert conditions to desert and from hot to mild (but it is mostly mild). In the northern part, there is no seasonality to precipitation; in the southern portion, winter precipitation is the rule.

The Kalahari is arid with summer precipitation and mild-to-hot temperatures in the north, and with winter precipitation and cool-to-warm winters and warm-to-hot summers in the south.

The northern terrain subdivision, comprising about 60% of the entire length of the Namib, and extending from Luanda to Walvis Bay, consists principally of bedrock surfaces with a sandy strip along the coast. The central subdivision from Walvis Bay to Luderitz is a vast extent of tremendous sand dunes with some crests 800 feet (244 m) above the troughs. They occur in windrows with a northwest-southeast orientation.

The true Kalahari is a huge sand-filled basin. The landscape is dominated by gentle dunes 100 to 500 feet (30.5 to 152 m) apart and often miles in length. There are no large areas of rock.

The soils of the Kalahari-Namib desert area are generally weakly developed. Except for the mountainous section inland from the Namib coast, the entire area is a plain broken by shifting sand dunes.

Australian Deserts

The Australian dry province occupies a large portion of the continent, with hot climates prevailing in the northern half of the province and mild climates in the southern. Records are lacking for much of the arid portion of Australia, and a considerable difference of opinion exists among Australians about the extent and nature of aridity there. It would appear that at least half and perhaps considerably more of the Australian continent is arid. Some deserts are sandy; the others are stony. The three largest deserts, the Great Sandy, the Great Victoria, and the Simpson (Arunta), consist of parallel sand ridges sometimes more than 100 miles (161 km) long. The stony desert areas include the Gibson desert in Western Australia, the desert area west of Lake Eyre in South Australia, and the Sturt desert in the northeast corner of South Australia extending into Queensland.

The arid land of Australia (Figure A-5) is affected by tropical weather in the north and by midlatitude cyclones in the south. The climate is of the monsoonal type north of about 20°S and Mediterranean type south of about 32°S. The intermediate area receives little benefit from either system. The entire arid area has mild winters and warm-to-hot summers.

The desert area of Australia lies mostly on the Great Plateau (1,000 to 2,000 feet or 305 to 610 meters elevation). Lying above this are longitudinal sand ridges of great extent. The landscape of arid Australia gives the appearance of a vast plain interrupted by occasional desert mountains, large and small tablelands, and sand dunes, with many saline depressions and floodplains for intermittent streams.

Monte-Patagonian Desert

The South American dry province is confined to a strip along the west coast and an area on the east side of the Andes toward the southern portion of the continent. The Monte-Patagonian Desert (Figure A-6) is located in the rainshadow of the Andes Mountains. The northern portion, the Monte, is an area of mountains, valleys, and extensive depressions occupied by saline deposits. Its extension into Bolivia is sometimes treated with Atacama information for convenience. The southern portion, the Patagonian Desert, consists of low tablelands dissected by stream valleys.

Monte. The Monte phytogeographical province extends from 24° 35'S to 44° 20'S in the center of Patagonia, and from 62° 54'W on the Atlantic coast to 69° 50'W inland. It is located in the pre-Andean region occupying intermountain bolsons (flat valleys) where the moist air currents rarely penetrate. Precipitation, which occurs mostly in summer, is generally less than 200 mm (8 in.). Winters are cool and summers are mild. No permanent streams reach the ocean from this area.

Monte type conditions develop in depressions, which are typically circular or elliptical. They are flat-bottomed and often limited by very high mountain ranges. Main landscape types are muddy depressions (barrioles), salt pans, dunes, slopes, badlands, permanent rivers, mountain torrents, brackish soils, alluvial cones, and tablelands.

Patagonian Desert. An arid zone is delineated along the entire length of Argentina, bordering the eastern base of the Andes Mountains to the west, stretching eastward an average distance of about 350 miles (563 km) into the plains, and extending southward all the way to the sea. It forms a coastal desert and steppe for 1,000 miles (1,609 m) from approximately 39° to 53°S. The Patagonian Desert (Figure A-6), the only high-latitude east coast desert, has no counterpart among the Earth's deserts. It owes its dryness to the Andes Mountains, which form a barrier to the rain-bearing air masses from the west and to the cold Falkland current off the east coast.

The climate is cold temperate, very dry, and windy. Precipitation varies from 150 to 300 mm (6-12 in.), falling principally during the warm season. The terrain consists of extensive plateaus more than 3,000 feet (914 m) high in many places. The plateaus slope toward the sea and end in cliffs along the coast. The rivers flow through deeply incised narrow valleys.

Atacama-Peruvian

The Atacama (Figure A-6) has been described as the driest coastal desert in the world; the vegetation must contend with an annual rainfall at Atica and Iquique of less than 0.04 inch (1.0 mm). At the southern limit of the Atacama, near the town of Copiapó, the annual rainfall is 2.52 inches (64 mm). On the basis of rainfall and vegetation, the Rio Limari, 60 miles (96.5 km) south of La Serena, is taken as the southern limit of the "regular" desert. To the north, the desert of Chile merges into the Peruvian coastal desert, which extends northward nearly to Ecuador.

The Peruvian coastal desert becomes slightly less arid northward as does the Atacama southward. The whole area has a mild climate year-round, with little variation in temperature from summer to winter. Heavy fogs and high humidity are the rule. East of the coast range, especially in Chile, the climate becomes more continental with a greater range in temperature, but it remains arid eastward to the lower slopes of the Andes.

The Peruvian portion is a narrow band dissected by more than 40 transverse valleys with a substantial flow of water from the Andes from October to April. The Atacama section of Chile is characterized by coastal ranges rising sharply almost from the water's edge to summits of 3,000 to 3,500 feet (914 to 1,067 m). East of this is the Longitudinal Depression, consisting of a series of undrained basins 25 to 50 miles (40 to 80 km) wide. The central plains have weakly developed coarse-textured soils and stony deposits. Marine coastal terraces continue into Peru; they are undeveloped in the south, but show moderate development northward. Sand dunes are common.

North American Deserts

The North American dry province resembles the North Africa-Eurasia province in variety of subdivision types, although the subdivisions are much smaller in North America. Dry upland areas are analogous to those of Iran, Turkestan, and upland Arabia.

The North American desert (Figure A-7) extends southward from central and eastern Oregon, embracing nearly all of Nevada and Utah except the higher mountains, into southwestern Wyoming and western Colorado, reaching westward in southern California to the eastern base of the Sierra Nevada, the San Bernardino Mountains, and the Cuyamaca Mountains. From southern Utah, the desert extends into northeastern Arizona and also into western and southwestern Arizona.

Desert areas extend southward along the eastern coast of northern Baja California, in the lee of the (mountain ranges) Sierra de Juárez and Sierra de San Pedro Mártir. South of these ranges it extends across the peninsula as far south as the northern end of Sierra de la Giganta; farther southward, it is limited to the Pacific coast, a very narrow strip along the coast of the Gulf of California, and parts of the lower elevations in the cape region at the tip of Baja California. On the mainland of Mexico, it occupies the lowlands of Sonora as far south as the delta of the Yaqui River.

On the highlands of southeastern Arizona and southern New Mexico, the continuity of the desert is broken by a desert-grassland transition. At a slightly lower elevation, it reappears in the valleys of the Rio Grande and Pecos River, extending as far east into Texas as the lower course of Devils River. Southward into Mexico, the desert extends continuously through eastern Chihuahua state and nearly all of Coahuila, being broken only by a few higher mountains and elevated areas of grassland. Farther south, the desert is confined to eastern Durango, northern Zacatecas, the western margin of Nuevo León, and the northern part of San Luis Potosi.

In the north, an isolated area of desert occupies part of the Columbia River basin in eastern Washington, while in the south several detached areas occur in Hidalgo and Puebla, notably the valleys of Ixmiquilpàn, Actopàn, Mezquital, and Tehuacàn.

The deserts of North America owe their aridity to a variety of conditions. Orographic barriers are most important in the north, while the southern portion comes under the influence of a subtropical high-pressure cell. The southern portion of the arid region has a summer maximum of precipitation. The intermediate regions, such as central Arizona, receive some precipitation in both seasons. There is an extremely arid area around the north end of the Gulf of California with limited extension northward in California. The Chihuahuan and Sonoran deserts have a mild-to-hot climate and the Great Basin desert has cold winters and warm summers.

Sand dunes and hummocks are smaller and cover much smaller proportions of the desert areas in North America than in desert areas of North Africa and Arabia.

III. MAPS AND TABLE

Figures A-1 through A-7 are general-location maps, and Table A-1 lists the deserts of the world (Ref A-4). The Extremely Arid, Arid, and Semiarid areas are delineated in accordance with Peveril Meigs' 1960 revision to his 1952 maps that accompanied "World Distribution of Arid and Semi-Arid Homoclimates" in Reviews of Research on Arid Zone Hydrology (UNESCO, Paris, 1953). Meigs' codes in the Extremely Arid and Arid portions have been repeated where space permitted, and some of his coding for the Semiarid zones has also been included.

In mapping the world distribution of arid and semiarid climates, Meigs indicated the season of precipitation by use of the letters "a" (no distinct seasonality of precipitation), "b" (summer concentration of precipitation), and "c" (winter concentration of precipitation). Noting that heat as well as water is essential to the growth and reproduction processes of plants, Meigs also included a consideration of temperature, indicating on his maps the mean temperatures of the coldest and warmest months, respectively. It is therefore possible to indicate, by means of Meigs' system, for each desert area the degree of aridity (extremely arid or arid), the season of the year when most of the precipitation occurs, and the temperatures of the hottest and coldest months.

IV. DESERT COASTAL ZONES

The narrow strips of coastal desert to be discussed border all five of the world's dry provinces. They are either of the west coastal or east coastal type. Each are characterized by humid air and low daily ranges of temperature. The west coast type is well developed in North and South Africa, North and South America, and Australia. These regions are cool for their latitude and in many areas are marked by frequent fogs.

The east coast type, along the Red Sea, Gulf of Aden, Persian Gulf, and Gulf of Oman, has very high humidities along with intense heat.

For the purposes of this report, the land strip of the desert coastal zone will be confined to a 5- to 10-mile (8 to 16 km) width. The width of the seaward strip will be kept flexible to allow for gentle, shelving bottoms on which waves may break far from the actual inshore zone, the presence of coral reefs or other obstructions offshore over which waves may break, and any other unusual feature or structure occurring some distance offshore in a desert coastal zone.

Location of Desert Coastal Zones

There are 14 general desert coastal zones that are described here. They are:

1. Northwest Mexico: Baja California and the Sonora-Sinaloa Coasts
2. Peru: The Coast
3. Chile: Northern Desert Coast
4. Argentina: Patagonia Coast
5. Australia: Western Coast
6. Australia: Southern Coast
7. North Arabian Sea: Iran bordering the Gulf of Oman to the Rann of Kutch/Kathiawar Peninsula
8. Persian Gulf
9. South Coast of Saudi Arabia: Muscat and Aden Protectorate
10. The Somali Coast
11. Red Sea
12. Mediterranean Coast of Africa
13. Northwest Africa
14. Southwest Africa

Northwest Mexico: Baja California and the Sonora-Sinaloa Coast

The desert coastal areas of northwest Mexico include the east and west coasts of Baja California and the arid Sonora-Sinaloa coast south to about the latitude of Los Mochis. The total length of this arid coastline is approximately 2,700 miles (4,344 km). The name "Baja California" is used here to include Baja California Norte, which became a state in 1952, and the Territory of Baja California Sur. The geographic-political boundary is in the extreme desert region at 28°N latitude.

Both Baja California and the Sonora-Sinaloa coast are readily reached from California and Arizona cities. Some good and some poor roads either follow the coast or lead to the coast in many places, but not all the coastal areas may be readily reached by land routes; many Baja California shores are more easily reached by ship, small boats, or by amphibious aircraft.

The Sonora-Sinaloa coast has been studied least. With isolated mountains and hills reaching the coast at several locations, wide alluvial plains, deltas and associated marshes and flats, and lagoonal areas, studies of this coast could serve as models for similar investigations in other parts of the world. Many areas are now irrigated and produce high quality food and cotton crops. This is also an excellent deep-sea sportfishing region and the coastal resorts are becoming more popular as transportation improves.

Peru: The Coast

The entire coast of Peru, about 1,400 miles (2,253 km) in length, is a desert coastal area. When the Atacama desert area of the Chile coast to the south is added, the total length is approximately 2,300 miles (3,701 km). Both areas are coastal deserts because the cool offshore Peru (Humboldt) Current combines with southwesterly winds to establish a stable air mass along the coast that produces very little rainfall. Humidity is high and winter fogs (July and August) are frequent. The area's desert climate results from conditions resembling those of the Pacific Coast of Baja California (both being related to a cold coastal current) with seasons reversed for the opposite hemispheres.

The Peruvian coastal desert averages about 60 miles (96.5 km) in width and is widest at the northwest and southeast ends. Numerous rivers, which head in the mountains to the east and derive their flow from rainfall and melting snow, cross the desert region. The rivers differ greatly from one another in the amount of water, seasonality of flow, fluctuation from year to year, and character of accessible irrigable lands. Maximum flow is during the southern summer (October to April), and many of the streams dry up completely during the winter. The water provided by these rivers, directly or through the intermediary of ground water, supports irrigation agriculture along the valley floors, the deltas by the coast, or the alluvial fans where the streams emerge from the mountains.

Offshore the nutrient-rich cool waters of the Peru Current support a huge fish population. The fish are food for the Peruvians and for large seabird populations. The accumulations of bird guano are mined from the desert islands and more recently from specially prepared nesting areas on the mainland.

Much of the Peru coast is a very low narrow desert plain. The sandy beaches are interrupted by rocky points and cliffs. Sand dunes are common near the coast, but in the northwest extensive areas inland are covered by shifting sands.

Chile: Northern Desert Coast

The desert coast of northern Chile merges with the Peruvian coast on the north and extends south to about the latutide of Coquimbo. It includes the coast of the Atacama desert area and an additional coastal strip between about 27° and 30°S latitude.

The coastal desert is a narrow strip because the Andes are but a few tens of miles inland. Along much of its length, the coast is a long line of steep cliffs broken now and then by a river channel. The rivers begin as mountain torrents in the Andes, but many disappear in the desert and never reach the sea. Where possible, the waters are used for irrigation, domestic, and industrial purposes. There are few good natural harbors along the coast. In places, the 100-fathom curve is less than a mile offshore and seldom is more than a few tens of miles offshore. Thus, the narrow shelf does not provide good fishing. The ports handle chiefly mineral products from the interior. Bolivia and Argentina, just to the east over the Andes, also use some of the port facilities.

Argentina: Patagonia Coast

The entire Patagonian coast, extending about 1,000 miles (1,609 km), is a desert. The same conditions prevail inland almost to the foothills of the Andes. In addition, the land surface of the territories of Rio Negro, Chubut, and Santa Cruz consists of extensive plateaus that slope toward the sea and usually end in cliffs. The only good coastal plain development is found to the north between Bahia Blanca and Golfo San Matias. South of this region the population seems to be concentrated either along the rivers or at one of the coastal ports.

Only a few of the coastal ports could be considered good natural harbors. The tidal range increases southward along the coast and presents problems. The continental shelf is wide (greater than 200 miles or 322 km) along most of this coast, which is paralleled by the cool Falkland Current.

Australia: Western Coast

The desert coastal area of Western Australia extends for a distance of approximately 1,100 miles (1,770 km), from just south of Shark Bay on the western coast northward to North West Cape and northeastward to just south of Broome on the northwest coast. The northwest coast is low and sandy south of Broome to Cape Keraudren and adjoins the Great Sandy Desert. From Cape Keraudren to Exmouth Gulf the coast is more marshy, with many mud flats and tidal creeks. Offshore islands, reefs, and shoals are numerous. This coastal strip is subject to severe tropical storms. Onslow has been severely damaged on many occasions and has the reputation of being hit by every storm. The whole coast is subject to extreme tidal range, at spring tides up to about 40 feet (12 m) at Broome, decreasing to about 25 feet (7.6 m) at North West Cape. A reported range of up to 40 feet (12 m) at Port Hedland probably resulted from a combination of spring tides and effects of cyclonic winds.

The coast from North Cape south to Carnarvon is less sandy, more hilly, with cliffs and an offshore reef. Shark Bay has a hilly coast except for the mud flats and mangrove flats south of Carnarvon. The coast from Dirk Hartogs Island south for 230 miles (370 km) consists of high precipitous cliffs that have not been reliably surveyed. The more hilly and cliffy coasts are part of the Great Plateau of Western Australia.

Denham (Shark Bay), Carnarvon, Onslow, Roebourne, and Port Hedland are the towns or smaller settlements along this stretch of the coast. Their combined population in mid-1965 was less than 5,000 persons. The Carnarvon district is sheep-raising country, but on irrigated land along the Gascoyne River tropical fruits and beans are grown.

Onslow, east of the mouth of the Ashburton River on the Indian Ocean, serves as a shipping center for the adjacent wool-growing area. Hamersley Iron Proprietary Ltd. is building port handling facilities at King Bay, which is in the Dampier Archipelago west of Nichol Bay. The population can be expected to increase when mining operations expand at Mt. Tom Price, about 190 miles (306 km) inland. Port Hedland is another shipping port for wool, sheep, and manganese ore. The harbor is being dredged to handle larger ore vessels to carry iron ore from the deposit now being developed 70 miles (113 km) inland at Mt. Goldsworthy.

Thus, this western desert coastal area seems to be chiefly an outlet for other activities taking place inland in desert and semidesert regions. Port facilities are being improved at several places and should bring in more permanent residents.

Australia: Southern Coast

The desert coastal area of southern Australia extends approximately from Israelite Bay on the west to Fowlers Bay on the east, a distance of about 600 miles (965 km). This semiarid coast is called the Nullarbor Coast after the Nullarbor Plain that extends inland to the north. A low annual rainfall of 5 to 12 inches (127 to 305 mm) has been cited for this area.

Much of the coastline is cliffed, with some cliffs reaching heights of 260 feet (79 m). At some places, the cliffs are buried by windblown sands. From the air the cliffs stand out boldly, and where sand is present, the whiteness of the sand contrasts with the blue of the sea and the darker-hued limestones of the cliffs.

The Eucla Basin and Nullarbor Plain coincide approximately; the Tertiary sediments (chiefly limestones) of the basin form the almost flat, featureless surface of the plain.

The Eyre Highway traverses the Nullarbor Plain, beginning in the east at Port Augusta and ending in the west at Norseman. The average distance between the highway and coast is about 20 miles (32 km), but the highway reaches the coast at Eucla. Less than 100 miles (161 km) to the north the Trans-Australian Railway links the state of Western Australia with eastern Australia.

North Arabian Sea: Iran Bordering the Gulf of Oman to the Rann of Kutch/Kathiawar Peninsula

Part of the Iranian coast, all of the West Pakistan coast, and the western part of the Kathiawar Peninsula of India compose the desert coastal area of the North Arabian Sea. This coastal desert is coextensive with the Persian Gulf littoral and at least the Iranian coast faces the Muscat coast of Saudi Arabia. The length of the coast is approximately 1,000 miles (1,609 km).

This coastal region can be divided into several parts. The Kathiawar Peninsula of India consists of a narrow coastal plain backed by outliers of the Deccan plateau that are capped by sheets of lava. The Indus delta consists of 120 miles (192 km) of coastline with mud flats, tidal marshes, and mangroves. Much of this region is an inhospitable wilderness. From Karachi west into Iran the coast consists of uplifted mountains and platforms separated by scalloped bays, wide sandy plains, salt marshes, and lagoons. Six or seven small sheltered fishing ports are found along this very sparsely settled coast of West Pakistan and Iran.

Persian Gulf

The Persian Gulf coast is about 2,000 miles (3,218 km) in length. Along the northeast the Gulf borders Iran; to the northwest at the head of the Gulf are Iran, Iraq, and Kuwait; to the south the Gulf borders the Kuwait-Saudi Arabia Neutral Zone and Saudi Arabia.

Most of the Persian Gulf is shallower than 200 feet (61 m). Much of the Iran coast is backed by mountains and has but a few alluvial coastal lowlands. At the northwest and southeast ends of this coast are more extensive alluvial lowlands. The north end of the Gulf also is a low-lying alluvial complex. This is a very productive area agriculturally because of irrigation by waters from streams that receive their waters from the north. The remainder of the coast is rather flat with numerous marshes, mud flats, lagoons, shallow bays, and low rocky shores.

South Coast of Saudi Arabia: Muscat and Aden Protectorate

The south coast of Saudi Arabia includes (1) the Muscat littoral along the Gulf of Oman coast and along the eastern half of the south coast, and (2) the western half of the south coast, included in the Aden/South Arabia Protectorate. Total length of these two stretches of coasts is about 1,800 miles (2,896 km). The western part of the Gulf of Oman coast is a sandy coastal plain backed by high mountains. Numerous streams drain the mountainous areas along the coast so that the stream alluvium may be cultivated for part of each year. Eastward the mountains become lower hills, lying closer to the coast, and forming bold headlands in many places. The remainder of the coast consists of steep cliffs and sandy lowlands.

The Somali Coast

This coastal zone extends 1,800 miles (2,896 km). Somalia forms the Horn of Africa and has an east and north coast. Part of the north coast was once British Somaliland. French Somaliland lies to the west, next to Ethiopian Eritrea, and forms part of the south entrance to the Red Sea.

The Red Sea

The Red Sea separates the desert coast of Africa from that of Arabia. The coast around the Red Sea is entirely desert; about 3,300 miles (5,310 km) long, it constitutes the longest coastal desert in the world.

The waters of the Red Sea have been navigated since the earliest days of exploration and trade in this part of the world. Peoples living near and on the coast today still depend upon the Red Sea for food and as an avenue of transportation. After the completion of the Suez Canal the Red Sea became even more important as an artery for ship traffic between Europe, the United States, and ports on the Indian Ocean and Persian Gulf.

Mediterranean Coast of Africa

The Mediterranean coast of Africa constitutes a desert coastal area along much of the east coast of Tunisia and Libya, Egypt, and the Sinai Peninsula. (Inland of the coastal desert is the extremely arid Sahara.) The length of this coast, from south of Tunis to Gaza, is about 1,800 miles (2,896 km). The Nile-Sinai Mediterranean littoral is examined closely. It has been emphasized that the Libyan littoral has no extreme desert climate, and only relatively small sections have enough moisture deficiency to be called desert at all.

Northwestern Africa

The arid and contiguous semiarid coastal areas of northwest Africa reach from Casablanca about 1,750 miles (2,816 km), roughly southward, to Dakar. The semiarid portions lie on the ends of this stretch, in Morocco on the north and Senegal and southern Mauritania on the south.

The topography inland from the northeastern portion of this coastal stretch differs greatly from the topography inland from the southwestern portion. In the northeast, the coast is backed by mountains. These give way to a low plateau in southern Morocco and to low extensive plains along the remainder of the coast.

Southwestern Africa

The Namib coastal desert is similar to the Peru-Chile coastal desert in that they are both cool, west-coast deserts. The Benguela Current supplies the cool coastal waters for this strip.

Total length of the Namib coastal desert is about 1,800 miles (2,896 km), extending from just north of Luanda, Angola, southwest to Cape Columbine on the South Africa coast. For much of its length, the Namib is less than 100 miles (161 km) wide.

V. DESERT HYDROLOGY

A very brief mention of the available water sources in desert areas has been included in Table A-1. Surface water sources are obviously easier to locate and map than subsurface ones. However, even these are highly variable, depending on climate and environmental conditions. Therefore, it is necessary to have accurate and up-to-date information regarding surface water location and its potability.

Subsurface water is harder to locate and extract. Presently the U.S. Army (Defense Mapping Agency, Hydrographic and Topographic Office) is mapping groundwater data at a scale of 1:250,000. There are many regions where groundwater sources are known to exist, some of which have been tapped, others not. However, due to the vastness and aridity of the dry provinces, a more detailed study of the intended region would be necessary in order to have quantifiable data on existing groundwater sources.

VI. REREReNCES

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A-3. U.S. Army. Field Manual FM 90-3, Desert operations, Baltimore, Md., Aug 1977.

A-4. UNESCO. Review of research on arid zone hydrology; world distribution of arid and semi-arid homoclimates, by Peveril Meigs. Paris, France, 1953.

Table A-1. Dry Provinces of the World

Region	Arid - Extremely Arid	Semi-arid	Climate		Geography	
			Precipitation	Temperature	Landforms	Hydrology
Eurasia (Turkestan Desert, Takla-Makan, Gobi)	X		Occasional summer days have infrequently moderate to heavy in intensity & rainfall amount. Winter precipitation usually very light snowfall. Total snowfall is rarely more than a few inches.	Arid - persistent winter cold & large annual range. Half of this region has extremely cold winters; summers are very warm. Ext. Arid - Adjacent to eastern shore of of Caspian with less severe winter temp; summers very warm to hot.	Eastern portion of dry Eurasia is very mountainous. Here lies the Tibetan Plateau with elevations 10,000 (3048 m) to 17,000 ft (5182 m) Tarion Basin & Gobi are plateaus at 2,000 to 5,000 ft (610 to 1524 m) above sea level & are surrounded by mountain ranges. In the western portion the land slopes down from the foot of Tyan Shan to the extensive low plain east of the Caspian Sea.	Caspian Sea; Aral Sea; Lake Balkhash; a few rivers to the east.
		X	Like arid parts, dry winters & most of its rainy days are from May-Sep, except east of the Caspian.	Mostly very cold in winter; east of Caspian hot summers.	Relatively flat from Black Sea eastward to ~85°E. Some broad plains in China. Most of semiarid Eurasia has a rugged relief, e.g., Himalayas.	Lake Baikal; some rivers originating near the interior edge of semiarid band; many northward flowing.
Southwest Asia (Arabian Desert, The Thar, Iranian Desert)	X		Most is confined to late winter or early spring.	All but coastal region very hot to extremely hot.	>half is plain or plateau. A major complex mountain mass constitutes the landscape of much of Turkey & Iran. Arabian Peninsula - salt flats, sand ridges up to 1,000 ft (305 m); desert pavement (abrasive lava flow); mountain ranges >10,000 ft (3048 m). Syria - rugged lava flows & sandy plains. Iraq & W. Pakistan - low & flat land, marshy sections in delta areas.	Potable surface water is scarce; artesian wells are found in Saudi Arabia 100 mi (61 Km) inland from the Persian Gulf. Wells are common in Iran. Interior drainage & withering rivers are found in W. Pakistan & interior basins of Turkey. Major rivers include the Tigris, Euphrates, and Inuds

continued

Table A-1. Continued

Region	Arid - Extremely Arid	Semi-arid	Climate: Precipitation	Climate: Temperature	Geography: Landforms	Geography: Hydrology
Southwest Asia (con't)		X	Very regular in India; very rainy in summer; heavy winter rains in Syria, Lebanon, & Israel; lighter in regions of Persian Gulf.	India is ext. hot; highly variable in Iraq; Afghanistan has a very cold winter & moderate summers.	Plateaus in India; rugged mountains in Afghanistan & regions bordering the Black & Caspian Seas. Low mountains along Persian Gulf coast.	Surface streams & rivers are common in semiarid regions of India, emptying into the Bay of Bengal; often polluted. Largest river is the Ganges. Potable surface water is scarce in other semi-arid regions. Most lakes in Iran & Turkey are salt lakes.
North Africa (Sahara, Somali-Chalbi)	X		Sporadic to non-existent in extremely arid; light rain in winter for arid areas.	Very hot, >105°F (40.5°C).	Flat, gently sloping or rolling; low mountains in Ethiopia.	Potable surface water very scarce; most lakes are saline; fresh groundwater sources do exist.
		X	Variable between northern & southern zones; extended periods of drizzle to heavy brief showers.	Very hot in areas near S. Sahara; little seasonal variation; coastal locations are moderate.	Predominantly hilly or mountainous.	During rainy season potable water is available in streams and lakes. Lake Chad is a permanent freshwater lake.
South Africa (Kalahari-Namib)	X		Summer maximum of rainy days; very dry winter; great year-to-year variability.	Small day-to-day & year-to-year variations; moderate-hot.	Coastal plain averages 50-100 mi (80 to 161 Km) wide; interior mountains separate the Kalahari and Namib.	Major rivers in the Kalahari include the Cunene & Orange.
		X	Abundant summer rains; dry winters in northern sections.	Cool temperature in high mountains; warm in low-laying valleys & on east coast. Hot along southeast coast and west coast of Madagascar.	Plains, hills, & mountains, Mt. Kilimanjaro, 19,590 ft (5971 m).	Lake Nyasa at 1,550 ft; 8,000 sq. mi; numerous rivers, many are tributaries to the Zambezi & the Limpopo Rivers, which empty into the Indian Ocean.

continued

Table A-1. Continued

Region	Arid - Extremely Arid	Semi-arid	Climate		Geography	
			Precipitation	Temperature	Landforms	Hydrology
Australia (Great Sandy, Great Victoria,	X		World's driest continent; ~1 rainy day/month to many without.	Very hot to cold depending on elevation.	Western Plateau 600 to 2,000 ft (183 m to 610 m) above sea level; some highlands to 5,000 ft (1524 m); sand ridges to 100 ft (30 m) in Great Victoria Desert; Artesian Basin, elevation -38 ft (-11 m) lies east of of the Plateau.	No large inland seas or lakes. Only the Murray-Darling river system maintains permanent flow. The Great Artesian Basin is an important source of underground water, 10 to 6,000 ft (3 to 1829 m).
		X	Summer rain in north; winter rain in south; 20 rainy days/month north, 12 rainy days/month south.	Highly variable depending on elevation & coastal influence; hot.	Coastal plains, low inland plateaus & eastern highlands (3,000-7,000 ft) (914 to 2134 m).	Streams are numerous in the eastern region; fed by rains of wet season. Murray-Darling river system is quite variable.
South America (Monte-Patagonian, Atacama-Peruvian)	X		World's driest climate along 2000 mi (3218 Km) of Pacific from N. Peru to Central Chile. In S. Argentina, 2-4 rainy days/month in winter, less frequent in summer.	Moderate due to maritime influence; cold winters at high elevations.	Western mountain coastal range to 5,000 ft (1524 m); Patagonian Plateau from 300-5,000 ft (91 to 1524 m); some deeply entrenched valleys; sand dunes common along Peruvian coast.	About 50 rivers flow from the Andes to the Pacific. Rivers in Patagonia flowing to the Atlantic include Colorado, Negro, & Chubut.
		X	From Ecuador to Argentina summer is wet season (Oct-Mar) from 6-7 rainy days/month on the Argentine Pampas to >20 near the equator. Northern regions have 2 wet periods, Apr-Jun; Oct-Dec; 8-12 rainy days/month. Jun-Aug in Central America have 15-20 rainy days/month.	Predominantly hot except at high elevations.	Majority is mountainous or highland 4,000-20,000 ft (1219 to 6096 m)	Numerous rivers & streams.

continued

Table A-1. Continued

Region	Arid - Extremely Arid	Semi-arid	Climate		Geography	
			Precipitation	Temperature	Landforms	Hydrology
North America (Mojave, Colorado, Sonoran, Chihuahuan)	X		Winters months have average of 1-2 rainy days; snow north of 33°N; wet summer months have 4-6 rainy days, thunderstorms.	Extremely arid mean daily max. temp of 105°F (40.5°C) in 2-4 months of yr. Very cold winters 5-6 months with mean daily min. temp. of 0-24°F (-18°C - -4.4°C).	Coastal and inland ranges of western North America; from 18,000 ft (5486 m) in Mexico to 6,000 ft (1829 m) of the Great Plains.	Major rivers that flow through arid regions are the Rio Grande, Colorado, Columbia, Snake, Saskatchewan, and Fraser. Lakes - Great Salt Lake. Availability of water from higher elevation runoff & from beneath the ground in many regions of U.S.
North America East of the Rocky Mtns. and Mexican Plateau		X	South U.S., Mexico winter dry; 0-1 rainy day in N. U.S. & Canada; 2-3 days/month snow. The wet season is May-Oct, 15-20 rainy days in S. U.S. & Mexico. 8-12 rainy days in N. U.S. and Canada. The region between the Rockies & the Pacific coast mountains has wet winters & dry summers.	Ranges from hot to very cold on the central high plains. Mexican Plateau - hot; Canada - extreme cold in winter.	High plains, plateaus, & intermountain highlands. Most is >1,000 ft (>305 m) above sea level.	There are several major river systems of U.S. & Canada from adjacent mountains. Mexico has short streams; little to no water in dry times.
			In general: A full range of thermal subtypes of arid & semiarid climates occur on this continent. Large range of temp. from summer to winter is the rule rather than the exception.			

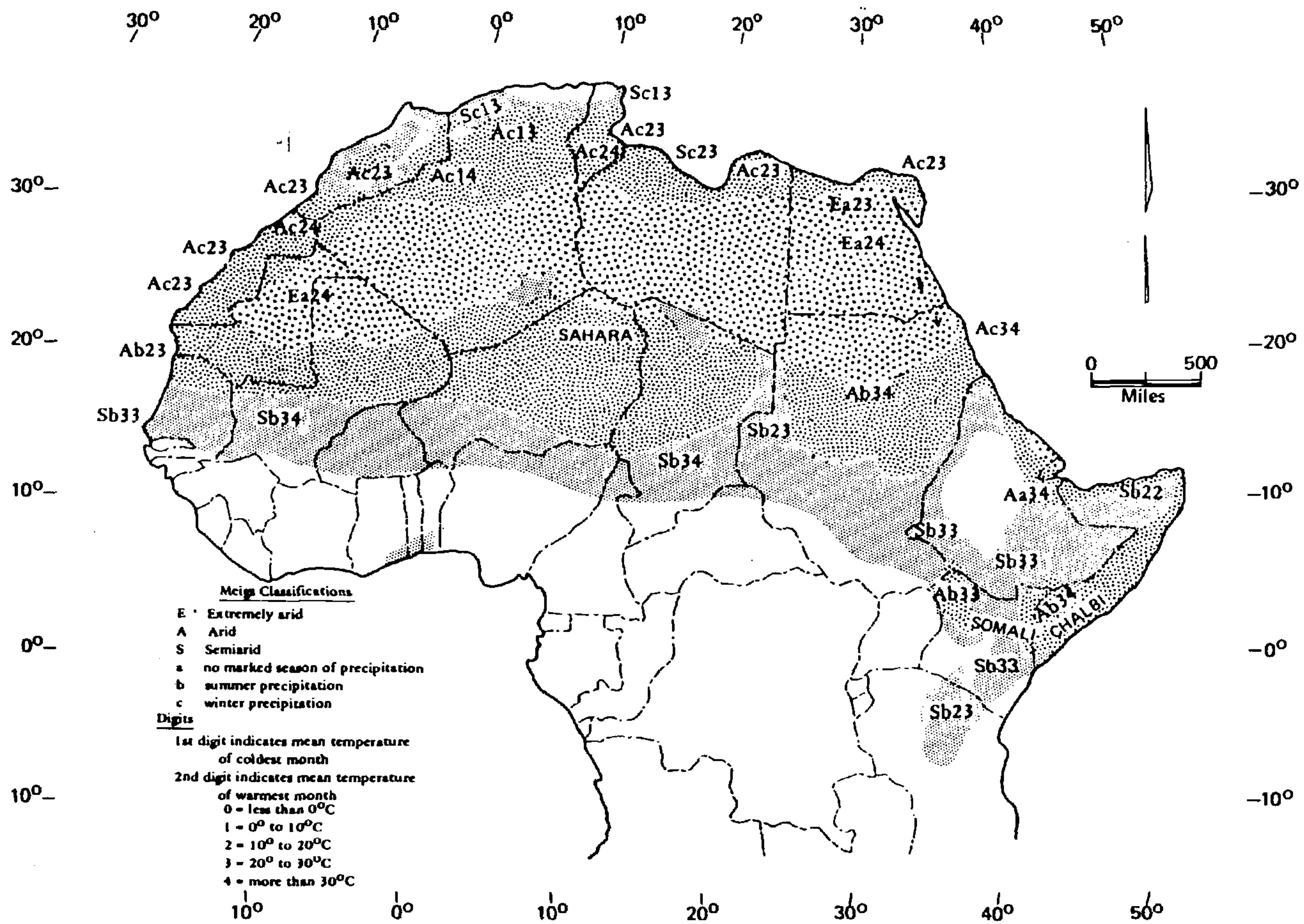

Figure A-1. Arid lands of Northern Africa (after Meigs).

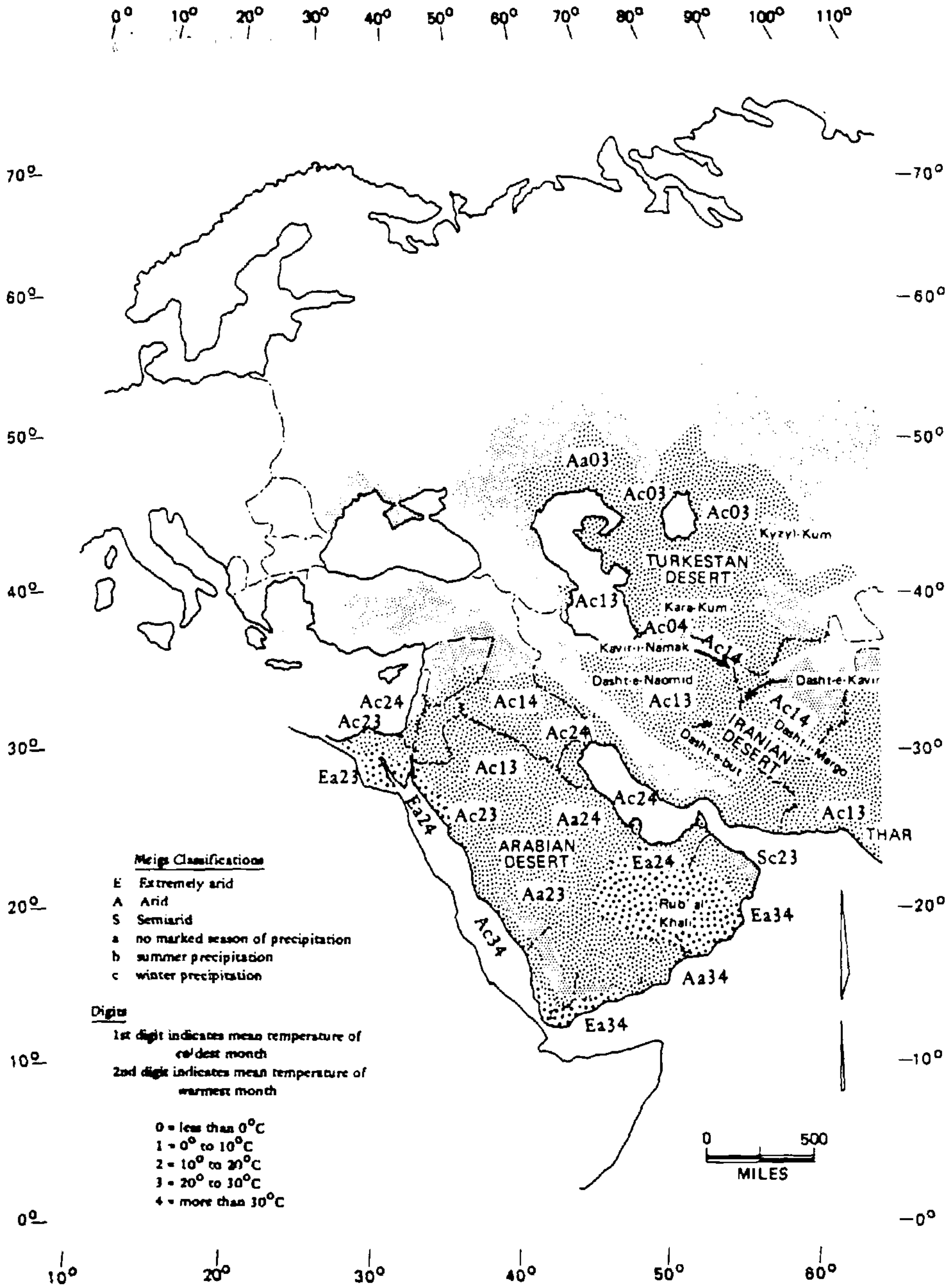

Figure A-2. Arid lands of Asia: Western portion (after Meigs).

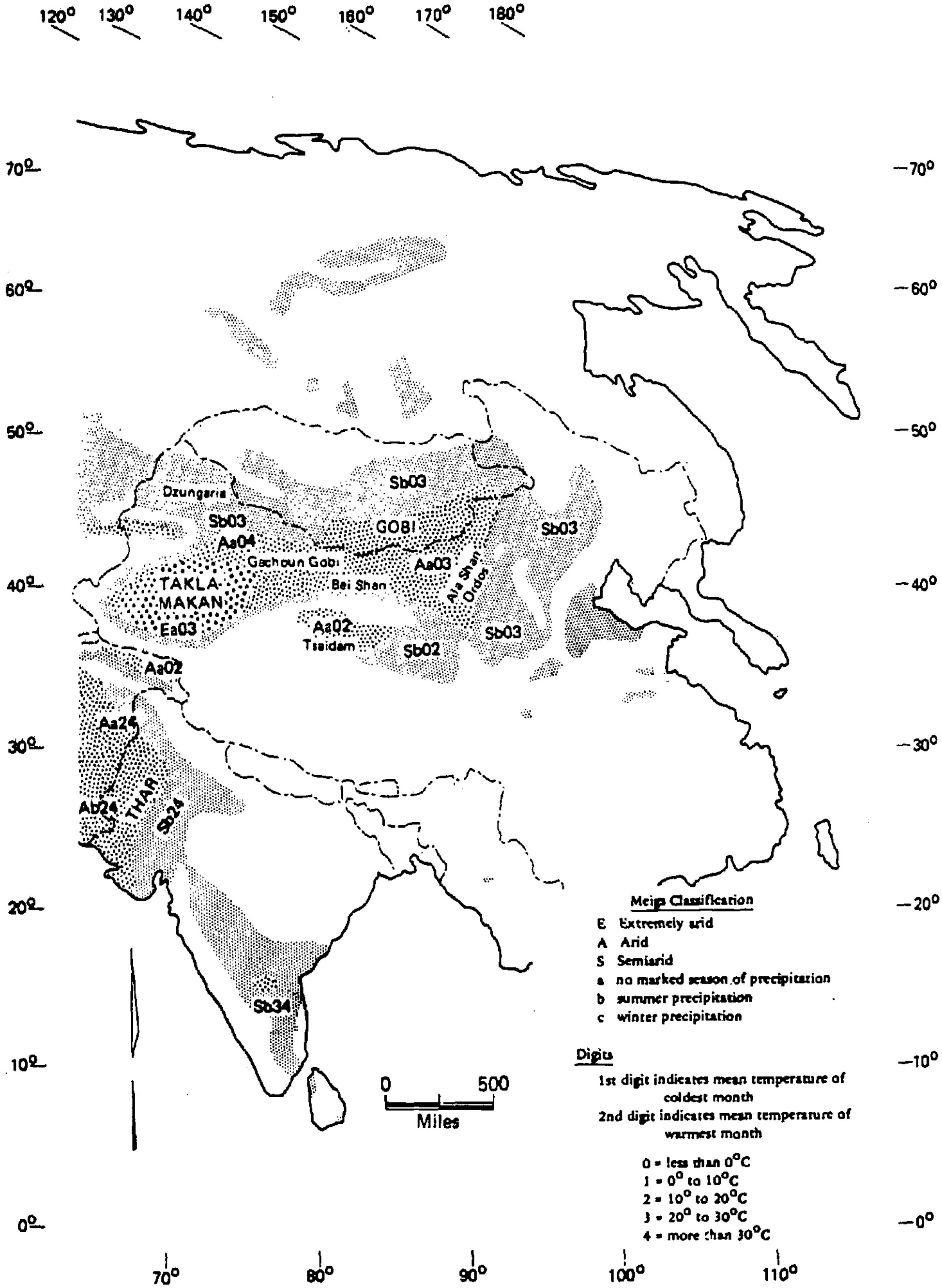

Figure A-3. Arid lands of Asia: Eastern portion (after Meigs).

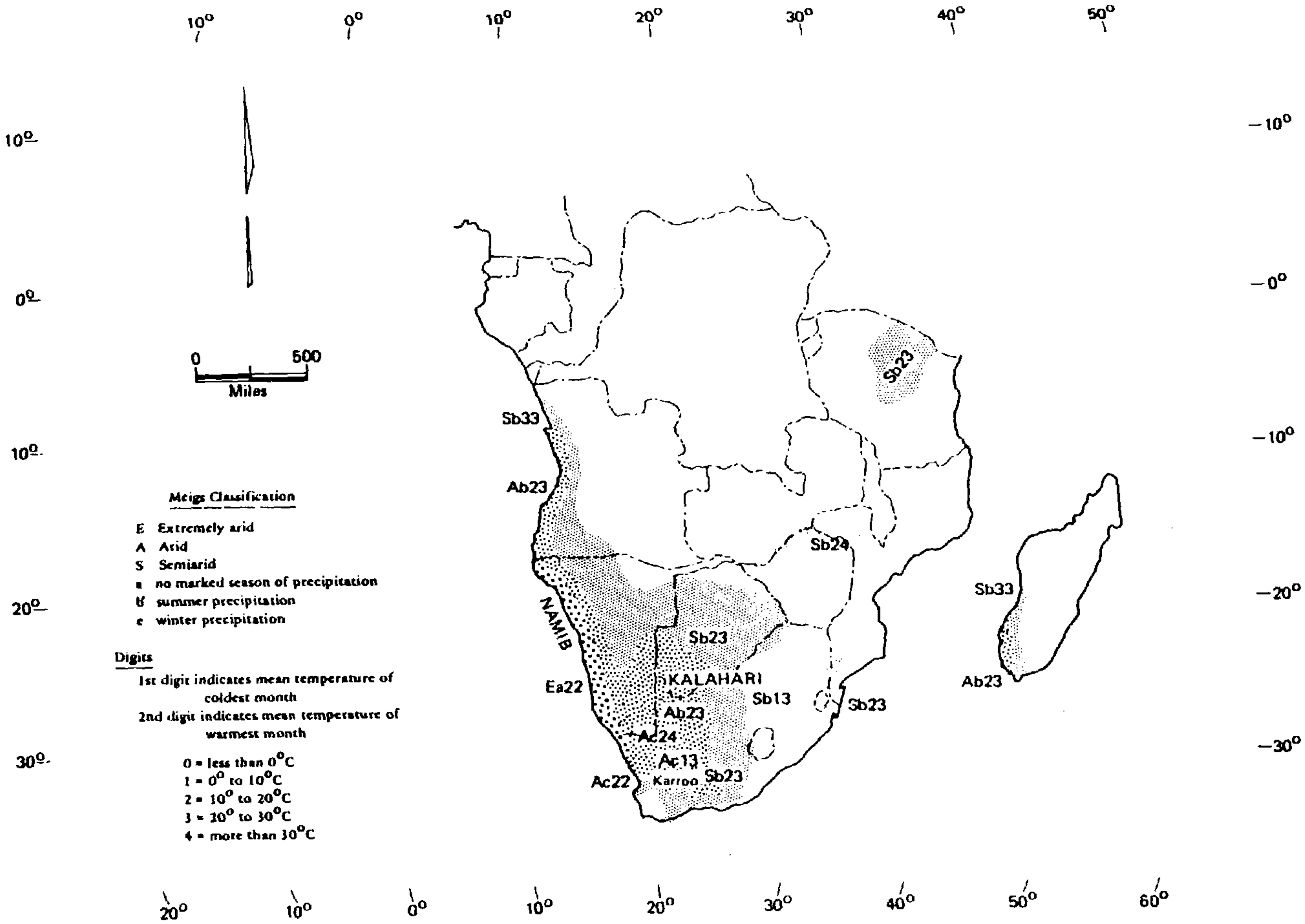

Figure A-4. Arid lands of Southern Africa (after Meigs).

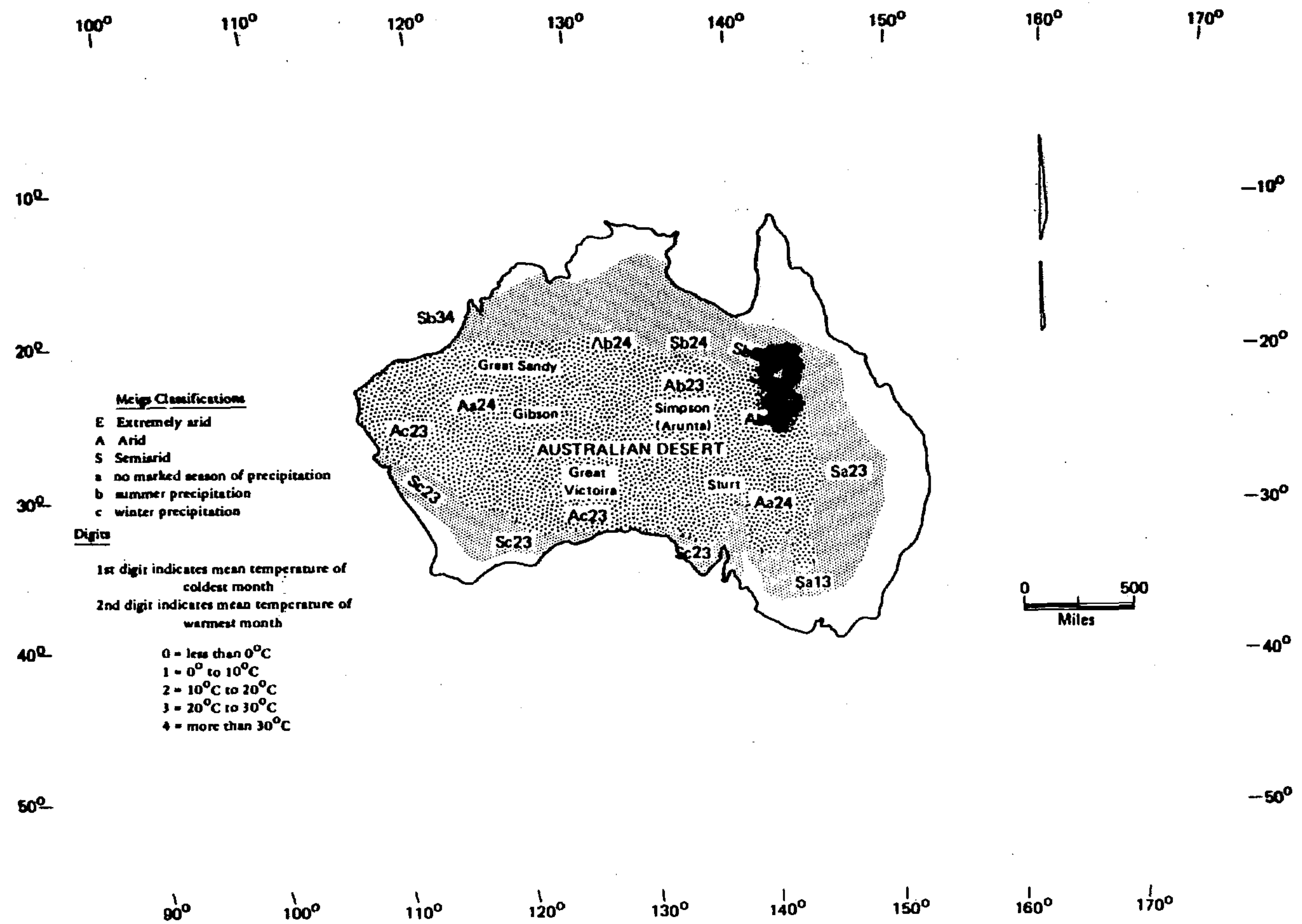

Figure A-5. Arid lands of Australia (after Meigs).

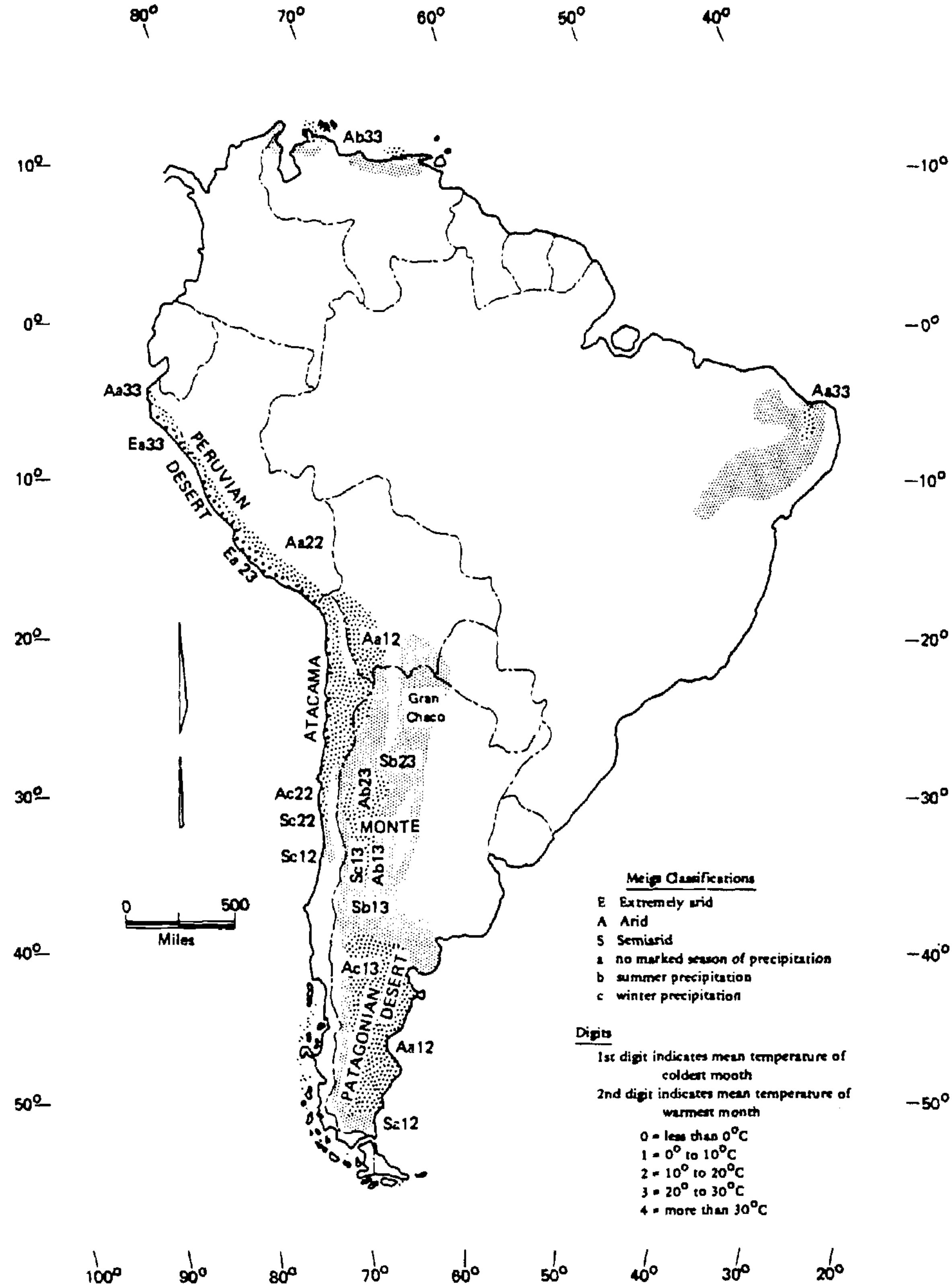

Figure A-6. Arid lands of South America (after Meigs).

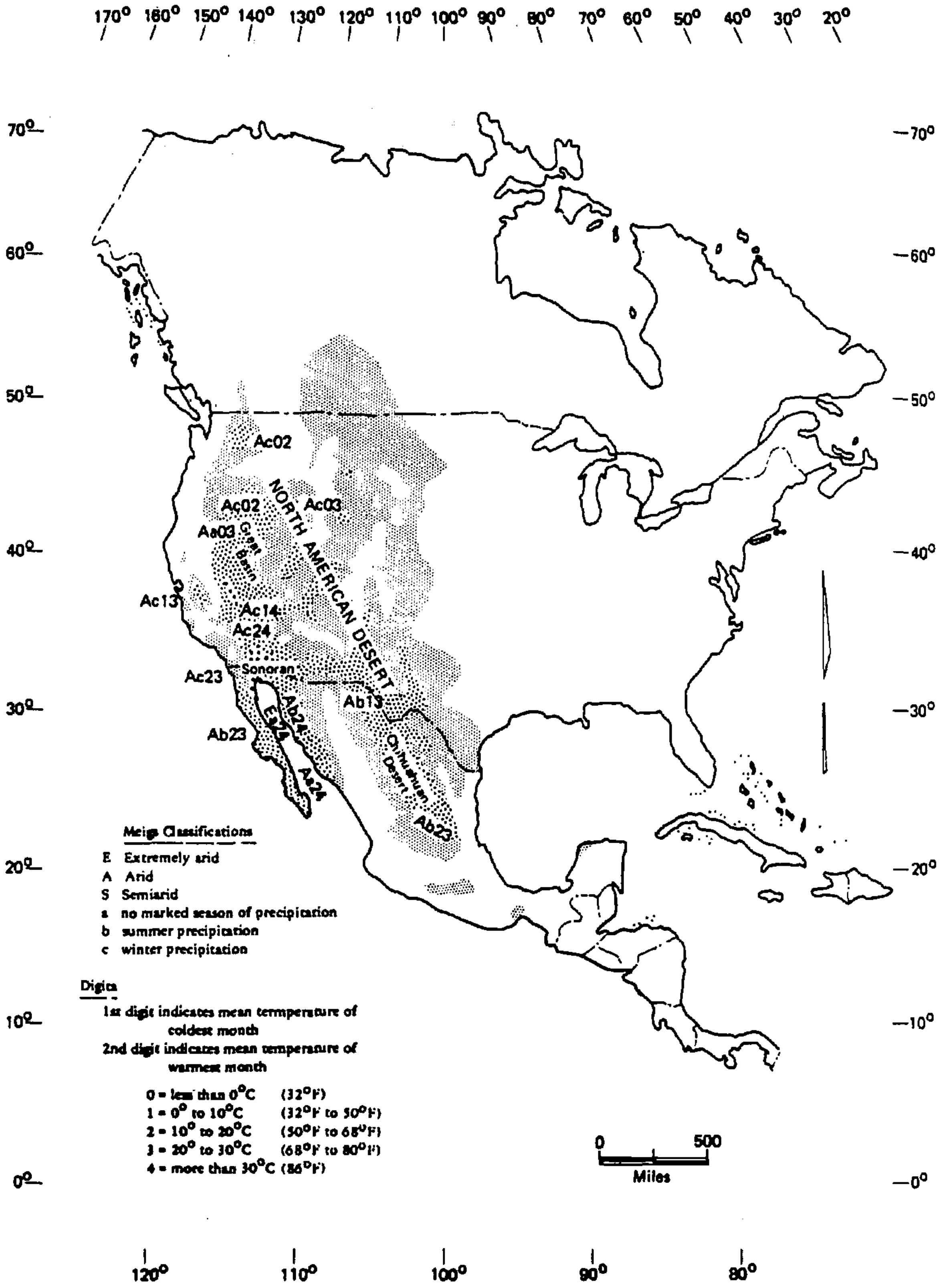

Figure A-7. Arid lands of North America (after Meigs).

Appendix B

PRELIMINARY TEST RESULTS FOR A PROTOTYPE DESERT CANTEEN

This investigation was done for the Marine Corps Education and Development Command by J. Crane and T. Kuepper. It was previously published as NCEL TM 54-82-07, which received very limited distribution.

CURRENT PROBLEM

At the present time the Marine Corps does not have, in inventory, canteens for the individual Marine that will maintain his drinking water supply within an acceptable temperature range for an extended period of time during hot desert operations. In addition, there are no current plans within DOD to address this problem.

BACKGROUND

The role of the Marine Corps within the Rapid Deployment Joint Task Force (RDJTF) may require deployment of amphibious forces into a hot desert region in the near-term. In such an environment personnel will be subject to dehydration, loss of effectiveness, and possible heat stroke. Although water discipline would receive priority attention, the availability of a potable water supply will not preclude serious dehydration since palatability of the supply may result in insufficient consumption to offset dehydration. Current knowledge indicates that personnel will not consume adequate quantities of water when water temperature exceeds 85°F, indicating a clear need for maintaining supplies below this temperature.

The Naval Civil Engineering Laboratory (NCEL) is addressing this need as part of a Desert Water Supply Project funded under the Marine Corps Advanced Base Logistics Program M51B.

OBJECTIVE

The primary objective of the NCEL effort is to develop a method for rapidly retrofitting existing stocks of standard issue plastic canteen, NSN 8465-00-889-3744, providing a contingency alternative to meet near term hot desert requirements. It is specifically not the intent of this effort to develop a new canteen system for long term application in the military.

CONCEPT

The current canteen systems are serviceable, however, the rate of heat transfer from the ambient environment into the contained water occurs fairly rapidly. The concept proposed at NCEL is to use a low to medium density polyurethane foam jacketing over the existing canteen to provide a heat transfer barrier. To preclude damage to the relatively soft foam jacketing, the concept includes a hard plastic, abrasion resistant, outer skin.

FABRICATION AND TESTING OF PROTOTYPE

One hundred and fifty standard issue plastic canteens were requisitioned through the supply system and forwarded to Igloo Corporation of Houston, Texas for modification by addition of insulating jackets.

Based on foam testing at NCEL, Igloo was instructed to use a 3/4-inch polyurethane foam layer of approximately 2-1/2 lb per cubic foot density. Igloo selected an ABS plastic for use as an outer skin material since it is relatively easy to work with in-limited production runs. In mass production, a less costly polyethylene material would probably be used, however, special tooling is required for use of the material. The prototype jacketed canteen is shown in Figure B-1. The jacketing is permanently affixed, however, a few prototype removeable sleeves were fabricated to demonstrate the concept. Removeable sleeves are shown in Figure B-2.

The caps of 1 prototype canteen and 1 standard issue canteen were fitted with thermocouples which reach to 2/3 depth inside the canteens Each canteen was then filled with 856 grams of water, representing 90% of the full volume capacity. Water temperature was 40°F at the time of filling. The canteens, with cap and thermocouple, were placed inside a laboratory oven which was maintained at 118°F ± 1.5°F for the test period. Test results are presented graphically in Figure B-3.

FINDINGS

Preliminary test data from Figure 3 indicates that a 50°F water supply will reach the 85°F potability limit in 3-1/2 hours, while the insulated prototype will maintain water below 85°F for approximately 9-1/2 hours. A chilled water supply at 70°F is more realistic than the 50°F value. Using the corresponding portions of the curves in Figure B-3 for a temperature rise from 70°F to 85°F, the standard canteen will maintain water for less than 2 hours, while the prototype will be effective for more than 5 hours. The insulative capacity of the canteens can be computed with the following equation:

$$\frac{T - T_\infty}{T_o - T_\infty} = c^{-\left(\frac{UA}{C_p M}\right)\tau}$$

where

T = Final temperature, °F

T_o = Initial temperature, °F

T_∞ = Ambient temperature, °F

C_p = Specific heat at 1 Btu/pound-°F

M = Mass, pounds

τ = Time, hours

UA = Overall heat transfer rate, Btu/hour-°F

Solving this equation for UA between 70°F and 85°F, the prototype characteristics were 0.141 Btu/hour-°F while the standard issue canteen permitted a transfer of 0.354 Btu/hour-°F.

CONCLUSIONS AND RECOMMENDATIONS

The insulating jacket concept is effective at maintaining water temperature for extended periods. Its use in hot desert operations would enhance the effective range and capabilities of the Marine Corps infantryman. It is recommended that the existing prototype be field tested to obtain data on field performance and user acceptability.

Figure B-1. Prototype desert canteen.

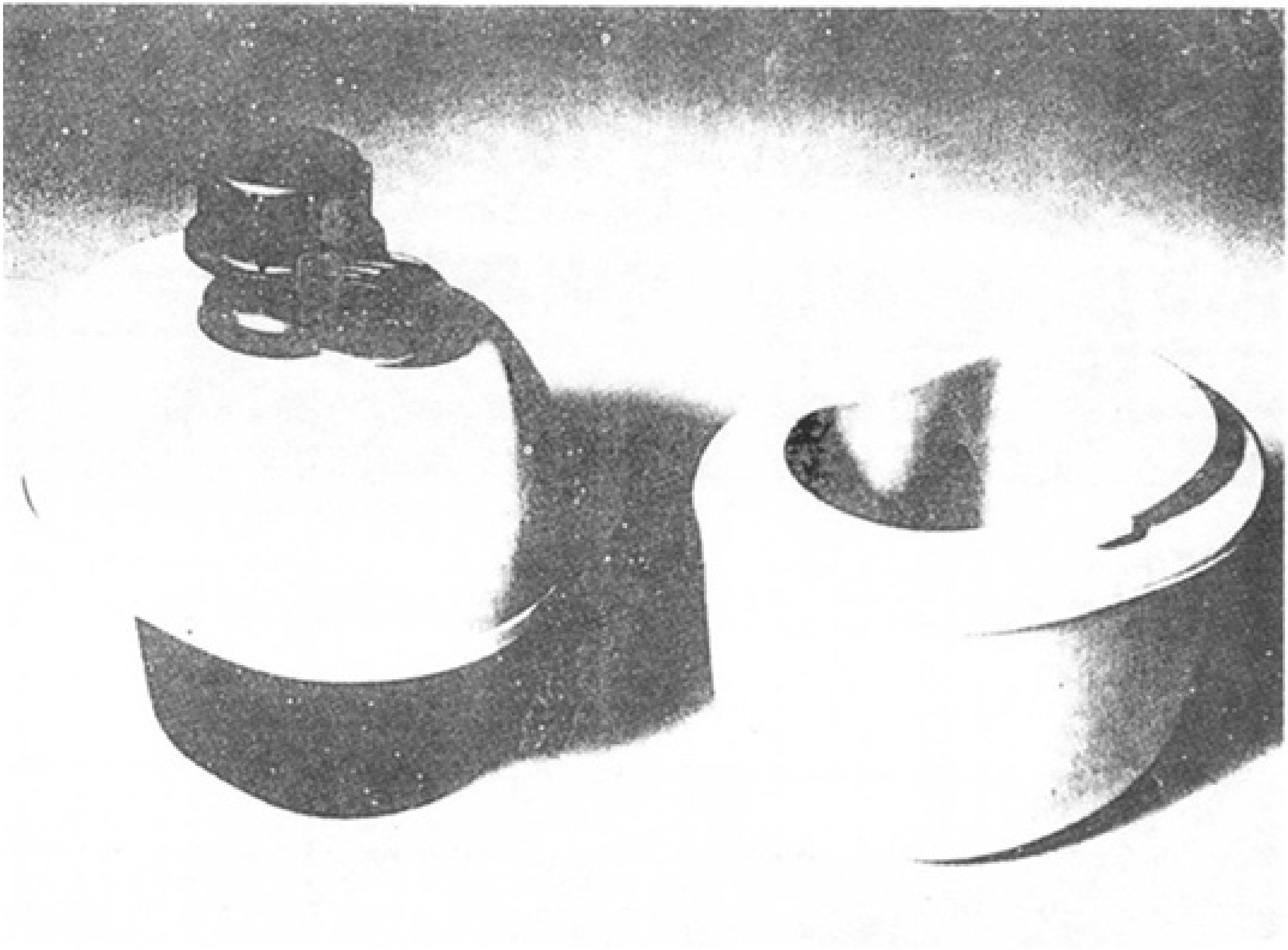

Figure B-2. Insulation removed from prototype desert canteen.

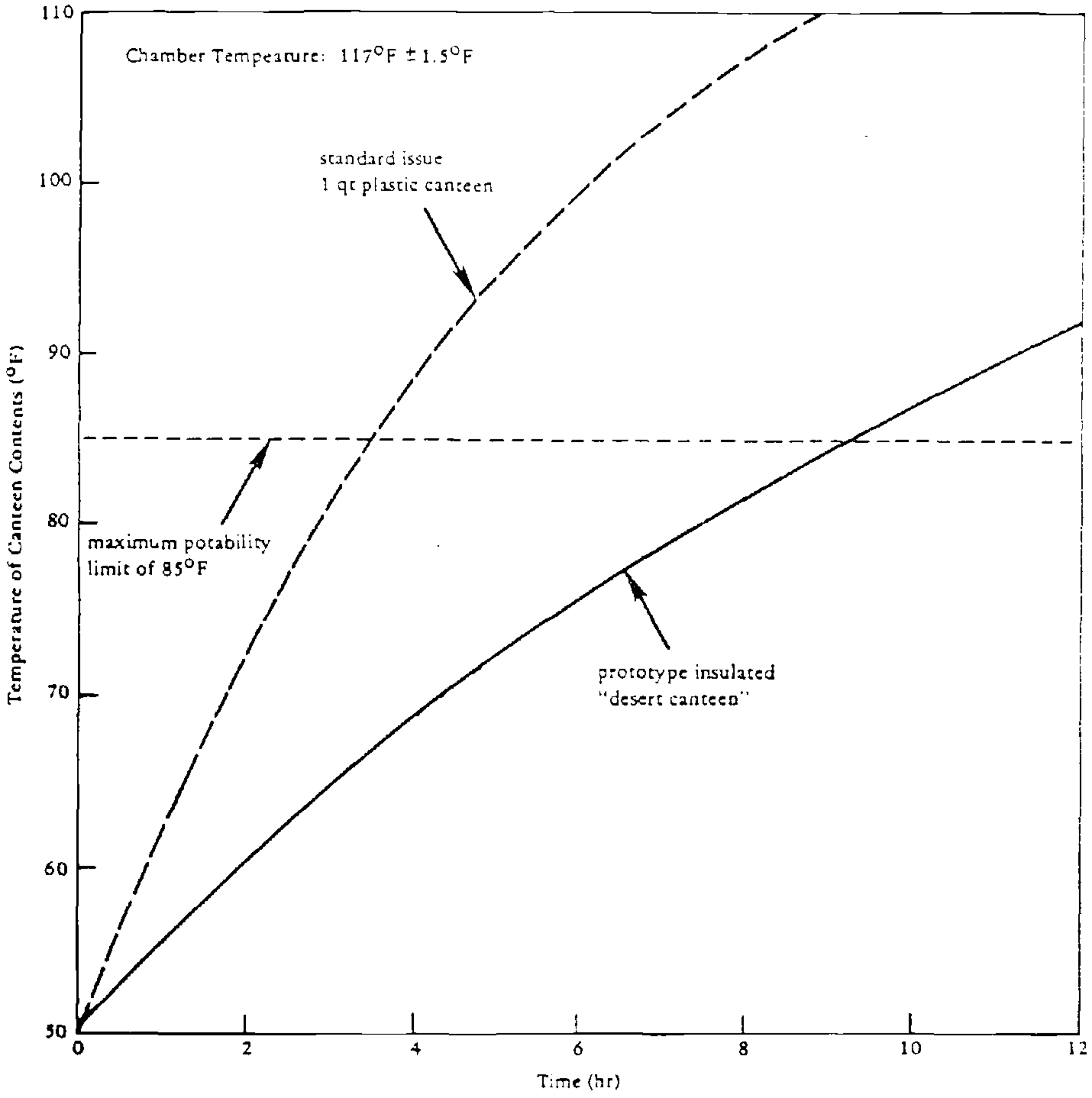

Figure B-3. Prototype desert canteen hot chamber tests.