EXECUTIVE SUMMARY

A large fraction of the World's population around 1.1 billion people - does not have access to improved sources of water. For many others, contamination of water during transport and in the household presents a significant health risk. For this segment of the world's population, use of effective technologies for household water treatment and storage is likely to have direct beneficial effects in the form of reduced infectious diseases and also contribute to greater productivity and other associated benefits from improved health. Household treatment often can provide these benefits to underserved populations much more quickly than it will take to design, install and deliver piped community water supplies.

Identifying the most accessible and effective methods for household water storage and treatment are matters of considerable importance and are the subject of this report.

The purpose of this report is to critically review the various candidate technologies and systems for providing microbiologically improved household water and to identify the most promising ones based on their technical characteristics and performance criteria. The characteristics and performance criteria for these are: effectiveness in improving and maintaining microbial water quality, reducing waterborne infectious disease, technical difficulty or simplicity, accessibility, cost, socio-cultural acceptability, sustainability and potential for dissemination.

This critical review considers methods and systems to protect water during storage, collection and use that improve microbial quality and thereby reduce pathogen exposure and risks of diarrheal and other waterborne diseases. Because it has been repeatedly demonstrated and is generally accepted that the most important and immediate risks to human health from using contaminated drinking water are those from enteric microbes of fecal origin or other sources, this review focuses on strategies and systems to protect and improve the microbiological quality of household water to prevent and control waterborne microbial diseases.

Systems for Household Storage of Collected Water to Protect Microbiological Quality

A review of the existing literature on collection and storage of household water revealed that such water often comes from fecally contaminated sources and therefore poses infectious disease risks to consumers. Furthermore, regardless of whether or not collected household water is initially of acceptable microbiological quality, it often becomes contaminated with pathogens of fecal origin during transport and storage due to unhygienic storage and handling practices.

Studies show that the use of containers with narrow openings for filling, and dispensing devices such as spouts or taps/spigots, protect the collected water during storage and household use. Many container designs also have handles, are lightweight, are made from durable, UV-resistant plastic and are affixed with a label containing informational/educational on their cleaning and use. Other appropriate containers for safe storage are those in which water can be directly treated by the physical method of solar radiation and then directly stored and dispensed for household use. These improved containers protect stored household water from the introduction of microbial contaminants via contact with hands, dippers, other fecally contaminated vehicles or the intrusion of vectors.
Treatment Technologies to Improve the Microbiological Quality of Household Water

A variety of candidate technologies for treatment of household water have been described and many are widely used in different parts of the world. The technologies to improve the microbial quality of household water and reduce waterborne disease include a number of physical and chemical treatment methods. The physical methods, include boiling, heating (fuel and solar), settling, filtering, exposing to the UV radiation in sunlight, and UV disinfection with lamps. The chemical methods include coagulation-flocculation and precipitation, adsorption, ion exchange and chemical disinfection with germicidal agents (primarily chlorine). Some water treatment and storage systems use chemicals and other media and materials that can not be easily obtained locally at reasonable cost and require relatively complex and expensive systems and procedures to treat the water. Such systems may be too inaccessible, complex and expensive to employ for treatment and storage of household water in some places and settings.

The efficacy of some treatment methods to physically remove particles (turbidity) and microbes or to inactivate microbes in household water has been documented, primarily for indicator bacteria. Some treatment methods, such as boiling, solar disinfection, UV disinfection with lamps, chlorination and the combined treatments of chemical coagulation-filtration and chlorination have been evaluated for reductions of bacteria, viruses and in some cases protozoans. However, the ability of some of these methods to remove or inactivate a wide range of known waterborne pathogens has been inadequately investigated and documented. The differences in the technologies of candidate treatment and water storage systems as well as the differences in the types, sizes and other properties of waterborne microbes that need to be removed or inactivated, have contributed to a lack of documentation of the efficacy of these methods for household treatment and storage of water.

With exception of chlorination and storage in a safe container and solar disinfection “SODIS” UV plus heat), most technologies for household water treatment and storage have not been studied for their ability to reduce diarrheal and other waterborne disease in household use. Such epidemiological studies of an intervention are essential in establishing the performance of the technology as well as its acceptance and sustainability by users.

Several candidate technologies for household water treatment and storage appear to be accessible, simple and economical for use in both the developed and developing countries. Some of these systems have been characterized for microbial efficacy and reduction of waterborne disease, and for community acceptance sustainability and cost recovery. Of the systems now available, the following appear to be the most widespread and promising for further development, characterization, implementation and dissemination:

- Boiling
- Solar disinfection by the combined action of heat and UV radiation
- Solar disinfection by heat alone ("solar cooking")
- UV disinfection with lamps
- Chlorination plus storage in an appropriate vessel
- Combined systems of chemical coagulation-filtration and chlorine disinfection.
The performance characteristics, advantages, disadvantages and estimated costs of these most promising technologies for household water treatment to improve microbial quality and reduce diarrheal disease are presented in the report.

**Treating turbid water: a special concern**

For the most promising household water treatment systems of chlorination with an improved storage vessel, solar disinfection with UV plus heat in clear bottles for sunlight penetration (SODIS), and UV irradiation with lamps, effective treatment of turbid water remains a challenge. This is because microbial reductions are decreased or prevented by turbidity particles that reduce access to target microbes or otherwise protect them from inactivation by other mechanisms. Suspended matter in water reduces the microbiocidal efficacy of chlorine and other chemical disinfectants, and it physically shields microbes from the UV radiation that is present in sunlight and emitted from mercury arc lamps and responsible for much of its disinfection activity. There is a need to investigate, characterize and implement physical and physical-chemical technologies for practical and low cost pre-treatment of treatment of household water prior to chlorination, solar disinfection with UV plus heat and UV disinfection with lamps. Appropriate physical and physical-chemical methods for effective pre-treatment for household water needed to be established, taking into consideration turbid waters of different quality with respect to particle characteristics and their removal efficiencies. In principle, some physical or physical-chemical methods may be highly effective for treatment of stored household water on their own. Pre-treatment technologies for removal of turbidity (suspended matter) from water suitable for such applications potentially include:

- Settling or plain sedimentation
- Fiber, cloth or membrane filters
- Granular media filters and
- Slow sand filter.

These methods will vary in their ability to remove interfering turbidity from water, depending on the nature of the turbidity particles. Especially important in this regard is their size and density. Of the listed methods, slow sand filtration is the least likely to be implementable and sustainable at the household level. This is because the preferred filter designs and installations often are larger and capable of treating more water than needed by individual households and because they require technical skills for maintenance and operation that may not be accepted by individual users.

**Need for behavioral, motivational, and economic support**

The use of technologies to treat and safely store household water is best accomplished if it is accompanied by or supported with economic incentives and other cost recovery methods and with programs designed to support community participation, education and other efforts to achieve acceptance and sustainability. Where such additional socio-cultural, behavioral and economic components of household water treatment and storage technologies are absent or lacking, successful implementation and sustained use are unlikely to be achieved. The importance of economic analyses and community participation, education and responsibility for household water treatment and safe storage can not be over stressed in future efforts to establish and disseminate this intervention for water sanitation.
Conclusions
Numerous studies have clearly shown that improving the microbiological quality of household water by on-site or point-of-use treatment and safe storage in improved vessels reduces diarrheal and other waterborne diseases in communities and households of developing as well as developed countries. The extent to which improving drinking water quality at the household level reduces diarrheal disease probably depends on a variety of technology-related as well as site-specific environmental and demographic factors that require further investigation, characterization and analyses. Reductions in household diarrheal diseases of 6-90% have been observed, depending on the technology and the exposed population and local conditions.

Further development, refinement, implementation, evaluation and comparison of household water treatment and safe storage technologies is both justified and encouraged.

Greater efforts to disseminate information about household water treatment and storage technologies and their benefits and advantages are merited.

The most promising and accessible of the technologies for household water treatment are filtration with ceramic filters, chlorination with storage in an improved vessel, solar disinfection in clear bottles by the combined action of UV radiation and heat, thermal disinfection (pasteurization) in opaque vessels with sunlight from solar cookers or reflectors and combination systems employing chemical coagulation-flocculation, sedimentation, filtration and chlorination. All of these systems have been shown to dramatically improve the microbiological quality of water. At least two of them, solar disinfection in clear plastic bottles (heat plus UV radiation) and chlorination plus storage in an improved vessel, have been shown in epidemiological studies of the intervention type to significantly reduce diarrheal and other infectious diseases, including cholera. These household water treatment and storage systems are considered the most promising and effective, based on their documented ability to improve the microbiological water and reduce waterborne infectious disease risks.

All of the household water treatment technologies described here have been tested independently and so far none have been tested in combination. Historically and with renewed recent interest, water treatment technology and practice have focused on the use of two or more treatment technologies as a multiple barrier approach. There is considerable interest and potential merit in the use of two or more treatment systems in succession for improved treatment and the creation of multiple barriers. In particular those treatments that provide no residual disinfectant, such as boiling, solar treatment, UV disinfection with lamps and filtration could be followed by chlorination and storage in a protected or improved vessel to prove a multibarrier approach that would result in appreciable microbial reduction, continued protection with a disinfectant residual and storage that is less prone to post-treatment contamination. Research and demonstration of such multibarrier treatment and storage approaches deserve consideration and are recommended as next steps in the development, evaluation and implementation of improved treatment and storage of water at the household level.

The introduction of improved water treatment and storage at the household level, if done effectively, is likely to increase personal and community knowledge and awareness of the importance of water hygiene and sanitation and the benefits to be derived therefrom. It is likely
that involvement in preparing and using safe water at the household level results in increased
knowledge of water hygiene and sanitation, recognition and appreciation of its contribution to
infectious disease prevention and control and improved health. Such awareness of the role of safe
drinking water in health promotion and diseased prevention support and facilitate the ultimate goal
of providing all of the world's population with community piped water that is accessible, safe and
affordable.