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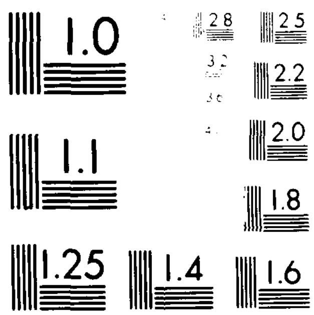

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MATHEMATICAL MODELING FOR EVALUATION OF FIELD WATER SUPPLY ALTERNATIVES

(Arid and Semi-Arid Regions)

FINAL REPORT

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A mathematical model has been developed which can be applied to evaluate the least-cost alternatives to meet the projected potable and non-potable water requirements of a US Army Corps-sized operation. It included the adaptation of the model to an existing solution technique, the Out-of-Kilter Algorithm (OKA), a search of the literature to obtain cost data for the various elements within the alternatives, a search of the literature for health and other related factors, a review of existing scenarios, a review of collateral

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issues pertinent to the production of water in an arid or semi-arid environment, and, finally, proposed systems for the re-use of laundry and shower wastewaters.

FOREWORD

V. J. Ciccone Associates, Woodbridge, VA acted as consultants in the performance of this contract.

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EXECUTIVE SUMMARY

Mathematical models of military water supply systems developed by the VMI Research Labs (VMIRL) in the early 1970's originally did not consider the aspect of waste water reuse but have been expanded in this report to include reuse alternatives made available by recent technological advances. The scenario used entails the rapid time-phased deployment of a reinforced corps that achieves the strength of approximately 100,000 by D-day plus 30 after which time the force embarks on a full scale offensive. The first light infantry forces are flown to the forward base 60 to 70 miles inland followed by various elements of air cavalry, mechanized infantry and armored forces. During the same period a sea coast base is established and a logistical link is made with the forward base.

The location of water sources largely dictates the requirements and alternatives for treatment and delivery means. During the lodgement, potable water requirements in the forward area will have to be met by desalting the local supply (ROWPU); the alternative is supply by air or overland. A pipeline, to be completed at D plus 10, will be built along the line of communication. Thereafter, adequate quantities of potable fresh water will be available at distribution points along the line and at the forward area. The ROWPU will then be free to support the planned offensive. At any stage, recycling and reuse of wastewater from laundry and shower operations would lessen the total water requirements and decrease the demands for treatment and delivery. The mathematical models developed have provided a set of operating rules in Section VI.

The major findings of this study are as follows:

1. There is no evidence to indicate adverse oral, dermal or ocular health effects in treated or recycled laundry and/or shower wastewaters for short-term usage. However, long-term risks for reusing such wastewaters cannot be completely ruled out.

2. The recycle and reuse of shower and laundry wastewaters are the best economic alternative when:

a. Only brackish or saline water sources are available and only ROWPU units are available for treatment.

b. Fresh water must be transported significant overland distances in bulk quantities by vehicle or pipeline.

3. Military standardized equipment for the reclamation of laundry and shower wastewaters is available.

4. Further pilot-scale testing is needed to validate the system performance; the economic gains through carbon reuse and the reuse quality criteria.

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I. INTRODUCTION

SUBJECT:

In the early 1970's, the VMI Research Laboratories (VMIRL) developed mathematical models of military water supply systems (1). The models represented combat units ranging in size from an airborne brigade to a Corps. The major accomplishment of the models was the development of water distribution schedules and the selection of water points from a list of candidate raw water sources using the advanced techniques of network theory and analysis. A major factor not considered in the models was the aspect of wastewater reuse, especially in arid regions. The developed mathematical models have been extended herein to include reuse alternatives made available by recent technological advances.

The emphasis today by planners of the possibility of an incursion into the Middle East-Persian Gulf-Southwest Asian region makes the extension of the earlier work timely. What is seriously needed at present are logistic concepts, doctrine and material concepts for the reuse of certain water by Army forces in the field.

The current study was jointly funded by the U. S. Army Medical Bioengineering Research and Development Laboratory and the U. S. Army Mobility Equipment Research and Development Laboratory.

OBJECTIVES

The objectives of the study are as follows:

a. To evaluate various alternative systems designed to meet the water demands within selected (existing) scenarios for Corps-sized military operations. These alternatives include the reclamation of generated wastewaters and their direct recycle/reuse either by blending reclaimed wastewater into a treated water supply or by a dual water supply system.

b. To determine the most suitable recycle/reuse capacity for which the selected system should be designed under a given scenario.

c. To identify currently available and developmental military or commercial equipment applicable to US Army field water/wastewater, recycle/reuse systems.

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1. Knapp, J. W., Sculley, J. R., Morgan, J. M., Jr., and Jamison, D. K., "Mathematical Models of Military Water Supply Systems," VMI Research Laboratories, Lexington, VA, 1974, AD 919522L.

d. To recommend to the US Army the best suited and least cost alternative for meeting the water demands within the scenarios studied.

e. To define future research and development requirements for wastewater reuse.

Items considered in the study include: Projected water demands, raw water qualities, transportation and distance factors, terrain or geophysical factors, treated water qualities desired, manpower resources required, fuel resources required, special logistical requirements, and system capital costs.

The effort has focused upon development of a methodology which can be applied to evaluate the least-cost alternative designed to meet the projected water requirements of a US Army Corps-sized operation; it included the adaptation of the methodology to computer analysis in order to simulate the alternatives considered, a search of the literature to obtain cost data for the various elements within the alternatives, a search of the literature for health and other related factors, an in-depth study of existing scenarios to obtain the least-cost solution for meeting the projected water demands, and, finally, a review of collateral issues pertinent to the production of water in an arid or semi-arid environment.

II. BACKGROUND

SCENARIO

US worldwide commitments include contingency plans for the rapid deployment of ground combat troops in any strength up to a reinforced corps. In the arid environments that prevail on every continent except Europe, logistical problems will be accentuated. The supply of water may be critical: sources scant, quality impaired, and time limited for development or acclimatization. The planners for a contingency force of any size must consider importing the potable water required during the initial military build-up or providing the water treatment equipment with concurrent development of local sources. It is axiomatic that in any opposed landing in an arid or desert region, by amphibious or airborne forces, the most critical item of supply will be ammunition, and water the second most critical. In an unopposed landing, in the same regions, water may be considered the most critical item of supply. As the size of force or the rapidity of build-up increases, the logistical burden will demand consideration of conservation measures, including recycling and reuse.

The analysis herein is based upon a corps contingency force deployed to the Middle East, as compiled and presented in the regular instruction given at the US Army Command and General Staff College. The scenario calls for the quick insertion of light infantry, 60 to 70 miles inland, followed by mechanized and armored forces and a link-up with logistical support established initially at the sea coast. The scheduled build-up reaches 100,000 troops at D-day plus 30. The early deploying units are organizational equipment to produce potable water until a pipeline can be laid from the coast to the forward base. Conditions are inherent in the scenario for considering recycling and reuse of certain wastewaters.

ANALYTICAL MODEL

The out-of-kilter algorithm (OKA) developed by Fulkerson (2) is used to solve the general minimum cost flow problem for networks. A network consists of nodes connected by arcs. Nodes are represented by lower case letters i and j; arcs originate at node i and terminate at node j. A description of the algorithm is included as Appendix A.

Arcs in the network system have both cost and capacity restrictions. The cost of the use of a particular arc per unit of flow is determined by water production cost, transportation cost or a combination of the two.

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2. Fulkerson, D. R., "An Out-of-Kilter Method for Minimum Cost Flow Problems," Journal SIAM, Volume 9, Number 1 (March 1961), pp. 18-27.

The capacity constraints are determined by demand and availability. In general, the algorithm arrives at a flow through the various arcs which will minimize the total operating cost. The analysis indicates when it is profitable to ship a unit of flow from one node to another, when the price of the unit flow at the second node outweighs the price of the same unit staying at the first node, plus the transportation cost of shipping the unit from the first to the second node. Flow is then increased or decreased to and from the various nodes until the least cost is determined around a circulation path.

The model has been formulated and is operative. Flow passes from a source to seven distribution points and is then directed from the distribution point to potable and non-potable nodes and finally to a sink. The flow to the sink from the potable and non-potable nodes is constant and determined by the demand. The flow to the potable and non-potable nodes varies depending on the percentage of flow to be recycled.

The model will allow any combination of distances, cost and recycle rates to be used and will determine the cost for any combination of the variables described. The results yield a family of curves which are functions of cost, distances, and recycle rates.

WATER REQUIREMENTS ANALYSIS

Consideration of water requirements necessary to satisfy the demands of the scenario focused upon the concept of a hierarchy of uses. The principle of using non-potable water reclaimed from selected wastewaters to satisfy certain demands was envisioned. The principle was applied to the two largest sources of wastewater within the Field Army which are considered best suited for reclamation and reuse, namely shower and laundry wastewaters. Further, the requirements for vehicular equipment and aircraft washdown were also included in the non-potable category. Water consumption factors for potable and non-potable use were developed from the most commonly accepted data for field water requirements and usage in an arid or semi-arid environment.

For the first ten days of commitment the forward elements of the contingency force must use organizational equipment to produce potable water from a single brackish source. During the same period, an eight-inch aluminum pipeline, with pumping stations and appropriately located collapsible or rigid reservoirs or tanks, is constructed to span the 60-mile distance. The pipeline is intended to provide potable water to the entire contingency force. However, certain non-potable demands will be met through recycling and direct reuse of selected wastewaters. Also included are the time and troop build-up schedules as well as the potable and non-potable water requirements for both forward and rear areas.

SYSTEMS HARDWARE

Previous DOD concepts and research efforts related to the treatment, reclamation, and direct reuse of wastewaters within a tactical zone (e.g. the Air Force Bare Base, and Army MUST systems). These systems focused upon the collection of a variety of wastewaters such as kitchen, laundry, showers, laboratories, their centralized treatment and subsequent distribution for reuse. The mixture of wastewaters, especially from the laboratories, introduced potentially toxic soluble compounds which were difficult to remove. The water treatment equipment systems necessary to achieve satisfactory field performance were technically complex and difficult to operate, a logistical burden requiring high-skill level operators. These efforts were not completely successful and further work was not carried out.

This study suggests only laundry, shower and vehicle wash wastewaters be considered as candidates for recovery, treatment and recycle to the processes from which they were generated. The proposed treatment and required equipment are not complicated and, in many instances, could be implemented through field expedients. For example, the system hardware considered in this study has as its basis, standard Army equipment assembled into two kits (laundry and shower) designed as pollution abatement systems for use with Army Field Shower and Laundry units. These kits developed by U. S. Army Mobility Equipment Research and Development Command (MERADCOM) under a Product Improvement Program (PIP), if appropriately modified and extended by the addition of filtration and chlorination unit processes will provide a simple, lightweight, compact, non-developmental system with an effective capability to reclaim both laundry and shower wastewaters for direct reuse. Treatment reclamation and direct reuse in this concept differs widely from the previous field test efforts. By utilizing standardized equipment presently within the military inventory, the value of the proposed concept is especially noteworthy for military operations in an arid or semi-arid environment.

Such a wastewater reclamation capability, when coupled with currently over-burdened US Army bulk water transportation assets, will permit redirection of other resources programmed for water transport such as trucks, trailers, and air and sealift space allocation. In addition, the effort to locate and develop suitable water sources in water-scarce areas, and the concurrent critical field sanitation requirements needed to dispose properly of generated wastewaters within troop areas, are both serious considerations to tactical and logistical planners. Any water which can be reclaimed for direct reuse thereby reduces the logistical burden.

HEALTH ASPECTS

Availability of sufficient water is the most single and important characteristic of desert living and therefore of sustaining soldiers in combat under desert conditions. All sources of water in arid and semi-arid regions -- fresh, brackish and saline -- will be stretched to the utmost in order to provide sufficient quantities of water to large numbers of troops in the field. Sufficient quantities of water will be necessary to maintain the general health of the troops and support successful completion of a combat mission.

Water reuse is a term generally relating to the treatment of wastewater emanating from one activity so that it may be used as the water supply for the same or another activity. The word reuse as used in this section denotes any water or wastewater recycle and reuse which may be used without deleterious health effects.

Elaborate or simple wastewater treatment may be required in the Field Army depending upon intended use. Direct reuse of water for consumption is not favored except for short periods of time and only then in cases of extreme emergency. Drinking water standards in combat for select physical specimens (Army troops in good physical condition) may be somewhat relaxed under such extreme circumstances. Young men in good physical condition are not subject to the same adverse physiological effects as are the very young or the very old in the general population. This study does not include consideration of recycling/reusing water for drinking purposes but only subpotable uses.

There are no finally adopted protocols, criteria or standards yet developed for the direct or indirect reuse of renovated water from laundry or shower sources. The reasons none exist are (a) the potential for major reuse efforts in the field is a relatively new concept, (b) the examination of the discharge of a variety of potentially toxic constituents has only recently been seriously considered, (c) automatic, reliable and transportable methods of treatment have not long been available, (d) relatively simple analytical techniques including automatic constituent monitors for quality control have become available only in the recent past, and (e) the United States has not committed forces into an arid environment even though such contingency plans have been developed. The U. S. Army Medical Bioengineering Research and Development Laboratory (USAMBRDL) recommended to the Surgeon General interim water quality criteria for shower and laundry reuse and recycle on 22 October 1980. Those interim criteria are shown in Appendix B, Table B-1.

Soldiers cannot be trained to require less water than their bodies need although they can tolerate temporary restrictions. When desired quantities of water are not available, rationing is the only alternative. Should water be rationed for a limited period, the length of the period will depend on the available supply and the required work load. Priorities for rationed use should be established. A suggested list of priorities from U. S. Army Field Manual 90-3, Desert Operations, is as follows: Vehicle and equipment cooling systems; personnel (for drinking only); work animals; and personnel (other uses) which includes, in order, medical aid, cooking, cleaning of mess equipment, washing the human body, and washing clothes.

Water discipline or rationing will always play a significant role for troops involved in any operations in an arid or semi-arid region. Appropriate commanders must establish the appropriate amount of recycled/reused water for any purpose; potable water saved can be utilized to lessen the magnitude of the water discipline. Where and for what period of time the recycled/reused water can be employed may be a command decision.

One health concern is that unintentional short-term ingestion of reused water not be damaging to health or life of the soldier. Another concern is that the wastewater product be free of oral, dermal and ocular toxicity. Ingestion of a high solids content liquid will place certain organic and inorganic salts, metals and even micro-organisms in the human system which may have a deleterious effect on the individual. If recycled/reused water is employed in combat areas every effort must be made to discourage its ingestion except under extreme circumstances.

A number of scientific investigators have sought toxicity data for compounds that were predicted to be present in shower or laundry waters. See Appendix C. The major toxicity considerations investigated were of an oral, dermal or ocular nature. For all substances for which information was available, none in laundry or shower concentrations was found to be toxic. However, there were some data gaps noted in the literature.

A number of water reuse research projects have been reviewed. See Appendix C. Many of them were sponsored by the Army and describe practical methods for recycle/reuse of laundry and shower wastewaters. A thorough study of available literature has revealed there are no data to indicate serious adverse oral, dermal or ocular health effects in treated or recycled laundry or shower wastes for short-term usage. Although no serious health implications were uncovered in the literature related to recycle/reuse, some risks for reusing such wastewaters cannot be completely ruled out.

III. COLLATERAL CONSIDERATIONS

FLOATING POTABLE WATER SOURCE - INDIAN OCEAN

The U. S. Navy Military Sealift Command through a new organization, MSC-Indian Ocean, exercises administrative control of a seven-ship Near Term Prepositioned Force (NTPF) which is now on station in the Indian Ocean. The unarmed ships comprising the NTPF were loaded at various ports in June 1980 and were deployed the following month. Operational control of NTPF is the responsibility of Commander Task Force 73, an element of the Pacific Fleet's Seventh Fleet. The announcement was made in the Command Action Report of the Military Sealift Command, May 1980.

The tanker ZAPATA PATRIOT, a 35,100 deadweight-ton ship owned by Zapata Product Tankers, Inc. of Houston, was chartered to carry a cargo of approximately nine million gallons of potable water for the Force. Two breakbulk ships were chartered from U. S. Lines, Inc. of Cranford, N. J., the AMERICAN CHAMPION and the AMERICAN COURIER, and they transport mostly ammunition but also have been loaded with medical supplies, food and replacement parts. Three roll-on, roll-off ships are loaded with tanks, trucks and other equipment. The seventh ship, USNS SEALIFT PACIFIC, is a tanker with a nine million gallon fuel capacity.

NTPF sealifts sufficient supplies to support a Marine amphibious brigade of approximately 12,000 men and several Air Force squadrons. Equipment will be removed from the ships at periodic intervals for maintenance and operational checks. The potable water filling the tanks of the ZAPATA PATRIOT will be periodically replenished as required after approximately six months' of on-board storage.

The potable water was loaded from an approved watering point which met the requirements of the Safe Drinking Water Act and was chlorinated to 5.0 ppm. The several tanks in the ship, one of which was to remain empty, were coated with a substance approved by Navy Bureau of Medicine and Surgery after being "butterworthed" to remove excess materials remaining in the tanks from previous usage. Each tank was cleaned with fresh water and a detergent, flushed, ventilated and inspected for watertight integrity. All piping connecting the tanks was flushed with fresh water and detergent. All tanks were either superchlorinated at a level of 100 ppm or all tank surfaces were hosed treated from a pressure nozzle with fresh water containing 200 ppm chlorine. All valves, lines and pumps to be used in handling the potable water were flushed with potable water containing 200 ppm Free Available Chlorine (FAC).

FAC of the stored water will be determined daily and will not be allowed to drop below 2 ppm. Aeration of the water will be accomplished weekly by pumping from a full tank to an empty tank. Weekly bacteriological examinations of the water are to be accomplished and physical characteristics determined. A ship water log will be maintained to include: Source of water (where taken aboard and amount); concentration of FAC when loaded; daily FAC; daily water temperature in each tank; weekly pH determination; results of all chemical laboratory testing; results of taste and odor tests; date and amount of hypochlorite added to maintain chlorine residual; dates of transfer from tank to tank; and, any other appropriate data.

At a consumption rate of 6 gallons per man per day, the ZAPATA PATRIOT currently provides a 125-day supply of potable water for a 12,000 man force, or a 15-day supply of potable water for a 100,000 man force. The Near Term Maritime Prepositioned Force is an immediate, but interim, method of enhancing the U. S. armed services rapid response capability in the Mid-East. It is anticipated there will be a Long Range Prepositioning Force. One plan envisions the construction of eight additional Maritime Prepositioning ships and the procurement of four existing roll-on, roll-off ships for conversion to prepositioning ships.

GROUNDWATER PRODUCTION CAPABILITY

It is assumed there is a method to evaluate and ultimately locate groundwater levels and resources in arid regions. It is further assumed that most of the shallow (less than 1,000 feet) groundwater resources will be most successfully and quickly found in or adjacent to river beds. Deep wells (more than 1,000 feet) may be too time-expensive to develop in the field.

Today the Army lacks a major groundwater production capability although some well drilling equipment is in the Army inventory. Well drilling equipment is bulky; at best it is difficult to transport, cannot be very well hidden or camouflaged and, depending on the depth and strata to be drilled, requires an inordinate amount of time for set-up preliminaries. Any well drilling equipment, obtained in the future, whether government purchased or contractor leased, must be sea- or air-transportable.

TACTICAL WATER DISTRIBUTION SYSTEMS

The Army lacks the capability of transporting large volumes of potable water over long distances. To meet the field needs of transportation, the concept of a Tactical Water Distribution System (TWDS) was developed. Components of the System are envisioned to be either standard items within the military inventory, are directly usable from commercial sources or are commercially adaptable. The equipment is conceived to consist of eight-inch aluminum pipe, collapsible reservoirs or storage tanks, and transportable pumps and power sources to serve as pumping stations. The concept envisions techniques for rapid pipe laying, for pumping station construction and operation, and the rapid installation of intermittent reservoirs or storage tanks.

The TWDS concept will not be fully realized until mid-1981. Assembly of TWDS in-country would be by a petroleum pipeline and terminal company and the maximum segment length of a pipeline segment to be constructed in a given time period is some seven to ten miles per day per company.

TEMPERATURE OF WATERS IN THE DESERT

Research has revealed that desert warfare has been greatly influenced by the availability of adequate water supplies. Location of adequate sources of drinkable water has often determined where desert campaigns have been fought and won. Not only is the availability of water important but also its temperature. U. S. Army Technical Bulletin TB MED 507, Prevention, Treatment and Control of Heat Injury (July 1980), indicates the "optimum drinking water temperature is between 50° and 60°F and flavoring the water lightly with citrus flavors (or extracts) enhances its palatability." This temperature range is unrealistically low for desert climes. It is well known that in desert regions water stored above ground, particularly in enclosed containers or tanks or reservoirs, may reach 110-120°F or higher. Few soldiers, except the most desperate, could be induced to ingest water at these high temperatures. Contrariwise, it is unrealistic to expect that ice-cold water be available to all troops fighting in the desert. Nevertheless, water if it is to be ingested must be cooled well below the 110-120°F figure. The capability to cool drinking water will surely be a critical issue to be faced by any force employed in a desert region. The need for adequate and reasonably cool waters for shower purposes is also an item of concern. However, soldiers will shower and bathe in waters of higher temperatures than they would drink.

Under certain tactical operational conditions it may be necessary to provide water cooling equipment or devices. Such devices include, among other systems: Evaporative coolers, earth cooling, night radiation, vapor cycle, absorption, thermo electric, air cycle, vortex tube and solar (3). The vapor cycle and absorption systems appear to be the best short- and long-term alternatives.

A one-gallon desert water bag (flax) has been used successfully by individual U. S. Marines on maneuvers in the Mojave Desert. Using the simple evaporative principle, the bags have been reported to keep waters 20°F cooler than ambient temperatures.

If evaporative cooling is to be used as a method of cooling water for drinking purposes, considered to be of only poor to fair effectiveness, anywhere from 20 to 40% of the water supply may be evaporated for that purpose and the precious potable water supply may be inordinately wasted. Recycled water could conceivably be used in evaporation schemes provided safeguards are instituted to prevent mixing at the recycled/potable interface.

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3. Rhodes, Robert A., "Desert Water Cooling for Tactical Operations," Electrical Power Laboratory, MERADCOM, July 1979.

TRANSPORTATION AND STORAGE EQUIPMENT

The Forward Area Water Point Supply System (FAWPSS) concept marries local distribution and water transportation into a single scheme, partly dependent upon aerial delivery.

Ground transportation of water for water-point and unit distribution is limited by the Army inventory to the following equipment capacities: 400 gallon (Trailer, Tank, Water; 1-1/2 ton); 1000 gallon (Truck, Tank, Water; 2-1/2 ton); and 5,000 gallon (Bulk Haul and Fuel Servicing Semi-Trailer). It should be noted that a semi-trailer designed to haul 5,000 gallons of fuel load should be expected to carry a reduced water load of approximately 4,000 gallons in normal delivery because of the difference in specific gravities of the two liquids. Desert terrain is extremely rough, good road surfaces are rare and constant jolting of heavy loads may quickly cause excessive vehicular damage.

Water may also be transported in any Army vehicles which can carry 5-gallon cans, 55-gallon drums, and 55-, 250-, or 500-gallon collapsible fabric containers.

For water storage purposes there are available in the Army inventory large collapsible fabric tanks. Vertical steel bolted tanks are also available in 100-, 250-, 500-, 1000-, 3000-, and 10,000-barrel capacities.

WATER PURIFICATION EQUIPMENT: PHASING OUT/PHASING IN

The approximate current inventory of US Army Water Purification Equipment is shown in Table C-3. There is some question about the exact number of available 150 GPH Distillation Units and the CW-BW Pretreatment Sets.

Erdlators were designed after World War II to provide a quick-response, transportable water purification system to treat polluted fresh water. The distillation units were designed to produce a potable water from brackish sources or, in some instance, highly saline or sea waters. The CW-BW Pretreatment Sets were designed as pre-treatment units to be used in conjunction with Erdlators for chemically and biologically contaminated waters. Ion Exchange units, very few of which are in the current inventory, were envisioned to be used as post-treatment equipment for any of the four Erdlators.

All of the above single-purpose units may now be considered to be in the phase-out stage by the Army. To enhance the family of water supply equipment, a highly sophisticated multi-purpose water purification unit known as the Reverse Osmosis Water Purification Unit (ROWPU) has been developed which will replace all of the water purification equipment now in the current inventory.

MERADCOM has recently awarded (4) a $3.2 million contract for the production of thirty 600-GPH units and the equipment will be manufactured by Univax-California. The initial unit was scheduled for testing in October 1980; all units contracted for should be delivered by August 1981. Each device is rated to produce 600 gallons per hour of potable water from a brackish (or polluted) source and as much as 400 gallons from salt water. The 600-GPH ROWPU is primarily designed for use by strike forces including airborne troops.

The standard water purification unit for field forces, which has also been developed, is a larger version of the 600 GPH ROWPU and has been designated the 3000/2000 GPH ROWPU. It is designed to treat 3000 gallons per hour of potable water from a brackish or polluted source and 2000 gallons per hour of sea or heavily saline waters. Type-classification of the large unit was scheduled for late 1984 although the schedule may be accelerated. Both the 600 and 3000/2000 ROWPU devices are anticipated to have some operational and maintenance problems in the early stages of usage. Nevertheless, they represent the next generation of water treatment equipment and should prove invaluable under field conditions in arid and semi-arid environments.

PHYSIOLOGY OF LIFE IN THE DESERT

Military historians have not generally spent much time on the topic of water in reporting desert campaigns. The few references found have been sparse or terse. Most regimental and divisional histories pass over the dim and sometime forgotten memories of discomfort caused by the lack of water, the heat and the unsanitary living conditions in desert regions.

British, German, Italian and American forces clashed in North Africa during the period 1940-1943. Major battles were fought under desert conditions. Both sides built pipelines to forward positions in order to supply water from treated or acceptable natural sources developed in rear positions. Many allied regimental and divisional histories, unclassified War Department records and other references have been searched for details of those efforts but to little avail. A number of personal histories and other autobiographical material has been reviewed but information on the subject is scant.

The Office of Scientific Research and Development, Washington, D. C., through its Committee on Medical Research, supported a study, Physiology of Man in the Desert, by E. F. Adolph and Associates of the University of Rochester, School of Medicine and Dentistry, which was published in 1947 by Interscience Publishers, Inc., under the same title. The authors who wrote the material in 1942-1945 had cooperation from personnel in a number of infantry, armored and engineer units, evacuation hospitals and aviation

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4. Army Times, 25 August 1980.

squadrons. Cooperation was also obtained from the Desert Warfare Board, the Chief Surgeon of the Desert Manuever Area, the Offices of the Surgeon General and the Quartermaster General and other interested headquarters. The study, perhaps the best of its kind, discusses such topics as the human body and the desert, heat exchanges in the desert, water requirements of man in the desert, water shortages in the desert, thirst, survival without drinking water in the desert and life in the deserts.

The best German source related to water usage and availability is Desert Warfare: German Experience in World War II by Generalmajor Alfred Toppe (translator and editor, H. Hertman). The report, in typewritten form, was prepared as a staff exercise, and was critiqued on 18 June 1952 by Generaloberst Franz Halder, a Chief of Staff of the German Army during World War II. General Toppe, who devoted two and one-half months to the study, collaborated with the leading German experts on the African Campaign. In the preface, the author stated a "prerequisite was that . . . German officers be induced to contribute who had had as broad as possible view in the conduct of overall operations, who possessed practical combat experience and, furthermore, had exact knowledge of as many factors as possible which exerted a determining factor on desert warfare . . . former members of the German Africa Corps also made contributions."

It is interesting to note many of the same problems which faced the allied and axis powers in North Africa almost 40 years ago are still items of deep interest for those who plan operations in the Mid-East today.

In summary, heat has always been the greatest antagonist against which combat forces operate in a desert or arid environment. Soldiers lose inordinate amounts of body water in hot desert temperatures through the simple process of sweating. To prevent heat injury, incapacitation and death the soldier must replace the lost fluid at frequent intervals. The sensation of thirst alone may not be sufficient to induce a soldier to increase his water intake to replace that lost by sweating, i.e., when the body is losing heat. Often, the soldier must be strongly encouraged or even forced to drink water against his will. He will do so willingly if the water is palatable and reasonably cool.

IV. THE SCENARIO

US military commitments overseas can be categorized in two operational scenarios for the engagement of ground troops in combat. One is the case represented by Europe or Korea where US forces are presently deployed; the second covers contingencies for projecting US power to any geographical area of the world. In either case under war conditions, the logistical support to sustain combat forces will be enormous. The contingency case is more problematical because the threat, the geography, and the force requirements are so wide ranging. Chances are that the region will be arid and that water supply will be a critical factor. From the standpoint of vital US interests in a potentially unstable region of the world, it is the Middle East that presents the most immediate concern for military planners, and, in terms of support, it represents perhaps the worst-case situation.

The Middle East contingency force is studied in US service schools and by military planners for training and force development. The standard scenario calls for the rapid deployment of ground forces in strength up to the size of a reinforced corps. The example used in this report is drawn from course material prepared at the US Army Command and General Staff College. Although the published scenario is fictional, it accurately reflects not only the geography of the region but also the political, economic, and military realities that could involve the commitment of US forces in an area like the Middle East. Open aggression by one or more Middle East states, assisted perhaps by an outside world power, against another Middle East state, which is allied with the US, could threaten collapse of the tenuous political stability in the region, undermine balance-of-power relationships, and disrupt the supply of oil to Western allies. On receipt of an official request for assistance, the US would respond to the threat by implementing a standing, joint service contingency plan.

In general, the plan entails the rapid, time-phased deployment of a reinforced corps that achieves a strength of approximately 100,000 men by D-day plus 30, after which time the force jumps off in a full scale offensive. During the build-up, US forces will bolster local defenses and engage in reconnaissance and only limited offensive operations. At first, light infantry forces are flown to a forward base, 60 to 70 miles inland, followed by various elements of air cavalry, mechanized infantry, and armored forces. During the same period a seacoast base is established and a logistical link is made with the forward base.

Figure 1 depicts the operational environment for the scenario and shows the available water sources. Figure 2 shows the growth in troop strength from D-day to D plus 30 days, and the time phases, as follows: Phase I, the lodgement, D-day to D plus 10; Phase II, the build-up, D plus 10 to D plus 30; and, Phase III, the offensive, D plus 30 to D plus 60. Table 1 summarizes the phased end strength and total water requirements based upon a consumption factor of 13.3 gpd per individual

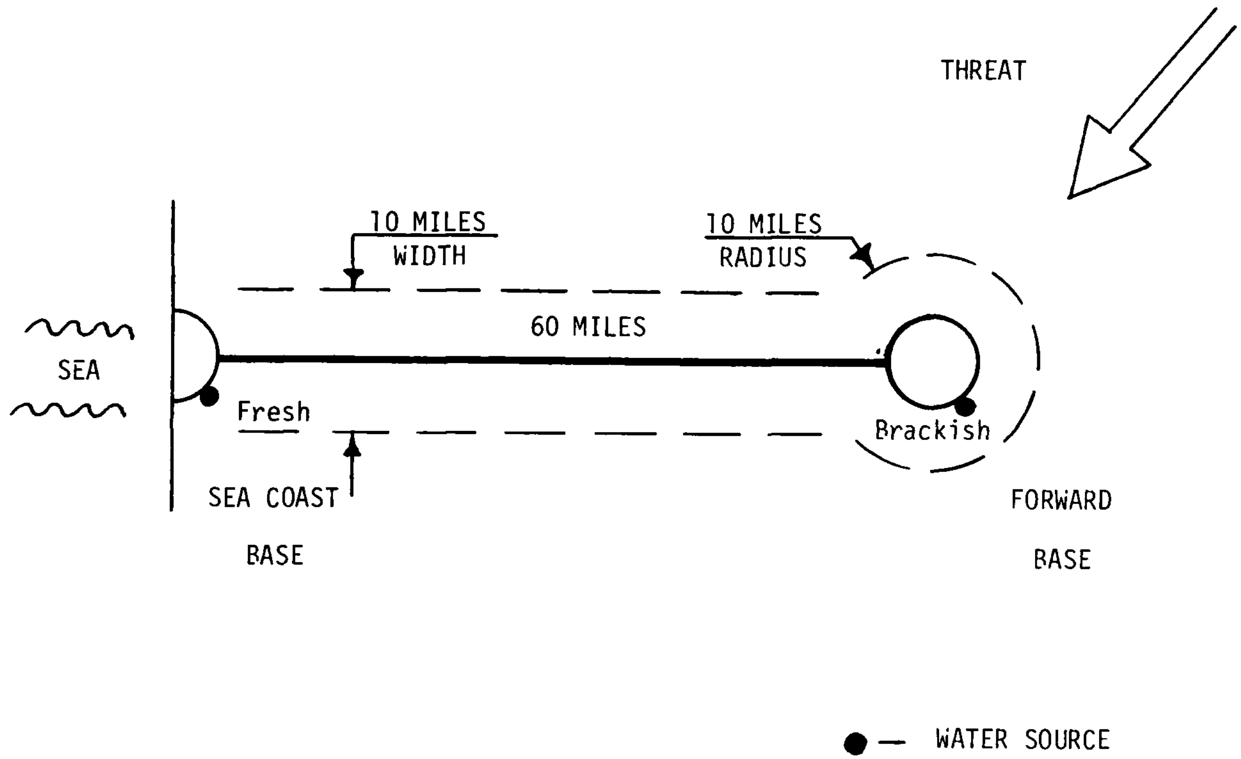


FIGURE 1. OPERATIONAL ENVIRONMENT SCENARIO

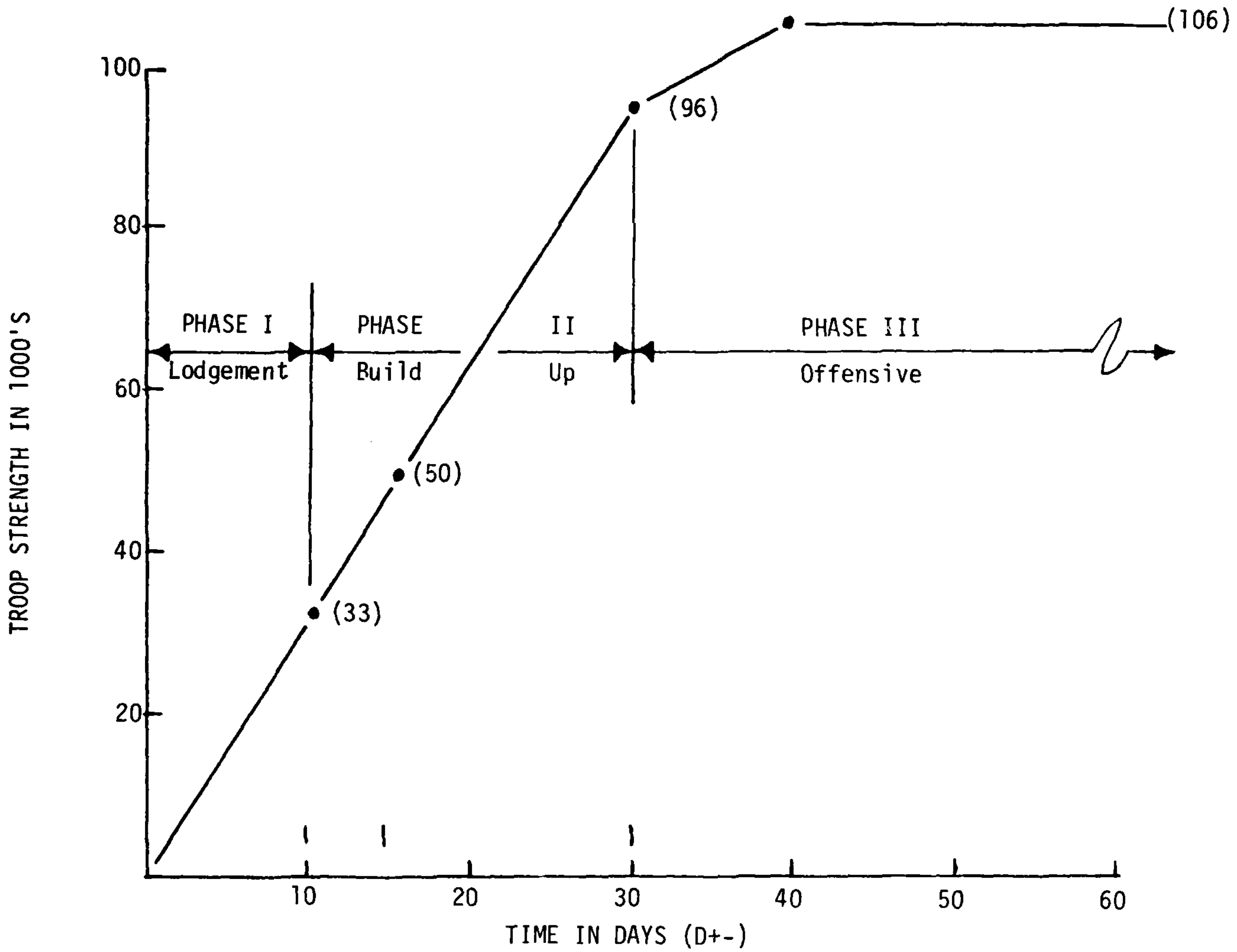


FIGURE 2. GROWTH IN TROOP STRENGTH

TABLE 1

Phased Strength and Total Water Requirements

Phase	Timing		End Strength	Water Use
	Begins	Ends		Q Total (MGD)
I - Lodgement	D-day	D + 10	33,000	0.44
II - Build-up	D + 10	D + 30	95,000	1.26
III - Offensive	D + 30	D + 60	106,000	1.41

for both potable and nonpotable use. The scenario assumes a constant division of troops between forward and rear. Two-thirds of the arriving troops will go directly into the forward area, and one-third will be distributed uniformly from the seacoast base along the 60 mile line of communication. During the lodgement, the principal troop concentration occurs in the forward base bridgehead which has a radius of 2.5 to 10 miles. During the build-up phase, rear area strength increases rapidly and, by the end of the phase, troops are dispersed uniformly along the line of communication which has a service width of 5 to 10 miles.

The location of water sources largely dictates the requirements and alternatives for treatment and delivery means. During the lodgement, potable water requirements in the forward area will have to be met by desalting the local supply; the alternative is supply by air or overland. A pipeline, to be completed at D plus 10, will be built along the line of communication. Thereafter, adequate quantities of potable fresh water will be available all along the line and at the forward area. The desalting equipment will then be free to support the planned offensive. At any stage, recycling and reuse of wastewater from laundry and bath operations would lessen the total water requirements and decrease the demands for treatment and delivery.

V. WATER REQUIREMENTS ANALYSIS

The following water requirements analysis is based upon meeting the water demands of a conventional contingency force in a desert area 60 miles from a source of potable water. Brackish water is locally available and the force must produce its own water for 10 days using Reverse Osmosis Water Purification Units (ROWPU) until a pipeline from a fresh water source is laid to it. Thereafter, potable water is provided by pipeline with non-potable requirements partially met through recycling.

Following D+10, troop strength is divided with 2/3 forward and 1/3 back, the latter being evenly dispersed over the distance to the bridgehead. The corridor is assumed to be 5-10 miles wide and the forward area has a radius of 2.5 to 10 miles. Figure 3 schematically shows the area analyzed and the water distribution.

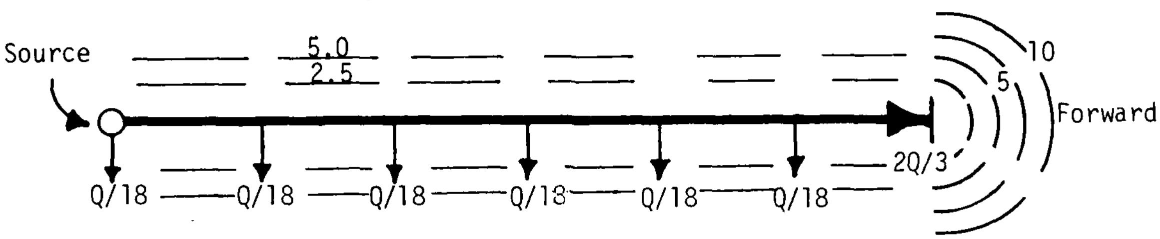


Figure 3. Water Distribution Schematic

The cost of providing water depends upon a number of factors which include the cost of production, cost of delivery, and the consumption rate.* This relationship is shown in the following equation.

$$\text{Cost factor } (f) = \frac{\text{Cost of production } (C_p) + \text{Cost of delivery } (C_d)}{\text{Daily Consumption } (Q)} = \frac{C_p + C_d}{Q} \qquad (1)$$

$$\text{Daily consumption } (Q) = \text{potable consumption } (Q_p) + \text{nonpotable consumption } (Q_n) \qquad (2)$$

$$= (\text{troop strength}) \cdot (\text{potable use factor}) + (\text{troop strength}) \cdot (\text{nonpotable use factor})$$

$$= SR_p + SR_n$$

Where S = troop strength during designated period
R_p = potable use factor = 9.26 gpd/indv
R_n = nonpotable use factor = 4.04 gpd/indv

*Symbols used in equations are listed in Table 2.

TABLE 2. EQUATION SYMBOLS

f	=	cost factor	D	=	distance delivered
f_t	=	cost of truck distribution ($/mi)	D_p	=	pipeline delivery distance
f_p	=	cost of pipeline distribution ($/mi)	D_t	=	truck delivery distance (round trip)
f_o	=	ROWPU production cost	D_{t_r}	=	truck delivery distance (rear-round trip)
f_s	=	source production costs	D_{t_f}	=	truck delivery distance (forward-round trip)
f_r	=	recycle costs	C_p	=	cost of production
Q	=	daily consumption	C_D	=	cost of delivery
Q_p	=	daily potable consumption	C_{p_p}	=	cost of potable water production
Q_n	=	daily nonpotable consumption	C_{p_N}	=	cost of nonpotable water production
Q_{fwd}	=	forward area consumption	C_{D_p}	=	cost of potable water distribution
Q_{rear}	=	rear area consumption	C_{D_N}	=	cost of nonpotable water distribution
S	=	troop strength during designated period	C_{p_t}	=	cost of all water production
R_p	=	potable use factor (gpd/indv)	C_{D_t}	=	cost of all water distribution
R_n	=	nonpotable use factor (gpd/indv)	C_T	=	total cost of water
			r	=	recycle rate

Consumption rates will be divided between forward and rear areas for computational purposes. The use factors are based on Army doctrine for the deployed force organization and are shown in Table 3.

The cost of production depends upon the method used to produce it and for the purpose of this study excludes the classical "capital" cost for equipment, it is assumed that the most cost effective equipment will be already in the Army's type classified equipment inventory. Instead, the production cost function is composed of a set of variables which reflect expendable items such as fuel, chemicals, filters, etc. . . and implies a consumable cost unit rather than the dollar value invested in the hardware system. Hence,

Cost of production = cost of potable water production using ROWPU or

= cost of recycle

The cost of delivery depends upon the method of delivery (e.g. pipeline or tanker truck) and the distance traveled usually in round trip numbers.

Cost of delivery = cost of pipeline delivery + cost of truck delivery

$$\text{Cost of }\underline{\text{pipeline}}\text{ delivery} = (\text{quantity delivered}) \cdot (\text{cost of delivery/mi}) \cdot (\text{miles}) = Qf_pD_p \tag{3}$$

$$\text{Cost of }\underline{\text{truck}}\text{ delivery} = (\text{quantity delivered}) \cdot (\text{cost of delivery/mi}) \cdot (\text{miles}) = Qf_tD_t \tag{4}$$

Where Q = quantity delivered
f_p = pipeline delivery cost
f_t = truck delivery cost
D_p = pipeline distance
D_t = truck distance (round trip)

The initial ten days of this simulated operation is called the "Build-up Period" with all troops located in the forward area and potable water requirements are met through the use of ROWPU. It is assumed that all potable water is produced at a single site at the center of the bridgehead and transported by 5,000 gallon petroleum tank trucks (adjusted to 4,000 gallon capacity when used for water) to single distribution points on the bridgehead perimeter. Recycled water is produced at the user's location.

Using a troop strength for the deployment periods and the use factors given in the reference, water requirements are calculated and shown in Tables 4 and 5. For example,

TABLE 3
WATER CONSUMPTION FACTORS

Use	TM 5-700	TRADOC Base Development Study	Logistics Center ME Working Group
POTABLE			
Individual consumption	6-13 gal/man/day	4-6 gal/man/day	6.00 gal/man/day
Food preparation	-	2-4 gal/man/day	2.00 gal/man/day
Bakeries	2600 gal/day/ bakery company	-	.10 gal/man/day
Hospitals	10/gal/bed/day	10 gal/bed/day	.93 gal/man/day
Graves registration	-	-	.23 gal/man/day
NON POTABLE			
Laundry	64,000 gal/day/ QM laundry company	.5 gal/man/day	1.61 gal/man/day
Shower	360,000 gal/day/ bath company	2-4 gal/man/day	1.94 gal/man/day
Vehicle consumption	.125-.56 gal/veh/ day	.94-.07 gal/man/ day	.08 gal/man/day
Aircraft turbine flushing	-	-	.41 gal/man/day
Aircraft washing	-	-	

TABLE 4
REAR REQUIREMENTS

Time Frame	Troop Strength	Potable Req. (GPD)				Total Potable	Non-Potable Req. (GPD)				Total Nonpot.
		Indv.	Hosp.	Kitch.	Other		Laundry	Shower	Vehicle	Aircraft	
Q_{N1}	0	0	0	0	0	0	0	0	0	0	0
Q_{N2}	16,500	99,000	15,345	34,650	3,795	152,800	26,565	32,010	1,320	6,765	66,660
Q_{N3}	31,700	190,200	29,481	66,500	7,291	293,540	51,037	61,498	2,536	12,997	128,068
Q_{N4}	35,300	211,800	32,829	74,130	8,119	326,880	56,833	68,482	2,824	12,997	141.136
Q_{N5}	35,300	211,800	32,829	74,130	8,119	326,880	56,833	68,482	2,824	12,997	141,136

TABLE 5
FORWARD REQUIREMENTS

Time Frame	Troop Strength	Potable Req. (GPD)				Total Potable	Non-Potable Req. (GPD)				Total Nonpot.
		Indv.	Hosp.	Kitch.	Other		Laundry	Shower	Vehicle	Aircraft	
Q_{p1}	33,000	198,000	30,700	69,300	7,600	305,600	53,100	65,300	2,600	13,500	134,500
Q_{p2}	33,500	201,000	31,155	70,350	7,705	310,200	53,935	64,990	2,680	13,735	135,340
Q_{p3}	63,300	379,800	58,869	132,930	14,559	586,160	101,913	122,802	5,064	25,953	255,732
Q_{p4}	70,700	424,200	65,751	148,470	16,261	654,680	113,827	137,158	5,656	28,987	285,628
Q_{p5}	70,700	424,200	65,751	148,470	16,261	654,680	113,827	137,158	5,656	28,987	285,628

where: p1 = D D+10
p2 = D+10 D+20
p3 = D+20 D+30
p4 = D+30 D+40
p5 = D+40 D+60

$S = 33{,}000 \quad R_p = 9.26 \quad R_n = 4.04$

$Q_p = (S)\ (R_p) = (33{,}000)\ (9.26) = 305{,}600$ gpd

$Q_n = (S)\ (R_n) = (33{,}000)\ (4.04) = 133{,}400$ gpd

The cost of production plus the cost of delivery equals the total cost. That is:

$$C_T = C_p + C_D \quad \text{Where } C_p = \text{cost of production}, \quad C_D = \text{cost of delivery}, \quad C_T = \text{total cost} \tag{5}$$

Cost of production is the product of the amount produced times the cost of unit production for the ROWPU. This production cost is calculated in Table 6.

$$C_p = (Q_p + Q_n)\ (f_o) \quad \text{Where } f_o = \text{ROWPU production cost factor (\$/gal)} \tag{6}$$

The cost of distribution is calculated by multiplying the quantity moved by the unit cost of distribution. The cost factors for water distribution by tank truck are calculated in Table 7.

$$C_D = (Q_p + Q_n)\ (f_t)\ (D_t) \tag{7}$$

Thus, the total cost of producing and delivering water for the bridgehead during the first ten days can be calculated using the following formula.

$$C_T = (Q_p + Q_n)\ (f_o + f_t D_t) \tag{8}$$

Transportation costs are \$.101/1000 gal/mi and production costs are \$20.36/1000 gal. Round trip transportation cost for various bridgehead sizes are determined by calculating the above formula with D_t = 5.0, 10.0, 15.0 and 20.0 miles.

If recycle of wastewater to satisfy nonpotable demands is used, the cost of water production for all requirements can be determined by the following formula.

$$C_T = C_{p_p} + C_{p_n} + C_{D_p} + C_{D_n} \tag{9}$$

where C_{p_p} is cost of potable water production

TABLE 6
WATER PRODUCTION COSTS FOR ROWPU

POTABLE (ROWPU) (600 gph)

Fuel	3 gph @ $2.00/gal x 1.67 hr/1000 gal	=	$10/1000 gal
Polymer	.4 lb @ $1.20	=	.48/1000 gal
Cl_2	.13 lb @ $1.33	=	.17/1000 gal
Acid	.12 lb @ $8.00	=	.96/1000 gal
SHMP*	.4 lb @ $3.21	=	1.28/1000 gal
Filters	.53 @ $14.00 ea.	=	7.47/1000 gal
	TOTAL		$20.36/1000 gal

*Sodium hexametaphosphate

TABLE 7. WATER DISTRIBUTION COSTS

TRUCK

Tractor consumes .125 gal/KM or .202 gal/mile*

Assume diesel is $2.00 per gallon

Therefore, f_t = (.202 gal/mi) (2 $/gal) = $.404/mi

Each tank carries 4,000 gallons, therefore cost per 1000 gallons is

$$\frac{\$.404}{4} = \$.101/1000 \text{ gal/mi}$$

PIPELINE

600 gpm pump uses 5 gph diesel fuel*

Assume one pump every 10 miles

600 x 60 = 36,000 gph water pumped at cost of 5 x $2.00/gal fuel

= $10.00

$$f_p = \frac{\$10.00}{36} = \$.278/1000 \text{ gal/10 mi} = \$.0278/1000 \text{ gal/mi}$$

*FM 101-10-1, July 1976

C_{p_n} is cost of nonpotable water production

C_{D_p} is cost of potable water distribution

C_{D_n} is cost of nonpotable water distribution

Since recycled water is obtained and treated at the user's location, the transportation cost, C_{D_n} equals zero. If we assume that 10% of the initial nonpotable requirements will be made up from ROWPU, then

$$C_{p_p} = Q_p f_o + (0.1)\ (Q_n)\ (f_o) + (1-r)\ (Q_n)\ (f_o)\ (0.9) \tag{10}$$

Where r = recycle rate

Therefore, nonpotable production costs are

$$C_{p_n} = (r)\ (0.9)\ (Q_n)\ (f_r) \tag{11}$$

while potable distribution costs are determined by the following formula.

$$C_{D_p} = Q_p f_t D_t = (0.1)\ (Q_n)\ (f_t)\ (D_t) + (1-r)\ (Q_n)\ (0.9)\ (f_t)\ (D_t) \tag{12}$$

Production cost for recycled water is calculated in Table 8. Using the above formulas and production/transportation cost factors, the cost of providing water can be determined by varying the recycle rate at .75, .85, and .95 and setting the round trip distance water is to be moved at 5.0, 10.0, 15.0 and 20.0 miles.

After D+10 the rear area buildup begins and troop strength distribution is 2/3 forward and 1/3 in the rear. Rear area troops are equally dispersed along a 50 mile long corridor from the port to the bridgehead, with water supplies being drawn from the pipeline at six points equally spaced at 10 mile intervals. The sector is 5 to 10 miles wide with water delivered to distribution points of the perimeter by tank truck.

The pipeline will provide all potable water requirements and non-potable requirements will be met through recycle at the user's location. The hospital requirements are distributed according to troop strength in the area. Potable water is produced at the source at no cost. Total troop strength in the area of operations varies from 50,000 to 95,000 to a maximum of 106,000.

Total cost of providing water can be calculated from the following formulae assuming no recycle. C_{p_t} is equal to a constant due to the assumption that potable water is produced at the same cost as that for the Erdlator.

TABLE 8
WATER PRODUCTION COSTS FOR RECYCLING

RECYCLE (500 gph)

Fuel	.25 gph x 2 hr @ $1.20	=	$0.60/1000 gal
*Carbon	16 lb @ .40	=	6.40/1000 gal
Type 1 polymer	.15 liter @ 2.53	=	.38/1000 gal
Type 2 polymer	2 gm @ .01	=	.02/1000 gal
	TOTAL		$7.40/1000 gal

*Carbon is to be reused at the following rates:

Dosage (ppm)	lbs/500 gallons	lbs/1000 gallons	Cost/1000 gallons
1920	8	16	$6.40
1440	6	12	4.80
960	4	8	3.20
480	2	4	1.60

$$C_T = C_{p_p} + C_{p_n} + C_{D_p} + C_{D_n}$$

$$C_{p_t} = C_{p_p} + C_{p_n} = K$$

$$C_{D_t} = C_{D_p} + C_{D_n}$$

$$C_T = C_{p_t} + C_{D_t}$$

With equal draw of water along the fifty mile pipeline, the average distance water is piped is 25 miles for the rear area; forward area water is piped 60 miles. Therefore,

$$C_T = C_{D_t} + C_{p_t}$$

$$= 25\ Q_{rear} f_p + Q_{rear} f_t D_t r + 60 Q_{fwd} f_p + Q_{fwd} f_t D_{tf} + C_{p_t}$$

and quantities moved can be calculated on troop strength as follows.

$$Q_{rear} = \frac{S\ (9.26 + 4.04)}{3} \qquad Q_{fwd} = \frac{2S\ (9.26 + 4.04)}{3}$$

The cost of moving the water by pipeline is calculated in Table 7. Using the above formulas, the cost of water can be calculated for the three troop strengths, rear area round trip tank truck distance of 5 and 10 miles, and forward area trucking distance of 5.0, 10.0, 15.0 and 20.0 miles.

If a partial recycle is used, the cost of water is defined once more by the basic formula, with the cost of production equal to K and recycle distribution cost equal to zero due to assumptions previously given. Therefore, the remaining terms can be determined as follows.

Using these formulas, water costs can be determined by adding recycle rates of .75, .85, and .95 to those used in the preceding calculations.

$$C_{D_n} = \emptyset$$

$$C_{p_p} = K$$

$$C_{p_n} = (r)\ (0.9)\ (Q_n)\ (f_r)$$

$$
\begin{aligned}
C_{D_p} = {} & (Q_{p_{rear}})\ (25)\ (f_p) + (25)\ (1-r)\ (Q_{n_{rear}})\ (f_p) + \\
& (Q_{p_{rear}})\ (f_t)\ (D_{tr}) + (1-r)\ (Q_{n_{rear}})\ (f_t)\ (D_{tr}) + \\
& (60)\ (Q_{p_{fwd}})\ (f_p) + (60)\ (Q_{n_{fwd}})\ (1-r)\ (f_p) + \\
& (Q_{p_{fwd}})\ (f_t)\ (D_{tf}) + (Q_{n_{fwd}})\ (1-r)\ (f_t)\ (D_{tf}) + \\
& (25)\ (0.1)\ (Q_{n_{rear}})\ (f_p) + (60)\ (0.1)\ (Q_{n_{fwd}})\ (f_p) + \\
& (0.1)\ (Q_{n_{rear}})\ (f_t)\ (D_{tr}) + (0.1)\ (Q_{n_{fwd}})\ (f_t)\ (D_{tf})
\end{aligned}
$$

$$
\begin{aligned}
C_T = {} & (Q_{p_{rear}} + (1-r)\ Q_{n_{rear}})(25f_p + f_t D_{tr}) + \\
& (Q_{p_{fwd}} + (1-r)\ Q_{n_{fwd}})\ (60f_p + f_t D_{tf}) + \\
& (0.1)\ (f_p)\ (25Q_{n_{rear}} + 60Q_{n_{fwd}}) + (0.1)\ (f_t)\ [(Q_{n_{rear}})\ (D_{tr}) + \\
& (Q_{n_{fwd}})\ (D_{tf})] + (0.9)\ (r)\ (Q_n)\ (f_r) + K
\end{aligned}
$$

VI. ANALYTICAL MODELS

Based on the scenario described in Section IV, two basic analytical models were developed. The first model for the Forward Base during Phase I and the second model for Phase II. Both analytical models developed are network models; a network consisting of nodes (junctions) and arcs (connections). A more detailed description of networks and the solution procedure, the Out-of-Kilter Algorithm (OKA) is presented in Appendix A. Using the results of Section V, Water Requirements Analysis, to specify the potable and non-potable water demands, costs of distribution to include production, transportation, transmission and recycling were used to formulate each of the two basic models.

During Phase I, the forward elements of the contingency force must use organizational equipment (ROWPU) to produce potable water from a single brackish source. The water is then distributed via truck throughout the Forward Base bridgehead which has a radius of 2.5 to 10 miles. Figure 4 is a schematic of Phase I distribution. Sixteen runs of the model were made varying the bridgehead radius, recycling rate and carbon dosage. Since the cost of production by ROWPU (see Tables 6 and 8) is from 3-8 times more costly than recycling and recycling eliminates transportation costs, maximum recycling is cost effective.

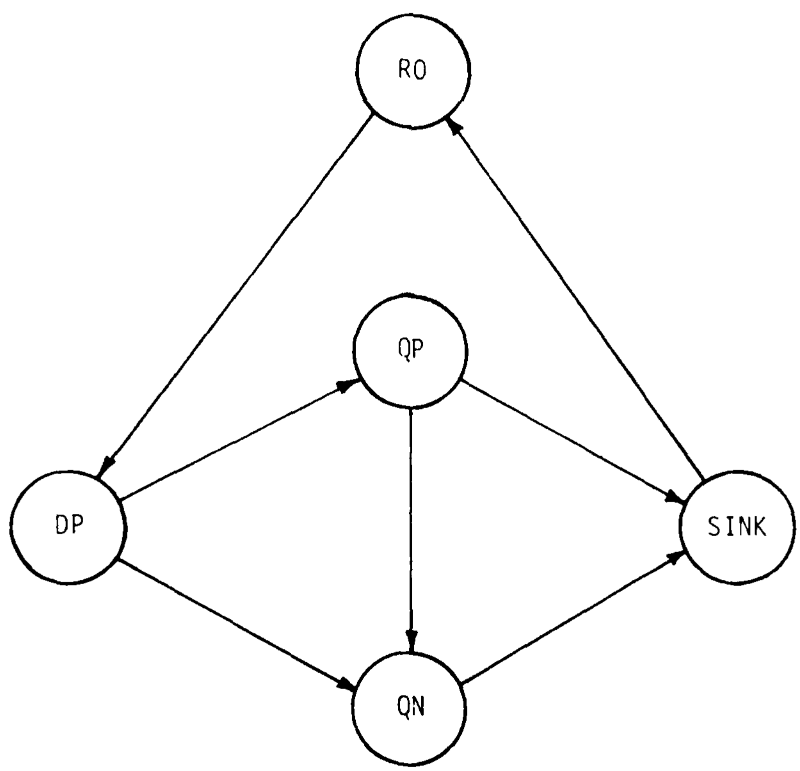
Figure 5 is a schematic of the analytical model for Phase II. The model as formulated consists of a fresh water source and seven distribution points. The quantity of flow withdrawn from each distribution point is constant and determined by the potable water demands with the remaining flow available to be diverted to meet non-potable needs. The flow to the non-potable nodes varies depending on the percentage of flow being recycled. Ninety computer runs were made consisting of roundtrip distances of five, ten, fifteen and twenty miles at five different recycling rates and at four different levels of carbon dosages. The results are illustrated in Figure 6 - Phase II Recycling Decision Guide. The four curves represent the carbon dosages in lbs/1000 gal or ppm and indicate that recycling should not be carried out to the left of a given dosage line.

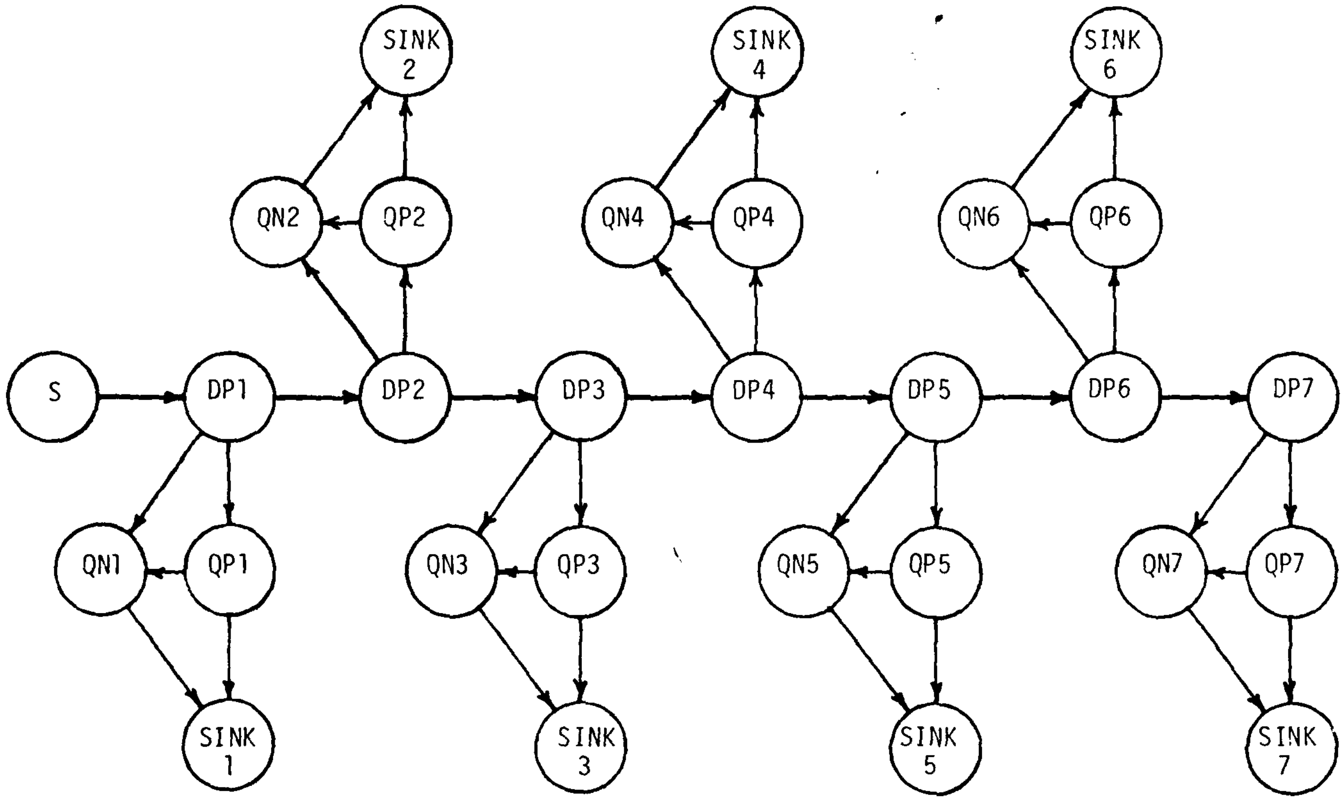
During Phase III, D + 30 to D + 60, fresh water will be available via pipeline in the original forward area. As the offensive continues and the distance between the FEBA and the end of the pipeline increases, the use of ROWPU becomes more attractive to meet potable water demands.

The cost of water delivered from the original fresh water source at the sea coast to the FEBA is the sum of source production costs (f_s) plus pipeline distribution costs (f_p) plus costs of truck distribution (f_t). The cost of water delivered to the end of the 70-mile pipeline is approximately $2.50/1000 gallons.

FIGURE 4. SCHEMATIC OF PHASE I ANALYTICAL MODEL

Nodes		Arc Representation
i	j	
RO	DP	Reverse Osmosis
DP	QP	Transportation for Potable Demands
DP	QN	Transportation for Non-Potable Demands
QP	SINK	Potable Demands
QP	QN	Recycling to Meet Non-Potable Demands
QN	SINK	Non-Potable Demands
SINK	RO	Continuity of Flow





*Conservation-of-Flow Arcs from Sinks to Source Not Shown.

FIGURE 5. SCHEMATIC OF PHASE II-III ANALYTICAL MODEL

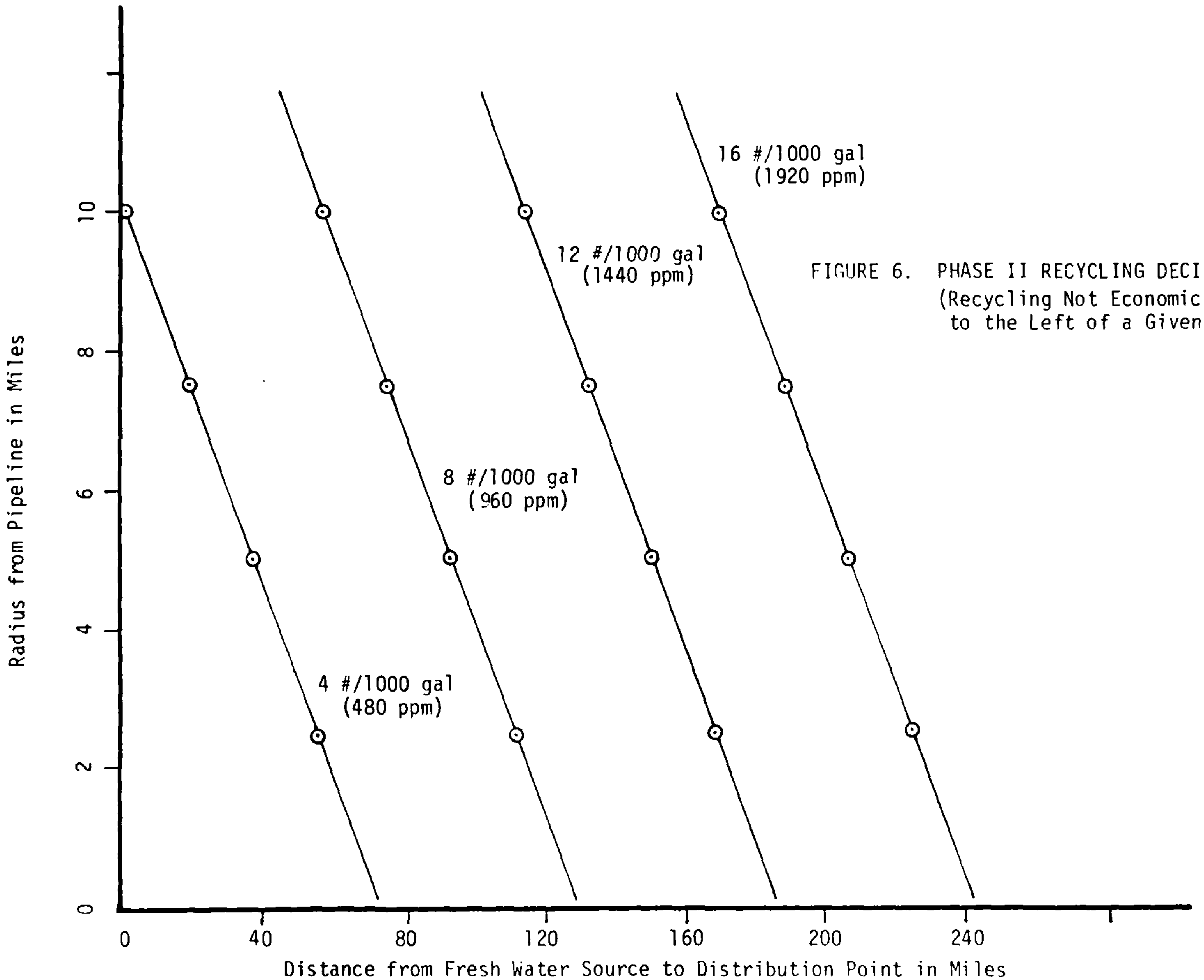


FIGURE 6. PHASE II RECYCLING DECISION GUIDE
(Recycling Not Economically Feasible to the Left of a Given Dosage Line)

Each round-trip mile of truck distribution adds approximately \$.20/1000 gallons to the total cost. With the cost of potable water as produced by ROWPU (f_o) the maximum distance, D_{tr}, from the pipeline end that water should be trucked is

$$D_{tr} = \frac{f_o - (M \times f_p) - f_s}{f_t}$$

where M is the pipeline length in miles. Using the operating costs developed in Section V as the criterion, this maximum distance is nearly 90 miles.

To meet the non-potable demands beyond the maximum trucking distance, D_{tr}, recycling at even the maximum carbon dosage is preferable to using ROWPU. Within the maximum trucking distance recycling is economically feasible if

$$f_s + (M \times f_p) + (D_{tr} \times f_t) > f_r$$

The values of f_r developed in this study range from #2.60/1000 gal to \$7.40/1000 gal, therefore, depending on the carbon dosage required, recycling can be economically feasible within a mile of pipeline end, or in the worst case of no carbon reuse, feasible at approximately 25 miles and beyond.

VII. WASTEWATER REUSE SYSTEM HARDWARE

GENERAL

There are known commercial wastewater treatment processes and hardware systems available today to reclaim laundry and shower wastewaters in an effective manner for direct reuse purposes. However, the systems are generally designed for fixed installations that must be supported by close-at-hand supplies and repair services. Military equipment in tactical zones cannot afford such luxuries. Consequently, simplicity and reliability of operation must be prime factors in the selection of field hardware systems. With these features in mind, it was determined that equipment with which the Army had previous operational and maintenance experiences would be a better basis for selecting any proposed wastewater reuse system.

The system hardware proposed herein provides for the collection, treatment, and recycle of the wastewater at locations where it is generated. Shower wastewater from a field bath unit can be collected and treated immediately adjacent to the shower facilities and reused in the bath unit. Similar procedures can be employed in laundry wastewater reuse. The same treatment equipment, with a minor change in wastewater treatment chemicals, could also be used for recycling vehicle cleaning wastewater. However, suitable methods for collection of this type wastewater would have to be improvised, depending on the location and type of vehicles to be washed.

The proposed system hardware, which has the potential for multiple uses, consists of an assemblage of supplies and hardware components that are now in military inventory and are currently documented for military procurement. In addition, operating, maintenance, and parts manuals for the majority of the components are available and have been used in the field for several years. The proposed hardware is also readily transportable, is easily loaded or off-loaded manually from a vehicle, and is easily erected in the field with or without a protective shelter, depending on climatic considerations.

DESCRIPTION OF SYSTEM HARDWARE

The proposed system hardware consists of two separate sets of equipment, namely; (1) Shower Wastewater Reuse Unit (SWRU), and (2) Laundry Wastewater Reuse Unit (LWRU). Both units employ the basic technology developed for the treatment of wastewater in the Army pollution abatement program. However, diatomite filtration and chlorination processes have been added to the pollution abatement treatment train to make the wastewater suitable for reuse by Army personnel. The pollution abatement kits are currently in Army inventory, along with the additional equipment required to increase storage capacity and to provide filtration and chlorination. A description of the proposed wastewater reuse units follows.

a. Shower Wastewater Reuse Unit (SWRU). A typical arrangement of the SWRU installed with the standard Portable Bath Unit (NSN 4510-00-168-1963) is shown in Figure 7. A field bath unit consists of a raw water pump, water heater, 3 KW electrical generator, and two shower stands with four shower nozzles per stand. Since shower nozzles do not have control valves, the discharge rate is a 16 gpm continuous flow. An improved bath unit scheduled for type classification FY 81 has the number of shower nozzles increased to nine and an individual control valve added to each nozzle. Under optimum conditions, the maximum rate of discharge of a shower unit is the capacity of the pumping unit, or 20 gpm. Normally, a field bath unit is located near a water source such as a lake or river, and the raw water is pumped from the source through the water heater to the shower nozzles. Every effort is made to locate clean water sources. Each bath unit is provided with an electrically driven raw water pump that delivers 18 - 20 gpm at 65 - 70 feet total dynamic head.

In semi-arid regions or areas where natural water sources are scarce, the proposed wastewater reuse system is designed to conserve fresh water. Following a basic format, 1500 gallons of potable water would be trucked or piped into the 1500 gallon fresh water storage tank. The raw water pump with the bath unit is used to transfer the water from the storage tank through the heater to the shower heads. The shower stands are installed on a shallow rectangular coated fabric tank to collect wastewater. From there it flows by gravity or is pumped to a 1500 gallon pillow-type storage tank. When the pillow tank is filled (approximately 1500 gallons), the wastewater is pumped to one of two open cylindrical 1500 gallon treatment tanks (Figure 7). Prior to pumping wastewater into the tank, 24 lb. of powdered activated carbon (1920 ppm) is manually added to the empty tank. Approximately 15 minutes is required to fill the tank and mix the activated carbon with the wastewater. When the tank is filled, 225 ml (40 ppm) of the cationic polyelectrolyte (Type I Polymer) is added and the three way plug valve on the pump suction is positioned to permit recirculation of the wastewater in the tank for approximately 30 minutes. After mixing is completed, 3 grams (0.5 ppm) of the non-ionic polyelectrolyte (Type II Polymer) is added and recirculation is continued for an additional 10 minutes. The recirculation is stopped and the coagulated wastewater is allowed to settle for approximately 30 minutes.

Following the 30-minute settling period, the water has been clarified and is ready to be filtered. Suction hoses attached to the filter are suspended by floats to permit withdrawal from the upper water level in the treatment tank. Two diatomite filters operating in parallel are used to maintain continuous delivery of 16 gpm to the fresh water tank. The diatomite filter from the Water Purification Unit 420 GPH (NSN 4610-00-937-0222) was selected because it can operate as a separate component. The filter is lightweight and can be manually handled. Further, it is self-contained with an electrically driven filter pump and has all necessary accessories for precoating and filter backwash. It is not proposed to use body feed because the precoat will provide sufficient cake thickness for one filter cycle or time to filter the contents of

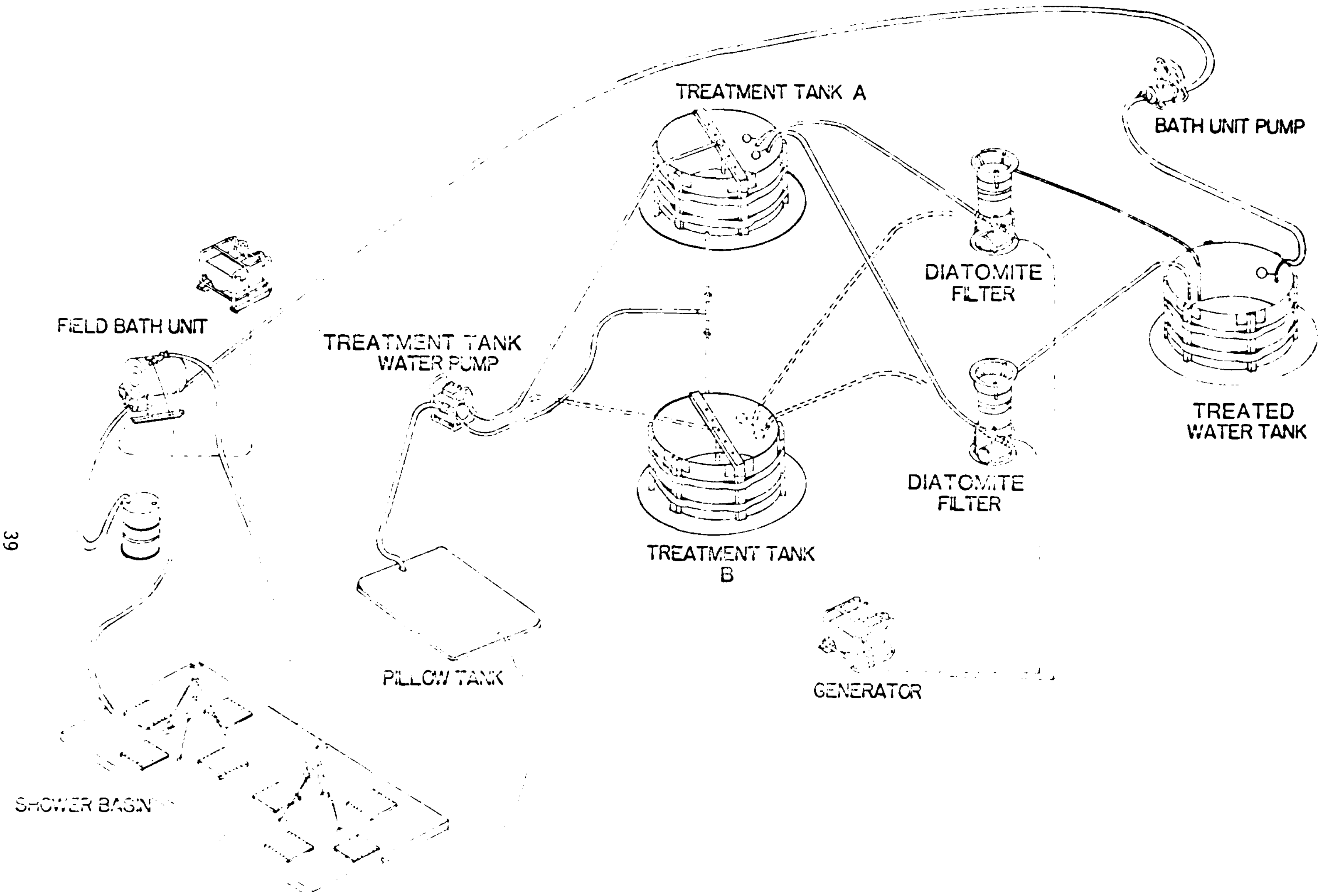


FIGURE 7. SHOWER WASTEWATER REUSE UNIT

one treatment tank. To each filter will be added a Dole flow control valve to control filter operations at the constant rate of 8 gpm over a variable pressure range.

A 3 KW engine-driven generator with circuit breakers and switch box would normally be required to operate the diatomite filter pumps. However, in hot arid regions where ambient water temperatures are relatively high, the requirement to operate the heater is reduced. Consequently, the filter pumps could be operated from the 3 KW generator provided with the bath unit.

The filtered water is collected in the 1500 gallon open-top type tank. Periodically, on a predetermined schedule, a measure of calcium hypochlorite must be added to chlorinate the stored water. The treated wastewater is chlorinated because of the presence of bacteria or microorganisms which can increase in number, especially in hot, sunny locations. Further, calcium hypochlorination is effective in destroying a difficult-to-remove contaminant, urea.

Some make-up water will be required periodically to compensate for losses. The principal water losses are from evaporation and retention on the body as individuals leave the shower. However, about 98% of shower wastewater in each cycle should be collected for treatment, where the water losses are minimal. Other losses include those associated with the periodic removal of sludge from the coagulation tanks and the backwashing of the filter which are estimated at less than 1%. In a 20-hour operating day, the total water loss would be approximately 3% or 575 gallons.

The SWRU as described above and shown in Figure 7 is a simple and effective field treatment system. A suggested set of equipment, consisting of items that are available from military sources is listed in Table B-3. Many component items, such as chemicals, hoses and the GED pump are the same as in the Shower Wastewater Treatment Kit, NSN 4610-01-023-4537 (Pollution Abatement Kit). Additional items required include diatomite filters and a 1500 gallon pillow-type water storage tank. The filters are available in existing 420 GPH ERDLator water purification units. Upon type classification of the 600 GPH ROWPU, the 420 GPH ERDLator filter could be made available for this set. The 1500 gallon pillow-type tank is not currently in the Army supply system, although it has been tested and military specifications have been prepared. The diatomite filters are available in existing 420 GPH ERDLator Water Purification Units. With the type classification of the 600 GPH ROWPU, the 420 GPH ERDLator filter could be made available for this purpose.

b. Laundry Wastewater Reuse Unit (LWRU). A typical layout of the LWRU to treat wastewater from the standard 60 lb. capacity, Trailer Mounted Laundry Unit, NSN 3510-00-782-5294, is shown in Figure 8. In many instances, field laundries operate as a team with two laundry units per team. Wastewater generated by a laundry unit is approximately 250

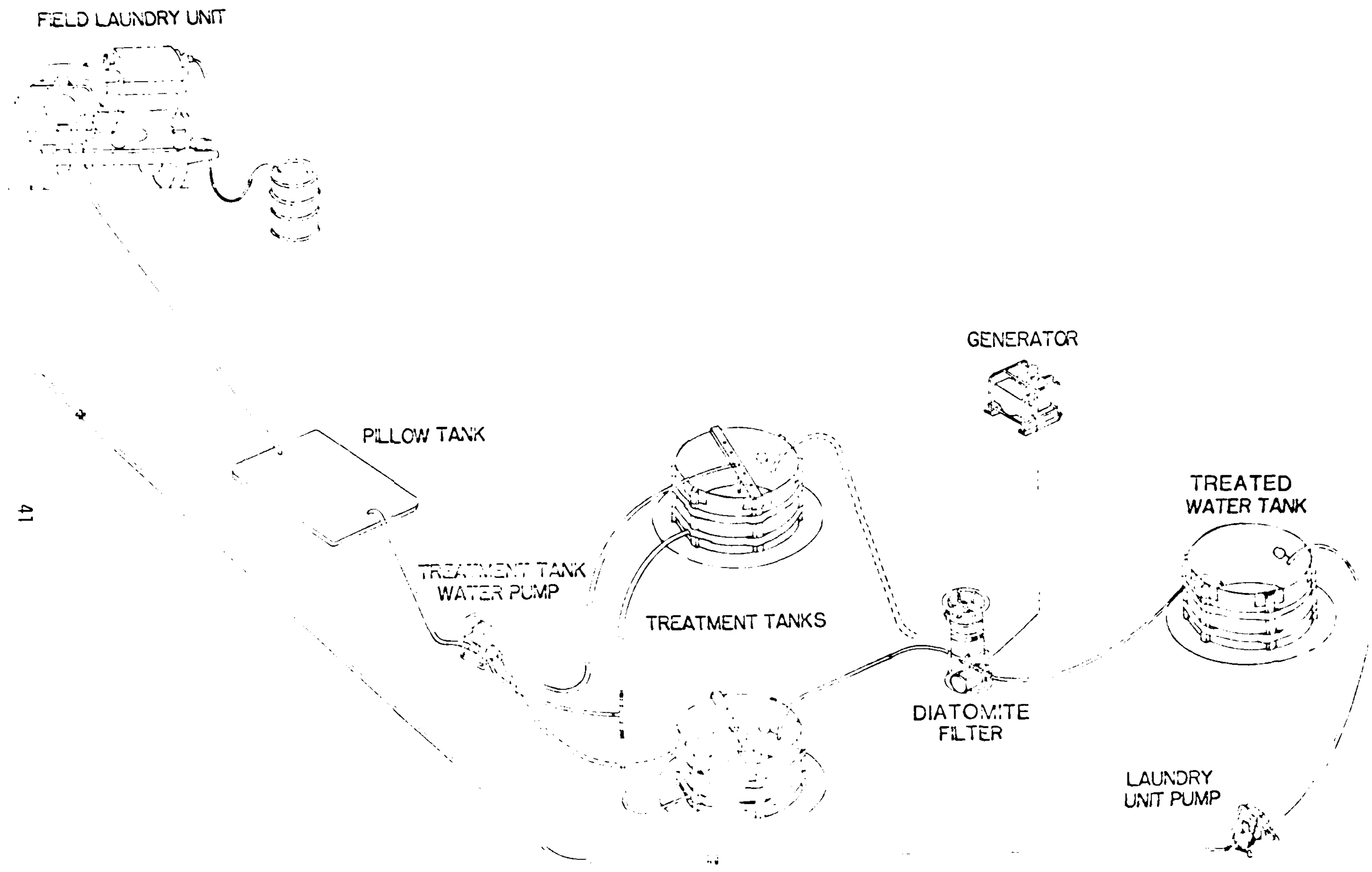


FIGURE 8. LAUNDRY WASTEWATER REUSE UNIT

gallons per hour; two units at one location would generate approximately 500 GPH of wastewater. Wastewater is discharged from the drain in the bottom of the trailer mounted unit which can be connected by hose to a 500 gallon pillow collection tank. If two laundry units are located within close proximity to one another, the drains would be manifolded before connection to the pillow tank.

The procedure for treating laundry wastewater is identical to that described for shower wastewater with two exceptions. The 1500 gallon treatment tank in the SWRU are replaced with 500 gallon capacity tanks. This reduction in size is possible because the quantity of wastewater from two laundry units is less than from one bath unit. In addition, only one diatomite filter is required for the laundry units. The chemicals and dosages (ppm) are the same and so is the method of operation.

A proposed set of equipment for the LWRU is listed in Table B-2. It basically consists of the Pollution Abatement Kit (Laundry Wastewater Treatment Kit, NSN 4610-01-023-4536) plus additional components such as a 420 GPH diatomite filter, portable generator, hose, tanks, etc.

PERSONNEL AND TRAINING REQUIREMENTS.

It is estimated that two men can assemble the SWRU for operation in approximately two hours. The LWRU would require two men and approximately one hour for assembly. The LWRU requires less time because the 500 gallon tanks are easier to field-erect than the 1500 gallon tanks. One man would be required per shift to operate either the SWRU or the LWRU. Operator level of training would be equivalent to what the MOS 52N receives today for the operation of ERDLator water purification units.

LOGISTIC SUPPORT.

The consumable supplies used in operation of wastewater reuse units are primarily chemicals and fuels. It is noted that the chemical requirements for activated carbon are high because the dosages are based on the initial charge. In bath coagulation, the activated carbon settles to the bottom of the tank and is resuspended with the new charge of carbon when the tank is refilled. The carbon particles not effectively used in the first treatment are returned to contribute to further treatment. If beneficial, the subsequent charges of activated carbon could theoretically be reduced. It is known that in the present batch coagulation system, the dosage of activated carbon is 1920 ppm. In field operational test using continuous flow clarifier equipment treating laundry and shower wastewater, effective results were obtained using 425 ppm activated carbon dosages. This is a significant difference when compared to the batch treatment. The amount of reduction is not well documented and the objectives of future proposed research are focused upon this anticipated reduction in logistic support.

PROCESS PERFORMANCE.

The treatment of shower and laundry using the SWRU or LWRU systems proposed herein has not been previously accomplished. However, the U. S. Army Mobility Equipment Research and Development Command has reported performance data on the principles employed in the "Pollution Abatement Kits" in two separate tests. In both tests, the wastewaters were collected and treated under field conditions.

At Fort A. P. Hill, potable water trucked to a bivouac site was used by Army Reserve Units at their field shower and laundry facilities. The wastewaters were treated with activated carbon and Type I polymer in a modified military up-flow clarifier at a continuous constant rate, followed by diatomite filtration. Data from the report is summarized in Table B-1.

On another occasion, water from Hunting Creek near Alexandria, Virginia, was used in the operation of standard field laundry and field bath units. The wastewaters were treated in a batch coagulation system using activated carbon, Type I and Type II polymers. The treatment process did not include filtration. Data from the report is included in Table B-1.

The two earlier tests revealed the effectiveness of carbon-polyelectrolyte-aided clarification/filtration in renovating wastewater for pollution abatement purposes. A comparison of the above results with the proposed OTSG interim water quality criteria for shower and laundry reuse is also shown in Table B-1.

VIII. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Based upon the findings of this study the following conclusions are made:

1. There is no evidence to indicate adverse oral, dermal or ocular health effects in treated or recycled laundry and/or shower wastewaters for short-term usage. However, long-term risks for reusing such wastewaters cannot be completely ruled out.

2. The recycle and reuse of shower and laundry wastewaters are the best economic alternative when:

   a. Only brackish or saline water sources are available and only ROWPU units are available for treatment.

   b. Fresh water must be transported significant overland distances in bulk quantities by vehicle or pipeline (See Figure 6, Phase II - Recycling Decision Guide).

3. Military standardized equipment for the reclamation of laundry and shower wastewaters is available (See Appendix B).

4. Further pilot-scale testing is needed to validate the system performance: the economic gains through carbon reuse and the reuse quality criteria.

RECOMMENDATIONS

It is recommended that:

1. Under water-scarce conditions (as exist in the Mid-East) field laundry and shower wastewaters be reclaimed and reused for nonpotable uses.

2. The Laundry Wastewater Reuse Unit (LWRU) and the Shower Wastewater Reuse Unit (SWRU) as described in Appendix B, be field tested to establish:

   a. System performance characteristics.

   b. Compliance with wastewater reuse quality criteria as established by the Army Surgeon General.

APPENDIX A

DESCRIPTION OF ALGORITHM

The out-of-kilter algorithm, OKA, developed by Fulkerson, solves the general minimum cost flow problem for networks. A network consists of a set of nodes which are connected by arcs. Nodes are defined by lower case letters i and j. Arcs originate at node i and terminate at node j. The term X_{ij} represents the amount of "flow" over a particular arc (i, j) in the direction i to j. X_{ji} means that flow goes from j to i.

Arcs in the network system may have cost and/or capacity restrictions. The cost of the use of a particular arc per unit of flow is represented by C_{ij}. Capacities or upper bounds on flows through arcs by U_{ij} whereas L_{ij} represents a minimum flow requirement.

The network problem can be described as follows: The flows through the various arcs must be found which minimize the total cost. Total cost is described as

$$\sum C_{ij}X_{ij} \quad \text{for all i and j}$$

(cost of unit flow times unit flow)

While concurrently satisfying

$$L_{ij} \leq X_{ij} \leq U_{ij} \quad \text{for all i and j}$$

(flow must be between established limits)

In a network problem, nodes have no storage capacity for any of the flow, so all flow must be in constant circulation, that is:

$$\sum_j X_{ji} - \sum_j X_{ij} = 0 \text{ for all i}$$

(conservation of flow must exist at each node)

Any flows in a network which satisfy the above three general constraints are called feasible flows.

When a unit of flow is shipped from node i to node j, a new net arc cost is entailed $\overline{C}_{ij}$.

$$\overline{C}_{ij} = C_{ij} + \pi_i - \pi_j$$

$\overline{C}_{ij}$ is the new arc cost (per unit of flow)

C_{ij} is the transportation cost from node i to node j (per unit of flow)

π_i is the node price at i

π_j is the node price at j

It can be seen from the above that it is profitable to ship a unit of flow from i to j when the price of the unit flow at node j, π_j, outweighs the price of the same unit staying at node i, π_i, plus the transportation cost of shipping the unit from node i to node j, C_{ij}. The total is the term $\overline{C}_{ij}$. When $\overline{C}_{ij} < 0$ it is profitable to ship. When $\overline{C}_{ij} = 0$, that is break even, no loss or gain from shipping, the flow can be anywhere between the limits U_{ij} and L_{ij}. When $\overline{C}_{ij} > 0$ it is unprofitable to ship, so flow should be minimal, $X_{ij} = L_{ij}$.

The equations below summarize those arc conditions which satisfy the optimal solution to the minimum cost circulation problem.

$$\text{If } \overline{C}_{ij} < 0 \text{ then } X_{ij} = U_{ij}$$

$$\text{If } \overline{C}_{ij} = 0 \text{ then } L_{ij} \leq X_{ij} \leq U_{ij}$$

$$\text{If } C_{ij} > 0 \text{ then } X_{ij} = L_{ij}$$

Any arc which does not meet the above conditions is not "in kilter", and hence the name of the algorithm, - the Out-of-Kilter Algorithm, OKA. A summary follows.

The program looks for an "out-of-kilter" arc. After finding this arc, attempts are made to find a circulation path between the two nodes of the out-of-kilter arc and bring the arc into kilter by adjusting the flows and node prices. When all of the out-of-kilter arcs are brought into kilter the algorithm terminates. A slightly more detailed description of the program method follows.

For an out-of-kilter arc, flow change is necessary. The out-of-kilter arc A(i, j) is brought into kilter by adjusting flows from node j along a circulation path back to node i. Flow can be adjusted in two ways. One is by increasing the flow from node i to node j. The other way is to decrease the flow from node j to node i. Both accomplish the same in that the total flow from node i to node j is increased.

As the least cost path is traced from node j through a circulation path to node i, the nodes along the path are labeled, and when the path tracing is completed to node i it is known as a breakthrough. If no extension of the path can be made during the labeling search, a program subroutine which raises the node prices is accessed. The subroutine raises the node prices of the unlabeled nodes, (the only ones still available for the path extension), by the smallest amount necessary. The amount the prices are raised is the minimum $\bar{C}_{ij}$ of the remaining arcs which have one node labeled and one node unlabeled. This means that at least one more path extension is possible, since at least one $\bar{C}_{ij} = 0$ (by raising the node price π_j to balance the C_{ij} and π_i costs) and though it is not profitable to ship, it is no longer unprofitable, it is a breakeven proposition. Flow may now be increased.

The path search routine is then accessed again, and either a circulation path is found back to node i, or the node price raising routine is called again, or the problem is infeasible after all of the remaining possible $\bar{C}_{ij}$ have been used to raise unlabeled node prices. When a breakthrough does occur, the flow along the discovered path is increased by the maximum amount possible which does not put any in kilter arc out-of-kilter. This is accomplished in a separate program subroutine. The process continues until each of the out-of-kilter arcs in the problem undergo the above procedure and all the arcs are either brought in to kilter, or the problem declared infeasible.

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APPENDIX B

SYSTEMS HARDWARE PARTS LIST

AND

WASTEWATER QUALITY AND REUSE CRITERIA

UNIT	PARAMETER		OTSG INTERIM REUSE CRITERIA	AP HILL TEST	HUNTING CREEK TEST
TABLE B-1 WASTEWATER QUALITY & REUSE CRITERIA					
SHOWER	pH	Infl		7.9	
		Effl	6.5 - 7.5	7.3	
	Turbidity (JTU)	Infl		59	20 - 110
		Effl	5	0.1	1.5 - 9.0
	TOC (mg/l)	Infl		15	63
		Effl		4	11
	Residual CL_2 (mg/l)	Infl			
		Effl	5(>20°C) 10(<20°C)		
	BOD (mg/l)	Infl		51	
		Effl		3	
LAUNDRY	Turbidity (JTU)	Infl		3800	46 - 248
		Effl	5	140	0.8 - 4.5
	TOC (mg/l)	Infl		258	12 - 30
		Effl		42	1 - 7
	LAS (mg/l)	Infl			17 - 30
		Effl			0.0 - 0.3
	BOD (mg/l)	Infl		339	
		Effl		55	

TABLE B-2

PROPOSED SET LISTING

SC 4610-97-CL-E

NSN	Description	U/I	QTY
4610-01	LAUNDRY WASTEWATER REUSE UNIT:	EA	1
	ADAPTER, STRAIGHT, PIPE TO HOSE:		
	Copper alloy:		
4730-00-277-6844	Pipe end, 1-1/2 in.-11-1/2 NPT, ext; hose end, 1-1/2 in.-11-1/2 NPSH ext; 81349-MIL-C-52404, type XVI, class C 97403-Dwg13218E0479-35	EA	2
4730-00-	Pipe end, 1 in.-11-1/2 NPT, ext; 1-1/2 in.-11-1/2 NPSH, ext.	EA	2
6145-00-	CABLE, POWER, ELECTRICAL; 3-conductor, 50 ft. lg., 81349-MIL-C-3432, type CO-03HLF	EA	1
6810-00-242-4770	CALCIUM HYPOCHLORITE; TECHNICAL: 3-3/4 lb. plastic bottle 81348-0-C-114, type I	CO	1

6630-00-087-1838	COMPARATOR, COLOR c/o: 1 ea BOTTLE, DROPPER: for orthotolidine solution 1 ea BOTTLE DROPPER: for sodium arsenite solution 1 ea BOTTLE DROPPER: for range pH indicator solution 1 ea COLOR COMPARATOR: w/prismatic eyepiece assy 4 ea CELL, COLORMETER: 1 ea DISK, COLOR STANDARDS: 0.1 to 10 ppm chlorine range 1 ea DISK, COLOR STANDARDS: 3.0 to 11.0 pH range; 81349-MIL-C-538 (79172) Pt. No. U20486 or equal	EA	1
6145-00-	CONTROL BOX, ELECTRICAL; single phase, 115/230, S.F. amps 9.4/4.7	EA	1
4610-00-	FILTER, ASSEMBLY: 420 gph; 97403-TA13217E7320	EA	1
	FLOAT, BALL TYPE: plastic, 8-in. dia.	EA	2

6145-00-	GENERATOR, 1-1/2 or 3.0 KW, 60 Hz;	EA	1
4720-00-542-4660	HOSE ASSEMBLY: rubber water; braided; 175 psi wp, hex nut; rigid ext thd and swivel int thd; brass cplg, 10 ft lg, excl cplgs, 1 in. 11-1/2 NPSH. 97403-TA13217E7770	EA	2
4700-00-542-4659	HOSE ASSEMBLY: nonmetallic; polyester fiber, rubber lined; single jacket; natural or synthetic; 300 psi, hex nut, rigid ext thd and swivel int thd; 1 in.-11-1/2 NPSH; WW-C-624, thpe A; 1 in. id; 25 ft lg, incl cplgs. 97403-TA13217E9700	EA	1
4720-00-542-4661	HOSE ASSEMBLY: nonmetallic; rubber water, braided; 175 psi wpi hex nut rigid ext thd and swivel int thd; brass; barbed insert couplings; black; 10 ft lg, excl cplg, 1-1/4 - 11-1/2 NPSH 1-1/4 in. id; 97403-TA13217E7771	EA	1

4720-00-202-6731	HOSE ASSEMBLY, NONMETALLIC: Water; wrapped, wire reinforced; guard, pin or rocker lug, rigid ext thd and swivel int thd, brass, exp ring cplg, 1-1/2 in. - 11 - 1/2 NPSH; 1-1/2 in. id; WW-C-624, type B1, 10 ft lg; 81348-ZZ-H-561, type I, grade B.	EA	2
6810-00-937-0975	INDICATOR SOLUTION pH WIDE RANGE: 4 oz plastic btl; (79172) Pt. No. UXD18895 or equal.	BT	1
7240-00-542-4639	MEASURE, DRY CHEMICAL: WATER PURIFICATION: plastic, calcium hypochlorite; 0.05 lb grad; 0120 lb; 81349-MIL-M-52372, class 3.	EA	1
7240-00-542-4641	MEASURE, DIATOMITE: 46 cu. in. graduations 0.40 lb cap.; 81349-MIL-52372, class 2.	EA	1
4730-00-	NIPPLE, PIPE: bronze or brass; 1-1/2 in; dia.; 2-1/2 in. lg; 81348-WW-P-460, class A.	EA	2

4730-00-	NIPPLE, PIPE: bronze or brass; 1 inch; dia.; 2 in. lg. 81348-WW-P-460, class A.	EA	1
6810-00-270-8293	O-TOLIDINE DIHYDROCHLORIDE SOLUTION: 4 oz plastic btl; (79172) pt. No. UXA421 or equal.	BT	1
7240-00-246-1097	PAIL, UTILITY: plastic or rubber; 3 gal; pouring lip; w/bail; 81349-MIL-P-14514, grade B, size 2.	EA	1
6810-00-937-0974	SODIUM ARSENITE SOLUTION: 4 oz plastic btl; (79172) Pt. No. UXA9930 or equal.	BT	1
4730-00-684-4296	STRAINER, SUCTION HOSE: brass; bbl; 1-1/2 in.-11-1/2 NPSH, int; 4-1/2 in. lg; hex or octagon; #35 inside cut v-slots; 81349-MIL-S-12165, type II	EA	1
	SUPPORT, SUCTION PIPE: 97403-Dwg13221E4682	EA	1

5430-00-171-4518	TANK, FABRIC, COLLAPSIBLE: nylon; water; 500 gal; 66 in. dia, 36 in. deep, w/staves, stakes, guy ropes, cover and gnd cloth; synthetic rubber coated; 81349-TL-MIL-T-14398, 97403-TA13201E9410	EA	2
4730-00-	TEE, PIPE: bronze or brass, 1-1/2 in.; 81348-WW-P-460, class A.	EA	1
4820-00-288-7568	VALVE, GATE: bronze; wedge disc, rising stem, inside screw, 125 psi wp; 1-1/2 in.-11-1/2 NPT; 81348-WW-V-54, type II, class A, style 1.	EA	2
4820-00-967-1713	VALVE FLOW CONTROL: Dole (orifice type) 3/4 in-14 NPT 8.0 gpm. 97403-Dwg13214E8909-f	EA	2

NOTE: When this set is to be used as a wastewater reuse unit, it requires Laundry Wastewater Treatment Kit 4610-01-023-4536 (SC 4610-97-CL-E14).

TABLE B-3

PROPOSED SET LISTING

SC 4610-97-CL-E

NSN	Description	U/I	QTY
4610-01-	SHOWER WASTEWATER REUSE UNIT:		
	ADAPTER, STRAIGHT, PIPE TO HOSE:	EA	1
	Copper alloy:		
4730-00-277-6844	Pipe end, 1-1/2 in.-11-1/2 NPT, ext; hose end, 1-1/2 in.-11-1/2 NPSH ext; 81349-MIL-C-52404, type XVI, class C. 97403-Dwg13218E0479-35	EA	2
4730-00-	Pipe end, 1 in.-11-1/2 NPT, ext; 1-1/2 in.-11-1/2 NPSH, ext.	EA	2
6145-00-	CABLE, POWER, ELECTRICAL; 3-conductor, 50 ft. log., 81349-MIL-C-3432, type CO-03HLF	EA	2
6810-00-242-4770	CALCIUM HYPOCHLORITE; TECHNICAL: 3-3/4 lb. plastic bottle. 81348-0-C-114, type I	CO	1

6630-00-087-1838	COMPARATOR, COLOR c/o: 1 ea BOTTLE DROPPER: for orthotolidine solution 1 ea BOTTLE DROPPER: for sodium arsenite solution 1 ea BOTTLE DROPPER: for range pH indicator solution 1 ea COLOR COMPARATOR: w/prismatic eyepiece assy 4 ea CELL, COLORMETER: 1 ea DISK, COLOR STANDARDS: 0.1 to 10 ppm chlorine range 1 ea DISK, COLOR STANDARDS: 3.0 to 11.0 pH range; 81349-MIL-C-538 (79172) Pt. No. U20486 or equal	EA	1
6145-00-	CONTROL BOX, ELECTRICAL; single phase, 115/230, S.F. amps 9.4/4.7	EA	1
4610-00-	FILTER, ASSEMBLY: 420 gph 97403-TA13217E7320	EA	2
	FLOAT, BALL TYPE: plastic, 8-in. dia.	EA	3

6145-00-	GENERATOR, 1-1/2 or 3.0 KW, 60 Hz.	EA	1
4720-00-542-4660	HOSE ASSEMBLY: rubber water; braided; 175 psi wp, hex nut; rigid ext thd and swivel int thd; brass cplg, 10 ft lg, excl cplgs, 1 in. 11-1/2 NPSH. 97403-TA13217E7770	EA	4
4720-00-542-4659	HOSE ASSEMBLY: nonmetallic; polyester fiber, rubber lined; single jacket; natural or synthetic; 300 psi, hex nut, rigid ext thd and swivel int thd; 1 in.-11-1/2 NPSH; WW-C-624, type A; 1 in. id; 25 ft lg, incl cplgs. 97403-TA13217E9700	EA	2
4720-00-542-4661	HOSE ASSEMBLY: nonmetallic; rubber water, braided; 175 psi wpi hex nut rigid ext thd and swivel int thd; brass; barbed insert couplings; black; 10 ft lg, excl cplg, 1-1/4 - 11-1/2 NPSH 1-1/4 in. id; 97403-TA13217E7771	EA	2

4720-00-202-6731	HOSE ASSEMBLY, NONMETALLIC: Water; wrapped, wire reinforced; guard, pin or rocker lug, rigid ext thd and swivel int thd, brass, exp ring cplg, 1-1/2 in. -11-1/2 NPSH; 1-1/2 in. id; WW-C-624, type B1, 10 ft lg; 81348-ZZ-H-561, type I, grade B.	EA	2
6810-00-937-0975	INDICATOR SOLUTION pH WIDE RANGE: 4 oz plastic btl; (79172) Pt. No. UXD18895 or equal.	BT	1
7240-00-542-4639	MEASURE, DRY CHEMICAL: WATER PURIFICATION: plastic, calcium hypochlorite; 0.05 lb grad; 0.20 lb; 81349-MIL-M-52372 class 3.	EA	1
7240-00-542-4641	MEASURE, DIATOMITE: 46 cu. in. graduations 0.40 lb cap.; 81349-MIL-M-52372 class 2.	EA	1
4730-00-	NIPPLE, PIPE: bronze or brass; 1-1/2 in; dia.; 2-1/2 in. lg; 81348-WW-P-460, class A.	EA	2

4730-00-	NIPPLE, PIPE: bronze or brass; 1 inch; dia.; 2 in. lg.	EA	2
6810-00-270-8293	O-TOLIDINE DIHYDROCHLORIDE SOLUTION: 4 oz plastic btl; (79172) Pt. No. UXA421 or equal.	BT	1
7240-00-246-1097	PAIL, UTILITY: plastic or rubber; 3 gal; pouring lip; w/bail; 81349-MIL-P-14514, grade B, size 2.	EA	1
6810-00-937-0974	SODIUM ARSENITE SOLUTION: 4 oz plastic btl; (79172) Pt. No. UXA9930 or equal.	BT	1
4730-00-684-4296	STRAINER, SUCTION HOSE: brass; bbl; 1-1/2 in.-11-1/2 NPSH, int; 4-1/2 in. lg; hex or octagon; #35 inside cut v-slots; 81349-MIL-S-12165, type II.	EA	2
	SUPPORT, SUCTION PIPE: 97403-Dwg13221E4682	EA	1

5430-00-171-4401	TANK, FABRIC, COLLAPSIBLE: nylon; water; 1500 gal; 7 ft 9 in. dia, 54 in. deep, w/staves, stakes, guy ropes, cover and gnd cloth; synthetic rubber coated; 81349-TL-MIL-T-14398, 97403-TA13201E9410	EA	2
4730-00-	TEE, PIPE: bronze or brass, 1-1/2 in.; 81348-WW-P-460, class A.	EA	1
4820-00-288-7568	VALVE, GATE: bronze; wedge disc, rising stem, inside screw, 125 psi wp; 1-1/2 in.-11-1/2 NPT; 81348-WW-V-54, type II, class A, style 1.	EA	2
4820-00-967-1713	VALVE FLOW CONTROL: Dole (orifice type) 3/4 in-14 NPT 8.0 gpm. 97403-Dwg13214E8909-4	EA	2

NOTES:

1. In the shower wastewater treatment kit (SC 4610-97-CL-E15), the 500 gallon pillow-type fabric tank 13219E1060 and the open-top type tank 5430-00-171-4518 can be removed and replaced with the 1500 gallon pillow-type tank specified in MIL-T-52943 and the open-top tank (5430-00-171-4401) MIL-T-14398 respectively

2. When this set is to be used as a wastewater reuse unit, it requires Shower Wastewater Treatment Kit 4610-01-023-4537 (SC 4610-97-CL-E15).

TABLE B-4

PARTS LIST

Find No.		U/I	Qty
1	TEE, PIPE: brass: 1-1/2 inch	EA	1
2	NIPPLE, PIPE: brass: 1-1/2 inch dia: 2-1/2 in. lg.	EA	2
3	VALVE, GATE: bronze: 1-1/2 in.-11-1/2 NPT	EA	2
4	ADAPTER, STRAIGHT, PIPE: TO HOSE: 1-1/2 in. 11-1/2 NPT, ext 1-1/2 NPSH ext.	EA	2
5	HOSE, ASSEMBLY: 1-1/2 in.-11-1/2 NPSH, 10 ft. lg.	EA	7
6	HOSE, ASSEMBLY: rubber water: braided: 1 in., 11-1/2 NPSH, 10 ft. lg.	EA	4
7	HOSE, ASSEMBLY: rubber water: braided: 1-1/4 in., 11-1/2 NPSH, 10 ft. lg.	EA	2
8	FILTER, ASSEMBLY: (420 GPH (7.0 gpm)	EA	2
9	NIPPLE, PIPE: brass: 1 in. dia.: 2 in. lg.	EA	2
10	VALVE, FLOW CONTROL: orifice type, 3/4-14 NPT, 8 gpm, with bushings.	EA	2
11	CONTROL BOX, ELECTRICAL: single phase, 115/230, S.F. amps 9.4/4.7.	EA	1
12	CABLE, ELECTRICAL: 3-conductor, 50 ft. lg.	EA	1
13	GENERATOR: 1-1/2 or 3 KW, 60 Hz: military standard	EA	1
14	HOSE, TEXTILE FIBER, RUBBER LINED: 300 psi, 1 in., 11-1/2 NPSH: 25 ft. lg.	EA	2
15	TANK, FABRIC, COLLAPSIBLE: nylon, water: 1500 gallon.	EA	3
16	FLOAT, BALL TYPE: plastic, 8 in. dia.	EA	3
17	SUPPORT, SUCTION PIPE	EA	1
18	PUMP, CENTRIFUGAL: 125 gpm, military standard GED	EA	1

APPENDIX C

HEALTH AND OTHER CONSIDERATIONS IN RECYCLE/REUSE OF CERTAIN WASTEWATERS IN ARID AND SEMI-ARID REGIONS

PURPOSE

The purpose of this section is to provide informat n relating to health and other considerations in the recycle/reuse of certain wastewaters during combat in arid and semi-arid regions of the world. All available literature has been reviewed and a bibliography of specific and general references has been prepared and is appended.

INTRODUCTION

Throughout history, the United States has been involved in numerous military operations. Some of the operations have been small, some large, some successful, some uncertain. In modern times, except for the North African Campaigns in World War II, there have been no major U. S. military operations in an arid or semi-arid region. In World War II, water supply problems were overcome by a number of applications of the technology then available. Today, the threats facing the Free World could escalate into an armed conflict which would require the insertion of a considerable body of foot and mechanized troops into arid or semi-arid regions. If such a requirement becomes necessary, modern water treatment and water recycle/reuse technology must be employed to assure adequate water supplies to troops in the field. The potable water saved by recycle/reuse techniques could then be effectively allocated for higher priority needs.

The reason for water recycle/reuse in an arid or semi-arid environment is obvious. The importance of wastewater as a conservable resource cannot be underestimated or overlooked in desert regions.

Wastewater recycle/reuse must be observed in one simple frame of reference. All use of water is actually reuse. As described by the "hydrological cycle," recycle/reuse has been in existence since the beginning of time. Most of the water on earth since creation, in one form or another, is present today on the earth or in the atmosphere. This is, at least by man, unplanned recycle/reuse. However, planned municipal and industrial reuse applications will greatly increase in the next two decades of this century and beyond. Numerous research and development projects assure the trend toward increased emphasis on recycle/reuse on both small and large scales, with advances in water treatment technology over the past two decades having made recycle/reuse possible under the most trying and difficult circumstances.

The literature is replete with references to successful commercial, industrial and municipal recycle/reuse practices. Technology is available and the needed equipment has been designed and is commercially available to recycle/reuse water in limited or large quantities. Although merits of water reclamation, renovation and reuse are well established, the practice of recycle/reuse is not without the problem of progressive build up of certain constituents, particularly dissolved solids. Equilibrium concentrations of dissolved solids can be predicted and controlled in any water recycling system. Naturally, the higher the quality criteria for the intended use of the recycled/reused water, the higher the range of costs. The standards or quality criteria will ultimately determine the quantity of and intended use of recycle/reuse by the supported troops. Nevertheless, the current emphasis in water quality criteria is on non-potable recycle/reuse for Field Army purposes.

In spite of not yet committing U. S. forces there, the relationship between need and availability of usable water supplies in the Middle East is gaining wide recognition by military planners, because American arms may one day be engaged there in ground warfare. In that mainly desert environment, one that is perennially short of water, a portion of the water-needs dilemma can be overcome by successful recycle/reuse of the sparse supplies available. In brief, water reuse is one feasible means of expanding the precious water supplies of the Middle East.

An assessment of water use requirements for a U. S. Corps in the Middle East and the potential of water reuse for laundry and shower purposes can probably be projected with some degree of accuracy (certainly within $\pm$ 20 percent). The total problem cannot, however, be handled simply as each requirement for use and recycle/reuse will be somewhat different. In addition to the military situation, factors bearing on the assessment will depend upon water sources, climate, geographic location, availability of water renovation equipment, attitudes of water users and competition among water users.

Shower and laundry wastewaters provide the most promising sources in combat conditions for recycle/reuse and closed-system treatment. It is quite feasible, with the technology and equipment already at hand or under development, to recycle laundry wastewaters for additional laundry purposes and to recycle shower wastewaters for shower or laundry purposes. Potable waters would be the initial feed waters and it is not unreasonable to expect that up to 98 percent of the laundry and shower wastewaters could be recycled thereby saving nearly 400,000 gallons/day for a U. S. Army Corps in the field.

The Army has had an interest in the area of wastewater renovation and recycle/reuse for at least two decades. Current long-range water resource plans in potential theaters of operation are examples of that interest. The planning envisions utilizing recycle/reuse techniques, surveying the present levels of recycle technology, the future needs for additional reuse equipment, and predicting the future water quality standards which will make possible the reuse of several wastewaters. The planning must also consider the inventory of recycle/reuse equipment, quality requirements for intended uses, and power costs for recycle/reuse equipment operation. The reuse for subpotable purposes suggests a dual system based on reusable waters cascading downward to levels of lesser quality requirements.

The net benefits of wastewater reuse will be situation-specific to conditions in the field. In each case, the benefits will vary with raw water availability and quality, the nature of the demand, equipment availability, and tactical considerations.

WATER IN ARID AND SEMI-ARID REGIONS

The sources of water in arid and semi-arid regions are often sparse while demand for water by combat troops in the field increases with arid climatic conditions. For these reasons, both advanced-level treatment and recycle/reuse of wastewater gain increased importance and must be recognized as highly important considerations in total water resource management.

Surface and ground waters in the arid and semi-arid regions are generally brackish. Less saline waters may be found in well supplies, but they are infrequently found in sufficient quantity to provide a suitable supply of "fresh water" for many troops. Therefore, water with a low saline content must be discovered and developed coincident with or shortly after the first troops are committed. Surface streams, where they exist at all, typically exhibit extreme variations in flow with extended periods of no flow. Low rainfall and low humidity coupled with high evaporation rates make reuse of water a necessity.

In arid and semi-arid environments care must be taken to maintain high standards of physical hygiene and field sanitation. Failure to do so may significantly reduce troop strength and combat readiness. Improved laundry and shower capabilities in the field are one method of precluding incipient problems of poor field sanitation practices.

Recycle/reuse of certain specific wastewaters must become accepted practice by Army troops in the field in arid regions for the following reasons. First, the need to reuse waters in certain locales is a foregone conclusion when the area has inadequate water sources to sustain large combat forces. Second, the treatment of wastewaters can be accomplished with equipment already developed and in inventory stock. Third, quality guidelines can be developed to insure the prevention of health hazards. Fourth, the expenditure in energy and transportation to develop new and distant sources could be prohibitive. Fifth, a valid assumption is that reuse treatment technology will improve.

U. S. ARMY WATER POLICY/DOCTRINE IN DESERT OPERATIONS

Basic information relating to the desert countries of the Middle East are available in the DA Pamphlet 550 series. The eighteen Middle East countries, with corresponding land area in square miles, which are wholly or partly covered by desert areas are listed below followed by the specific pamphlet series number in parentheses:

1.	Algeria	-	919, 591 sq. mi.	(44)
2.	Bahrein	-	231	(92)
3.	Egypt	-	386,660	(43)
4.	Iran	-	636,293	(68)
5.	Iraq	-	167,924	(31)
6.	Israel	-	7,992	(25)
7.	Jordan	-	37,737	(34)
8.	Kuwait	-	6,880	(92)
9.	Lebanon	-	4,015	(24)
10.	Libya	-	679,359	(85)
11.	Oman	-	85,000	(92)
12.	Qatar	-	4,000	(92)
13.	Saudi Arabia	-	830,000	(51)
14.	Syria	-	71,516	(47)
15.	Tunisia	-	63,170	(89)
16.	United Arab Emirates	-	32,000	(92)
17.	Yemen (Aden)	-	111,075	(92)
18.	Yemen (Sinai)	-	75,290	(92)

U. S. Army Field Manual 90-3, Desert Operations, published 19 August 1977, delineates policy/doctrine describing how U. S. Army forces fight in desert (arid and semi-arid) regions. The manual provides an appendix with brief descriptions of these countries and a listing of the deserts of the world. Updated and detailed terrain analysis information can be obtained from the Defense Intelligence Agency. Nowhere in FM 90-3 does the policy refer to recycle/reuse of wastewaters. The opening lines of the Field Manual are highly descriptive of what is to be expected whenever desert operations are contemplated:

> Conditions will be encountered in the desert that have a profound effect on military operations. Desert operations require, among other things, special equipment, special training and acclimatization, and a high degree of self-discipline if operations are to be successful.

In desert climates, according to FM 90-3, operations will probably be conducted in four phases appropriately supported by U. S. Naval and Air Forces. The phases are: (1) establishment of the lodgement area, (2) buildup of the logistic base and combat forces, (3) defensive operations to secure the initial area of operations, and (4) offensive operations to destroy the enemy. The lodgement area may be initially seized by air landing, air assault, or by over the beach operations.

Desert climes are harsh, living conditions are often primitive and extremely uncomfortable, and the desert environment can kill the unprepared soldier. The conditions and factors which make up the arid and semi-arid environment have been enumerated in FM 90-3 and are enumerated below.

DESERT TERRAIN

Deserts are arid, barren regions of the earth incapable of supporting normal life due to the lack of fresh water. The terrain varies considerably from place to place, the sole common denominator being lack of water with its consequent environmental effects. The three types of desert terrain are: mountain, rocky plateau, and sandy or dune deserts. In the mountains, with scattered ranges or areas of barren hills, infrequent rainfalls generally occur on high ground and water runs off rapidly. The accumulated water rapidly evaporates often leaving the mountainous region as barren as before. Rocky plateaus may be interspersed with steep-walled eroded valleys, the narrower of which can be extremely dangerous when flash flooding occurs after intermittent rains. Sandy or dune deserts are extensive flat areas covered with sand or gravel, the product of age-old deposits or more recent wind erosion. Any rainfall occurring in these regions often quickly percolates immediately and surface waters are generally absent in this terrain.

RAINFALL

All deserts have an absence of or infrequent rainfall which in turn gives these regions a common arid characteristic. When rain does occur it may consist of a violent and short-lived storm with quick and almost complete surface runoff. The desert rains generally fall in a brief span of time, are over very quickly and, as the storms cause high runoff, are seen as liabilities by those in their midst even though the rainfall may be desperately needed. Distant flooding is also a likelihood. A large storm which runs off quickly may cause surface water damage miles away.

TEMPERATURE

Temperature fluctuations are often wide in desert regions. Low temperatures can be influenced by strong winds which produce high chill factors and rapid temperature changes invariably follow strong winds. High temperatures may cause inordinately high evaporative rates. Diurnal temperature fluctuations may be as high as 72°F which can impose unusual strain on personnel and not infrequently affect equipment operation and maintenance.

DEVELOPMENT OF WATER SUPPLIES

Water supply is the single most important mission of engineers in the desert. The search for sources requires continuous, intensive reconnaissance. Water may be obtained by drilling in beds of dry water courses, or by deepening dry wells. Once found, brackish or saline water must be made potable and stored or transported. Since water purification trucks may be high priority targets, and barely sufficient for the task, any force operating in the desert must be augmented with water supply units, including well drilling, water purification and water distillation teams, and extra transportation.

GROUND WATER

Ground water in such places as oases and near-surface wells has as its source subsurface seepage from considerable distances. Subsurface water may be so far below the surface, or so limited in quantity, that wells are normally inadequate to support any great number of troops. Therefore, potable water supplies can never be taken for granted as adequate supply must be maintained. Thus, any relatively large natural water supply may be both tactically and strategically important in desert warfare.

RECONNAISSANCE

Reconnaissance for surface supply sites is essential. Equipment for treating surface supplies such as ponds, rivers or lakes is available and water purification units are available to divisional engineer battalions and other engineer organizations.

LOSS OF HUMAN BODY FLUID

Approximately 75 percent of the human body is fluid. All chemical activities in the body occur in a water solution. Water assists in the removal of toxic body wastes and plays a vital part in the maintenance of an even body temperature. A loss of two quarts of body fluid (2.5 percent of body weight) decreases efficiency by 2- percent and a loss of fluid equal to 15 percent of body weight is usually fatal.

Units performing sustained heavy activities, such as a forced march or digging in, may require more than three gallons of drinking water per man at 80 degrees Wet Bulb Globe Temperature Index, and any increase in the stress will increase this need. A guide to water requirements is shown in Table C-1. Depending upon salt and water depletion from the body, addition of table salt or saturated salt solution to drinking water may be required.

Water carries a higher priority than food in desert environments.

Table C-1

WATER REQUIREMENTS[1]

Activity	Typical Duties	Quarts per man per day for drinking.[2] (WBGT index being used[3].) Less than 80 degrees	Greater than 80 degrees
Light	Deskwork. Guard duty. Radio operating	6	10
Moderate	Route march on level ground. Tank operations[4].	7	11
Heavy	Forced marches. Route marches with heavy loads or CBR clothing. Digging in.	9	13

Notes:

1. This is a guide only.
2. Extra water will be required for cooking, vehicle radiators, etc.
3. 80 degrees Wet Bulb Globe Temperature (WBGT) = approximately 105 degrees Fahrenheit dry bulb temperature in a hot dry desert.
4. Dry bulb temperature inside a tank may be considerably higher than outside temperature. Vehicles of some countries have inside insulation, and some vehicles are equipped with air conditioning.

Source: FM 90-3

POTABLE DRINKING WATER

While water is vital and local desert supplies may be scarce or nonexistent, the lack of water may be calamitous. Potable drinking water is the most basic need in the desert. Soldiers must be informed that water is undoubtedly the most important factor in desert survival and be trained not to waste water.

LOGISTICAL CONSIDERATIONS

Basically stated, the accepted doctrine for Army equipment is that it should be simple, lightweight, compact, require few personnel to handle or support, and only the minimum of training and experience should be needed for its successful operation. While certain water treatment equipment may be considered fairly easy to operate, components of any mechanical system are complicated and do require considerable training and relatively long experience for sustained operation. Successful operation under combat and adverse environmental or climatic conditions adds an additional dimension for qualified and skilled personnel. As technology advances, water treatment equipment will become more rather than less complex, therefore more sophisticated operator training may be required.

Certain criteria must be met to insure that the Army's logistic goals can be accomplished. The criteria include readiness, sustainability, modernization of equipment, support of policy and doctrine, appropriate concern for energy consumption, effective management and security assistance. Readiness is an assurance that the total Army forces are logistically prepared for rapid transition to wartime operations and fully capable of performing their combat mission. To sustain the Army in the field requires the development and maintenance of balanced logistic force structure and the material capability necessary to equip and sustain a fighting force on the battlefield. To insure modernization it is necessary to exploit innovations to improve integrated logistics, logistics material, facilities, packaging and procedures. To comply with Army policy/doctrine it must be insured that logistics doctrine supports the tactical doctrine. To conserve energy, the Army's energy vulnerability must be protected whenever possible from dependency on any one single type of energy and also protected from unnecessary consumption of energy.

To insure appropriate direction of logistical goals it is essential to manage effectively the existing and programmed resources in a spartan environment. To protect the security of rear areas it is always necessary to enhance collective security with allies and friendly military forces and effectively administer any in-place security assistance program.

Successful logistical support of Army units on a battlefield is often difficult to accomplish. Water, weighing one-thirty second of a ton per cubic foot, is a very heavy supply commodity. Hence it must be produced, or treated, as near to the point of consumption as possible. Water, its use, conservation and limited transportation requirements for delivering it to the consumer, are keynotes in the successful logistical support of troops employed in arid or semi-arid regions.

The concept of water resource development in the combat area recognizes the development of a water supply source or importation of the supply, conservation of that supply, total use of the supply, and recycle/reuse wherever the possibility for same exists. The decision for reusing or recycling or reclaiming a given water supply must be made in advance of a combat operation and the resources -- mechanical, supply and manpower -- must accompany or immediately follow the off-loaded combat troops.

In the field, the soldier becomes a true consumer-dependent upon the Army or Theater supply system for every bodily need and want. His attitude as a consumer is important. If he can be assured that recycle/reused water is guaranteed to be as safe or better than the original supply he will willingly accept and use the water without hesitancy. Assuming that guarantee could be made, then the degree of acceptance of reused water would very probably decrease as the highest use -- ingestion -- is proposed. His degree of acceptance for lower uses -- bodily contact, such as showering, shaving, washing clothing -- would probably be high and that degree of acceptance would be based on educational level. Reuse of water in the Army can be "sold" to a soldier population through a well-planned, well-conceived educational or training program. The expanded practice and continued development of recycle/reuse in the future in the civilian economy will help mold attitudes of tomorrow's soldiers.

Water recycle/reuse systems for applications in arid environments must be simple; if fool-proof and part of a once-through process, they would be ideal for combat operations. At once, the treatment device should not be heavy, should be compact and easily transportable. Power requirements should be low. Operational life of the treatment system should be for a relatively long term. Equipment should be designed to require minimum maintenance and repair. Wherever possible, frills should be eliminated from the treatment device and pre- and post-treatment chemical requirements should be held to a minimum.

It goes without saying that recycle/reuse of wastewater from laundry and shower facilities will result in improved logistical support by the very nature of the conservation practiced. It is not unreasonable to expect that logistic and tactical considerations may be the governing factors in the choice of recycle/reuse treatment systems.

The U. S. Army currently has available in inventory water purification equipment to treat certain problem waters in the field. The equipment type and the latest inventory (Lindsten, October 16, 1978) are shown in Tables C-2 and C-3. Currently the Army has standardized an additional water treatment unit, the 600 GPH Reverse Osmosis Water Purification Unit (ROWPU). There is an additional need (Lindsten, October 12, 1979) for a 3000/2000 GPH ROWPU patterned after the 600 GPH ROWPU. The new unit, if type classified in 1982-83 should reach initial operational capability in 1985-86, and would supply water at the division level. The 3000/2000 unit would replace the following current inventory equipment: 420, 600, 1500, 3000 GPH EERDLators; 150 GPH distillation unit; 3000 GPH BW-CW pretreatment unit; and the 3000 GPH ion exchange unit.

The number of currently available water purification units to accompany any Army Corps (contingence force) will vary with the troop list, and strategic deployment will depend upon each scenario. Combat engineer battalions, construction engineer battalions and combat engineer companies of separate brigades must be scheduled to load varying water purification units depending upon the mission. In arid and semi-arid regions additional well drilling rigs may also accompany any contingency force.

TRANSPORT OF WATER

Warfare in an arid region has often been constrained by the lack of a continuous and available water supply. Tactical alternatives in arid regions, particularly in summer months, have not infrequently been constrained by the lack of unlimited or even limited sources of water. Fresh water supplies are often difficult to uncover in desert environments and those sparse supplies which may be developed are often highly brackish and may even be saline.

In an arid environment, water may be distributed by aircraft, pipeline, 5000-gallon tanker trucks, trucks, and unit-level trailers. Aircraft distribution is extremely costly in terms of energy expended per unit of water delivered. The preferred method of transport from a treatment source to the user (or distribution point) would be by tanker trucks, trucks or trailers. A single 400-gallon trailer provided company-size units probably will not be sufficient to supply those units in a desert environment; more than one trailer may be required per company.

The amount of transport required for wholesale and retail water distribution will depend upon the location of such sources (information related to and location of such sources can be obtained from the U. S. Army Intelligence and Threat Analysis Center at Fort Bragg), the deployment distances of units from the sources, the estimation of road distances, the water demands of the various troop units and of the military operations, and the availability rate of truck tankers, trucks and trailers.

Aircraft and pipeline distribution of treated water require special consideration. Aircraft need secure landing sites while in

Table C-2. US Field Army Water Purification Equipment

Problem Water	Purification Equipment
Polluted fresh water	Erdlator Units 3000 GPH 1500 GPH 600 GPH 420 GPH
Sea water	Distillation Unit 150 GPH
CW Agent contaminated water	CW-BW Pretreatment Set used with any size Erdlator unit
BW Agent contaminated water	CW-BW Pretreatment Set used with any size Erdlator unit
RW Agent contaminated water	Any size Erdlator followed by Post Ion Exchange Unit

Source: Lindsten (October 16, 1978), USAMERADCOM

Table C-3. Inventory, US Army Water Supply Equipment

Purification Equipment	No. of Units Available
Erdlator Units	
3000 GPH	225
1500 GPH	600
600 GPH	40
420 GPH	30
Distillation Unit, 150 GPH	12
CW-BW Pretreatment Set	55
Ion Exchange Unit	2

Source: Lindsten (October 16, 1978), USAMERADCOM a turn-around status. Water transported by aircraft may be contained in drums, cans, etc. Pipelines may require security guards even though they pass through rear areas. Pumping stations must also be secured. The pipe, in some instances, may be laid directly on the surface of the terrain or may be buried. Pipelines in combat areas are generally considered to be temporary.

It is well known by Army planners that the need to transport water supplies to largely mobile forces in the field has severely taxed the logistical support system. Existing Army water transportation equipment will not completely meet the needs to distribute adequate bulk water supplies for troops operating in arid or semi-arid regions. Therefore, water recycle/reuse would assist in reducing those bulk requirements. Reducing requirements would result in manpower and energy savings. For these reasons, the effluent from field laundry and shower facilities are considered as potential sources to increase available water supplies.

WATER CONSERVATION AND WATER DISCIPLINE

Water conservation practices by troops in the field can and does assist in reducing the need to treat and transport great volumes of water. There is much to be said for conservation. However, in an arid environment, the need to shower and perform bodily ablutions frequently may become an unusually high morale factor. Showers should be permitted at least twice weekly. The frequent necessity to wash or exchange soiled clothes and linens also bears on morale. Therefore, while water conservation can be directed toward some irreducible minimum, adequate shower and laundry facilities will surely be essential to maintain troop morale and health.

SOME HEALTH CONSIDERATIONS

To prevent heat illness at the battalion/company-level, drinking water requirements from 6 to 13 quarts per man per day is the recommended requirement depending upon the work activity level. In desert regions it is not uncommon for active men walking in the sun to require replenishment of some 1-1/2 quarts of body fluids each hour, without which they may become ineffective. Bulk drinking or "deliberate rehydration" will be required to prevent combat units from becoming ineffective in the desert. It has been estimated that six percent of body weight liquid loss will result in incapacitation for most active men and that, at four percent of body weight loss, dehydration will occur in the desert sun within five hours at 105°F for troops simply walking. The importance of the availability of shower facilities as a morale factor and deterent to dehydration is immediately obvious.

One health concern is that unintentional short-term ingestion of reused water not be damaging to health or life of the soldier.

Another concern is that the wastewater product be free of oral, dermal and ocular toxicity.

Potable water is ordinarily manufactured by purification of a raw water supply from a proven source. While the treatment product is primarily intended for ingestion, potable water is also used for myriad other uses including bathing and day-to-day chores necessary for comfortable living conditions. Some of these waters may be recycled/reused for subpotable purposes. The recycled water may be used for human contact (say for laundry or shower purposes) or for non-human contacts (say for equipment wash-down). For indirect human contact, the recycled water should be safe and the risk of reuse should be relatively small. Consideration must also be given to the period of usage. The full implications of long-term human contact are not completely known although short-term usage appears to have no deleterious effect insofar as can be determined by extensive literature search and review. Important in toxicological considerations are dermal absorption, skin irritancy, eye irritancy, and skin sensitization.

Risks are inherent in any military operation and they involve the life and health of the soldier in combat as well as non-combatant injuries. Risks for reusing water are also inherent in any military operation. Therefore, while the quality of the recycle/reused water should be as high as possible, the risks cannot be entirely eliminated. Inadvertent ingestion of recycled/reused water may occur. Ingestion of a high solids content liquid will place certain organic and inorganic salts, metals and even micro-organisms in the human system which may have a deleterious effect on the individual. If recycled/reused water is employed in combat areas every effort must be made to discourage its ingestion.

Every military campaign contingency for recycle/reuse must consider certain principles. First, every water recycle/reuse project will probably be unique. Second, every water recycle/reuse project must be efficiently operated on the proper economy of scale. Third, power requirements may be an overriding consideration in recycle/reuse. Fourth, the recycle/reuse waters should be returned to the same system from which they were a source. Fifth, the personnel to operate the recycle/reuse system should be trustworthy and carefully trained. Sixth, the recycled/reused waters must be obtained on the basis of a reasonable return on the expended water renovation effort.

The recycle/reuse system must operate under an effective and reliable quality control system. There must be no deleterious health effects associated with the system's operation (organic, inorganic or biological pollutants).

Recycle/reuse of shower water, with adequate clorination control and comparative reliability of disinfection, would prevent shower points employing untreated supplies as a source of water from becoming sources of infectious disease.

BRIEF DISCUSSION OF SOME RESEARCH RESULTS

The results of a literature search revealed that research, much of it Army sponsored, initiated in the 1960's and continued with increasing emphasis throughout the 1970's, has improved the basis for practical methods which will solve the increasingly important problems related to recycle/reuse of waters in Field Army situations. A number of the studies bear mentioning. One of the first efforts to treat laundry, shower, kitchen and hospital waste was a prototype study begun in the 1960's with field testing conducted in the early 1970's at Fort Lee, Virginia under the Army Surgeon General's MUST (Medical Unit, Self-Contained, Transportable) program. While no health hazards were evaluated, it was early determined that the quality of the recycled/reused waters was highly dependent on the sensitivity of chemical feeders and operator initiative. The MUST water processing element consisted of a water treatment unit and water purification unit. The tests conducted on synthetic shower, kitchen, x-ray, operating room, laboratory and laundry waste waters were not conclusive.

Following these inconclusive tests, four Army-sponsored research efforts -- Tardiff and Mullaney (1972), McNamara (1974), Grieves and Bhattacharya (1976), and Witherup and Emmett (1977) -- assisted in the assessment of recycled/reused shower and laundry water. Almost universally, no toxic hazards were uncovered by these later reports.

A comprehensive report, Human Safety and Environment Aspects of Major Surfactants (A. D. Little, Inc., 1977) was prepared for the Soap and Detergent Association of New York, New York. The exhaustive report assessed "the depth and scope of available environmental and human safety data for a group of surfactants which have either present commercial importance or possible future wide use." Each of the seven major and minor surfactants (ranked by amounts synthesized and compounded into commercial products) was reviewed for four major areas of interest: (1) environmental distribution and fate, (2) biodegradation, (3) environmental effects of surfactants and biodegradation products, and (4) human safety as judged from studies of animal toxicity and pharmacology and from human exposure.

For the four major surfactants (linear alkybenzene sulfonates, alkyl sulfates, alcohol ethoxylates, and alcohol ethoxy fulfates) the report indicated that these substances as a class pose no threat to human health. With respect to the surfactants of lesser commercial importance (alkylphenol ethoxylates, alpha olefin sulfonates, and secondary alkane sulfonates) there was less complete support as to their acceptability for human safety. Nevertheless, the report suggested that there would be a degree of safety and acceptability for the latter group of surfactants because of the general structural similarity between the major and lesser commercially important groups of surfactants.

Life Systems, Inc., has developed a 3,500 gallon per 20-hour day, automated wastewater reuse system with the objective of permitting reuse of non-sanitary wastewaters for non-potable hospital requirements to be used in water deficient areas (Lee, Yang, Wynveen and See, 1978). The system was designed either for non-potable reuse or for treatment of natural fresh and brackish waters for potable use. The system pilot plant consists of four units: (1) a water treatment unit, (2) a water purification unit, (3) an ultraviolet/ozone oxidation unit and (4) an automatic instrumentation unit. The delivered system has undergone extensive testing and is now physically located at the U. S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, Maryland.

In an interim report, Development of Data Base Requirements for Human Health Based Water Quality Criteria for Military Recycle/Reuse Applications (A. D. Little, Inc., September 1979) highlighted the increasing need for recycle/reuse of wastewater by the military establishment, both in garrison and field. The three major military services -- Air Force, Army and Navy -- were identified as contributing development work to the opportunities for recycle/reuse under various conditions and environments.

The interim report noted the absence of water quality criteria for recycle/reuse applications and stated that it was necessary to develop an approved protocol for subpotable and non-potable applications. The purpose was further defined to consider: (1) conditions of exposure, (2) the population exposed, (3) quality of the wastewater, and (4) the treatment process employed.

The interim report outlined 11 military recycle-reuse applications and assigned them four priorities by field and fixed installations. Laundry and shower (washroom) sources were listed as two of three categorized in the first priority. The approach to development of health effects criteria were enumerated, suggested duration of exposure to potential toxic materials were grouped (acute, 0-4 days; subacute, 5 days-1 year; chronic, 1 year to life), and the population to be exposed was discussed.

A final report, Evaluation of Health Effects Data on the Reuse of Shower and Laundry Waters by Field Army Units (Cogley, Light, Foy, Mason and Eaton, 1979) prepared by the staff of Walden Division of Abcor, Incorporated, and the March 1979 summary, same topic, prepared for presentation at the Water Reuse Symposium, are probably the most comprehensive publications to date relating to recycle/reuse of laundry and shower waters. The report and summary discuss the feasibility of short-term shower and laundry water recycle/reuse by Field Army units. Four topics were investigated: (1) composition of short-term shower and laundry wastewaters as a function of the health care products employed, (2) an engineering evaluation of the treatability of the products, (3) oral, dermal and ocular toxicity of the product ingredients, and (4) previous Army-sponsored research related to shower and laundry water reuse.

The four wastewater systems evaluated included the following systems: (a) ultrafiltration followed by reverse osmosis, (b) an ultrafiltration system alone with membranes having a smaller porosity than that in (a), (c) a suspended solids removal with a pre-treatment unit followed by activated carbon absorption and then by an ion exchange unit, and (d) an ERDLator configured system.

The investigators sought toxicity data for compounds that were predicted to be present in shower or laundry waters. The major toxicity considerations were oral, dermal and ocular. For all substances for which information was available, none in laundry or shower concentrations was found to be toxic. However, there were some data gaps noted.

Health assessments of recycle/reuse were suggested for short-term (1-7 days) and long-term (greater than 7 days). The study recommended the following work to be continued: (1) preparation of an assessment of the benefits of short-term shower and laundry reuse by Field Army units, (2) preparation of an assessment of acceptable risks associated with short-term shower and laundry water reuse in a combat situation, (3) preparation of criteria defining acceptable risks for human test subjects in clinical trials of water reuse, (4) preparation of a protocol for annual studies designed to assess the possibility of human toxic response to shower and laundry water reuse, and (5) preparation of a protocol for human clinical trials of short-term shower and laundry water reuse.

RAPID DEPLOYMENT FORCE

The Rapid Deployment Force (RDF) concept has been in existence in one form or another as a long-standing U. S. military plan. The assignment of combat and combat support troops to the Force is proceeding apace and is now beyond the planning stage. Four criteria governing the RDF concept are: timely and effective decision making, tactical readiness, adequate tactical and logistic back-up, and forward positioning in the region of crisis.

The concept has become a reality as evidenced by the following. In the Indian Ocean/Persian Gulf area, sometimes referred to as the Arabian Sea, the U. S. has already established a military presence -- two carrier battle groups, 150 warplanes and, until recently, a 2,000-man Marine amphibious unit. At least seven freighters and tankers constituting a Near Term Prepositioned Force are on station in the Indian Ocean with two to four weeks' supply for fighter squadrons and a 12,000-man Marine amphibious brigade. The ships are loaded with unit equipment, supplies, fuel and potable water. The seven-ship force is composed of commercial-type vessels including roll-on, roll-off ships break-bulk cargo ships and tankers. The prepositioned supply fleet is scheduled to allow the amphibious unit and the U. S. Air Force squadrons to operate until further logistical support can arrive from the U. S. should the need arise.

The requirement to insert U. S. ground forces into the Middle East arid or semi-arid land mass will depend upon the international situation. Therefore, the need for testing the recycle/reuse of wastewaters concept, establishing protocols and developing criteria becomes pressing.

THE NATIONAL TRAINING CENTER

In July 1981 Fort Irwin, California, will become the Army's National Training Center. The huge post, with approximately the same land area as the State of Rhode Island, will have room for two battalion task force manouever areas, an instrument range and a live fire range each of which can be operable without affecting the other. The Army has long been seeking a locale to conduct battalion level task force exercises where units could independently deploy as if in combat.

The size, location and terrain of the Center are ideal for simulated arid or semi-arid conditions. The terrain is generally parched, brown flatlands. There are two mountain ranges, many rock outcroppings and gullies. Several dry lake beds, which become inundated after sporadic heavy rainstorms, dot the site. Temperatures in July and August reach 110^{o}F (the Center is about 40 miles from Death Valley, one of this continent's hottest places). Nights can be cold. Winter temperatures drop to 20^{o}F with 35 to 40 miles per hour winds not uncommon. The Center may be described as having an "intense" environment.

In March 1980, Exercise "Gallant Eagle" involved more than 25,000 soldiers, airmen and marines at the Center in a two-week exercise under desert conditions. National Guard and Reserve units provided combat service support. In the first three days of the exercise, more than 100 tons of food and equipment, 300,000 gallons of water and 350,000 gallons of fuel were transported to the troops in the field.

The National Training Center would make an ideal proving ground for testing recycle/reuse equipment envisioned in this report. Water quality criteria and approved protocols for subpotable recycle/reuse short-term applications also might well be investigated with the Center as the locale.

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APPENDIX D

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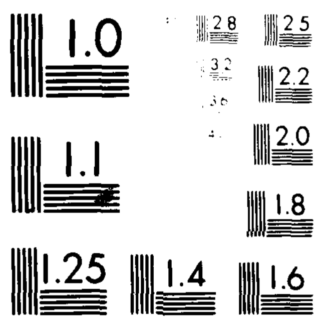

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