A Review of the U.S. Army Construction Engineering Research Laboratory Program for Recycling and Reuse of Laundry and Shower Wastewater (1986)

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A Review of the U.S. Army Construction Engineering Research Laboratory Program for Recycling and Reuse of Laundry and Shower Wastewater

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Water Science and Technology Board

Commission on Engineering and Technical Systems

National Research Council (U.S.).

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PREFACE

The U.S. Army must be prepared to maneuver in any environment, including harsh desert regions, where both permanent bases and field operations may be required. A major need at such sites is a reliable supply of potable water. Besides requiring water for human consumption and food preparation, a large amount of nonpotable water (water not suitable for drinking) is needed for a variety of purposes. Unfortunately, the only water available in most desert regions is brackish ground water and, in some locations, the ocean. Such source limitations dictate that all available water be managed and used with maximum efficiency. Thus, the Army has had an interest in water conservation, reuse, and recycle as a viable means of reducing the logistic burden of supplying water for military operations in desert areas.

Under a contract executed in December 1985 between the National Academy of Sciences and the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL), the National Research Council (NRC) agreed to form a Committee on Recycling, Reuse and Conservation in Water Management for Arid Areas. This committee, established under the NRC's Water Science and Technology Board and consisting of specialists knowledgeable in water supply and wastewater treatment technology and in environmental toxicology, microbiology, and public health, was charged to review the CERL's program concerning water recycling and reuse of field laundry and shower wastewater and to advise on the implementation of a research and development program designed to meet the Army's water requirements in arid areas.

The committee held it first meeting in Washington, D.C., on February 6-7, 1986. At this meeting the committee heard presentations by CERL personnel and others on the Army's needs and proposed methods to supply water of suitable quality for water use in the field. In concert with representatives of CERL, the committee agreed to focus initially on the reuse of general personnel field laundry and shower wastewater and associated health-related issues. To this end, CERL supplied the committee with numerous reports on the subject for its review and use in preparing its report. It should be pointed out that this report is not a comprehensive state-of-the-art review of water reuse-recycle, even as it might apply to shower and laundry wastewaters. Rather, based on review and evaluation of the Army's past research program on the recycling of shower and laundry wastewaters, it addresses the important issues associated with the recycling of shower and laundry wastewaters and as a result, makes specific recommendations that the Army can use as guidance in developing its future research program.

The members of the committee and their affiliations are listed in the front of this report, while a brief biography of each individual is provided in Appendix C. Because of the short time available to prepare this report, the members gave willingly of their time and as a result, actively participated in the effort. All deserve equal credit for the substance and recommendations found in this report. The valuable assistance provided by Sheila D. David, Staff Officer, and other staff of the NRC's Water Science and Technology Board; E. D. Smith, Project Officer, and R. Scholze, both associated with the Water-Quality Management Team of the Environmental Division at CERL; and others with the U.S. Army who attended the committee's meetings, is gratefully acknowledged.

Richard S. Engelbrecht, Chairman
Committee on Recycling, Reuse and
Conservation in Water Management
for Arid Areas

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SUMMARY

The committee wishes to commend the U.S. Army Construction Engineering Research Laboratory (CERL) for having the foresight to review concepts of water recycling, reuse, and conservation at various types of Army installations. Significant water, energy, and cost savings could be realized by instituting a water-management program and by using state-of-the-art technology to conserve water and recycle or reuse wastewater.

The overall objective of the committee's study was to evaluate the CERL's program on recycling and reuse of field laundry and shower wastewater with respect to its technical and scientific merit and to recommend additional research needs, if any, required to achieve the goals of the recycling/reuse program. Since Army policy, as presented to the committee, prohibits water recycle/reuse under conditions of nuclear, biological, or chemical warfare; the assessment of the CERL's program was posed against a background of water use as it might occur in a normal population.

The studies funded to date by the CERL and other branches or agencies within the Department of Defense on recycle/reuse of laundry and shower wastewaters in military field operations and reviewed by this committee provide only a limited data base to evaluate the overall technical feasibility of recycle/reuse options, with respect to assessing any potential health risks.

TREATMENT SYSTEMS

The technical feasibility of treatment systems has received the greatest attention in the studies reviewed by the committee, with only limited attention to water-quality constituents of health concern.

The recycling of laundry wastewater presents a substantially different exposure of troops than that of recycled wastewater from showers. Specifically, wearing clothing laundered in recycled water can be viewed as an indirect exposure to residuals in such clothing, while exposure to chemicals or microorganisms that could be present in recycled shower water would be direct. Thus, more stringent criteria (and hence testing) will be required to ensure the safety of direct exposure to recycled wastewater. While the committee believes that both recycling options are achievable with existing treatment technology, additional pilot and field tests should be performed for evaluating the success of the treatment system in reliably providing a safe supply for both water uses.

The apparent success of the recycle studies performed to date indicates that laundry recycle seems to be aesthetically viable for use in military combat operations. There is a clear need, however, to expand the testing of recycle systems in the area of health effects considerations if shower recycle is pursued. The performance evaluations of the treatment system have not gone far enough in assuring the public health safety of either the shower or laundry recycle practice. Four specific issues must be addressed in completing this evaluation, as follows:

1. A characterization of the wastewaters with respect to organic, inorganic, and microbial constituents of potential health concern must be completed. To date this task has received inadequate attention.
2. Any proposed treatment system should be evaluated against the established standards to determine the adequacy of the proposed treatment technology.
3. The reliability of the treatment methodology must be assessed in the context of the recycle and treatment operations that are anticipated by the military.
4. Surrogate water-quality characteristics should be defined for operational monitoring of the treatment system during field application of the recycling systems.

HEALTH EFFECTS CONSIDERATIONS

Two major routes of exposure need to be considered when using recycled wastewater for shower and laundry: inhalation and topical contact. Presumably, incidental ingestion of recycled water would be minimal, as specific instructions could be issued to personnel using shower facilities under these conditions. In addition, two levels of exposure should be recognized: that of the operators who work in the facility and those who use the facility (e.g., shower) or its product (i.e., laundry).

With the use of recycled water for showering, the inhalation and topical routes must be considered the primary routes for systemic exposure for most chemical and microbiological agents. The inhalation route has essentially been overlooked in past Army studies.

Chemicals

Because of the importance of the inhalation route of exposure, the committee recommends that some modeling work (including experimental confirmation) be considered for any chemical that appears to be present at sufficient concentrations in the recycled wastewater. Testing of the water-treatment systems proposed for recycling shower and laundry wastewaters has relied heavily on general treatment parameters. While these parameters are of use in judging the general efficiency of the water-treatment system, from a toxicological point of view they are virtually useless for determining whether the final water is safe for the proposed use.

The committee recommends that any additional testing of treatment systems focus on the characterization of chemicals being introduced into the water by its previous use, as well as documenting their individual occurrence in the wastewater and in the finished, recycled water. The available literature can then be searched for adverse health effects of concern that are associated with those chemicals that remain at appreciable concentrations in the recycled water.

Those chemicals for which adequate data do not exist (except those that may generally be regarded as safe, such as normal dietary constituents) should be investigated for those toxic effects that are considered unacceptable under battlefield conditions. In particular, studies should focus on respiratory and topical irritation. These data should be used to develop standards where it seems appropriate.

An alternative to the approach of assessing the toxicology of individual chemicals that should be considered is toxicological testing of concentrates of the organic elements present in product waters by appropriate routes in experimental animals. If such an approach is adopted, care must be taken to document the performance of any concentration techniques that are used. It is also possible to prepare an artificial concentrate based on known organic chemical constituents in the product water. If this approach is used, care should be taken to include by-products of treatment processes in the mixture that are qualitatively and quantitatively similar to those produced under field conditions.

An issue that has clearly received too little attention in the reuse and recycling of field laundry and shower wastewater is the level of chlorine that is used for disinfection, the nature of the by-products that are potentially irritating to the skin and mucous membranes, and the extent to which some of these by-products might accumulate in the recycled water. High levels of chlorine have been associated with depressed immune function when administered in drinking water. The extent to which this might be produced by other routes of administration, particularly inhalation, is not clear.

Therefore, the committee recommends that explicit consideration of the concentrations of chlorine and its by-products in air that are achieved in the laundry room or shower is necessary. These data should then be compared with the literature-based information on the inhalation toxicology of these compounds to determine whether workers in the laundry or showers are at risk from repeated inhalation.

Microorganisms

Recycle of water for showering could theoretically provide a direct avenue for microbial infection, predominantly by inhalation of aerosols or nasal deposition of larger droplets, by dermal contact, or by ingestion. The conjunctiva and the alimentary, respiratory, and urogenital tracts offer easier pathways for microbial penetration than in the case of intact outer skin. It is noteworthy that the infectious dose for many viruses associated with respiratory diseases such as rhinovirus, adenovirus, and Coxsackievirus A21 can be very low when administered by nasal drops or aerosols.

The infection of individuals through the wearing of clothing laundered in recycled water seems remote. Selected bacterial pathogens as well as enveloped viruses should be susceptible to the action of detergents. In addition, many microorganisms are relatively susceptible to desiccation and should be inactivated by the process of clothes drying. Thus, multiple barriers of both wastewater treatment and laundry processes should adequately protect individuals from infectious agents transmitted by clothing. Furthermore, the major route of exposure for personnel would be contact with external skin, a relatively impenetrable barrier. However, the exposure of laundry operations personnel could parallel that discussed above for shower exposure.

Since an infectious epidemic could be devastating in a combat situation, wastewater recycle must be designed to ensure the removal of infectious agents. The most effective means to accomplish this task is adequate and consistent disinfection (i.e., chlorination). If any variation in chlorination practice is made necessary by the generation of unacceptable levels of toxic chemical by-products, the effectiveness and safety of any alternative disinfection processes must be well documented. Infectious agents, including bacteria, viruses, protozoa and helminths may be found in raw domestic wastewater. Sewer workers and others associated with treatment and disposal of domestic wastewaters are likely to have a high incidence of exposure to infectious microbial agents. Studies have been performed in the last 10 years to determine the health risk associated with this exposure. Therefore, CERL personnel may want to review this body of literature with respect to its significance in evaluating health risks associated with recycling of laundry and shower wastewaters.

Of the reports provided to the committee, only one documented a single experimental series in which an indicator bacterial group (total coliforms) was enumerated during the course of shower wastewater recycle. The committee recommends that further studies, specifically with regard to shower wastewater recycle, begin by characterizing the microbial content of untreated wastewater. Subsequently, organisms detected in such wastewaters can be enumerated in recycled waters to assess the efficacy of the treatment train and the potential health effects of this water. Additionally, the establishment of such a data base would provide a better framework from which to address the applicability of water-quality criteria and standards to microbial health effects associated with shower and laundry wastewater recycle.

WATER-QUALITY CRITERIA AND STANDARDS

As defined by the committee, water-quality criteria are those scientifically established values that have been identified as being important in assessing the intended use of a given water and that are ideally expressed in terms of a dose-response relationship.

Standards may subsequently be developed from criteria taking into account special conditions or requirements such as degree of personnel exposure, acceptable health risks, availability of water-treatment technology, and costs of various treatment options. The development of water-quality standards is impeded by lack of scientific information defining the dose-response of chemical constituents and biological organisms in humans. Thus, establishment of standards often depends on experimental work in animals in the case of chemicals or from past experience in which water of a given quality (as evaluated by indicator organisms) has been safely used by a consuming population in the case of microorganisms.

Recently, the Department of the Army promulgated standards for recycled water for other than potable uses, setting maximum acceptable limits for pH, turbidity, and hardness and requiring free chlorine residuals for a prescribed contact time. It should be recognized that the established values, reflecting operational measurements, have not evolved through the process of establishing water-quality criteria and subsequently applying judgments to reach standards. Rather, these standards presumably reflect positive, historical experiences in the use of water meeting these constituent levels.

The committee believes that further development of health criteria for shower and laundry wastewater recycling must first resolve the following:

- What are acceptable and unacceptable health effects?
- What is the probability within stated degrees of confidence that an adverse health effect may occur?

Clear policy statements in these two areas will greatly simplify the development of standards from available literature and provide a clear focus for any experimental work that is deemed necessary. For example, if diarrhea is considered an unacceptable health effect, then some decision needs to be made concerning the upper limit of incidence that is acceptable (perhaps considering background incidence of this disease in combat areas). To date the only condition placed on potable water by the Army is that no performance degradation should result from its use. Recycled waters should not impair the health of exposed personnel, and no increased risk should be placed on personnel by water reuse/recycle. Such general, qualitative statements ignore the realities of water use and reuse.

An evaluation of the likely health effects from each type of product water will have to consider

- Volume of water ingested,
- Volume of water inhaled,
- Estimation of the dose of volatilized and aerosolized constituents inhaled,
- Effective dose to the skin,
- The combined systemic dose derived from each of these routes, and
- Local and systemic toxic effects of chemical constituents.

Integration of the above information for individual components and/or the product waters as a whole will allow determination of which alternate recycle options are safe. Implementation of laundry or shower wastewater recycle requires the establishment of water-quality criteria and standards. Therefore, the committee recommends that the process of criteria review and standards development ongoing for potable water be extended to nonconsumptive water use as soon as possible. Judicious consideration should be given to the various routes of exposure described above for both troops and operations personnel, recognizing that individuals in the latter group will have the greatest exposure.

RESEARCH NEEDS

The committee believes that the available data are encouraging for the field Army laundry wastewater recycle. The data required to ensure the safety of field laundry wastewater recycle are achievable with minimal additional studies. A pilot-scale study should be performed with the proposed laundry treatment system. A representative source water should be used and the laundry operated through a number of recycles. It is possible that characterization of laundry wastes is not necessary, provided that topical and toxicological studies are conducted and no sensitization is observed in human volunteers.

Since shower wastewater recycling will involve direct human exposure largely through inhalation and dermal contact, the committee recommends more detailed studies to provide the data necessary to ensure safe shower wastewater recycle. Additional pilot studies should be performed to better characterize the quality of water associated with the shower recycle system. The tests should be designed to ensure that an adequate number of recycles are included to achieve operational steady state (system is running in equilibrium). The data made available to the committee indicate that steady state was either not accomplished or just minimally reached in previous testing.

The committee believes that the emphasis of this program should be focused on characterizing the wastewater with respect to chemical and microbiological quality. In the development of the data base necessary to conclude this program, the committee recommends that a quality assurance program be developed. Particular attention should be focused on the area of detection limits of analytical procedures, reproducibility of results, microbiological determinations, and the validation of zero recovery results.

The committee believes that the proof of the success of the treatment process can only be accomplished through additional interdisciplinary studies. Engineers, chemists, and microbiologists must identify the contaminants to be added to the water by its previous use and determine the extent to which the treatment processes alter the composition of the wastewater. This type of information is needed before toxicological and microbiological data that establish dose-response relationships can be used to develop health criteria appropriate to the specific use. Because decisions in one area invariably have an impact on another, it is essential that contributors from all these disciplines be involved from the beginning of the project.

1

INTRODUCTION

The reuse of water, including domestic and industrial wastewaters, is not a new concept. The indirect reuse of wastewater, which occurs "when water, already used one or more times for domestic or industrial purposes, is discharged into fresh surface or underground water and used again" (World Health Organization, 1975), is a common, everyday practice. In this sense, our rivers and lakes often receive treated and sometimes untreated domestic and industrial wastewaters and at the same time, serve as sources for potable water supplies. Likewise, the planned, deliberate reuse of domestic or industrial wastewaters for some beneficial purpose or direct reuse is not a new concept or practice. Throughout the world, wastewaters have been reclaimed for irrigation purposes for many years. There also have been instances of reclaiming wastewaters as a source water for recreational ponds and for ground water recharge. Industries frequently use reclaimed wastewaters for cooling, quenching, and washing operations. Further, the reclamation of wastewater for potable reuse in arid countries or areas where a water shortage exists has been investigated in the United States and elsewhere in the world. As a result of extensive research studies initiated in South Africa in the early 1960s, a full-scale, advanced wastewater reclamation facility was constructed and has been providing intermittently 13-20 and, occasionally, up to 50 percent of the total potable water consumed by the city of Windhoek, Namibia (South West Africa), since 1969 without any observed health effect due to microbial diseases. Although there has been no apparent health effect in Windhoek to date as a result of chemical contaminants in the water, additional studies are required before this issue can be answered unconditionally (Water Research Commission, 1985).

Water reuse may also be practiced under special circumstances. For example, there are three types of artificial swimming pool: recirculating, fill-and-draw, and flow-through. Of these, the recirculating type is most common. In a typical recirculating-type swimming pool, the water is removed from the pool, filtered through either a gravity rapid-sand filter, a pressure sand or anthracite filter, or a diatomaceous earth pressure or vacuum filter, disinfected, usually by the addition of chlorine, and returned to the pool. Water lost by evaporation, splashing, and backwashing of the filters is replaced by fresh water, usually using a municipal potable supply; however, a minimum amount of makeup water is normally required. Such systems are generally operated to replace the water in the pool, on the average, every 6 to 8 hours. If constructed, operated, and maintained properly, recirculating-type swimming pools are accepted from the public health point of view, despite the fact that the water is subject to bodily contamination from the users of such pools. A fraction of the population is sensitive to chlorine; however, this risk is accepted. As another example of a special case of water reuse, The National Aeronautics and Space Administration (NASA) is currently investigating wastewater reclamation and reuse for its space station program.

In considering the subject of water reuse, the term "water reuse" is frequently differentiated from "water recycle." While water reuse would refer to the reclamation of a wastewater and its subsequent use for a different purpose, water recycle would involve using reclaimed wastewater for the same purpose. In this context, the use of treated domestic wastewater for irrigation purposes would be an example of water reuse. On the other hand, water recycle might involve an industry treating a waste washwater and using it again in the same washing operation that generated the waste washwater.

A tactical Army base, operating in an arid climate, requires water for a variety of purposes. In addition to potable water for human consumption, personal hygiene, and mess/kitchen operation, these include

- Shower operations,
- Laundry operations,
- Hospital operations,
- Construction activities,
- Aircraft and other vehicle equipment cleaning,
- Photoprocessing, and
- Firefighting.

Different water-quality requirements are associated with these various uses, ranging from a high-quality potable water to possibly the use of untreated wastewater, which could be used in certain construction activities. Based on the expected quality of the used waters, the principal sources of water that could be recycled or reused, simply and without creating a significant problem, include the wastewaters from the shower, laundry, and mess/kitchen operations associated with either temporary field or fixed-base installations. In the case of a field operation, the used water from the other use categories would be so limited in volume or of such a poor quality as to preclude its reuse.

In view of the above and after discussing the matter with representatives of the Construction Engineering Research Laboratory (CERL), it was agreed that the committee would initially focus its attention on the reuse of general personnel laundry and/or shower wastewater as generated at a temporary field installation. The term "general personnel" is used to differentiate this source of used water from that produced from the same operations in a hospital. In this regard, it is interesting to note that another investigative laboratory of the Army is studying the treatment requirements of using recycled hospital laundry rinse water in both hospital and nonhospital settings.

The major reuse-recycle options associated with shower and laundry wastewaters, under field conditions, include

- Shower use/recycle to shower,
- Shower use/reuse with laundry,
- Laundry use/recycle to laundry,
- Laundry use/reuse with shower,
- Mixture of shower and laundry wastewater and reuse/recycle with either shower or laundry.

In each case, the wastewater would be collected, treated to achieve an acceptable quality, and reused/recycled as indicated. Having identified the various water reuse/recycle options, a decision was made to narrow the committee's focus further by considering only the possibility of recycling shower wastewater for shower use and laundry wastewater for laundry use. This decision is reinforced by the statements made in the Department of the Army Technical Bulletin, TB MED 577 (March 1986), "Occupational and Environmental Health: Sanitary Control and Surveillance of Field Water Supplies." The following is quoted from this publication:

The concepts of water conservation, recycle, and reuse have not been widely practiced in the field. However, in certain areas where water supplies are few and demand is high, recycle and reuse of water may be necessary to effectively use those quantities of water that are available.

Certain types of wastewater, mainly from shower and laundry operations, can be treated on site and recycled for the same purpose. Shower and laundry wastewater can be collected, batch treated, disinfected, and pumped back to the unit. Such recycling operations are more easily used in a cantonment area than in mobile field operations.

Field laundry and shower operations require large quantities of water. Table 1.1 gives an estimate of the daily shower and laundry water requirement for 100,000 personnel at a field installation, the quantity of new water saved with recycling (assuming 90 percent recycle because of water losses), and the quantity of new water required. Without any recycling, potable water would normally be used with a once-through mode of operation. To produce the potable water needed each day for shower water for 100,000 personnel would require, without any recycling, the availability and operation of 10-600 gal/h or 2-3000 gal/h reverse osmosis treatment units, which is the Army's standard treatment process for producing potable water in the field. Likewise, in the case of the required laundry water without any recycling, 15-600 gal/h or 3-3000 gal/h reverse osmosis units would be needed to produce the potable water required. Thus, with 90 percent recycling of shower and/or laundry wastewater, the logistic burden of providing the additional reverse osmosis units to produce potable water and their cost of operation would be eliminated. The cost of producing potable water by the Army's reverse osmosis treatment units is approximately $20 per 1000 gallons, excluding

TABLE 1.1 Daily Water Requirement and Saving with Shower and Laundry Recycle (gal/100,000 personnel)

Operation	Water Requirement	Water Saving with Recycle	New Water Requirement with Recycle
Shower	130,000	117,000	13,000
Laundry	200,000	180,000	20,000

SOURCE: Department of the Army, 1986.

capital, transportation, labor, and distribution costs, while a comparable cost of separately treating shower or laundry wastewater for recycle has been estimated to be less than half that amount. In addition to economic considerations, a number of other benefits would be realized by recycling shower and/or laundry wastewater, e.g., with a limited source of water, recycling would permit more personnel to be accommodated or provide more water for other purposes.

2

SUMMARY OF REPORTS

OVERVIEW

The overall objective of the committee's study was to evaluate the CERL's program on recycling and reuse of field laundry and shower wastewater with respect to its technical and scientific merit and to recommend additional research needs, if any, required to achieve the goals of the recycling/reuse program. Toward this end, the committee was provided with 29 documents or reports produced since 1971 that addressed the full range of issues associated with the program. The preparation of these documents was directed by CERL or by other agencies in the Department of Defense with interest or statutory responsibilities in recycle/reuse in field situations.

The contents of these documents are summarized in Table 2.1. Included is the document number (see Appendix B for full bibliography), the date and author(s), recycling alternative investigated or evaluated, technologies evaluated, and finally whether the document is a literature review; whether it reports on bench-scale, pilot-scale, or field-scale studies of alternatives; and whether health effects data and standards development were discussed. Twelve of the reports are either literature reviews or contain reviews of certain key issues as part of a more extensive report. Only six of the reports contain data on bench- or pilot-scale studies evaluating the technical feasibility of recycle/reuse options. Only limited resources have been invested in field-scale evaluations of any options for recycle/reuse of shower or laundry wastewaters, and only two of the studies attempted to demonstrate recycle alternatives at that scale. Finally, four of the documents discuss

TABLE 2.1 Summary of Documents Reviewed by NRC Committee on Recycling, Reuse and Conservation in Water Management for Arid Areas

Document No. (see Appendix B)	Date/[a] Author	Recycling Alternative	Technology[b] Evaluated	Lit. Review/ Paper Study	Bench Tests	Pilot Tests	Field Tests	Health Effects Tests	Standards Developed	Objectives
1	1971/ NAS/NRC	Wash water in manned spacecraft	NA	No	No	No	No	No	Yes	Tentative standards proposed
2	1973/U.S. Army Mobility Equip. R&D/Lent/ Ross	Shower, laundry, kitchen recycle	ERDLator unit	No	No	Yes	Yes	No	No	Field test of ERDlator on synthetic wastewater; limited water quality testing
3	1975/ Ciccone	Evaluated reuse for latrines, laundry, industrial, photo	15 individual and combined processes evaluated	Yes	No	No	No	No	No	Feasibility study, computer model, economic analysis
4	1977/ Botros/ Best	Laundry Recycle	COAG/FILT	Yes	Yes	No	No	No	No	Lab study to optimize coagulant dose for laundry recycle; inadequate data

[a] "Date" refers to year of publication, "author" is lead author or institution responsible for work.
[b] The following abbreviations are used:
COAG, coagulation with inorganic chemicals or organic polymers;
PAC, addition of powdered activated carbon;
SED, sedimentation;
DE, diatomaceous earth filtration;
FILT, filtration in porous media;
UF, ultrafiltration (i.e., membrane filtration);
IX, ionexchange;
RO, reverse osmosis;
DIS, disinfection using appropriate chemicals;
AC, activated carbon;
NA, not applicable.

5	1977/ Phull/ Lindsten	Laundry recycle	13 methods evaluated	Yes	No	No	No	No	No	Laundry recycle on naval air-craft carriers; cost effective-ness analysis
6	1977/Ford	Laundry recycle	Various processes evaluated	Yes	No	No	No	No	No	Economic feasi-bility analysis
7*	1977/ Witherup/ Emmett	Laundry/laundry, shower/shower	UF/DIS	No	Yes	Yes	No	Yes	No	Evaluated toxi-cology of treated waters, concentrates
8	1979/ Cogley et al.	Shower/shower, laundry/laundry, shower and laundry recycle	US/RO/DIS, UF/DIS, DEF/GAC/IX, EROLator/DIS, Dilution/DIS	Yes	No	No	No	No	No	Paper study, feasibility analysis of recycle technologies
9	1979/ Adams/ Kent	Shower/laundry reuse, other sources possible	RO, UF, Air Flotation, DE/AC	Yes	No	No	No	No	No	Cost analysis of alterna-tives; limited discussion of quality issues
10	1980/ Shooter/ Anderson	Shower/laundry recycle, mixed wastewaters	NA	Yes	No	No	No	No	No	Methodology for setting standards for recycle
11	1980/ Office Surgeon General	Shower/laundry reuse/recycle	NA	No	No	No	No	No	Yes	Background document, basis for standards development
12	1981/ Adams	Shower/laundry recycle	Filtration/DIS, DE, FILT/GAC/DIS	No	Yes	Yes	No	No	No	Evaluated nu-merous filters, disinf. alter-natives; no health effects information

13	1982/ USA-CERL/ USA-WES	Review of total water supply problems for tactical units in Southwest Asia	NA	No	No	No	No	No	No	Background info for water sources, water uses for tactical arid field units
14	1983/U.S. Army	NA	NA	No	No	No	No	No	No	Water consumption planning factors for tactical units
15	1983/ Ciccone	Evaluated all use/ reuse options in a military field situation, "closed-loop water use concept"	ERDLator, ROWPU	Yes	No	No	No	No	No	Feasibility analysis of options for reuse
16	1983/U.S. Army	Supply of potable water in field	NA	No	No	No	No	No	No	Overall water support concept for U.S. Army; no discussion of recycle
17	1984/ Woosley	General survey	NA	Yes	No	No	No	No	No	Air Force rejects reuse; RO of seawater
18	1984/ Johnson	Independent evaluation report (IER) for field laundry unit	NA	No	No	No	No	No	No	Background document, evaluation of equipment - status of field laundry unit
19	1984/VMI/ Ciccone	Laundry/shower recycle	ERDLator system	NA	No	No	No	No	No	Test plan for field experiments; background document; inadequate water-quality testing

20	1984/VMI/ Ciccone	Test plan for study in reference 13	NA	No	No	No	No	No	No	Background document
21	1985/VMI/ Ciccone	Shower/shower	COAG/PAC/SED/DE, Chlorine Disin.	Yes	No	No	No	No	Yes	Operations manual
22	1985/VMI/ Ciccone	Shower recycle	COAG/PAC/DE/DIS	No	No	Yes	No	No	No	Major pilot study; batch systems tested; large data base; inade-quate water-quality charac-terization
23	1985/VMI/ Ciccone	Laundry/laundry recycle	COAG/PAC/DE/DIS	No	Yes	No	Yes	No	No	Three batch cycles of system; limited water-quality data
24	1985/U.S. Army, USAF Water Resources Mgmt. Action Group	Shower/laundry recycle	NA	No	No	No	No	No	No	Background document
25	1985/ Curley	Shower-water reuse	NA	No	No	No	No	No	No	Background memo
26	1986/ Dept. of Army	Technical Bulletin, Sanitary Control and Surveillance of field water supplies	NA	No	No	No	No	No	Yes	Army Tech. Bulletin on control of field water supplies

27	1986/ Anspaugh et al.	Criteria recommendations for drinking water in Field Situations	NA	Yes	No	No	No	No	Yes	Criteria and standards for 9 water-quality parameters
28	1986/ Bandy et al.	Laundry/laundry	COAG/PAC/SED/DE/ DIS	No	Yes	Yes	No	No	No	Multicycle operation, 11 water-quality parameters measured
29	Miller/ Unpub-lished	Concepts of Army field water supply	NA	Yes	No	No	No	No	No	Background document

* This is the only report where actual health effects tests were completed. Other reports discuss potential health effects issues without actual animal or human testing.

health effects data but only one provides new health data that specifically address health risks from a recycle situation. Five of the reports addresses the key issue of developing appropriate standards for recycle/reuse of the wastewaters for laundry or shower uses.

As discussed in the introduction, the committee's evaluation focused primarily on the laundry and shower recycle options that have been evaluated by CERL. This brief review of the reports focuses on the success of the studies completed to date in answering a number of questions that seem critical to the committee in assessing the technical and scientific merit of the overall program. In turn, the success or lack thereof of the program in answering these questions sets the stage for recommended additional research work. These questions are as follows:

1. Have the studies adequately evaluated the conceptual basis for field recycling/reuse in combat situations?
2. Have the shower and laundry wastewaters and recycled waters been adequately characterized with respect to contaminants of potential health concern?
3. Have the appropriate technologies been selected for evaluation/testing?
4. Have the technologies selected been tested sufficiently to determine treatment efficiencies in removing contaminants of concern and to determine treatment reliability?
5. Has a risk-assessment analysis been completed, and if so was the analysis adequate to define potential health risks to the users of the recycle system?
6. Have standards been developed that will permit assessment and acceptable operation of the recycling technologies under realistic conditions?

In this chapter, the committee has not attempted a detailed evaluation of each of these questions, but rather some of the successes and deficiencies of the current program are highlighted. More detailed critiques regarding each of these questions can be found in subsequent chapters of this report.

ADEQUATE CONCEPTUAL BASIS

Several reports have evaluated the technical and economic feasibility of recycle options and the potential health effects of these options (Ciccone, 1975; Ford, 1977; Phull and Lindsten, 1977; Adams and Kent, 1979; Cogley, et al., 1979; Ciccone, 1983). Ciccone (1983) evaluated all military water-using field activities and specified the types of water that might be required by each of these activities as summarized in Table 2.2. Shower and laundry needs are assumed to be satisfied with "fresh, nonpotable water." The report by Cogley et al. (1979) provides the best overview of the quality, technology, and health effects issues associated with shower and laundry wastewater recycle.

In general, these reports adequately define the conceptual basis for the recycling/reuse options in field situations. One shortcoming of these conceptual studies is inadequate attention to the actual conditions under which the recycle options would be implemented. In addition, the reports fail to address realistically the issue of level of risk that would be acceptable for implementation of the systems. Thus, the conceptual studies completed to date have been too limited in scope and have not adequately identified the constraints that must be met by any recycle system especially with respect to potential health risks associated with the recycle options.

CHARACTERIZATION, TREATMENT EFFICIENCY, AND RELIABILITY

Four early studies have attempted to characterize laundry or shower wastewaters and treated waters with respect to water-quality constituents of operational importance. In some of the studies, treatment efficiency and reliability were determined but for only a limited number of constituents. The report by Lent and Ross, (1973), presented water-quality data including pH, turbidity, total dissolved solids (TDS), total and orthophosphate, silica, hardness, alkalinity, sulfate, chloride, and detergents (MBAS), surrogate organic constituents [biochemical oxygen demand (BOD) and total organic carbon (TOC)]. Pilot and field studies of the performance of the ERDLator, a batch physical-chemical treatment processes, were performed using synthetic wastewaters selected to simulate shower, laundry, and

TABLE 2.2 Military Water-Using Field Activities

Activity	Types of Water: Potable	Fresh Nonpotable	Other Nonpotable[a]
Major Uses			
Mess operations (food preparation and utensil cleaning)	X		
Personal hygiene (washing, shaving, teeth brushing)	X		
Showers		X[b]	
Laundry		X[b]	
Drinking	X		
Decontamination		X	X
Construction		X	X
Dust control		X	X
Medical treatment and patient care	X		
Aircraft cleaning		X	
Minor Uses			
Vehicle cooling makeup		X	
Graves registration		X	X
Bakery operations	X		
Photo developing	X		
Well drilling		X[b]	
Pesticide spraying		X	
Firefighting		X	X

[a] Includes relatively clean seawater and brackish waters and renovated shower and laundry wastewater.
[b] Nonpotable water can be used, but it must be clean and free of pathogenic organisms.

SOURCE: Ciccone (1983).

kitchen wastewaters. Five to six recycle sequences were tested, using several different blends of the three synthetic wastewaters. The study concluded that the ERDLator can be utilized effectively for treating these wastewaters generated in Army field situations.

A report by Botros and Best (1977) addressed laboratory-scale optimization of coagulant dose for treatment of laundry wastewaters. No water-quality data were reported. Adams (1981) presented the results of a laboratory- and pilot-scale evaluation of a portable laundry and shower unit for use in combat situations that would include water recycling. This study focused primarily on process variables for various filtration and disinfection alternatives and presented only limited water-quality data. In addition to the constituents measured by Lent and Ross (1973), these investigators also measured color, ammonia, urea, chemical oxygen demand, and conductivity. However, data were not sufficient to characterize adequately the water-quality of the wastewaters or the treated waters. In particular, the study provided limited data on the time variability of process performance. Thus, treatment efficiency could not be characterized statistically, which eliminates the evaluation of treatment reliability.

The most recent studies funded by CERL on shower or laundry recycle were performed by Virginia Military Institute Research Laboratories (VMI) and V.J. Ciccone and Associates (1985a, 1985b, 1985c) and by Bandy et al. (1986). Bandy et al. measured a similar set of physical and general mineral constituents as observed by Lent and Ross (1973). The study by VMI and Ciccone expanded the number of constituents to include microbiological characterization, i.e., total coliforms as well as chlorine residual, and, for the first time in any study available to the committee, chlorinated hydrocarbons measured with a liquid-liquid extraction technique followed by gas chromatography mass spectrometry (GCMS) analysis. In each of these studies, up to eight batch recycle operations were conducted to evaluate the fate of the various water-quality constituents in the treatment process.

While these studies provide a reasonable data base characterizing laundry- or shower-water recycle operations with respect to several inorganic constituents of aesthetic and operational concern, insufficient attention has been given to constituents of health concern. Neither microbiological constituents nor organic constituents have been adequately evaluated. Only one study measured any microbiological constituents, and, in this case, only the indicator bacterial group, total coliforms, was measured. Only one study attempted to quantify specific organic constituents either present in the wastewaters or formed by the disinfection process that could have a potential impact on the health of the user in a recycle situation, particularly in a shower recycle system. Use of the liquid-liquid extraction technique can provide information on only a limited number of compounds, and, furthermore, chloroform was used for the extraction thus biasing the results with respect to chlorination by-products. Thus, the data base generated in bench-scale or pilot treatment studies is inadequate for addressing any health effects questions regarding recycle or reuse options of shower or laundry wastewaters, which then precludes any risk-assessment analysis.

HEALTH EFFECTS DATA

Four of the reports have discussed water-quality issues that could have an impact on user health should reuse/recycle be implemented in combat situations. These reports are discussed in detail in subsequent chapters of this report. Only one of these studies (Witherup and Emmett, 1977) has undertaken the task of testing concentrates of actual or synthetic shower and laundry wastewaters, with respect to acute oral toxicity, and irritation properties, for both skin and eye in laboratory animals. In addition, a limited amount of skin testing was completed in human volunteers. Over 95 water samples including wastewater concentrates were tested. No acute toxicity or skin or eye irritation was observed from tests conducted using wastewaters treated by ultrafiltration and post chlorination. Several of the concentrated untreated wastewaters produced mild to severe skin and eye irritation and were toxic at high doses when administered to mice. These tests suggest that recycle of laundry and shower wastewaters is unlikely to cause any acute effects due to chemical constituents in the treated wastewaters. Unanswered questions include acute effects from inhalation exposure and chronic health effects of recycle and impacts of potentially pathogenic microorganisms in shower recycle/reuse options.

CONCLUSIONS AND RECOMMENDATIONS

The studies reviewed by the committee and funded by CERL and other branches or agencies in the Department of Defense on recycle/reuse of laundry and shower wastewaters in military field operations provide only a limited data base to evaluate the overall technical feasibility of recycle/reuse options and to assess any potential health risks associated with such a program. Technical feasibility of several treatment systems has received the greatest attention in the studies presented to date, with only limited attention to water-quality constituents of health concern.

Health effects data are also limited but do suggest that incidental ingestion or skin contact with recycled shower or laundry wastewaters due to chemicals are likely to be minimal. No information, however, exists concerning a major route of systemic exposure in the shower, i.e., inhalation of volatiles and mists. A significant expansion of the water-quality data base is needed to address health effects issues and treatment reliability issues and to provide a quantitative basis for defining the health risks associated with any of these options. Subsequent chapters in this report address the specific data base needs with respect to technological evaluations and health effects issues.

3

EVALUATION OF TREATMENT OPTIONS AND RELIABILITY

A key component of any field recycling system is a treatment system that can remove contaminants or classes of contaminants present in the recycle water to levels presumed to present negligible or no risks to human health. A number of treatment process combinations have been evaluated by CERL contractors, in theoretical analyses, bench-scale testing, and pilot or demonstration level projects. In the context of shower or laundry recycle, treatment options tested appear to show promise for achieving the system objectives designated by CERL, namely, ease of operation, ease of transportation and construction, and capability to produce recycled water of acceptable quality.

INTRODUCTION

The success of reusing shower or laundry water in the military context is dictated primarily by the availability of suitable treatment for renovating the shower or laundry wastewater. In order for the treatment to be suitable it must meet critical logistical requirements, and it must be capable of reliably producing an acceptable quality of water at a reasonable cost.

The logistical constraints arise because of the nature of water-use patterns accompanying military field operations. Any treatment system must be suitable for deployment to remote locations where it will be operated on a part-time basis by Army personnel having minimal operations experience. In this context, a number of criteria have been identified by the Army that serve as a point of reference for evaluating appropriate treatment methods. These criteria are as follows:

- The treatment system must be lightweight, compact, durable, and readily transportable.
- The system components and consumable supplies must be readily available in the military supply system.
- The setup, operation, maintenance, and repair requirements must be consistent with the capabilities of a minimally trained operations staff.
- The system performance must be relatively constant, with minimal requirements for performance testing and operational monitoring.
- The system must be operable with minimal power requirements.

Beyond these logistical constraints the treatment must be demonstrated to be capable of reliably achieving a renovated water-quality that conforms to water-quality standards determined to be appropriate for either shower or laundry water use in the military context. These standards must take account of both aesthetic and health-effects considerations. Standards have been developed for shower- and laundry-water recycle that place limitations on acceptable levels of pH, turbidity, soap hardness, and free available chlorine. The levels specified are included later in this report in the chapter dealing with water-quality criteria and standards (see, for example, Table 5.3).

Characteristics of Waste Streams

Shower and laundry wastewaters are suspected of containing a complex mixture of constituents. The theoretical chemical composition of field shower and laundry wastewater has been developed and is shown in Tables 3.1 and 3.2, respectively (Cogley et al., 1979). A detailed list of the theoretical wastewater constituents has been obtained from the above source and is presented in Tables 3.3 and 3.4, for shower and laundry wastewaters, respectively (Cogley et al., 1979). A combined theoretical wastewater composition, based on a mix of 55 percent shower and 45 percent laundry has also been formulated (Table 3.5; Cogley et al., 1979). These data represent the best available information on the probable composition of shower and laundry wastewater and

TABLE 3.1 Theoretical Shower Wastewater Products

Product	Concentration, mg/L
Shower cleaner	100-220
Salt	60-180
Soap, deodorant	50-150
Hair oil	25-150
Soil (kaolinite)	20-50
Talc	20-50
Hair shampoo	10-50
N,N-Diethyl-m-toluamdie (DEET)	1-20
Epithelium	18
Lactic acid	5
Urea	1-3
Toothpaste	2
Hair	2
Potassium	1.5
Shaving preps	1
Disinfectant	1
Lotions	1
Mouthwash	1
Deodorant	1
Suntan preps	1

SOURCE: Cogley et al. (1979).

Table 3.2 Theoretical Laundry Wastewater Products

Product	Concentration, mg/L
Sodium carbonate	499
Detergent Type I	433
Detergent Type II	172
Vegetable oil	166
Kaolinite clay	133
Sour (Downey)	116
Urea	13
DEET	12

SOURCE: Cogley et al. (1979).

TABLE 3.3 Theoretical Shower Wastewater Constituents

Product	Concentration, mg/L
Silica flour	100-210
Sodium chloride	60-180
Castor oil	20-130
Isopropyl alcohol	18-105
Ethanol	15-85
Kaolinite	20-50
Oleic acid	16-50
Talc	41
Tallow	13-38
Stearic acid	11-31
Coconut oil	9-30
Castor oil, sulfonated (75%)	6-30
Ultrawet 60-L	5-25
Ammonium lauryl sulfate	5-25
Sodium lauryl sulfate	5-22
Epithelium cells	18
N,*N*-Diethyl-*m*-toluamide	1-15
Sodium dodecylbenzenesulfonate	3-13
Sodium tripolyphosphate	5-11
Olive oil, sulfonated (75%)	2-10
Tannic acid	1-8
Triethanolamide alkylbenzene sulfonate (60%)	1-7
Potassium oleate (20%)	1-6
Kaloin, colloidal	5
Lactic acid	5
Triethanolamine	1-5
Urea	1-3
Glycerol	1-3
Potassium hydroxide	0.7-3
Zinc stearate	3
Coconut diethanolamine (92%)	0.5-3
Hair	2
Mineral oil	0.5-2
Potassium	1.5
Calcium carbonate	0.9
Aluminum hydroxide	0.9
Sorbitol	0.7
Dicalcium phosphate	0.6
Sodium-*ortho*-phenylphenolate	0.6
Sodium-4-chloro-2-phenylphenolate	0.5
Sodium metaphosphate	0.4
Aluminum formate solution	0.4
Propylene glycol	0.3
Tricalcium phosphate	0.2
Volatile silicone	0.2
Tegacid	0.2
Aluminum chlorhydrate	0.2
Tween 80	0.2

The Following Compounds Are Present at <0.2 mg/L
Alumina
Aluminum chloride
Aluminum sulfate
Ammonium alum
Beeswax
Boric acid
Cetyl alcohol
Corn starch
Bentonite
Hexachlorophene
Isopropyl myristate
Magnesium carbonate
Magnesium oxide
Glycerol monostearate
Methyl paraben
Lanolin
Petrolatum
PABA
Isopropyl palmitate
Polyethylene sorbitan mono-stearate
Saccharin sodium
Sodium-6-chloro-2-phenyl-penolate
Sodium hydroxide
Sorbitol
Spermaceti
Sorbitan monostearate
Stannous fluoride
Veegum
Zinc chloride
Sodium stearate

SOURCE: Cogley et al. (1979).

TABLE 3.4 Theoretical Laundry Wastewater Constituents

Product	Concentration, mg/L
Sodium carbonate	530
Vegetable oil	170
Kaolinite	130
Sodium alkylbenzenesulfonate	120
Sodium sulfate	110
Sodium tripolyphosphate	90
Sodium silicate	80
Sodium fluosilicate	80
Ethoxylated alcohol	60
Urea	13
N,*N*-Diethyl-*m*-toluamide	9
Sodium carboxymethylcellulose	6
Protease	3
Fluorescent whitening agents	3
Ethanol	3

SOURCE: Cogley et al. (1979).

provide a point of departure for evaluating suitable treatment technology for shower and laundry wastewater recycle/reuse.

Tables 3.1 to 3.5 contain theoretical estimates of constituents in wastewaters. Actual data are scarce, but the information provided by Bandy et al. (1986) provides some indication of the water-quality of laundry wastewater. The data, adapted from Bandy et al., are shown in Table 3.6.

Candidate Treatment Systems

Limited data are currently available that characterize the actual constituent mixture in either laundry or shower wastewaters. It can be assumed, however, that a range of inorganic and organic constituents will be present as dissolved material, and the remainder of material can be considered to be colloidal in nature (less than about 0.5 micrometers in size) or suspended solid material (greater than 0.5 micrometers in size).

TABLE 3.5 Theoretical Constituents of Mixed Wastewater (55 Percent Shower Water, 45 Percent Laundry Water)

Product	Concentration, mg/L
Sodium carbonate	240
Silica flour	50-110
Sodium chloride	33-100
Kaolinite	70-90
Vegetable oil	75
Castor oil	12-70
Isopropyl alcohol	10-60
Sodium alkylbenzenesulfonate	55
Sodium sulfate	51
Ethanol	10-50
Sodium tripoly-phosphate	40-45
Sodium silicate	35
Sodium fluosilicate	35
Ethoxylated alcohol	30
Oleic acid	10-30
Talc	20
Tallow	1-21
Stearic acid	6-17
Coconut oil	5-16
Castor oil, sulfonated	3-16
Ultrawet 60L	3-14
Ammonium lauryl sulfate	3-14
N,N-Diethyl-m-toluamide	5-12
Sodium lauryl sulfate	2-12
Epithelium cells	10
Urea	6-8
Sodium dodecyl benzenesulfonate	1-7
Olive oil, sulfonated	1-5
Tannic acid	0.7-5
Triethanolamide alkylbenzenesulfonate	0.7-4
Potassium oleate	0.7-3
Kaolin, colloidal	3
Sodium carboxymethylcellulose	3
Lactic acid	3
Triethanolamine	0.5-2
Glycerol	0.8-2
Potassium hydroxide	0.4-1
Zinc stearate	1
Coconut diethanolamine	0.3-1
Fluorescent whitening agents	1
Hair	1
Mineral oil	0.2-0.9
Potassium	0.8

Product	Concentration, mg/L
Calcium carbonate	0.5
Aluminum hydroxide	0.5
Sorbitol	0.4
Dicalcium phosphate	0.3
Sodium *ortho*-phenyl phenolate	0.3
Sodium 4-chloro-2-phenylphenolate	0.3
Sodium *meta*-phosphate	0.2

Compounds Present at <0.2 mg/L
Alumina
Aluminum chlorhydrate
Aluminum chloride
Aluminum formate
Aluminum sulfate
Ammonium alum
Beeswax
Boric acid
Cetyl alcohol
Corn starch
Bentonite
Hexachlorophene
Isopropyl myristate
Isopropyl palmitate
Magnesium carbonate
Magnesium oxide
Glycerol monostearate
Methyl paraben
Lanolin
Petrolatum
PABA
Propylene glycol
Polyethylene sorbitan monostearate
Saccharin sodium
Sodium-6-chloro-2-phenylphenolate
Sodium hydroxide
Sodium stearate
Spermaceti
Sorbitan monostearate
Stannous fluoride
Tegacid
Tricalcium phosphate
Tween 80
Veegum
Volatile silicone
Zinc chloride

SOURCE: Cogley et al. (1979).

TABLE 3.6 Characteristics of Laundry Wastewater [(Adapted from Characterization Studies of Wastewater Generated from Military Installations, CALSPAN Report No. ND-5296-M-1 (CALSPAN, April 1973)]

Parameter (mg/L Except as Noted)	Military Field Unit Average	Military Field Unit Maximum	Observed range, Commercial Laundry
Turbidity, JTU[a]	1362.7	3800.0	
pH, unit	7.4	7.6	9.0 to 10.3
Total dissolved solids	500.0	800.0	
Suspended solids	-	-	210 to 540
Total solids	-	-	800 to 2100
Volatile solids	-	-	<1500
Detergent	2.8	6.5	
Total phosphate	75.7	128.0	
Orthophosphate	-	122.0	
Polyphosphate	-	6.0	
Sulfate	81.0	175.0	
Silicate	94.0	150.0	
Total hardness ($CaCO_3$)	30.0	34.0	
Calcium hardness ($CaCO_3$)	22.7	32.0	
Magnesium hardness ($CaCO_3$)	7.3	12.0	
Total alkalinity ($CaCO_3$)	227.0	286.0	<511
Chloride	130.0	-	
BOD, 5-day	339.0	-	370 to 635
TOC	100.2	258.0	
Oil and grease	-	-	170 to 550

[a] Jackson Turbidity Unit.

SOURCE: Bandy et al. (1986).

In addition to chemical and physical constituents, microbial constituents would be present, such as bacteria, viruses, and fungi. As a basis for selecting the possible treatment systems, this broad range of constituents can be sorted into several convenient groups, namely, colloidal material, suspended solids, dissolved organics (nonvolatile), dissolved organics (volatile), dissolved inorganics, and microorganisms. Table 3.7 lists those treatment processes capable of "significant" reduction of the designated groups of contaminants. "Significant" in this context is qualitative but indicates those processes whose primary function is removal of the contaminant group. It should be noted that in many instances there will be some reductions in the concentrations of other constituents. As an example, the treatment sequence involving coagulation-flocculation-sedimentation can contribute in varying degrees to the removal of microorganisms and some dissolved inorganic constituents depending on the coagulant chemicals utilized.

Treatment Systems Tested

In assessing laundry and shower recycle, CERL has contracted for the evaluation of numerous treatment systems consisting of one or more of the treatment processes shown in Table 3.7. The major systems studied and considered technically feasible (i.e., producing a product water meeting proposed criteria/standards) are summarized in Table 3.8. Shown are only those treatment systems that have been tested on either bench or pilot/field scales.

Most of the experimental evaluations performed by the military to date have been directed at assessing the treatment effectiveness using the concept of the ERDLator, which has been used successfully for years by the Army in treating water in the field. The components of this system are shown schematically in Figure 3.1. The system provides treatment of either shower or laundry wastewaters with a treatment system consisting initially of batch coagulation, flocculation, and sedimentation, i.e., in the treatment tank. Cationic and anionic polymers are added manually to the wastewater stream as coagulants. These are supplemented by powdered activated carbon for adsorption of dissolved organic constituents and sulfuric acid for pH adjustment. Mixing required for coagulation and flocculation is achieved by recirculation pumping. Settling of the flocculated solids is accomplished in the treatment tank by maintaining

TABLE 3.7 Wastewater Treatment Processes

Treatment Process	Primary Constituent Removals					
	Colloidal Material	Suspended Solids	Dissolved Inorganics	Dissolved Organics: Volatiles	Dissolved Organics: Other	Micro-organisms
Sedimentation[a]	X	X				X
Flotation[a]	X	X				X
Filtration[a] (sand, multimedia)	X	X				X
Filtration, diatomaceous earth		X				X
Carbon adsorption (GAC, PAC)[b]				X	X	
Air stripping						
Chlorination, free						X
Ozonation						X
Ultraviolet						X
Reverse osmosis	X		X		X	X
Ultra-filtration	X	X			X	X
Electrodialysis		X	X			
Ion exchange			X		X	

[a] Requires pretreatment by coagulation and/or flocculation,
[b] GAC, granular activated carbon;
PAC, powdered activated carbon.

TABLE 3.8 Treatment Systems Studied and Considered Technically Feasible for Treating Shower and Laundry Wastewater Recycling

Reference	Wastewater Tested	Treatment System
Adams, 1981	50% laundry	(a) Cartridge filtration/ chlorination
	50% shower	(b) DE Filtration/ GAC/chlorination
VMI, Ciccone, 1985	Shower	PAC/coagulation/ sedimentation/ DE filtration/ chlorination
VMI, Ciccone, 1985	Laundry	PAC/coagulation/ sedimentation/ DE filtration/ chlorination
Lent, 1973	Laundry, kitchen, shower, blend of all three	Modified ERDLator/ PAC/coagulation/ sedimentation/ chlorination/ DE filtration
Bandy et al., 1986	Laundry	PAC/coagulation/ sedimentation/ DE filtration

DE, diatomaceous earth
GAC, granular activated carbon
PAC, powdered activated carbon

quiescent conditions for an appropriate time period. Following completion of the settling step, the supernatant from the treatment tank is subjected to diatomaceous earth filtration for additional suspended solids removal. The filtrate is collected in a treated-water holding tank where calcium hypochlorite is added as a disinfectant.

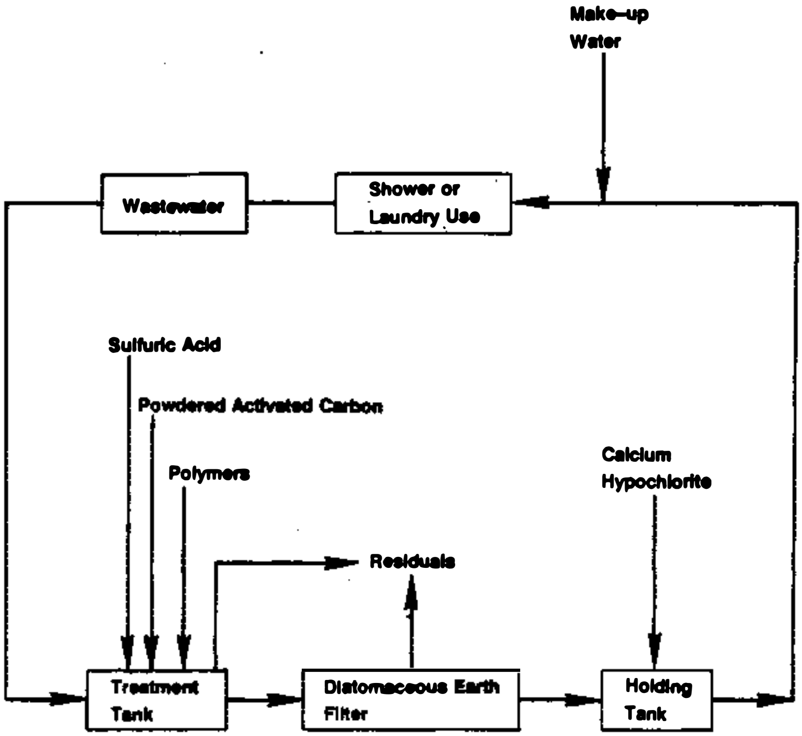


FIGURE 3.1 Schematic of batch wastewater treatment and recycle system for shower and laundry.

The treatment system shown in Figure 3.1 has some obvious advantages in military applications because of the familiarity of its components to military personnel. These components have been demonstrated to be transportable; the operational complexity is consistent with the levels of skilled personnel available for operations; and the batch nature of the treatment has been demonstrated to be appropriate with the level of reliability of the available power sources and consistent with the use patterns.

Evaluations of this treatment system have been performed by the military with the treatment applied in both the shower and laundry recycle modes (see Table 3.8). The shower recycle evaluation has included full-scale testing with human subjects actually using the treated recycle water for bathing. The water-quality impacts of shower use and renovation treatment were monitored through analyses for alkalinity, total dissolved solids (TDS), linear alkyl sulfonate (LAS), total organic carbon (TOC), sulfate, turbidity, pH, total hardness, free residual chlorine, total coliforms, chemical oxygen demand (COD), and some trace organic constituents. These analyses were performed over two different testing phases, the first involving 8 shower recycles and the second involving 11 recycles. A summary of key data abstracted from these analyses is presented in Table 3.9.

A conclusion drawn from this study was that the batch coagulation/filtration process can effectively treat shower wastewater to permit it to be recycled in military bath facilities. The data, however, are not adequate to support such a conclusion.

While results are encouraging for removal of suspended solids, soap and detergents, and bacterial organisms, the data are inadequate to characterize statistically the reliability of the process. In addition, the concentration of some other constituents increased consistently throughout the recycle series because of minimal or incomplete removal by the treatment system. Notable in this category were hardness, TDS, and TOC. The reported hardness and TDS concentrations could be expected to be of some aesthetic concern to bathers, although the study report indicated that lathering was not a problem in this assessment. The observed increase in TOC warrants further investigation, however, to document that the organic constituents that accumulate in the recycle stream do not have adverse health effects.

TABLE 3.9 Summary of Reported Water-Quality Data Shower Water Recycle

		Final Treated Water			
Characteristic[b]	Source Water,	Waste water, 8 cycles	Settled water, 8 cycles	Phase I After 8 Cycles	Phase II After 11 Cycles
Alkalinity	360.5	-	-	65[a]	109[a]
Total hardness	145.5	-	-	430.5[a]	661[a]
Turbidity (NTU)	0.2	252	2.25	0.39	0.16
Residual chlorine	0.26	-	-	0.25	0.40
LAS	0.07	0.88	-	0.05	0.04
TDS	174.88	-	-	1524.33[a]	1682.33[a]
COD	253	625	-		
TOC	6.4	180	-	26.0	31[a]
pH units	8.45	7.0	5.9	6.4[a]	7.5[a]
Total coliforms[c] (MPN)					< 2.2/100 ml

[a] Following filtration, but prior to disinfection.
[b] All units in mg/L, unless otherwise noted.
[c] MPN, most probable number.

SOURCE: VMI (1985a).

An assessment of laundry recycle operations was performed during field exercises in 1985 (VMI, 1985b). The treatment system employed in renovating the laundry wastewater for recycle was also the same as that used in the shower wastewater recycle evaluation. This system of coagulation, flocculation, sedimentation, filtration, and chlorination had apparently shown promise for treating laundry wastewater in previous laboratory testing (VMI, 1985c). Unfortunately, no water-quality data were reported for the field testing operation. In a subsequent report, however, some water-quality evaluations were included from other tests involving the same field laundry wastewater recycling system (Bandy et al., 1986). In these tests, several batches of water were subjected to varying numbers of washing and treatment recycles. The treatment system included the batch coagulation, flocculation, sedimentation, and filtration processes discussed previously. Powdered activated carbon was added prior to the coagulation step. In this case, however, the addition of calcium hypochlorite was not practiced.

Most of the water-quality data were reported for the settled water, with only turbidity reported for the filtered water. There was considerable variability in the reported concentrations for many constituents through the different washing-treatment cycles. Some of this variability was likely attributable to differences in the manner in which batch treatment was performed for different cycles, and some was associated with a buildup of certain constituent concentrations because those constituents were not effectively removed by the treatment sequence. This variability is reflected in the data summary of Table 3.10.

In reviewing the data of Table 3.10, the broad range of concentrations for some constituents raises concerns relative to the reliability of the treatment system in the context of military combat operations. Notable in this category were the turbidity, pH, and TOC. In several different cycles, the treated water pH and turbidity were reported at levels above the established interim standards. The free available chlorine addition apparently was discontinued in the performance of these tests. In spite of these apparent shortcomings, the report concluded that the treatment method was viable for treating laundry water in military recycle applications.

TABLE 3.10 Ranges of Reported Settled Water-Quality Characteristics for Laundry

	Range of Concentrations (mg/L)		
Characteristics	Batch 4 6 cycles	Batch 5 8 cycles	Batch 6 6 cycles
pH	7.0-7.55	7.1-8.0	7.0-7.6
Turbidity	4.15-45.7[a] NTU	0.61-10.9[a] NTU	0.75-27.0[a] NTU
TDS	1376-1478	767-2350	934-2055
Alkalinity	412-509	336-496	275-526
Calcium	73-84	39-80	55-80
Sulfate	64-430	142-883	112-487
Orthophosphate	7.6-15.0	11.5-75.3	17.9-69.3
Total phosphate	47-141	64-421	129-424
LAS	0.11-0.78	0.11-0.30	0.2-0.69
TOC	---	0.1-12.0	0.1-18.8

[a] After settling and filtration.

SOURCE: Bandy et al. (1986).

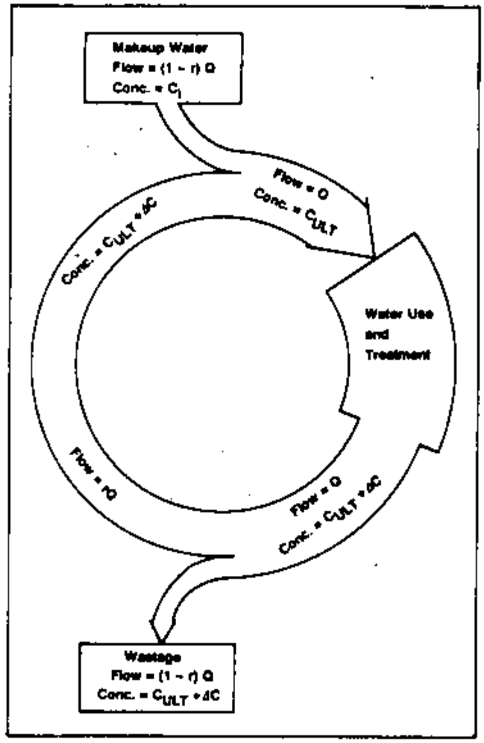
CONCLUSIONS AND RECOMMENDATIONS

The apparent success of the recycle studies performed to date indicates that laundry recycle seems to be aesthetically viable for use in military combat operations. There is a clear need, however, to expand the testing of recycle systems in the area of health effects considerations if shower recycle is pursued. The performance evaluations of the treatment system have not gone far enough in assuring the public health safety of either the shower or laundry recycle practice. Additional pilot and field tests should be performed for evaluating the reliability of the treatment system in providing a safe supply for the two water-use applications. This is especially important for shower recycle applications.

Four specific issues must be addressed in completing this evaluation, as follows:

1. A characterization of the wastewaters with respect to organic, inorganic, and microbial constituents of potential health concern must be completed. To date this task has received inadequate attention.
2. Any proposed treatment system should be evaluated against the established standards to determine the adequacy of the proposed treatment technology.
3. The reliability of the treatment methodology must be assessed in the context of the recycle and treatment operations that are anticipated by the military.
4. Surrogate water-quality characteristics should be defined for operational monitoring of the treatment system during field application of the recycling systems.

A suggested approach for completing the assessment is detailed in Chapter 6 on Research Needs. In making the health effects evaluations, there must also be cognizance of the fact that multiple recycles will result in a buildup of the concentrations of some contaminants in the recycle water with each cycle of use. This buildup will occur because no acceptable treatment system will be completely effective in removing all contaminants. The reality of this fact was demonstrated in the data summary for shower-water recycling presented earlier in this chapter. The nature of the buildup that occurs is shown schematically in Figure 3.2 and described mathematically in the equation that appears in the Figure 3.2 caption (Dick and Snoeyink, 1973). It is the ultimate



$$C_{ULT} = C_I + \Delta C\left(\frac{r}{1-r}\right)$$

Conc = **concentration**

C_{ULT} = **Ultimate concentration of constituent X approached after a number of recycles.**

C_I = **Concentration of constituent X in original and makeup waters.**

ΔC = **Incremental change in concentration of agent X during each use and treatment cycle.**

r = **Fraction of total flow Q, which is recycled.**

FIGURE 3.2 Water recycle schematic.

SOURCE: Dick and Snoeyink (1973).

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concentrations described by this equation that must be addressed in assessing the adequacy of the treatment and the acceptability of the recycle practice. It should also be recognized that the input of makeup water (perhaps in excess of the assumed 10 percent loss through the system) could be used to extend the number of recycles while still meeting recycled water standards.

The recycling of laundry wastewater presents a substantially different exposure of troops than that of recycled wastewater from showers. Specifically, wearing clothing laundered in recycled water can be viewed as an indirect exposure to residuals in such clothing, while exposure to chemicals or microorganisms that could be present in recycled shower water would be direct. Thus, more stringent criteria (and hence testing) will be required to ensure the safety of direct exposure to recycled wastewater. While the committee believes that both recycling options are achievable with existing treatment technology, additional pilot and field tests should be performed for evaluating the success of the treatment system in reliably providing a safe supply for both water uses.

4

EVALUATION OF OPERATIONAL INFORMATION AND HEALTH EFFECTS DATA

EXISTING WATER-QUALITY DATA BASE

Chemical Constituents

Shower and laundry wastewaters represent waters in which the chemical contaminants can be reasonably well identified (relative to domestic wastewaters with widely variable inputs of industrial chemicals). It is possible to anticipate many of the chemicals that may be expected in shower and laundry wastewaters (Cogley et al., 1979). In the case of treated laundry and shower wastewater it is more difficult to anticipate the chemical contaminants because of their influence by the treatment process. The problem of toxic by-product formation, as a result of treatment processes (especially disinfection), has been well documented with domestic water supplies. Both laundry and shower systems have undergone limited field testing and the results have been summarized by Bandy et al. (1986) and VMI and Ciccone, (1985a,b,c).

The report by Bandy et al. (1986) described three experiments in which laundry wastewater was recycled from six to eight times. From the report it appears as though no chlorine was used during these experiments. Inorganic analyses for standard water-quality parameters were performed and summarized in Tables 4.1 to 4.3. LAS and TOC were also determined in these experiments. Results from the most extensive experiment presented show that the TOC and LAS concentration was (after the first recycle) below 1 mg/L. However, the level of organic carbon increased dramatically to 7.30 mg/L just prior to the end of the test. Except for the last high measurement this is very encouraging and does provide positive evidence for good removal of organic material.

TABLE 4.1 Turbidity of Settled and Filtered Waters During Batch Run 6

Cycle	Quantity of Carbon Added (lb)	Turbidity (NTU) Settled Water	Filtered Water
1	6.5	65	10
2	6.5	8	1
3	4.0	6	0.8
4	2.0	9	0.75
5	0	27	7.4
6	0	99	27

NTU - Nephelometric Turbidity Units

SOURCE: Bandy et al. (1986).

TABLE 4.2 Mean Concentration of Selected Inorganics by Reuse Cycle for Settled Water During Batch Run 5

Inorganic Constituent	Concentration (mg/L) Cycle: 1	2	3	4	5	6	7	8
Total dissolved solids	767	1005	1194	1509	1695	1795	2036	2351
Total Phosphate	93	64	144	214	160	250	344	421
Ortho-phosphate	12	16	20	37	54	53	63	75
Sulfate	180	249	403	450	619	142	670	883

SOURCE: Bandy et al. (1986).

TABLE 4.3 Mean Concentration of Selected Inorganics by Reuse Cycle for Settled Water During Batch Run 6

	Concentration (mg/L)					
Cycle:	1	2	3	4	5	6
Inorganic Constituent						
Total dissolved solids	934	1018	1267	1585	1700	2055
Total Phosphate	129	210	229	225	308	424
Orthophosphate	18	21	25	45	56	69
Sulfate	209	318	305	453	487	112

SOURCE: Bandy et al. (1986).

Unfortunately the experiment should have been continued to observe the longer term trends. It is not possible to assess potential health effects from either LAS or TOC data. No specific organics analyses were performed, and because chlorination was not used, the presence of chlorination by-products (as might be determined by TOX and specific halogenated organics determinations) cannot be determined. Although the data are very encouraging, methods for identifying specific compounds should be used to better define the organic constituents.

A similar test series was performed using recycled shower wastewater. A batch treatment process was employed involving two tests. The treatment processes used were coagulation/flocculation and settling, using powdered activated carbon and polyelectrolytes, filtration through a diatomaceous earth filter, and disinfection with calcium hypochlorite. The two tests involved 8 and 11 cycles (designated Batch 1 and Batch 2) respectively. Standard chemical water-quality analyses were performed. The organic carbon characterization included the determination of COD, TOC, and LAS.

Summaries of the two tests are shown in Figures 4.1 to 4.3, for LAS, COD and TOC, respectively. The LAS appears to be reduced consistently to below 0.1 mg/L in both tests following coagulation-flocculation, settling,

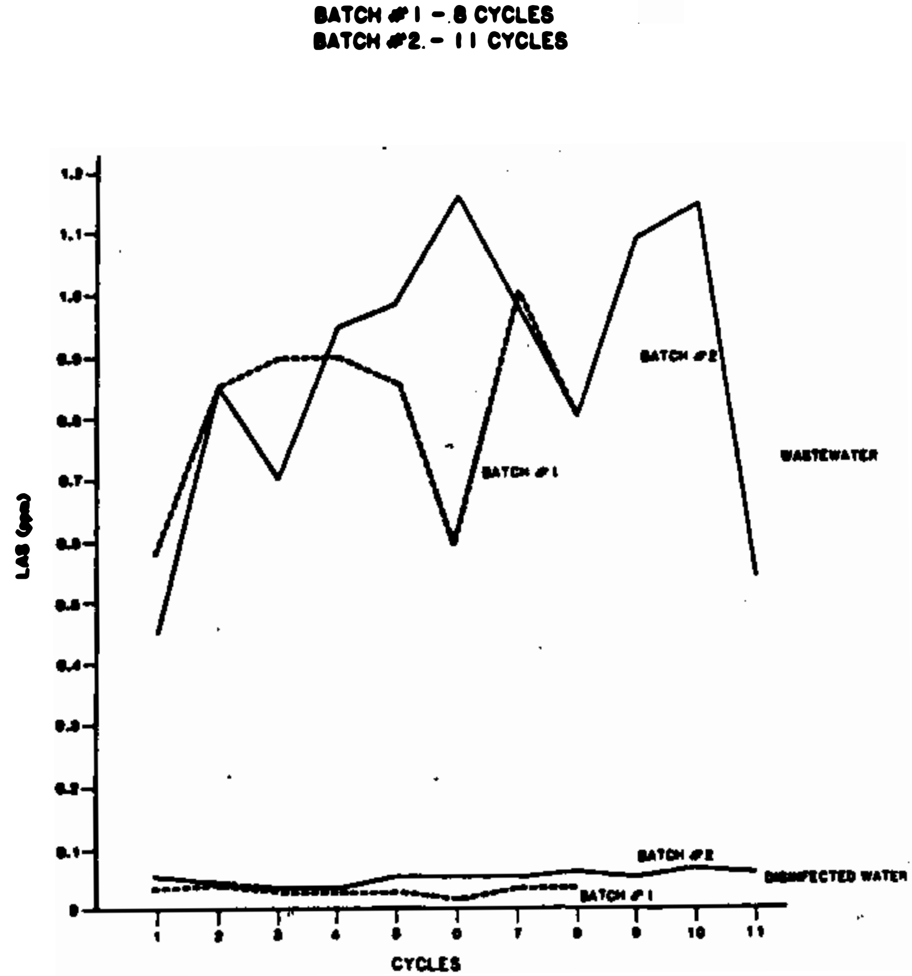


FIGURE 4.1 Linear alkyl sulfonate (mean concentration in milligrams per liter) in shower wastewater and treated effluent.

SOURCE: VMI and Ciccone (1985a).

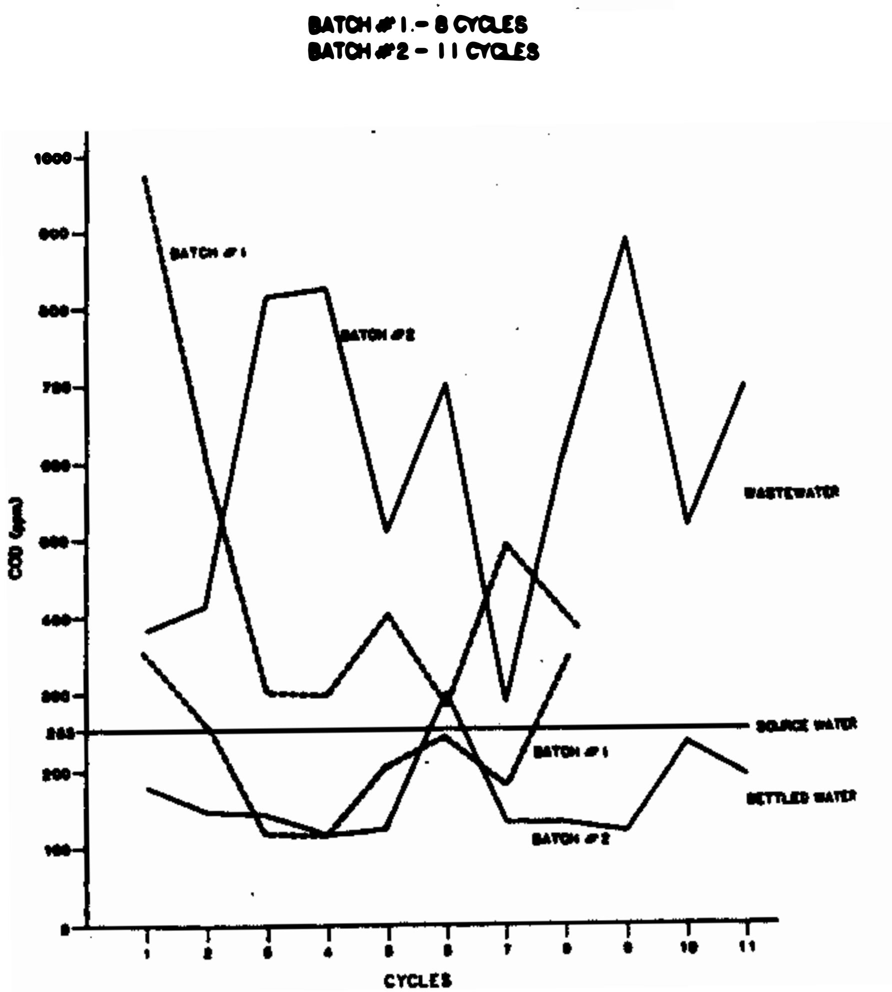


FIGURE 4.2 Chemical oxygen demand (mean concentration in milligrams per liter) in shower wastewater and treated effluent.

SOURCE: VMI and Ciccone (1985a).

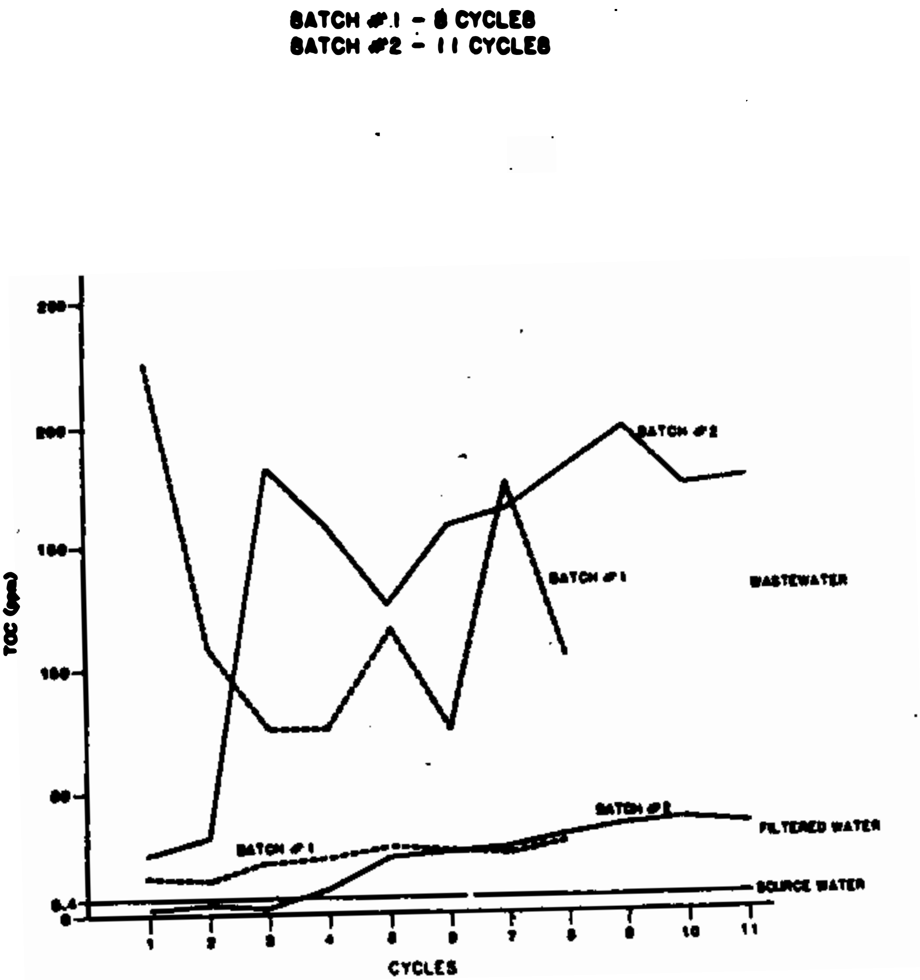


FIGURE 4.3 Total organic carbon (mean concentration in milligrams per liter) in shower wastewater and treated effluent.

SOURCE: VMI and Ciccone (1985a).

filtration and disinfection and does not appear to be a problem or even a potential problem in this treatment scheme. In most cases, the COD was below the source-water mean concentration of 253 mg/L and is removed effectively following coagulation-flocculation and settling. The TOC results (Figure 4.3) in both tests show a gradual increase from below the source water strength to between 26 and 32 mg/L, following coagulation-flocculation and settling.

A limited number of samples were analyzed by liquid-liquid extraction (LLE), using a chloroform extract, followed by gas chromatographic mass spectrometric analysis for each test. The compounds that were identified were phthalates, fatty acids, and hydrocarbons. They occurred in the untreated shower wastewater and were reduced to near source-water concentration after treatment. Concentrations ranged from <0.1 to 10 μg/L and thus do not represent a significant portion of the organic load. No chlorinated compounds were found. No analyses of the organic compounds by headspace or direct aqueous injection, capillary chromatography, and flame ionization or electron capture detection were performed. Consequently, there are inadequate data on chemical constituents in the product water on which to base judgments regarding potential health hazards. Additional research is needed to better characterize the organic chemicals present in the treated/recycled water.

Microbiological Constituents

Within any relatively large group of people, a background of disease and carrier states exists. As a result, both shower and laundry wastewaters can be expected to contain infectious microorganisms, albeit at greatly reduced levels when compared to domestic wastewaters. These microbes could be shed by infected individuals in normal body excretions (i.e., saliva, semen, urine, and feces) or derived from the skin surface. Similarly, clothing contaminated by such routes or soiled with microorganisms from the environment could contribute to the microbial load of these wastewaters. Hence, a wide assortment of bacteria, viruses, fungi, and parasitic ova and cysts could enter shower and laundry wastewaters. A summary of microorganisms identified as being of concern to the military in the use of field water is presented in Table 4.4. Organisms considered important in evaluating the risk of illness resulting from nonconsumptive exposure to water are identified within each group of infectious agents (see footnote to Table 4.4). This listing was initially based on the identification of all water-related diseases documented in available published literature since 1970. Notably, recently recognized pathogens implicated in waterborne disease transmission such as non-A, non-B hepatitis virus(es) and the coccidian protozoan parasite, Cryptosporidium species, are not included. While the behavior of the newest viral agent(s) of hepatitis may be expected to resemble that of other waterborne viruses listed in Table 4.4, the apparent chlorine resistance of Cryptosporidium cysts may be unique. In addition, other microorganisms such as enveloped viruses shed by infected individuals (e.g., herpes virus and cytomegaloviruses) and not previously associated with water-related disease transmission owing to their relative instability outside of a human host, may be a consideration in a closed-loop system having a relatively short recycle time. In addition, it must be recognized that predicting the microbial content of recycled waters in different geographic regions of the world is exceedingly difficult, as the indigenous microflora within native populations (e.g., in Africa) can be dramatically different than that found in the United States.

In the reports provided to this committee for review, only one study has evaluated the occurrence and removal of bacteria in wastewater recycle. Limited bacterial monitoring was done as part of a full-scale test program of shower wastewater recycling (VMI and Ciccone, 1985). A multiple-tube fermentation, most probable number (MPN) procedure was used to enumerate total coliform bacteria in the untreated wastewater, diatomaceous earth (DE) filtered water, and disinfected water to which calcium hypochlorite was reported to have been added to achieve a residual greater than 8 mg/L of free available chlorine (FAC). Notably, a discrepancy exists between this stated level of FAC and the measured chlorine residual in disinfected waters, which never exceeded 0.4 mg/L.

Bacterial analyses were performed during the second recycling test beginning with cycle 6 and continuing through the end of the test with cycle 11 (Table 4.5). As expected, the level of total coliforms in untreated shower wastewater was low, ranging from 2.2 to 16 MPN/100 ml. (Notably, in domestic wastewaters, total coliforms

TABLE 4.4 Infectious Organisms of Military Concern Associated with the Use of Field Water

Infectious Organisms	Description
Bacteria	Bacillary dysentery (*Shigella* spp).
	Cholera (*Vibrio cholerae*)
	Diarrhea (*Campylobacter*)
	Diarrhea (*Escherichia coli*)
	Leptospirosis (*Leptospira* spp.)[a]
	Salmonellosis (*Salmonella* spp.)
	Typhoid fever (*Salmonella typhi*)
	Skin infections (*Pseudomonas* spp., *Staphylococcus* spp., *Aeromonas* spp., and noncholerae *Vibrio* spp.)[a]
	Yersinoisis (*Yersinia* spp.)
Virus	Enteroviruses
	Gastroenteritis, Norwalk agent, and rotavirus
	Hepatitis A (hepatitis virus)
Parasite	Acanthamebiasis (*Acanthamoeba* spp.)[a]
	Amebic dysentery (*Entamoeba histolytica*)
	Ascariasis (*Ascaris lumbricoides*)
	Balantidium dysentery (*Balantidium coli*)[a]
	Dracontiasis (*Dracunculus medinensis*)[a]
	Giardiasis (*Giardia lamblia*)
	Meningoencephalitis (*Naegleria* spp. and *Acanthamoeba* spp.)[a]
	Schistosomiasis (*Schistosoma* spp.)[a]
	Cercarial dermatitis (*Trichobilharzia* spp., *Gigantobilharzia* spp., and *Austrobilharzia* spp.)[a]

[a] Organisms of concern in nonconsumptive water exposure.

SOURCE: Cooper et al. (1986).

TABLE 4.5 Bacteriological Results of Shower Wastewater Recycling

Sample Test	Cycle	Sample[a]	Sample (Positive/ Total)	Total Coliform MPN/100 ml
2	4	D	(0/5)	<2.2
2	6	W	(4/5)	16
		F	(1/5)	2.2
		D	(0/5)	<2.2
2	7	W	(3/5)	9.2
		F	(0/5)	<2.2
		D	(0/5)	<2.2
2	8	W	(2/5)	5.1
		F	(1/5)	2.2
		D	(0/5)	<2.2
2	9	W	(2/5)	5.1
		F	(0/5)	<2.2
		D	(0/5)	<2.2
2	10	W	(1/5)	2.2
		F	(0/5)	<2.2
		D	(0/5)	<2.2
2	11	W	(1/5)	2.2
		F	(0/5)	<2.2
		D	(0/5)	<2.2

[a] W, wastewater;
F, filtered water;
D, disinfected water.

SOURCE: VMI and Ciccone (1985a).

are typically enumerated at levels ranging from 10^6 to 10^9/100 ml.) While DE filtration reduced the bacterial level to less than 2.2/100 ml in most instances (4 of 6 cycles), disinfection was required in the remaining two cycles to reach this level. However, it should be recognized that no significant difference can be attributed to achieving an MPN level of 2.2 coliforms versus <2.2 coliforms since this number reflects the limit of detection sensitivity. While results of this single test series are encouraging, the applicability of the experimental data is limited by both the choice of a single surrogate indicator and the relative insensitivity of the analytical method used for its detection. The use of a membrane filtration technique would have allowed the sampling of larger volumes of water and hence the enumeration of lower levels of total coliforms. In addition, analyses for known human pathogens (e.g., Salmonella enteric viruses) as well as more chlorine-resistant bacterial populations (e.g., heterotrophic plate count or Pseudomonas) should be performed under similar test conditions before any final judgment on the efficacy of recycle treatment and hence health criteria can be made.

EVALUATION OF HEALTH EFFECTS DATA

Health risks associated with the recycling of laundry and shower wastewater encompass two broad areas: microbiological and chemical contaminants. The health risks also involve different levels of potential exposure that can be broadly graded from the wearing of clothes washed in recycled wastewater to the individuals responsible for operating the laundry facility to those using the shower facility and finally to those responsible for managing the treatment system(s). The committee assumes that the operator of the treatment system will be adequately trained with respect to the proper disposal of residual wastestreams. Exposure of those individuals wearing clothes laundered in recycled laundry wastewater essentially revolves around questions of skin sensitization that are best evaluated by direct experimentation in humans. Hazards presented to workers in the laundry facility might extend to questions of inhalation of chemical and microbiological contaminants and may require more careful consideration. Exposures to chemical and microbiological contaminants in the shower, where the inhalation route is heavily involved, presents a case where more careful evaluation of the health hazards must be made. The following sections deal with the adequacy of the health effects information made available to the committee by CERL. The committee also provides general guidance to approaches that might be used to fill in rather large deficiencies that have been identified in the data base.

Toxicological Considerations

A paper study was undertaken to define toxicological effects of chemicals that would occur in shower and laundry wastewaters (Cogley et al., 1979). The basis of toxicological information was not clear in the Cogley report, and conclusions often seemed inconsistent with scientific information cited in the text. When toxicological information did exist for chemicals, the nature of the toxic effect considered critical was often not specified. The only health effects explicitly considered were a lethal dose for 50 percent of the test population (LD_{50}s) and the extent to which chemicals were irritating to the skin, eyes, or lungs. In the executive summary of the report by Cogley et al. (1979) it was concluded that no toxic effects were found that would preclude the recycling of shower and laundry wastewaters. Although a short reference list was provided, there was no clear indication of how this body of literature was arrived at or why it was considered to include all the critical information on the chemicals of concern. The methodology that was used to evaluate the available data was not specified nor was there any indication of how this information was used to determine that these contaminants posed no health hazard. Furthermore, a critical issue is the extent to which the chemicals reviewed in the Cogley et al. paper actually applies to the wastewaters being dealt with by CERL. A later report (Shooter and Anderson, 1980) provided a reasonably standard methodology for evaluating such data and was presented in some detail.

The alternate approach, direct testing of the product water or its concentrate, was taken by Witherup and Emmett (1977). Of the reports provided to the committee by CERL, this appears to be the only experimental work on the toxicological health effects of laundry and shower wastewater. Studies of acute oral toxicity in mice, primary skin and eye irritation in rabbits, and mutagenesis testing in the *Salmonella*/microsome assay (Ames test) were conducted with synthetic laundry wastewaters, synthetic and actual shower wastewaters, ultrafiltrates of these waters, and 10-1,000-fold concentrates of each of the above. In addition, concentrates of laundry and shower wastewaters were tested for irritancy to skin of human volunteers. Lexington, Kentucky, tap water and freeze concentrates thereof (to a maximum of 33X) were used as the control waters.

Unfortunately, there are a number of shortcomings in the Witherup and Emmett (1977) study that preclude the direct application of the results for assessing the safety of shower and laundry wastewater recycling as currently envisioned. These include:

1. The lack of a clearly stated design makes interpretation of the results from this study very difficult. It is virtually impossible to sort through the data to determine whether there is evidence of consistent dose-response information with similar samples. There are no clear rationale for relating the results from one sample to another.
2. The treatment process was applied to synthetic laundry and shower wastewaters prepared at 10X and levels higher than projected in actual wastewaters. These samples were then subjected to freeze concentration. These multiple variables were not systematically controlled for and obscure the relevance of ultrafiltration as a treatment process.
3. Inadequate description of how samples were prepared, particularly synthetic mixtures at above projected concentrations, concentrates prepared from actual wastewaters and ultrafiltrates prepared from these samples. Samples were also made or taken at different times, but the quality control procedures instituted to ensure that consistent samples were prepared over time were not provided. That this might have been a problem can be illustrated by comparing the TOC concentrations of synthetic mixtures prepared at different multiples of the theoretical concentrations. For example, samples S3, S5 and S6 were theoretically 10X and ranged between 210 and 296 mg TOC/L. But sample S18 which was supposed to be a 20X concentrate contained 1030 mg TOC/L and samples S30, S31, S32, and S34 (30X concentrates) contained 1620 mg TOC/L. Such inconsistencies are much too large to be

accounted for by analytical error. These difficulties were further exacerbated by inconsistent descriptions of the samples tested (e.g. samples S6 and S7 in Table 1A, p. 49 versus Table 1, p. 66 of the Witherup and Emmett report).

4. The derivation of LD_{50} values based on TOC content is vague at best. TOC values varied considerably between samples of the same type (Table 2, page 13, and Table 5, page 19, of the Witherup and Emmett report) and failed to consider samples of different derivation. These data should not be taken as indicative of the toxicity of different wastewaters.

5. Results from studies of skin irritation in rabbits indicated that positive results could be obtained at something slightly greater than 1X to over 50X the concentrations of synthetic laundry wastewaters depending on the type of detergent used (Figure 3, page 22 of the Witherup and Emmett report). In practice no control is to be exercised over the detergent used in field recycling operations. Therefore the effectiveness of the treatment system being evaluated by CERL for removal of the offending component must be evaluated.

6. Dose-response information was lacking in human studies of skin irritation and systemic toxicity in animals. Within 17 days a 100X synthetic shower wastewater produced severe skin irritation in >90 percent of those tested. Similar, but more rapidly progressing effects were seen at 50X of synthetic laundry wastewaters. Samples of 250-1000X synthetic laundry and shower wastewaters were administered to rabbits (route unspecified) and produced "severe physiological changes" (p. 134). None of these effects was observed with unconcentrated actual wastewaters, but no intermediate doses were tested. This establishes a safety factor of 1X, clearly inadequate considering the group sizes tested.

7. The mutagenic tests yielded negative results even after chlorination. While mutagenic effects of *Salmonella* have marginal relevance to the overall risk assessment (in the absence of mammalian data), this finding calls into question the methods of sample preparation. The presence of mutagenic activity should have been detectable with concentrated source water alone if these methods were adequate. This has been repeatedly established in the drinking water literature.

8. There was a lack of data relevant to the inhalation route of exposure to constituents of shower wastewater.

Perhaps the most critical problem with the study of Witherup and Emmett (1977) is the failure to recognize that the inhalation route may be the most critical route of exposure for shower water. Mucous membranes lining the respiratory tree are often much more sensitive to irritation than is the skin. Any further studies of the toxicology of recycled water intended for use in showers and concentrates therefore should consider this route of exposure.

The route of exposure is perhaps the most important issue in the recycling of shower and laundry wastewaters. Recycling wastewater for showering will produce exposures to virtually all personnel, whereas recycling of water in the laundry facility will be greater for those individuals working within that facility than the wearer of the clothes. Dermal contact and skin sensitivity are likely to be important considerations with both uses of recycled water. With the use of recycled water for showering, the inhalation route must be considered the primary route for systemic exposure for most chemical constituents. Volatile chemicals in the gaseous phase and chemicals that are present in the aerosolized mist produced in showering are likely to be rapidly and efficiently absorbed. The inhalation route was considered in only a very general way in the report of Shooter and Anderson (1980) and was not considered in the report of Cogley et al. (1979). The exposure to chemicals in the gaseous phase will depend largely on the design of the showering facility, whereas exposure to chemicals present in the mist should be less dependent (but not independent) on the shower design. Because of the importance of this route of exposure, some modeling work (including experimental confirmation) should be considered for any chemical that appears to be present at sufficient concentrations in the recycled wastewater to be a problem.

Testing of the wastewater treatment systems proposed for recycling shower and laundry wastewater has relied heavily on general treatment parameters. While these parameters are of use in judging the general efficiency of the wastewater treatment system, from a toxicological point of view they are virtually useless for determining whether the final water is safe for the proposed use. Consequently, it is not possible to draw clearcut conclusions about any health aspect of water recycling from the data provided to the committee.

In the event that establishing standards based on individual constituents is considered the most cost-effective, the committee recommends that any additional testing of a treatment system(s) focus on the characterization of specific chemicals being introduced into the water by its previous use, as well as documenting their individual occurrence in the wastewater and in the finished, recycled water. The available literature can then be searched for adverse health effects of concern that are associated with those chemicals that remain at appreciable concentrations in the recycled water. Those chemicals for which adequate data do not exist (except those that may be generally regarded as safe, such as normal dietary constituents) should be investigated for those toxic effects that are considered unacceptable under battlefield conditions. These data should be used to develop standards where it seems appropriate.

If the alternative approach of toxicological testing of concentrates of the product waters by appropriate routes in experimental animals is considered most appropriate, it is absolutely necessary to conduct such studies with the CERL's proposed treatment system. Care must be taken to document the performance of any concentration techniques that are used. Inherent in this approach is the possibility of preparing artificial concentrate based on known chemical inputs into the system. If this approach is used, care should be taken to include by-products of treatment processes in the mixture that are qualitatively and quantitatively similar to those produced under field conditions.

Chlorine and Its By-products

An issue that has clearly received too little attention in the recycling of field laundry and shower water is potential problems due to the level of chlorine used. This is especially true with respect to the nature of the by-products that will be produced by disinfection with chlorine and the extent to which some of these by-products might accumulate in the recycled water (probably mostly polar compounds). A free-chlorine residual of 10 mg/L or more could result in significant levels of volatile products in enclosed areas. One potential product is nitrogen trichloride, NCl_3, which is a lachrymator. Monochloramine, formed as a reaction product with ammonia, is a potent lung irritant; however, this could not exist in the presence of free chlorine. Therefore, explicit consideration of the concentrations of such substances in air that are achieved in the laundry or shower room is necessary. These data should be compared with literature-based information on the inhalation toxicology of these compounds to determine whether workers in the laundry or users of the showers are at risk from repeated inhalation of the high concentrations of chlorine or chloramine compounds.

Recently it has become apparent that some chlorination by-products are electrophilic compounds capable of alkylating various macromolecules. Most of these by-products fall into the polar group and have yet to be completely characterized. Proteins altered by these agents may well be antigenic and could produce hypersensitization and/or autoimmune effects in certain individuals. Additionally, chlorine and iodine are known to react directly with proteins, a second means of producing an altered protein that could be antigenic. Such alterations in membrane proteins have been shown to elicit an autoimmune response that appears responsible for the fulminant hepatotoxic effects that are elicited in certain patients exposed repeatedly to halothane anethesia.

High levels of chlorine have been associated with depressed immune function when administered in drinking water. The extent to which this might be produced by other routes of administration, particularly inhalation, is not clear.

Microbiological Considerations

Recycle of water for showering could theoretically provide a direct avenue for microbial infection, predominantly by inhalation of aerosols or nasal deposition of larger droplets, by dermal contact, or by ingestion. The conjunctiva and the alimentary, respiratory, and urogenital tracts offer easier pathways for microbial penetration than in the case of intact outer skin. It is noteworthy that the infectious dose for many viruses associated with respiratory diseases such as rhinovirus, adenovirus, and Coxsackievirus A21 can be very low when administered by nasal drops or aerosols (Ward and Akin, 1984).

The infection of individuals by clothing laundered in recycled water seems highly remote. Selected bacterial pathogens as well as enveloped viruses should be susceptible to the action of detergents. In addition, many microorganisms are relatively susceptible to desiccation and should be inactivated by the process of clothes drying. Thus, multiple barriers of both wastewater treatment and laundry processes should adequately protect individuals from infectious agents transmitted by clothing. Furthermore, the major route of exposure for personnel would be contact of clothing with external skin, a relatively impenetrable barrier in the absence of lesions. However, the exposure of laundry operations personnel could parallel that of shower exposure.

As described in the previous section, the respiratory route of infection due to inhalation has been largely ignored and yet presents a significant avenue of exposure to microorganisms which might be present in recycled shower water. It should be noted that shower design, as it affects aerosolization of water, could help minimize such exposure. However, at the present time, no microbiological data are available to allow an assessment of potential health risks associated with shower wastewater recycle.

Since an infectious epidemic could be devastating in a combat situation, wastewater recycle must be designed to ensure the removal of infectious agents. The most effective means to accomplish this task is adequate and consistent disinfection (i.e., chlorination). Notably, in support of recently promulgated standards for water recycle, the Army has stated that chlorine residuals should be monitored hourly at the shower head to ensure compliance with residual standards (Department of the Army, 1986). If any variation in chlorination practice is made necessary by the generation of unacceptable levels of toxic chemical by-products, the effectiveness and safety of any alternative disinfection processes must be well documented.

Infectious agents, including bacteria, viruses, protozoa and helminths may be found in raw domestic wastewater and although the density may be reduced following the usual degree of treatment, such agents also may be detected in treated effluents. Thus, sewer workers and others associated with the treatment and disposal of domestic wastewaters, as well as those living near such facilities, are likely to have a high incidence of exposure to infectious microbial agents. During the past 10 years, a number of studies have been performed to determine the health risk associated with this exposure (Clark et al., 1976; Johnson, et al., 1978; Carnow, et al., 1979; Johnson et al., 1980; Pahren and Jakubowski, 1980; Clark et al., 1981; Pahren and Jakubowski, 1981; Clark et al., 1984; Linneman et al., 1984). Although these reports and others on the subject indicate that the outdoor exposure of persons to domestic wastewaters generally has no adverse health effects due to microbial infections, it is suggested that a more in-depth review of this body of literature be undertaken with respect to its significance in evaluating the health risk associated with recycling laundry and shower wastewaters.

CONCLUSIONS AND RECOMMENDATIONS

The data developed on other projects by the Army on a compound by compound basis (Cogley et al., 1979) or by studies of the toxicology of whole wastewaters or synthetic wastewaters at actual or greater than actual concentrations are of limited usefulness concerning shower and laundry wastewater recycling. This is partially attributable to the inadequacies of these studies but also reflects the different scenarios toward which these studies were directed. Considerable complexity is introduced by the unwillingness to restrict chemical inputs (i.e., types of products that will be used in these facilities) and the failure to consider the influence of treatment processes (particularly disinfection) on the nature of chemical exposures that result.

Given the inability to specify the inputs to the wastewaters, evaluations of the hazards posed by recycling shower and laundry wastewaters must depend on one of two approaches: (1) a relatively complete characterization of the chemicals that penetrate the treatment process employed in terms of concentrations attained and their toxicological effects or (2) the testing of product waters for the health effects considered important under battlefield conditions at concentrations sufficiently above those actually encountered to provide a definable margin of safety. A third approach, which is a hybrid of these two approaches, is also worthy of consideration. The hybrid approach would use an individual compound approach (i.e., number 1) to address those chemicals that are easily measured (e.g., volatile organics) and concentrate studies (i.e., number 2) for those which are difficult analytically (e.g., nonvolatile organics).

With respect to microbiological considerations, the committee recommends that further studies, specifically with regard to shower wastewater recycle, begin by characterizing the microbial content of untreated wastewater. Subsequently, organisms detected in such wastewaters can be enumerated in recycled waters to assess the efficacy of the treatment train and the potential health effects of this water. Additionally, the establishment of such a data base would provide a better framework from which to address the applicability of water-quality criteria and standards to microbial health effects associated with shower and laundry wastewater recycle.

5

WATER-QUALITY CRITERIA AND STANDARDS

Ultimately, the adequacy of the proposed treatment technology must be evaluated against established water-quality standards. It is therefore essential to the institution of water recycle and reuse that water-quality criteria be established and that subsequent standards be determined for nonpotable (nonconsumptive) water use. Water-quality criteria are developed from the health effects data base and the methodology used to convert this information into levels of risk associated with various levels of a contaminant in water. Stated another way, criteria express the damage to health that can be expected from exposure to a contaminant in water at a specific concentration and for a specific time. Standards for particular water uses may subsequently be developed from criteria that take into account special conditions or requirements such as degree of personnel exposure, acceptable health risks under a given set of circumstances, availability of water-treatment technology, and costs of various treatment options.

The development of water-quality standards continues to be impeded by the lack of unified scientific information defining directly the dose-response of chemicals and microorganisms in humans. Furthermore, the occurrence of specific pathogens or toxic chemicals in a given water is more often a matter of conjecture rather than the result of direct measurement. In practice, surrogate measurements such as indicator bacteria (e.g., total coliforms) or total organic carbon (TOC) are used to characterize water-quality. In some cases, selected parameters are interpreted to reflect the general behavior of other water constituents. For example, while indicator bacteria may not cause disease, their presence is a warning that pathogenic microorganisms could be present. Thus some surrogate measurements (e.g., turbidity and total coliforms) are taken to reflect the relative safety of water for specified uses. However, measurements such as TOC, total organic halogens (TOX), or dissolved solids do not allow one to make judgments concerning the actual health risks that might be associated with a particular use of a water. Such an assessment must be based on a determination of whether a pathogenic organism or toxic chemical is present, its concentration, and the dose-effect relationship involved in the health effects that they produce.

Appropriate epidemiological or toxicological study of humans or experimental animals exposed to water from a particular source, treated in a specific manner, and distributed with regard for protection of the water-quality can establish whether a water can be produced for human use without undesirable effects. To the extent that operational or surrogate measurements confirm that the source has remained unchanged, the treatment process has been operating effectively, and the water has not been contaminated in distribution, it can be concluded that the health risks associated with use of that water are similar to that observed in the original experiments. Thus, with this approach it is not necessary to develop criteria for specific microbial agents or chemicals. However, that does not allow these operational or surrogate parameters to be applied to another source water or treatment process. Therefore, they have no intrinsic relationship to adverse health effects.

DEVELOPMENT OF WATER-QUALITY CRITERIA AND STANDARDS BY THE U.S. ARMY

Several groups within the U.S. Army share responsibility for the quality of treated water used by military personnel. The Corps of Engineers is responsible for reconnaissance, identification, and compilation of data pertaining to water sources. The Preventive Medicine Branch of The Army Surgeon General's Office approves water sources and provides routine surveillance to ensure that water-quality meets appropriate standards. Water-purification equipment operators ensure that the purification equipment is functioning properly and that water is being adequately treated by analyzing both untreated and treated water

(Department of the Army, 1983). It should be recognized that the bases for criteria and/or standards applied to these two activities are quite different. Standards based on scientifically established health-effects criteria govern the acceptability of water for a specified use, wheareas operational criteria will be applied to the routine evaluation of treatment processes.

The suitability of water for bathing was initially addressed in the report on Sanitary Control and Surveillance of Water Supplies at Fixed and Field Installations (Department of the Army, 1975). At that time, either potable or nonpotable water was accepted for showering, as long as the latter was clean, free of pathogenic organisms, and approved for use by the responsible medical authority. Potable-water standards for selected chemical and physical constituents based on a daily water consumption of 7 L/day also were set forth as outlined in Table 5.1. At exposure times of one week or less, only standards for arsenic, cyanide, and turbidity were applicable. Additional standards including those shown for radionuclides were included for water use lasting longer than one week.

The advent of water reuse possibilities in arid regions resulted in the issuance by the Army of interim water-quality criteria. These criteria for recycled water used in shower and laundry operations reflect operational (i.e., treatment) characteristics and were based on a series of explicit assumptions (Department of the Army, 1980) including that:

- The initial source water and makeup water is potable (reverse osmosis water purification unit treated or equivalent processes with well sources);
- A treatment train for recycled water includes adsorption by powdered charcoal, flocculation with polyelectrolyte, filtration through diatomaceous earth, and disinfection with chlorine (with demonstrated treatment effectiveness);
- 10 to 20 percent makeup water is added in each treatment recycle; and
- Recycle is not to be used in an integrated battlefield when nuclear, biological, or chemical contamination is threatened.

Based on these provisions, the Army's Medical Bioengineering Research and Development Laboratory recommended the interim water-quality criteria

TABLE 5.1 Potable Water Standards, 1975

Field-Water Contaminant	<7 Days	>7 Days
Arsenic	2 mg/L	0.2 mg/L
Magnesium	--	150 mg/L
Sulfate	--	400 mg/L
Total dissolved solids	--	1500 mg/L
Chloride	--	600 mg/L
Turbidity	Reasonably clear	5 units
Color	--	50 units
Cyanide	20 mg/L	2 mg/L
Radionuclides		
Gross beta	[a]	1000 pCi/L
Strontium-90	[a]	10 pCi/L
Radium-226	[a]	3 pCi/L

[a] If occupancy of water point is permitted, the water is suitable for consumption for a period not to exceed one week.

SOURCE: Department of the Army (1975).

(Department of the Army, 1980) for shower and laundry recycle shown in Table 5.2. Revisions to these initial interim criteria were subsequently recommended in 1984 and also appear in Table 5.2.

Recently, the Department of the Army promulgated standards for recycled water for other than potable uses, setting maximum limits as shown in Table 5.3 (Department of the Army, 1986). Water recycled for uses involving human contact is to be tested hourly for chlorine residual with samples for all analyses being collected directly from shower heads. It should be recognized that these values, reflecting operational measurements, have not evolved through the process of establishing water-quality criteria and subsequently applying judgments to reach standards. Rather, these standards presumably reflect positive, historical experiences in the use of water meeting these constituent levels.

To date, no water-quality criteria based on the consideration of health effects have been identified for nonconsumptive human exposure to water (i.e., shower and

TABLE 5.2 Interim Water-Quality Criteria for Recycle of Shower and Laundry Wastewater

Constituent	1980	1984
pH	6.5-7.5	4.5-9.5[a]
Turbidity	<1 turbidity unit, desirable <5 turbidity unit, permissible	<1 NTU[b]
Free available chlorine[c]	5 mg/L, >20°C 10 mg/L, <20°C	5 mg/L, >20°C 10 mg/L, <20°C
Soap hardness	Adequate lathering/ detergency	Adequate lathering/ detergency
Total dissolved solids	--	5000 mg/L

[a]pH <8.0 may be required for disinfection.
[b]Removal of protozoan cysts, parasitic eggs, and cercaria (or other infectious life stages) possibly resistant to disinfection.
[c]Assuming a minimum contact time of 30 min.

SOURCE: Department of the Army (1980) and S. Schaub, U.S. Army Medical Bioengineering Research Laboratory (1986) personal communication.

laundry water reuse or recycle). Therefore, the ongoing development of potable water-quality criteria and standards by the U.S. Army will be briefly reviewed, as the decision-making process for shower and laundry water would most likely be identical in these cases, even though the resulting water-quality standards may be different. As a first step in establishing physical-chemical requirements for military field-water quality, a study performed by the Lawrence Livermore Laboratory identified those contaminants that could have an adverse impact on the use of water by humans (Anspaugh

TABLE 5.3 Recycled Water Standards

Constituent	Maximum Acceptable Limit
pH	6.5-7.5
Turbidity	5 NTU
Hardness	500 mg/L
Free available chlorine[a]	5 mg/L, >20°C
	10 mg/L, <20°C

[a] Target residuals with a minimum contact time of 30 min.

SOURCE: Department of the Army (1986).

et al., 1986). Not only health concerns but also aesthetic constraints that could lead to lowered water intake by military personnel were considered. Subsequently, a broad-based, scientific literature review was completed to define, where available, the occurrence, sources, existing standards, analytical techniques, and documented health effects of each constituent. Based on this information, proposed standards were developed (Anspaugh et al., 1986). These proposed standards are intended to prevent performance degradation or irreversible health effects in troops.

Major uncertainties were noted in the establishment of these recommended standards owing to deficiencies in available data as they affect humans. Therefore, assumptions were made to fill these gaps in current knowledge. Recommendations from this study are shown in Table 5.4 and consider a broader range of personnel exposure conditions ranging from 1 week to 1 year with water consumption at levels of either 5 or 15 L per capita per day. Standards recommended for turbidity, color, TDS, and chloride are based solely on maximizing the palatability of water, as no evidence of a direct relationship to human health effects could be documented. Thus, the major health consideration was adequate water consumption to avoid dehydration. Standards proposed for magnesium, sulfate, and arsenic are based on a straightforward calculation of an assumed maximum tolerable concentration of either 5 or 15 L of

TABLE 5.4 Recommendations for Potable Water Standards, 1986

	Recommendations for Standards (mg/L)			
	7-Day Exposure Period		1-Year Exposure Period	
Field water contaminant	5 L/Day[a]	15 L/Day[a]	5 L/Day[a]	15 L/Day[a]
Arsenic	0.3	0.1	0.06	0.02
Magnesium	100	30	100	30
Sulfate	300	100	300	100
Cyanide	9	2	9	2
Total dissolved solids	1000		1000	
Chloride	600		600	
Turbidity	5NTU		5NTU	
Color	50CU		15CU	
Radionuclides (Ci/ml)				
Alpha, unspecified	4×10^{-6}	1×10^{-6}	1×10^{-7}	4×10^{-8}
Beta, unspecified	8×10^{-4}	3×10^{-4}	3×10^{-5}	9×10^{-6}
Specified	9 x CRW[b]	3 x CRW[a]	0.3 x CRW[b]	0.1 x CRW[b]

[a] Per capita consumption.

[b] Limiting concentrations of radionuclides in water (CRW) as specified in the Code of Federal Regulations (CFR), 10 CFR 20, U.S. Government Printing Office, Washington, D.C. (1983) for 259 radionuclides.

SOURCE: Anspaugh et al. (1986).

water consumed per day based on available scientific literature. Proposed recommendations for cyanide are based on the highest blood concentration that presumably does not produce performance degradation. The theoretical concentration of cyanide in blood after consumption of contaminated water was estimated using a one-compartment pharmacokinetic model assuming first-order absorption and elimination. Proposed standards for radioactivity in water are calculated from current standards for workers in the nuclear industry.

At this time, standards for the microbial quality of potable water and nonconsumptive water use are undergoing a similar review and recommendation process. To this end, Cooper et al. (1986) have completed a study assessing the risk of illness due to exposure to water-related infectious organisms. Scientific literature, primarily published since 1970, was reviewed to characterize organisms identified with waterborne, water-washed, or water-based disease transmission. Information sought as part of this study included organism occurrence, latency, persistence, infective dose, prevalence (infection rate), attack rate (new cases), multiplication, environmental and disinfection resistance, and relationship to indicator organisms. This comprehensive data base will now be used by the Army in the subsequent development of water-quality standards for potable and nonconsumptive uses.

Additional Considerations for Development of Criteria and Standards

Further development of health criteria for shower and laundry wastewater recycling must first resolve the following:

- Identification of acceptable and unacceptable health effects.
- Definition of a probability within stated degrees of confidence that an adverse health effect may occur.

The initial decisions that must be made in establishing health criteria require clear policy statements. First, an explicit definition of what health effects are unacceptable in a given situation must be established clearly. Subjective statements have been made by the Army in this regard for both potable and recycled waters. Standards for chemical constituents in potable water are calculated theoretically to prevent performance degradation or irreversible health effects in troops (Anspaugh et al., 1986). A major consideration in the development of interim criteria for field-water recycle was that military personnel should not experience any health effects over a 1-year period owing to exposure to substances in such water. However, chronic and irreversible health effects such as carcinogenicity, mutagenicity, or teratogenicity are excluded from consideration in this case (S. Schaub, U.S. Army Construction Engineering Research Laboratory, 1986, personal communication). Such general, qualitative statements ignore the realities of water use and reuse. Although absolute safety may be a goal, even conventional treatment of water is not uniformly effective for the removal of all chemicals and microorganisms.

To further refine acceptable and unacceptable health effects, a variety of social and aesthetic considerations beyond simple questions of the seriousness of the health effects must also be factored into such decisions. For example, mild cases of skin irritation might be acceptable in soldiers under battlefield conditions. As the irritation progresses to moderate or severe forms, it is likely to interfere with their combat effectiveness. As a result, skin irritation might be considered a more serious health effect in a combat zone than it would be in civilian life. Conversely, a minor increase in lifetime risk for cancer will be less important, while in the civilian sector such exposures are taken very seriously. Substantially different considerations govern the acceptability of exposure to microorganisms. While health effects due to chemical exposure may be viewed as self-limited (i.e., each individual must encounter the primary exposure), microbial infection of very few individuals can be rapidly amplified by secondary spread throughout a military unit. Discussion of this type of question is beyond the scope of this document. However, it is important to recognize that these factors need to be clearly defined by the Army before health-effects criteria can be developed.

Establishing a probability at which an unacceptable effect can be allowed to occur is the second step that must be taken. Sensitivity to both chemicals and infectious organisms varies considerably among individuals. The dose-response curves normally used in toxicology essentially describe a distribution of sensitivities to a chemical. The transmission of an infectious organism to produce actual disease follows analogous rules, with host age and immune status being primary considerations. However, since military personnel engaged in battlefield and support operations are likely to be in good overall health and within a defined age bracket, the establishment of such probabilities could be approached realistically.

If there is a probability at which an unacceptable effect can be allowed to occur, the accuracy required of the estimate of that probability must be considered. All toxicological and microbiological testing data are inherently variable. There is also variability associated with interspecies extrapolation.

The issues discussed above are essentially policy decisions. Once they are clearly made, the job of developing health criteria becomes straightforward if suitable data are available. To this end, chemical and microbiological constituents introduced into shower and laundry wastewaters must be identified. Subsequently, the health impact (toxic effects or infectious disease) produced by these chemicals or microorganisms in the exposed population must be described. Finally, the removal of these constituents along with that of selected surrogate constituents by various treatment options can be characterized.

Once an unacceptable adverse health effect is associated with a chemical or biological constituent, estimating the likelihood that it will produce that effect in a given situation must be based on adequate dose-response information, the estimated degree of exposure, and the most probable route of exposure. If such information is not available, it cannot be stated that the wastewater can be treated to the point that it produces no unacceptable health risks. The degree of exposure is a function of the concentrations of the agent in the wastewater, the influence of the treatment process on that concentration, and the duration (or volume) of that exposure.

Three routes of exposure need to be considered when using recycled wastewater for shower and laundry: inhalation, ingestion, and topical contact. Of these, inhalation and topical contact represent the most likely avenues impacting an individual's health, assuming that ingestion of recycled water is discouraged by education of exposed personnel. In addition, two types of exposure should be recognized:

exposure of those individuals who work in the facility and of those who use the facility or its product (e.g., clean clothes). The evaluation of health effects from each type of product water will have to consider

- Volume of water ingested;
- Volume of water inhaled;
- Estimation of the dose of volatilized and aerosolized constituents inhaled;
- Effective dose to the skin;
- The combined systemic dose derived from each of these routes;
- Local (i.e., skin, eyes, and mucous membranes) and systemic toxic effects of chemical constituents.

Given this systematically developed information, criteria can be established for each constituent that is of concern and likely to penetrate the treatment train. This type of determination then allows consideration of which alternative recycle options described previously are safe. Without such a formal treatment of the available information or actual experimental verification of the absence of unacceptable health effects there is no *a priori* reason to conclude that one source/recycle option is better or worse than any other.

CONCLUSION AND RECOMMENDATION

Implementation of laundry or shower wastewater recycle requires the establishment of water-quality criteria and standards. Therefore, the committee recommends that the process of criteria review and standards development ongoing for potable water be extended to nonconsumptive water use as soon as possible. Judicious consideration should be given to the various routes of exposure described above for both troops and operations personnel.

6

RESEARCH NEEDS

It is the opinion of the committee that the available data are very encouraging for field Army laundry wastewater recycle. However, the committee believes that additional data are needed to ensure the safe recycle of these waters. The data that are required to ensure the safety of field laundry wastewater recycle are achievable with minimal additional studies. However, because of the direct human exposure to the recycled shower wastewater the committee recommends more intensive and coordinated studies in this area.

Recycling of laundry or shower wastewaters in a combat zone could lead to significant water savings and thereby reduce the logistical requirements for water. The implementation of this concept places unusual demands on the research program required to establish the health effects safety of this practice. It is unlikely that in a combat zone monitoring programs will be used for chemical and microbiological contaminants that are of health concern. Consequently, the problem becomes one of proving that the treatment process developed can dependably produce a water that meets the proposed standards. The committee believes that the proof of the treatment process can be accomplished by additional pilot-plant studies.

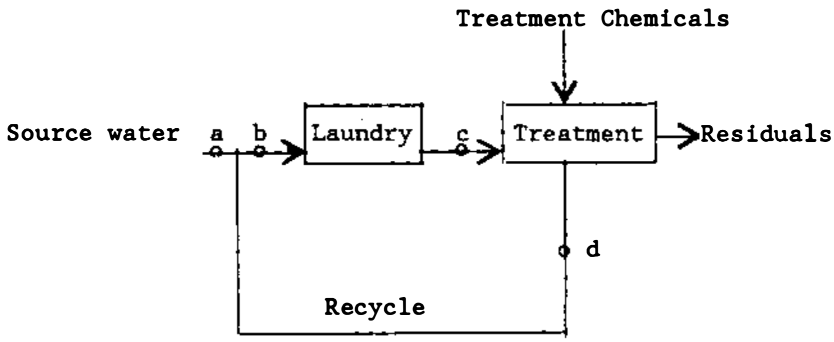
Such a project requires broad-based cooperation that goes beyond that which is normally expected even in recognized interdisciplinary programs. Engineers, chemists, and microbiologists must identify the contaminants expected to be added to the water by its prior use <u>and</u> determine (experimentally, if the data have not been previously developed) the extent to which the treatment processes alter the composition of the wastewater. This type of information is needed before health criteria appropriate to the specific use can be developed.

The following is a more detailed discussion of the research required before laundry or shower wastewater recycle should be implemented in the field. For each of the recycle options an overall flow diagram is provided. The committee does not feel the need to give a detailed research plan for the entire research program. However, some detail is provided for operational consideration of pilot-plant testing and analytical characterization of microbial and chemical contaminants.

LAUNDRY WASTEWATER RECYCLE

It is the committees opinion that there are some data voids in the area of field-laundry wastewater recycle. However, it is possible that minimal additional work is necessary to ensure safe practice in field Army laundry recycle operations. A generalized recycle scheme for testing laundry wastewater for recycle is given in Figure 6.1.

Figure 6.2 is a research approach flow chart of the steps necessary to perform a comprehensive study to determine the feasibility of recycling laundry wastewater.



(a, b, c, d are sampling points for analytical characterization)

FIGURE 6.1 Schematic system for recycling laundry wastewater.

Pilot Studies Phase I

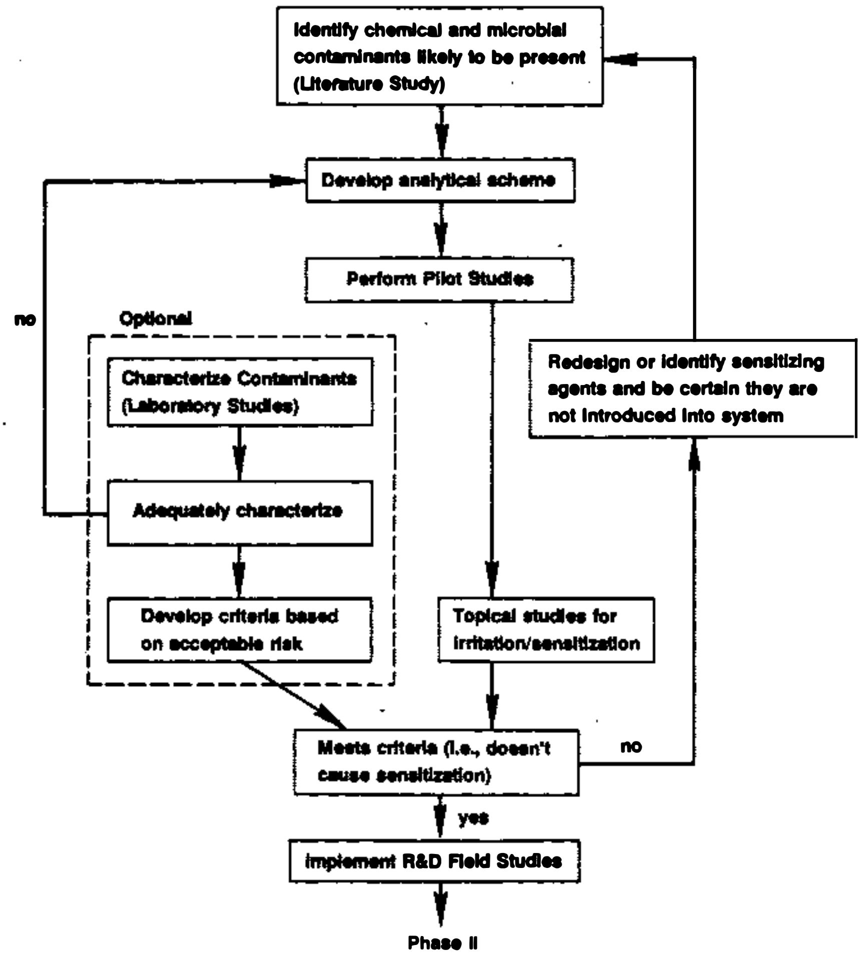


FIGURE 6.2 A research approach flow chart for studying field Army laundry recycle.

Field Studies Phase II

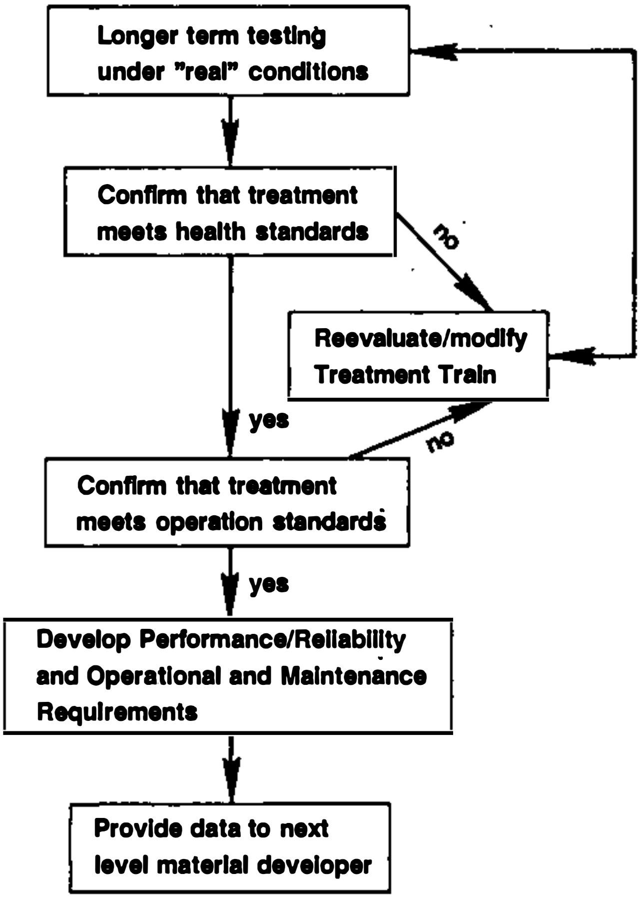


FIGURE 6.2 A research approach flow chart for studying field Army laundry recycle (continued).

A pilot-scale study (Phase 1, Figure 6.2) should be performed with the laundry treatment system proposed for field use. A representative source water should be used and the laundry operated through a number of recycles. If the makeup requirements average 10 percent, then a minimum of 15 recycles (steady state) should be a goal of the study, with sampling at points a, b, c, and d, a minimum of 7 times evenly spaced throughout the duration of the testing. If the makeup requirements average 20 percent, then a minimum of 8 recycles (steady state) should be the goal of the study, with sampling at points a, b, c, and d a minimum of 5 times.

It is possible that characterization of laundry wastes is not necessary, provided that topical and toxicological studies are conducted and no sensitization is observed in human volunteers. If characterization is necessary, the analytical scheme presented in Appendix A, although somewhat general, has been developed specifically to evaluate the recycle of wastewater generated from either laundry or shower operations in the field. The water-quality characterization necessary for laundry recycle is Level 1 as shown in Appendix A (this is the least complex of the analytical schemes). The characterization should be performed as outlined previously, the frequency and absolute number of samples dependent on operational considerations, i.e., number of recycles needed to complete the test.

Microbiological analyses of untreated and treated laundry wastewater can be focused initially on a rather limited number of bacterial groups. Based on the assumption that the microbial density of a laundry wastewater will be low, an enumeration of its general bacterial content as represented by a heterotrophic plate count should be done. In addition, an analysis of large sample volumes for total coliforms using a membrane filtration technique should be undertaken to define the occurrence of this group of indicator organisms. Finally, as a challenge to the wastewater treatment system (specifically, chlorination), an organism with acknowledged resistance to both environmental stress and disinfection should be monitored. Since mycobacteria species are common soil inhabitants, members of this bacterial group may be present in laundry wastewater at sufficient levels to allow their use as such resistant, surrogate organisms.

In the event that either total plate count or coliform bacteria are recovered from disinfected laundry effluent, attempts should be made to identify the organisms surviving the treatment process. A decision could then be made as to the likely health problems posed by these bacteria.

It should be noted that a minor modification of sampling points to include both prechlorination and postchlorination would allow an evaluation of bacterial removal/inactivation by coagulation-flocculation, and settling DE filtration as opposed to chlorination. Such data would allow an improved assessment of the reliance that can be placed on the treatment processes prior to disinfection.

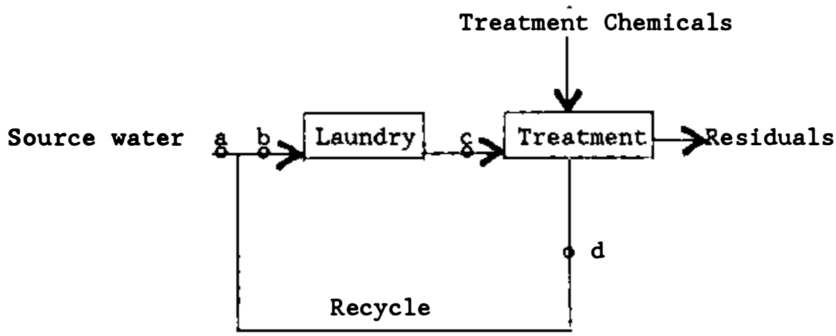
Phase II (Figure 6.2) field studies should then be conducted. These field studies are an integral part of the Research and Development (R & D) effort and should be conducted under conditions as close to "real field Army" as possible. This would ultimately provide the data necessary for the material developer.

SHOWER WASTEWATER RECYCLE

Because of the direct human inhalation and topical exposure, the committee recommends more intensive studies to provide the data necessary to ensure safe field Army shower wastewater recycle. A recycle scheme for testing shower wastewater recycle is shown in Figure 6.3. Figure 6.4 is a research approach flow chart of the steps necessary to evaluate the feasibility of shower wastewater recycle.

The committee recommends that additional pilot studies (Phase I, Figure 6.4) be performed to better characterize the quality of water associated with the shower recycle system. Shower recycle will involve direct human exposure to recycled water, and it is felt that additional data are required. Another purpose of this detailed pilot study is to determine any additional research requirements necessary to implement field shower reuse.

The tests to be performed should be designed to ensure that an adequate number of recycles are included to achieve operational steady state. The guidelines for the laundry recycle are adequate, provided analytical results indicate that the water-quality (chemical and microbiological) constituents have reached steady state. (The data available to date indicate that steady state was either not accomplished or just minimally reached in previous testing.)



(a, b, c, d are sample points for analytical characterization)

FIGURE 6.3 Generalized system for testing shower wastewater recycle.

The committee believes that the emphasis of this program should initially be to better characterize the wastewater, with respect to chemical and microbiological quality. This is necessary prior to the health assessment and criteria development. The analytical characterization required for this study is either Level 2 or Level 3 as shown in Appendix A. The need for Level 3 chemical characterization will depend primarily on the ability to characterize the organic constituents in Level 2. It should be noted that the use of gas chromatography mass spectrometry (GCMS) is not necessarily recommended. It should only be used if structural confirmation is required. Unless absolutely necessary, the use of GCMS can be a waste of resources, when the use of capillary gas chromatography may provide adequate information at a much reduced cost.

In addition to the microbiological monitoring described for laundry recycle testing, untreated shower wastewater should be analyzed for specific indicators of human fecal pollution (i.e., fecal coliforms) and pathogens of documented concern to U.S. Army preventive medicine personnel. Specific pathogens for which analytical techniques are readily available include bacteria as represented by *Salmonella*, *Shigella*, and *Legionella*; human enteric viruses as represented by polioviruses, Coxsackieviruses, and echoviruses; and parasitic cysts such as those of *Giardia lamblia*. In addition, opportunistic bacterial pathogens of waterborne concern

Pilot Studies, Phase I

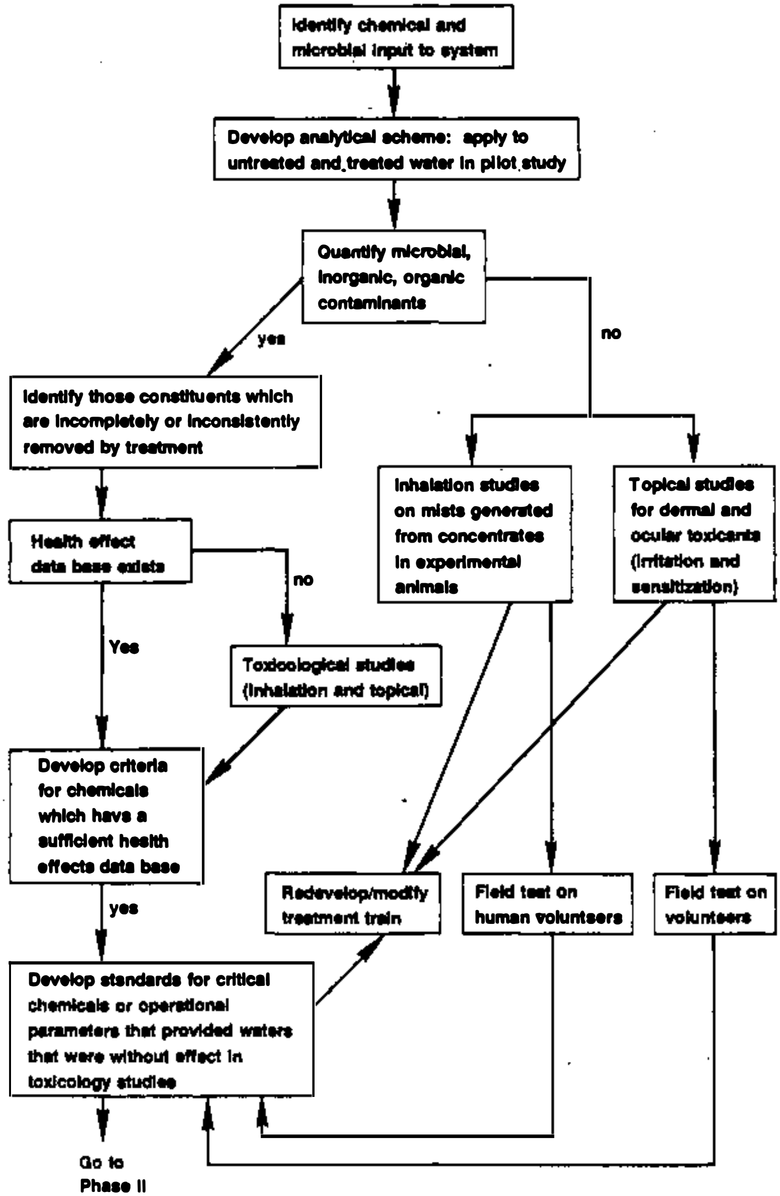


FIGURE 6.4 A research approach flow chart for studying field Army shower wastewater recycle.

Field Studies, Phase II

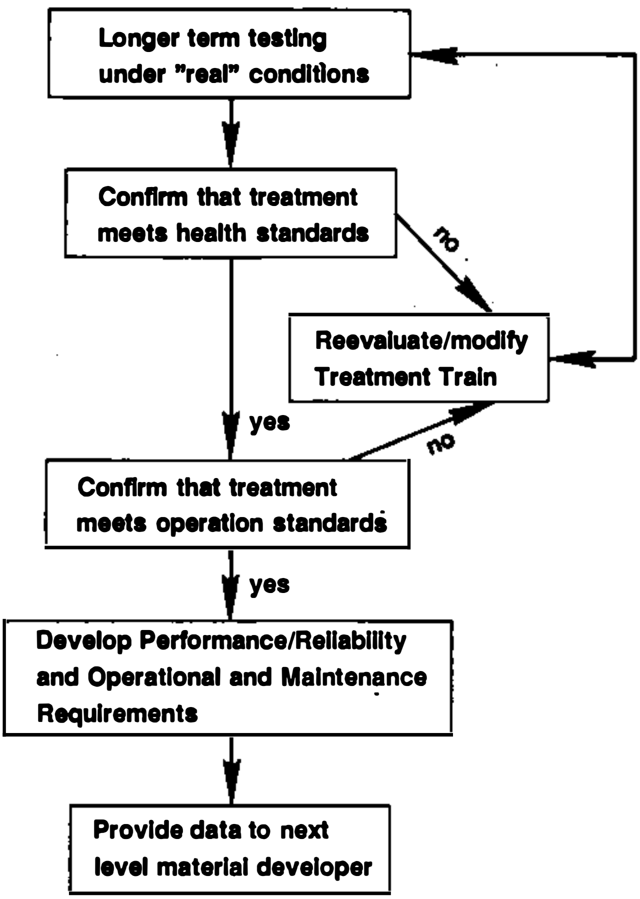


FIGURE 6.4 A research approach flow chart for studying field Army shower wastewater recycle (continued).

such as *Staphylococci* or *Pseudomonas* could be included in screening shower wastewater. Wherever possible, large volumes of wastewater should be analyzed to maximize detection sensitivity. While procedures for bacteria may be limited to several hundred milliliters, flow-through procedures for viruses and parasitic cysts should allow sampling in the range of 100 L of wastewater.

If any of these pathogens are detected in untreated wastewater, their removal by the treatment process should be demonstrated. As discussed under Level 1 analysis, any organisms (either pathogens or fecal coliform bacteria) surviving the treatment process should be identified and their health significance evaluated.

The first major decision point is reached after the characterization of the microbial and organic chemical constituents. It is at this juncture that the literature is searched to identify which chemicals have an adequate health effects data base and which do not. Then a decision must be made as to whether testing of individual chemical constituents or concentrates of recycled water generated in the field would be most appropriate and cost-effective. In this latter case, the recycle water must be compared with the potable water source as the control (i.e., sample points a and d). The type of toxicological testing required will depend on what the Army decides is an unacceptable health risk.

From the flow chart in Figure 6.4 it is apparent that there are several subsequent decision points that are critical, and development of processes should parallel these decisions. Phase II (Figure 6.4) field studies should be conducted after the completion of Phase I. The shower recycle field studies should be conducted under "real field Army" conditions. The goal of these experiments is to provide data necessary for the material developer.

TREATMENT RESIDUALS

In the treatment trains for either laundry or shower recycle, microbial concentration will occur on the DE filter. If functioning properly, the backwash from this unit process will contain most of the microbiological contaminants present in the wastewater. Other treatment residuals from the coagulation/flocculation process may contain chemical and microbial contaminants as well. The committee recommends that consideration be given to the proper disposal of these treatment residuals.

QUALITY ASSURANCE

In the development of the data base necessary to conclude this program the committee recommends that a quality assurance program be developed. There are numerous examples and guidance manuals available in this regard. Particular attention should be focused on the area of detection limits of the analytical procedures, the reproducibility of results, and, for microbiological determinations, the validation of zero recovery results. For example, it is necessary that the microbiological result of "no organisms" recovered be substantiated in the laboratory by confirming the recovery of the organisms from comparable samples, thus ensuring that the analytical procedures are functioning adequately.

CONCLUSIONS AND RECOMMENDATIONS

The committee believes that the available data are encouraging for field Army laundry wastewater recycle. The data required to ensure the safety of field laundry wastewater recycle are achievable with minimal additional studies.

A pilot-scale study should be performed with the proposed laundry treatment system. A representative source water should be used and the laundry operated through a number of recycles. It is possible that characterization of laundry wastes is not necessary provided that topical and toxicological studies are conducted and no sensitization is observed in human volunteers. It must be recognized, however, that operators of the laundry facility would fall within a separate exposure group.

Since shower wastewater recycling will involve direct human exposure through inhalation and dermal contact, the committee recommends more involved studies to provide the data necessary to ensure safe shower wastewater recycle. Additional pilot studies should be performed to better characterize the quality of water associated with the shower recycle system. The tests should be designed to ensure that an adequate number of recycles are included to achieve operational steady state. The data available to date indicate that steady state was either not accomplished or just minimally reached in previous testing.

The committee believes that the emphasis of this program should characterize the wastewater with respect to chemical and microbiological quality. (See Figures 6.1 to 6.4.) In the development of the data base necessary to conclude this program, the committee recommends that a quality assurance program be developed. Particular attention should be focused on the area of detection limits of analytical procedures, reproducibility of results, microbiological determinations, and the validation of zero recovery results.

The committee believes that the proof of the success of the treatment process can only be accomplished through additional studies that are interdisciplinary. Engineers, chemists, and microbiologists must identify the contaminants added to the water by its previous use and determine the extent to which the treatment processes alter the composition of the wastewater. This type of information is needed before toxicological and microbiological data that establish dose-response relationships can be used to develop health criteria appropriate to the specific use. Because decisions in one area invariably have an impact on another, it is essential that contributors from all these disciplines be involved from the beginning of the project.

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GLOSSARY

Definitions reprinted from: Glossary, Water and Wastewater Control Engineering, by permission. Copyright 1981, American Water Works Association, American Public Health Association, American Society of Civil Engineers, and Water Pollution Control Federation.

Cantonment - temporary quarters for troops

Coagulation - The conversion of colloidal (<0.001 mm) and dispersed (0.001 to 0.1 mm) particles into small visible coagulated particles (0.1 to 1 mm) by the addition of a coagulant, which compresses the electrical double layer surrounding each suspended particle, decreases the magnitude of repulsive electrostatic interactions between particles, and thereby destabilizes the particles.

Diatomaceous Earth Filter - A filter used in water treatment, in which a built-up layer of diatomaceous earth serves as the filtering medium.

Disinfection - (1) The killing of waterborne fecal and pathogenic bacteria and viruses in potable water supplies or wastewater effluents with a disinfectant; (2) the killing of the larger portion of microorganisms, excluding bacterial spores, in or on a substance with the probability that all pathogenic forms are killed, inactivated, or otherwise rendered non-virulent.

Effluent - Wastewater or other liquid, partially or completely treated, or in its natural state, flowing out of a reservoir, basin, treatment plant, or industrial plant.

ERDLator - Standard Army Water Purification Unit

Field Army Shower/Laundry Wastewater Recycle System - A system to recycle and reuse shower and laundry wastewater used for temporary army installations.

Filtration - The process of contacting a dilute liquid suspension with filter media for the removal of suspended or colloidal matter, or for the dewatering of concentrated sludge.

Flocculation - In water and wastewater treatment, the agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means. In biological wastewater treatment where coagulation is not used, agglomeration may be accomplished biologically.

Gas Chromatographic Mass Spectrometer (GCMS) - An analytical technique involving the use of both gas chromatography and mass spectrometry, the former to separate a complex mixture into its components and the latter to deduce the atomic and molecular weights of those compounds. It is particularly useful in identifying organic compounds.

Influent - Water, wastewater, or other liquid flowing into a reservoir, basin or treatment plant, or treatment process.

Polyelectrolytes - Complex polymeric compounds, usually comprised of synthetic macromolecules that form charged species (ions) in solution: water-soluble polyelectrolytes are used as flocculants; insoluble polyelectrolytes are used as ion exchange resins.

Reverse Osmosis - An advanced method used in water and wastewater treatment which relies upon a semipermeable membrane to separate the water from its impurities. An external force is used to reverse the normal osmotic flow, resulting in movement of the water from a solution of higher solute concentration to one of lower concentration. Sometimes called hyperfiltration.

Total Dissolved Solids - The sum of all dissolved solids (volatile and non-volatile) in a water or wastewater.

Total Organic Carbon - The amount of carbon bound in organic compounds in a sample. Because all organic compounds have carbon as the common element, total organic carbon measurements provide a fundamental means of accessing the degree of organic pollution.

Ultrafiltration - The process of removing colloidal and dispersed particles from a liquid by passing the liquid through a membrane under high pressure.

Wastewater - The spent or used water of a community or industry which contains dissolved and suspended matter.

Wastewater Reuse - The direct or indirect use of treatment plant effluent for municipal, industrial, agricultural, recreational, or water recharge applications.

Water Quality Criteria - Scientific standards on which a decision or judgment may be based concerning the suitability of water of a specific quality to support a designated use.

APPENDIX A

ANALYTICAL CHARACTERIZATION SCHEME FOR FIELD LAUNDRY OR SHOWER RECYCLE

Water-Quality Characterization

A. Level 1

1. Chemical
   a. Total Organic Carbon (TOC)
   b. Total Organic Halogen (TOX)

      - purgeable organic halogen
      - nonpurgeable organic halogen

   c. UV/visible spectra 200-700nm (10-cm cell)
   d. Chlorine residual

      - free chlorine
      - total chlorine

   e. Conductivity
   f. Methylene blue active substances (MBAS)
   g. Standard water-quality characteristics

      - alkalinity
      - total hardness
      - turbidity
      - total dissolved solids
      - pH
      - color

2. Microbiological
   a. Heterotrophic plate count
   b. Indicator bacteria (total coliforms)

c. Resistent surrogate bacterium, e.g., mycobacteria
d. Fungal plate count (i.e., dermatophytes)

B. Level 2

1. Chemical

A. Organics Characterization

1. TOC <1 (very difficult to characterize)
   a. static head space/distillation head space for polar organics using flame ionization detection (FID).

2. TOC >1
   a. static/dynamic head space with FID
   b. liquid-liquid extraction (pentane/ether) flame ionization, Hall electrolytic conductivity (HEC) and electron capture (EC) detectors
   c. high-performance liquid chromatography (HPLC), e.g.,

      - amino acids
      - phenols (carbon and chlorine by-products)
      - low-molecular-weight acids
      - aldehydes

3. TOX, Purgeable organo halogens (POX) and Nonpurgeable organo halogens (NPOX) <1
   a. static or dynamic headspace with HEC and EC detectors
   b. direct aqueous injection, HEC and EC detectors

4. TOX (POX and NPOX) >1
   a. head space to HEC and EC detectors

b. liquid-liquid extraction (pentane or ether) for HEC or EC detectors
c. High Performance Liquid Chromatography (HPLC)

- amino acids
- phenols
- low-molecular-weight acids
- aldehydes

B. Inorganic Characterization

Ion chromatography can be used to complement the more standard water-quality characterization, e.g., Cl^-, SO_4^{-2}, PO_4^{-3}, NO_3-

C. Microbial Characterization

1. Indicator bacteria (fecal coliforms)
2. Pathogens

- Bacteria (Salmonella, Shigella, Legionella, Staphylococci)
- Viruses (total human enteric)
- Parasites (Giardia lamblia)

C. Level 3 - Gas Chromatography Mass Spectrometry

Where compounds are indicated and not identified in Level 2 then further characterization will be necessary. This requires more highly concentrated samples.

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APPENDIX B

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APPENDIX C

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

RICHARD S. ENGELBRECHT (Chairman) was born in March 1926. He received his A.B. from Indiana University and his M.S. and Sc.D. from the Massachusetts Institute of Technology. Since 1954 he has been on the faculty of the University of Illinois at Urbana-Champaign. He is a Professor of Environmental Engineering and has distinguished himself in the fields of water-pollution research and water-quality control. Dr. Engelbrecht is a member of the National Academy of Engineering and was a founding member of the National Research Council's Water Science and Technology Board.

RICHARD J. BULL was born on October 25, 1940. He received his B.S. in Pharmacy from the University of Washington in 1964 and his Ph.D. in Pharmacology from the University of California, San Francisco, in 1971. Until recently he was Director of the Toxicology and Microbiology Division of the Health Effects Research Laboratory, U.S. Environmental Protection Agency. His responsibilities include the administrative and technical direction of a multidisciplinary research program. Principal program areas included definitive chemical and microbiological hazards associated with drinking water, municipal and industrial wastewater, and ambient water. Dr. Bull is active in a number of societies and in 1984 he accepted a position in the College of Pharmacy at Washington State University.

WILLIAM J. COOPER was born on December 1, 1945. He received his B.S. in Chemistry at the Allegheny College in 1969 and his M.S. in Organic Geochemistry at The Pennsylvania State University in 1971. Currently he is Associate Research Scholar/Scientist (Associate

Professor) at the Drinking Water Research Center, Florida International University, Miami. Research interests are in the areas of halogen/organic interactions and photochemistry. Mr. Cooper is active in a number of societies and has written many papers and articles concerning analysis organics in water and test procedures for water disinfectants. He also edited a two-volume book titled Chemistry in Water Reuse.

MICHAEL C. KAVANAUGH was born in 1940 and received his Ph.D. in sanitary engineering in 1974 from the University of California, Berkeley. He has served as a lecturer for the Department of Civil Engineering at Stanford University and the Department of Civil Engineering at the University of California, Berkeley; supervising engineer for Montgomery projects on a variety of water and wastewater investigations; and principal engineer on the Potomac Estuary Experimental Water Treatment Plant. In 1980 he became Vice President at Montgomery Engineers and is currently manager of the Hazardous Waste Division. Projects include site characterization and feasibility studies at abandoned hazardous waste sites, underground tank removal, and ground-water modeling. Dr. Kavanaugh is a member of the Water Science and Technology Board.

K. DANIEL LINSTEDT was born on November 6, 1940. He received his B.S. from Oregon State University in 1962 and his M.S. and Ph.D. from Stanford University in 1963 and 1968, respectively. At present he is Project Manager with Black & Veatch Consulting Engineers. He is also an Advisor to the Denver Board of Water Commissioners on wastewater reuse. Previously he was Professor of Sanitary Engineering at the University of Colorado. Dr. Linstedt is a Professional Engineer in the states of Colorado and New Mexico and is active in a number of societies. He has published many papers and reports concerning water reuse and advanced wastewater treatment processes.

BARBARA E. MOORE was born on March 18, 1949. She received her B.A. and M.A. in Microbiology from the University of Texas at Austin in 1970 and 1975, respectively, and is currently completing her Ph.D. At present she is a Research Scientist Associate, Environmental Health Engineering, with the Department of Civil Engineering at the University of Texas at Austin. She is a Consultant with the Southwest Research

Institute, San Antonio, and has been a member of an American Society for Testing and Materials Committee on Human Infective Viruses in the Aquatic Environment since 1977. Previously she was with the Center for Applied Research and Technology, University of Texas at San Antonio as a Research Scientist Associate. She has published many papers concerning virus survival in water and wastewater systems among others.