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WATER AND HUMAN HEALTH

by
F. Eugene McJunkin

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Preface

This volume, *Water and Human Health*, is intended to provide an overview of the relationship between water and human health The primary focus is on water and health in the developing world as influenced by provision of safe, adequate, accessible, and reliable drinking water supplies Attention is also given to diseases associated with occupational and recreational contact with water and with animate vectors of disease which live or breed in water habitats. Emphasis throughout is on microbiological agents of disease These are the water-related diseases of highest priority in the developing world The relationships of organic and inorganic chemicals, natural and man-made, radionuclides, physical characteristics (e.g., "hardness"), *et al* have been intensively reviewed recently by the U S. Environmental Protection Agency, the National Academy of Sciences, and the World Health Organization Water supply and disposal of human excreta and wastewater are closely linked, not only technically but epidemiologically. Recent World Bank publications address the direct health aspects of human excreta disposal.

Section 1 of this volume provides background and general overview Sections 2, 3, 4 and 5 cover water and health aspects of specific diseases Sections 6, 7 and 8 address health considerations in production of drinking water. Section 9 reviews published epidemiological and other models of the health impact of water supplies, primarily in developing countries. Section 9 may be of special interest to those involved in implementation of programs related to the International Decade for Water Supply and Sanitation.

The manuscript was prepared by the Environmental Services Corporation, Chapel Hill, North Carolina under contract to National Demonstration Water Project. The primary author of the book is F. Eugene McJunkin, formerly Vice-President of the Environmental Services Corporation, now Chief, Community Water Supply and Sanitation Division, Office of Health, Bureau for Science and Technology, U.S. Agency for International Development. James C Lamb, III, prepared Sections 6, 7, and 8 Frances Clements of George Mason University edited the manuscript for publication under the direction of Mary E Morgan, Institute for Rural Water

Full responsibility for the accuracy of and views expressed in *Water and Human Health* rests with National Demonstration Water Project The book in no way represents the formal or informal policy of the U.S. Agency for International Development Further information regarding *Water and Human Health* may be obtained from the Development Information Center, Agency for International Development, Washington, D.C., 20523, U.S.A.

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Washington, D.C.

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SECTION 1

WATER AND HUMAN HEALTH: AN OVERVIEW

"Water contributes much to health."—Hippocrates

Introduction

On November 10, 1980, the United Nations inaugurated the International Water Supply and Sanitation Decade (1981-1990), with the goal of worldwide availability and use of readily accessible, safe, reliable, and adequate community water supplies and sanitation by the year 1990. The "Decade" was stimulated by the gross inadequacy of these basic human needs in the developing world, where perhaps 1.5 billion people lack reasonable access to safe water (See Table 1-1) The situation is even more bleak for sanitation According to statistics compiled by the World Health Organization (WHO), the rural areas of Africa, Asia, and Latin America, in particular, are poorly served—only one in five residents has access to safe water.

Also during 1980, the World Health Assembly (WHO's directing authority, composed of member country representatives) adopted the goal of "Health for All by the Year 2000," with increased emphasis to be placed on the goal of "primary health care." Water supply and sanitation are by WHO (and UNICEF) definition, a component of primary health care (WHO, 1978a, UNICEF-WHO Joint Committee, 1979.)

Water is, of course, an absolute necessity for life. However, water can also be a carrier of suffering and death Conversely, the ready availability of water makes possible a hygienic environment that prevents or limits spread of many human and animal diseases

In the United States, with occasional exceptions, endemic and epidemic waterborne disease has been of minor consequence in the overall national health status for over half a century. It is often forgotten that during the 19th-century cholera pandemics, thousands died of waterborne cholera in such American cities as New York, New Orleans, and St. Louis. Much of our understanding of the epidemiology of typhoid fever is due to the pioneering studies by William T. Sedgewick of water supplies in New England in the 1890s and by Wade Hampton Frost of Ohio River Valley communities during the first decades of the 20th century At the turn of the century, diarrheal diseases killed small children in the United States at rates comparable to those of today in the developing world, where, in many countries, one child in four never reaches his fifth birthday (See Figure 1-1).

The World Health Organization estimates that 500 million diarrheal episodes occur each year in children under five in Asia, Africa, and Latin America. Three to four percent of these end in death (WHO, 1979, also see Rohde and Northrup, 1976; Barker, 1975, and Gwatkin, 1980). These illnesses are the result of poverty, ignorance, malnutrition, and poor environmental sanitation, particularly inadequate water supply and excreta disposal.

To put these numbers in perspective, recall the crash on May 10, 1979, of a DC-10 airplane during takeoff at Chicago's O'Hare airport Two hundred and seventy-five persons lost their lives. Coverage by news media was intense and worldwide and continued for weeks. DC-10s were temporarily grounded at great expense.

Table 1-1. Estimated Population Having Reasonable Access[1] to Safe Water[2] in 1975 in 71 Developing Countries[3]

WHO Region	*Population*					
	Urban[4]		*Rural*[5]		*Total*	
(Countries)	*Millions*	*Percent*	*Millions*	*Percent*	*Millions*	*Percent*
Africa (16)	14,152	65	19,272	21	32,710	29
Americas (21)	145,650	81	21,753	30	104,091	57
Eastern Mediterranean (15)	46,272	80	23,955	16	67,673	34
Europe (2)[6]	10,980	81	20,180	63	40,160	71
South-East Asia (8)	127,521	68	145,118	19	272,639	29
Western Pacific (9)	36,036	91	18,046	30	54,082	54
TOTALS[7]	450,000	77	313,000	22	763,000	38

[1]"Reasonable access", in an urban area, was defined as a public fountain or stand post located not more than 200 meters from a house In rural areas, reasonable access implied that "the housewife or members of the household do not have to spend a disproportionate part of the day in fetching the family's water needs "

[2]"Safe water" supply includes treated surface waters or untreated but uncontaminated water such as that from protected boreholes, springs, and sanitary wells

[3]Not including the population of China

[4]The national definition as determined by each country

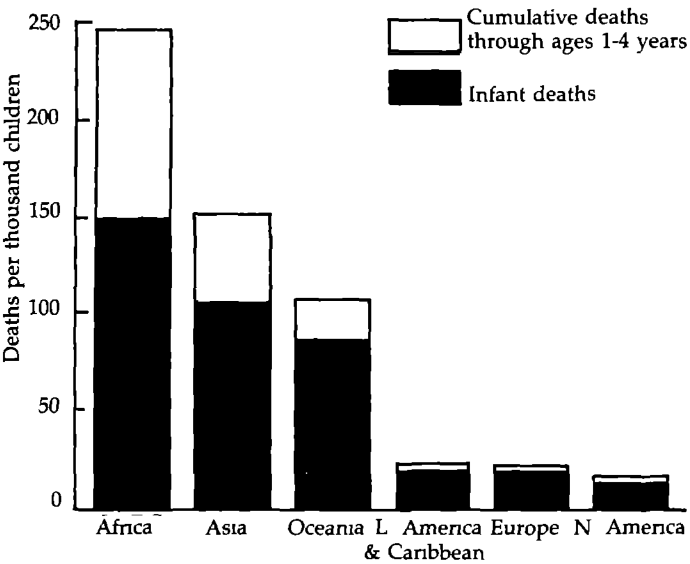
[5]See note 4 above

[6]Algeria and Turkey.

[7]Extrapolated to include the 95 countries surveyed in 1970.

SOURCES: Pineo (1975), Twenty-Ninth World Health Assembly (1975), U.N Water Conference (1977), WHO (1976); WHO (1977)

Figure 1-1. Probability of Dying Before the Age of 5 Years in Major Regions



SOURCE: WHO (1978a)

During the same hour that the DC-10 passengers died in Chicago, some six times as many children under five years of age died of diarrhea in the developing world. Imagine the publicity if a DC-10 crashed every 10 minutes, 24 hours a day, 365 days a year. Yet an equivalent number of children die each year of largely preventable diarrhea . with little public notice

Cholera, typhoid, and diarrheal diseases can be significantly reduced by adequate water supply and sanitation, as can many other diseases The role of water supply in improvement of health is not limited to those diseases transmitted through ingestion of water in food or drink. With adequate water supplies for bathing, washing of clothes and cooking utensils, food preparation, and other hygienic purposes, water can have significant effects on diseases of the eyes and skin, diseases transmitted by ectoparasites (lice, scabies, and the like), food-borne diseases, and others, particularly those controllable by hand washing (See Table 1-2.)

Water contact, with skin penetration by pathogenic agents of disease, is important in the tropics. Because many occupations require the use of water—irrigation farmers, fishermen, women with no alternative to surface waters for washing clothes, utensils, and children, persons performing religious ablutions, children swimming or washing animals in hot climates, and others—much exposure can not be readily prevented Some of these diseases are major health problems in many countries, e g , schistosomiasis. Also vectors of many diseases live part or all of their lives in a water environment Mosquitoes and certain fly and snail species are examples.

These diseases—malaria, onchocerciasis, schistosomiasis, etc are, of course, important However, because (1) our major focus is on water supply interventions and (2) a huge literature on these diseases is available, coverage here will be shortened.

Sanitation, especially disposal of human excreta (feces, urine, and vomitus), is closely allied with water supplies, however, an extensive treatise on sanitation/health relationships prepared at the London School of Tropical Medicine and Hygiene for the World Bank has been published (Feacham *et al* , 1980), therefore, coverage is limited to one section which provides guidance for program design

With the exception of diseases sometimes associated with water supplies (for example fluorosis), diseases associated with water metabolism in the body (for example diabetes insipidus) are not included, again because of our primary focus on water supply interventions Chronic diseases, such as cancer and heart diseases, are covered only in passing inasmuch as their relationship to water is highly controversial, priorities for water supplies in developing countries make the issue largely irrelevant, and an extensive literature review is available from the National Academy of Sciences and the Environmental Protection Agency (References are provided in the appropriate later section)

One other omission should be noted Many respiratory diseases could be termed "waterborne" in that they may be transmitted via droplets and aerosols composed largely of water These are not affected by provision of water supplies Remarks here are confined to health hazards which might arise from certain methods of wastewater treatment

Table 1-2. Estimated Proportion of Preventable Water-Related Disease in East Africa in 1966

Diagnosis	Percent Reduction Expected If Water Supply Were Excellent
Guinea Worm	100%
Typhoid	80
Urinary Schistosomiasis	80
Leptospirosis	80
Trypanosomiasis, gambiense	80
Scabies	80
Yaws	70
Inflammatory Eye Disease	70
Schistosomiasis, unspecified	60
Trachoma	60
Bacillary Dysentery	50
Amebiasis	50
Dysentery, unspecified	50
Tinea	50
Gastroenteritis, 4 wk to 2 yr	50
Gastroenteritis, over 2 yr	50
Skin and Subcutaneous Infections	50
Diarrhea of the Newborn	50
Paratyphoid and other *Salmonella*	40
Louseborne Typhus	40
Intestinal Schistosomiasis	40
Ascariasis	40
Louseborne relapsing fever	40
Otitis Externa	40
Classic skin (leg) Ulcer	40
Trypanosomiasis, unspecified	10
Dental caries	10
Overall	52

SOURCE: White, *et al* (1972)

Purpose

Water supply and sanitation to meet the goals of the International Water Supply and Sanitation Decade and of the Health for All by the Year 2000 initiatives will require prodigious investments, both for new construction or rehabilitation and for recurrent operation, maintenance, and replacement costs Even with assistance from external donors, most of these costs must be borne by the developing countries themselves, many, if not most, of whom have severely limited resources and many competing needs

This treatise is written in the hope that it will assist the effective and efficient use of resources in the water supply sector, one of the explicit goals of which is to improve health status, through a better understanding of the relationships between water supplies and health

Historical Development of Our Understanding of Water Supply and Disease

Introduction

This discussion of the relationship between water supply and sanitation and disease can be conveniently divided into (1) the wisdom of the ancients, (2) natural experiments, (3) sanitary revolution, (4) biological plausibility, (5) studies of epidemic disease, (6) studies of endemic disease All these categories of course overlap

Wisdom of the Ancients

Numerous savants of the ancient world related water and health For example, Hippocrates was remarkably accurate in his observations on goiter and water supply. Several ancient religious codes endorsed hygienic practices which even today remain appropriate.

Natural Experiments

The industrial revolution and the rise of large urban populations requiring public water supplies during the 19th century were often accompanied by massive epidemics, many of which could be considered natural experiments

The classic epidemiological study by Dr John Snow of an 1854 outbreak of cholera in London was a pioneering effort of scientific understanding. Over 700 deaths from cholera occurred in St. James Parish in a 17-week period Snow's detailed study showed that most of the victims had used water from the Broad Street Pump and, further, that a leaky sewer which passed adjacent to the well for the pump drained the house at No 40 Broad Street, site of the original cholera case Remarkably, Snow's study predated Pasteur's germ theory of disease by one decade and Koch's identification of the causative organism, *Cholera vibrio*, by three decades.

A serious epidemic of cholera occurred in Hamburg in 1892 when unfiltered water from the River Elbe was supplied to the city In that outbreak Koch succeeded in isolating *Cholera vibrio* from the river water Hamburg and the contiguous town of Altona both drew water from the River Elbe and discharged sewage to it at a number of points The water of Altona—being downstream from Hamburg—was initially the more polluted, but Altona filtered its water through slow sand filters and Hamburg did not In the course of a few weeks 18,000 persons in Hamburg were attacked by the disease and 8000 died. The death rate from cholera in Hamburg was 13 4 per 1000 of the population, Altona suffered much less, the death rate being 2 3 Almost all of the cases that occurred in Altona had drunk Hamburg water In Hamburg itself there was a block of tenements housing some 400 persons, these tenements were supplied with Altona water and the inhabitants escaped untouched

Sanitary Revolution

The work of Edwin Chadwick in England, Lemuel Shattuck in Massachusetts, and others fostered a sanitary revolution in their countries in the latter half of the 19th century Diseases associated with poor sanitation and crowded environments decreased in numbers even without planned interventions, curative medicine, or immunizations Lifespans increased (McKeon and Record, 1955, Wain, 1970)

It can be argued that many LDCs are repeating or on the verge of repeating western history in this regard The following examples are illustrative

Cvjetanovic (1975) shows the similarity of decline in enteric disease in the United States and in 51 developing countries if the time scale is adjusted (See Figure 1-2)

A study (Johnson, 1916) of the fall (65 percent), in typhoid mortality in 20 American cities following introduction of water supply filtration bears a remarkable similarity to the fall in typhoid mortality (63 6 percent), in 14 Indian towns following introduction of water purification a half-century later than in the U S. cities (Zaheer, *et al* , 1962).

In the Punjab some 15 years ago, the infant death rate from diarrhea in the second six months of life was 56 per 1000 A half-century earlier in New York City, the rate was precisely the same (Rohde and Northrup, 1976)

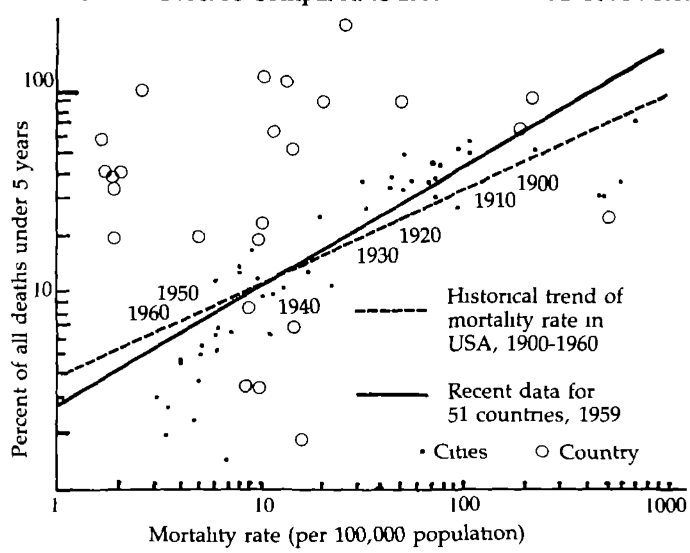
Biological Plausibility

Although the London cholera studies by John Snow are considered epidemiological classics (and appear as examples in most standard epidemiological textbooks), they had little impact on then current practices Only after Pasteur, Eberth, Koch, *et al* , identified the causative pathogenic micro-organisms did full acceptance come—aided immensely by Koch's "postulates" for confirming that a bacterium was indeed the agent of a specific disease

This of course led to identification of the "portal of entry" of the micro-organisms to the human body Many, of course, were through the mouth to the gastroenteric tract, carried by water or food

It could be conclusively demonstrated for such diseases as cholera and typhoid that fecal-oral routes were predominant in transmission of the disease. (See Section 3) Thus any intervention which broke the fecal-oral cycle could be effective obviously keep feces out of water, milk, and food and/or destroy or remove pathogens in water, food, or soil or on hands through treatment (e g., disinfection), cooking, or cleansing

Figure 1-2. Historical Trend of U.S. Mortality Rate for Gastroenteric Disease Compared to 1959 Data for 51 Countries.



SOURCE: Cvjetanovic (1975)

Studies of Epidemics

Snow's and Koch's findings have been duplicated for hundreds of common source outbreaks, due to cholera, typhoid fever, and other enteric diseases No doubt remains that these diseases can be transmitted by drinking contaminated water

Waterborne diseases were widely prevalent in the U S. and in other western countries during the late 19th and early 20th centuries and were then among the leading causes of death and illness Many of our largest cities suffered through awesome cholera outbreaks during the 19th-century pandemics

The decline of waterborne diseases in the U S closely paralleled the establishment of public water supplies and sewerage and, it should be noted, economic development Correlations were particularly strong for cities taking their water supply from unprotected watersheds with major declines following, first, filtration and then chlorination of their water supplies Many epidemic outbreaks were traced to breakdowns or other deficiencies in community water systems

Studies of Endemic Diseases

Although control of epidemics is important in the developing world, the on-going, continuing, everyday levels of disease are more important—if less professionally exciting and news generating—in the aggregate.

Endemic disease is not so clear-cut in its relationship to water supply: for many diseases, there are alternative routes of transmission However, both the experience cited earlier, a mammoth body of empirical evidence, and over 100 published studies support the water supply and health relationship Although the relationship exists, it is not easy to precisely quantify, either prospectively or in retroprospect

An extensive World Bank review (Saunders and Warford, 1976) found that

> Other things being equal, a safe and adequate water supply is generally associated with a healthier population. This has been unequivocally demonstrated for urban areas and in varying degrees for rural situations The difficulty lies in measurement rather than in qualitative trends The problem with collecting field observations on the health effects of water supply is that on a cross-section basis other things are never equal On a through-time basis other things usually cannot be held constant or accurately controlled. Consequently, it is extremely difficult to identify and measure exactly the health effects of improved water supply, and there is a limit to the precision attainable Furthermore, even if a case were found where governmental, physical, environmental, economic, cultural and educational factors which affect health could be reasonably controlled, the detailed findings of a health and water supply study are unlikely to be transferable from that particular setting to situations elsewhere

Other reviews include Hughes (1981), McJunkin (1969), World Health Organization (1980); National Academy of Sciences (1977), Wall and Keeve (1974), White, Bradley, and White (1972), and Miller (1962)

Interventions

Interventions for controlling waterborne transmission include the following·

Water Supply

(1) Selection of uncontaminated sources, e g , wells from deep aquifers.
(2) Treatment of raw water, especially chlorination
(3) Replacement of contaminated water supplies by more convenient, reliable, safe supplies
(4) Protection of watersheds.
(5) Water quality surveillance

Sanitary Excreta Disposal

(1) Protection of water supplies.
(2) Protection of environment
(3) Support of water supply and excreta control activities
(4) Destruction, removal, isolation, or dilution of fecal wastes.

Health Education

(1) Personal and community hygiene
(2) Protection of environment
(3) Support of water supply and excreta control activities

Transmission of Water-Related Diseases

For convenience the more important water and excreta-related diseases are categorized in terms of appropriate interventions:

Waterborne-Microbiological Diseases

Basically, these are diseases in which the pathogens are in the water and, when ingested at a sufficient dose, infect the drinker. The majority of these pathogens reach the water through contamination with human excreta and ultimately enter the body through the mouth, hence, the term "fecal-oral transmission " Many fecal-oral diseases are readily transmitted through other means, for example, fecally-contaminated food or hand to mouth. Thus, not all typhoid, for example, is waterborne

The more important of these diseases include amebic dysentery, shigellosis, cholera, diarrheas (non-specific etiology), *E coli* diarrheas, viral diarrheas, hepatitis A virus, and typhoid fever Section 2 covers these and others in depth.

Waterborne-Chemical Diseases

Basically, these are illnesses associated with ingestion of water containing toxic substances in harmful concentrations These may be of natural origin or man-made. They are generally locality-specific. Interventions include their removal (generally expensive) or selection of alternate sources On a global basis, these are not major problems in non-industrial countries and are generally of lower priority than microbiological diseases

Water Hygiene Diseases

These are diseases whose incidence, prevalence, or severity can be reduced by using water to improve personal and domestic hygiene These include many of the fecal-oral transmission diseases also listed as waterborne Most of these diseases may also be transmitted by food, hand-to-mouth contact, and numerous other means Some of them, e g , shigellosis, are possibly more predominantly transmitted in these ways than through drinking water.

Other hygienic diseases include those of the skin, e g , tinea, and eyes, e.g., trachoma Some hygienic skin diseases are associated with insect infestations, for example, scabies is caused by mites, pediculosis by lice. Lice also can transmit other diseases, for example, louseborne typhus

Sufficient water must be available for hand washing, bathing laundering, and cleaning of cooking and eating utensils. This quantity is needed in addition to that used for drinking.

A fallacious argument is sometimes advanced that quantity of water is important, quality of water is not Economically—and inevitably—only one water supply is feasible, this must provide waters for *both* drinking and hygiene. Microbiologically, safe water can satisfy *both* purposes even large quantities of unsafe water cannot Even where waterborne transmission does not appear to be endemic, the epidemic risk of common source outbreaks in community water supply systems should be avoided by public agencies. In the majority of instances, the cost differential is negligible

Water Contact Diseases

These are diseases transmitted by skin contact with pathogen-infested water The most important of these diseases is schistosomiasis (bilharzia) Schistosome eggs in human excreta hatch on reaching water The resulting larvae must invade suitable snail hosts or perish Following a multiplication process within the snail, the free-swimming schistosome larvae (cercariae) escape from the snail and find and invade man by penetrating his immersed or wetted skin.

This important tropical disease infects over 200 milion people, and its prevalence is probably increasing Current control methods, primarily drugs for those infected and chemical control (molluscіciding) of snails, have had limited success Both of these methods require periodic repetition.

Controlling schistosomiasis by limiting the need for human water contact through provision of public water supplies has shown promise in St Lucia, Brazil, Puerto Rico, and South Africa and is being tested in Swaziland by UNEP/UNICEF/WHO.

Water Vector Habitat Diseases

These are diseases which depend during part of their life cycle on animal vectors which live all or part of their lives in or adjacent to a water habitat. The archetypes are schistosomiasis (associated with snails), malaria (associated with mosquitoes), and onchocerciasis (associated with aquatic flies)

The relationship of schistosomiasis to water supply was previously described Water supply has little role in other snail-vector diseases which are not dependent on water contact Sanitary excreta disposal could theoretically interrupt the life cycle of these diseases However, this has not been demonstrated in practice The issue is further complicated by the presence of the diseases in wild and domestic animals

Mosquito-vectored diseases are not affected by water supply except, sometimes, in a negative way Breeding may be promoted by sullage and wasted water and uncovered water-storage containers. Filariasis transmission is increasing in many urbanized areas where the vector *Culex fatigans* breeds readily in polluted ditches and streams and even in privies flooded by high water tables.

Other than direct attacks against the vectors, i e , spraying of insecticides, sanitary engineering has little direct impact on *aquatic* fly-borne diseases An indirect effect of a developed water supply is to reduce human contact with tsetse flies, vectors of African trypanosomiasis, which for certain species are found primarily in riverine habitats These same habitats are often the source of hand-carried water supplies, particularly during dry seasons and droughts.

Excreta Disposal Diseases

These are diseases whose transmission may be effectively interrupted by sanitary disposal of human feces and urine They include most of the fecal-oral diseases previously described under waterborne diseases, (theoretically) the snail-vectored parasitic diseases, and the following helminthic infections of the intestinal tract ascariasis (roundworm), hookworms, strongyloides (threadworm), trichuris (whipworm), and several others of lesser importance Ascariasis and trichuris are fecal-oral route diseases, primarily by hand to mouth and by ingestion of contaminated soil.

Water As a Basic Human Need

Physiological Needs of Man

Water is physiologically necessary for human survival Long-term water intake and water losses must be in equilibrium Water is taken into the body in food and drink, including water and water-based fluids, and leaves the body in urine and perspiration, and to a lesser extent, in feces and as water vapor exhaled from the lungs

Individual water intake varies widely with body weight and surface area, ambient temperature and humidity, diet, activity (e g , work), culture, clothing, and health status However, a common average value of daily water intake for adult intake is 2 to 2.5 liters per capita per day (lcd) Women and children take less Table 1-3 summarizes the average daily water intake for adult males

Table 1-3. Average Daily Water Intake for Adult Males

Source of Information	*Average Daily Intake in Liters per Capita (lcd)*
World Health Organization (1971)	2 5
Environmental Protection Agency (1976)	2 0
National Academy of Sciences (1977)	2 0
White, Bradley, and White (1972)	1 8 to 3.0
Saunders and Warford (1976)	5

[1]This is water that is actually drunk, *not* design capacity

The chief means by which the human body regulates internal temperature in warm climates is through evaporation of sweat from the skin Hard work, in the sun, at 100°F (38°C.) daily mean air temperature may require a daily water intake of as much as 15 lcd (White, *et al* , 1972) Individuals with high salt intake will require a higher fluid intake. Also individuals with certain diseases, e g , diabetes insipidus, may require much more water than the normal

Role of Human Physiological Need in Establishment of Drinking Water Criteria

The daily intake of organisms or of substances dissolved or suspended in water taken for drinking is the product of the number or the concentration of the impurities in a fixed unit volume, such as one liter, multiplied by the number of volume units ingested. For example, for water containing 2 milligrams per liter (mg/1) fluoride, a person who averages consumption of 2 liters per day of such water will ingest 2 x 2 or 4 milligrams per day of fluoride with his or her water. To this fluoride intake must be added that from other sources, particularly food and air

Fluoride occurs naturally and at an optimum intake is highly beneficial for prevention of dental caries However, excessive body intake may result in dental mottling or in crippling skeletal fluorosis

Thus, in establishing quality standards for fluorine (and for other substances), the long term average intake by the body from all sources of fluoride must be weighed against the quantity of fluoride which might be hazardous to health Adding a safety factor, the allowable maximum concentration in drinking water can be determined The margin of safety for fluoride in drinking water at not more than 1 mg/day is 2 to 8 fold of that for dental mottling and 20 to 40 fold of that for skeletal fluorosis (NAS, 1977)

This, greatly simplified, is the process used by the United States Environmental Protection Agency, the World Health Organization, and other authorities for establishment of drinking water standards.

Drinking Water and Maternal and Child Health[1]

Women and children of the developing world are the chief beneficiaries of improvements in water supply and sanitation Women benefit because they are responsible for collecting, transporting, and storing water in a vast majority of cases, all at the cost of a considerable expenditure of energy Children benefit because the heaviest burden of morbidity and mortality from water-related disease falls upon them. As will be shown, these benefits are cross-linked Their importance is underlined by the United Nations Children's Fund (UNICEF) which presently devotes over one-fourth of its budget to improving water supply and sanitation in the developing world

Women and children in the developing world are ubiquitous as drawers of water Consider water drawing and transport as a form of caloric demand White *et al.*, (1972) estimated the average East African rural woman used about 9 percent of her estimated 2,840 kilocalories (KCal) daily intake in providing water This proportion represents a number of calories roughly equivalent to the number of additional calories required a day during pregnancy. This figure of 9 percent, however, applies only to the average. Women who must traverse steep or hilly terrain may use from 15 to 27 percent of their caloric intake in water drawing.

Water collection is but one of several tasks making a demand on a woman's energy. Table 1-4 summarizes the caloric demands of these tasks Childrearing or childbearing, when combined with water drawing, may account for a sizeable share of the daily caloric demand Food gathering/cultivation and wood gathering are estimated as requiring together the same number of calories as are demanded for water drawing alone (based on an estimate that the distance traveled for these tasks is roughly the same as that for water drawing, but that both tasks are done simultaneously) When these numbers are added, the cumulative percentage for the pregnant woman becomes 25 percent, that for the breastfeeding woman 53 percent, or over half her daily caloric intake When the 30 percent required for nighttime metabolism is added, the breastfeeding woman is left with only 17 percent of her daily calories to expend on other tasks, the pregnant woman, 45 percent

If a mother can reduce the 9 percent of more of her caloric intake spent on water collection to, perhaps, 1 percent, then she will have that much additional energy for childbearing or rearing, for other household tasks, or for herself. A fascinating commentary on these inter-relationships is found in the study of White, *et al* (1972) in East Africa When rural women were asked what they would do with time saved through having water piped in, with little hesitation they agreed almost unanimously that they would prefer to spend more time on other household tasks—like sewing and cooking—and expressed almost no regret at the potential loss of social contact at the river, well, or spring

Water may be contaminated at several points, including the source itself (spring, well, or pond), the receptacle, the domestic storage vessel, or the cup (White, *et al* , 1972) If the infant is artificially fed, contaminated water may lead to rapid multiplication of organisms in an unhygienically prepared formula Contaminated water used for mixing "gruel" and "pap" for young children is another potential hazard

Prevention of diarrhea, therefore, requires more than simply improving the quality of water at the source or even the accessibility, it also involves protection of water from the source in transport vessels, in storage vessels, and during handling. It involves using safe water to wash hands, vessels, and containers

Table 1-4. Caloric Demands of Various Household Tasks for East African Women (In Kilocalories and as Percent of Daily Caloric Intake)

Task	*Demand (K Cal/day)*	*Daily Intake (Percent)*
Nighttime metabolism	840	30
Childbearing	200	7[1]
Childrearing (breastfeeding)	1,000	35[2]
Food gathering/cultivation	120	4 5
Wood gathering	120	4 5
Water drawing and transport	240	9[3]
Other household chores	60	2
Commercial activity	60	2
Average daily caloric intake	2,840[4]	

[1]National Academy of Sciences (1970)
[2]See Note 1 above
[3]White, G *et al* (1972)
[4]Gale, G W (1960)

SOURCE: Isely (1981)

[1]This section draws heavily on ideas developed by Raymond B Isely, M D , Associate Director, Water and Sanitation for Health project (WASH), Rosslyn, Va

and using proper sanitary means of waste disposal, such as pit latrines and garbage pits It is not just a question of water alone, but of water use and all associated human behavior If the Drinking Water and Sanitation Decade reaches its goal of improving children's health, it will be only by a comprehensive approach to diarrhea prevention.

Water Supply and Nutrition

The interaction between diarrhea and malnutrition is well known The linkage of contaminated water supply and malnutrition, through malabsorption of food associated with frequent or severe enteric disease episodes, is well established (Chen, 1980)

Water, Sanitation, and Primary Health Care

Availability and use of adequate, safe water supplies and hygienic means of waste disposal are integral parts of primary health care and so recognized and recommended at the International Conference on Primary Health Care, convened by WHO-UNICEF at Alma Ata in 1978 (Declaration VII)

Water supply and sanitation interventions should be integrated with other primary health care activities in particular, with health education and promotion in both the home and the community and with maternal and child health care. Examples which seem obvious but are often overlooked include sanitary protection of stored household water from contamination and mosquito breeding, promotion of breast feeding, use of safe water in preparation of weanling foods, and promoting the use of safe water and sanitary excreta disposal Because in many countries, water supply and sanitation may be the responsibility of other than health authorities, project design may require special attention to interagency linkage and coordination and to supplementary training of village health workers, for example, teaching them how to do simplified sanitary surveys

Neither water supply nor any other primary health care information can by itself meet the full objectives of primary health care. Most real world programs will incorporate a mix of activities, but for many poorer countries, a necessarily incomplete program This means that the level and extent of primary health care activities must be weighed in accordance with their contribution to current national objectives, health and otherwise This cannot be determined *a priori*, but must be tailored to specific circumstances. These include the capacity of local institutions and their staff and their interest in finding resources, the primary health care infrastructure already in place, the expressed needs and wishes of the local population, and the strength of other relevant sectors—agriculture, education, *et al*

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SECTION 2

WATERBORNE DISEASES

Introduction

Definition

These are diseases in which the pathogen, i e , a disease-producing agent or microorganism, enters the body as a passive component of drinking water Two other criteria should be included in a pragmatic definition

(1) A significant proportion of the disease is transmitted via drinking water, and, a corrolary,

(2) removal of the pathogen from drinking water will in many instances have a significant impact on incidence of the disease, in other words, the provision of safe water supply will have a significant effect on transmission of the disease

Waterborne diseases can be further categorized as those due to microbiological organisms and those due to inanimate toxic substances suspended or dissolved in the water. A major difference in the two subcategories is that microbiological waterborne disease for individuals is generally manifested in acute episodic form, whereas, disease due to toxic chemicals may be manifested in acute or cumulative, chronic form depending on the concentration in the water

Waterborne Microbiological Diseases: Fecal-Oral Transmission

Many of these diseases are transmitted through "fecal-oral" or "anus to mouth" pathways Sources of drinking water are contaminated by human excreta (or for a few "zoonotic" diseases by animal excreta) voided by someone with an infection That person may be someone ill or a "carrier " A carrier harbors the disease organisms within his body without manifest symptoms Carriers are often more important in transmission than those persons actually ill "Typhoid Mary" Mallon is a classic example Working as a cook in homes and hospitals in New York State a half-century ago, she carried typhoid fever to thousands of unfortunate victims

Most of the fecal-oral diseases are manifested in the intestinal tract, that is, they are "enteric diseases " The most common syndrome is diarrhea, i e , frequent, loose stools The etiologic agent, i e., the pathogen, may be one of many candidate organisms, including viruses These diseases may also spread to other parts of the body

Other Pathways

Animals transmit some waterborne disease Leptospirosis, for example, may be transmitted via water contaminated by the urine of infected rats Tularemia can be transmitted by the urine of infected rabbits

An important although localized disease transmitted by drinking water, and only by drinking water, is guinea worm, or dracontiasis Ova (eggs) of the worm enter the water from the adult female worm as it protrudes from the skin of an infected person who is collecting water from an open well, pond, or stream Ingested by a small crustacean animal of the genus *Cyclops* living in the water, the eggs develop into the infective stage Man swallows the infected copepods by drinking water from the contaminated source The larvae of the guinea worm are liberated during digestion, migrate through the viscera to the subcutaneous tissues beneath the skin From these the gravid female worm protrudes through an ulcerated blister in the skin, discharging eggs to the water, reinitiating the cycle

Waterborne Disease Due to Chemical or Physical Agents

Illnesses due to chemical or physical agents are caused by ingestion of water containing harmful or toxic substances Injury may be acute in rare cases but normally results from long-term ingestion at low concentrations Many of the toxic substances derive from the activities of man-spraying of pesticides, for example Others may occur naturally—arsenic is an example, fortunately rare

In the United States research attention has recently been focused on the role of water supplies in the incidence of cancer and of heart disease Do some cancers have some relationship to the many organic chemicals which find their way into the water supplies of industrial areas? Is heart disease related to water hardness or other water quality parameters? Studies to date are conflicting and controversial Even under the worst assumptions, only a small number of people would be affected The cost of removing some chemicals from drinking water would require huge investments

In poor countries where large numbers of children die of conventional waterborne diseases, priority on "adequate supplies for the many rather than perfect supplies for the few" seems more appropriate. In many places, the entire issue can be avoided by judicious selection of sources of water

Summary of the Waterborne Diseases

Table 2-1 summarizes waterborne diseases In rough order the more important are diarrheal diseases, cholera, typhoid, bacillary dysentery or shigellosis, guinea worm disease, and leptospirosis Diarrheas are often unspecified but the causative agents of much diarrhea are *E coli* bacteria and enteric viruses, particularly rotaviruses

Amebiasis

Introduction

Although amebiasis actually means infection with amebas, the word is generally construed as meaning infection of the large intestine by *Entamoeba histolytica* because only this species of the six amebae that naturally parasitize the human intestine causes significant disease However, *Dientamoeba fragilis* apparently can cause mild intestinal symptoms

Amebiasis is found world wide, with perhaps 10 percent of the population infected Prevalence in areas with poor hygiene and sanitation is much higher, often 30 percent, and within some developing countries as high as 83 percent (WHO, 1969)

Amebiasis is an asymptomatic carrier state in most infected individuals, but diseases ranging from chronic, mild diarrhea to fulminating dysentery may occur Extraintestinal complications

Table 2-1. Waterborne Diseases[1]

Microbiological Sources

Disease or Syndrome[3]	*Fecal-Oral Pathways*[2]
Amoebic Dysentery (Amebiasis)	Epidemics mainly by water, endemic spread by water, food, and hand-to-mouth contact Resistant to chlorination
Ascariasis (Giant roundworm)	Usually soil-borne but also waterborne on occasion
Bacillary Dysentery (Shigellosis)	Also by food and milk, flies, and direct contact
Balantidial Dysentery (Balantidiasis)	Epidemics mainly by water Endemic spread by water, food, and flies
Campylobacter enteritis	Only recently recognized as important cause of pediatric diarrhea.
Cholera (Classical and El Tor)	Classical waterborne disease, now pandemic High fatality in untreated cases
Coccidiosis	Rare, mild
Diarrheas (Including Weanling Diarrheas and Gastroenteritis)	Clinical syndromes of varied etiology, generally unidentified, especially in LDCs, where frequently listed as the leading causes of death Primarily fecal-oral
E coli (Enteroinvasive, Enteropathogenic, and Enterotoxic)	Growing understanding of role in diarrhea of children and of travelers
Enteric viruses	Many are pathogenic Role not well understood. May cause diseases of central nervous system
Giardiasis	Receiving increasing attention. Resistant to chlorination
Hepatitis A virus	Several transmission routes including fecal-oral 30,000 cases in 1955-56 New Delhi outbreak
Hookworm and strongylodiasis	Normally larvae in soil penetrate bare skin, usually of foot May also be transmitted in water
Hydatid Disease (Echinococcosis)	Transmitted by ingestion of infective eggs in water and food contaminated by dog feces.
Non-cholera Vibrios	Increasingly recognized as a cause of diarrheal disease
Norwalk virus infection	Apparently a significant cause of diarrhea
Paratyphoid Fever	Direct or indirect contact with feces or urine of patient or carrier Indirect spread usually through food, esp milk and shellfish, and, occasionally, through water supplies
Poliomyelitis	Waterborne transmission has been observed but is rare
Rotavirus infection	Newly identified agent of infantile diarrhea. Probably fecal-oral
Salmonellosis	An acute gastroenteric, infectious disease usually spread by fecally contaminated food Waterborne epidemics are known, e g , 15,000 cases in Riverside, California, in 1966 from contamination of a public water supply
Schistosomiasis	Waterborne transmission occurs, but skin penetration the major portal of entry
Travelers' Diarrhea	Often due to one of many serotypes of *E coli* bacteria
Trichuriasis (Whipworm)	Usually soil-borne but also waterborne on occasion.
Typhoid Fever	Spread through contaminated water and food. Urinary carriers frequent in *S hematobium* areas
Yersinosis	Worldwide but rarely recognized

[1] Transmitted by ingestion of contaminated drinking water
[2] In some fecal-oral diseases, the pathogens may also be found in urine (e g , typhoid) and vomitus (e g , cholera)
[3] Diseases of major importance are italicized

Table 2-1 (Continued)

Other Pathways

Disease or Syndrome	*Remarks*
Anthrax	Transmission by drinking water dubious although cited by various authors
Brucellosis	Documented but probably very rare
Cysticercosis (Bladder Worms)	Ingestion of eggs in food or water Larval infection with *T solium* Other transmission routes A serious disease
Gongylonemiasis (Scutate Threadworm)	Rare Ingestion of water containing larvae from disintegrated insect hosts.
Guinea Worm Disease (Dracontiasis)	Complex transmission route with intermediate vector (*Cyclops*) *Not* fecal-oral. Found only in LDCs and transmitted only by water
Leeches (Hirudiniasis)	Infestation by young aquatic leeches
Leptospirosis (Weil's Disease)	A zoonosis Transmission more often by skin contact with contaminated water
Liver Fluke Disease (Clonorchiasis, *et al*)	Occasional ingestion of drinking water containing metacercariae from decomposed fish. Most infections from eating raw fish
Melioidosis	Rare Southeast Asia
Sparganosis	Ingestion of water containing *Cyclops* infected with certain cestode larvae Other transmission routes
Tularemia	Ingestion of untreated water from watersheds when infection prevails among wild animals, esp rabbits, is one of several transmission mechanisms.

Chemical and Other Sources

Source	*Disease or Syndrome*	*Remarks*
Metals	Toxicoses	Intake of metals in drinking water, food, and air from both natural sources and human activities These include arsenic, cadmium, copper, chromium, lead, mercury, selenium, vanadium, zinc, *et al* Can be important on a local basis, e g , arsenic in parts of Argentina
Organic Chemicals	Toxicoses Cancers Mutations Birth Defects	Intake of certain chemicals, esp certain synthetic organic chemicals, including some pesticides Also some trihalomethane byproducts of chlorination are suspect carcinogens Not now a high priority problem in LDCs
Radionuclides	Cancers	Natural and man-made radioactivity Now now a high priority in LDCs
"Hardness"	*Cardiovascular Disease*	Some epidemiological evidence indicates an inverse correlation of cardiovascular diseases with hardness of drinking water
Others	Fluorosis	Damage to teeth and bones resulting from long-term ingestion of high concentrations of naturally occurring fluorides.
	Methemoglobinemia	Serious, sometimes fatal poisoning of infants following ingestion of well waters containing nitrates (NO_3) at concentrations higher than 45 milligrams/liter.
	Endemic Goiter	Iodine-deficient water or water containing goitrogens
	Asbestosis and Mesothelioma	Asbestos in lungs known to cause cancer Fate in gastrointestinal tract unknown
	Hypertension	Sodium-restricted diets necessary for parts of population

may occur through spread of amebae via the blood stream or by intestinal ulceration and perforation by invasive ameba The most common complications are liver abscess and peritonitis The case fatality rate is generally less than 5 percent (Plorde, 1977).

Transmission

Man becomes infected with *E histolytica* by swallowing the cysts (the only infective forms), which reach the mouth through fecally contaminated food, water, or other objects, e g., fingers Transmission is highest in areas of poor sanitation

Fecal contamination of water for drinking and food preparation, use of night soil as a fertilizer for vegetables eaten raw, lack of handwashing, especially by food handlers, and mechanical contamination of food by house-flies and roaches are possible sources of infection. General health and nutrition of the infected population are important factors in the severity of the disease Also, strains of *E histolytica* isolated in tropical areas are generally more virulent than those from temperate zones (WHO, 1969)

Water Supply

Certain factors are relevant to understanding the role of water supply in transmission and prevention of amebiasis

(1) Amebiasis is manifested primarily in endemic form The incubation period is variable, from a few days to several months or years, although most commonly 2 to 4 weeks Thus epidemic "peaks" are relatively flat and often unrecognized in the community. Further, many people harboring *E histolytica* do not develop disease but may pass the cysts for years Also multiple sources of infection are common

(2) A water supply contaminated with *E histolytica* can result in epidemic amebiasis The first *recognized* water-borne outbreak was in Chicago in 1933, where a cross connection between a sewer and water supply for two hotels resulted in an outbreak with 1,409 cases with 98 deaths (Bundesen, 1936) Despite such spectacular outbreaks, the majority of cases probably stem from cumulative, chronic, contamination Nevertheless, these outbreaks serve as a reminder of the need for surveillance of drinking water quality.

(3) The cysts of *E histolytica* can survive for weeks in water

(4) The cysts survive chlorination at normal levels. Filtration, preferably through diatomaceous earth, is required to insure their removal. (Chang and Fair, 1941)

(5) "Freshening" of raw vegetables by sprinkling with cyst-contaminated water can result in transmission

(6) Handwashing following defecation is important

Very little quantitative information is available on water supply/amebiasis relationships One study from Lagos, Nigeria (Oyerinde, *et al* , 1979) estimated the prevalence of amebiasis in respondents who had tap-water in their homes to be 12.6 percent The rate among those who drank well water was 23 4 percent. The authors suggest that the higher rate of prevalence in the well-water users may have been due to contamination by pit latrines close to the wells and by containers used to draw the water Those using toilet paper for cleansing after defecation showed a lower infection rate (9.9 percent) than did those who used water for cleansing (14 6 percent)

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Bacillary Dysentery (Shigellosis)

Introduction

Shigellosis is an acute bacterial disease, primarily of the large intestine, characterized by diarrhea, fever, nausea, and sometimes, cramps, vomiting, and tenesmus Shigellosis is a serious disease with significant mortality, especially in infants and children There are four species in the genus *Shigella dysenteriae*, *S flexneri*, *S. boydii*, and *S sonnei* *S dysenteriae* Type 1 is the "shiga bacillus" of Kiyoshi Shiga, isolated during a severe epidemic in Japan in 1897, associated with a mortality rate of 25 percent *S dysenteriae* virtually disappeared after 1920 until it returned in 1969 in Central America with an estimated 112,000 cases, with 8,300 deaths in the first 10 months in Guatemala alone (Gangarosa, *et al.*, 1970) *S sonnei* and *S flexneri* are the most prominent forms, in that order, in the United States The disease has always flourished under crowded conditions with poor sanitation

Low Infectious Dose

Infecting only humans and certain other primates, only a very few shigella organisms need be ingested to cause clinical illness. In the case of *S dysenteriae*, as few as 10 to 100 bacteria suffice to produce symptomatic disease in 10 to 40 percent of adult volunteers. Because of this miniscule inoculum, shigellae can spread by contact without need for a vehicle such as food, water, or milk to amplify the infectious dose (Keusch, 1979) A thin veneer of infected feces on the fingers may be all that is required Viable shigella have been regularly cultured from the fingers hours after experimental inoculation of bacteria on the skin (Christie, 1968). The likelihood of transmission is enhanced, however, when sanitation is poor or there is opportunity for organisms to reach food or water. Epidemic shigellosis is often traced to such happenings and may involve faulty water supply or sanitation

Importance of Water Quantity

The significance of a low infectious dose was shown in a series of studies during the 1950s, shown in Table 2-2. Studies in poor communities in the United States and Guatemala showed that the convenience and, implicitly, the quantity of water close at hand, and convenient excreta disposal, had a significant impact on prevalence of shigellosis. Prevalence of shigellosis in the community could vary as much as 12-fold, for example, depending on the location of water and sanitation facilities

Role of Water

The studies described in the table and the low infectious dose have resulted in shigellosis being labeled a "water washed," or a "water hygiene," disease. However, it is also a waterborne disease Black, Craun, and Blake (1978) in a 15-year review (1961-1975) of 110 U.S outbreaks of shigellosis found that 38 were waterborne, primarily in small "semipublic" water supplies A review by Rosenberg, *et al* (1976) found more person-to-person contact, but waterborne transmission was still significant. Several large waterborne outbreaks have been documented, including those in Newton, Kansas (Kinneman and Beelman, 1944), with 3,000 cases, in Roosevelt, Utah (Drachman, *et al* , 1960), and in Montrose, Scotland (Green, *et al* , 1968)

Table 2-2. Shigella Prevalence[1] Rates by Levels of Water Supply and Sanitation

Sanitary Facilities for Each Dwelling	*Kentucky 1954-56 %*	*Guatemala 1955-56 %*	*California 1952-53 %*	*Georgia 1949-53 %*	*Means of Means %*	*Ratios of Means to Lowest Means*	*Ratios of Means to Highest Means*
Water Inside/Flush Toilet Inside	1.1	-	1.6	0.4	0.4	1.0	0.15
Water Inside/Privy Outside	2.4	6.3	3.0	2.2	2.2	3.5	0.54
Water Outside/Privy Outside	5.9	9.4	5.8	5.0	5.0	6.5	1.0
Water on Premises	5.8	-	-	4.1	4.1	5.0	0.70
Water off Premises	6.0	-	-	5.8	5.8	5.9	0.89

[1] Positive cultures from preschool children in Kentucky and from children 10 years of age and under in Guatemala For Guatemala, water inside, privy outside is for facilities in more than 50% of dwellings, water and privy outside is for facilities in less than 50% of dwellings

SOURCES: Schliessman, *et al.* (1958), Beck, Munoz and Scrimshaw (1957), Hollister, *et al* (1955), Stewart, *et al* (1955)

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Campylobacter Enteritis

Diarrhea due to infection by *Campylobacter jejuni* (Vibrio fetus) is an acute, self-limiting, enteric disease characterized by diarrhea, abdominal pain, malaise, fever, nausea, and vomiting. Transmission is by contaminated food or water—and by contact with infected animals or infants

Thorough cooking of food, milk pasteurization, control of infections in pets and domestic animals, screening of food handlers, and proper hand washing are preventive measures for campylobacter

Although well-known to veterinarians, campylobacters' role in human diarrhea was only realized during the 1970s, in part, because of the special laboratory techniques required to identify them

Butzler and Skirrow (1979) cite several waterborne outbreaks, the most dramatic that of a Vermont town of 15,900 population in which 3,000 people were affected with overwhelming evidence that the water supply was at fault (Tiehan and Voght, 1978) Longfield, *et al* (1979) describe a case who drank water from a flowing stream in West Virginia

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Cholera

Introduction

Cholera is an acute illness which results from colonization of the small intestine by *Vibrio cholerae*, the cholera bacillus The disease is characterized by its epidemic occurrence and the production in the more severe cases of massive diarrhea with rapid depletion of extracellular fluid and electrolytes.

Vibrio cholerae produces a protein enterotoxin which appears to be responsible for all known *pathophysiological processes* in cholera. The incubation period is generally from 6 to 48 hours. This is followed by the abrupt onset of watery, generally painless diarrhea. In the more severe cases, the initial diarrheal stool may be in excess of 1,000 ml, and several liters of fluid may be lost within hours, leading rapidly to profound shock· Vomiting generally follows, but occasionally precedes, the onset of diarrhea, the vomiting is characteristically effortless and not preceded by nausea. As saline depletion progresses, severe muscle cramps, commonly involving the calves, occur.

Epidemiology

Cholera has been endemic for a century and a half in the Gangetic Delta of West Bengal and Bangladesh and is often epidemic throughout South and Southeast Asia. The seventh and most recent pandemic spread of this disease, from 1961 to 1975, extended from the Celebes northward to Korea and westward to the whole of Africa and Southern Europe The last major epidemic of cholera in the Western Hemisphere occurred during 1866-1867.

The majority of major epidemics have clearly been waterborne, but direct contamination of food by infected feces probably contributes to spread during major outbreaks. Poor sanitation appears to be primarily responsible for the continuing presence of cholera, but host factors, such as relative or absolute achlorhydria (abscence of hydrochloric acid), also play an important role in the susceptibility of the individual to infection. In endemic areas, cholera is predominantly a disease of children, in rural Bangladesh attack rates are ten times greater in the one- to five-age group than in those above fourteen years of age However, when the disease spreads to previously uninvolved areas, the attack rates are initially at least as high in adults as in children.

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Diarrheal Diseases

Introduction

The dramatic symptoms of diarrheal diseases have claimed the attention of man from time immemorial Today all countries recognize that these are to a major extent diseases of an insanitary environment Lack of adequate, safe water, lack of protection from human excreta, contaminated food, filth, and flies—all promote diarrhea

Diarrhea is so universal and the result of so many etiologies (see Table 2-3) that it can have no precise definition other than the abnormally frequent evacuation of watery, loose stools The bowel habits of healthy people vary widely, thus the term diarrhea has limited meaning except when viewed as a change from the individual's customary pattern.

Diarrhea of abrupt onset occurring in otherwise healthy persons is most often related to an infectious process A variety of accompanying symptoms is often observed, including fever, headache, anorexia, vomiting, malaise, and myalgia, but they cannot always be used to distinguish the causative agent with certainty.

Only during the past decade has medical science been able to identify with reasonable certainty the pathogens of many of the more important diarrheal diseases, e.g., rotaviruses The role of *Escherichia coli* has turned out to be much more important than originally believed. Campylobacter enteritis, yersiniosis, and

Norwalk-type viral diarrhea similarly have received increased recognition

Table 2-3. Some Potential Causes of Diarrheas

Having Infectious Agents

Acute infectious non-specific gastroenteritis (AING)
Amebiasis (amebic dysentery)
Balantidiasis (balantidial dysentery)
Campylobacter enteritis
Capillariasis, intestinal
Cholera
Clonorchiasis (Chinese liver fluke)
Coccidiosis
Diphyllobothriasis (fish tapeworm)
Escherichia coli diarrhea
(Enteroinvasive, enteropathogenic, enterotoxigenic)
Fasciolopsiasis
Giardiasis
Guinea-worm (dracontiasis) disease
Leishmaniasis
Malaria, pernicious
Non-cholera vibrio disease
Opisthorchchiasis
Paratyphoid fever
Rotavirus gastroenteritis
Salmonellosis
Schistosomiasis
Shigellosis
Strongyloidiasis
Trichinosis
Tuberculosis
Trichuriasis
Tularemia
Typhoid fever (constipation more common than diarrhea)
Viral Diarrhea (Norwalk type)
Yersiniosis
And Others

Having Noninfectious Agents

Amyloidosis
Cancer
Cathartics
Crohn's disease
Diverticulitis
Drugs
Endocrine disorders
Erratic colon
Malabsorption disorders (e.g , sprue)
Poisoning
Chemical
Food (e.g , staphyloccal and botulinal toxins, natural toxins in fish, mushrooms, *et al*)
Radiation
And Others

The Intestine

The alimentary tract of the human body is a muscular tube commencing at the throat, which conveys food and fluid to the sac-like dilation of the stomach, then follows some 21 feet (6 4 meters) of torturous and freely movable small intestine with a diameter in the adult of 1 5 inch (3 8 cm), this opens into the large intestine of considerably greater diameter and 5 feet (1 5 m) in length, which terminates at the anus The stomach and small and large intestine, together with the liver, are the larger organs filling the abdominal cavity This is separated from the chest cavity, containing the heart and lungs, by the muscular diaphragm

The small intestine (duodenum, jejunum, and ileum, in order) both digests contained food and absorbs its nutrients The large intestine, or colon, coverts the liquid effluent from the ileum to solid fecal material and advances it by rhythmic squeezes to the rectum where it is evacuated through the anus The colon absorbs fluid (excess water) and electrolytes during these processes

In the normal adult about eight liters (about 8 5 quarts) of water enter the duodenum each day, made up of about one liter of saliva, two of gastric juice, two of pancreatic juice, and one of bile, together with perhaps two liters in food and drink. In the small intestine further fluid is added but absorption is such that 0 5 to 1.0 liter of water enters the large intestine There, net absorption results in only 0 1 liter appearing in the stools as fecal water (Rowland, 1978, Goldfinger, 1977)

Excessive water losses during diarrhea, resulting in dehydration, can become a serious threat to health, even to life Thus, despite their diverse etiology, most diarrheal illnesses can be thought of as a single entity since the basic fluid and electrolyte replacement therapy required to prevent a fatal outcome is similar for all.

Diarrhea in Children

Diarrheal disease is a particularly devastating problem during early infancy and childhood, killing 10 to 20 million children each year, most of them in the developing countries The child has less nutritional reserve, weaker immunity and, often, less protection from gastric acidity and intestinal peristalsis Most importantly perhaps, the child has a relatively large volume of extracellular fluid and large surface area of small bowel in proportion to his body weight compared to an adult. The effects of an infant's fecal losses of water and solute approach the danger levels much more quickly than they do in an adult "Dehydration, electrolyte imbalance, acidosis and shock can progress with lightening speed" (Gall and Hamilton, 1977)

The mortality from acute diarrheal disease among young children in developing countries would be even higher if it were not for the near universal practice of breast feeding A good and clean food is thus provided where nutrition and sanitation are major public health deficiencies However, supplementary foods ordinarily have to be added when nursing is prolonged beyond 6 months or so

So close is the connection between foods of poorer nutritional quality prepared in unsanitary conditions and pediatric diarrhea that the disease has a special name, "weanling diarrhea" (Gordon, Chitkara, and Wyon, 1963)

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Escherichia Coli Diarrhea

Introduction

Pathogenic *E coli* include at least three types (WHO, 1979)

Enterotoxigenic E coli (ETEC)

As late as 1968 the importance of ETEC as a cause of diarrhea was unrecognized These organisms are a major cause of diarrheal illness in children in the developing world and are by far the most common cause of *travellers' diarrhea* They are responsible for a severe cholera-like disease in children Although a common cause of diarrhea in the developing world, they are an infrequent cause in the developed world, except in areas where sanitation is poor They appear to be transmitted in water and food and, in nurseries, person to person

Enteropathogenic E coli (EPEC)

Certain EPEC serotypes have been known to cause infantile enteritis since the 1940s Epidemic EPEC is largely absent in developed countries today, and its epidemiology not well defined in the developing countries Waterborne outbreaks are known

Enteroinvasive E coli (EIEC)

E coli serogroups causing a shigella-like disease were recognized in 1967 EIEC have been known to cause waterborne outbreaks

Role of Water

These organisms are spread by contaminated food, water, and fomites Lack of hand washing, poor personal hygiene, and poor environmental sanitation contribute to spread of the disease

An inoculum of 10^6-10^9 organisms is required to cause disease For this reason only food and water, rather than person to person contact, serve as a means of transmission of diarrheagenic *E coli* (Gangarosa, 1978)

Rowe (1979), noting that the peak incidence for EPEC disease in the developing countries is at weaning, suggests that this is due to the infants' exposure "to the hazard of environmental contamination especially from food and water " EIEC has been associated with several waterborne outbreaks, ETEC with many (Rowe, 1979)

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Travelers' Diarrhea

As noted above, over 70 percent of cases of travelers' diarrhea are believed to be the result of infection by enterotoxigenic *E coli*.

Merson (1975) describes travelers' diarrhea as follows

> The clinical syndrome of travelers' diarrhea generally follows a typical pattern Within two weeks after arrival in a foreign country, and often within the first week, the traveler experiences the acute onset of water diarrhea, with sometimes as many as 10 to 20 episodes a day. This diarrhea is frequently accompanied by abdominal cramps, nausea, malaise, vomiting, chills, or fever, with temperatures as high as 39.4°C The illness is usually self-limiting, although in severe cases it may incapacitate the otherwise active visitor.

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Viruses

Introduction

"Thirty years have passed since the first studies on the presence of human enteric viruses in water were begun in earnest, but the public health significance of such contamination has yet to be evaluated" (WHO, 1979) More than 100 different virus types are known to be excreted in human feces More than 1,000,000 infectious virus particles may be excreted per gram of feces by infected persons Viruses are common in sewage They survive for months in water, soil, and shellfish They may resist some water treatment processes

Human viruses that may be present in water are summarized in Table 2-4 A long list of diseases is associated with these viruses, including systemic and central nervous system disease. However, authenticated reports of these diseases are few The viruses for which water probably plays a significant role in transmission of disease are hepatitis A virus, gastroenteritis viruses of the Norwalk type, and rotaviruses Evidence is strong enough for these viruses that a WHO Scientific Group recommends that "all potable water supplies from virus-contaminated sources should be disinfected "

Hepatitis A Virus

A worldwide disease, viral hepatitis is common where environmental sanitation is poor It occurs at an early age and is transmitted person to person Common-vehicle outbreaks due to contaminated water and food, especially milk and shellfish, occur frequently Illness varies from mild to fulminating with fever, anorexia, malaise, and jaundice Fatality rate is low Preventive measures recommended include health and hygiene education, personal hygiene, proper excreta disposal, and careful handwashing

Viral Diarrheas

Viral agents commonly causing diarrhea include at least two entities with distinct epidemiological differences Norwalk type diseases and rotaviruses

Norwalk Type Viral Diseases

These are diseases presenting acute gastroenteritis of viral origin, named after the location of the outbreak where they were first identified (Norwalk, Hawaii, Ditchling, *et al*) Their biophysical properties resemble those of parvoviruses They are now found worldwide Transmission is not fully known but is probably fecal-oral Several outbreaks strongly suggest food and waterborne transmission All age groups appear to be vulnerable. These viruses are probably *not* major causes of severe diarrheal illness of infants and children (Kapikian, *et al* , 1972) This disease is also known as "winter vomiting disease "

Rotaviruses

Rotaviruses are associated with severe diarrheal illness predominately of infants and small children and with significant

Table 2-4. Human Enteric Viruses That May be Present in Water

Virus group	*No of types*	*Disease caused*
Enteroviruses:		
Poliovirus	3	Paralysis, meningitis, fever
Echovirus	34	Meningitis, respiratory disease, rash, diarrhoea, fever
Coxsackievirus A	24	Herpangina, respiratory disease, meningitis, fever
Coxsackievirus B	6	Myocarditis, congenital heart anomalies, rash, fever, meningitis, respiratory disease, pleurodynia
New enteroviruses	4	Meningitis, encephalitis, respiratory disease, acute haemorrhagic conjunctivitis, fever
Hepatitis type A (probably an enterovirus)	1	Infectious hepatitis
Gastroenteritis virus (Norwalk type agents)	2	Epidemic vomiting and diarrhoea, fever
Rotavirus (Reoviridae family)	?	Epidemic vomiting and diarrhoea, chiefly of children
Reovirus	3	Not clearly established
Adenovirus	>30	Respiratory disease, eye infections
Parvovirus (adeno-associated virus)	3	Associated with respiratory disease in children, but etiology not clearly established

Note Other viruses which, because of their stability, might contaminate water are the following

(1) SV40-like papovaviruses, which appear in the urine The JC subtype is associated with progressive multifocal leukoencephalopathy

(2) Creutzfeld-Jakob (C-J) disease virus Like scrapie virus, the C-J virus resists heat and formaldehyde It causes a spongiform encephalopathy, characterized by severe progressive dementia and ataxia

SOURCE: World Health Organization "Human Viruses in Water, Wastewater and Soil " WHO Technical Report Series 639 Geneva P 7 1979 mortality in developing countries They were only identified within the past decade (1973), but a viral pathogen of diarrhea had been long suspected The stability of the virus, together with the large amounts excreted, makes environmental contamination more or less inevitable (Banatvala, 1979)

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Giardiasis

Introduction

Giardia enteritis is a protozoan (*Giardia lamblia*) infection of the upper small bowel Often asymptomatic, it may present with chronic diarrhea, steatorrhea, abdominal cramps, frequent loose, pale, greasy, malodorous stools, fatigue, and weight loss

It occurs worldwide in areas of poor sanitation Approximately 30 waterborne outbreaks, affecting over 10,000 persons, have been reported in the U S since 1970 Giardiasis is prevalent in the tropics, and children are infected more often than adults Maximum rates occur in children suffering from malnutrition (Knight, 1978)

Transmission is fecal-oral by water, food, and hand to mouth, with water a common source of outbreaks, partly because the usual concentrations of chlorine for water disinfection do not kill giardia cysts. Some evidence of animal contamination of water supplies also exists, particularly by beavers

Role of Water

Reports, beginning about 1970, of waterborne, epidemic giardiasis in travelers to the Soviet Union may have been responsible for increased attention to this disease within the United States. Since then numerous small outbreaks of waterborne giardia have been documented, including a 1974-75 outbreak in Rome, N Y , affecting some 5,000 people (Craun, 1979) Giardia outbreaks have occurred in communities with filtered water supplies also Camas, Washington (Kirner, *et al* , 1978) and Berlin, New Hampshire (Lippy, 1978)

A 1978 Symposium on Waterborne Transmission of Giardiasis gives an excellent overview of the current knowledge (Jakubowski and Hoff, 1978)

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Non-Cholera Vibrios

Many cases of gastroenteritis are caused by *Vibrio* species which are not *Vibrio cholera,* the bacterium which causes cholera These other vibrios are known collectively as "non-cholera vibrios " They cause sporadic cases and outbreaks of cholera-like disease, but have not been associated with large epidemics or pandemics At least six species have been implicated, the most common being *V cholerae* (non-01) and *V parahemolyticus*

V cholerae (non-01) are so named because they do not agglutinate in *V cholerae* 0-group 1 antiserum, a biochemical test to identify *V cholera, V cholera* (non-01) have often been referred to as non-cholera vibrios (NAGs) *V cholerae* (non-01) strains are widely distributed in the environment in Asia, Europe, and the United States, especially in sewage, estuarine waters, and seafoods (Blake, 1980) They appear to be autochthonous (of local origin) estuarine bacterial species They are pathogenic (Spira, in press) but the proportion of diarrheal illness associated with these organisms is unknown (Blake, 1980) Transmission is probably almost exclusively by contaminated food or water (Blake, 1980) An outbreak due to contaminated well water has been documented in the Sudan (WHO, 1969)

V parahemolyticus was first recognized as a cause of food poisoning in Japan in the early 1950s and since has been found to be a significant cause of diarrheal illness in many parts of the world It appears to be transmitted almost exclusively by food, particularly by food from salt-water environments

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Typhoid Fever

Introduction

Typhoid fever is a systemic, infectious disease characterized by sustained fever, headache, anorexia, slow heart beat, rose spots on the trunk, constipation more commonly than diarrhea, and on occasion, intestinal hemorrhage or perforation. Untreated fatality rate may be 10 percent Mild and inapparent cases occur, especially in endemic areas (Benenson, 1981) The infectious agent is *Salmonella typhi,* the typhoid bacillus

Occurring worldwide, the disease is spread by food or water contaminated by the feces or urine of a patient or carrier Shellfish and milk are also important vehicles for transmission

History

That typhoid can be a waterborne disease was recognized as early as 1839 by Dr William Budd, an English physician, who described its transmission by water some three decades before the bacillus was identified Budd's famous report was actually preceded by that of Dr Austin Flint, based on a little known study of an outbreak at North Boston, New York, a year before Budd's report

Thus typhoid, along with cholera, was the first disease identified as waterborne Cholera, however, was rarely identified in the United States after the 1873 pandemic Typhoid became the standard measure of all waterborne diseases in the United States and was thoroughly studied by early sanitary engineers and epidemiologists, including such pioneers as William T Sedgewick (1892), James H Fuertes (1901), George C Whipple (1907), and Wade Hampton Frost (1914) The work of the Massachusetts State Health Department's Lawrence Experiment Station, led by Sedgewick, early established the link between typhoid and drinking water Figure 2-1 is illustrative Figure 2-2 repeated the experience for post-war Greece during reconstruction.

Table 2-5 shows early studies, by Wade Hampton Frost, then with the U.S. Public Health Service, on the Ohio River, where initiation of water treatment reduced the typhoid death rate by over 80 percent A study by Johnson (1916) for other cities showed a reduction of 64 percent (See Table 2-6)

For the United States, "the improvement of public water supplies has been the largest single factor in the decline of typhoid" (Anderson, Arnstein, and Lester, 1962, p 220) Europe had similar experiences (Moore, 1971).

Military campaigns and disasters often produced virulent outbreaks In the 19th century, in many campaigns the death toll from typhoid exceeded that from gunfire.

Typhoid also gave its name to America's best known carrier, "Typhoid Mary" Mallon, a cook for upper class New York families and for hospitals, who was responsible for numerous outbreaks

In the United States, typhoid is rare However, in those countries that still have inadequate water supply and sanitation, it continues as a significant public health problem

In the United States and in England, typhoid and cholera were major factors in the sanitary reforms in both countries, epitomized by the work of Edwin Chadwick and Lemuel Shattuck

Table 2-5. Typhoid Death Rates for 26 Ohio River Cities Without Water Treatment Plants in 1906 and for the Same Cities in 1914 Following Initiation of Water Treatment in 16 of the Cities

Number of Cities/ Status of Water Treatment	*Typhoid Death Rate per 100,000 Population In 1906*	*In 1914*
10 Cities		
No Treatment in 1906	76 8	74.5
No Treatment in 1914		
16 Cities		
No Treatment in 1906	90 5	15 3
Treatment in 1914		

Note Source of water supply for each of the 26 cities was unchanged between 1906 and 1914

SOURCE: Frost (1941)

Causes of Typhoid

Typhoid fever, unlike most other salmonelloses, is strictly limited to man Infection results from ingestion of *S typhi*, experimentally in the range of 1,000 to 100,000 organisms. In nature the infectious dose is probably lower. The sources of

Table 2-6. Reduction in Typhoid Fever Death Rates in American Cities Following the Filtration of Their Public Water Supplies (Averages for Five Years Before and Five Years After Filtration)

City	*Average Typhoid Fever Death Rates* Before Filtration	After Filtration	*Percent reduction in typhoid fever death rates which followed the filtration of the public water supply*
Albany, N Y	109	28	74
Charleston, S C	106	62	41
Cincinnati, O	56	11	80
Columbus, O	83	17	78
Harrisburg, Pa.	72	33	54
Hoboken, N J	18	13	28
Indianapolis, Ind.	46	28	39
Lawrence, Mass	110	23	79
Louisville, Ky	57	24	58
New Haven, Conn.	40	25	38
New Orleans, La	39	26	33
Paterson, N J	29	9	69
Philadelphia, Pa	63	20	68
Pittsburgh, Pa	132	19	85
Providence, R I	19	13	31
Reading, Pa	53	35	34
Scranton, Pa	25	10	60
Springfield, Mass	22	22	0
Washington, D.C	55	31	43
Wilmington, Del	35	24	31
Weighted averages	60	21	65

SOURCE: Johnson (1916)

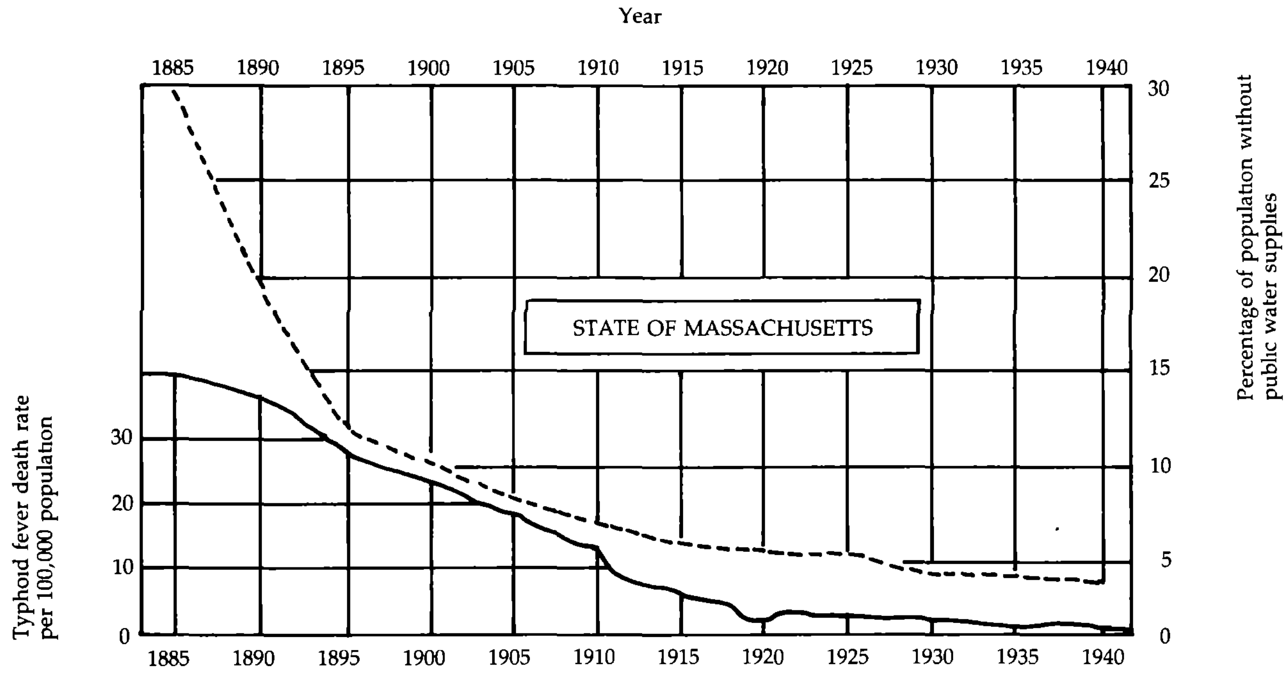
infection are the sick, or more often, carriers who excrete *S typhi* in their stools or urine

The epidemiology of typhoid has been thoroughly studied Numerous observations leave no doubt about the role of food and water (Cvjetanovic, 1973) Infection is often transmitted by contaminated water Because *S typhi* can survive in sea water, seafood, particularly shellfish, collected near sewage outlets is particularly dangerous

Prevention of Typhoid

Preventive measures include detection and treatment of carriers, immunization, and personal and community hygiene, particularly water supply and sanitary excreta disposal Immunization is effective but is overwhelmed by large doses of *S typhi* organisms, 10^9 or more (Cvjetanovic, 1973, Mandal, 1979) An epidemic model (Cvjetanovic, Grab, and Uemura,

Figure 2-1. Typhoid Rate Versus Water Supply Over Time: Massachusetts

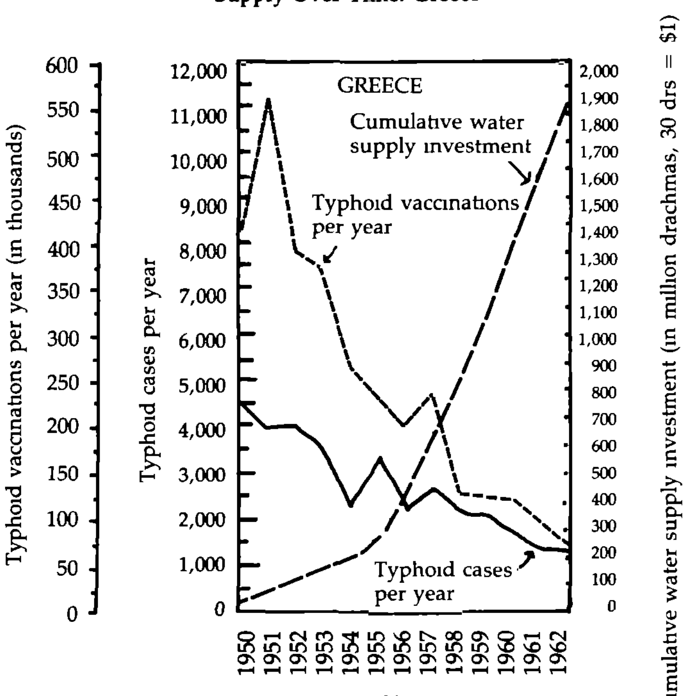


SOURCE: Fair, *et al* (1966)

1971), using cost data for southeast Asia, showed sanitation to be a more cost-effective control measure than immunization when its influence on control of other diseases is also considered

The success of water supply interventions in the United States in reducing the incidence of typhoid fever has been duplicated in many areas of the developing world Bahl (1976), Misra (1971), Zaheer, *et al* (1962), and Zebec (1980, reporting work in the 1920's) describe dramatic reductions in typhoid in cities in Zambia, India, and Yugoslavia, following introduction of community water supplies

Figure 2-2. Typhoid Cases and Vaccination Versus Water Supply Over Time: Greece



SOURCE: Costopoulus (1968)

Paratyphoid Fever

Introduction

Paratyphoid Fever is a bacterial enteric fever clinically similar to typhoid fever, but generally milder and with lower fatality rates Mild and asymptomatic infections occur

Three main groups of infectious agents are recognized

Salmonella paratyphi A,
Salmonella paratyphi B (*S. schottmulleri*),
Salmonella paratyphi C (*S hirschfeldii*),

all of predominately human origin

Transmission is fecal-oral, by food or food handlers Occasional outbreaks are related to water supplies, including swimming water.

Prevention

Preventive measures are similar to those for typhoid However, standard vaccines are less effective

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Salmonellosis

Introduction

Salmonellosis is an acute, infectious, bacterial disease with sudden onset of abdominal pain, diarrhea, nausea, fever, and sometimes vomiting Fatality is low except among the young, the old, and the debilitated Over 2,000 serotypes of Salmonella are pathogenic, with *S typhimurium* the most common Typhoid fever and paratyphoid fevers are salmonelloses but are discussed in a separate section Salmonellosis is very much associated with animals as well as man

Transmission

Transmission is fecal-oral from person to person and via contaminated food or water Epidemics are usually traced to food or milk Fecal contamination of chlorinated public water supplies has been involved in some extensive outbreaks Salmonellae are found worldwide.

One of the most noteworthy waterborne outbreaks of waterborne salmonellosis was that at Riverside, California, in 1965 (Ross, Campbell, and Ongerth, 1966, Greenberg and Ongerth, 1966), which affected an estimated 18,000 people This epidemic was attributed to *S typhimurium*

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Guinea Worm Disease

Background

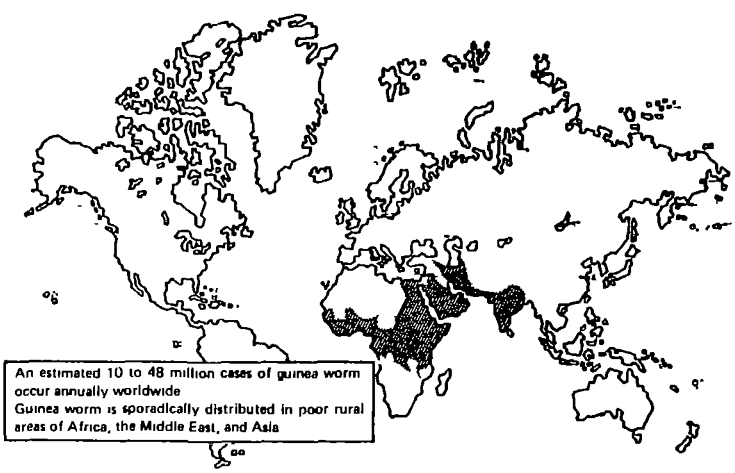
Guinea worm (*Dracunculus medinensis*) is a threadlike parasitic worm, 30 to 120 centimeters (12 to 48 inches) long, which inhabits the subcutaneous and intramuscular tissues near the skin of its human host It is found in Africa, Asia, and the Middle East. (See Figure 2-3) Not a killing disease, except when tetanus appears as a sequela, it can be severely incapacitating Arthritic complications are not uncommon. Kale (1977) cites the average duration of incapacity from effective work as 100 days in western Nigeria Annual reinfection is common

Guinea worm is the example *par excellence* of a disease for which transmission can be totally interrupted by provision of safe drinking water supplies In this regard the eradication of the disease has been promoted as part of the International Water Supply and Sanitation Decade by the Centers for Disease Control of the U.S Public Health Service (1981a, 1981b), the United Nations Development Programme (1981), and the (West Africa) Organization Centrale Contre les Grand Endemies (OCCGE, 1980). An estimated 10 to 48 million people suffer from the disease each year

Transmission

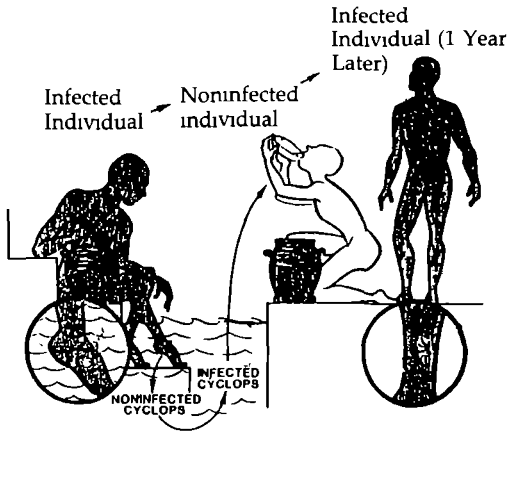
The life cycle of the parasite, *D medinensis,* shown in Figure 2-4, is the reason that transmission is so readily stopped by safe water supplies Guinea worm enters its human host only via drinking water If the water can be protected from contamination by larvae issuing from a guinea worm in an infected person, transmission ceases Simply sealing dug wells and step wells with sanitary covers and installing hand pumps will stop transmission from these wells. Guinea worms and their copepod intermediate hosts are readily removed from drinking water by filtration They are readily destroyed by boiling or chlorination

Figure 2-3. Geographic Distribution of Guinea Worm



SOURCE: Muller, R (1971)

Figure 2-4. Life Cycle of Dracunculus Medinensis



- The mature female worm pierces the skin of the lower leg causing an ulcer
- When the ulcer is in contact with water, larvae are discharged into the water
- The larvae infect Cyclops, a small crustacean
- The water, conatamınated with the infected Cyclops, is consumed
- The ingested larvae mature in humans in one year
- Guinea worm disease is transmitted entirely by drinking water
- The contaminated water is typically from open surface sources such as stagnant ponds or "step wells "

SOURCE: Muller, R (1971)

Effectiveness of Water Supplies

Numerous examples exist which show the effectiveness of water supplies against guinea worm disease Endemic guinea worm was eliminated in Tashkent and Samarkand by filling in step wells and providing protected wells The construction of piped water for a town of 30,000 population in Nigeria reduced the incidence of guinea worm from over 60 percent to zero within two years

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Leptospirosis

Introduction

Leptospirosis is a group of diseases caused by various serovars (formerly serotypes) of Leptospires e.g , *L icterohaemorrhagiae* Symptoms include fever, headache, chills, severe malaise, vomiting, myalgia, and others Fatality is low except for cases with jaundice and kidney damage

The pathogens are transmitted through skin contact with water, soil, or vegetation contaminated with the urine of infected rats or other hosts or occasionally through ingestion

Exposure is largely occupational with farm or fish workers or others who are frequently in contact with contaminated water or with infected animals and their urine Recreational exposure is also important, e g , with swimmers in contaminated water

Role of Water Supply

"Leptospirosis in man is so frequently associated with water that this disease has often been classified as a waterborne zoonosis" (Crawford, *et al* , 1971). The first reported waterborne epidemic of leptospirosis in the United States occurred in 1939 (Havens, *et al* , 1941) Crawford, *et al* (1971) review 11 other U.S epidemics, all attributable to swimming in contaminated water Cattle or swine were the probable sources of the leptospires for most of the outbreaks.

Christie (1974) suggests that "in the vast majority of cases leptospirosis in the human results from rat-contaminated water or soil " He also notes that sewer workers have suffered from the disease and reports transmission by drinking water

However, Gillespie (1963) and Diesch (1956) emphasize the hazard of *L. pomona* from domestic cattle.

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Tularemia

Introduction

"Tularemia is a congeries of syndromes" (Hornick, 1975) related to the route of introduction and the virulence of the pathogen, *Francisella tularensis*, a zoonotic coccobacilli When transmitted by ingestion, it may produce pharyngitis, intestinal pain, diarrhea, and vomiting Most commonly the skin is the portal of entry, and the most common form is as an indolent, febrile disease with a skin ulcer and draining lymph nodes. Pneumonia, typhoid, and oculoglandular forms also occur

Rarely transmitted from one person to another, it is most commonly acquired through handling of the carcass or eating the undercooked flesh of infected animals Rabbits are the most common animal victims

Role of Water

Sporadic episodes and epidemic tularemia have occurred among humans following contact with water and fish contaminated by infected animal carcasses (Cluff, 1977) Quan, McManus, and von Fintel (1956) have shown that *F tularensis* in water can penetrate unbroken skin

A domestic water supply in the USSR, contaminated with *F tularensis*, resulted in "over 43 cases" in a group of farm laborers (Jellison, *et al* , 1950) Natural waters in the U S have often been found contaminated by beavers and muskrats (Parker, *et al* , 1951) Drinking water directly from streams in areas where the disease is known to exist should be avoided

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Cardiovascular Disease and Hardness of Drinking Water

Associations have been found between the hardness of local drinking water and local cardiovascular mortality rates Most of these studies have been limited to geographic units wherein mortality rates are related to the average concentrations of various constituents of drinking water. They have not demonstrated the biological plausibility of these geographic associations Many authors, in fact, have questioned whether constituents in drinking water comprise a substantial enough proportion of human daily ingestion to affect human metabolism or health Further, no clear patterns have emerged in the studies Sharrett (1979) concludes in an extensive review that "the findings on waterborne trace elements and mortality should be accorded little credence at this time " In another extensive review, Comstock (1979) noted that "the more rigorous the experimental design, the less the association at best " Further, "its effect, if any, must be very weak compared with the effects of known risk factors "

A recent review of this issue by the National Academy of Science (1979) concluded· "Given the current status of knowledge regarding water hardness and the incidence of cardiovascular disease, it is not appropriate at this time to recommend a national policy to modify the hardness or softness of public water supplies "

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Carcinogens in Drinking Water

The increasing number of organic chemicals reaching water supplies in industrial areas has generated growing concern as to their carcinogenic potential in drinking water. Some compounds known to be carcinogenic (in tests of animals exposed to high doses) have been found in water supplies, albeit in low concentrations One of these is chloroform, which can be a by-product of the chlorination process for water disinfection, a process practiced in the U S since 1908 which has undoubtedly prevented great loss of life.

The question of the effect of potential carcinogens found in drinking water has been intensively studied by the National Academy of Sciences (NAS), which recently reported on chloroforms and other trihalomethanes (THMs) in drinking water The NAS has summarized (1980), based on its review of 12 epidemiological studies, that any association between THMs and bladder cancer "was small and had a large margin of error" and that inherent methodological complexities make it "virtually impossible to establish a causal link between THMs and an increase in cancer of the bladder or of any other site"

This subject has also been recently reviewed by Wilkins, Reiches, and Kruse (1979), who found that "the association between organic chemical drinking water contaminants and cancer is not well confirmed," and "at present, the evidence of a few statistically significant results must be tempered by recognizing the large number of test statistics that have been computed, as well as their reported levels of significance." However, "even though strong drinking water-cancer relationships have not emerged in these exploratory efforts, there still appears to be a justification for pursuing the drinking water question"

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SECTION 3

WATER HYGIENE DISEASES

Introduction

Water hygiene diseases are those whose incidence, prevalence, or severity can be reduced by regularly using water in sufficient quantities to improve personal and domestic hygiene These include most of the fecal-oral transmission diseases, also listed as waterborne. Many of these diseases may also be transmitted by food, hand-to-mouth contact, and other means Some of them, e g , shigellosis, are possibly more predominantly transmitted in these ways than through drinking water [1]

Other hygienic diseases include those of the skin (example yaws) and eyes (example trachoma) Some hygienic skin diseases are associated with ectoparasitism, i e , insect infestations For example, scabies is caused by sarcoptic mites, pediculosis by lice. Lice also can transmit other diseases, for example, typhus fever

Sufficient water must be available for hand washing, bathing, laundering, and cleaning of cooking and eating utensils This quantity is needed in addition to that used for drinking See Figure 3-1 for the impact of hand washing on the spread of shigella in Dacca, Bangladesh (ICDDR, 1979)

A fallacious argument is sometimes advanced that quantity of water is important, quality of water is not Economically, only one water supply is often feasible, this must provide waters for *both* drinking and hygiene With judicious source selection and protection, particularly of groundwater sources, microbiologically safe water can often be found to satisfy *both* purposes even large quantities of unsafe water cannot Even where waterborne transmission does not appear to be endemic, the epidemic risk of common source outbreaks in piped community water supply systems should be avoided by public agencies In most instances, the cost difference is negligible

Table 3-1 summarizes water hygiene diseases

[1]Some *Shigella* are very virulent, i e , they are infective at very small dosages However, they have a low lifespan in natural waters and are rarely identified during waterborne epidemics They may be the causative agents of much non-differentiated diarrhea

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Enteric Diseases

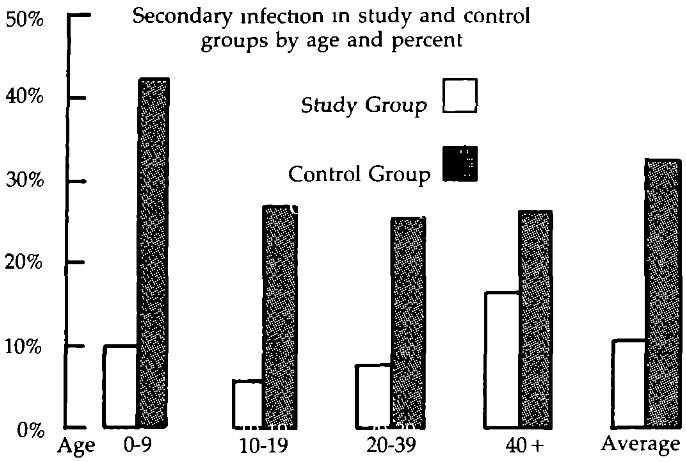
Reliable, regular, conveniently accessible water supplies of at least 20, preferably 40 to 50, liters per person per day have been shown conclusively in Section 9 to reduce the level of enteric diseases in the communities served Field evidence is particularly strong for shigellosis (bacillary dysentery) Most of the other fecal-oral diseases are also favorably impacted Section 2 describes these diseases and gives bibliographies

Table 3-1. Water Hygiene Diseases[1]

Disease or Syndrome	*Remarks*
Enteric Diseases	
Diarrheas, Dysenteries, Gastroenteritis, etc	Prevalence of most fecal-oral diseases is less with adequate quantity of water
Skin Diseases	
Otitis Externa, Scabies, Skin Sepsis and Ulcers, Tineas (Ringworm)	Prevented by personal hygiene, including frequent bathing and laundering with use of soap
Louse-Borne Diseases	
Louse-borne Fever, Pediculosis, Relapsing Fever, Typhus Fever, Wolhynian Fever	Prevented by personal hygiene, including bathing and laundering and changing of clothing
Treponematoses	
Endemic Syphilis, Pinta, Yaws	Prevented by general public and personal hygiene Non-venereal
Eye Diseases	
Conjunctivitis, Trachoma	Trachoma rare where ample water is available

[1]Transmission reduced by use of water for cleansing Quantity, convenience, reliability of water supply important

Figure 3-1. Effect of Hand Washing on the Spread of Shigella in Families in Dacca City.



Intervention of Shigellosis by hand washing

SOURCE: International Centre for Diarrheal Disease Research, 1980

Skin Diseases[1]

Introduction

Skin diseases are a considerable problem in many of the developing countries, often a leading complaint presented at health units. Prevalence rates may be as high as 80 percent and complications and secondary infections are not uncommon (Clark, 1970, Jelliffe, 1972, Masawe, 1975, Morley, 1973, Porter, 1977, Vibhagool, 1970, *et al*)

Scabies

Scabies is a disease resulting from infestation by the itch mite, *Sarcoptes Scabiei* Barely large enough to be seen by the naked eye, its discovery in 1687 marked scabies as the first disease of man with known cause (Orkin, 1971). It is found worldwide whenever personal hygiene is lacking Epidemics appear to wax and wane over long-term cycles The mite burrows under the skin Resulting itching can be intense. Transfer of parasites is by direct skin-to-skin contact and to a limited extent by contact with clothing or bedding contaminated by infested persons It is frequently acquired during sexual contact

Dermatophytoses (Ringworm infections)

Ringworm is a general term applied to fungal diseases of keratinized areas of the body (hair, skin, and nails) These diseases are subdivided by site of infection scalp, nails, groin and perianal region, body, and foot Strict personal hygiene can help prevent transmission. However, the infections may be found globally

Lopez Martinez (1980), in one of the apparently few quantitative studies published, found in a Mexico City study, that dermatophytes could be isolated from the scalp of 14.8 percent of persons living in "dirty" sanitary conditions, but in only 4 6 percent in "clean" conditions Children were found to be infected twice as often as adults

Other Skin Diseases

Many other skin diseases can be prevented or controlled by personal and public hygiene, assisted by adequate, convenient water supplies These diseases include pediculosis (covered in a separate section), pyodermal infections with various bacteria, primarily *Staphylococcus aureus, Streptococcus pyogenes,* and *Corynebacterium diphtheriae,* mycobacterial ulcers, tropical ulcer, impetigo, otitis externa (infection of the outer ear), other skin sepses, and secondary infections and sequelae of other parts of the body, e.g , acute glomerular nephritis, septicemia, *et al* Children are the most often infected

[1]Does not include systemic disease with symptoms or syndromes which appear on the skin, e g , measles

Role of Water Supply

The control of many of these diseases is unlikely without an adequate supply of water (Clark, 1970, Jelliffe, 1972, Morley, 1973, Porter, 1977, and Vibhagool, 1970) Some dramatic examples of reductions in skin diseases are described by Misra (1971) in India and Henry (1981) in St Lucia, when scabies dropped 98 percent and skin diseases at clinics dropped 82 percent respectively

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Williams, Roger W "Scabies" Chapter 110 in Hoeprich, Paul D, Editor, *Infectious Diseases* 2nd Ed, Harper & Row, Publishers, Hagerstown, Md Pp 870-873 1977

Louse-Borne Diseases

Introduction

> The louse is confined (to those) who live in great distress and great poverty But there are still many of these with us and there are regions of the earth where life is still primitive, where bathtubs remain luxuries The louse will never be completely exterminated, and there will always be occasions when it will spread widely to large sections of even the most sanitated populations And as long as it exists, the possibility of typhus epidemics remains (Zinsser, 1935)

One of the serendipitous byproducts of community water supplies and the practices of personal hygiene fostered thereby has been the virtual elimination in modern communities of the body louse, vector of epidemic typhus and relapsing fevers However, Zinsser's remarks of almost a half century ago remain true today

Table 3-2 shows those diseases for which the human lice are the vectors The most important disease is epidemic typhus fever, which has historically been a major enemy of mankind Indeed, typhus may have changed the course of history (Cartwright, 1972, McNeill, 1976, and Zinsser, 1935) For example, legend has it, reinforced by Tolstoy's *War and Peace*, that almost the whole of Napoleon's army was destroyed in the retreat from Moscow But the legend is wrong More soldiers perished on the way to Moscow, through Poland and western Russia, than on the retreat (Cartwright, 1972) Disease, led by typhus, killed more of Napoleon's troops then did the Russian soldiers

Epidemic typhus fever occurs today in Africa, Asia, and Latin America, with major endemic foci in Ethiopia, Burundi, Rwanda, and the Andean countries (Tarizzo, 1973) The potential for major outbreaks is high, especially under conditions of social stress, such as war, insurrection, famine, natural disaster, and severe poverty

"Normal" conditions favoring lousiness include lack of water and soap for bathing and laundering of clothing, inadequate changes of clothing, harsh climate (cold, wind, sun, or wind-blown sand—encouraging wearing of clothing), sleeping in clothing, crowding—especially of sleeping quarters, malnutrition, and ignorance about lice and disease

Lice

Man is infested by three kinds of lice, commonly called body, head, and pubic lice Pubic lice are also colloquially known as crab lice The common names are derived from the portion of the human body that is the common habitat of the particular louse The body louse and the head louse are varieties of the same species. The body louse is the common vector of the febrile louse-borne diseases

Lice normally pass their entire lives on their human host and if detached attempt at once to regain their place on the original or

Table 3-2. Louse-Borne Diseases

Disease/Synonym	*Case Fatality Rate*	[1]*Vector*	*Infectious Agent*	*Occurrence*	*Remarks*
[2]Typhus fever, epidemic louse-borne (classical typhus fever)	10 to 40% sometimes 70%	Body louse	*Rickettsia prowazeki*	Africa, Asia, E Europe, Latin America	Major epidemics in crowded unsanitary environments under stress
Brill-Zinsser disease (Recrudescent typhus)	Uncommon	Body Louse	*Rickettsia prowazeki*	Worldwide	Flare-up of old typhus infection
[3]Relapsing fever, epidemic louse-borne	2 to 10% sometimes 50%	Body louse	*Borrelia recurrentis* (a spirochete)	Limited areas of Africa, Asia, Latin America	Relapses are common
Wolhynian fever (Trench fever, Quintana fever, Five-day fever)	Non-fatal	Body louse	*Rickettsia quintana*	Europe, Russia, Ethiopia, North Africa, Mexico	Wartime epidemics among soldiers
Pediculosis (Lousiness, Vagabond's disease)	Extremely rare	Body louse Head louse Crab (pubic) louse	Infestation with one or more spp (var) of lice (Note *not* an infection)	Worldwide	Associated with poor hygiene, lack of clothes washing, and crowding
Skin diseases from secondary infections (Dermatitis, eczema, furunculosis, impetigo, pyoderma, *et al*)	Rare	Lice and man as mechanical vectors, e g, biting and scratching respectively	Staphylococci and streptococci and other bacteria	Worldwide	Secondary infections of lousy skin

[1]Body louse (*Pediculus humanus corporis*) and head louse (*Pediculus humanus capitis*) are closely related and head lice may also be vectors of febrile louse-borne diseases Crab or pubic louse (*Phthirus pubis*) is not
[2]Flea-borne and mite-borne forms of typhus fever also exist
[3]A tick-borne form of relapsing fever also exists

another human host Lice will die within hours or days (depending on the ambient temperature) if they do not find a new host Lice prefer a narrow temperature range and will leave a host whose skin temperature is too warm due to fever or too cold due to death The louse's preference for man and its aversion to abnormal temperatures (e g , fevers or chills of its host) causes the spread of louse infestation in the community

Adult lice have been recorded as moving at a rate of 9 inches (23cm) per minute, but they never move in straight lines Experiments have shown that a louse-free person lying in the same bed as a lousy person will begin to complain of lice in 5 to 6 hours (Busvine, 1969)

Lice live solely on blood When they are feeding, the skin of the host is pierced by parts (stylets) of the mouth of the louse, a salivary secretion to prevent coagulation of the host's blood is injected into the wound and up to one milligram of blood sucked out at a feeding

Lice can only be acquired, directly or indirectly, from an infected person The liklihood of acquiring an infection depends on the general prevalence of infestation in the community and the intimacy of human contact and crowding

Under modern civilized conditions, body louse infestations are very rare and are virtually restricted to people of obviously low standards of hygiene who rarely change their underwear and commonly sleep in their clothes Regular laundering of undergarments makes it impossible for body lice to survive (Busvine, 1969) Body lice are still quite prevalent in some communities with low hygienic standards whose residents are unable to wash and change their clothing

Head lice are much more prevalent than body lice and are found worldwide, including in the United States. Long, unwashed, and uncombed hair can result in a thriving nursery for lice and their nits (eggs) Fortunately, head lice are not the serious health hazard that body lice are

Water Supply and Lice

The relationship of water supply and lice, particularly body lice, already described, may be summarized to prevent or reduce lousiness, water should be readily available in sufficient quantity for frequent bathing and for washing of clothes Bathing loses its value for lousy persons if the old clothing carrying the lice and nits is put on again without being freed from the lice The impact of bathing and changing of clothing is enhanced when done at the same time within groups living in the same household Bathing and laundering and changing of clothes are required on a continuing community scale to be fully effective and to prevent reinfestation with body lice Total eradication of lice is preferable, but low levels of prevalence and of lice per person will generally suffice to prevent epidemic louse-borne disease.

The effect of clothes washing and changing on community prevalence of lice infestation was shown by a recent study in Ethiopia Prevalence of lousiness is as high as 97 percent among those who do not wash or change their clothing and as low as 14 percent among those who do As important as the prevalence, the average number of lice per infested person for those who wash and change their clothing at least once a week is a single louse (Sholdt, *et al* , 1979)

Prior to the development of insecticides such as DDT, bathing and disinfestation of clothing by physical measures, e g , heat, were common lice control measures Insecticides are today the method of choice for frank lousiness and have many advantages immediate effectiveness, low cost per person, minimal necessary action by population at risk, *et al* However, lice have proven their ability to develop resistance to insecticides and to readily reinfest communities when basic hygienic conditions are unchanged The majority of communities in developed countries were freed of louse-borne disease before the advent of chemical insecticides

Epidemic Louse-Borne Typhus Fever

Louse-borne typhus is an acute, highly infectious, febrile, exanthematous (characterized by a rash) disease which manifests itself in epidemic form In the absence of specific therapy, the case fatality rate varies from 10 percent to 40 percent and increases with age and malnutrition It is found in Mexico and Guatemala, the Andean countries, much of Africa and the Middle East, mountainous regions of Asia, and eastern Europe

The infectious agent, *Rickettsia prowazekii*, is transmitted from man to man by human lice, principally the body louse (*Pediculus Humanus* var *corporis*), but at times the head louse (*Pediculosis humanus* var *capitis*) (Faust, Russell, and Jung, 1970) The louse is infected (and dies within two weeks) by feeding on the blood of a typhus-infected person Infected lice excrete rickettsia in their feces and usually defecate at the time of feeding Man is infected by rubbing feces of lice into the wound made by the louse bite or into skin abrasions resulting from scratching Inhalation of dried infectious louse feces or dust from dirty clothes may account for some infections (Benenson, 1975)

Preventive measures include repeated applications of residual insecticides, e g , DDT or malathion, immunization (with annual booster dose), and improvement of living conditions, with provisions for frequent bathing and for washing and changing of clothes

Brill-Zinsser Disease

This disease, first observed by Brill in New York in 1910, was found by Zinsser in 1934 to be a mild, recrudescent form of louse-borne typhus (Woodward, 1977) The early confusion was due to the appearance of the disease in louse-free environments

Clinical recovery from an attack of epidemic typhus fever does not necessarily mean that the rickettsiae have been eradicated After years of quiescence the rickettsiae may again become activated Thus man himself serves as the carrier of the disease between epidemic outbreaks Thus return of body lice to an apparently typhus-free part of the world may result in new epidemics of typhus fever

Epidemic Louse-Borne Relapsing Fever

Relapsing fever is the name given to a disease characterized by 1, 2, or even 10 relapses of the primary febrile paroxysm There are two main forms, the epidemic form transmitted by body lice, and the endemic form, transmitted by certain ticks The infectious agent is *Borrelia recurrentis*, a spirochete

Symptoms include abrupt onset, shivering, headache, body pain, sometimes nausea or vomiting, fever of 102° to 104°F , jaundice in 20 to 60 percent and bronchitis in 40 to 60 percent of those attacked Temperature falls in 3 to 9 days and relapse may occur 11 to 15 days later Pregnant women abort With good conditions, case fatality is 5 percent or so, during war or famine, fatality may reach 70 percent (Wilson and Miles, 1975) Transmission of epidemic louse-borne relapsing fever is similar to that for typhus fever However, the louse lives longer, up to 40 days

Devastating outbreaks have occurred in Europe, during the Irish famine of 1846-50 and during World War I in Russia and central Europe An outbreak during the 1920s killed hundreds of thousands in northern Africa, over 200,000 in the Sudan alone The majority of current cases reported continues to come from Africa (Tarizzo, 1973)

Like epidemic typhus fever, "relapsing fever is associated with poor sanitation and personal hygiene, particularly overcrowding, undernutrition, and dirty, infected clothing" (Wilson and Miles, 1975)

Prevention and control measures are similar to those for epidemic typhus, however, no vaccine is available for relapsing fever.

Wolhynian Fever (Trench Fever)

A nonfatal, acute incapacitating, febrile, self-limiting infectious disease caused by *Rickettsia quintana* (syn. *R pediculi*, *R weiglii*, and *R wolhynica*) Epidemics occurred among soldiers in European battlefields in both World Wars Sporadic cases in areas of endemic foci probably go unrecognized Endemic foci of infection have been detected in Poland, Russia, Mexico, Ethiopia, and North Africa. The organism probably can be found wherever man and the human body louse co-exist Prevention is by louse control measures as for other louse-borne diseases

Pediculosis (Lousiness)

Pediculosis is infestation by human body lice, head lice, or pubic lice Pediculosis, especially with infestation by body lice, is a warning of the potential transmission of life-threatening disease such as typhus fever However, the cutaneous lesions resulting from lousebites invariably cause a desire to scratch the affected sites. Frequently the skin becomes scarred and at times thickened and bronzed by pigment, a condition known as *vagabond's disease* The saliva and feces of the louse may induce a dermal (skin) hypersensitivity

Skin Diseases

Lesions from lousebites and from skin irritation, sensitivity, and severe scratching may result in secondary dermatitis and infections with staphylococci, streptococci, and other bacteria, as manifested by eczema, furunculosis, impetigo, pyoderma, and other pathologic skin conditions Although rarely death-threatening, these conditions can be important in the aggregate For example, 10,000 (10 percent) of the British Second Army's total admissions to casualty stations in 1917 were for inflammatory skin conditions attributable to lice (Buxton, 1947)

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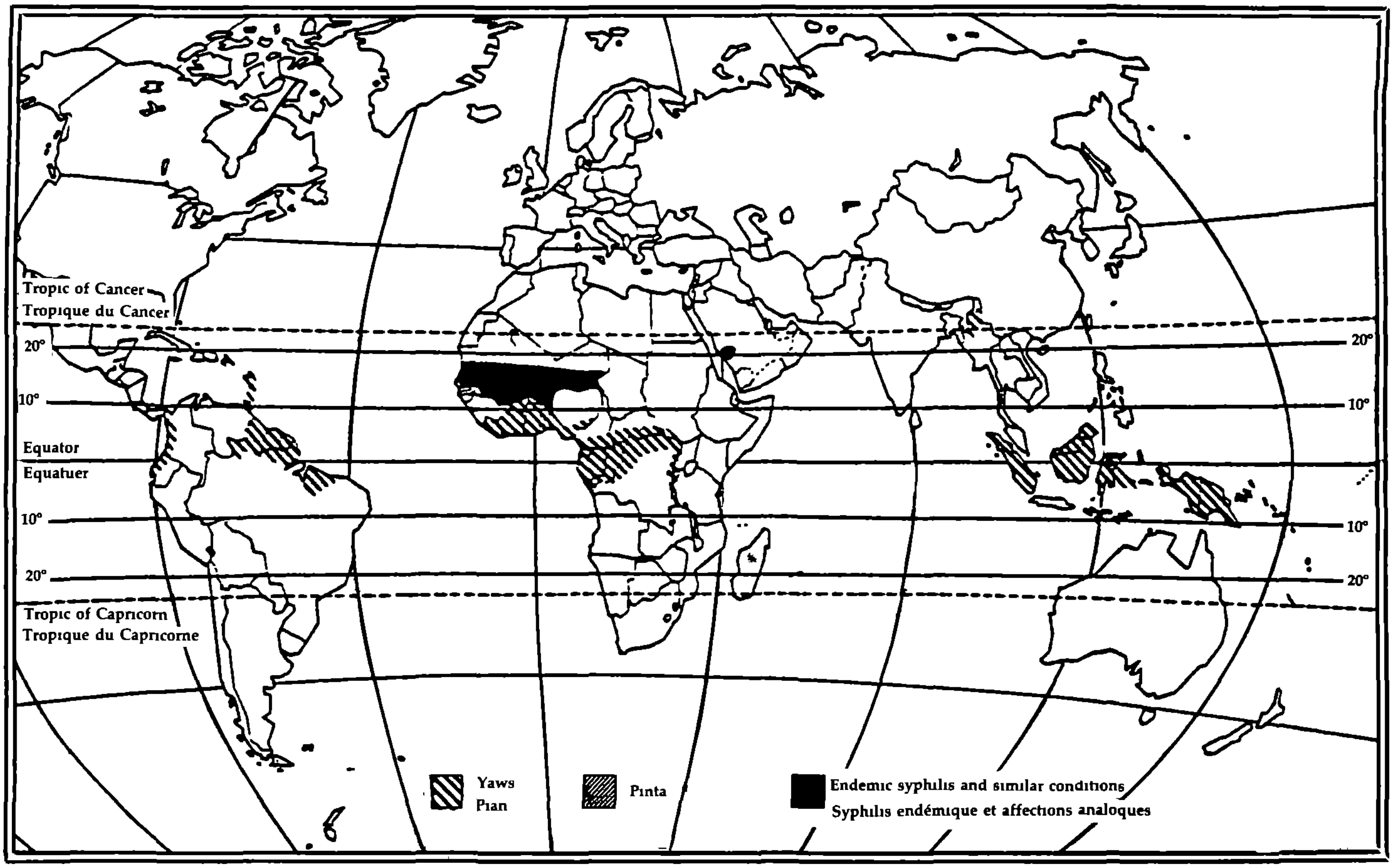
Nonvenereal Treponematoses: Yaws, Pinta, and Endemic Syphilis

Introduction

Yaws, pinta, and endemic syphilis (bejel) are diseases of man caused by infectious agents that are morphologically indistinguishable from *Treponetoma pallidum*, the spirochete that is the infectious agent of venereal syphilis. However, yaws, pinta, and endemic syphilis are not sexually transmitted They are diseases of children and are associated with poverty and with poor personal and community hygiene

Endemicity has declined with improved standards of living and of hygiene. Yaws was the target of a massive global campaign of penicillin treatment during the 1950-1960's However, nonvenereal treponematoses are still found over a wide area, as shown in Figure 3-2, primarily in tropical Latin America and the Caribbean, Africa, and southeastern Asia and the Pacific Yaws is found in humid areas and endemic syphilis in arid areas Recent WHO surveys of endemic syphilis in the Sahel region of Africa have found approximately 2.8 million of the region's 30 million people at risk (WHO, 1981) Yaws has resurged in parts of Africa and scattered foci persist in the Americas

Figure 3-2. Geographical Distribution of the Endemic Treponematoses in the early 1980's



SOURCE: WHO, 1981

Table 3-3. Etiology, Epidemiology, and Clinical Manifestations of the Treponematoses

	Venereal syphilis	*Endemic syphilis*	*Yaws*	*Pinta*
Organism	*T pallidum*	*T pallidum endermicum*	*T pertenue*	*T carateum*
Transmission	Sexual, transplacental[1]	Household contacts Mouth-to-mouth or via drinking, eating utensils	Skin-to-skin ? Insect vector	Skin-to-skin ? Insect vector
Usual age	Adult	Early childhood	Early childhood	Adolescent
Primary lesion	Cutaneous ulcer (chancre)	Rarely seen	Framboise (raspberry), or "mother yaw"	Nonulcerating papule with satellites
Secondary lesion	Mucocutaneous, occasional periostitis	Florid mucocutaneous lesions (mucous patch, split papule, condyloma latum), osteoperiostitis	Cutaneous papulo-squamous lesions	Pintides
Tertiary	Gumma, cardiovascular, and CNS lues	Destructive cutaneous osteoarticular gummas	Destructive cutaneous osteoarticular gummas	Dyschromic, achromic macules

[1] *Since the nonvenereal trepanematoses are usually acquired in childhood and treponemal bacteremia ceases with time, only in adult-onset venereal syphilis is there any likelihood of a mother giving birth to an infected child*

SOURCE: Holmes and Harnisch, 1977

Characteristics of the Treponematoses

Table 3-3 summarizes the etiology, epidemiology, and clinical manifestations of the treponematoses (Holmes and Harnisch, 1977). Transmission of endemic syphilis is of particular interest Considerable evidence suggests that common drinking vessels are an important transmission mechanism (Demis, 1977, Grin, 1953, Guthe, 1969, and Willcox, 1970) The infectious agent is transmitted from lesions in the mouth of the infected person The moisture of the cup enables the fragile spirochete to survive in its external environment until ingested by a new host

Nonvenereal treponematoses are rarely fatal but can be disfiguring and disabling As many as 10 percent of untreated yaws victims can be invalided (Guthe, 1969)

Role of Water Supply for Control of Yaws, Pinta, and Endemic Syphilis

At the close of World War II, there were perhaps 100 million people infected by yaws, with a prevalence of 25 percent in endemic areas of Africa, Asia, and Latin America (Guthe, 1969) Pinta and endemic syphilis were also widespread (WHO, 1981) Although the penicillin campaigns accelerated the reduction of prevalence, all three diseases were declining without direct attention as endemic areas achieved better environmental hygiene. The efficacy of water supply as a preventive measure for these diseases is well established The following quotes are illustrative

". an important factor in reducing the prevalence of yaws in a community, probably by reducing transmission, is the presence of a moderately readily available and adequate water supply . . . of about five gallons per head per day- . . more water conveniently located where water supplies may not be adequate at all times of the year" (Hackett, 1960)

"Health education should aim at improvement of personal hygiene (soap) and community hygiene (water)" (Guthe, 1979)

"Endemic syphilis is easily prevented by improving the general level of hygiene and the standard of living" (Demis, 1977).

"Simply introducing the use of soap and water has regularly been followed by a diminution in the number of cases of yaws" (Demis, 1977)

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Trachoma

Background

This disease is the world's leading cause of preventable loss of vision and blindness An estimated 400 to 500 million people are afflicted with trachoma, with two million blinded and eight million at risk of blindness (Helen Keller International, 1980, WHO, 1979, WHO, 1973) In areas of severe endemicity, uncontrolled trachoma may result in blindness in one percent or even up to three percent of the population (WHO, 1979)

The disease is widespread, and the worst affected areas are North Africa, the Middle East, and certain regions in Africa and Southern Asia Trachoma is a disease of low infectivity Its absence in physicians and tourists in epidemic areas suggests that long term, repeated exposure is necessary to establish the disease Unsanitary habits, lack of water for personal hygiene, overcrowding and abundant houseflies characterize endemic areas

The course of the disease varies considerably. In some cases, reinfections, possibly associated with hypersensitivity reactions and/or related infections (e g , bacterial conjunctivitis), may lead to progressive damage to the eye and ultimately to blindness Mechanical irritants, particularly dust and smoke, may play an important role

Pathology

Trachoma is a word derived from the Greek and may be literally translated as "rough eye" (Gilkes, 1962) The term is of considerable antiquity and was used by Hippocrates The disease is basically a severe and prolonged inflammation of the conjunctiva of the eye, with associated corneal lesions and scarring, which in their gross form are known as pannus [1] Later stages of trachoma may lead to cicatrization (scarring) of the conjunctivae, which may lead to gross deformity of the eyelids, progressive visual impairment and blindness. The margins of the eyelid may turn inwards (entropion) as well as the eyelashes (trichiasis). Lacrimation (tear function) may also be impaired. This process may develop insidiously and over decades

The infectious agent is *Chlamydia (Bedsonia) trachomatis*, a parasite with some properties of both viruses and of bacteria, e g , it multiplies only intracellularly, as do viruses, but contains both ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), as do bacteria (Wilson and Miles, 1975)

Epidemiology and Control

Trachoma is basically transmitted eye to eye in endemic regions, although venereal transmission is possible Susceptibility is general and there is no evidence that infection confers immunity (Benenson, 1981). No effective vaccine has yet been proven for field use (Holmes, 1981; Helen Keller International, 1980, *et al*)

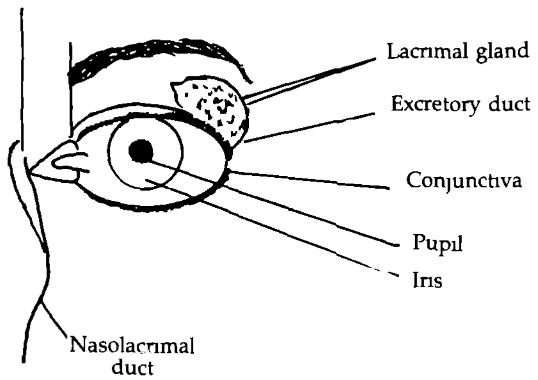
In endemic areas,children generally have active disease more frequently than adults. Severity of disease is often related to environmental conditions—lack of water, dust and dry sand, dry winds, flies, poor hygienic conditions, and overcrowding

Prevention and control measures include

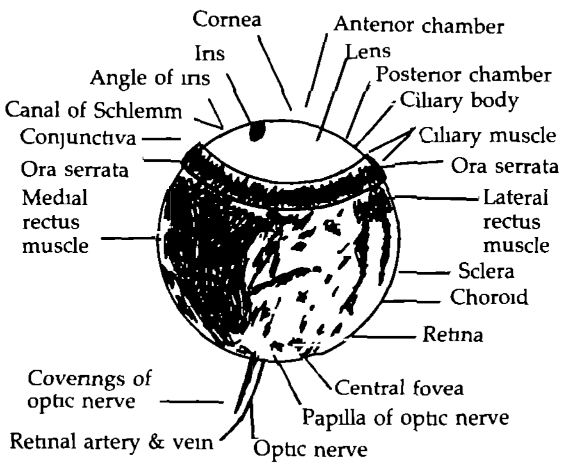
(1) Case-finding and treatment, especially of young children
(2) Health education, especially personal hygiene The risks of common wash basins and towels should be emphasized, as should the role of mothers in transmission
(3) Chemotherapeutic treatment with antibiotics The most extensively used is tetracycline ointments as oil suspen-

[1]The *conjunctivae* are the delicate membranes lining the eyelids and covering the eyeball The *cornea* is the transparent front part of the eye *Pannus* is invasion of the cornea by blood vessels and small, rounded masses of tissue during the healing processes, forming a veil over the corneal surface See Figure 3-3 "The Human Eye "

Figure 3-3. The Human Eye



THE LACRIMAL APPARATUS



HORIZONTAL SECTION OF THE EYE

SOURCE: Adapted from *Dorland's Pocket Medical Dictionary,* W B Saunders Co , Philadelphia, Plate XIII, 1977

sions Treatment requires repeated application over many months.

(4) Surgical treatment when tissues have been damaged or destroyed by the infection process or by scarring

(5) Improved basic sanitation, especially availability and use of soap and water

Water Supply and Trachoma

Most authorities are in general agreement that personal and public hygiene emphasizing the *use* of water is the most effective method for prevention or reduction of trachoma *Use* of water is emphasized An ample *quantity* of water should be readily *accessible,* i e , close at hand *Chlamydia trachomatis* can be transmitted directly by water, especially through use of common wash basins However, this is only one of numerous mechanisms for transmission Direct contact with discharges from infected eyes or materials soiled by such discharges (for example, a mother's apron used to wipe the faces of her children) is probably the most important means of transmission

Water's role in prevention is that when it is readily available, trachoma infections do not "take," i e , lead to manifestations of disease.

Three extant studies demonstrate this through quantitative field measurements

(1) Trachoma in the Ryukyu Islands during 1960s (Carter, 1968) Trachoma was six times more prevalent *(24 1%) in a* city without piped water to households than in another city (4.1%) with piped water to households. Trachoma prevalence in a village without piped water (42%) was almost ten times as high as prevalence in four villages with piped water (4 5%).

(2) Trachoma in Baribanki Bloch, Uttar Prasdesh, India (Misra, 1971) and (Cvjetanovic, 1980) Following introduction of a piped water supply in 1965, trachoma morbidity dropped 90 percent and conjunctivitis fell by 80 percent.

(3) Trachoma in Taiwan during 1970-71 (Assaad, *et al* , 1969). Trachoma prevalence in a population using water from household taps was 14 5 percent Prevalence increases to 24.1 percent for users drawing water from wells attached to their houses. When the population had to go 100 meters or more, the prevalence of trachoma doubled

Although the number of rigorous quantitative field studies is limited, the importance of water supplies in prevention and control of trachoma (and conjunctivitis) is widely recognized.

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SECTION 4

WATER CONTACT DISEASES

Introduction

Water-contact diseases are transmitted by skin contact with pathogen or toxin-infested water The most important of these diseases is schistosomiasis (bilharzia) Schistosome eggs in human excreta hatch on reaching water The resulting larvae must invade suitable snail hosts or perish Following a multiplication process within the snail, the free-swimming schistosome larvae (cercariae) escape from the snail, find, and invade man by penetrating his immersed or wetted skin

This important tropical disease infects over 200 million people, and its prevalence is probably increasing Current control methods, primarily drugs for those infected and chemical control (molluscididing) of snails, have had limited success Both of these methods require periodic repetition

Controlling schistosmiasis by limiting the need for human water contact through provision of public water supplies has shown promise in St Lucia, Brazil, Puerto Rico, and South Africa and is being tested in Swaziland by UNEP/UNICEF/WHO

Leptospirosis and tularemia are the next most important contact diseases One portal of entry for their causative agents, *Leptospira serotypes* and *Francisella tularensis*, is the penetration of abraded skin or mucous membrane when man is immersed in water contaminated by infected animals Because they are also transmitted by drinking water, leptospirosis and tularemia are reviewed in Section 2

Many diseases can be acquired during occupational or recreational exposure to open water Most of these are due to infections of the skin, eye, ear, nose, and throat, i e , the surfaces and orifices of the body

Table 4-1 presents a summary of these diseases

Schistosomiasis

Background

Schistosomiasis (Bilharziasis[1], snail fever) is a parasitic disease of man transmitted in over 70 countries of the tropics and subtropics Authoritative estimates by the World Health Organization are that over 200 million people are currently infected An additional 600 to 800 million are constantly exposed to the risk of infection

The parasitic worm or *Schistosoma*[2] *must* spend part of its early life in a water environment in order to be transmitted from one person to another It must also infect an intermediate snail host before infecting man, the definitive host Both infections require water contact Thus the dynamics of schistosomiasis transmission are intimately related to water-resources development, including irrigation, hydro-electric power, dams, reservoirs, fisheries and other development efforts Such development, without proper attention to potential schistosomiasis transmission, may actually increase the burden of schistosomiasis through increased human exposure to infection and creation of environments more favorable to the parasites and their intermediate snail hosts

Table 4-1. Water Contact Diseases[1]

Disease or Syndrome	*Remarks*
	Direct Contact
Drowning	7,000 deaths by drowning per year in the U S
Enteric Disease	Ingestion during bathing or swimming
Granulomal Skin Infections	Mycobacteria in water. Swimming or occupational exposure
Ichthyotoxism	Poisonous coelenterates or fish
Hirudiniasis	Aquatic leeches
Leptospirosis	Zoonosis, contact of abraded skin or drinking of water contaminated by infective rat urine.
Otitis	Ear infection from immersion
Pharyngoconjunctival Fever	Virus infection associated with swimming pools
Primary Amoebic Meningoencephalitis	Rare but fatal disease of swimmers and divers
Rhinosporidiosis	Fungal disease marked by large polyps often of nasopharynx.
Schistosomiasis	Free-swimming cercarial larvae penetrate skin, over 200 million people infected worldwide The most important disease transmitted by water contact
Sinusitis	Sinus infection from immersion.
Swimmers' Itch	Avian schistosomiasis, aberrant in man.
Tuberculosis	Infection from near-drownings
Tularemia	Inoculation of skin with water contaminated by blood or urine of infected animals
	Indirect Contact
African Trypanosomiasis (*T b gambiense* only)	Riverine tsetse flies (e g *G palpalis* live and bite near waterholes, especially in dry season).

[1]Transmission by water contact with skin, eye, or cavities of head

While much exposure is occupational for farmers and fishermen, many, if not the majority, of infections are through exposure of women and children during bathing, laundering, drawing of drinking water, and other domestic activities The International Water Supply and Sanitation Decade (1981-90) will offer many opportunities for reduction of schistosomiasis as well as classical waterborne enteric diseases

[1] Often used in Africa after Dr Theodor Bilharz, a German physician, who during a postmortem examination in Cairo in 1851 first identified one of the schistosome worms responsible for the disease In 1966, the World Health Organization officially designated the name as schistosomiasis in the interest of uniformity

[2] Greek for "split, divided body" after the appearance of the adult male worm, which is flat, with the sides of its body inverted so as to form a groove in which it carries the female

Table 4-2. Examples of Increased Prevalence of Schistosomiasis Resulting from Water Resource Development Projects

Country	Project (year completed)	Pre-project prevalence (percent)	Post-project prevalence (percent)	Schistosome species
Egypt	Aswan Dam (first) (1900)	6%	60% (3 yrs later)	*S haematobium* *S mansoni*
Sudan	Gezira Scheme (1925)	0%	30-60% (15 yrs later)	*S mansoni* *S haematobium*
Tanzania	Arusha Chini (1937)	low	53-86% (30 yrs later)	*S mansoni*
Zambia and Rhodesia	Lake Kariba (1958)	0%	16% adults 69% children (10 yrs later)	*S mansoni* *S haematobium*
Ghana	Volta Lake (1966)	low	90% (2 yrs later)	*S haematobium*
Nigeria	Lake Kainji (1969)	low	31% (1 yr later) 45% (2 yrs later)	*S haematobium*
Iran	Dez Pilot Irrigation Project (1965)	15%	27% (2 yrs later)	*S haematobium*

SOURCE: Rosenfeld, P L , and Bower, B , 1978

Schistosomiasis is spreading, its severity is increasing in established foci, and successful control programs have been implemented in only a few areas of the tropical world While direct mortality from the disease is low, the sheer size of the epidemiological phenomenon, the high global prevalence, and the multiplicity of the chronic pathological sequalae of infection represent a major burden on the public health and medical services in countries where transmission is endemic

Table 4-2 gives some examples of the association of schistosomiasis with water resources development

Pathology

Schistosomiasis is the state of infection with worms of one or more of the species of *Schistosoma*, usually *S hematobium*, *S mansoni*, or *S japonicum*

While a short-lived itchy rash of the skin where the schistosome larvae (cercariae) penetrated may develop, along with a temporary fever and cough, 2 to 4 weeks following the infection, the major damage to the body results from long-term (typically 2 to 5 years) egg-laying by the adult female worm and the response of the body to the eggs and the migration of the eggs Eggs that lodge in human tissues may cause development of fibrosis, granuloma, lesions, ulceration, bleeding, diarrhea, ascites (accumulation of serous fluid in the abdomen), liver and spleen enlargement, and other major disturbances Occasionally aberrant eggs may result in brain, lung and heart complications and even paraplegia (paralysis of the lower body)

Egg laying by *S mansoni* and *S japonicum* occurs in the small mesenteric veins of the bowel Egg laying by *S hematobium* is in the small veins of the bladder, i e , the vesical veins The relative locations of egg-laying characterize the common course of the disease In *S hematobium*, blood commonly appears in the urine Late stages of these infections may manifest urinary tract diseases, such as calcified bladders, non-functioning kidneys, and ureteric deformity. Many authorities suggest a strong correlation of *S hematobium* and cancer of the bladder *S mansoni* and *S japonicum* eggs have a greater predilection for the liver and spleen and for portal hypertension

The seriousness of the infection is proportional to the number of eggs and, therefore, to the number of adult, egg-laying worms Unlike bacteria, schistosomes cannot complete their life cycle without re-entering the external water environment Thus one cercarial larvae entering the body can develop into only one adult worm (A significant percentage will not mature) Infrequent infection by only a small number of worms generally does not result in significant illness Ordinarily the disease develops slowly as more and more worms are acquired during childhood, with the maximum number reached at about 15 to 20 years of age

The worm/egg/disease relationships of schistosomiasis are important in evaluation of the seriousness of schistosomiasis transmission and the efficiency of control measures Three evaluation measures in common use are the following

Prevalence:	percent of the population testing positive for schistosome infection (for example, excreting eggs as determined by a urine or stool examination)
Transmission	survey of prevalence by age in children repeated at yearly intervals The actual prevalence rate is compared with the "expected" rate based on previous years If today's 10-year olds have the same prevalence as today's 12-year olds had two years ago, transmission is constant, if less, transmission is declining, if more, increasing
Intensity	as for prevalence but refined to include for each person the number of eggs per unit of urine or feces

Ordinarily, intensity increases with increasing prevalence Situations may exist where prevalence appears high but intensity may confirm that most of the schistosomiasis is asymptomatic or aclinical

Symptoms

During the invasive stage, symptoms may or may not occur A fever and cough may develop 2 to 4 weeks after exposure, lasting only a few days

After egg laying begins, *S hematobium* victims micturate more frequently than normal with the last portion of urine containing blood Micturition may be difficult or painful *S mansoni* and *S japonicum* infections are characterized by diarrhea with blood, feeling of lassitude or weariness, sleepiness, lack of concentration, dull aches, cramps, and loss of weight

Positive diagnosis can be assured only when living ova (eggs) are found in the stool or urine or by rectal biopsy Mass programs may rely on serological tests based on the detection of an antibody-antigen reaction by the body The most widely used is the skin test, in which a minute amount of schistosome proteins is injected under the skin Formation of a lump is a strong positive indication of infection

Treatment

Drugs have been available for over 60 years. However, available drugs may be toxic, have serious side effects, be contraindicated for specific patients, require medical administration, be expensive for developing countries, and not be universally effective

There is no drug yet available to prevent infection, either through prophylaxis or by immunization Prior infection does not prevent the cured patient's being reinfected if he or she returns to a schistosome cercariae-infested environment Further, because of the huge numbers of eggs that a single infected person can discharge to the environment, thereby keeping the transmission cycle alive, treatment must necessarily be on a community basis to stop transmission

Public Health Impact

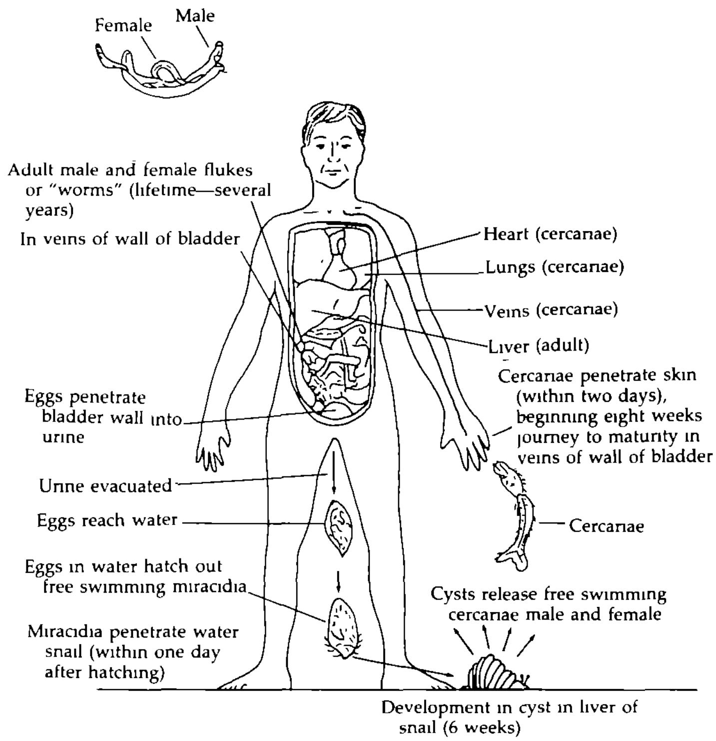
Mortality (deaths) attributable directly to schistosomiasis is generally low However, in endemic regions, schistosomiasis is a contributing factor to many syndromes and diseases, ranging from liver and kidney diseases to cancer Severity of infections is generally proportional to cercarial exposure, worm load, and intensity of egg laying Significant geographical differences exist even for the same schistosome species *S japonicum* is generally the most severe infection and the most difficult to cure The disease, untreated in a single victim, may last for many years, with increasing ill effects due to cumulative damage to tissues and to repeated re-exposures

Transmission Cycle of Schistosomiasis

An understanding of the life cycle of the schistosomes is essential to understanding transmission and control of the disease of schistosomiasis Figure 4-1 shows a schematic of the cycle for *S haematobium* With the exceptions previously noted, i e , egg ovi-position in the small veins of the bowel and egg evacuation via fecal evacuation, Figure 4-1 applies also to *S mansoni* and *S japonicum*

Sexually mature schistosomes found in man, the definitive host, vary in length from about 7 to 26 mm and in width from about 0 3 to 1 mm and have the appearance of elongated threads Once mated, the male and female schistosomes proceed in pairs, *S mansoni* and *S japonicum* generally to the veins of the bowel and *S haematobium* generally to the veins of the bladder, where the females deposit their ova or eggs A few eggs are carried in the blood stream to the liver, lungs, and other parts of the body, but most go through the vein walls into the surrounding tissues

Figure 4-1. Life Cycle of *Schistosoma haematobium*



SOURCE: McJunkin, 1970

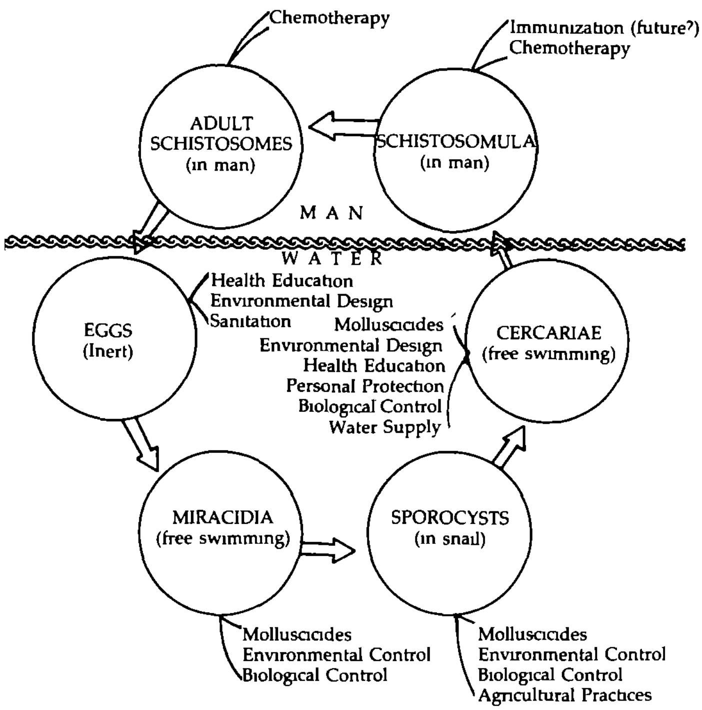
Some become trapped in the tissues and die, but others work their way into the bowel or bladder and leave the body in feces or urine As the disease progresses, tissues around the veins thicken and the proportion of arrested eggs increases

To survive, the eggs (70-170 microns long, 40 to 70 microns wide) must reach water within a month, a task greatly aided by inadequate sanitation The change of osmotic pressure in the water results in the hatching from each egg of a small, ciliated, swimming larva known as a "miracidium " Miracidia must penetrate the body of a suitable freshwater snail (the intermediate vector host) within 24 hours or die

In the snail the miracidia undergo an essential development stage, lasting 4 to 8 weeks, and, by a process of asexual reproduction, each miracidium may produce a thousand larvae known as cercariae Liberation, or "shedding," of cercariae from the snail may continue over a period of several months The barely visible fork-tailed cercariae may average 0 4 to 0.5 millimeters in length, swim about vigorously, tail first, for 24 to 72 hours without feeding and die if they fail to contact their definitive host, which as a rule must be man for *S mansoni* and *S haematobium* and is often man for *S japonicum*, but may also be dogs, cats, rats, cattle, pigs, deer, or horses

Upon making contact with human skin, the cercariae attach by means of suckers and penetrate their host within several minutes Within hours they are in the blood stream and are eventually carried to the liver, where they grow to maturity within a few weeks They mate and travel together against the flow of blood to small blood vessels in the wall of the intestine or bladder Egg production starts about six weeks after penetration of the skin by the cercariae The infection has been known to persist for over 30 years in man, but the life-span of the schistosomes is generally much less than that, typically from 1 to 5 years

Figure 4-2. Life Stages of Human Schistosomes Showing Possible Entry Points for Control of Transmission



Species of schistosomes which are parasitic in other mammalian hosts may produce infections in man. These include *S bovis*, a parasite of cattle and sheep and found in Africa, *S mattheei*, a parasite of domestic and wild animals also found in Africa, *S intercalatum*, found in Zaire, *S. margrebowi*, a parasite of Central African antelopes and practically indistinguishable from *S japonicum*, and possibly *S rodhaini* These animal schistosomes are of relatively little public health importance

Control Measures

The six stages of the life cycle of human schistosomes, together with possible control measures for each, are shown schematically in Figure 4-2 Complete disruption of any one stage would terminate transmission Four stages occur generally in a water environment (eggs are initially deposited in the human host, then found in the host's excreta, but they must ultimately find water, sporocysts of *S japonicum* are specific to the amphibious snail genus *Oncomelania*) The worms may be attacked directly using drugs (chemotherapy); classical sanitation (protection of the snail from infection), creation of a land environment that limits contact with water (protection of man), and creation of a water environment unfavorable to snail vectors (use of toxic chemicals to destroy snails or habitat modification, i e , environmental control)

Snails

Before it attacks man, each schistosome worm lives as a parasite of a snail Thus a water habitat favorable to *specific* snail hosts is essential Environmental changes in snail habitats may result in increased or decreased transmission of schistosomiasis, depending on their effect on the vector snails Schistosomiasis control projects, and especially those using environmental, biological, or chemical control of snail vectors require project field expertise in snail biology (malacology) and identification

Schistosomiasis, Man, and Water

Role of Water Contact

Three animals—the parasites, the snails, and man—are involved in transmission of schistosomiasis Most pest control programs have emphasized attacks on the parasites (chemotherapy) and the snails (molluscicides) Recent years have seen increasing interest in working with the third and most intelligent animal, i e , man How does human behavior affect transmission of schistosomiasis? Can human behavior be modified so as to disfavor schistosomiasis transmission?

On theoretical grounds the answer is clear If man avoids skin contact with water containing schistosome cercariae or if he avoids contaminating his water resources with his feces or urine (and thereby schistosome eggs), the cycle of transmission of schistosomiasis would be broken

Observations of human water contact in areas endemic for schistosomiasis indicate the following

(1) Much contact is occupational—for males primarily through agricultural and fishing activities, for females through collection of domestic water supply, washing of cooking utensils, and laundering of clothes

(2) Much contact by children is through bathing and playing For younger children, contact often occurs while accompanying their mothers during collection of water, washing, etc.

(3) For adults water contact activities are often essential to their livelihood, e.g , farming and collection of drinking water These adults are generally members of the "poor rural majority."

(4) The risk of infection for different water contact activities depends on the extent of body surface exposure, duration of contact, and the time of day due to the diurnal shedding of cercariae. Cercariae of *S japonicum* are shed at night, whereas those of *S mansoni* and *S haematobium* are released during the daylight hours

Washing of clothes may be associated with prolonged water contact of hands and legs This activity is frequently performed from mid-morning onwards and thus at the peak period of cercarial density While the women are washing, children accompanying their mothers to the washing sites usually splash and play in the water for several hours, often with a high degree of body exposure at a time of maximum cercarial density Bathing carries with it a considerable risk of infection since it involves total bodily exposure even if for only a short period of time (Jordan and Unrau, 1978)

(5) In general, females have more frequent water contacts than males, and children have more water contact than adults

(6) A similar study in St Lucia showed that important water contact activities for the males were mainly swimming and bathing and for the females it was clothes washing, bathing and swimming These activities accounted for 66 percent of the contacts and 95 percent of the contact time (Dalton, 1976)

Importance of Site Locations

One important method of limiting human contact with infective watercourses is to increase the distance between these components of the transmission cycle The settlements need to be sited away from canals and natural watercourses and provided with their own adequate supplies of safe water This is most easily accomplished in the planning and design phase of a new scheme

In connection with Egypt's Aswan High Dam it was recommended that new canals be constructed at least 500 meters away from villages (Ayad, 1965) That communities located some distance away from infected watercourses have lower prevalence than those nearby has been documented In a study of physical factors related to schistosomiasis in children in the Sudan Gazira, the only factor which appeared to influence the incidence of infection was the distance (1000 meters or more) of the village from the irrigation canal (Greany, 1952) This supports the theory that "convenience" is one of the most effective motivating forces on human behavior It must be easier to get at safe water than unsafe water, both for consumption and clothes washing

In the Philippines the snail habitats nearest to housing were found to have the highest infection rates (Hairston, 1973) Consequently the siting of residential areas away from water courses results in two-fold actions which complement each other and will go a long way to reduce infection in both man and snail

Physical barriers may also be used to alter the water contact pattern In South Africa (Pitchford, 1970) human access to potentially dangerous water was reduced in the immediate vicinity of habitations by fencing dams and streams and by building fenced bridges over streams

Use of pipes to convey irrigation water and for drains is highly desirable due to low transportation losses from leakage and evaporation This practice limits the human water contact. In addition, closed conduits have lower maintenance costs and eliminate weeds, insect and snail habitats Pipes cannot be used in large canals having capacities over 10 cu meters/sec The initial cost is high, but in some areas the cost can be justified by the saving of land and protection of the population In the Nile Delta an estimated 7 percent of the usable land is taken up by rights-of-way for canal and drains (Lanoix, 1958). But for measures that limit human contact to be successful, alternate water supply sources for domestic and recreational purposes must be available

Health education is a desirable but insufficient means of avoiding cercariae or environmental contamination The most successful programs have emphasized passive participation by the population at risk, e g , a good water supply—closer, more reliable, and more convenient—to replace trips to canals, streams, or lake-shores

Role of Community Water Supplies

Recognizing the role of human contact with water supporting infective snails as a prerequisite for continued transmission of schistosomiasis has prompted many suggestions for reducing the contact. A study of environmental factors in Egypt (Farooq, *et al.*, 1966) concluded that a more abundant piped water supply distribution would result in a diminishing incidence of schistosomiasis and certain other infections. As an alternative to continued contact with cercariae-infested water bodies, a safe and adequate water supply for domestic and recreational use rates a high order of priority, however, the effectiveness of water supplies as a schistosomiasis control measure is not as well documented

In Japan the incidence of infection tended to decrease wherever safe water was supplied for drinking, washing and bathing (Yokogawa, 1974)

The provision of safe potable water and simple swimming pools, along with fencing nearby infested stream, in an endemic area of South Africa appeared to be the reasons for gradual reduction in prevalence of *S haematobium* and *S mansoni*, following the start of these measures. No comparison area was available for study (Pitchford, 1970)

In Brazil, evidence of reduced transmission was obtained following the provision of well-water, laundry, shower and latrines Some reduction was also noted in villages without these facilities but to a much lesser degree (Barbosa, 1971).

The effects of a domestic water supply on the transmission of schistosomiasis was investigated in a detailed pilot study in St Lucia which involved household water supplies, communal laundry-shower units, and simple swimming pools (Unrau, 1975, Jordan, *et al* , 1975, 1978). Five rural communities with a total population of about 2000 were provided with a household water supply In addition, laundry-shower units and simple swimming pools were located at strategic locations in the communities Water contact studies made under similar conditions as pre-controlled studies showed a reduction of 82 percent in the number of contacts and 96 percent reduction in contact time a year after water was supplied to the first village. (See Table 4-3)

Table 4-3. Number and Duration of Water Contacts Before and After Water Was Supplied in Grande Ravine

	1969		*1970*	
Age	*Number of Contacts*	*Total Time (Minutes)*	*Number of Contacts*	*Total Time (Minutes)*
0-4	48	2,320	3	1
5-9	104	3,299	9	9
10-14	84	2,767	23	31
15-19	71	1,414	5	89
20-29	38	953	3	81
30-39	21	536	7	6
40-49	2	89	5	156
50	7	189	11	70
Total	375	11,563	66	443

Observations were made on the same day of the same months in the two years (Dalton, 1976)

Figure 4-3. Incidence of New *S. mansoni* Infections Before and After 5 Years of Water Supply in Grande Ravine, St. Lucia (Unrau, 1978)

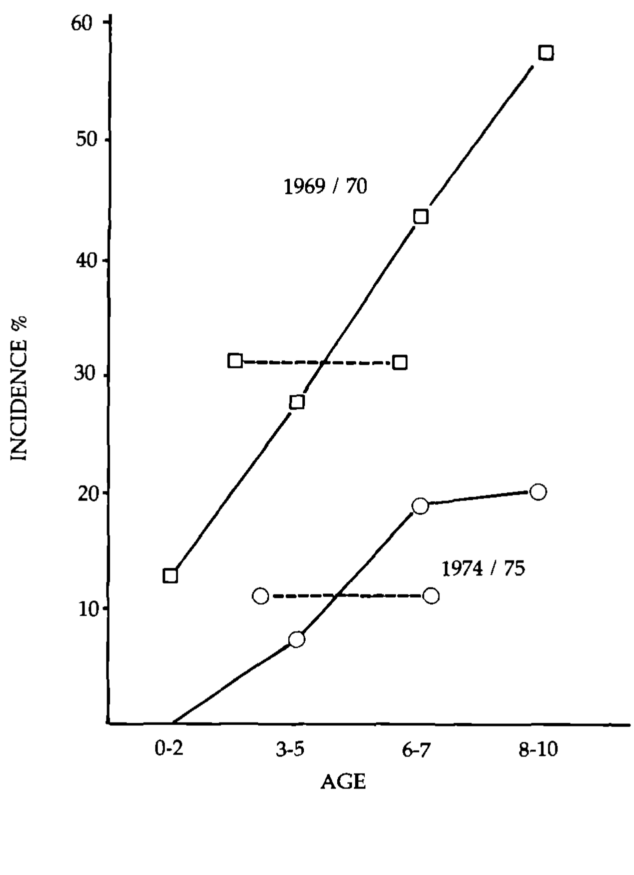
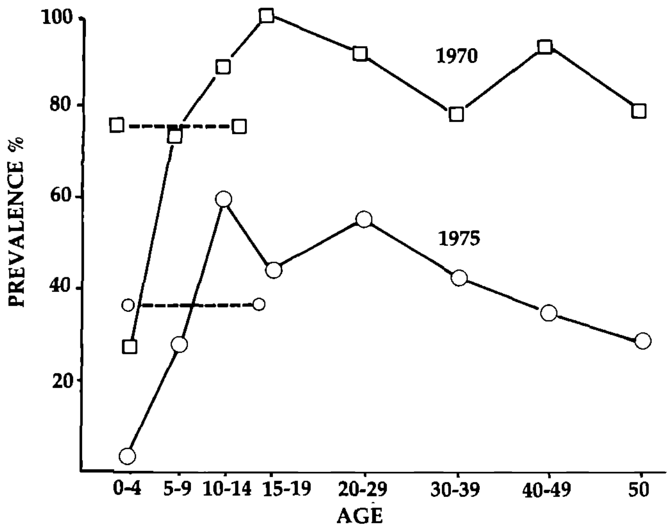


Figure 4-4. Prevalence of *S. mansoni* Infections After 5 Years Water Supply in Grande Ravine, St. Lucia (Unrau, 1978)



The change in incidence of new S *mansoni* infection in children up to ten years old living in the first village to be supplied with water fell from 31 percent to 12 percent after five years of water supply (See Figure 4-3.) The change in prevalence rate for all ages in this same village dropped from 72 percent to 36 percent in five years of water supply Changes in prevalence are registered more slowly because the infection of S *mansoni* is retained for many years (See Figure 4-4)

The intensity of S *mansoni* infection as measured by egg output is relevant because numbers of eggs excreted are related to the degree of contamination of the environment and also because people with light infection may have very little health impairment A measurement of the environmental pollution with S *mansoni* eggs is obtained by using the sum of the prevalence multiplied by the intensity of different age groups and the proportion of the age groups in the population to develop an index of potential contamination.

The intensity of infection was generally higher in the project area than in the comparison area prior to the water installation Over a five year period the potential contamination was reduced by 70 percent in the communities provided with a water supply. Hence, the chances of becoming infected by water contact were greatly reduced

The comparison area included six settlements in the same valley, where the government of St Lucia had installed a water supply comprised of communal standpipes at 200 to 300 meter intervals along the main road. All indices of infection increased in the comparison area during the same five-year study period, and the water supply system had no effect on transmission of schistosomiasis, even though this source provided essentially all the water for home use The rivers continue to be used for washing, bathing and swimming

The experimental water project in St Lucia has demonstrated that impressive results can be obtained in the reduction of transmission of schistosomiasis when adequate, reliable and conveniently delivered water supplies are available The water supply in the comparison area was unreliable, inadequate, and inconvenient during the study period and thus had no effect on the transmission of schistosomiasis Not only was there a reduction in the prevalence of infection but also a reduction in the intensity of infection, which may be more important over a longer time span The project also demonstrated that conveniently delivered water can change old customs and habits, such as washing and bathing in the river As a result of the reduced water contact, not only is infection prevented but contamination of the water is decreased

Aside from the direct benefit associated with safe water supplies, there are many other "quality of life" benefits which place water supply on a high priority when community improvements are considered Because water supplies are not disease specific, local authorities may find them more acceptable when interested in the broad spectrum of social and health programs (Unrau, 1978)

One of the conclusions in a report on 25 years of schistosomiasis control in Puerto Rico (Negron-Aponte and Jobin, 1979) was that water supply improvement accounted for 80 percent of the decrease in skin test positivity in areas without snail control The data showed a direct relation between decreased schistosomiasis as measured by skin tests and water supply improvements

Effectiveness of Water Treatment Processes in Removing Cercariae

Storage

Storage can provide simple and effective water treatment under favorable conditions Storage can be valuable in the control of schistosomiasis, inasmuch as the miracidia must find the intermediate host, the fresh water snail, within a few hours after hatching and the cercariae from the infected snail must find a mammalian host in less than 48 hours in order to survive In practice, penetration of the skin usually takes place within 24 hours. Thus two days' storage capacity is sufficient to constitute a significant barrier to transmission, provided infected snails do not enter the reservoirs

The effect of the total time taken for water to pass through the system (from collection through delivery) is such that if it exceeds two days, no live cercariae will be delivered in the water

Ample storage is also necessary to ensure an uninterrupted supply, avoiding the possible need for users to resort to contaminated sources Any storage period will reduce the number of organisms, but some short circuiting of the water in a reservoir is difficult to prevent and, therefore, treatment should not rely solely on storage

Coagulation, Flocculation and Sedimentation

A commonly used process for domestic water treatment is clarification by means of a coagulant and sedimentation Tests performed to determine whether schistosome cercariae are affected by the clarification of water by coagulation and sedimentation indicate that although some cercariae are entangled in the floc formed, they soon free themselves to return to the supernatant These results suggest that the use of aluminum sulfate alone or with lime is not effective against cercariae (Leiper, 1916, Witenberg and Yofe, 1938, Jones and Brady, 1947, Pellegrino, 1967)

Filtration

One of the most important and universally used forms of water treatment is filtration. Various types of filters can be used to improve the physical, chemical, and bacteriological quality of domestic water

The two principal types of filters used in community water supplies are the slow sand or biological filters and the rapid sand filters

Attempts to use sand filters for removing the schistosome larvae are not new (Leiper, 1916), and some of the past laboratory experiments with vertical sand columns reported negative results (Leiper, 1916; Witenberg and Yofe, 1938) Other references (WHO, 1970, Wagner and Lanoix, 1959, Benarde and Johnson, 1971) state that cercariae are removed by sand filtration The reasons for the differing reports are speculative, but may in part be due to the great variety of filtering media and experimental procedures used Most of these tests were conducted with a clean, vertical column of sand Since filtration is more involved than simply straining a fluid through a sand bed, there remains some uncertainty of the applicability of test results to field situations

Disinfection (Clorination)

The final method of treatment is water disinfection Although water can be disinfected by boiling, this is difficult, tedious, and expensive in localities where fuel is scarce or boiling is done in charcoal pots Chlorination is usually the cheapest method, but the chlorine supplies must be reliable for there is little value in spasmodically treating a supply

The World Health Organization has stated that 1 0 milligram per liter of residual chlorine, maintained for thirty minutes, will kill all cercariae without reference to the related pH of the water

Several factors may effect the cercaricidal activity of chlorine Perhaps the most important are water pH and contact time. Failing to take them into account may affect the value of chlorine dosages (Witenberg and Yofe, 1938) Some of the early experimental work produced inconsistent and conflicting results, as no attention was given to pH and the contact time (Pellegrino, 1967). Frick and Hillyer (1965) found the minimal free chlorine concentrations to inactivate *S mansoni* cercariae in 30 minutes at 20°C were 0.3 mg/l at pH 5 0, 0 6 mg/l at pH 7 5 and 5 0 mg/l at pH 10 0

Sanitation

The basic reason for transmission of schistosomiasis is the low-level sanitation that allows the schistosome eggs to enter water containing susceptible snails It follows that if the safe disposal of human wastes could be accomplished, it would eliminate not only schistosomiasis but many fecal-borne infections

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Diseases Associated with Swimming

Surprisingly, perhaps, bathers can swim in waters that are heavily sewage-laden and not contract diseases, apparently because little of the water is ingested Sewage-laden water is a potential source of organisms that cause enteric disease (Cabelli, 1978, 1979) Mallman (1970) lists numerous typhoid outbreaks associated with swimming in fresh and sea waters

Swimming pools present a somewhat different setting—pollution is limited to those organisms discharged from the body of the swimmer, dilution is limited, and disinfection with chlorine is the usual practice

Inflammations of the ear (otitis), sinuses (sinusitis), eye (conjunctivitis), and skin (dermatitis) are not uncommon A skin infection of abrasions, usually on knees and elbows, known as "swimming pool granuloma" also is found among pool users (and occupationally as well) It is caused by *Mycobacterium balnei* (Feldman, 1974) A mild viral infection, of the nose, throat, and eyes known as pharyngoconjunctival fever is also associated with swimming pools (Bell, 1957)

"Swimmers' itch," also called schistosome dermatitis, is found in swimmers and waders in several areas. This is an Avian schistosomiasis in which cercariae attack the skin of man but are unsuccessful in establishing themselves The itch is an allergic reaction Most skin infections of swimmers are mild and heal rapidly (Hicks, 1977).

Ichthyotoxism (poisoning by fish) is occasionally a threat to swimmers or fishermen who encounter the toxins or venoms of jellyfish, eels, coelenterates or certain fish species.

A rare but often fatal disease of divers, particularly, is "primary amebic meningoencephalitis " Certain pathogenic amebae species may enter the brain through the upper nasal cavities and the cribiform plate with dire consequences (Chang, 1972).

Cases of tuberculosis have been documented for swimmers in highly polluted water who have come close to drowning (Miller and Anderson, 1954, Greenberg, 1957)

Rhinosporidiosis is more an occupational disease than a recreational one Found in India, and in a few other areas, among workers who spend much of their time in streambed sand and gravel quarries, it is characterized by the growth of sometimes grotesque, large polyps in the nasal cavities.

Blood-sucking leeches are also found in some natural waters and may attach themselves to the skin or to the membranes of the throat if ingested in drinking water

But the most serious disease associated with swimming, in endemic areas, is schistosomiasis

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SECTION 5

WATER HABITAT VECTOR-BORNE DISEASES

Introduction

These are diseases which depend for transmission during part of the life cycles of their pathogens on animal vectors which live all or part of their lives in or near a water habitat The archetypes are schistosomiasis (associated with snails), malaria (associated with mosquitoes), and onchocerciasis (associated with aquatic flies) These and others are major public health problems in the developing world

Insect vectors directly transfer the pathogens through their biting and blood-sucking activities Snail vectors do not bite but liberate free-swimming larval forms which penetrate the immersed skin of man, or which invade aquatic animals later eaten by man, or which encyst on aquatic vegetation and are inadvertently eaten by man In a few diseases (but *not* schistosomiasis), transmission to man is by his ingestion of infested snails.

The more important of these diseases are described in Table 5-1

Snail Vector Diseases

Schistosomiasis

The most important of these is schistosomiasis This disease is described in some detail in Section 4, "Water Contact Diseases," including the role of snails in the transmission of the disease However, there are several other significant diseases for which various species of aquatic snails are vectors

Clonorchiasis

Also known as Chinese or Oriental liver fluke disease, clonorchiasis is a chronic disease of the bile ducts, which may follow ingestion of the trematode, *Clonorchis sinensis* Toxemia, loss of appetite, diarrhea, and a sensation of abdominal pressure are early symptoms Severe cases may have bile duct obstruction, cirrhosis, progressive ascites, and edema but are not often fatal. The disease is found in Asia—China, Japan, Korea, and Vietnam

Man is infected by eating raw fish containing encysted larvae. Fish culture in fecally contaminated ponds fosters transmission of the disease Dogs, cats, and some other animals may also be infected Certain species of snails are the first intermediate hosts, fish the second

The disease could be readily prevented by thorough cooking of fish However, food habits are difficult to change and the cost of cooking (or deep frying) is prohibitive for many Public awareness may be helpful Sanitary disposal of feces to avoid contaminating sources of food fish is also important

Table 5-1. Water Habitat Vector Diseases[1]

Disease or Syndrome	*Remarks*
Snail Vector Diseases	
Schistosomiasis	Major tropical disease transmitted through direct contact and penetration of immersed skin by schistosome cercariae 200 million people are infected
Clonorchiasis (Asiatic liver fluke)	Human infection by eating raw or partly cooked infective fish
Opisthorchiasis (Cat liver fluke)	Human infection by eating raw or partly cooked infective fish
Fascioliasis (Liver fluke)	Human infestion by eating raw, infective aquatic plants, especially watercress
Fasciolopsiasis (Intestinal fluke)	Human infection by eating raw, infective aquatic plants, especially water chestnut and water caltrop
Paragonimiasis (Lung fluke disease)	Human infection by eating raw or partially cooked, infective crabs or crayfish
Others	
Mosquito Vector Diseases	
Arboviruses	Many different viral diseases including yellow fever and dengue
Filariasis	Bancroftian form increasing in populous areas due to propensity of *Culex fatigans* for breeding in polluted waters 250 million people are infected
Malaria	Classical tropical disease with high death toll
Fly Vector Diseases	
Loaiasis (Loa Loa)	Mangrove fly of genus *Chrysops* breeds in water in West and Central Africa
Onchocerciasis	*Simulium* spp breeds in flowing water in Africa and Central America Blindness common in W Africa
African Trypanosomiasis (Sleeping Sickness)	Some tsetse fly vectors live and breed in riverine and waterhole areas

[1] Transmission by vectors living all or part of their lives in water

Opisthorchiasis

Opisthorchiasis is an infection of man and other mammals resulting from ingestion of raw fish infested with the cysts of the trematodes *Opisthorchis felineus* or *O viverrini* Found in parts of Europe and Asia, it is said to infect 3 5 million Thais (Malek, 1980) Prevalence has increased in the U S S R as a result of construction of dams on certain rivers, especially the Volga and the Dnieper (Malek, 1980)

Control and prevention measures are similar to those for clonorchiasis

Fascioliasis

Fascioliasis is a disease of the liver caused by large trematodes that are natural parasites of herbivores, especially sheep and cattle The infectious agents, readily visible to the eye (3 cm or more in length), are *Fasciola hepatica* and *F gigantica* They may cause tissue damage and enlargement of the liver, biliary colic, and jaundice

Human infection is found in sheep and cattle-raising areas of South America, the Caribbean, Europe, the Middle East, and Australia Infection is acquired by eating aquatic plants, such as watercress, which are infested by encysted larval forms known as metacercariae

The disease is controlled by killing the intermediate host vector snails with toxic chemicals (molluscicides), drainage, and chemotherapy for livestock Public awareness may help

Fasciolopsiasis

Fasciolopsiasis is also a trematode disease, caused by *Fasciolopsis buski*, a fluke which may reach 4 5 cm in length (almost 2 inches). A disease of the small intestine, it may result in inflammation, ulceration, obstruction, toxic effects, diarrhea alternating with constipation, and vomiting However, death is rare Though the disease is found only in Asia, especially China, local prevalence is often extremely high Pig, man, and dog are definitive hosts, snails are intermediate hosts

Transmission is through infective metacercariae encysted on aquatic plants, especially water caltrop and water chestnut. Infection from the latter frequently results when its hull or skin is pulled off with teeth and lips.

Prevention is by boiling or drying plants, prevention of fecal pollution by man or pig of ponds used for growing aquatic food plants, and public education

Paragonimiasis

Paragonimiasis is a trematode disease of man, dog, cat, and other carnivores caused by *Paragonimus westermani* and other species in Asia, *P africanus* and *P uterobilateralis* in Africa, and other spp in the Americas Three and a half million people are infected, primarily in Asia (Malek, 1980) The intermediate snail hosts are often found in swift mountain streams Lungs are most often parasitized, with development of fibrous, cystic lesions Other organs may also be infected

Transmission to man is by ingestion of infective, raw crabs and crayfish Prevention is possible by thorough cooking of the crustacea Education, sanitary excreta disposal, and molluscicding are other measures

Other Snail Vector Diseases

Other snail vector diseases include gastrodisciasis (*Gastrodiscoides hominus*), heterophyiasis (*Heterophyes heterophyes*), and metagonimiasis (*Metagonimus yokogawai*) The first occurs in Asia, the second in the Far East, the Middle East, Turkey, the Balkans, and Spain, but particularly in the Nile delta, the third in the Far East and Siberia Gastrodisciasis is transmitted through ingestion of raw, infective aquatic plants, the other two by ingestion of raw, infective fish Prevention includes cooking of plants and fish Most human cases are benign

Angiostrongyliais (rat lungworm), unlike the other snail-related diseases, is caused by a nematode (roundworm) Further, its snail vectors include land as well as aquatic snails Man is an accidental host, a dead end in the life cycle of the parasite, *Angiostrongylus cantonensis* Transmission is by eating raw, infective plants, snails or slugs, fish, or crustacea. Control or prevention is similar to that for other snail vector diseases

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Mosquito Vector Diseases

Arboviruses

General

An arbovirus is a virus that multiplies in a blood-feeding arthropod (mosquito, tick, sandfly, midge, or gnat) and is transmitted by bite to a vertebrate animal (mammal or bird) These "arthropod-borne" *virus* infections are thus classified ecologically rather than taxonomically

There are over 300 known arboviruses Only about 100 of these infect man, about 40 may produce significant disease Some arboviruses are highly lethal, for example, yellow fever, dengue, and the encephalitic arboviruses The more important mosquito-borne arboviruses that infect man are listed in Table 5-2

Most human arboviruses are mosquito-borne[1] zoonoses, accidentally acquired (often through occupational exposure, e g , by forest workers), with man an unimportant host in maintaining the transmission cycle Most arboviruses are endemic only in the tropics but are responsible for sporadic summer epidemics in temperate zones Fortunately, the majority of arbovirus infections of man are subclinical, i e , for every identified case, there are hundreds of inapparent infections

Clinical manifestations can be quite varied, not only for different arboviruses but for different cases due to the same arbovirus For convenience of description, arboviruses are categorized in five clinical groups below (Sanford, 1977)

[1]Rocky Mountain spotted fever is an important tick-borne arbovirus endemic in the United States

Table 5-2. Mosquito-Borne Arboviruses[1]

Virus/Disease	*Disease in Man*	*Distribution*
Apeu	Fever	South America
Banzi	Fever	Africa
Bunyamwera	Fever	Africa
Bussuquara	Fever	South America
Bwamba	Fever	Africa
California	Encephalitis	U S A , Canada
Caraparu	Fever	South America
Catu	Fever	South America
Chandipura	Fever	India
CHIKUNGUNYA	Fever, hemorrhagic fever, arthralgia	Africa, Southeast Asia, Philippines
DENGUE 1, 2, 3, and 4 (Breakbone Fever)	Fever, rash, hemorrhagic fever, polyarthalgia	Africa, Asia, Pacific Islands, South America, Caribbean, New Guinea, Australia
Eastern equine	Encephalitis	Americas
Germiston	Fever	Africa
Guama	Fever	South America
Guaroa	Fever	South America, Panama
Ilheus	Fever, encephalitis	South America Central America
Itaqui	Fever	South America
JAPANESE	Encephalitis	Asia, Pacific Islands
Kunjin	Fever	Australia, Sarawahk
La Crosse	Encephalitis	U S A , Canada
Madrid	Fever	South America
Marituba	Fever	South America
Mayaro	Fever	South America
Mucambo	Fever	South America
Murray Valley	Encephalitis	Australia, New Guinea
Murutucu	Fever	South America
Nyando	Fever	Africa
O'NYONG-NYONG	Fever, arthralgia	Africa
Oriboca	Fever	South America
Oropouche	Fever	South America
Ossa	Fever	South America
Pira	Fever	South America
Restan	Fever	South America
Rift Valley	Fever	Africa
Ross River	Arthritis, rash	Australia
Shuni	Fever	Africa
Sindbis	Fever	Africa, Southeast Asia, Philippines
Spondweni	Fever	Africa
St Louis	Encephalitis	Americas, Jamaica
Tahyna	Fever	Europe
Usutu	Fever	Africa
Venezuelan equine	Fever, encephalitis	South America, Mexico, U.S A
Wesselsbron	Fever	Africa, Asia
WEST NILE	Fever, encephalitis, rash	Africa, India, Middle East, Europe
Western equine	Encephalitis	Americas
Wyeomyia	Fever	South America, Panama
YELLOW FEVER	Hemorrhagic fever, hepatitis, jaundice, polyarthalgia	Africa, South and Central America
Zika	Fever	Africa, Southeast Asia

[1]The most important mosquito-borne arboviruses are shown in capital letters

SOURCES: Benenson (1975) and Fenner and White (1976)

Arbovirus Infections Presenting Chiefly with Fever, Malaise, Headache, and Muscle Pain

These infections tend to be abrupt but short-lived, often mild, without lasting effect other than immunity to reinfection Fatalities are rare Arboviruses in this group include Venezuelan equine encephalitis, Rift Valley fever, Mayaro, Zika, Apu, Caraparu, Itaqui, Marituba, Murutucu, Oriboca, Restan, Madrid, Ossa, Bunyamwera, Germiston, Ilesha, Guaroa, and Wyconyia

Arbovirus Infections Presenting Chiefly with Fever, Malaise, Joint Pain, and Rash

These are somewhat more widespread, more serious infections characterized by the sudden onset of distinctive joint pains The most widespread is Chikungunya virus, found in eastern and southern Africa, India, and southeast Asia O'nyong-nyong fever is a similar disease also found in East Africa In an outbreak there from 1959-1961, 2 million cases of O'nyong-nyong fever were recorded Ross River virus is a similar disease found in Australia

Arbovirus Infections Presenting Chiefly with Fever, Malaise, Lymph Node Pathology, and Rash

This grouping includes dengue fever, second only to yellow fever in importance among arboviruses, and found over large areas of the tropics and subtropics Dengue is discussed in more detail in a later section

West Nile virus is found from South Africa to India but is a cause of signficant disease only in the Near East where it can produce a disease clinically similar to dengue The disease is highly endemic in Egypt but goes largely unrecognized, presumably the adult population is immune and the infection in childhood is an undifferentiated febrile illness (Sanford, 1977) *Culex univittatus* is the principal vector in Egypt In Israel, most patients are young adults, evidence of another disease in which exposure at a later age results in a more severe attack (Polio is another example—also due to a virus) Fatalities in this group are rare

Arbovirus Infections Presenting Chiefly with Central Nervous System Involvement

Some dozen arboviruses are capable of causing serious central nervous system (CNS) disease, including encephalitis (inflammation of the brain) and meningitis (inflammation of the membranes covering the brain and spinal cord) Four are recognized as numerically important causes of CNS disease in the United States St Louis encephalitis virus, eastern equine encephalitis virus, western equine encephalitis virus, and the California encephalitis group of viruses

Clinical features of arboviral encephalitis differ among age groups In infants symptoms may be confined to sudden onset of fever, often accompanied by convulsions Older children are acutely ill, febrile, and lethargic and may also present with nausea, vomiting, muscular pain, photophobia and/or convulsions Adults commonly present with fever, nausea with vomiting, severe headache, mental aberrations, and sometimes coma. Mortality can be high for clinical cases, ranging from 2 percent or less for California encephalitis to over 50 percent for eastern equine encephalitis Children have lower rates than adults but a greater likelihood of developing severe disability

Arbovirus Diseases Presenting Chiefly with Fever and Hemorrhagic Manifestations

The striking feature of this lethal syndrome is hemorrhage (bleeding) which appears as petechiae (minute red spots due to escape of small quantities of blood) and ecchymoses (swelling due to blood escaping from vessels into the tissues) on the skin and mucous membranes, with bleeding from all the body orifices, the gums, and into the visceral organs In fatal cases the victim collapses from hypotensive (low blood pressure) shock.

The three arboviruses which can manifest hemorrhagic syndromes are Chikungunya virus, dengue virus, and yellow fever virus All three may result in morbidity without hemorrhagic syndromes Chikungunya was described earlier as causing fever with joint pain Dengue virus infection often exhibits a similar pathology Yellow fever may also result in jaundice and nephritis

The term mosquito-borne hemorrhagic fever was first used in the Philippines in 1953 Subsequently, hemorrhagic fevers have grown steadily as a disease problem in Southeast Asia Hemorrhagic dengue and chikungunya (and also yellow fever) are all caused by viruses transmitted by *Aedes aegypti*, mosquitos well adapted to breeding in the water habitats of urbanized areas Outbreaks have occurred in the Philippines, Vietnam, Cambodia, Thailand, Malaysia, Singapore, and India Hemorrhagic fever is a disease of children Most outbreaks occur during rainy seasons

Yellow Fever

Yellow fever is an acute infectious disease of short duration and extremely variable severity It remains the most dramatic and the most serious arbovirus disease of the tropics As late as 1905, southern ports in the United States experienced at least 5,000 cases and 1,000 deaths Its role in thwarting French ambitions in the New World are legendary DeLessups' failure to build the Panama Canal and Napoleon's loss of Louisiana, deriving ultimately from the loss of 33,000 French soldiers to "yellow Jack" in Haiti A tenth of the population of Philadelphia died of yellow fever between April and September of 1793 (Cartwright, 1972)

A sylvatic form of the disease, "jungle yellow fever," in which treetop species of *Haemagogus, Sabethes*, or *A africanus* mosquitoes maintain transmission in wild primates means that the potential for human exposure and reestablishment of man-*A aegypti* mosquito-man transmission cycles with urban outbreaks is ever present (See Figure 5-1) *Aedes aegypti* is widespread in Asia Why there is no yellow fever in Asia has never been satisfactorily explained Yellow fever leaped the Atlantic Ocean from Africa to America Why not the Indian Ocean from Africa to Asia?

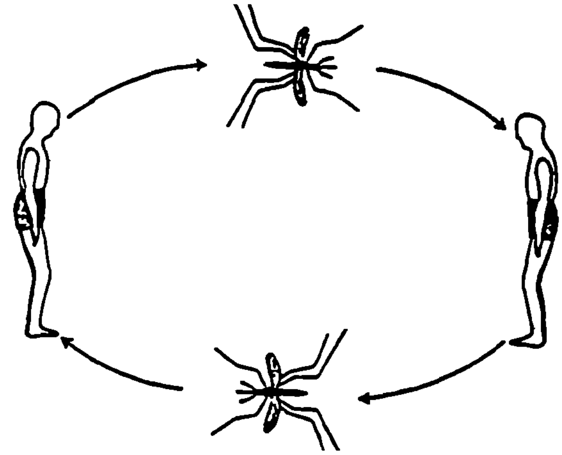
Protective measures must continue to be maintained against human disease, as demonstrated by recent outbreaks in Trinidad in 1954, Central America in 1948 to 1957, the Congo in 1958, the Sudan and Ethiopia in 1959 to 1962, Senegal in 1965, central West Africa in 1969, Panama and Columbia in 1974, Ecuador in 1975, and the Gambia in 1979 and 1980 Fifteen thousand to thirty thousand people died of yellow fever in the Ethiopian outbreak

Figure 5-2 shows the areas of Africa and the Americas which remain endemic to yellow fever

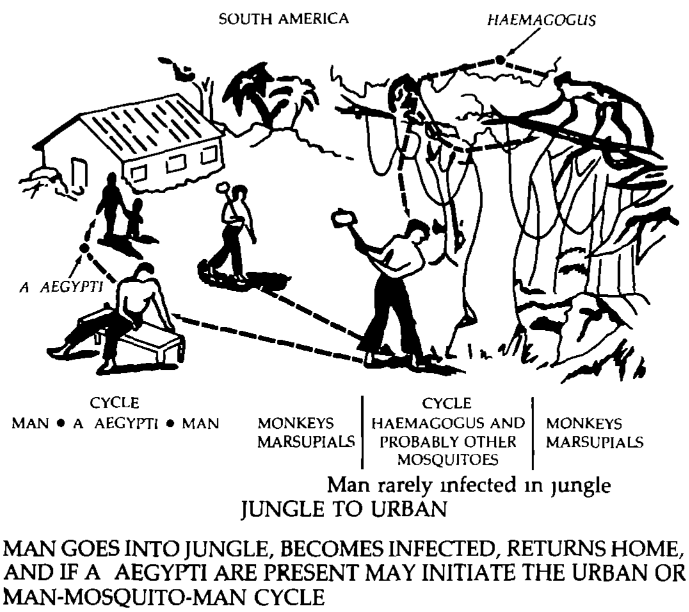
Dengue Fever and Dengue Hemorrhagic Fever

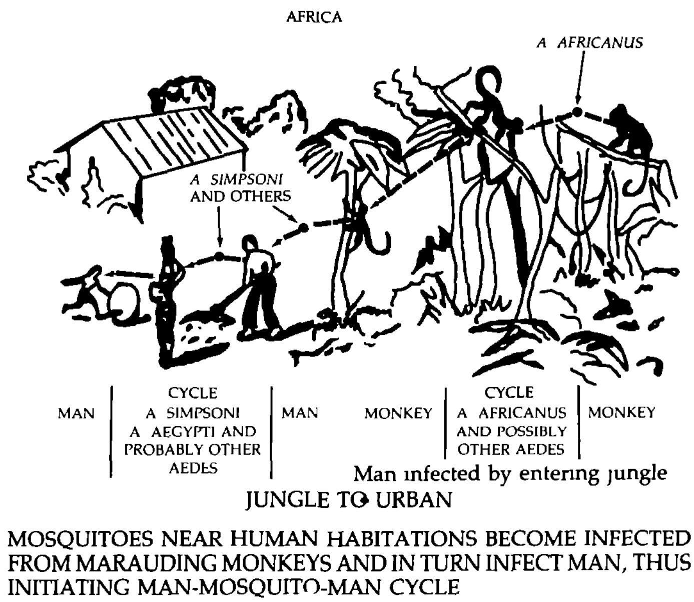
Dengue occurs in two forms, dengue fever (also known as "breakbone fever") and hemorrhagic dengue fever Dengue fever is an acute febrile disease of sudden onset with fever for about 5 to 7 days and various other symptoms including headache, pain behind the eyes, joint and muscle pains, and rash Recovery may be associated with prolonged pain and depression Epidemics are explosive, but fatality is low Dengue fever occurs in most of tropical Asia, in much of the Caribbean, in

Figure 5-1. Transmission of Yellow Fever



Infection Chain of Urban Yellow Fever



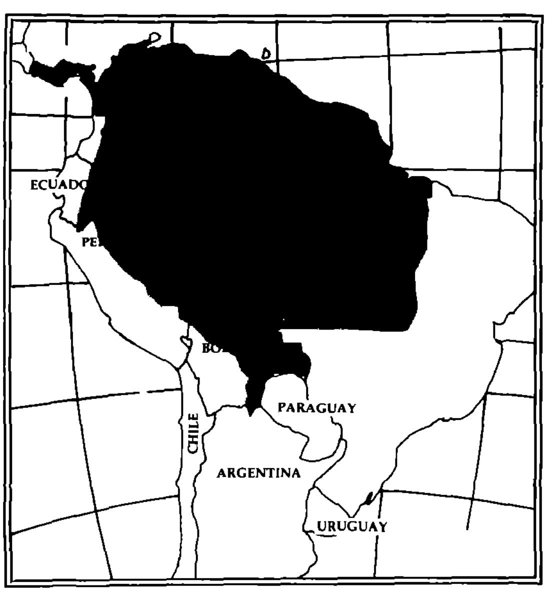


SOURCES: Meyer, 1955 and Pratt, 1976

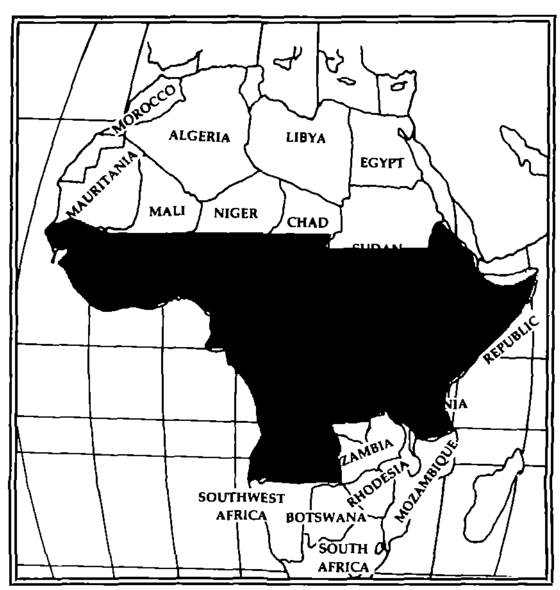
Epidemiology of Jungle Yellow Fever

Figure 5-2. Yellow Fever Endemic Zones

IN THE AMERICAS



IN AFRICA



SOURCES: Myer, 1955 and Pratt, 1976

several Latin American countries, in Polynesia, and in East and West Africa It is the most widely distributed arbovirus

Hemorrhagic dengue fever is a much more serious disease caused by the same virus Its pathology is described in the section on hemorrhagic fevers The hemorrhagic form is found only in Asia

Both forms are transmitted by the bite of an infected *Aedes* mosquito. *A aegypti* is a common vector

Role of Water

As for malarial and filariasis vectors, mosquito vectors of arboviral diseases live in water during their larval life stages Most common species are *Aedes* and *Culex*, but *Mansonia*, *Psorophora*, *Anopheles*, *Eretmapodites*, *Culiseta*, *et al* also may transmit some arboviruses.

Japanese encephalitis is transmitted by the mosquito *Culex tritaeniorhynchus*, a rural mosquito which breeds in rice fields. *Culex tarsalis* is another vector associated with rural irrigation, a vector of encephalitides in the United States. In urban-suburban epidemics of encephalitides, the vectors have been mosquitoes of the *Culex pipiens* complex (See section on filariasis)

Yellow fever, dengue, and chikungunya viruses are transmitted by *Aedes aegypti*, an urban vector *par excellence* often found in water storage containers The maintenance of *A aegypti* in water casks of 16th- to 19th-century sailing vessels was responsible for outbreaks which decimated their crews and led to stories of ghost ships such as the Flying Dutchman

Prevention of Arbovirus Disease

Preventive measures include the destruction of mosquitoes directly through use of insecticides and larvicides and indirectly through elimination of aquatic breeding sites for mosquitoes through alteration of habitats (e g , by drainage) These measures have been demonstrated to be effective against urban yellow fever and dengue and other arboviruses transmitted by *A aegypti*

Other measures include spraying of human habitats, screens and bed nets in living and sleeping quarters, use of repellants, health education, and, for yellow fever and Japanese encephalitis, use of vaccines

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Filariasis

The World Health Organization estimates that at least 250 million people are infected with the filarial nematode parasites *Wuchereria bancrofti* and *Brugia malayi*, transmitted by mosquitoes (WHO, 1974). The adult worms live in various parts of the human lymphatic system, causing the diseases known as Bancroftian and Brugian filariasis Persons may harbor the parasites with no apparent symptoms, or the filarial worms may cause inflammation and other complications In some persons who have had prolonged and repeated infections, there may be extreme enlargment of the external genitalia, breasts, or legs, hence the clinical term elephantiasis for pronounced enlargement of parts of the body, often with a thickened rough skin

The young filarial worms are transmitted from person to person by various species of mosquitoes. These nematodes undergo developmental changes in the mosquito, which is an essential link in the cycle of transmission The immature worms, called microfilariae, occur in the human bloodstream Here they are picked up by mosquitoes as they feed A minimum of 10 to 11 days is required for the developmental stages in the mosquito thorax before infective forms migrate to the mosquito proboscis, from which point they reach the new host at the next feeding. The infective filariae are not injected into the new host by the mosquito but actively penetrate the skin, perhaps at the site where the mosquito punctured the skin. Important vectors of *Wuchereria bancrofti* include species of the genera *Culex*, *Aedes*, and *Anopheles* The generally accepted vectors of *Brugia malayi* are mosquitoes in the genus *Mansonia*

Filariasis is widespread in many tropical and subtropical regions throughout the world The Bancroftian type of filariasis is apparently an increasing public health problem in many of the larger cities in southeastern Asia, in part because it adapts itself readily to transmission by *Culex pipiens fatigans*, one of the commonest tropical mosquitoes, which breeds in sewage and latrines In the Western Hemisphere it occurs in the West Indies, Venezuela, Panama, and the coastal portions of the Guianas and Brazil. Filariasis control programs are based on control of the mosquito vectors and treatment of the human cases with drugs.

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Malaria

Introduction

Of all vector-borne, water-related diseases, malaria is the most important, the most widespread, the greatest killer Malaria still causes more than a million deaths per year, most of them in tropical Africa, and approximately 150 million clinical cases annually (Wernsdorfer, 1976) It occurs or has occurred in all continents in areas extending roughly from 60° North latitude to 40° South latitude About 1 2 billion poeople live in areas currently endemic for malaria About 350 million of them, mostly in Africa, live in areas unprotected by any specific anti-malaria measures.

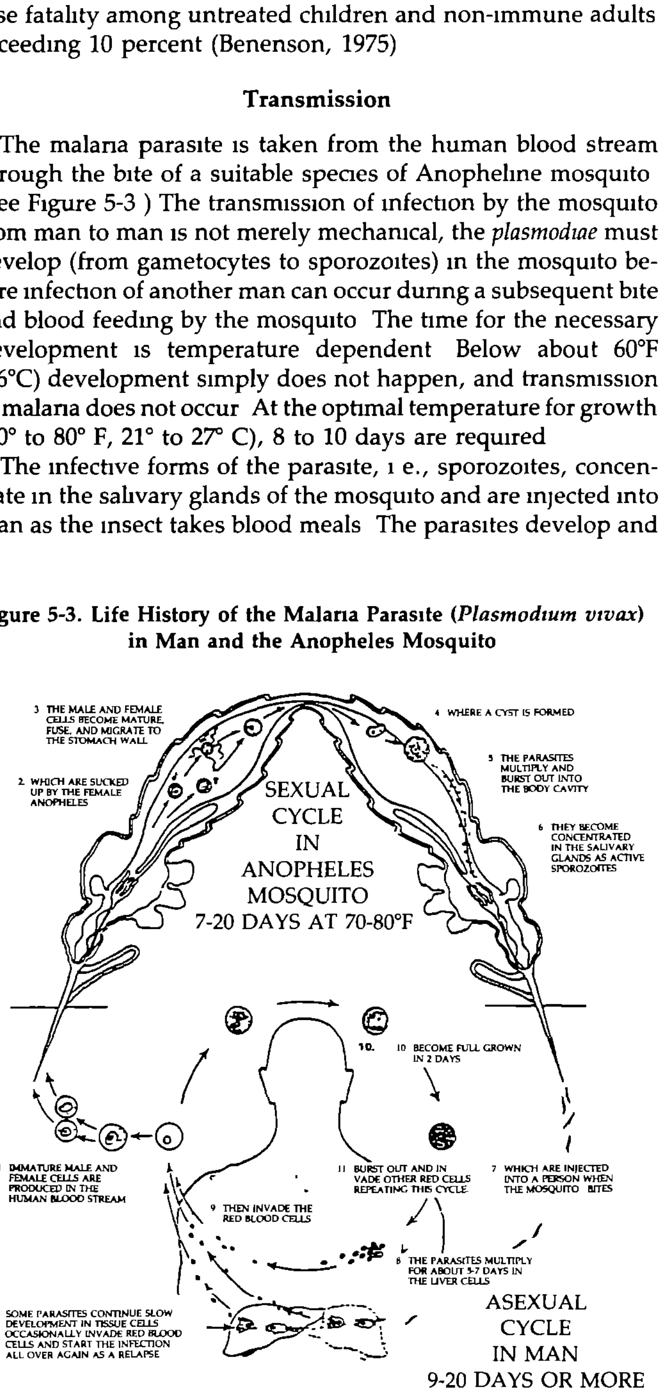
Malaria is an infectious disease caused by four protozoan parasites of the genus *Plasmodia* and transmitted by female mosquitoes of the genus *Anopheles* The disease is characterized clinically by fever, often periodic, chills, sweating, anemia, enlargement of the spleen, and various complications resulting from the involvement of the liver, spleen, kidneys, and other organs and the circulatory system The most serious form of malaria, falciparum, or malignant tertian, malaria may have a case fatality among untreated children and non-immune adults exceeding 10 percent (Benenson, 1975)

Transmission

The malaria parasite is taken from the human blood stream through the bite of a suitable species of Anopheline mosquito (See Figure 5-3) The transmission of infection by the mosquito from man to man is not merely mechanical, the *plasmodiae* must develop (from gametocytes to sporozoites) in the mosquito before infection of another man can occur during a subsequent bite and blood feeding by the mosquito The time for the necessary development is temperature dependent Below about 60°F (16°C) development simply does not happen, and transmission of malaria does not occur At the optimal temperature for growth (70° to 80° F, 21° to 27° C), 8 to 10 days are required

The infective forms of the parasite, i e., sporozoites, concentrate in the salivary glands of the mosquito and are injected into man as the insect takes blood meals The parasites develop and

Figure 5-3. Life History of the Malaria Parasite (*Plasmodium vivax*) in Man and the Anopheles Mosquito



SOURCE: Pratt, Darsie, and Littig (1976)

multiply in the liver of the human host, invade the red blood cells, and produce new cells (gametocytes), which when sucked into the stomach of the female mosquito reinitiate the development of sporozoites The mosquito is then infective to man at its next blood-feeding bite

Prevention

All mosquitoes live the juvenile stages of their lives in water, i e , as eggs, larvae, and pupae. Early control efforts in Cuba, Panama, and Malaysia and in the Tennessee River Basin of the United States focused on measures such as drainage, reduction of breeding sites, and destruction of mosquito larvae in the water through use of larvacides (including oils) and mosquito fish (Magoon, 1945, TVA, 1947) These methods are feasible only where the local vector species and surface water characteristics are suited to such measures On national levels, including rural areas, they have limited utility for most endemic areas in comparison with use of residual insecticides to kill adult mosquitos

Most mosquito vectors bite at dusk, night, or dawn, indoors, and rest on nearby walls for hours The advent of DDT during World War II provided a cheap, effective insecticide with residual killing power. Readily applied to walls, an effective method of breaking the cycle of transmission of malaria was within the reach of the malaria-endemic developing countries (Smith, 1977) Successful malaria control projects were undertaken in the post-World War II years in numerous countries

By 1955, these successes stimulated the launching by the World Health Organization (WHO) malaria eradication programs on the premise that the means were at hand to eradicate by a two-pronged program of wall spraying and surveillance and treatment of all remaining cases of malaria (Smith, 1977, WHO, 1972, WHO, 1974). Some 37 countries have been certified by WHO as having achieved eradication of malaria However, this leaves nearly 50 other countries which attempted eradication and did not succeed. Nevertheless, overall, the annual incidence of malaria has been reduced worldwide from 300 million to 150 million cases

Eradication refers to complete interruption of transmission of the malaria parasite, not to elimination of vector mosquitoes. The goal of wall-spraying is to kill infective mosquitoes, thereby breaking the transmission cycle Treatment of malaria infected persons reduces not only the number of infected people but the number of infected mosquitoes As the numbers and density of infected people and mosquitoes decline, the parasite population (i.e , the *plasmodiae*) ages and dies out

Other control measures include chemotherapy and chemoprophylaxis (drugs to cure and prevent malaria) The Agency for International Development, the World Health Organization (through its Tropical Disease Research Programme), *et al.*, are supporting vaccine research, but this is some years away yet from field trials and further yet from widespread use.

Increasing resistance by mosquitoes to insecticides, increasing resistance to drugs by the parasites, and increasing costs of insecticides and drugs are leading to increased interest in integrated pest management programs for mosquito control and, consequently, renewed interest in old methods of attacking mosquitoes by changing their water environment. (See WHO, 1973, McJunkin, 1975, NAS, 1973)

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Water Related Fly Vectors

Loiasis (Loa Loa)

Sometimes called the "eye worm" disease, this chronic filarial infection is found in tropical West and Central Africa In the Congo River basin up to 90 percent of the indigenous population in some villages are infected Infections are accompanied by migration of the adult worm through the body, causing transient swelling, pain, and pruritus (itching) Occasionally the highly mobile worm may come dramatically and rapidly into full view as it crosses the white of the eye

The deer or mango flies of the genus *Chrysops* which transmit *L loa*, a nematode, are generally found in shady woodlands, especially forest swampland Their eggs are laid in water or in branches overhanging water and the larvae drop into the water or mud below on hatching. Densely shaded, slow-flowing streams are preferred

Loiasis affects more than one million people Where it is highly endemic, it is a major cause of lost worktime, and the treatment of heavily infected persons can be highly unpleasant and even dangerous to the patient

Onchocerciasis

Onchocerciasis, or "river blindness," is caused by the filarial worm, *Onchocerca volvulus*, and it occurs throughout Africa south of the Sahara (except South Africa) and in Yeman, Guatemala, Mexico, Venezuela, and Colombia. A disease of underdeveloped areas, it infects over 30 million people. It does not shorten life The most important complications are eye lesions causing loss of vision, frequently blindness, with its attendant personal tragedy and socio-economic problems, intense pruritus, dermal and lymphatic lesions and tumors, and fear In many parts of west and equatorial Africa more than 50 percent of the inhabitants are infected, 30 percent have impaired vision, and 4 to 10 percent are blind. In some villages of the Upper Volta and Ghana, blindness may reach 35 percent

Some of the most fertile valleys in tropical Africa are infested by the onchocerciasis vector, *Simulium* flies, and consequently are being abandoned by riverine populations plagued by skin and eye diseases. The presence of *Simulium* flies and the fear of onchocercal blindness may threaten implementation of irrigation and dam-building projects on which future agricultural and industrial productivity of developing countries depends.

The vector *Simulium* species require highly aerated running water for breeding. Thus the construction of dams and their spillways often creates new sites of superabundant breeding that spread onchocerciasis to new areas.

The principal control measures in current use are addition of larvicides to infected streams and chemoprophylaxis of infected populations

African Trypanosomiasis

African trypanosomiasis or African sleeping sickness is a severe, frequently fatal, disease caused by *Trypanosoma brucei gambiense* and *T b rhodesiense*, hemoflagellates. Occurrence of the disease is confined to the tropical African range of its tsetse fly vectors (*Glossina* spp)

Where flies of the *Glossina palpalis* group are the principal vectors, as in West and Central Africa, infection occurs mainly along streams This characteristic both explains transmission patterns and suggests ecological control measures, particularly, destruction of the tsetse fly habitat by clearing of tsetse-protective brush along selected watercourses and around villages

Nash (1970) describes this water-related transmission pattern eloquently

> In the dry season, the requirements of man and fly are similar, man sites his village near a stream at a point where he knows that water will be available even in the driest year Such places are vital to the survival of the riverine tsetse, which vacate long stretches of waterless stream-bed and concentrate at the permanent pools where they obtain the benefit of suitable microclimates and of a steady food supply Since man, his stock and wild animals are dependent on the same pools for water, the hosts have to come to the riverine tsetse whose dry season behavior resembles that of the spider in its web

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SECTION 6

METHODS FOR EVALUATING THE QUALITY OF DRINKING WATER AS TO THE RISK OF TRANSMISSION OF MICROBIOLOGICAL DISEASE

Introduction

In approaching this subject, it must be recognized that assessing the risk of contracting water-borne disease is a complicated matter It cannot be evaluated simply by determining the presence or absence of pathogens because this is not a question which can be resolved in terms of "yes or no," "black or white," or "go or no-go " The probability of becoming a victim of water-borne disease is a statistical question related to many variables, especially the type and number of pathogens ingested Not all types have equal virulence, and a very high percentage of any given type may be ineffectual in causing the disease because of inactivation by unfavorable environmental conditions in the intestinal tract, or for several other reasons

Table 6-1 (Rohlich, 1977) summarizes observations of some investigators on the relationship between numbers of different types of pathogens ingested and the number of instances which resulted in actual transmission of diseases The data demonstrate clearly that doses required for infection vary substantially among different types of pathogens For example, some Shigella are highly virulent and caused infection after ingestion of relatively few cells, while some of the other organisms required much higher doses for the same result The table indicates, further, that there is a wide range in the number of cells, even of a single type of organism, required to cause infection, demonstrating that virulence may vary widely within each group For example, it was observed that Shigella dysenteriae could cause infection with a dose as low as 10 organisms, while other strains of Shigella could be safely administered at much higher doses of organisms Although there are substantial variations in the data, Table 6-1 shows that the probability of contracting disease generally increased with increase in the dose of pathogens

With that background, and without becoming very technical or profound, one can reasonably conclude that the risk of contracting a disease via the water route depends upon the type of organism and the number of viable cells ingested Other data compiled over the years have demonstrated that the statistical risk also depends upon influence of several other variables affecting virulence of the pathogen to the potential victim Some variables affecting this complex system may be summarized as follows (Rohlich, 1977)·

1. The type of pathogenic organism under consideration,
2. Virulence of the specific strain of organisms, which can vary widely because of several factors,
3. The number of viable cells ingested,
4. Age of the potential victim (infants and the aged often exhibit greater susceptibility),
5. General health of the individual,
6 Extent to which the individual may have acquired immunity to the pathogen through earlier exposure, and
7. Many other factors affecting the relationship between organism and individual, including presence of certain types of chemicals or synergistic relationships with other organisms which may be present simultaneously

Relying on this limited discussion of some factors which may affect the complex statistical system involved here, we will explore a few alternatives which are available for evaluating risk of water-borne disease transmission. This also will make it possible to identify some practical tools which are used to assess the public health safety of water supplies and to understand advantages and limitations of each technique

Enumeration of Pathogens

Techniques are available which can be used to identify and enumerate most of the common types of pathogens in water They have been employed successfully in research activities concerned with occurrence and survival of those organisms and in studies conducted during outbreaks of water-borne diseases It appears reasonable to employ those methods to identify and enumerate pathogens in a water supply as a direct method for evaluating risk to the public health However, this "direct" approach to the question is not used in practice because it has several limitations and because other alternatives are available which are better suited for evaluating the risk (McFeters, 1978, Rohlich, 1977) We will explore this briefly before proceeding to consider the techniques which actually are used

A recent major publication on drinking water and health (Rohlich, 1977) points out that there is no single procedure which can be employed to test for presence of pathogens Each type of pathogen must be assayed separately, using different laboratory techniques, and the tests require significant expertise for reliable execution. Also, most of the available techniques are best suited for grossly contaminated waters, in which pathogen populations are relatively high Enumerating the pathogens in a typical finished water supply would be much more difficult, higher in cost, and less reliable. The procedures available now which are judged to be sufficiently accurate for practical use are capable of enumerating only Salmonellae organisms Existing methods for enumerating Shigella, Vibrio, Leptospira and many other pathogens are judged to be inadequate (Rohlich, 1977)

Above and beyond the difficulties and expense of direct enumeration of pathogens, this approach has a severe, or even fatal, limitation for assaying risk of water-borne disease transmission It is capable of evaluating that risk only in samples actually containing the pathogens in question It is highly desirable for risk evaluation to go beyond merely enumerating pathogens when they happen to be present—which should be rare in potable water—to provide a measure of the probability that pathogens might be present in that water supply on other occasions The importance of this can be illustrated by pointing out that water contaminated by sanitary sewage often may contain few or no pathogens simply because an active case of the disease may not be a contributor to the wastewater system at that time Although the absence of pathogens would infer that the sample of water tested is safe, clearly the risk could increase quickly upon addition of a case or carrier to the contributing population

In summary, then, direct enumeration of pathogens is not usually used to assess the safety of a potable water That is not merely because of difficulty or expense involved in conducting the necessary tests, which may be considerable It is a matter of choice, because simpler and more economical methods are avail-

Table 6-1. Infective Doses for Man of Bacterial Enteric Pathogens

Enteric Pathogen Dose Viable Cells	Subjects Infected/Total Tested								
	10^1	10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9
Shigella dysenteriae									
Strain M131	1/10	2/4	7/10	5/6					
Strain A-1		1/4		2/6					
Shigella flexneri									
Strain 2A#		6/33	33/49	66/87	15/24				
Strain 2A##				1/4	3/4	7/8	13/19	7/8	
Salmonella typhi									
Strain Quailes			0/14		32/116		16/32	8/9	40/42
Vibrio chloerae									
Strain Inaba									
With $NaHCO_3$				11/13		45/52		2/2	
No $NaHCO_3$				0/2		0/4	0/4	2/4	1/2
Enteropathogenic E. coli									
Strain 4608				0/5		0/5		4/8	

SOURCE: Rohlich, 1977

able which actually can assess the risk more reliably, as we will demonstrate.

The Concept of Using Indicator Organisms

The limitations inherent in attempting to evaluate public health safety of water through direct enumeration of pathogens have caused the water supply field to use "indicator organisms" instead. These do not necessarily have direct relationship to the numbers of pathogens present in a given water sample but are more useful for assessing the degree to which that water has been polluted by fecal contamination from humans and other warm-blooded animals Thus, instead of attempting to determine the actual risk of contracting some specific disease through consuming the water, this test provides a measure of opportunity for transmitting any type of water-borne disease which might result from fecal contamination. In many respects, this method is more meaningful because the results are not limited only to specific pathogens but relate to overall opportunity for contracting a wide variety of water-borne diseases

Desirable characteristics of indicator organisms have been discussed by many authors (Rohlich, 1977, McFeters, et al, 1978, Anonymous, 1976, Allen, 1978), and some may be summarized as follows:

1 Laboratory tests for the organisms should be applicable to all types of water to be investigated, both raw and treated,
2. The indicator organisms should be present in sewage and polluted waters when pathogens are present,
3. They should be present in polluted waters even when pathogens are not present, if they reasonably may be expected to enter the water at some future date after an active case or carrier of the disease becomes part of the pollution system;
4. They should be present in polluted waters in numbers greater than the pathogen population,
5. The population of indicator organisms should be correlated with the degree of pollution and opportunity for pathogens to be present,
6. They should be easy to identify through relatively simple laboratory tests, in a short period of time;
7. They should be easy to enumerate in those laboratory tests,
8 They should have well-defined characteristics to permit accurate laboratory tests and should be consistent in their reactions in those tests,
9. The indicator organisms should not multiply under conditions where pathogens do not multiply;
10 Survival time for the indicator organisms under unfavorable environmental conditions should exceed survival times for pathogens This insures safety of waters which have been treated to produce very low or zero populations of indicator organisms;
11. They should be more resistant to disinfectants and other stresses in the aquatic environment than pathogens,
12. They should be harmless to man and animal.

As might be expected, no indicator organism has been found which meets all of those criteria, and it's reasonable to suppose that none ever will be. Nevertheless, the criteria are helpful by providing a basis for evaluating different types of organisms for this purpose and for identifying advantages and limitations of those actually used in assessing water quality

The Coliform Group of Bacteria

In 1884, studies by Escherich established that high populations of certain specific bacteria were present in the intestinal tracts of humans. Subsequently, it was recognized that presence of those organisms (Escherichia coli) in water may be interpreted as evidence that the water has been contaminated with fecal matter and their population is a function of the extent of that contamination.

The "coliform group" of bacteria includes Escherichia coli, as well as numerous other bacteria originating in fecal discharges and from many non-fecal sources, as well (Allen, 1978, Anonymous, 1966; Anonymous, 1976) It has been estimated that the coliform bacteria in fecal discharges amount to, perhaps, 200 x 10^9 cells per person per day.

For over 70 years, the coliform group has been employed widely to evaluate sanitary quality of drinking water. It should be emphasized that the rationale behind using this group of bacteria as "indicators" is not based on potential for causing disease in humans, although under some circumstances certain coliforms may cause infections They are valuable as indicators simply because large numbers are present in fecal discharges and their population is related to the extent of pollution by those discharges. Presence of the coliform group does not establish that pathogens of any type necessarily are in the water. Results of the test should be interpreted as a measure of the opportunity for pathogens to be in that water either then or, perhaps, at some subsequent time, as outlined earlier.

The coliform group meets several of the criteria for indicator organisms outlined earlier, but possesses serious limitations in several respects For example, the group includes many types of bacteria which may not originate in the intestinal tract of man and which have little or no relationship to the potential for presence of pathogens from that source Further, many coliform organisms are capable of multiplying under conditions present in treatment facilities or streams. This can result in very high populations of coliforms having little or no sanitary significance because pathogens do not multiply under those same environmental conditions

Table 6-2 summarizes die-off rates of several types of fecal indicator bacteria and enteric pathogens (McFeters, et al, 1978). With respect to survival in streams and treatment systems, coliform organisms usually outlast most of the common pathogenic bacteria However, that is not always true with respect to viruses and certain other types of important pathogens. Work by Butterfield and other investigators (Rohlich, 1977) established that coliforms and pathogens are similar in sensitivity to disinfection. On the other hand, viruses typically survive longer than bacterial pathogens or coliforms (Rohlich, 1977, Sobsey, 1979)

Table 6-2. Comparative Die-Off Rates (Half-Time)[1] of Fecal Indicator Bacteria and Enteric Pathogens

Bacteria	*Bacteria Half-time (h)*	*No of Strains Analyzed*
Indicator Bacteria		
Coliform bacteria (avg.)	17 0	29
Enterococci (avg)	22 0	20
Coliform from raw sewage	17 5	
Streptococci from raw sewage	19.5	
Streptococcus equinus	10 0	1
S. bovis	4.3	1
Pathogenic bacteria		
Shigella dysenteriae	22 4	1
S Sonnei	24.5	1
S flexneri	26 8	1
Salmonella enteritidis ser. paratyphi A	16 0	1
S. enteritidis ser paratyphi D	19 2	1
S enteritidis ser typhimurium	16.0	1
S. typhi	6 0	2
Virbio cholerae	7 2	3
S enteritidis ser paratyphi B	2 4	1

[1]The half-time was determined as the time required for a 50% reduction in the initial population

SOURCE: McFeters, et al (1978)

Difficulties in interpreting the significance of coliform tests sometimes are compounded by the fact that there are two accepted procedures for enumerating them, and results yielded by those procedures often may be significantly different. The two will be outlined briefly in the following paragraphs.

The MPN Test

The MPN (Most Probable Number) test is based on inoculating tubes containing lactose broth with samples of the water being tested and observing them after 48 hours of incubation to determine whether gas has been produced in each The presence of gas in a tube is considered to be evidence of the presence of coliform organisms, whose identity is further confirmed by additional tests.

Under this procedure, the "coliform group" is defined as including all "aerobic and facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria which ferment lactose with gas formation, within 48 hours at 35°C" (Rohlich, 1977). Most, but not all, E. coli and several other organisms are capable of forming gas under these conditions, and those which do are considered to be members of the "coliform group "

Using data for the amount of sample introduced into each tube, the number of tubes tested and the number showing gas formation, statistically derived tables show a "most probable number" of coliforms in the water. This method of enumerating bacteria is very imprecise, as pointed out by past investigators (Woodward, 1957, Litsky, 1978) This is illustrated in Table 6-3, which shows variations in results obtained for triplicate samples of marine waters, chlorinated sewage effluents and laboratory-chlorinated sewage effluents. Litsky (1978) points out that the resulting MPN's are spread over a ten-fold range, in spite of the tests' being conducted carefully by a technician with 10 years of laboratory experience Woodward (1957) pointed out that the 95% confidence limits for a typical MPN test covered 13- and 33-fold ranges for two examples presented by him

The lack of precision in determining population of coliform organisms by the MPN procedure makes it difficult, or even impossible, to attribute much significance to results of one or a few tests without extensive further confirmatory work This inherent variability must be recognized in interpreting results from the MPN coliform test to avoid erroneous conclusions.

The MF Test

Currently, there is a second accepted technique for determining the number of coliform organisms in water. The membrane-filter (MF) method is based on passing a known volume of sample through a special filter which, subsequently, is incubated on special media under standard conditions Using this test, the "coliform group" is defined as including all organisms which produce a dark colony (purple-green) with a metallic sheen within 24 hours.

The "coliform bacteria" detected and enumerated by this technique are not necessarily the same as those capable of fermenting lactose in the MPN procedure, although they are generally accepted as having the same sanitary significance. The MF test procedure has the advantage of improved reproducibility over the MPN technique However, results obtained by the two procedures usually are numerically different, creating difficulties in interpretation

Other Advantages and Limitations

Some deficiencies of coliforms as indicator organisms have been outlined previously Additional shortcomings include the fact that coliform growth may be suppressed by high populations of other organisms (Geldreich, *et al* , 1978; Rohlich, 1977) Also, Geldreich, *et al* (1978) reported that suspended matter in water may preclude use of the MF procedure because deposits

Table 6-3. Triplicate Fecal Coliform MPN Range

SAMPLE	*MPN/100 ml*		
Marine	49	310	310
	79	350	540
	94	220	350
	8	1,300	1,300
	700	1,700	7,900
Chlorinated	2,200	7,900	13,000
Effluent	49,000	130,000	490,000
	490,000	790,000	2,400,000
Lab	35,000	110,000	240,000
Chlorinated	240,000	540,000	2,400,000+
Effluent	49,000	130,000	490,000

SOURCE: Woodward, 1957 and Litsky, 1978

on the membrane surfaces interfere with filtration Further, they indicated that coliforms trapped in turbidity particles may not produce gas in the MPN procedure unless the organisms are released by vigorous agitation. They concluded that drinking water turbidity should not exceed one unit as measured by a standard test and that bacterial densities over 500 organisms per milliliter, as measured by total plate count, should not be tolerated False negative results because of strains which are unable to ferment lactose sometimes may lead to an unwarranted sense of security and false-positive test results may occur because gas-producing organisms outside of the coliform group are not uncommon.

These objections and limitations notwithstanding, the coliforms remain the preferred indicator organism group because of their origin, ease of detection and enumeration, survival characteristics, and historical use

Fecal Coliforms

Fecal coliform bacteria are a subgroup of the total coliforms, discussed earlier, and are thought to include organisms more likely to have originated in the intestinal tract Accordingly, they exhibit improved correlation with extent of fecal contamination Fecal coliforms are characterized by ability to ferment lactose and produce gas at a temperature of 44 5°C Also, they may be determined by the MF technique by conducting the test at higher temperature.

Because fecal coliforms are less subject to regrowth in streams and provide more reliable correlation with amount of fecal pollution, they now are used extensively in the U S.A for evaluating stream quality, especially its suitability for bathing or shellfish production (Geldreich, 1966, Deaner, 1969) Also, the fecal coliform test now is widely used for evaluating microbiological quality of effluents from wastewater treatment facilities Of course, the change from total coliforms to fecal coliforms has made it necessary to reduce the permissible concentrations considerably because fecal coliforms are far fewer in number than the total coliform group

However, this test has not been employed to a significant extent for evaluating the quality of potable water This is not attributed to shortcomings of the fecal coliforms as indicators of pollution, but to the perceived value of the total coliform group for evaluating performance of treatment systems This was expressed by Kabler and Clark (1960) as follows

> The presence of any type of coliform organism in treated drinking water suggests either inadequate treatment or access of undesirable materials to the water after treatment . . . The presence of coliform organisms in treated water calls for definitive action for their elimination

Accordingly, the coliform group is considered to be the most reliable indicator for evaluating adequacy of water treatment and is preferred to the fecal coliform group for that application

Other Indicator Organisms

For many years,investigators have searched for indicator organisms better suited to needs of the water field than the coliform and fecal coliform groups Fecal streptococci have been used occasionally in stream pollution control investigations but have demonstrated poor recovery rates and poor agreement with other methods for evaluating microbiological quality of drinking water supplies Geldreich and Kenner (1969) point out that fecal coliform bacteria are more numerous than fecal streptococci in the feces of man, providing a coliform/streptococcus ratio always greater than 4 0 in domestic wastewaters Conversely, fecal streptococci are more numerous than the coliforms in feces of farm animals, cats, dogs and rodents, producing a coliform/streptococcus ratio of less than 0 7 in wastes flows from farms This suggests that simultaneous analyses for fecal coliforms and fecal streptococci and calculation of the ratio between the two could be helpful in evaluating the probable source of coliforms found in stream waters

Other organisms which have been suggested as indicators, but have found even less acceptance, include Clostridium perfringens, Klebsiella pneumoniae, several species of Aeromonas, Pseudomonas species, bifidobacterium and some pathogenic Salmonella species (McFeters, et al, 1978, Rohlich, 1977).

In summary, although several alternates have been proposed from time to time, and some used intermittently as adjuncts to the coliform tests, no organism has yet been found which appears convincingly to be better than the coliform group

Bacteria Plate Counts

It has been proposed that more attention should be devoted to use of standard plate counts (SPC) for drinking water, based on plating water samples in nutrient agar medium and incubating aerobically for 1-2 days at 20-35°C. Bacterial concentrations commonly mentioned as acceptable by health agencies are at various levels up to about 500/ml

One rationale for this test is that it may more accurately assess finished water quality because the higher numbers of organisms detected may provide improved opportunity for observing changes in bacteriological quality This is viewed as a practical method for monitoring effectiveness of chlorine throughout a distribution network and warning of deterioration in treatment plant performance Also, the SPC limitation may reduce the problems which have been reported (Geldreich, 1977, Rohlich, 1977, McFeters, et al , 1978) concerning interference by non-coliform bacteria with detection of low concentrations of coliforms

This approach, philosophically, is consistent with the rationale involved in using the total coliform group to evaluate water treatment and distribution systems instead of using the more specific fecal coliforms As summarized by McFeters, et al , (1978)

> The philosophical basis that we consider fundamental to the indicator concept is that an indicator system that is more encompassing is better than one that is more restric-

tive, in terms of the source of the contamination that will be detected. Additionally, false negatives are to be avoided more than false positives if one has to select the lesser of two evils.

Among those discussed here, the least encompassing, or most restrictive, indicator would be to use E coli, followed by fecal coliforms, total coliforms and SPC, in order of reduced restrictiveness In a well-treated and properly protected water supply system, most of the bacteria should be at or very near zero in concentration That leaves the SPC as the test which might provide the most sensitive indication of quality changes simply because it is the only test among the group of alternatives which yields significant numbers of bacteria, even in a properly operated treatment and distribution network.

Measurement of Chlorine Residual

A relatively recent development is the adoption of chlorine residual measurements to substitute for some of the indicator organism monitoring in U S A water distribution systems (Anonymous, 1976) The rationale is based partly on the observation that a substantial proportion of disease outbreaks can be attributed to deficiencies in disinfection Also, studies have demonstrated an inverse correlation between chlorine residuals in distribution systems and coliform bacteria in samples taken from those systems (Anonymous, 1976, Craun, 1978, McCabe, 1978)

The extent of substitution is limited to 75% of the required bacteriological samples The remaining 25% must be monitored for indicator organisms to assess adequacy of disinfection and to assure continuity of water quality records Also, whenever the chlorine residual is determined to be less than the level specified for the system in question, samples for total coliform analyses must be taken immediately from that same sampling point. When this approach is adopted, the number of chlorine residual samples analyzed must be at least four times the number of microbiological samples discontinued with a further requirement for at least daily measurement of chlorine residual This is feasible to require because the chlorine residual test is easy, quick and economical to perform

Table 6-4 summarizes effects of different levels of free chlorine residual on the number of instances in which coliform organisms were observed in a major distribution system Also, the average Standard Plate Counts in the system are presented (Geldreich, et al, 1978). Table 6-5 shows the percent of water supply systems in a major U S A. study to have average total coliforms exceeding the drinking water standard of one organism per 100 ml of water (Anonymous, 1976) Eight to one hundred percent of the systems which were not chlorinated were observed to contain coliforms in excess of the standard Systems in which chlorination was practiced without producing residual chlorine showed lower incidence of coliform organisms Those systems in which a detectable residual was maintained produced the lowest incidence of coliforms, varying from 0 to 3 percent of those surveyed

Table 6-4. MPN Coliform Occurences vs. Free Chlorine Residuals (DPD)[1]

Free Chlorine Residual (mg/1)	*Number of Coliform Occurrences*	*SPC Average (bacteria/ml)*
<0.1	58	3040
0 1-0 5	13	860
0 6-1 0	4	50
>1.0	1	79

[1]Typical values for finished waters were 1-2 mg/l free chlorine
SOURCE: Geldreich, et al (1978)

Table 6-5. Percent of Various Types of Water Supply Systems Found To Have Average Total Coliforms Greater Than 1/100 ml

Type of System	*Non-Chlorinated*	*Chlorinated No Residual*	*With any Detectable Residual*
Spring	39	17	0
Combined Spring and Well	41	28	0
Well	8	5	0
Surface	64	7	2
Combined Surface and Well	100	16	3

SOURCE: Anonymous (1976)

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SECTION 7

PUBLIC HEALTH EFFECTIVENESS OF WATER TREATMENT

The Public Health Role of Water Treatment

Evaluation of water treatment as a tool for protecting the public health requires understanding of its role within the context of many measures for controlling health impacts in potable water systems.

In a very real sense, treatment should be considered as a last resort Sometimes local conditions make it impossible or uneconomical to produce satisfactory potable water without treatment In other instances, adoption of treatment may reflect failure by planners, engineers and administrators to develop suitable water supply through simpler, more reliable and cheaper alternatives which could be available but not recognized Treatment should not be installed without good reason because far better solutions often may be developed

Provision of a safe potable supply begins with the crucially important step of source selection Selection involves three fundamental considerations, the first of which is that water must be adequate in quantity Clearly, there is no substitute for providing enough water to meet needs of the community in question and goals of a water supply project cannot be met without adequate flow It is important to note that public health integrity of a system often is seriously compromised if water cannot be supplied continuously in quantities adequate to meet needs of the municipality, maintaining satisfactory pressures throughout the distribution system at all times

Given adequate quantity, the next most important characteristic of a source is water quality There is no absolute measure of quality in a practical water system Its health suitability may be viewed as depending upon the statistical probability of adverse impacts. In evaluating those risks, water supply professionals tend to be conservative because of heavy responsibility for protecting the health of large segments of the public Accordingly, standards for protecting water quality typically begin with selection of the best quality source among those available, within reasonable economic constraints

Where alternative sources are both adequate in quantity and entirely satisfactory in quality, the third important consideration is total costs

Selection of municipal water sources and their subsequent protection depend heavily on the sanitary survey This inspection identifies and evaluates conditions which might be potentially dangerous to the integrity of the water system. Often, the sanitary survey includes sampling and laboratory analyses, but it goes far beyond that type of data collection to evaluate basic hazards in the source and other system elements which might cause problems in the future, whether or not water quality deficiencies actually exist at the time of sampling The survey is a key factor in establishing the need for treatment (McJunkin, 1976).

To illustrate the importance of source selection in determining the type and extent of required treatment, consider a community having a choice between using a surface stream as a supply source or developing a groundwater system. Almost all surface supplies are subject to pollution from runoff and point sources of wastewaters and usually require extensive treatment before use as a potable supply. On the other hand, where an opportunity is available to use springs or wells, the combined effects of time of travel and filtration during passage through soil often provide very effective natural removal of objectionable constituents Accordingly, water taken from a good groundwater source often needs little or no further treatment to correct deficiencies in quality, although chlorination may be used to insure a residual throughout the distribution system to protect consumers from subsequent water contamination

The distribution system is of crucial importance in maintaining adequate quality of water delivered to the consumer It must be adequate in capacity and other design features and free from opportunities for contamination which might undo the results of careful source selection and appropriate water treatment

The importance of proper surveillance in safeguarding water quality from source to consumer cannot be over-emphasized It must be considered, however, in a broad context because proper surveillance goes far beyond mere sampling and bacteriological or chemical analyses to include all activities necessary to insure that components of the system function without risk of failure In this respect, it has been stated that (McJunkin, 1976)

> Surveillance is not merely finding out what is wrong and putting matters right, it includes undertaking remedial action to reduce or eliminate health hazards and advising on, assisting with, and stimulating improvements whenever possible Surveillance also includes more general activities to promote the safety of water supplies—operator training and health education of the public in the prevention of waterborne enteric disease, for example

It is principally through surveillance that knowledgeable individuals and agencies are able to identify current problems, anticipate others which have not yet occurred but are at risk and, most importantly, prevent them from occurring

It should be clear that water treatment represents only one part of a complex matrix of tools available for controlling health impacts in potable water systems It should be applied judiciously and only within the context of all alternatives within the matrix

Various Goals of Water Treatment

As indicated earlier, the basic role of municipal water treatment is to correct deficiencies in quality It should be recognized, however, that not all of the deficiencies are health-related Some standards, especially those relating to bacterial quality of water, are based specifically on protecting the public health Other standards established because of concerns about potential impacts on health include those for heavy metals, radioactive substances, nitrates, fluorides and selected organic chemicals

Treatment often is directed towards correcting aesthetic characteristics of water, with little or no relationship to real or potential health problems. For example, removal of iron, manganese, color, phenols and other substances capable of producing undesirable tastes and odors sometimes form the principal motivation for treatment Also, treatment often is undertaken to correct the corrosiveness of water or the tendency to form scale in pipelines and water heaters

In some instances, treatment may correct a characteristic which otherwise could interfere with use of the water in certain industrial processes In some communities, this has been done because of the importance of the industry in the community and recognition that treatment to provide water suitable for its needs could be more economical at the municipal plant than at the industry itself. In other instances, special treatment may be better left to the industrial organization because of excessive cost of applying those steps to all waters used in the municipality

Evaluation of Water Quality

The types of treatment processes which should be used in water purification plants and efficiencies which must be attained by them ultimately depend on constituents in the raw water and concentrations acceptable in uses to which the water will be placed. The specific degree of removal necessary for each constituent is that required to correct the quality of the raw water to meet needs specified for the finished product To reach those decisions, we should be able to define water quality goals in terms which, preferably, are both quantitative and accurate

With respect to protection of health, we need a basis for evaluating risks accompanying various concentrations of specific constituents in water. When that type of information is available, information about the concentration of each constituent in the raw water and the final concentration which would be acceptable in the finished supply can be used to specify what treatment must accomplish Correlations between constituents in water and health risks incurred by their presence often can be established through epidemiological studies or through animal studies Unfortunately, however, difficulties often are encountered in either because low levels of chronic or genetic damage may appear only after consuming the water for many years

Sometimes it is possible to evaluate conditions through direct measurement of constituents, perhaps using very complex and sophisticated analytical techniques, but in other instances even those cannot produce the information required for an accurate assay of health risks In those it may be necessary to use parameters other than the concentration of one or more specific constituents in the water A few aspects of evaluating water quality to estimate health risks will be discussed briefly

Communicable Diseases

One obvious method for evaluating water quality with respect to disease transmission would be to enumerate the numbers of pathogenic organisms in representative samples of the water, but this could present serious problems Many types of pathogens can be transmitted via the water route They have wide differences in characteristics, numbers ingested to produce probable infection, numbers discharged in wastewaters from infected hosts, rates of dieoff outside the hosts in natural waters, and resistance to destruction or removal by various water treatment processes.

Direct enumeration of pathogens would be both difficult and expensive Many techniques would be necessary for isolating and identifying different types because methods appropriate for one would not be suitable for assaying others Some (for example, the hepatitis virus) are not quantifiable at all The necessary expertise seldom is available in water laboratories to conduct these types of tests, and even if it were, analytical difficulties and tedious work necessary to measure the low number of pathogens in most waters, especially after treatment, would result in very high costs. Beyond those disadvantages, results from such analyses would not be the most desirable type of information, in any event. Success or failure in isolating a pathogen could depend upon only whether or not it happened to be in the specific sample of water studied A water indicated to be safe by this approach might, nevertheless, become unsafe shortly thereafter upon receiving waste discharges from one or more persons infected with the disease in question

A far preferable approach would be to employ a technique which measures "risk" in terms of opportunity for receiving pathogens or, in other words, the extent of recent pollution by wastewater discharges This potential for transmitting communicable diseases commonly is evaluated through enumerating "indicator organisms " One such organism is *Escherichia coli*, which is discharged in large numbers from intestinal tracts of all humans Measurements of numbers of E coli in water indicate the degree to which the water has been polluted by fecal contamination from humans This provides a better measure of the "risk" of transmitting waterborne pathogens, both presently and at some future time

Indicator organisms most commonly used in the water treatment field are the "coliform group" which includes, in addition to E coli, some organisms derived from other animals and soils This broader group of bacteria is present in larger numbers and is easier to identify and count under conditions found in most water laboratories Also, it provides a more conservative evaluation of treatment plant operation because good performance should be successful in reducing even this larger and more diverse group to the vanishing point In general, studies have indicated that survival characteristics of coliforms are similar to those of important pathogenic bacteria, providing confidence that the water should be safe once the coliform group has been eradicated by treatment.

Unfortunately, absence of coliforms provides a less accurate measure of safety with respect to pathogenic viruses and protozoa Serious reservations often have been expressed about reliability of this test, leading to searches for other types of indicator organisms which might be better suited for the purpose To date, no consensus has been reached on any of several proposed alternative organisms

Today, the safety of water with respect to transmission of communicable diseases is evaluated principally in terms of its population of coliform bacteria. Drinking water standards presently used in many areas of the world allow approximately 1 coliform organism per 100 ml of water This does not entirely exclude the possibility of acquiring intestinal infection but is a practical standard, established partly through expedience It can be attained economically in most water supplies and appears to limit the incidence of waterborne diseases to a level below the detection threshold A recent major study in the U S A reached the following conclusion (Rohlich, 1977)

> The present coliform standards appear adequate to protect public health when raw water is obtained from a protected source, is appropriately treated, and is distributed in a contamination-free system Current coliform standards are not applicable for water reclaimed directly from wastewater

This suggests that the standard, which appears to be entirely adequate in many industrialized nations where incidences of waterborne diseases are low, may be less satisfactory in countries with high incidences of those diseases In an area having a high incidence of waterborne disease, treatment to produce the same level of coliform organisms would be expected to result in ingestion of more pathogens because of increased ratios of pathogens to coliforms in wastewater discharges.

For purposes of monitoring daily operations, other more rapid types of analytical procedures have been employed. One involves measurement of turbidity at frequent intervals at the plant and throughout the distribution system Significant departures from the very low turbidity levels which are customary with properly operated systems would signal that an unsatisfactory situation has arisen, perhaps improper treatment plant operation or cross-connections in the distribution system Measurements of chlorine residuals also have been used for similar purposes. Using these types of tests, in addition to bacteriological analyses, offers the advantage of rapid and easily conducted methods for identifying presence of water quality hazards

Inorganic Chemicals

The allowable content of an inorganic chemical in water usually can be defined directly in terms of concentration of the chemical in question Accordingly, evaluation of raw water quality in this respect usually involves measurement of concentrations of heavy metals, chlorides, sulfates, nitrates, fluorides and others through use of readily available analytical methods Treatment requirements then can be established through comparing those data with allowable concentrations specified for potable waters

Organic Chemicals

Specifying allowable concentrations of organic chemicals in potable water presents special problems because of difficulties in analyzing water for low concentrations of those constituents For several years, U S A standards included a maximum recommended concentration for "carbon chloroform extract (CCE) " This empirical measurement of organic matter was accomplished by filtering a large sample of water through activated carbon and subsequently eluting organics from the carbon with chloroform The test was of little value for assaying safety of a water because of its very gross nature and absence of definitive information about the types of organics present The rationale simply was that organic content of the water should be kept at a low level. If the raw water contained what was considered, empirically, to be excessive organics, steps should be taken to reduce them during treatment, usually by using activated carbon for adsorption.

Currently, standards have been established for several types of specific insecticides, widely recognized as having significant health implications in potable water and for certain other organic compounds Chlorinated hydrocarbons, especially the trihalomethanes, are receiving extensive interest in some countries currently Identification of most trace organics in water requires very sophisticated analytical techniques, usually going far beyond the capability of analytical equipment and personnel at typical water treatment facilities. If analyses are required for these constituents, special analytical instrumentation and personnel usually must be provided, often on a consulting basis

Mechanisms for Reducing Health Risks Through Treatment

Physical Removal

Some water treatment processes function by simply removing the undesirable constituent without significantly changing its character. For example, sedimentation or filtration may remove bacteria and viruses from water efficiently without influencing viability of the organisms Of course, viability of the organisms is important when evaluating disposal of sludges and other by-products from treatment facilities because they usually contain much higher concentrations of undesirable constituents than water entering the plant. Other processes which function principally through separation include distillation, reverse osmosis and other membrane processes

Pretreatment to Enhance Removal

In some instances, constituents may be separated after pretreatment to facilitate the removal process For example, heavy metals often are removed through precipitation to convert the soluble ions to insoluble forms, followed by settling and, perhaps, filtration Removal of bacteria and viruses may be improved substantially by coagulation to agglomerate them into larger particles before settling. Removal of iron and manganese may be enhanced by aeration or chlorination to oxidize the metal to a higher valence state, facilitating its precipitation and removal by subsequent settling and filtration.

Destruction

Other types of processes operate through destroying objectionable characteristics of the constituent, either before removal by a subsequent process or sometimes without removal at all For example, chlorination of water can oxidize sulfides and other reducing agents to different chemical forms which no longer are objectionable In similar fashion, cyanides may be oxidized to produce innocuous products which do not require subsequent removal On the other hand, organic iron compounds sometimes are oxidized by chlorine or ozone to break the bond between the organic molecule and iron, facilitating subsequent precipitation of the iron. In general, disinfection processes function through chemical reaction with enzymes or other cell components to inactivate the organism and effectively destroy it as a living system

Secondary Effects

In some instances, treatment occupies a role which may be secondary, but important, in determining efficiency of disinfection. It has been observed that disinfection of turbid waters may be difficult to accomplish efficiently because some organisms are shielded within turbidity particles, blocking contact between them and the chlorine compounds Subsequently, they may be separated from the turbidity particles and remain viable in the water after the chlorine has been dissipated. Accordingly, removal of turbidity is considered to be an important facet of water treatment for destruction of pathogenic bacteria and viruses, even though the turbidity itself has no direct role in disease transmission

Protection from Bacterial Pathogens

An important consideration in designing, constructing and operating a water treatment plant is reduction in risk of transmitting pathogenic bacteria to the public

For reasons discussed earlier, bacteriological quality of water actually is assessed through enumerating coliform bacteria. That also permits evaluation of effectiveness of the treatment system in reducing risk of transmitting waterborne diseases, whether or not pathogens happen to be present at the time of measurement. Some investigators have adopted an even broader approach to evaluating efficiency by analyzing removals of bacteria, represented by total plate counts instead of only the coliform organisms.

Effects of Storage on Bacteriological Quality

It long has been recognized that self-purification processes in nature serve to reduce risks of transmitting waterborne diseases

This has been observed through measurements of pathogens, as well as monitoring of coliform organisms or total bacterial populations

Some have observed that for a short time after discharge of municipal wastewater into a stream there is an increase in population of coliform organisms. Some have attributed that to breaking of clumps of bacteria, producing only an apparent increase. Others have concluded that growth of coliform organisms actually was occurring in the stream On the other hand, growth of pathogens has not been observed in receiving streams, where conditions are unfavorable as compared with the rather specialized environmental needs of most pathogens

Subsequently, the numbers of pathogens and coliforms both have been observed to decrease with time, due to dieoff. Many factors affect the dieoff rate, including temperature, pH, presence of predator organisms, and concentration of pollutional materials in the water It has been reported (Fair, Geyer, and Okun, 1968) that destruction of enteric bacteria is more rapid in heavily polluted waters than in clean streams, in warm weather than in cold, and in shallow turbulent streams than in deep, sluggish bodies of water.

Specific removal rates reported by past investigators vary widely depending on experimental conditions under which their studies were conducted Accordingly, great caution should be exercised in attempting to project any quantitative relationships between time of storage and extent to which pathogens may be reduced in numbers Data summarized by a few past investigators suggest removals ranging from 50% to over 99% of enteric bacteria with storage times of three to sixty days (Wagner, 1959, Fair, Geyer, and Okun, 1968, Anon., 1979). McJunkin (1976) reports that storage of water for 48 hours results in death of cercariae responsible for transmission of schistosomiasis.

Physical Removals in Water Treatment Plants

Slow sand filtration has been reported to remove 85-99% of bacterial pathogens from water. This can be attributed to effectiveness of the filtration process in removing suspended matter, including bacteria, and to natural dieoff of those bacteria during storage in the filter under conditions environmentally unfavorable to their survival (Wagner, 1959).

Higher efficiencies usually can be attained in properly operated rapid sand filter plants Coagulation and settling are capable of removals in the range of 95-99% of the bacteria When followed by rapid sand filters, overall removals well in excess of 99% should be readily attainable in a properly operated plant

Disinfection

Extensive removal of bacteria by various water treatment processes notwithstanding, disinfection remains the principal line of defense against transmission of waterborne diseases. Even removals well in excess of 99.9% of coliform organisms from typical surface waters usually will be inadequate to insure safety from waterborne diseases as represented by commonly accepted drinking water standards. Accordingly, production of a finished product consistent with those standards almost always depends heavily upon effective disinfection Slow sand filtration, or coagulation, settling and rapid sand filtration, followed by disinfection of the treated water can virtually assure freedom from significant risks of transmitting communicable diseases via the drinking water route.

The disinfectant which has been used for three quarters of a century with great success is chlorine. It must be recognized that addition of chlorine to water actually may result in formation of several different disinfectants because of subsequent reaction between the chlorine and constituents of the water Addition of chlorine to water results initially in formation of hypochlorous acid (HOCl), in accordance with the following reaction·

$$\underset{\text{Chlorine}}{Cl_2} + \underset{\text{Water}}{H_2O} \longrightarrow \underset{\text{Hypochlorous Acid}}{HOCl} + \underset{\text{Hydrochloric Acid}}{HCl} \quad (1)$$

The hypochlorous acid subsequently dissociates in water to yield hypochlorite ions (OCl^-), as shown in the following equation

$$\underset{\text{Hypochlorous Acid}}{HOCl} \rightleftharpoons \underset{\text{Hypochlorite Ion}}{OCl^-} + \underset{\text{Hydrogen Ion}}{H^+} \quad (2)$$

It generally is accepted that the hypochlorous acid is the most effective killing agent In a water in which the above reactions are the only ones which occur, the percent of hypochlorous acid present depends principally on pH (acidity) of the water The sum of the hypochlorous acid and hypochlorite ion is termed "free residual chlorine "

It is worthwhile to point out that a "free chlorine residual" may be produced in water through addition of agents other than chlorine gas For example, addition of sodium hypochlorite (NaOCl) can result in introduction of hypochlorite ions to the water They subsequently enter into exactly the same chemical equilibrium as that presented above·

$$\underset{\text{Sodium Hypochlorite}}{NaOCl} \longrightarrow \underset{\text{Sodium Ion}}{Na^+} + \underset{\text{Hypochlorite Ion}}{OCl^-} \quad (3)$$

$$\underset{\text{Hypochlorite Ion}}{OCl^-} + \underset{\text{Hydrogen Ion}}{H^+} \rightleftharpoons \underset{\text{Hypochlorous Acid}}{HOCl} \quad (4)$$

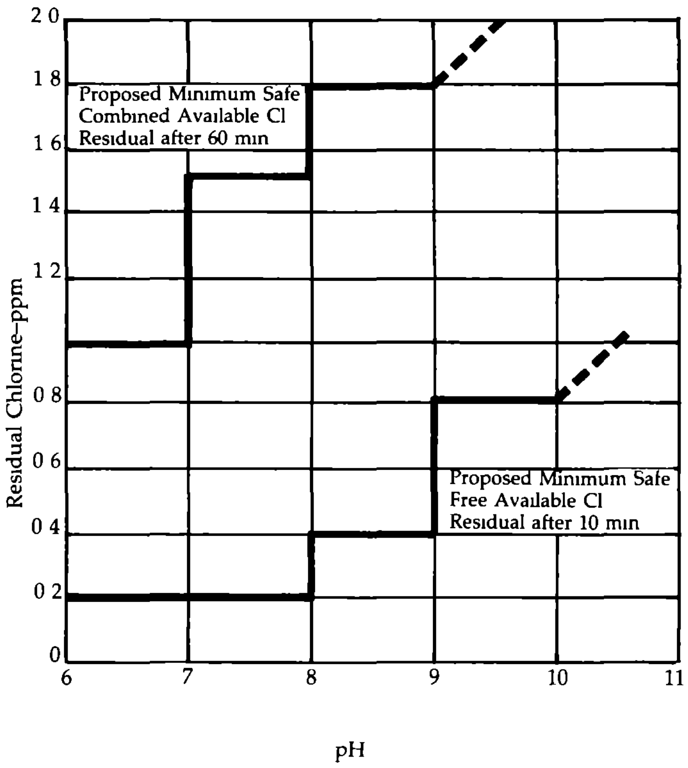
Effectiveness of the disinfectant in this instance is identical with that produced through addition of an equivalent amount of chlorine because, clearly, the same products ultimately are produced in solution (Equation No 4) and have the same potential for killing bacteria, whatever their source. Although hypochlorites may be effective in producing the desired type of chlorine residual, it should be noted that commercial products tend to lose strength over time Accordingly, caution must be exercised in storing and applying those products to insure that they remain effective when used.

Figure 7-1 summarizes some chlorine residuals and contact times which have been recommended over many years for disinfection of drinking waters (Anon , 1951) Wagner (1959) has suggested maintenance of a residual of 0 5 mg/l for thirty minutes contact for ordinary disinfection and 2 mg/l free chlorine residual for thirty minutes contact to control amebic cysts

Because of possible interference by turbidity with contact between chlorine and organisms, the most effective time for chlorination is after filtration In many plants multiple chlorination has been employed for treatment of water with high bacterial counts This involves addition of a high chlorine dosage when water first enters the treatment plant and maintenance of a residual throughout the entire process, usually over several hours After filtration, additional chlorine may be added, if needed, to raise the residual to the desired level before pumping water into the distribution system In other instances, sulfur dioxide or some other reducing agent may be added to reduce chlorine residual if it remains too high after passage through the entire plant

High residual chlorination produces extremely effective disinfection, but recently a reluctance has developed in the U S.A to continue that approach That can be attributed to recent recognition that undesirable chlorinated hydrocarbons may be formed through reaction between chlorine and organic constituents of

Figure 7-1. Minimum Free or Combined Available Chlorine Residuals Proposed by Butterfield



SOURCE: Anonymous (1951)

the water One way to prevent their formation is to withhold chlorination until after most of the organic content has been removed by the coagulation, sedimentation and filtration processes. Because of uncertainty about possible health effects of chlorinated products, several U S A communities have discontinued prechlorination of water

Many communities throughout the world now employ ozone for water disinfection Ozone offers the advantage of producing a highly active disinfectant which does not react to form products comparable with chloramines, causing slower or less efficient disinfection Also, there is less tendency to form odorous compounds, which sometimes are produced through reactions between chlorine and organic constituents On the contrary, often the ozone actually oxidizes some of the organics and reduces tastes and odors in the treated water Reaction products which may be formed by ozone to produce the same ultimate problems as chlorinated hydorcarbons, referred to above, are not known at this time, but are presumed by some to offer less risk than chlorine

Ozone has the disadvantage of being substantially more expensive than chlorine Also, it must be produced at the point of use when needed, without opportunity for storage. Further, it is not feasible to maintain a residual of disinfectant which persists throughout the distribution system if ozone is used Many who favor maintenance of a residual, therefore, prefer chlorine, which does produce a residual that can be maintained throughout the distribution system to afford some degree of protection against subsequent contamination through cross-connections, infiltration of raw water into pipes when pressure drops, or other inadequacies

Protection from Pathogenic Viruses

The state of knowledge for evaluating water quality and treatment effectiveness with respect to viruses is much poorer than for bacterial pathogens The problem originates with inadequate knowledge about quantities of viruses which must be ingested to cause disease, making it virtually impossible to define the goal which treatment processes must attain Much of that problem, in turn, can be related to the difficulty, and in some cases impossibility, of accurately enumerating viruses in water because of problems inherent in growing many of them (for example, hepatitis) in the laboratory

Major problems exist in trying to establish probable relationships between commonly used indicator organisms (coliforms) and viruses in water to evaluate risks of viral infections Further, the relative survival patterns and resistances to disinfectants of coliforms and viruses are not known. Some viruses which can be enumerated in drinking water might prove useful eventually as indicators for pathogens, but the relative relationships between those organisms are not yet known A recent major U S A publication on water and health (Rohlich, 1977) indicated that "safety of drinking water, from the virus standpoint, cannot at present be defined in numerical terms "

Processes used today to treat potable water originally were not developed specifically to remove or destroy viruses, but most do have substantial impact in that respect Evaluation of virus removals is difficult because current analytical techniques permit accurate measurement only of very high numbers—much higher than those which occur normally in water considered for human consumption All of the problems notwithstanding, results of many laboratory and epidemiological studies give ample reason to believe that current water treatment technology is capable of insuring substantial protection from waterborne viral diseases This section will describe briefly some findings of past investigators with reference to removal or destruction of viruses in drinking water by various processes.

Coagulation and Sedimentation

These processes are used to agglomerate and remove suspended and colloidal matter from water, including bacteria and viruses Several extensive studies have indicated that virus removals ranging from 90% to substantially higher than 99% can be achieved in carefully operated coagulation and settling systems (Rohlich, 1977; Sobsey, 1979). It has been pointed out, however, that viruses removed by adsorption on floc in this fashion usually are not inactivated, but remain viable Accordingly, the sludges often contain high concentrations of enteric viruses and may require further treatment to inactivate or destroy them before disposal

Filtration

Slow sand filtration has proved capable of removing viruses from water in excess of 99%, in laboratory studies. One investigator (Slade, 1978) conducted a field study in which enteric viruses were removed from polluted waters at 97-99 8% efficiency, averaging 98% He concluded that virus removals were comparable to coliform removals in those filters

Because of large grain size, rapid sand filters alone are relatively ineffective for removing viruses However, they typically are used only in conjunction with coagulation and sedimentation The combination of the three processes commonly produces removals in excess of 99% through settling, adsorption, and incorporation into suspended matter large enough to be mechanically removed

Lime Softening

Lime softening is employed in some plants to remove calcium or magnesium, or both Precipitation of calcium at a pH of about 10 has been reported to produce about 75% removal of viruses, principally through entrapment in the precipitate, similar to coagulation and sedimentation. When the excess lime process is used to precipitate magnesium, pH customarily is raised to levels above 11 Under those conditions, viruses not only are removed by the floc, but also are inactivated by the high pH This has been observed to produce removals over 99%

Disinfection

Chemical disinfection appears to be the most reliable method for inactivating viruses in water Treatment by other processes prior to disinfection serves principally to reduce virus load on the disinfection process and to prepare the water for efficient disinfection by removing suspended matter and other interfering substances

Most enteric viruses are more resistant to chlorine than are enteric bacteria As observed for coliforms and other bacteria, hypochlorous acid appears to be the most efficient disinfectant, and chlorine dosages and pH should be maintained which insure that the residual is present predominantly in that form Sobsey (1979) has concluded that "it is likely that enteric virus reductions of greater than 99 9% can be obtained in relatively clean water having low turbidity, low dissolved organics and a pH below 8 5 by using a free chlorine residual of 0.5 mg/l and a 30-minute contact time " Other laboratory studies have indicated that free chlorine residual of 0 4 mg/l, with 30 minutes contact, can inactivate infectious hepatitis viruses. Chloramines have been found to be much less effective than free chlorine residual—perhaps by a factor of 50

Chlorine dioxide (ClO_2) is less reactive with ammonia and less affected by temperature and pH, offering some advantages over chlorine. Ozone has been shown to be very effective for virus inactivation at dosages of 0 3-1 0 mg/l A disadvantage of these agents is their inability to maintain residuals until delivery to the ultimate consumer Accordingly, they alone do not provide protection against further contamination in the distribution system

Summary

Sobsey (1979) has summarized effectiveness of water treatment systems for reducing viruses as shown in Table 7-1 Overall, a typical alum or iron coagulation, sedimentation, filtration and chlorination system is expected to reduce enteric virus concentrations by over 99 9999% when operated properly

A recent field study using a pilot treatment system, including those elements and activated carbon adsorption, actually attained virus removals in excess of 99 9995% (Lamb, 1980) Under normal operating conditions, expected virus reductions by a typical rapid sand filter water treatment plant should approximate 5 0 to 6 0 logs (99 999 to 99 9999%)

Table 7-1. Expected Virus Reductions in a Water Treatment System[1]

Treatment Process	Virus Reduction - % Unit Process	Virus Reduction - % Cumulative
Coagulation-flocculation and Sedimentation	99	99
Filtration	90	99 9
Chlorination	>99 9	>99 9999

[1]From Sobsey (1979)

Reduction in Inorganic Chemical Content

Removals in Conventional Treatment Systems

The water treatment systems commonly employed in municipal practice range in removal of inorganic constituents from zero to 100%, depending upon many factors Clearly, a key consideration is identity of the constituent and its chemical and physical characteristics, especially particle size Generally, relatively large suspended particles should be removed efficiently by water treatment processes commonly employed for reducing turbidity Also, most colloidal materials could be reduced substantially by processes which are effective in reducing colloidal turbidity and many natural organic constituents Removal of dissolved inorganic substances will be much less efficient unless they become involved in floc formation or are precipitated through change in pH, oxidation by chlorine, or other treatment steps

Effectiveness of the process in removing inorganic constituents also depends heavily upon the specific process employed and its operating conditions Removal of an inorganic substance at relatively low pH during coagulation could be radically different from that in lime softening at very high pH For example, softening would be very efficient in removal of many metals from water, whereas typical coagulation may be ineffective Many ground waters may be subjected to no treatment other than disinfection, using chlorine That would not remove most inorganic constituents, but could be excellent for oxidizing sulfides. On the other hand, some constituents might be rendered more objectionable through oxidation For example, oxidation of ferrous (Fe^{+2}) iron to the ferric (Fe^{+3}) form could cause precipitation and discoloration of the water Sometimes that problem may be avoided by adding certain chemicals to the water to prevent precipitation upon addition of chlorine or oxygen

Pretreatment to Enhance Removal

Sometimes removal of an inorganic constituent during conventional treatment can be enhanced substantially by appropriate pretreatment or change in process parameters. For example, many metals can be removed very efficiently through precipitation at moderately high pH Accordingly, if that goal must be imposed on a coagulation, sedimentation and filtration system, additional treatment steps often may be avoided by modifying the process Sometimes metal removals may be enhanced by changing lime and alum dosages to operate the process at a pH somewhat above the normal optimum range In other instances, it is preferable to change coagulants, perhaps to an iron compound which may be better suited for floc formation in a pH range which produces good removal of the metal

Chlorination before coagulation frequently is used to enhance removal of some constituents Inorganic iron usually can be removed by coagulation and settling if the iron is present in the trivalent form (Fe^{+3}) Sometimes, iron is encountered in raw waters in the divalent (Fe^{+2}) state or may be combined in a complex with organic matter Prechlorination often can enhance removal of iron by oxidizing it to the ferric state or by breaking the organic complex Other oxidizing agents also have been used for similar pretreatment, including ozone, chlorine dioxide and potassium permanganate

Several other constituents may require change in valence before effective removal by coagulation, precipitation and settling

Arsenic is easily removed in its oxidized state (As^{+5}), but not by coagulation in its reduced states (As^{+3}) The oxidation may be accomplished by adding chlorine or potassium permanganate Trivalent chromium (Cr^{+3}) is readily removed by coagulation with ferric sulfate in a pH range of 6 5-9 3, or less effectively by alum coagulation at pH 6 7-8 5 On the other hand, hexavalent chromium (Cr^{+6}) is not removed effectively by alum or ferric sulfate coagulation, or even by lime softening Efficient removal of chromium requires its reduction to the trivalent form (Cr^{+3}), by pH adjustment and addition of a reducing agent, followed by precipitation at higher pH

These examples are provided to illustrate that sometimes relatively simple changes in treatment processes may greatly influence the removal of certain inorganic constituents Detailed coverage of this subject is beyond the scope of this publication

Special Treatment for Removal of Inorganics

Many inorganic constituents are influenced little or not at all by conventional treatment processes It is infeasible to remove chlorides, sulfates, sodium, potassium and many other inorganics without resorting to more sophisticated (and more expensive) processes Where conventional processes are not effective enough in removing inorganics and cannot be made suitable through pretreatment or process modifications, it may be necessary to resort to reverse osmosis, ion exchange, distillation, electrodialysis, freezing or other approaches These processes have been employed successfully to remove inorganic constituents from sea water or saline well waters where alternate supplies are not available at acceptable costs All of them are more expensive than conventional systems discussed earlier, and their justification requires careful analyses of capital and operating costs

It is unusual to use these processes to treat large flows for municipal supplies Where other alternatives make them necessary, consideration also should be given to desirability of employing dual supplies A relatively small flow of expensive desalted water could be produced and be used for drinking, cooking and other purposes requiring high quality. The saline water, after minimum treatment, could be employed for other purposes for which water of higher salinity may be entirely satisfactory

Examples of Treatment Systems

Treatment systems which have been found effective for removal of inorganic constituents are summarized in Table 7-2 (Anonymous, 1977) This is only a partial summary of some of the more effective methods and is not intended to be a comprehensive treatment of the subject

Table 7-2. Most Effective Treatment Methods for Inorganic Contaminant Removal

Contaminant	Most effective methods
Arsenic	
As^{+3}	Ferric sulfate coagulation, pH 6-8 Alum coagulation, pH 6-7 Excess lime softening Oxidation before treatment required
As^{+5}	Ferric sulfate coagulation, pH 6-8 Alum coagulation, pH 6-7 Excess lime softening
Barium	Lime softening, pH 10-11 Ion Exchange
Cadmium Cd^{+3}	Ferric sulfate coagulation, above pH 8 Lime softening Excess lime softening
Chromium	
Cr^{+3}	Ferric sulfate coagulation, pH 6-9 Alum coagulation, pH 7-9 Excess lime softening
Cr^{+6}	Ferrous sulfate coagulation, pH 7-9 5
Fluoride	Ion exchange with activated alumina or bone char media
Lead	Ferric sulfate coagulation, pH 6-9 Alum coagulation, pH 6-9 Lime softening Excess lime softening
Mercury	
Inorganic	Ferric sulfate coagulation, pH 7-8
Organic	Granular activated carbon
Nitrate	Ion exchange
Selenium	
Se^{+4}	Ferric sulfate coagulation, pH 6-7 Ion exchange Reverse osmosis
Se^{+6}	Ion exchange Reverse osmosis
Silver	Ferric sulfate coagulation, pH 7-9 Alum coagulation, pH 6-8 Lime softening Excess lime softening

Reduction in Organic Chemical Content

Naturally occurring organic chemicals, many derived from decomposition of vegetation, long have been of concern in water treatment because of their capability for causing objectionable color, tastes and odors Except for those constituents, phenol, and a few other organics which cause objectionable odors or other aesthetic problems, removal of organic substances from drinking water received surprisingly little attention until only a few years ago Interest in possible health implications of organics in water first peaked as a result of increasing use of pesticides, for which toxic implications were obvious During the past decade, in particular, concern about health effects of organics in water has increased rapidly until now it occupies a position of major significance and concern in the U S A and other industrialized countries

Potentially toxic organics may enter drinking water supplies from nonpoint sources, such as runoff from agricultural and urban areas, and from accidential spills They also may be introduced through point source discharges from industrial manufacturers or users A source which has created special concern in the U S A during the past few years is production of chlorinated hydrocarbons during chlorination of potable waters There has been a great amount of research to evaluate the extent to which these chemicals occur in drinking waters, their potential impact on health of persons consuming those waters over many years, and methods for reducing their concentrations A detailed review of this question is beyond the scope of this publication, but information is available elsewhere (Harris, 1977, Rohlich, 1977).

Removal of Organics by Conventional Treatment Systems

Conventional treatment processes have been developed over the years to correct quality deficiencies in drinking waters arising from, among many other things, excessive concentrations of naturally occurring organic substances which can produce objectionable color, tastes and odors. Accordingly, it is reasonable that typical water treatment systems based on coagulation, sedimentation and filtration are capable of attaining efficient removal of many of those organics. In some instances, typical treatment systems have been supplemented by adding oxidizing agents or using activated carbon to destroy or remove some of those chemicals.

On the other hand, removal of pesticides and many other organic chemicals by conventional water treatment systems usually is relatively ineffective, as reported by many investigators (Anon., 1979, Blanck, 1979, Robeck, 1965; Rohlich, 1977). Table 7-3 summarizes removal of selected organics by conventional water treatment processes (Anon., 1977). Endrin was removed to the extent of 35%, although other authors have reported lower removals. All of the other chemicals listed there were removed to a negligible degree, if at all, by coagulation and filtration.

In instances where removal of organics is necessary in water treatment, it must not be assumed that conventional systems will attain significant efficiency. Some chemicals may be removed efficiently but others could be untouched. The effectiveness of removal depends upon many factors, especially characteristics of the chemical in question and whether it is adsorbed or otherwise enmeshed in suspended matter in the water or floc developed during treatment.

Special Treatment for Removal of Organics

Table 7-3 also summarizes experience reported by some investigators in removing certain pesticides, using powdered activated carbon, granular activated carbon, and oxidation by chlorine, ozone or potassium permanganate. Activated carbon has demonstrated excellent capability for adsorption and removal of many chemicals. When combined with conventional treatment for surface water, it appears that activated carbon often could be effective in attaining substantial removals of pesticides and for many other organic chemicals, as well.

Granular activated carbon has exhibited greater efficiency than powdered carbon for removing many organics. That can be attributed to the hydrodynamic characteristics of carbon columns, which are capable of more effective adsorption than single-stage addition of powdered activated carbon in a conventional treatment system. Economic considerations of the two approaches for using activated carbon are very different. Powdered carbon can be added in conventional treatment systems, with little or no additional capital investment. On the other hand, granular activated carbon columns require substantial investment for construction of the treatment facilities. In return, however, operating costs for carbon purchases are lower because of more efficient carbon utilization, and treatment efficiency is substantially higher.

Some organic chemicals can be destroyed effectively by chemi-

Table 7-3. Percent Organics Removed by Water Treatment Processes

Process	*Endrin Reduction* %	*Lindane Reduction* %	*Toxaphene Reduction* %	*2,4-D reduction, percent*			
				Sodium salt	*Isopropyl ester*	*Butyl ester*	*Isooctyl ester*
Coagulation, filtration	35	<10	<10	<10	<10	<10	<10
Coagulation, filtration, and adsorption with							
Powdered activated carbon, mg/l							
5-9	85	30	93				
10-19	92						
	80	55			90	90	90
20-29	94	80-90					
30-39				90			
40-49					97	97	
50-59	98						97
70-79		99			98		
Granular activated carbon, 7-5-minute full bed contact time	>99	>99					
Oxidation:							
Chlorine, mg/1							
5	<10	<10					
8		<10					
50		<10					
100			<10	<10	<10	<10	<10
Ozone, mg/l·							
11		<10					
38		55					
Potassium permanganate, mg/l·							
10		<10		<10	<10	<10	<10
40		<10					

cal oxidizing agents, including chlorine, ozone and potassium permanganate Effectiveness of each depends on the type of chemical used, dosage applied, and environmental conditions Chemical oxidation has been used only infrequently because its cost usually exceeds that of attaining equivalent removal by activated carbon

It is generally considered that granular activated carbon columns provide the most stable and reliable treatment They can be used without pretreatment on ground waters or other low turbidity supplies Where the raw water contains significant turbidity, it usually is necessary to precede granular carbon columns with conventional water treatment Otherwise, rapid clogging rates are experienced, causing premature termination of the run and more frequent purchase of expensive replacement carbon.

Removal of Precursors

It has been mentioned earlier that a topic of substantial concern currently in some industrialized nations is formation of chlorinated hydrocarbons by reactions between chlorine and humics or other organics in raw water supplies There is irony in this situation because chemicals which could be potentially harmful are formed through reaction between innocuous, naturally occurring organics in the raw water and chlorine, which is added for disinfection to protect the public health

Concern about the resulting chlorinated hydrocarbons is based on the fact that some have been demonstrated or suspected to have capability for causing cancer in humans when applied at high dosage The question of crucial importance here is the risk, if any, incurred by the public in drinking water containing very low concentrations of chlorinated hydrocarbons over many years There is substantial controversy on the question now, and it is unlikely that a definitive answer will be obtained soon

In the U S A , a standard currently is being established to limit concentration of trihalomethanes (THM) in drinking water to a maximum of 0 1 mg/l This group of chemicals includes chloroform and other potentially harmful organics produced during chlorination of water

A recent study (Blanck, 1979) of operating water treatment plants in the U S A indicated that THM's in water supplies can be reduced by 59-90% The trihalomethanes can be removed through adsorption on granular activated carbon to the extent of 23-60% A change in the type of disinfectant used to pretreat water at the plant influent by using chlorine dioxide was capable of reducing THM by 59-90%

A very effective method for reducing THM concentration in the finished water is through preventing its formation by removing precursors before chlorination That can be accomplished by adsorbing the precursor organic chemicals on granular activated carbon, or by changing the location of disinfection to a point after removal of most of the organics through coagulation and sedimentation This was capable of reducing THM formation by 76% and sometimes could be accomplished at a net cost savings (Blanck, 1979)

Treatment to Enhance Beneficial Effects

No discussion of health effects of potable water treatment would be complete without at least mentioning fluoridation Exhaustive investigations over many years, beginning in the 1930's, have demonstrated conclusively that incidence of dental caries decreases sharply with rise in fluoride content of drinking water consumed by children. Beyond some concentration of fluoride, however, discoloration of tooth enamel (mottling) occurs with increased frequency The optimum fluoride concentration appears to be in the vicinity of 1 0 mg/l, which produces substantial protection against caries without incurring significant risk of mottling

Today, the water supplies to millions of persons are being treated to increase fluoride content to a level calculated to produce most of the benefit, while minimizing the risks In the U S A , this is accomplished by adding fluoride to produce a total concentration in drinking water between 0 7 and 1.2 mg/l, depending upon ambient temperature in the locale Current U S A drinking water standards limit fluoride concentrations to a maximum of 1.4-2 4 mg/l, depending upon ambient temperature The importance of temperature lies in the relationship between the amount of water ingested by children and air temperature

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SECTION 8

PUBLIC HEALTH EFFECTIVENESS OF EXCRETA AND WASTEWATER TREATMENT AND DISPOSAL

Potential Health Impacts

Constituents of excreta and municipal and industrial wastewaters which can offer significant risks for adversely affecting health of persons consuming or otherwise contacting waters in streams receiving them have been discussed earlier and the details do not require repetition here They include many types of infectious agents and a wide variety of inorganic and organic chemicals which are potentially harmful.

Infectious agents in excreta and domestic wastewaters include pathogenic bacteria, capable of causing the classical waterborne diseases and discussed earlier Also, viruses and other pathogens commonly are encountered in those wastewaters Often, coliform organisms are employed to evaluate health risks associated with use of water, but those indicator organsims may not always provide a reliable measure of the actual risks

Many types of inorganic and organic chemicals may be present in municipal wastes and, to an even larger extent, in discharges from industrial establishments, but health implications are understood accurately only for relatively few of them In some instances, their discharges are regulated to control known adverse impacts In others, they are regulated because of concern about suspected, but unknown, effects In many, they are not regulated at all because knowledge is unavailable about their potential impacts and concentrations which might be objectionable in the environment

Basic Mechanisms for Reducing Health Risks

The health risks attending discharge of excreta and wastewaters involve the probability of (a) release of the harmful agent to the environment, (b) its transmission from the point of disposal to a person who might be adversely affected, and (c) subsequent interaction of the agent with the victim, actually producing adverse effects Viewed in the broadest terms, reduction or elimination of the risks may be based on attacking this chain of events at one or more locations to reduce probability that the harmful agent ultimately will reach and interact with the recipient It should be recognized, however, that this simplistic scenario is influenced greatly by many factors between the origin of the discharge and the potential victim, either diminishing or enhancing the chances for unfavorable impacts

To illustrate, excreta from humans may include infectious agents which sometimes may be transmitted directly via food, ingestion of water, or body contact with water to produce disease in other humans In other situations the transmission route may be less direct, involving an intermediate host with a key role in the life cycle of the disease-producing organism, as illustrated by schistosomiasis In this instance, another factor is introduced into the transmission pattern and another point is provided at which the disease transmission may be interrupted

In similar fashion, harmful effects of chemicals discharged in industrial wastewaters sometimes may result from their direct transmission via the water route to a human who may suffer ill effects as the result of consuming water from the receiving stream In other instances, the path of transmission may be far less direct. For example, a chemical present in the receiving water at low concentration may be accumulated in aquatic organisms, magnifying its concentration through food chains until it finally reaches unacceptable levels in fish or other aquatic life which may be consumed by humans In this fashion, chemicals initially present at innocuous concentration in the water may be "bio-accumulated" to levels which are very harmful to the person at the end of the food chain

Considering the many patterns in which objectionable constituents may be transmitted and factors affecting those processes, there clearly are several basic mechanisms which may be employed to reduce health risks attending excreta and wastewater disposal These are techniques which can be employed to interrupt movement of objectionable agents from their origins to consumers and include (a) isolating the discharges from the population at risk, (b) storage to provide time for natural reactions to reduce risks, (c) treatment of the excreta or wastewater to remove or destroy objectionable constituents and (d) control of host organisms which sometimes may represent a necessary step in the transmission process Each mechanism will be discussed briefly in this section before reviewing the specifics of selected approaches employed in practice

Isolation

Perhaps the most direct method for breaking the chain of transmission in excreta disposal is adoption of systems which do not utilize water carriage of the waste at all These rely upon separate collection and disposal in ways designed to minimize contact with persons or insect vectors through preventing premature dispersion of the wastes to the environment Some techniques for accomplishing this are discussed in detail by Feachem, *et al* (1978) in a detailed review of the health aspects of excreta and wastewater management

Three types of systems employed for this purpose include the pit latrine, the composting latrine, and cartage systems, all of which will be discussed briefly in a subsequent section If poorly operated, these types of systems may result in major health risks through increasing opportunity for disease transmission On the other hand, in communities where these systems are employed and managed properly, they are capable of producing substantially the same health benefits as far more expensive water carriage systems Accordingly, movement from this type of domestic wastes handling system to water carriage should be done only after serious evaluation of alternatives available to the community Often, a more cost-effective approach could be to improve the systems for collecting, treating and disposing of nightsoil instead of moving prematurely to adoption of full water carriage of human wastes, with its opportunity for broader dispersal of infectious agents to the environment

Control or elimination of the problems resulting from inorganic or organic chemicals often may be approached most effectively at their sources This technique has been used extensively in industrialized countries and is attracting increased attention today as pollution control regulations are tightened, causing increased costs for end-of-the-pipeline solutions through treatment Typically, this approach involves changing manufacturing operations to eliminate the use or production of objectionable wastewater constituents by installing treatment and recovery systems within the manufacturing plant at the point of wastewater generation or by changing the manufacturing process itself Decisions between inplant control of these wastewater constituents and application of more conventional end-of-pipeline treatment systems usually depend heavily upon the economics of the alternatives

In many manufacturing industries, some wastes are segregated in concentrated form at the point of production before release into the wastewater collection system. These wastes, which usually are relatively small in volume, may be disposed of in dumps or landfills. The intent here is isolate the toxic or otherwise harmful chemicals to prevent contact with the human population Where properly controlled, this represents a viable approach to the problem On the other hand, inadequate controls can lead to unacceptable or even highly hazardous conditions in the future

A classic example in which isolation represents the principal approach is the field of radioactive wastes disposal. Lack of suitable technology for reducing radioactivity of wastes requires that they be collected, concentrated and stored for many years, or centuries, under conditions which can be guaranteed to avoid dispersal into the environment or contact with humans

Die-away

It has long been recognized that conditions outside of the human body usually are unfavorable to survival of pathogenic organisms because of adverse physical and chemical environmental factors, as well as competition and predation by other organisms Accordingly, only in a few instances have pathogens demontrated capability to multiply under conditions found in receiving streams On the contrary, most pathogens in wastewater discharges or receiving streams have been observed to decrease in number over extended periods, ultimately reducing risks of transmitting waterborne diseases

Sometimes, Chick's Law has been used to describe the decrease in population of pathogens (Anonymous, 1975; Fair, Geyer and Okun, 1968).

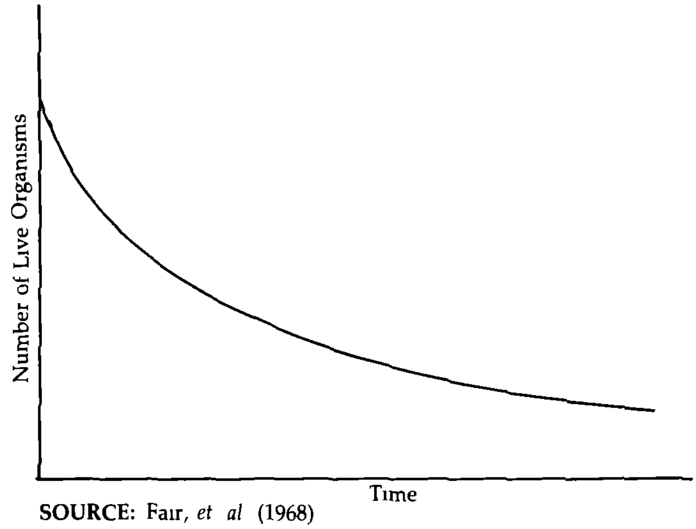
$$\frac{-dN}{dt} = kN$$

$$\text{or. } (N_0 - N_t) = e^{-kt}$$

where N_t = bacterial at time t
N_0 = initial bacterial population
k = rate constant (logarithms to base e)
t = time of exposure

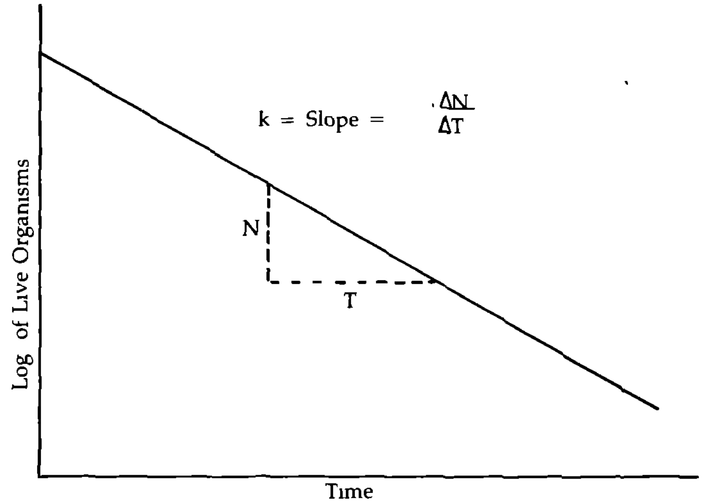
This "law" is based on the concept that for a given set of environmental conditions there will be a constant death rate Stated differently, under a given set of conditions the number of organisms dying per unit time is directly proportional to the number of organisms present in the system at that time This indicates that a constant percentage of the organisms in the system would be inactivated in each succeeding time interval and provides a relationship similar to the curve in Figure 8-1 When plotted in terms of the logarithm of organisms remaining in the system, as shown in Figure 8-2, a straight line results with a slope k The death rate constant would depend upon many factors, including the type of organism, temperature of the system, pH, presence of inhibitory substances, and many aspects of the environment Although this relationship often provides an acceptable approximation of the die-away curve, it seldom is true when viewed rigorously, as pointed out by Fair, Geyer and Okun (1968).

Figure 8-1. Die-Away Curve



SOURCE: Fair, *et al* (1968)

Figure 8-2. Semi-Logarithmic Die-Away Curve



SOURCE: Fair, *et al* (1968).

According to Feachem, *et al* (1978), viruses and protozoa always decrease in number outside of the body, but some bacteria may multiply under suitable conditions. For example, this can occur with Salmonellae in certain foods and *E coli* have been observed to multiply in sewage effluents after chlorination. However, multiplication of pathogens in streams is very uncommon and highly unlikely to continue for long Feachem, *et al* (1978) summarized the survival of pathogens in feces and nightsoil as shown in Table 8-1

The rate of die-off depends on many factors, including especially temperature and competition. Most organisms survive for longer periods at reduced temperatures Presence of diverse populations, including predators, results in more rapid die-off of the pathogens Viruses may survive substantially longer than bacteria, especially at lower temperatures Feachem has reported two months as a likely maximum survival time at 20-30°C and nine months for 10°C Protozoan cysts survive poorly, with a likely maximum for *Entamoeba histolyctica* in sewage or polluted water at about 20 days Helminth ova vary widely from very fragile organisms to *Ascaris* ova, which may survive more than a year

Although there may be substantial regrowth of coliforms in waters polluted with organics, ultimately die-away occurs and survival is very unlikely to exceed 50 days, with 20 days being a

Table 8-1. Survival of Organisms in Feces and Nightsoil

Type of Organism	*Usually Less Than*	*Maximum*
Enteric viruses	3 months	5 months
Indicator Bacteria	4 months	5 months
Salmonellae, shigellae	1 month	5 months
Vibrios	5 days	
Tubercle bacilli	5 months	2 years
Protozoan cysts	10 days	1 month
Helminth Ova -		
Ascaris	Many months	
Others	Highly variable	

SOURCE: Feachem, *et al* (1978)

more reasonable maximum survival time. Salmonellae have been observed to survive as long as three months, but one month is a more common limit Shigella and *Vibrio cholerae* are less persistent and seldom survive longer than 20 days

This information provides a practical approach for preventing dissemination of waterborne diseases, in many instances This can be accomplished by storing the excreta or domestic wastewaters long enough to allow die-away to reduce population of pathogens to acceptable levels This die-away will occur naturally because of unfavorable environmental conditions and predation by other organisms in the stored wastes This approach is discussed in more detail with respect to die-away in waste stabilization ponds in the publication by Gloyna (1971) The addition of chlorine or other chemicals as disinfectants or elevation of temperature acts principally by accelerating the die-away process through various mechanisms to accomplish more rapid reduction in pathogen population In many instances, the same basic types of relationships (Chick's Law, for example) still apply to the process, although rate constants would be substantially different under the less favorable environmental conditions As pointed out by Fair, Geyer and Okun (1968),

> We arrive at the paradoxical conclusion that the destruction of enteric bacteria is more rapid (1) in heavily polluted streams than in clean streams, (2) in warm weather than in cold weather, and (3) in shallow, turbulent streams than in deep sluggish bodies of water

The die-away mechanism also is significant in many instances for removal of objectionable organic materials, many of which are biodegradable For these chemicals, provision of adequate storage time, in the presence of appropriate bacteria, can result in extensive reduction or elimination of the chemical from the wastewater This approach is practiced often through application of various types of biological treatment systems for reduction of chemicals causing biochemical oxygen demand (BOD) and other biodegradable constituents of wastewaters. However, it must be noted that in many instances there may be little or no significant die-away of some organic compounds, which cannot be degraded by organisms, as well as most inorganic chemicals and slow-decaying radioactive materials Although these may be removed from the water environment through volatilization, absorption on suspended matter and settling, or other mechanisms, it must be recognized that they have not been destroyed but only removed to a different niche in the environment, from which they may return to cause problems subsequently

Wastewater and Water Treatment

Treatment processes can be employed to remove or destroy pathogens or objectionable chemicals before discharge of the excreta or wastewater to the environment This approach often can be employed to prevent the objectionable material from entering the environment, from which it may return subsequently to endanger man An alternative or supplementary approach involves utilization of treatment processes to remove those organisms and other constituents from water prior to its delivery to the population for potable purposes

Many treatment processes are capable of removing substantial numbers of bacteria, viruses and chemical precipitates through settling or other separation techniques Removal by this type of mechanism may have little or no effect on character of the constituent, but may improve quality of the discharge by removing the objectionable constituent from the flow released to the receiving stream This frequently results in corresponding increases in concentration of the same constituents in sludges produced by the process and subsequently requiring treatment and disposal This may have important implications in disposing of those sludges because of increased risks which may be encountered in handling them or in distributing them into the environment Processes which function principally through this mechanism of physical removal include settling, flotation, filtration, distillation, reverse osmosis and membrane processes

Sometimes, the removal of wastewater constituents through physical separation may be enhanced by flocculation, chemical coagulation, or biochemical agglomeration These function through agglomerating small particles which otherwise might not be removed efficiently by the process in question into larger particles which may be more readily removed Sometimes, that is accomplished through natural turbulence in the system or by inducing gentle mixing through use of mechanical equipment (flocculation) Usually the efficiency of agglomeration may be enhanced by adding appropriate chemicals to form gelatinous floc to coagulate the bacteria, viruses and small precipitates into larger masses ahead of settling, filtration and other physical separation systems Removal of metals, for example, usually may be enhanced substantially by proper pH adjustment and addition of chemicals to improve formation and growth of precipitates

These same types of flocculation-coagulation reactions can occur extensively in biological treatment systems, often leading to efficient removal of constituents which otherwise might be largely unaffected by the biological reactions For example, precipitate particles, bacteria and viruses may be enmeshed in the biological floc. Also, organisms which function actively in the biological process may produce chemicals having capability for inducing precipitation, adsorption or coagulation of the constituents Accordingly, it often is observed that biological treatment processes may provide relatively high efficiency of removal of bacteria, viruses, metals and many other inorganic and organic chemicals, many of which are not involved in the biochemistry of the process itself

Disinfection may be applied to reduce health risks from pathogenic bacteria and viruses. Often, this can be accomplished merely through providing storage which insures adequate time for natural die-away of the pathogens As pointed out earlier, die-away usually is enhanced by presence of diverse populations of organisms and increased temperatures in the system The so-called "disinfectants" function through increasing die-away rates because of toxic action of the chemical or its reaction products to the organisms in question. The most common disinfectants in wastewater treatment include chlorine and ozone, which are viewed as functioning principally through reaction with enzymes or other key components of the organisms, thereby interferring with their metabolic activities or inactivating them by other mechanisms

Strong chemical oxidizing agents, such as ozone, chlorine dioxide and chlorine, also can be used to destroy certain organic chemicals through direct chemical reaction Sometimes, these reactions result in disintegration of the molecules into relatively small and innocuous compounds, while other possibilities may involve only certain key sites upon the molecule and leave by-products which are very complex but of substantially different character It should be recognized that sometimes those byproducts also may have potentially harmful health effects, as illustrated by current concern over formation of chlorinated hydrocarbons through reactions between chlorine, used a disinfectant, and various organic molecules in waters or wastewaters

Most of the treatment systems employed for municipal wastewaters reduce health risks through a combination of the above mechanisms Removal and destruction of pathogenic organisms in conventional end-of-the-pipeline treatment plants is accomplished partly through physical removal and accumulation in sludges and partly by destruction of organisms through die-away because of extended detention times and increased populations of competitors and predators The practical effects of these mechanisms will be discussed in more detail later

Control of Host Organisms

Transmission of many diseases in which water plays a major role requires functioning of an intermediate host for pathogenic organisms between discharge of excreta and subsequent infection of a victim This situation is true of schistosomiasis and many mosquito-borne diseases

Where this situation prevails yet another mechanism is made available for controlling transmission of the diseases That involves taking appropriate steps to control or eradicate the intermediate host, thereby breaking the chain of transmission of the pathogens Accordingly, much interest has been directed towards the possibility for controlling schistosomiasis through eradication of certain snail populations which serve as intermediate hosts for pathogens causing that disease, in a fashion similar to application of mosquito control techniques to reduce instances of the many diseases in which those insects play a key role in development of the pathogens and their transmission between humans

Systems Which Minimize Discharges to Surface Waters

Systems considered in this category attempt to prevent the spread of waterborne diseases through preventing contact between excreta and population for extended periods of time, or perhaps indefinitely Some are based on use of virtually no carriage water in attempts to minimize volume of discharges requiring treatment and disposal In other instances, limited quantities of carriage water are employed, but the resulting wastewaters are subjected to treatment and disposal in ways which minimize discharges to streams and dispersal in the environment

Quantities of excreta vary widely depending upon diet, climate and state of health of the population, ranging from 20-1500 grams/capita/day Feachem, *et al* (1978) summarized a substantial amount of data on characteristics of waste produced in different countries, leading to the conclusion that a reasonable working assumption for a developing country is a per capita production of about 350 grams of feces and 1200 grams of urine per day in rural areas and 250 grams of feces and 1200 grams of urine in urban areas Typically, nightsoil volumes approximate 1 5-2 0 liters per capita per day, with a solids content overall of about 3%

Table 8-2 summarizes typical composition of human feces and urine, as reported by Gotaas (1956) and Feachem, et al (1978) The very low carbon/nitrogen (C/N) ratios require addition of a carbon source, such as garbage, vegetable leaves or sawdust, for successful composting, in which the ratio is required to be about 20-30 for efficient operation

Pit Latrines

The pit latrine is the simplest on-site disposal system, consisting of a hole in the ground which is replaced by a new pit when about 2/3 full Cleanliness in this unit is of utmost importance because otherwise the installation may become a focus for disease transmission Also, insect control is very important because otherwise the pit latrine may become a breeding site for flies and mosquitoes

When about 2/3 full, the typical latrine is filled and may not be disturbed for many years, if ever Under these circumstances, survival of pathogens is virtually impossible, but shorter periods of storage could reduce the margin of safety drastically The use of pit latrines may be undesirable where ground water is high and wells are used nearby because there is potential for transmission of organisms through the soil for short distances

Composting Latrines

Both continuous and batch composting toilets require addition of a carbon source for adjustment of the carbon/nitrogen ratio Continuous composting units, similar to the Swedish "multrum" toilet, have had only limited application in developing

Table 8-2. Composition of Human Feces and Urine[1]

	Faeces	*Urine*
Quantity (wet) per person per day	100-400 g	1 0-1 31kg
Quantity (dry solids) per person per day	30-60 g	50-70 g
Moisture content	70-85%	93-96%
Approx composition (% dry weight)	—	—
Organic matter	88-97	65-85
Nitrogen	5 0-7 0	15-19
Phosphorus (as P_2O_5)	3 0-5 4	2 5-5 0
Potassium (as K_20)	1 0-2 5	3 0-4 5
Carbon	44-55	11-17
Calcium (as CaO)	4 5	4 5-6 0

[1]Adapted from Gotaas (1956)

countries and very little data exist on their performance or on survival of pathogens.

Batch composing toilets are common in China and Vietnam, but worthwhile microbiological data on these units do not exist, according to Feachem, *et al* (1978) Compost from these units usually is applied to agricultural land, requiring that pathogen destruction be as complete as possible The efficiency of pathogen destruction depends principally on time and temperature The temperature, in turn, depends on rate of air supply, the C/N ratio and moisture content Anaerobic composting systems seldom rise beyond 35°C but aerobic units may involve temperature rise to 50-70°C if C/N ratio and moisture content are proper It is suggested that a minimum retention time of 3 months is required to produce a product free of pathogens, except for the most persistent helminth ova

Cartage Systems

Cartage systems are based on collecting nightsoil in containers in or near each house and periodically transporting it elsewhere for treatment and disposal Potential health impacts of cartage systems depend upon sanitary safeguards in deposition, collection, transportation, treatment and reuse of the wastes The collection and transportation systems offer the greatest risks, unless carefully established and supervised Use of good equipment and well-trained personnel operating vacuum trucks to collect nightsoil from the vaults can be a hygienic and risk-free operation On the other hand, bucket latrines always present health hazard problems Spillage of the material during transfer or transportation represents the greatest hazard in this type of operation For this reason, well-equipped and operated vacuum trucks are considered to be preferable

Nightsoil can be digested and dewatered like sludge or it can be mixed with sewage and subsequently treated in conventional plants or stabilization ponds Often, nightsoil is buried in trenches although this may offer serious health implications because of potential hazards to those who work in the area used or otherwise have access to it.

Reuse in agriculture is practiced widely, but is highly undesirable because of adverse health implications, unless treatment or long-term storage are practiced before application to the land These systems are discussed in considerably more detail by Feachem, *et al* (1978) and Rybczynski, *et al* (1978)

Nightsoil Composting

Thermophilic composting is capable of producing a product which is safe for agricultural reuse within two months Compost produced by this process is useful as a soil conditioner and source of nutrients for plant growth This approach has been discussed in detail by Gotaas (1956) and Shuval (1977) All of the approaches for composting require addition of a carbon source, such as refuse or sawdust, to achieve a C/N ratio of about 20-30 Optimal performance also requires control of moisture content to 20-60%

As indicated earlier, the temperature achieved during composting depends on the C/N ratio, moisture content, and oxygen content of the material, as well as particle size and pH Relatively little change in temperature is produced during anaerobic composting, which typically releases gases with foul odors Aerobic composting generates substantial heat and produces organic breakdown more rapidly with little or no odor This may lead to temperatures of 55°C or higher in the center of the compost pile Periodically it is necessary to mix the pile to provide adequate oxygen for maintaining the thermophilic composting temperatures Feachem, *et al* (1978) indicate that in well-managed theremophilic aerated compost systems, temperatures can rise as high as 80°C, and that all parts of the pile may be maintained for several hours above 60°C, producing rapid destruction of pathogens. *Ascaris* ova are the most hardy pathogens, but the following time-temperature combinations will guarantee even their destruction

1 hour at 62°C
1 day at 50°C
1 week at 46°C
1 month at 43°C

Fly breeding is a major problem in management of compost systems. Attainment of high temperatures (above 51°C) in all parts of the compost pile is essential for control of fly larvae Improper control of flies may result in health hazards because of potential for carrying pathogenic organisms

Wastewater Treatment and Subsoil Disposal

Typically, a septic tank is designed to receive all wastewaters from a house, both excreta and sullage, and to provide an average retention time for the liquid of about 1-3 days After anaerobic digestion for that period, effluent from the tank normally passes into a cesspool or soakaway or to an undergound tile field for subsurface disposal through leaching An aqua privy usually is located directly under the toilet and receives only excreta and small volumes of flushing water Liquid retention times in this unit may be as much as 60 days and effluents typically flow to soakaways or small sewerage systems If the aqua privy also receives sullage water, retention times may be as low as a few days

Principal processes affecting removal of pathogens in these units include settling of solids, with entrainment of many bacteria and viruses, as well as ova and cysts Pathogen die-away in the unit depends heavily on retention time and ability of the organism in question to withstand anaerobic conditions in the tank It is impossible to generalize, but it appears that most pathogens in septic tanks will be removed to an extent equivalant to less than 2 orders of magnitude (<99%) Aqua privies which receive sullage and have short detention times probably perform in similar fashion. On the other hand, a well-designed aqua privy with deterntion time exceeding 20 days should produce substantially better quality effluent because of increased opportunity for die-away

Effluent from either type of system should be assumed to be highly populated with pathogens, precluding safe discharges to surface waters or application to agricultural lands except after further treatment Subsurface disposal, as often practiced for these effluents, usually represents a much safer approach because of extensive removal of pathogens during filtration of the liquid through soil Nevertheless, care must be exercised to prevent hazards through ground water pollution of nearby wells or failure of the system hydraulically, with overflow of inadequately treated wastewater to the surface of the ground The latter is especially prevalent where large quantities of water are used and soil conditions are unfavorable Properly designed and operated septic tank and subsurface disposal systems are capable of safe long-term operation where satisfactory soil conditions exist Commonly, failure of these systems occurs through inadequate maintenance Typically, the failure may result from clogging of the soil surrounding the cesspool or tile field by particles escaping from the septic tank after it has become filled with sludge This can be delayed or even prevented through regular pumping of sludge from the tank for subsequent treatment and disposal With proper maintenance, this type of approach can provide a satisfactory solution and protection against waterborne health hazards for extended periods of time

Land Treatment and Disposal

Health risks resulting from application of nightsoil, sludges or wastewaters to land may be classified as (a) an occupational hazard to those involved in applying the waste to land and tending the crops and (b) the risk of infection through subsequent handling and consumption of the crops by man. Although it appears rational that those who work in fields contaminated by wastes containing pathogens suffer risks greater than other persons, there actually is little or no epidemiological evidence which convincingly demonstrates that. Whatever the risks, they can be minimized or eliminated by reusing only wastes which have been treated to render them free of pathogens. Accordingly, it appears to be reasonable policy to require that wastes applied to agricultural land should be very low in pathogen content.

Survival of enteric bacteria on soils is affected significantly by moisture content, temperature, pH, sunlight, organic matter and antagonism by other organisms. Under some conditions, fecal coliforms may survive for as long as several years, but 99% reduction appears to be likely in about 25 days, in warm climates. *Salmonellae* may survive up to a year in moist soil, but 50 days is considered to be more typical maximum. Viruses which adsorb on soil particles appear to become protected to some degree, resulting in survivals up to 3 months in warm weather and up to 6 months in winter. Protozoan cysts are unlikely to survive more than 2-10 days, but helminth survivals vary widely, up to several years. Table 8-3 summarizes observations reported by Feachem, *et al.* (1978).

Bacteria and viruses do not penetrate undamaged vegetable skins, but may adhere to and survive for extended periods on their surfaces. The extent to which pathogens become attached to crop surfaces depends upon the method of waste application and type of crop. Their death rates increase in the presence of extensive sunshine and low humidity. Table 8-4 summarizes survival characteristics of some organisms on crops, indicating little or no survival projected past two months.

Table 8-3. Survival of Pathogens on Soil

Type of Organism	*Usually Less Than*	*Maximum*
Viruses	3 months	6 months
Bacteria	2 months	>1 year
Protozoa	2 days	10 days
Helminth ova	2 years	7 years

SOURCE: Feachem, *et al.* (1978)

Table 8-4. Survival of Pathogens on Crops

Type of Organism	*Usually Less Than*	*Maximum*
Enteric viruses	1 month	2 months
Indicator bacteria	1 month	Several months
Salmonellae	1 month	6 months
Vibrios	7 days	—
Cysts	2 days	5 days
Helminth ova	1 month	5 months

SOURCE: Feachem, *et al.* (1978)

A recent publication by Crites and Uiga (1979) compares health risks between land treatment of wastewater and activated sludge treatment and discharge to surface waters. They conclude that although more concerns are voiced about the health effects of land treatment, the risks of human exposure to pathogens is as low with land treatment as it is with conventional treatment and discharge. They conclude that land treatment removes viruses to a higher degree than conventional treatment and disinfection. Also, land treatment systems involving slow infiltration were found to offer greater protection against parasites and viruses, trace metals, nitrates, trace organics and halogenated organics. Tables 8-5 and 8-6 summarize some of the data reported by them concerning removal and survival of indicator organisms and pathogens on soils and vegetation.

Conventional End-of-Pipeline Treatment

Goals of Typical Systems

In treating potable water, protection of the public health clearly has top priority. Effective treatment to that end is accomplished through removing or destroying pathogens or chemicals present in the raw water at concentrations above levels judged to be acceptable for potable purposes. Sometimes, treatment is undertaken to correct aesthetic or other deficiencies not directly related to consumer health, but even in those instances quality of the finished water still is judged principally on its suitability and safety for human consumption.

Wastewater treatment, on the other hand, typically is based on a very different priority system. Most treatment plants in industrialized countries are constructed and operated principally to remove oxygen demanding materials, suspended matter and other constituents which could have undesirable impacts on aesthetics or aquatic life in the receiving stream. In the U.S.A., for example, performance of virtually all municipal wastewater treatment plants is judged according to biochemical oxygen demand (BOD) in the plant effluent, in response to concern about dissolved oxygen levels in receiving streams. Clearly, this criterion is not motivated by public health consideration because it never has been demonstrated that there is any relationship between dissolved oxygen content of water and health of persons consuming it. Accordingly, whenever pollution control regulations are based on oxygen demand, that indicates that program goals clearly must be directed towards maintaining watercourse quality adequate for supporting aquatic life, protecting recreational uses, and maintaining desirable aesthetic characteristics.

It is not suggested that health protection never is an important consideration in planning, constructing, and operating wastewater treatment facilities in the U.S.A., or other industrialized countries. On the contrary, it may be a major factor in controlling certain industrial wastewaters, as well as in regulating bacterial populations in municipal wastewaters discharged into shellfish producing or recreational waters. Even in those instances, however, most of the treatment facility, as well as its capital and operating budgets, is intended principally to remove oxygen demanding materials, suspended matter, and other constituents not directly related to the public health. Concern about health aspects typically is reflected in *additional* requirements for disinfection of plant effluents and limitations on allowable concentrations of coliform or other indicator organisms. These aspects of treatment, which are related principally to protection of the public health, usually represent a relatively minor proportion of the facility and its capital and operating budgets.

Table 8-5. Removal of Enteric Microorganisms by Soil Systems

Enteric microorganisms	*Location*	*Removal, %*	*Observed concentration No /mL*	*Observation depth, ft*
Fecal coliforms	Hanover, New Hampshire	Essentially complete	<1/100	5
Coliforms	Lodi, California	Essentially complete	1/100	4-7
Coliforms	Whittier Narrows, California	Complete	None	>4
Fecal streptococci	Santee, California	99 5	20/100	—a
Fecal streptococci	Santee, California	99 8	6 8/100	—b

a 200 ft of lateral undergound flow
b 1,500 ft of lateral underground flow

SOURCE: Crites and Uiga (1979)

Table 8-6. Survival Times of Enteric Microorganisms on Soil and Vegetation

Enteric microorganisms	*Environment*	*Survival time, days*	*Estimated die-off after 7 days, %*[a]
Coliforms	Fodder	6-34	98
	Vegetables	35	90
	Soil surface	38	88
Shigella sp	Fodder	<2	Below detection
	Leaf vegetables	2-7	Below detection
	Orchard crops	6	Below detection
Salmonella sp.	Fodder	12-<42	94
	Soil surface	15-46	93
	Leaf vegetables	1-40	98
	Orchard crops	0 75-<2	Below detection
Enterovirus	Leaf vegetables	15-60	89
E histolytica	Leaf vegetables	2	Below detection

a Calculated from median survival time

SOURCE: Crites and Uiga (1979)

It is crucial that this situation should be understood clearly by those responsible for planning and implementing pollution control programs in the less developed countries If the goals of their programs relate principally to protecting the receiving stream and its aquatic life, then some of the treatment technology currently being employed in the highly industrialized nations could be appropriate for consideration On the other hand, if the principal goal is to protect the public health of downstream consumers by reducing risks of waterborne diseases or adverse impacts by inorganic or organic chemicals, then entirely different treatment approaches may be necessary As expressed by Feachem, *et al* (1978),

> Those whose job it is to select and design appropriate systems for the collection and treatment of sewage in developing countires, must bear in mind that European and North American practice does not represent the zenith of scientific achievement nor is it the product of a logical and rational design process Rather, developed countries practice is the product of history, a history that started about 100 years ago when little was known about the fundamental physics and chemistry of the subject and practically none of the relevant microbiology had been discovered
>
> . The historical and conservative nature of the development of current practice in industrialized countries . . is not especially clever, nor logical, nor completely effective and it is not necessarily what would be done today if those same countries had the chance to start over again
>
> The conventional sewage treatment works were originally developed in order to prevent gross organic pollution in European and North American rivers and they were never intended to achieve high removals of excreted pathogens

Even though not constructed principally for that purpose, wastewater treatment systems currently employed in industrialized countries usually do have significant impact on concentrations of organisms and other constituents which may be important from a public health viewpoint This chapter will examine briefly some of those effects

Primary Treatment

In many conventional, end-of-pipeline wastewater treatment plants, the first treatment step consists of settling to remove suspended matter. Typically, this involves sedimentation for 2-4 hours, during which perhaps ⅔ of the suspended solids are removed from municipal wastewaters The removals can include some pathogens large enough to attain adequate settling velocities, such as ova Also, many other pathogens too small to settle to a significant extent may be removed by being enmeshed in larger suspended matter

Bacterial removals in primary settling may approximate 50-90% of organisms in the raw wastewater, but viruses are removed to a much lower degree—perhaps 0-30% Larger organisms (for example, schistosome ova) may be removed to a higher degree because of larger size and correspondingly faster settling velocities Table 8-7 summarizes the observations of Feachem, *et al* (1978) on removal of various types of organisms in primary settling units, ranging from none to a maximum of 2 orders of magnitude (99%) The removals may be improved significantly through flocculation and coagulation of the sewage before settling

This process is effective only in removing suspended matter significantly heavier or lighter than water and large enough to attain terminal settling velocities permitting separation from the liquid throughout within detention time available in the tank It will be relatively inefficient in removing small and slowly-settling particles and will not remove colloidal or dissolved constituents at all unless they become associated with settleable particles Accordingly, metals and other constituents may or may not be removed efficiently, depending upon physical characteristics of the particles in which they exist in the wastewater In many instances, particle size and other characteristics may be altered radically through precipitation or other chemical reactions, thereby influencing removal efficiency in primary settling

Table 8-7. Removal of Pathogens in Primary Settling

Type of Organism	*Reduction Log_{10} Units*	*% Removal*
Viruses	0-1	0-90
Bacteria	0-1	0-90
Protozoa	0-1	0-90
Helminths	0-2	0-99

SOURCE: Feachem, *et al* (1978)

Secondary Treatment

Trickling filters appear to be relatively inefficient in removing viruses from sewage (15-75%), but bacteria and protozoa are removed to a slightly higher extent (80-95%) Trickling filter treatment plants, including primary settling, trickling filter and secondary settling, usually attain removals of pathogens less than 2 orders of magnitude Activated sludge systems appear to be slightly more effective in removing pathogens, with virus removals reported as high as 90% (Sobsey, 1979 and Feachem, *et al* , 1978) Bacteria removals usually fall in the range of 60-99%

Table 8-8 summarizes data from literature surveys by Feachem, *et al* (1978) for removal of pathogens by secondary treatment plants, indicating removals less than 2 orders of magnitude Table 8-9 presents similar information from the publication by Crites and Uiga (1979)

Table 8-8. Removal of Pathogens by Trickling Filters and Activated Sludge

Type of Organism	*Reduction Log_{10} Units*	*% Removal*
Viruses	0-1	0-90
Bacteria	0-2	0-99
Protozoa	0-2	0-99
Helminths	0-1	0-90

SOURCE: Feachem, et al (1978)

Table 8-9. Enteric Microorganism Reduction By Conventional Treatment*

Microorganism	*Primary treatment removal, %*	*Secondary treatment removal, %*
Total coliforms	<10	90-99
Fecal coliforms	35	90-99
Shigella sp.	15	91-99
Salmonella sp.	15	96-99
Escherichia coli	15	90-99
Virus	<10	76-99
Entamoeba histolytica	10-50	10

*Without disinfection

SOURCE: Crites and Uiga (1979)

Sludge Digestion and Dewatering

Sludge from primary settling and final settling tanks in trickling filter and activated sludge plants commonly is subjected to anaerobic sludge digestion Typically, digesters operate at detention times of 2-15 weeks, depending upon operating temperature and degree of digestion required Continuous flow digesters release higher concentrations of pathogens than batch units, and effectiveness of pathogen destruction increases with rise in temperature Feachem, *et al* (1978) indicate that virtually no protozoa survive digestion, small numbers of ova and bacteria may survive thermophilic digestion for two weeks, while some bacteria and ova persist for 4-15 weeks in digesters operated at lower temperatures The only digestion process producing pathogen-free sludge is batch thermophilic digestion

Sludge dewatering by drying on open beds for 2-3 months destroys most (possibly even 100%) of enteric viruses and bacteria at temperatures exceeding 20°C Protozoa also will be destroyed, leaving only persisent ova surviving in significant numbers Other dewatering processes, including vacuum filtration, pressure filtration and centrifugation have relatively little effect upon pathogen content High temperature systems, such as the Zimmerman and Carver-Greenfield processes, result in sterilization of the sludge

Oxidation Ponds

Oxidation ponds are large, shallow earthen basins which provide opportunity for destruction of organic matter over extended periods The most common types of ponds are facultative installations, with retention times of 10-40 days, in which oxygen is supplied through algal photosynthesis Maturation ponds may receive effluent from facultative ponds or other treatment units to improve effluent quality before discharge Frequently, they are designed for detention times of 5-10 days Sometimes, anaerobic ponds with 1-5 days detention may be used for pretreatment ahead of facultative or maturation ponds

Ponds are discussed in detail by Gloyna (1971), Feachem, *et al* (1978) and many others Because these ponds provide long detention times, more opportunity is afforded for die-away of pathogens, leading to very effective destruction of those organisms Investigators have reported coliform removals of 70-85% at 20°C in 3 5 days, with lower removals at 9°C Single facultative and aerobic ponds with 10-30 days detention may provide from 80 to over 99% removal at various temperatures

Feachem, *et al* (1978) indicate that a desirable system to insure low pathogen survival involves multiple ponds in series For example, a good design may incorporate a facultative pond followed by 2 or more maturation ponds in series to provide efficient treatment Strong wastes may be pre-treated through use of anaerobic lagoons ahead of facultative ponds to minimize land requirements Three or more ponds in series have been reported to provide pathogen removals in excess of 99 99% A series of 5-7 ponds, each with 5 days detention, can produce an effluent containing less than 100 fecal coliforms and fecal streptococci per 100 ml, making this effluent suitable for unrestricted use in irrigation Investigators have reported removals of 90-99% Salmonellae and other pathogenic bacteria and have indicated that complete elimination of those organisms can be achieved in pond systems with long detention times, especially at temperatures over 25°C Much less is known about the fate of viruses in warm climates and developing countries Essentially 100% removal has been reported for protozoan cysts and helminth ova by multi-cell ponds with detention times exceeding 20 days Hookworm larvae may survive up to 16 days in aerobic ponds, but have not been reported in the effluent from ponds with over 20 days detention Table 8-10 summarizes data reported by Crites and Uiga (1979) on removal of enteric microorganisms by lagoon systems

Unfortunately, waste stabilization ponds sometimes may provide excellent mosquito breeding sites Species commonly found include *Culex pipiens,* which serve as vectors for disease transmission. With proper maintenance, this can be controlled by preventing growth of vegetation in ponds and making them over 1 meter deep, as well as using concrete slabs or rip-rap at the water surface.

Table 8-10. Maximum Removal of Enteric Microoganisms By Lagoon Systems

Enteric microorganism	*% Removal*
Coliforms	60-99 99
Fecal coliforms	99
Total bacteria	99
S typhi	99 5
Virus	99 99[1]
P aeruginosa	99 69

[1]Laboratory Study

SOURCE: Crites and Uiga (1979)

Summary

Tables 8-11 through 8-13 summarize data reported by Feachem, *et al* (1978) on removal of bacteria, viruses and cysts and ova by various types of wastewater treatment systems Most conventional secondary treatment plants appear capable of producing pathogen removals of 90-99% This suggests high efficiency, but often is really very poor when the goal is to protect the public health Feachem, *et al* (1978) point out that even 99% removal represents 1% survival and that it is the population of pathogens remaining in the water which determines the degree of risk With an influent sewage containing 10^5 pathogenic bacteria per liter, 99% removal would leave 10^3 pathogenic bacteria per liter in the effluent, which often may be inadequate for protection of downstream populations who come into contact with the water or use it for potable purposes.

Accordingly, conclusions about relative effectiveness of various types of conventional treatment plants with respect to pathogen removal would have little significance because none are satisfactory in most instances As pointed out earlier, these processes actually were not developed for the purpose of pathogen removal, but for removal of oxygen demanding substances and suspended matter Satisfactory removal of pathogens would require not the 90-99% levels attained by those systems, but numbers perhaps in excess of 99 999%. Of the conventional end-of-pipeline treatment systems, only oxidation ponds appear to be capable of producing those types of removals consistently, due largely to their long detention times, which provide extended opportunity for die-away of the organisms Even those installations, however, are reliable for high efficiency of pathogen removal only when employed as multiple cells in series and with generous detention times Of course, similar effects can be attained through using maturation ponds after conventional secondary treatment plants

Where land is relatively reasonable in cost, however, facultative ponds followed by maturation ponds provide economical and reliable approaches for control of pathogens in municipal wastewaters These offer the additional advantages of avoiding the complex equipment and operations involved in trickling filter and activated sludge plants and of capability for construction using local labor and materials entirely

Crites and Uiga (1979) summarized information on removal of trace metals from municipal wastewaters by primary and secondary treatment plants, as well as by two types of land treatment systems This information is presented in Table 8-14 and indicates removals in conventional treatment systems ranging from 20 to 80% of the influent metals Removal by slow rate land treatment usually was successful in reducing metal concentrations to levels lower than those specified in current drinking water standards Land treatment involving rapid infiltration was less effective

Disinfection

In most instances, chlorination has been the technique employed for wastewater disinfection Its use has been a direct result of success enjoyed for so many years in the water supply field, although conditions in that application are substantially different from those in wastewater systems The differences raise some serious questions about effectiveness of chlorination, as commonly applied in the U S A , in insuring safety from pathogens

It must be recognized that wastewater effluents have high organic and ammonia contents, as contrasted with municipal water supplies That results in more extensive side reactions

Table 8-11. Removal of Bacteria in Wastewater Treatment

Processes	Per Cent Removal			
	E. coli	*Salmonellae*	*Shigella*	*Cholera vibrio*
Primary Settling	50-90	50-90	50-90	50-90
Trickling Filter Plant Primary Settling Trickling Filter Secondary Settling Sludge Digestion Sludge Drying	90-95	90-95	90-95	90-95
Activated Sludge Plant Primary Settling Aeration Final Settling Sludge Digestion Sludge Drying	90-99	90-99	90-99	90-99
Oxidation Ditch, Settling, Sludge Drying	90-99	90-99	90-99	90-99
Stabilization Ponds 3 cells 25 days Detention	99.99-99.99999	99.99-100	99.99-100	100
Septic Tank	50-90	50-90	50-90	50-90
Tertiary Lagoons	99-99.9999	99-100	99-100	99-100
Land Application or Slow Sand Filters	99.99-100	100	100	100
Chlorination	<100	100	100	100

SOURCE: Feachem, *et al.* (1978)

Table 8-12. Removal of Viruses in Wastewater Treatment

Processes	*Influent No./liter*	*Effluent No./liter*	*Per Cent Removal*
Primary Settling	10^3-10^5	10^3-10^5	0-30
Trickling Filter Plant Primary Settling Trickling Filter Secondary Settling Sludge Digestion Sludge Drying	10^3-10^5	10^2-10^4	90-95
Activated Sludge Plant Primary Settling Aeration Final Settling Sludge Digestion Sludge Drying	10^3-10^5	10-10^4	90-99
Oxidation Ditch, Settling, Sludge Drying	10^3-10^5	10-10^4	90-99
Stabilization Ponds 3 cells 25 days Detention	10^3-10^5	0-10	99.99-100
Septic Tank	0-10^9	0-10^8	50
Tertiary Lagoons	10-10^4	0-10^2	99-100
Land Application or Slow Sand Filters	10-10^4	0-10^2	99-100
Chlorination			Uncertain

SOURCE: Feachem, *et al.* (1978)

Table 8-13. Removal of Cysts and Ova in Wastewater Treatment

	Per Cent Removal				
Processes	*Entamoeba histolytica*	*Hookworms ova*	*Ascaris ova*	*Schistosomes ova*	*Taenia ova*
Primary Settling	10-50	50	30-50	80	50-90
Trickling Filter Plant Primary Settling Trickling Filter Secondary Settling Sludge Digestion Sludge Drying	50?	50-90	70-100	50-99	50-95
Activated Sludge Plant Primary Settling Aeration Final Settling Sludge Digestion Sludge Drying	50?	50-90	70-100	50-99	50-95
Oxidation Ditch, Settling, Sludge Drying	50?	50-90	70-100	50-99	50?
Stabilization Ponds 3 cells 25 days Detention	100	100	100	100	100
Septic Tank	0	50-90	50-99	50-90	50-90
Tertiary Lagoons	100	100	100	100	100
Land Application or Slow Sand Filters	100	100	100	100	100
Chlorination	100?	0	0	100?	0

SOURCE: Feachem, *et al* (1978)

between chlorine and organic constituents, with production of many chloro-compounds having markedly different disinfection capabilities. Further, effective control of pathogens in municipal water systems frequently requires use of "free" chlorine residuals, attained through breakpoint chlorination. That approach is not feasible in wastewater treatment because the high levels of ammonia would require prohibitive additions of chlorine to reach the breakpoint. Accordingly, substantially all wastewater chlorine residuals are present as chloramines, or other combined forms of chlorine, demonstrated repeatedly to be far less effective in killing pathogens than free chlorine residual.

It is possible to achieve relatively low coliform concentrations in wastewaters by using high chlorine dosages and generous contact times. Chlorination also is relatively effective against pathogenic bacteria, provided chlorine demand of the wastewater is not too high. In many instances, regrowth of coliforms has been observed following chlorination, although it is unlikely that regrowth of pathogens represents a significant problem, or even occurs. Data in Table 8-11 show chlorination to be relatively effective for destruction of bacteria, but Tables 8-12 and 8-13 show that its utility for destroying viruses and ova is dubious. Sobsey (1979) estimated that chlorination of effluents from secondary treatment produced virus reductions estimated at 50%. This resulted in overall removal of viruses in the entire treatment system of about 97.5% (Table 8-15).

In summary, chlorination of wastewater treatment plant effluents must be viewed as controversial with respect to effectiveness for reducing pathogen content. Exceedingly high dosages, with long contact periods, would be capable of producing efficient removals, but effectiveness of the type of chlorination commonly practiced in the U.S.A. and other countries is unconvincing. In many countries, chlorination of wastewater effluents is not practiced because of doubts about its benefits and concern over possible harmful effects in the stream and on subsequent water users through production of chloro-organic compounds. This question has not been adequately resolved and will require considerable study before conclusions are reached as to whether effluent chlorination would be reliable in developing countries.

Other disinfectants which could be used include ozone and chlorine dioxide. These circumvent some of the difficulties with respect to formation of chloro-compounds but, unfortunately, are substantially more expensive than chlorine in most areas of the world. Also, equipment required for their production and application to wastewater is much more expensive and complex to operate. Further, even less is known about their effectiveness in reducing pathogen content than for chlorine.

"Advanced" Wastewater Treatment

Most advanced wastewater treatment processes, beyond biological treatment, have been directed towards correcting specific chemical and physical wastewater quality problems. In no instance have they been adopted to control pathogens.

Undoubtedly, many of the advanced processes could be very effective in removing or destroying pathogens, but little actually is known about their performance, and it is clear that they would represent extraordinarily expensive systems for that purpose. Without detailed data on effectiveness of those processes for pathogen removal and without economic evaluations, they should not be considered seriously.

Table 8-14. Summary of Trace Metal Information, Concentrations, and Removals

Component	*EPA drinking water standard, mg/L*	*Raw municipal wastewater concentration, mg/L*	*Primary treatment removal, %*	*Secondary treatment removal, %*	*Mass removal by land treatment, %*	
					Slow rate	*Rapid infiltration*
Arsenic	0 05	0 003	—	—	<drinking water standards	—
Cadmium	0 01	0.004-0 14	30	60	≤drinking water standards	<10
Chromium	0 05	0 02-0 7	40	40-80	<drinking water standards	—
Copper	1 0	0 02-3 4	40	60-70	<drinking water standards	90
Fluoride	1 4-2 4	—	—	—	—	—
Iron	0 3	0 9-3 5	60	50	—	—
Lead	0.05	0 05-1 3	50	50-60	≤drinking water standards	20
Manganese	0 05	0.11-0.14	30	20	—	—
Mercury	0 002	0 002-0 05	—	70-80	<drinking water standards	30-40
Selenium	0 01	—	—	—	—	—
Silver	0 05	0 05-0 60	50	70	<drinking water standards	—
Zinc	5 0	0 03-8 3	50	60	<drinking water standards	40-80

SOURCE: Crites and Uiga (1979)

Table 8-15. Estimated Virus Reductions and Remaining Virus Concentrations Produced by Conventional Sewage Treatment

Treatment Process	*Estimated Virus Reduction*		*Virus concentration (I U /l)*
	Unit Process	*Cumulative*	
None (raw sewage)	—	—	1,000-10,000
Primary Treatment	50	50	500-5,000
Secondary Treatment	90	5	50-500
Chlorination	50	2.5	25-250
Sludge Digestion	90	—	1,000-10,000[1]

[1] Based on an estimated initial virus concentration of 1,000-10,000 Plaque Forming Unit per liter (PFU/l) in undigested sludge (Lund, 1978)

SOURCE: Sobsey (1979)

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SECTION 9

HEALTH IMPACTS OF COMMUNITY WATER SUPPLIES

Introduction

Although the transmission of waterborne diseases by a water supply is generally accepted without argument, the proven ability of public water supplies to prevent enteric and other disease is not always obvious Most of these diseases have multiple means of transmission, and a few have portals of entry to the body other than the mouth Further, a perfect water supply in an otherwise filthy community may have a limited effect on reduction of smouldering endemic enteric disease

Thus, several questions may—and do—arise

(1) Is there any relationship between provision of water supplies and better community health status?

(2) Is this relationship quantifiable?

(3) Can the health impacts of water supplies be evaluated?

(4) Are there studies that show positive, significant public health benefits deriving from community water supplies in developing countries? This question is sometimes phrased, "Why are there no such studies?"

Field Studies of Water Supply/Disease Impacts

Perhaps 100 such studies have been attempted on a formal basis during the last 30 years Approximately 200 publications have been reviewed Two summary tables are included at the end of this section which describe the methodology and findings of some 25 of these studies

Early Studies of Water Supply/Disease Impacts

The 19th-century studies of John Snow (1849, 1854, 1856) and William Budd (1874) for cholera and typhoid respectively in England and of Robert Koch (1894) for cholera in Germany, Egypt, and India are epidemiological classics and one or more of these studies appears in most standard epidemiological texts

The United States had its pioneers also William T Sedgewick (1892, 1910), Hiram F Mills (1890), at the Massachusetts Health Department's Lawrence Experiment Station, James H Fuertes (1897); George C Whipple (1907, 1908, 1921), George A Johnson (1916), Wade Hampton Frost (1914); and others

Frost's U S Public Health Service Studies showed a reduction in typhoid rates for Ohio River cities which had built water treatment plants by 1914 (See Table 9-1) Johnson found typhoid death rates reduced by 65% in a 1916 study of 20 American cities (See Table 9-2.) In the United States, over a thousand epidemiological studies of waterborne disease over the years, generally studies of common-source outbreaks, have established the reality and threat of waterborne disease The widespread availability of controlled water supply, sanitation, other public health measures, along with good nutrition, fewer carriers, and universal literacy, have reduced immensely the incidence and effects of waterborne infectious disease in the United States and the industrially developed countries

Table 9-1. Typhoid Death Rates for 26 Ohio River Cities Without Water Treatment Plants in 1906 and for the Same Cities in 1914 Following Initiation of Water Treatment in 16 of the Cities

Number of Cities/ Status of Water Treatment	*Typhoid Death Rate per 100,000 Population In 1906*	*In 1914*
11 Cities		
No Treatment in 1906	76 8	74 5
No Treatment in 1914		
16 Cities		
No Treatment in 1906	90 5	15.3
Treatment in 1914		

Note Source of water supply for each of the 27 cities was unchanged between 1906 and 1914

SOURCE: Frost (1941)

More Recent Field Studies of Water Supply-Sanitation/Disease Impacts

Even though most of the United States population has a safe water supply and indoor flush toilets and has low rates of waterborne disease, there are still situations in which recent studies have tested the effect of improving water supply and sanitation facilities

Hollister, *et al* (1955) in a study of migrant labor camps in California found the prevalence of shigella infections lowest with water and flush toilets inside dwellings, 3 6 times higher with water and privy outside Similar findings were found in poor communities in Georgia by Stewart, et al (1955), McCabe and Haines (1957), and WHO (1964). These well-implemented studies established the importance of convenient access to adequate quantities of water for control of diarrheal disease

Peterson and Hines (1960) found a strong statistical correlation (P less than 0 01) for rate of gastroenteric illness versus water quality for 6 towns in Colorado The level of contamination would be considered minor for rural water supplies in developing countries.

Berg and Mowery (1968) in a study of 1,943 American Indians living on reservations in four states found that the number of enteric disease outpatients fell modestly (15%) for a group with one or two water taps and mixed toilets and pit privies while enteric disease outpatients for a group without inside taps and with pit latrines rose slightly

Rubenstein, *et al* (1969), in a study of a Hopi Indian village, found that clinic visits for diarrhea per inhabitant dropped from 2 0 per year to 0 85 per year following installation of an indoor plumbing supply In a control area without indoor plumbing, clinical visits dropped from 3.1 to 2 6 per year over the same time span

In the developing countries studies using a variety of test criteria and methodologies provide further insight into the relations between water supply-sanitation and waterborne disease

The following studies from Latin America, Africa and Asia are illuminating

Moore, *et al.* (1965) found diarrhea morbidity in Costa Rican children 0 to 4 years of age to be one-fourth less in those using water systems classified as "better" than in those using water systems classified as "worst"

Bruch, *et al* (1963) reported in Guatemala that a village with mixed piped water (10%) and public taps had a diarrheal attack rate of 32 4 for children using piped water and 38 0 for children using standposts A nearby village using water from multiple sources, some contaminated, had attack rates of 128 6 and 134 8 for piped water and standpost water respectively Villagers on mixed sources of drinking water had diarrhea about 4 times as frequently as villagers obtaining water from a protected gravity spring

Henry (1981) describes the introduction of piped household yard taps into two areas of St Lucia, W I One area also received water-seal latrines A third area served as a control Diarrhea in one year olds was 70 percent less in the water supply and latrine area than in the control area (the latter served with public standposts), ascaris was 30 percent less, and the number of children treated for diarrhea and for skin diseases was 47 percent and 82 percent less respectively

Pontes and Ramos (1971) report on long-term infant mortality in two areas of Sao Paulo, Brazil, receiving improved water supplies and in two "control" areas Infant mortality fell 68 to 80 percent, to approximately the rates of older subdivisions with previously existing water supplies

Reiff (1981) has plotted for Costa Rica a graphical correlation analysis for water supply development and the simultaneous fall of diarrhea-gastroenteritis over time. The timing of other social interventions is also shown (See Figure 9-1) Similar analyses were developed prior to World War II for many U S cities Baltimore, Chicago, Philadephia, *et al*

The Center for Disease Control (1978) and Thacker, *et al* (1980) attempted to establish the effect of per capita water use on health during a breakdown in the water supply of Port-au-Prince, Haiti Little effect was found, possibly as a result of an 8-month recall required on the part of interviewees

Koopman (1980) in a Cali, Colombia-based study found that houses with latrines had 36 percent more cases of diarrhea than those with sewer connections Homes with no provision for excreta removal had 60 percent more cases than those with latrines, and 127 percent more than those with sewer connections.

Kourany and Vasquez (1969) similarly found piped water and flush toilets more effective in Panama

An expansion of piped water supplies to slum areas of Lusaka, Zambia, resulted in the typhoid morbidity rate for the city dropping by 90 percent Diarrheal morbidity dropped 37 percent (Bahl, 1976)

Fenwick (1966), in an intensive study of the health impact of a new rural water supply for Zaina (Kenya), found that days of illness declined remarkably (over 50 percent for children under 6) for children in Zaina, while rising slightly in Thegenge, a control area Also see Strudwick (1962) and White, Bradley, and White (1972)

Table 9-2. Reduction in Typhoid Fever Death Rates In American Cities Following the Filtration of Their Public Water Supplies (Averages for Five Years Before and Five Years After Filtration)

City	*Average Typhoid Fever Death Rate*		*Per cent reduction in typhoid fever death rates which followed the filtration of the public water supply*
	Before Filtration	*After Filtration*	
Albany, N Y	109	28	74
Charleston, S C	106	62	41
Cincinnati, O	56	11	80
Columbus, O	83	17	78
Harrisburg, Pa	72	33	54
Hoboken, N J	18	13	28
Indianapolis, Ind	46	28	39
Lawrence, Mass	110	23	79
Louisville, Ky	57	24	58
New Haven, Conn	40	25	38
New Orleans, La	39	26	33
Paterson, N J	29	9	69
Philadelphia, Pa	63	20	68
Pittsburgh, Pa	132	19	85
Providence, R I	19	13	31
Reading, Pa	53	35	34
Scranton, Pa	25	10	60
Springfield, Mass	22	22	0
Washington, D C	55	31	43
Wilmington, Del	35	24	31
Weighted averages	60	21	65

SOURCE: Johnson (1916)

White, Bradley, and White (1972) found the prevalence of diarrhea for 34 sites in East Africa was 3 4 percent for piped water, 19.0 percent for unpiped water supplies

Bokkenheuser and Richardson (1960), and Richardson, et al (1963, 1965, 1966, 1968, 1968) examined transmission of shigellosis and salmonellosis in South Africa over an extended period Before and after data for an improved water supply for one village were shigellosis, 25 6 percent before, 19 6 percent after, and salmonellosis, 35 5 percent before, 19 6 percent after, as measured by positive cultures from schoolchildren

A series of WHO studies of diarrhea (Van Zijl, 1966, WHO, 1960, 1961a, 1961b, 1962, 1963, 1966a, and 1966b) were carried out in seven countries Sri Lanka, Bangladesh, Iran, Mauritius, the Sudan, Egypt, and Venezuela. Taking the seven studies as a whole, general conclusions include the following

(1) Reported difference of diarrhea rates for areas with and without piped water supplies were highly significant ($X^2 = 60\ 34$, P less than 0 001, n = 4)
(2) Similarly, difference of rates for detection of shigellae were highly significant for the two areas ($X^2 = 23\ 04$, P less than 0 001, n = 5)
(3) "The importance of water, as well as other factors of sanitation, was demonstrated "

A study in Egypt by Weir, et al (1952) concluded that "the installation of sanitary water supply and latrines did not alter the infant mortality rate or crude death rate in any of the villages " A review of this study, with today's knowledge, suggests that neither the wells nor the latrines were "sanitary " Also see Kawata (1978a)

Zaheer, *et al* (1962) found reductions of 74, 64, 23, and 43 percent in death rates for cholera, typhoid, dysenteries and diarrhea respectively after establishment of water treatment plants in 14 towns in Uttar Pradesh State, India Average water use was 13 gallons per capita per day These results are shown in Table 9-3

Misra (1971) in a study of rural water supply in seven villages in Uttar Pradesh State, India, found that the introduction of piped water with household taps was followed by declines in prevalence of diarrhea of 77 percent, dysentery of 76 percent, scabies of 98 percent, and trachoma of 90 percent. Typhoid fever disappeared Reduction in prevalence of diarrhea by public standposts was approximately 2/3 as effective as house connections

Cvjetanovic (1980) reports a continuing long-term drop in the incidence of diarrhea following the water supply improvements reported by Misra (1971). Diarrhea in children 5 years of age or younger fell 40 percent in the first year following introduction of water supply improvements and continued to fall in the second and third years afterwards

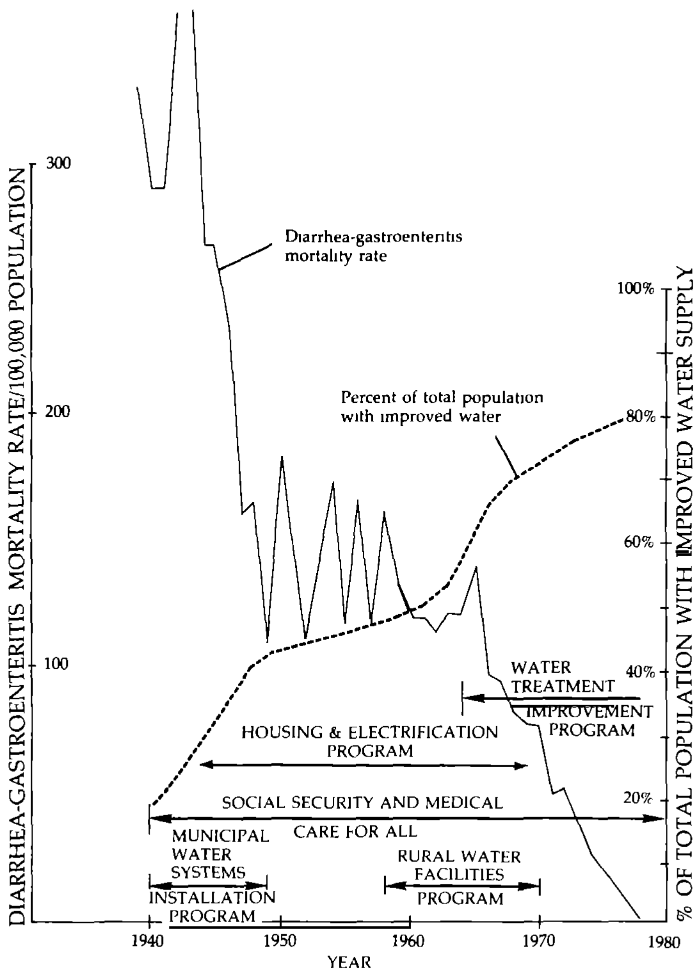
Rajasekaran, Dutt, and Pisharoti (1977) in a study of Indian rural water supplies found that the prevalence of shigellosis for homes with water taps was 1/2 that of wells and 1/3 that of public standposts

Trevedi, Gandhi, and Shukla (1971) undertook to chlorinate 48 rural water supply wells in three villages near Kanpur, India There was a 6-fold reduction in the before and after incidence of diarrhea for the experimental wells and an 11-fold reduction when compared to the control wells

Khan (1978) found that a refugee camp in Dacca, Bangladesh, with piped water supply and latrines had 62 percent less cholera than two nearby refugee camps with tubewells, ponds, and surface latrines

Positive results are also reported from three industrially developed countries where improved water supplies were introduced in rural areas or were restored following World War II

Figure 9-1. Diarrhea-Gastroenteritis Mortality Rates in Costa Rica Versus Time and Percent of Total Population with Improved Water Supply Versus Time



SOURCE: Reiff (1981)

Zebec, Bujevic, and Cvjetanovic (1980) describe the 1926 installation of sanitary wells and latrines in Mraclin, a Yugoslavian village The infant mortality rate was reduced by 40 per 1000 live births per year and the annual mortality among children age 1 to 4 was reduced 45 percent

Costopoulos (1968) reported a dramatic fall in waterborne illness in post-World War II Greece following restoration of water supplies. (A graph appears under "Typhoid" in Section 2)

Dieterich and Henderson (1963) describe a report by the Japanese government to the World Health Organization on installation of safe water supplies in 30 rural areas of Japan Following installation, infectious intestinal diseases fell 71 5 percent, trachoma fell 64 percent, and death rates for infants and young children fell 51 7 percent.

Field Studies with Unclear or Negative Results

Several recent field studies have been difficult to interpret and have been, on occasion, misinterpreted Examples come from Guatemala, Lesotho, and Bangladesh

An extensive, long-term study, sponsored by the Agency for International Development (AID) and carried out in the field in Guatemala by the University of North Carolina (UNC) and the Institute of Nutrition for Central America and Panama (INCAP), found that "the introduction of water and the attempts to improve sanitation did not significantly effect diarrheal disease "

(See Shiffman, *et al*, 1978d Also see Schneider, Shiffman, and Faigenblum, 1978, and Shiffman, *et al*, 1978a, 1978b, 1978c) A later analysis of part of the data, by an AID staff member, yielded decidedly contrary conclusions (Dworkin and Dworkin, 1980) AID, being in a quandary, convened an external expert panel to independently review the project and report its findings (Cvjetanovic, *et al*, 1981) The panel concluded that the data would not support a firm conclusion with regard to the impact or non-impact of the intervention

A study sponsored by the British Ministry of Overseas Development, OXFAM, and the Government of Lesotho and executed by an interdisciplinary team evaluated village water supplies in Lesotho One part of this interesting study examined health impacts (Feachem, *et al*, 1977)

The health impact study was handicapped by lack of baseline health data in the villages surveyed The analysts sought to overcome this difficulty by using retrospective clinical records for villagers from villages with and without improved water supplies. Data on diarrheal disease was expressed as its ratio to certain other diseases in order "to provide a measure which is independent of differential village attendance (at the clinic) and population size" These ratios for villages were then tabulated versus differing village water supply status and subjected to Chi-square statistical tests No significant differences were found between villages in the ratios of their clinically reported diseases to other diseases, irrespective of the quality of water supply service

The authors of the Lesotho report argue that "village water supplies, *as they have been constructed and used in Lesotho*, have not led to reductions in disease" (p 179, italics added) The qualifier is important in at least two ways (1) there is no difference in quantity used from improved and unimproved water supplies, approximately 20 liters per capita per day Twenty lpcpd is a minimal quantity for promotion of hygiene, (2) contamination of unimproved water supply sources is mild, with fecal coliform counts rarely exceeding 10^3 in magnitude Thus the question were the water supplies in the test really different?

Another question is the "sensitivity" of the ratio procedure used Clinically reported cases of diarrhea were low, less than 2 per village per month. This ingenious method might profitably be tested in a setting where both clinical and village data series are available

The authors are more cautious than some others who have extrapolated the Lesotho findings to the different setting of Sahelian West Africa (Commission of the European Communities, 1978)

Bangladesh is in the heart of cholera's ancestral home (Pollitzer, 1959) It is also the home of the International Centre for Diarrheal Disease Research (nee Cholera Research Laboratory) and of a major UNICEF hand pump and tubewell program This has led to several studies of the efficacy of tubewells in prevention of cholera

Several such studies have questioned this role (Briscoe, 1978, Levine, *et al*, 1976a, 1976b, Feachem, *et al*, 1977), asking even if

Table 9-3. Average Specific Death Rates for Five Years Prior to and After the Establishment of Water Purification Plants in the State of Uttar Pradesh, India

		Average death rates							
	Year of establishment of purification plants	*Cholera*		*Typhoid*		*Dysenteries*		*Diarrhoeas*	
Towns		*Before Installation*	*After Installation*	*Before Installation*	*After Installation*	*Before Installation*	*After Installation*	*Before Installation*	*After Installation*
Roorkee	1953	0.01	0.00	0.37	0.04	0.25	0.14	0.77	0.38
Ghaziabad	1954	0.04	0.00	0.12	0.08	0.21	0.19	0.15	0·02
Etawah	1951	0.39	0.03	0.04	0.00	0.45	0.08	3.27	1.62
Orai	1945	0.30	0.13	0.21	0.11	0.25	0.06	1.56	0.48
Gorakhpur	1954	0.04	0.02	0.07	0.06	0.76	0.72	1.11	0.42
Banda	1950	0.43	0.06	0.42	0.21	0.21	0.14	0.26	0.10
Bahraich	1951	0.34	0.00	0.12	0.03	0.26	0·15	1.13	0.65
Hardoi	1954	0.29	0.00	0.22	0.02	0.22	0.13	0.49	0.28
Basti	1954	0.13	0.01	0.52	0.00	0.15	0.08	0.09	0.01
Mirzapur	1953	0.11	0.00	0.01	0.00	0.98	0.62	0.62	0.27
Moghulsarai	1949	0.86	0.06	0.25	0.03	0.18	0.03	0.18	0.17
Sandila	1954	0.20	0.57*	2.46	0.05	0.84	0.70	1.07	1.03
Deoria	1954	0.04	0.00	0.11	0.06	0.02	0.04*	0.01	0.03*
Vrindaban	1943	0.60	0.16	0.10	0.37*	0·72	1.12*	3.76	2.86
Average for 14 towns		0·27	0.07	0.22	0.08	0.39	0.30	1.03	0.59
Percentage of reduction in the death rates		74.07		63.63		23.08		42.72	

*Figures asterisked do not show a decline

SOURCE Zaheer, *et al*, (1962)

cholera was waterborne More recent studies (Hughes, et al , 1977, Spira, et al , 1980) have found that tubewells are cholera-free *and* that cholera is transmitted by water other than tubewell. Further, tubewell numbers are inadequate for the number of users, a problem compounded by not infrequent breakdowns of hand pumps Also entering the picture is the role of iron in groundwater in Matlab Thana, where most of the studies have been carried out (Kawata, 1978a, 1978b)

Numerous examples are extant of the health impact of improved water supplies in Bangladesh, especially outside Matlab Thana (See, e g , Curlin, *et al* , 1977a, 1977b, Greenough, 1981, Khan, 1978, Rahaman, 1978, 1981, Skoda, Mendis, and Chia, 1977, 1979, and WHO, 1974) Figure 9-2 shows the relationship between number of tubewells and mortality due to cholera, typhoid, and dysentery for Bangladesh as a whole

Health Impact for Varying Levels of Water Supply Service

As Table 9-4 (with service and cost level data from Brazil) illustrates, the level of water supply service, from community water point to full household plumbing, has a significant impact on cost. Health impacts tend to increase with rising service levels. Do health benefits rise as rapidly as costs? Unfortunately there are few studies from which the marginal health benefits can be delineated by level of water supply services The study by Misra (1971) is one of the few Table 9-5 draws from this study

Note that for this instance, the major portion of health benefits can be obtained from standpoints With the same budget, more people served with standposts might reduce diarrhea more than a smaller number with house taps, depending on the relative cost per capita for standposts and house taps

The costs of additional health benefits of complementary activities are also relevant Again there are few studies One of interest is that of Azurin and Alvero (1974) for a cholera intervention in the Philippines In that study the reduction of cholera from water supply alone was 72 9 percent, from sanitation alone the reduction was 68.0 percent, and for *both* water supply and sanitation the reduction was 76 4 percent, only 3 5 percent more than water supply alone Again, the mix of water supply and sanitation might depend on relative costs *if* we were able to estimate health impacts a priori with precise accuracy

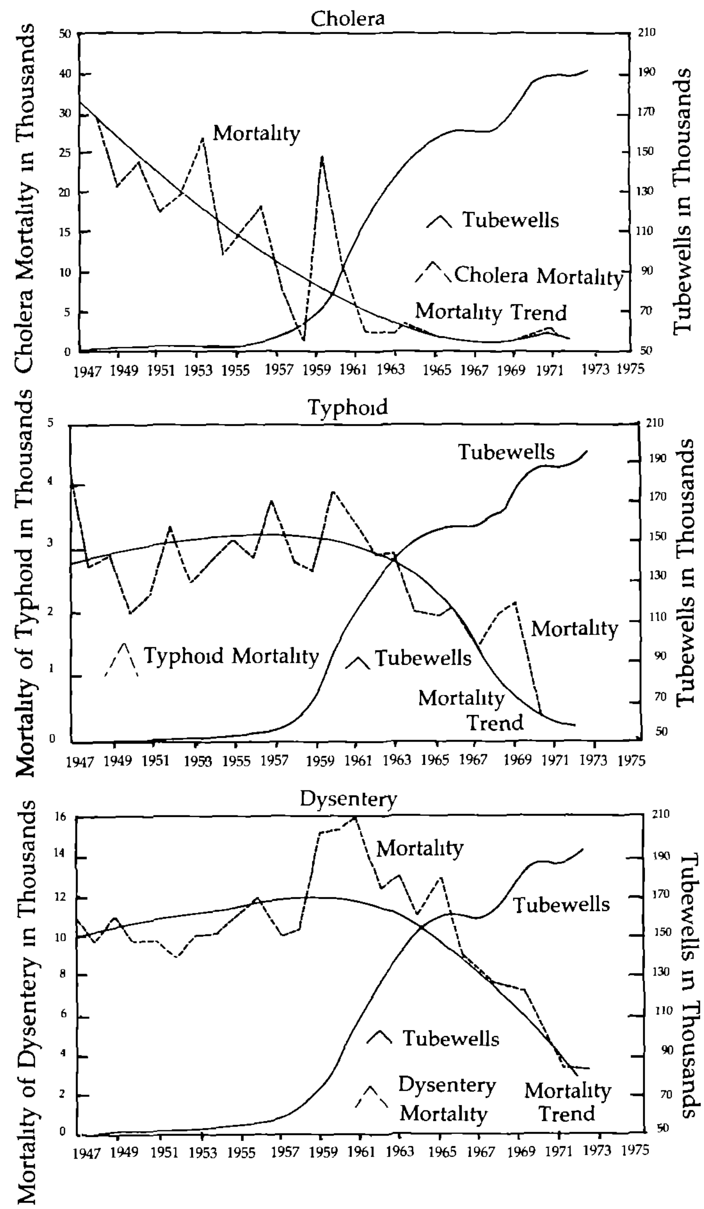
Impacts on Nutrition

Increasing evidence suggests that the "malnutrition problem" is not due simply to insufficient availability of food The heavy burden of pediatric diarrhea and other infections and infestations retards growth and physical development and under some circumstances may precipitate or exacerbate frank clinical malnutrition Inasmuch as the quality and quantity of domestic water supply is associated with the incidence of infections and infestations, water is a factor in nutritional status A few studies relating improved water supply to measureable improvements of nutritional status, especially growth of children, are now reaching the literature These include Adrianzen and Graham (1974), Henry (1981), Rowland and McCollum (1977), Tomkins, et al (1978), Whitehead (1977), and others Evidence to date suggests that water supply-nutrition linkage warrants greater attention.

Impacts on Non-Diarrheal Diseases

Field studies of water supply impacts on health status have historically focused on diarrheal diseases However, there are numerous examples of impact studies for other diseases Particularly noteworthy examples include Assaad, Maxwell-Lyons, and Sundareson (1969) and Marshall (1968) for trachoma, Sholdt, Holloway, and Fronk (1979) for pediculosis (lice), and Unrau (1978) for schistosomiasis These and other studies were reviewed in proceeding sections

Figure 9-2. Relationship Between Number of Tubewells and Mortality Due to Cholera, Typhoid, and Dysentery in Bangladesh



SOURCE: WHO (1974)

Historical, Statistical, and Econometric Models

These are studies that look at large scale data series, often for multiple interventions, over extended time periods Multiple regression analysis techniques are popular with these analysts These are *not* epidemiological models

Among the earlier works of this type are those of Thomas McKeown and his colleagues (McKeown, 1976, McKeown and Record, 1962, and McKeown, Brown, and Record, 1972), who attempt to explain the rise of population in modern Eurcpe through analysis of historical birth and death rates, disease-

Table 9-4. Costs of Alternative Water Supply and Sanitation Service Levels: An Example

I. Annual Costs Per Capita by Service Level

Category	*Service Level* I	II	III	IV	V
Water Supply	$2	$4	$ 7	$ 7	$11
Excreta Disposal	$2	$4	$ 7	$10	$12
Water Supply and Excreta Disposal	$4	$8	$14	$17	$23

II Characteristics of Alternative Service Levels

Service Level	*Average Per Capita Water Demand (liters/day)*	*Total Maximum Day Water Demand (meters³/day)*	*Water Distribution Facilities (Source and Treatment Included in Costs)*	*Sanitation Excretal Wastewater Disposal Facilities*
I	25	405	Public standposts serving 200-400 people within 100 m	One privy per household
II	50	810	One yard hydrant per household	One pour-flush toilet with soak pit per household
III	100	1,620	One kitchen tap and shower per household	One pour-flush toilet with septic tank per household
IV	100	1,620	Same as III	Same pour-flush toilets, but small-bore street sewers to lagoons
V	200	3,240	Full plumbing	Conventional waterborne sewerage with lagoon treatment of wastes

NOTES Estimates are for the town of Rio Pasca, State of Minas Gerais, Brazil, present population, 6,000, design population 12,800, service area of 83 hectares, average household size of six, town is divided by a river and has irregular topography Water use on peak day is 150% of average daily use Construction costs converted to annual costs using 20 year design period and an interest rate of 10% N B *water and sanitation costs are site-specific and vary widely* with local climatic, hydrologic, geologic, topographic, demographic, economic, and other conditions

SOURCE: Lauria (in press)

Table 9-5. Comparison of Diarrheal Incidence Among Children Under Five Years of Age According to Source of Drinking Water

Source	*Diarrheal Incidence %*	*Reduction From Open Well %*
Open Well	18 4	—
Standpost	7 8	57 7
House tap	6 2	66.3

Adapted from Misra (1971) for seven Indian villages for August-December 1968

specific mortality rates, nutritional levels, environmental change, and other variables during the latter half of the 19th century and the earlier 20th century

Their findings are that the decline of mortality was due to a reduction of deaths from infectious diseases Among relevant findings to this review is that "from the second half of the nineteenth century a substantial reduction of mortality from intestinal infections followed the introduction of hygienic measures—purification of water, efficient sewage disposal, and improved food hygiene " Reductions which preceded advances in hygiene were attributed to nutrition improvements due to greater food supplies "The fall of mortality was not influenced substantially by immunization or therapy before 1935 "

A similar, but less extensive, analysis by Arriaga and Davis (1969) for 13 Latin American countries, plus some 8 other countries, of data from the late 19th century through 1960 found that after about 1930, for Latin America, public health measures were exerting a strong influence independently of local economic development Health measures cited included water and sewage and personal hygiene

Barnum, *et al* (1980) in a mathematical optimization model of health interventions, at low "levels of resources," selected activities for emphasis "health promotion, water and sanitation (public fountains, latrines, and covered sewerage), and well baby clinics " The input data were derivative from Colombian experience Koopman (1980) in a study also in Colombia (Cali) found that houses without latrines had 60 percent more diarrhea than those with latrines and 127 percent more cases of diarrhea than did houses with sewers Another Colombian-based study (Koopman, 1981) found that hygiene had a strong relationship to child growth

A multiple regression, multiple intervention study of Chilean data (Livingstone-Balbontin, 1976) found that "the increase in the percentage of houses with sewerage systems and potable water will have immediately a direct effect on the death rates of the infant and child population."

A similar analysis for Sri Lanka (Patel, 1980) found regional variations in the nature of the water supply more strongly associated with infant mortality than regional variations in public health expenditures (r = 0.82, significant at 99 percent level for water supply).

A statistical analysis of 35,000 deaths of children less than 5 years of age in 10 Latin American countries found strong inverse correlations between postneonatal mortality and percentage of houses with piped water. The authors (Puffer and Serrano, 1973) concluded that "the provision of water supplies and sanitary facilities to much higher proportions of families in many urban and rural areas is essential for bringing about major reductions in postneonatal mortality." A study of the same communities (Burke, York, and Sande, 1979), based on 30,000 household interviews confirmed the relationship of the inverse association between availability of piped water and high mortality among young children.

Another multiple regression analysis of national data on water supply, *interalia*, "provided no explanation of variation in the mortality series." The water supply data series were very dubious, and so noted by the author (Sloan, 1971).

Simple and multiple regression analyses of multiple interventions which might impact on life expectancy ranked water supply behind literacy, but equal or superior to most other interventions (Hicks, 1979). Data series for water were from 69 countries.

A similar study (Grosse, 1980), using 1962 water supply data from 65 developing countries, found the percent of urban population with water taps among the "dominant categories" associated with life expectancy.

A study (Butz, DaVanzo, and Habicht, 1981) of determinants of infant mortality variations in Malaysia, using a linear probability model, found infants in houses with piped water and toilet systems had significantly lower mortality. Communities with water supply and sanitation tended to have significantly lower mortality among non-nursing infants.

Reduction of child mortality by water from taps appeared "to be influencing child mortality" in an econometric model using 1971 Indian census data (Evenson, Rosenzweig, and Wolpin, 1981, Rosenzweig and Wolpin, 1981).

An econometric model of fertility and infant and child mortality, based on Malaysian census data, found piped water supply and "bucket waste disposal" significant. The author (Heller, 1976) suggests that "jeopardy to a child's health from an unsanitary environment principally occurs after the first year, probably at the time of weaning."

Shuval, Tilden, Perry, and Grosse (1981) hypothesize a "general theory" (an "S"-shaped, logistic curve) for impact on life expectancy of water supply interventions. Both the model and the data used for verification are problematical and lack economic inputs or comparisons with other alternative interventions.

A less ambitious regression model correlates hydraulic characteristics of the water supply distribution and the sewerage systems of Worcester, Massachusetts, with reported cases of hepatitis A virus infections. Old pipes in low pressure areas were associated with the highest incidences of hepatitis (Hoffman, 1979).

Summary of All Studies

Many of these studies had one or several serious shortcomings. failure to establish adequate baseline data, failure to measure or control for significant cofactors and covariables, inadequate control populations, inadequate length of time to measure significant changes, inadequate refinement to distinguish "signals" from background "noise", inadequate sample size, overreliance on use of questionnaires and accurate recall, inability to control the intervention, (surprisingly) inadequate measurement of water quality and of quantity actually used by households, inadequate controls or statistical design for confounding variables such as income, literacy, housing and diet.

With all their deficiencies, reviewing these studies in the aggregate indicates that

(1) There is a health impact where safe water is readily accessible in adequate quantities—40 to 60 liters per person per day.
(2) The relationship is strictly quantifiable *a priori* only in the broadest sense (better water, better health) and varies widely with specific circumstances.
(3) Health impacts can be evaluated but not without a major investment of time, skilled manpower, and resources which may well exceed the cost of a rural water supply.
(4) Other things being equal, health impacts improve as water supplies move from central wells or standpipes to yard patios to house connections. Complementary activities in sanitary excreta disposal and hygiene education incrementally assist impacts. Availability of soap is also helpful.
(5) Several studies show remarkable benefits, the prime examples coming from India, Yugoslavia, the Philippines, Kenya, the Near East, Venezuela, and migrant labor and mining camps in the United States.
(6) The studies that are unclear or negative tend to occur in situations where the greatest poverty and underdevelopment dominate the situation. These results strongly emphasize that the control of the waterborne diseases is complicated and difficult and cannot be achieved by technical means alone. Such factors as human behavior patterns, lack of education, crowding, poverty, and lack of basic understanding of personal and household hygiene can over-ride the proven health enhancing potential of even safe water and sanitary excreta disposal systems.

Other Reviews

Several other reviews are worthy of note.

A review of 28 studies undertaken by the World Bank (Saunders and Warford, 1976) summarized that

> the twenty-eight studies provide evidence to reinforce the intuitive belief that the incidence of certain water-washed, waterborne, water-based, and water-sanitation associated diseases are related to the quantity or quality of water and sanitation available to users. They give us little help, however, in determining exactly how much improvement in health can be expected from a specific water supply and sanitation-related improvement in any particular area.

A WHO Scientific Working Group (WHO, 1979) reviewed 25 studies and reported that

> the results of these studies taken together do suggest that improvements in water quality and water availability can often lead to a reduction in acute diarrhoeal disease, while improvements in water availability can result in a decrease in the prevalence of *Shigella* infection.

Also,

> In impact studies where water supply improvements showed clear reductions in diarrhoea rates, the intervention was probably effective in two ways First, the improvement of water quality reduced the load of water-borne pathogens Secondly, the increased access to water (e g , a piped supply in the home) reduced the incidence of diarrhoeal disease due to person-to-person transmission, especially in the case of *Shigella,* presumably because the intervention facilitated personal cleanliness and prevented water-washed transmission

Wall and Keeve (1974) concluded that

> Although many of the studies reviewed suffered from poor conceptualization or inadequate implementation, taken as a whole, the studies represent significant evidence that improved water supply is associated with decreased incidence of enteric disease Further, for most diarrheal diseases and skin infections, incidence appears inversely related to volume of water used Households that have more convenient sources of water and have more facilities for use of water (indoor latrines, showers, baths, basins) have lower infection rates These findings confirm conclusions many have arrived at by intuition or common sense The studies do not provide a basis for estimating incremental health benefits that can be expected from incremental investments in water supply systems

The conclusion of an expert panel convened by the World Bank has been widely cited (Expert Panel, 1976)

> Other things being equal, a safe and adequate water supply is generally associated with a healthier population. This has been unequivocally demonstrated for urban areas and in varying degrees for rural situations The difficulty lies in measurement rather than in qualitative trends The problem with collecting field observations on the health impact of water supply is that on a cross-section basis other things are never equal and on a through-time basis other things usually cannot be held constant or accurately controlled Consequently, it is extremely difficult to identify and measure exactly the health effects of improved water supply, and there is a limit to the precision attainable Furthermore even if a case were found where governmental, physical, environmental, economic, cultural, and educational factors which affect health could be reasonably controlled, the detailed findings of a health and water supply study are unlikely to be transferable from that particular setting to situations elsewhere.

The Bank's Expert Panel also addressed the issue of project evaluation The Panel recommended that

> While long-term longitudinal studies of large size and expense are probably the only means through which there is any chance of isolating a specific quantitative relationship between water supply and health, separate from the multitude of other interrelated factors, the very high cost, limited possibility of success and restricted application of results lead the panel to recommend that the Bank does not undertake such studies Furthermore, given the current state of knowledge, attempts at a rigorous quantification of the health benefits of Bank water supply projects are likely to be futile It should be sufficient to accept the universally recognized fact that the provision of an adequate quantity of safe water is a basic necessity for the maintenance of good health and productivity

Hughes (1981) in an extensive review of 43 published studies that have quantified indicators of diarrheal disease in populations with different levels of water supply and/or excreta disposal facilities concluded that

> The data suggest that morbidity reductions of 20% or more are usually statistically significant and have been observed frequently enough to suggest that previous attitudes concerning the lack of documentation of health benefits may be unnecessarily pessimistic . . . ,

and that

> Data from these studies suggest that although tap water in the house is preferable in terms of health benefit to water outside the house, available water near the house may yield health benefits also . data from these studies suggest that volumes in the range of 20-30 lpcpd (liters per capita per day) may be a minimum to yield reductions in diarrheal disease morbidity

Conclusions

In the aggregate, these studies and reviews support the following conclusions

(1) A significant body of evidence supports the positive linkage between sanitary water supply and excreta disposal and long-term improvements in health status This linkage is supported by long-term empirical observations in both the developed and less developed countries

(2) The present state-of-the-art of epidemiological forecasting, however, makes it difficult if not impossible to predict with precise accuracy the incremental health status improvement that might be expected from incremental improvements in water supply and santitation For substantial interventions in settings where pediatric diarrheal morbidity and mortality are high, improvements of 20 to 40 percent are not unusual

(3) Not only are specific *a priori* statements difficult, but after the fact measurements present formidable problems and require considerable resources

(4) Health improvements associated with sanitary improvement are linked with numerous other aspects of personal and community life, especially nutrition, personal hygiene, food sanitation, primary health care, and the like

(5) In developing countries the major direct beneficiaries are young children and the poorer members of the society

(6) Benefits are directly related to user convenience and success House connections are superior to yard hydrants, which in turn are superior to communal water points (Economics/level of service is an important, related issue)

(7) Water quantity, as well as quality, is an important factor in establishing health benefits for reducing the incidence and prevalence of numerous diseases Fifty (50) liters per capita per day should be a minimum goal.

(8) Water supply and sanitation measures are more effective in the long run than vaccination programs for waterborne diseases

(9) Water supply can play an important role in control of vector-borne diseases, particularly schistosomiasis and epidemic typhus

(10) Non-specific etiologic agents are of major importance

The role of rotaviruses in diarrheal illnesses of young children needs better resolution

(11) Water-related diseases in the developing world must be reduced if their people, particularly children and the poor majority, are to satisfy their basic human need for a healthful environment

(12) Water supply and sanitary excreta disposal are necessary for reduction and prevention of water-related disease

(13) At the present state-of-the-art, rigid, *quantitative* evaluation of the health benefits of water supply projects and programs is impractical as a routine activity and should be limited to research projects with substantial resources

(14) Water supplies must be provided that are adequate in quality, quantity, and reliability and conveniently accessible if these interventions are to be effective as health measures Further they must be *used*

Tables 9-6 and 9-7 summarize the methodology and findings of selected studies associating diarrheal diseases and stool cultures with water supply and/or excreta disposal

Table 9-6. Studies Assessing the Association of Diarrheal Disease or Related Conditions with Water Supply and/or Excreta Disposal

Adapted from Hughes (1981)

Reference	*Variable(s) Assessed*	*Location of Study*	*Specific Indicator*	*Age Group*	*Type of Study*	*Site Collection Indicator Data*	*Duration*	*Results*
Petersen & Hines (1960)	Water quality	Colorado USA	Gastro-intestinal illness* incidence	All	Cross-sectional	Single home-visit (3 month recall)	3 months	Incidence in poor water quality communities 13 19% In good water quality communities 8 8%
Levine et al (1976a)	Water quality	Bangladesh	Diarrhoea incidence	All	Record review	Clinical and hospital	11 years	Incidence tube well non-users 3 2/1000/yr tube well users 7 5/1000/yr
Watt et al (1953)	Water availability	California USA	Diarrhoea incidence	All	Cross-sectional Longitudinal	Home visits once or every 4-6 weeks (6 week recall) Rectal swabs for children under 10 years	6 months	Data pointed to water use as factor which may significantly lower *Shigella* prevalence when risk of acquiring was great
Schiffman et al. (1978d)	Water quality and availability	Guatemala**	Diarrhoea incidence	All	Longitudinal	Home visits monthly (2 week recall) and clinic record review	3 years	Incidence 39 7/1000/yr initially, 39 5/1000/yr 3 years later
Bahl (1976)	Water quality and availability	Zambia	Diarrhoea incidence	All	Record review	Clinic and hospital	4 years	Incidence 338/1000/yr before, 212/1000/yr 2 years after piped water provided
Feacham et al (1978)	Water quality and availability	Lesotho	Diarrhoea incidence	All	Record review	Clinic and hospital	39 months	No difference in diarrhoea incidence in villages with and without improved supplies
White, Bradley & White (1972)	Water quality and availability	Kenya	Diarrhoea prevalence	All	Cross-sectional	Single home visit (1 week recall)	1 week	Illness in 19 0% households without piped water, only 3 1% of households with piped water
Shaffer et al (1978)	Water quality and availability	Kenya	Diarrhoea prevalence	All	Cross-sectional	Single home visit (7 week recall period)	Short	Prevalence 7%, no differences

*Definition specified

**Specific intervention evaluated

Table 9-6 Continued

Reference	*Variable(s) Assessed*	*Location of Study*	*Specific Indicator*	*Age Group*	*Type of Study*	*Site Collection Indicator Data*	*Duration*	*Results*
Strudwick (1962) Fenwick (1972)	Water quality and availability	Kenya**	Gastrointestinal illness	All	Longitudinal	Home visits biweekly (2 week recall)	9 months	Decrease as percentage of total illness from 23% to 20% in infants and from 31% to 18% in children aged 1-2 yrs.
Schliessmann et al (1958)	Water availbility,excreta disposal	Kentucky USA	Diarrhoea incidence	All	Longitudinal	Home visits monthly (1 month recall)	29 months	Incidence/1000/yr without indoor plumbing 349, with 135
Rubenstein et al (1969)	Water availbility, excreta disposal	Arizona USA	Diarrhoea incidence	1 year	Record review	Clinic and hospital	6½ years	Incidence/person/yr before indoor plumbing 2 0, after 0 9
Berg et al. (1968)	Water availability, excreta disposal	Five states USA	Diarrhoea incidence	All	Record review	Clinic	6 years	Incidence 59/1000/yr before indoor plumbing, after 136/1000/yr
Wolff et al (1969)	Water availability, excreta disposal	Venezuela	Diarrhoea incidence	All	Longitudinal	Home visits monthly (1 month recall)	1 year	Children under 8 years, 2 communities without available water, and incidence 24 2%, 27 4% 4 communities with 11.8%, 12 0%, 12 5%, 17 9%
Freij et al (1975)	Water availbility, excreta disposal	Ethiopia	Gastro-enteritis* incidence	Less than 4 years	Longitudinal	Home visits biweekly (1 day recall)	1 year	When water available, lower incidence with private than non-private latrines
van Zijl (1966)	Water availbility, excreta disposal	Seven countries	Diarrhoea incidence	Less than 9 years	Cross-sectional	Single home visit (1 month recall)	1 month	Incidence 2 0-48 7% where water less available, 2 0-39% where water available
Bruch et al (1963)	Water quality, water availbility, excreta disposal	Guatemala	Diarrhoea incidence	All	Longitudinal	Home visits biweekly (2 week recall)	4 years	Incidence/1000/yr without privies 224, with privies . . 168, Incidence 3 times higher with limited water availability

Table 9-6 Continued

Reference	*Variable(s) Assessed*	*Location of Study*	*Specific Indicator*	*Age Group*	*Type of Study*	*Site Collection Indicator Data*	*Duration*	*Results*
Moore et al (1965)	Water quality, water avail-bility, excreta disposal	Costa Rica	Diarrhoea* incidence	All	Longitudinal	Home visits weekly (1 week recall)	1 year	Incidence/1000/yr 0-1 Water using facilities per house 490 3 or more facilities per house 240 No excreta disposal facility 210 Privy 400 Septic tank 270

Table 9-7. Studies Assessing the Association of Stool Cultures with Water Supply and Excreta Disposal

Adapted from Hughes (1981)

Reference	*Variable(s) Assessed*	*Location of Study*	*Specific Indicator*	*Age Group*	*Type of Study*	*Site and Method of Specimen Coll*	*Duration*	*Results*
Sommer et al (1972)	Water quality	Bangladesh	Cholera incidence	Under 11 years	Longitudinal	Home and hospital, rectal swabs	2 years	Classical cholera Incidence those living further from tube wells 25 3% living close to tube wells . 3 7%
Levine et al (1976a)	Water quality	Bangladesh	Cholera incidence	All	Record review	Clinic & hospital, rectal swabs or stools	11 years	Incidence/1000/yr. Tube well non-users . 8 4% users 14 2%
Watt et al (1953)	Water availability	California USA	*Shigella, Salmonella* prevalence	Under 10 years	Cross-sectional/ longitudinal	Home and clinic, rectal swabs	6 months	*Shigella* prevalence Homes without water . . 6 6% Homes with water 2.1%
Hollister et al (1955)	Water availability	California USA	*Shigella, Salmonella* prevalence	Under 10 years	Longitudinal	Home, rectal swabs	7 months	*Shigella* prevalence Homes without water 7 2% Homes with water 0 7%

Table 9-7 Continued

Reference	*Variable(s) Assessed*	*Location of Study*	*Specific Indicator*	*Age Group*	*Type of Study*	*Site and Method of Specimen Coll*	*Duration*	*Results*
McCabe et al (1957)	Excreta disposal	Georgia* USA	*Shigella* prevalence	Under 10 years	Longitudinal	Home; recal swabs	31 months	*Shigella* prevalence before . . . . 4 7% after . 2 8% privies improved
Stewart et al (1955)	Water quality & availability	Georgia USA	*Shigella* prevalence	?	Longitudinal	Home, rectal swabs	3 years	*Shigella* prevalence of families without nearby water . 5 8% of families with nearby water . . . 4 1%
Azurin et al (1974)	Water quality, excreta disposal	Philippines*	Cholera incidence	All	Longitudinal	Home, rectal swabs	4½ years	El Tor cholera incidence/1000/yr No improvments 46 0% Improved excreta disposal . 14 7% Improved water 12 5% Improved water & excreta disposal 10 8% by communities
Schliessmann et al. (1958)	Water availability, excreta disposal	Kentucky USA	*Shigella*, *Salmonella*, EPEC** prevalence	Under 5 years	Longitudinal	Home; rectal swabs	29 months	*Shigella* prevalence Without indoor plumbing . 6.4% With indoor plumbing 0 7%
Berg et al (1968)	Water availability, excreta disposal	Five States USA	*Shigella*, *Salmonella* prevalence	All	Record review	Hospitals, stools	6 years	Low incidence, data not presented
Beck et al (1937)	Water availability, excreta disposal	Guatemala	*Shigella*, *Salmonella* prevalence	Under 10 years	Cross-sectional	Clinics; rectal swabs	6 months	*Shigella* prevalence Communities with private wells or municipal supply to 0-50% of houses 6.3% Municipal supply to more than 50% 9.4% Communities with privies or flush toilets in 0-50% of houses 4.8% In those with more than 50% . . 11.2%

*Specific intervention evaluated
**Enteropathogenic *Escherichia coli*

Table 9-7 Continued

Reference	*Variable(s) Assessed*	*Location of Study*	*Specific Indicator*	*Age Group*	*Type of Study*	*Site and Method of Specimen Coll*	*Duration*	*Results*
van Zijl (1966)	Water availbility, excreta disposal	Seven countries	*Shigella, Salmonella,* EPEC** prevalence	Under 10 years	Cross-sectional	Home, rectal swabs	1 month	*Shigella* prevalence Where water less available . 4-14% Where water available 2-6 4%
Kourany et al. (1969)	Water quality, water availbility, excreta disposal	Panama	*Shigella, Salmonella,* EPEC** incidence	Infants	Cross-sectional	Clinic, stool, examination method unclear	unknown	*Shigella* incidence Without indoor plumbing 0 9-2 5% With indoor plumbing 0 0%
Moore et al (1965)	Water quality, water availbility, excreta disposal	Costa Rica	*Shigella, Salmonella,* EPEC** prevalence	All	Longitudinal	Home and clinics, rectal swabs and stools	1 year	*Shigella* prevalence 0-1 in-house water connections 7% 2-3 in-house water connections 1% Privy or no facility 4% Septic tank 0%

**Enteropathogenic *Escherichia coli*

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SECTION 10

EPILOGUE

The list of diseases related to deficiencies in water is long. The prevalence of these diseases is widespread and high in the less developed countries (LDCs). In many LDCs, they are among the leading causes of death, often first but invariably among the top ten They weigh heavily on the poor and are especially deadly to infants and small children They are exacerbated by increasing population densities

Safe, convenient, reliable water supply and sanitary excreta disposal are basic human needs for healthy, productive lives Without them, maintenance of a healthful environment is practically impossible Nevertheless, they are not in themselves sufficient to assure good health People must use them properly and this requires education in health and hygiene They must be accompanied by adequate nutrition, food sanitation, security, housing, primary health care, and adequate institutions and infrastructure for their long-term finance, operation, maintenance, and replacement

* * * * *

ANNEX A

GLOSSARY

Aedes	a genus of mosquitoes, including some vectors, e g , *Ae Egyptii*, a vector of yellow fever
anerobe	an organism that lives and grows in the absence of molecular oxygen
Anopheles	a genus of mosquitoes, many of which are vectors of malaria, e g , *An Gambia*
anorexia	lack or loss of appetite for food
anuria	complete suppression of urine formation by the kidney
anal	pertaining to the anus
anus	the opening of the rectum on the body surface, the final orifice of the alimentary canal, through which feces are discharged to the external environment
arbovirus	arthropod-borne virus
ataxia	failure of muscular coordination
autochthonous	originating in the same area in which it is found
bejel	a nonveneral form of syphilis
bradycardia	slowness of the heart beat
cachexia	a profound and marked state of constitutional disorder, general ill health and malnutrition
carrier	an infected person (or animal) who harbors a specific infectious agent without apparent clinical disease and serves as a potential source of human infection Carriers may never develop the disease (asymptomatic carriers) or may be carriers during the incubation, convalescent, or post-convalescent periods for short or long time periods "Typhoid Mary" was a famous example
cataract	an opacity of the lens of the eye
catarrh	inflammation of a mucous membrane, particularly of the head and throat
catharsis	a cleansing or purging
chemoprophylaxis	use of a chemical(s), including antibiotics, to prevent development or progression of an infection
chemotherapy	use of a chemical(s), including antibiotics, to cure or control a clinically recognizable infectious disease
cicatrix	a scar, fibrous tissue left after healing of a wound
colic	acute paroxysmal abdominal pain
coliform	resembling or being *Escherichia coli* bacteria
colitis	inflammation of the colon
colon	the part of the large intestine extending from the cecum to the rectum
conjunctiva	the delicate membrane lining the eyelids and covering the eyeball
conjunctivitis	inflammation of the conjunctiva
contagious	capable of being transmitted from one person to another
Culex	a genus of mosquitoes found throughout the world, many species of which are vectors of disease-producing organisms
culicine	mosquito of the genus *Culex* or related genera
cyanosis	a bluish discoloration of the skin due to excessive concentration of reduced hemoglobin in the blood
dermato	*word element, Greek for skin*
dermatitis	inflammation of the skin
dermatophytosis	a fungus infection of the skin
dermatosis	any skin disease, especially one without inflammation
diarrhea	abnormally frequent evacuation of watery stools
disease	a definite morbid process, often with a characteristic train of symptoms
disinfect	to kill or inactivate pathogenic organisms
disinfest	to kill or remove insects, rodents, or other animals present on the person, in clothes, or in the immediate environment, which may transmit disease
disinfestation	any physical or chemical process for killing or removing ectoparasites, arthropods, or rodents
distal	remote, farther from a point of reference
duodenum	first part of the small intestine, extending from the pylorus (of the stomach) to the jejenum
dysentery	intestinal disorder marked by inflammation, especially of the colon, with abdominal pain, tenesmus, and frequent stools containing blood and mucus
dyspepsia	impairment of digestion, usually applied to epigastric discomfort after meals
dysphagia	difficulty in swallowing
ectoparasite	a parasite living on the outside of the host's body, e g , the louse
endemic	any disease of man maintained at a fairly constant low level in the community over a period of years
enteric	pertaining to the small intestine
enteritis	inflammation of the intestine
epidemic	any disease of man in which the number of cases exceeds that normally expected
fatality rate	percentage of persons diagnosed for a specific disease who die as result of that episode of that disease
fecal	adjective form of feces
feces	excrement discharged from the bowels through the rectum
fulminate	to occur suddenly with great intensity
gastric	pertaining to the stomach

gastroenteritis	inflammation of the stomach and intestine
gastroenterology	the study of the stomach and intestine and their diseases
Hippocrates	famous Greek physician (5th century B C) generally regarded as the "Father of Medicine "
host	a man or animal harboring or capable of harboring a disease-producing parasite under natural conditions Some protozoa and helminths spend different life-stages in different hosts Hosts in which the parasite attains maturity or passes its sexual stage are *definitive* hosts Other hosts (e g , snails for schistosomiasis) are *intermediate* hosts
hyperdiuresis	excessive excretion of urine
incidence rate	number of diagnosed or reported cases of the specified disease during a defined period of time divided by the population in which the disease occurred Usually expressed as the number of cases per 100,000 per year for specific populations
incubation period	the time interval between exposure to an infectious agent and the first sign or symptom of the disease in question
infection	the entry and multiplication or development of an infectious agent in the body, either manifest disease or inapparent infection
infestation	parasitic attack or subsistence on the skin, hair, or clothing by insects
jejunum	that part of the small intestine extending from the duodenum to the ilium
labile	chemically unstable
larvicide	a substance that kills larval stages of insects
marasmus	a form of protein-calorie malnutrition occurring usually in the first year of life with retarded growth and wasting of fat and muscle
morbidity	condition of being diseased or sick, rate of sickness in the community
mortality	death rate
neonatal	pertaining to the first four weeks after birth
nosocomial infection	infection acquired in a medical facility
oliguria	diminished secretion of urine in relation to fluid intake
otitis	inflammation of the ear, O externa (outer ear), O media (middle ear), O interna (inner ear)
parasite	a plant or animal that lives upon or within another living organism at whose expense it obtains some advantage
pathogen	an organism or substance capable of causing disease
pediatric	pertaining to diseases of children
pharynx	the throat
polyuria	excessive secretion of urine
portal of entry	the pathway by which pathogenic agents enter the body
postnatal	occurring after birth
prevalence	ratio of number of persons sick with the specified disease at a particular moment in time to the total population in question
pruritus	itching
pyoderma	any purulent skin diseases
pyogenic	producing pus
pyrexia	a fever or febrile condition
reservoir (of disease)	usually the host or hosts in which a disease producing parasite is principally found and which accounts for its maintenance in nature from year to year Sometimes a reservoir is passive or inanimate
septicemia	blood poisoning
serotype	the type of a microorganism determined by its constituent antigens, a taxonomic subdivision based thereon
tenesmus	ineffectual and painful straining at stool or urination
teratogen	an agent or influence that causes physical defects in the developing embryo Thalidomide is an example
therapy	treatment of disease
tinea	ringworm
toxic	poisonous
toxin	a poison, e g , botulinus toxin
transmission	any mechanism by which a susceptible human host is exposed to an infectious agent
trauma	wound or injury
urine	the fluid excreted by the kidneys, stored in the bladder, and discharged through the uretha to the external environment, colloquially, "passing water "
urticaria	hives, skin reaction often attended by rash and severe itching
vector	the living transporter and transmitter of the causative agent of a disease
vectorborne	descriptor of any disease transmitted to man directly or indirectly by non-human animate carriers
viremia	the presence of virus in the blood
virulence	the degree of pathogenicity of a disease-producing parasite
virus	a noncellular infectious agent which can reproduce only in living cells, most viruses are too small to be seen under a light microscope
vomitus	matter vomited
WHO	World Health Organization
zoonosis	a disease of animals that may be transmitted to man

ANNEX B

SUMMARY ANALYSES OF SELECTED FIELD STUDIES

Adrianzen T., Blanca, and George G. Graham. "The High Cost of Being Poor/Water." ***Archives Environmental Health,*** **28:312-315. 1974.**

A longitudinal anthropometric and socioeconomic assessment was made of 127 families of children admitted with malnutrition to the British American Hospital in Lima, Peru, during the years 1961-1971. This study analyzes the types of water supplies, quantities used, and costs of water in absolute terms, in relation to incomes and in relation to the time worked to pay for water Water is linked to malnutrition through the relative growth of children, based on the ratio of height to age for children with similar mid-parental heights.

Mean heights for age for ex-patients and siblings of families without piped water service were significantly lower than for children in two other groups one with piped household service, the other with piped water to taps shared with other families. The poorer families were served by water purchased from tank trucks and stored in their homes. These families had a mean income 60 percent lower, paid 16 times as much per unit of water, used one-sixth as much water, paid two and a half times as much for total water use, and paid 2 7 percent of their income for water versus 0 7 percent by families with piped household water supplies. A worker from the non-served group of families would have to work 24 minutes (average) to pay for water for one tub bath, the worker with a household connection would have to work 0 8 minutes.

Arriaga, Eduardo E., and Kingsley Davis. "The Pattern of Mortality Change in Latin America." ***Demography,*** **6(3):223-242. 1969.**

This article examines the mortality trends for 13 Latin American countries, England and Wales, Sweden, the United States, Japan, Mauritius, Ceylon, India and Taiwan, using data from the late nineteenth century through 1960. The decline in mortality rates was extremely slow in the more backward Latin American countries until around 1930, while in the more advanced countries, a more rapid decline in mortality occurred before 1930 After 1970, in both groups of countries, the pace of decline was faster than ever and virtually the same for both groups of countries.

The authors suggest that after about 1930 for Latin America, "public health measures were exerting a strong influence independently of local economic development " This finding replicated the past history of now-developed countries. Similarities were also found in the Asian countries. Health measures cited were "eradication of disease vectors, chlorination of drinking water and good sewage systems, as well as individual health practices such as vaccination, dietary supplements, use of new drugs, and better personal hygiene "

The authors conclude that "In most underdeveloped countries, whether in Latin America or elsewhere, mortality change seems increasingly independent of economic improvement and dependent on the importation of preventive medicine and public health from the industrial countries "

Assaad, F.A., F. Maxwell-Lyons, and T. Sundaresan. "Use of Local Variations in Trachoma Endemicity in Depicting Interplay between Socio-economic Conditions and Disease." ***Bulletin World Health Organization,*** **41:181-194. 1969.**

This trachoma prevalence study conducted in Taiwan during 1960-1961 also collected data on socioeconomic and living conditions crowding, water supply, and occupation of the head of household

Crowding was measured as the number of persons per residence, sleeping room and bed Household water supplies were categorized by type· tap, draw-well, hand-pump, and "others" (mostly mountain springs) They were also categorized by distance in meters from the dwelling. Occupation was classed in six categories ranging from professionals to unemployed, presumably in order of education and/or income

Trachoma 1) increased as crowding increased (rapidly at first, then slowly), 2.) increased as distance from water supply increased, and 3) increased in the "lower occupational categories " For example, trachoma prevalence among professionals was 12 1 percent but 24 8 percent among fishermen and farmers (and their households) Generally, the higher the occupational level of the head of household, the less the crowding and the better the water supply

In the statistical relationships found between water supply and trachoma in this study, trachoma prevalence was lowest (15 4 percent) in households with attached taps. Whether water was supplied by "draw-wells" or by hand pumps made little difference in the prevalence of active trachoma (24.5 and 24.2 percent respectively). Regardless of the type of water supply, prevalence of active trachoma increased as distance to the source of household water supply increased This relationship may result from smaller per capita use of water as distance to the source increases. No data on per capita water use (quantity) or on water quality were reported

Azurin, J.C., and M. Alvero. "Field Evaluation of Environmental Sanitation Measures Against Cholera." *Bulletin World Health Organization,* 51: 19-26. 1974.

This study, sponsored by the Joint Philippines/Japan/WHO Cholera El Tor Research Project, took place from mid-1968 to the end of 1972, in four communities in the Philippines near Bacolod City: West Visayan (pop 743), Dawis (803), Magsungay (787), Sibucao (756). The objectives of the study were "to test the effect of either improved water supply or improved waste disposal (or both) against cholera infection in an area in which cholera is known to be endemic"; and to determine "the effect of either safe water supply or waste disposal facilities or both in containing the spread of infection that has gained access to such communities "

The four communities selected were similar in size, geographic characteristics, and demographic composition. Different levels of sanitation were provided to each community

1. *West Visayan* (control) had a poor water supply and no toilets. Water came from three tubewells provided with pitcher pumps. The water supply was untreated, improperly protected and without quality surveillance. People defecated wherever convenient.

2. *Dawis* had an improved water supply, directly from the Bacolod municipal system. Less than half the residents had piped connections There were no good disposal facilities; the people used a relatively dirty beach for defecation.

3. *Magsungay* had improved communal toilet facilities, one for about every four households (i.e., one per 25-30 residents). Toilets were the "water-seal" squat type, one liter of water was enough to flush the toilet Water was supplied by four wells with hand pumps, two privately-owned, two government-owned. Sites were unsanitary and water potability questionable.

4 *Sibucao* had both improved water supply and improved toilet facilities The piped water system provided "adequate, accessible and safe" water on a continuous basis from an artesian well, delivered to ten "outlets" (standposts) so located that no house was more than ten meters distant. For excreta disposal, three buildings were provided, each housing eight flush-type, glazed water closets—segregated by sex—and each site having its own septic tank. One toilet was provided per 20-30 residents

Data collection in all communities was by an "epidemiological aide" who visited the community daily and made a house-to-house canvass taking a rectal swab from each person found to have diarrhea Specimens were examined at the project laboratory for cholera vibrios Once a diarrheal case was confirmed as cholera, surveillance was intensified. The evaluation indicator was the number of bacteriologically confirmed cholera infections

The data collected show that the provision of sanitary facilities for human water disposal can reduce the incidence of cholera by as much as 68 percent, while provision of a safe water supply can reduce it by 73 percent When both toilets and water supply are provided, the incidence can be reduced by as much as 76 percent. The evidence also indicates that cholera introduced into the community after improvement in water supply and/or sanitation is significantly less likely to spread. The population group that benefited the most was children in the age group 0 to 4 inclusive

Worthy of note is the reduced incidence of cholera in the communities provided with improved water supplies even though the majority of households did not have piped house-connections. Also, motivation was apparently high—the communities contributed all unskilled construction labor plus some locally available materials. The communities also accepted the new facilities and the need for more hygienic habits even though apparently no formal education program was provided.

Bahl, M.R. "Impact of Piped Water Supply on the Incidence of Typhoid Fever and Diarrhoeal Diseases in Lusaka." *Medical Journal of Zambia,* 19 (4):98. 1976.

This study was conducted by the Medical Officer of Health for the City of Lusaka, Zambia. It took place in 1970 through 1975 in acquired urban and peri-urban settlements, previously termed Squatter Compounds, of Lusaka. The objective of the study was to determine the effects of water-supply improvement as indicated by changes in the number of cases of typhoid fever and of diarrhoeal diseases.

Data were assembled on the number of "notified" cases of typhoid fever in the entire city for the years 1970 through 1975. These cases were admitted and confirmed at the University Teaching Hospital in Lusaka The data on diarrhoeal disease were obtained (for 1972-1975) from the urban health centers and clinics in the city. These data were examined in the light of water-supply improvement during the observation periods In 1973 residents of the acquired urban and peri-urban areas began to raise money for piped drinking water. A threat of cholera resulted in Central Goverment grants for piped drinking water to all of the major self-help settlements. Previously water came from government-provided wells and pumps, but many shallow wells continued in use. With the piped system, standpipes were installed so that all residents had access to potable water The author says, "Besides the supply of water, there has been no other improvement in the environments of these (self-help settlements in the urban and peri-urban) areas "

The findings do show a drop in disease rates For typhoid fever the annual case rate dropped from 9 per 100,000 people to 0 8 per 100,000. The drop for the annual diarrhoeal disease rates was from 338 per 100,000 to 212 per 100,000. The author concludes that the provision of piped water supply "has helped in the reduction of both typhoid fever and diarrhoeal disease in the City as a whole." The data support the hypothesis that typhoid fever incidence is a more sensitive indicator of the health benefits of water-supply improvements than are diarrhoeal diseases.

The author recognizes that the disease data are city-wide, while the water supply improvements were only to the self-help settlements. He notes that the people from these areas are extremely mobile and in sickness may move to a relative in a different part of the city Also, these areas had no health centers or clinics, so people sought medical aid in other areas of the city. Thus the Medical Officer of Health of Lusaka states: "The evidence in this paper is indirect, but it does show that other things being equal, provision of piped water helps in the reduction of the incidence of enteric fever and diarrhoeal diseases in the community "

Barnum, Howard, Robin Barlow, Luis Fajardo, and Alberto Pradilla. *A Resource Allocation Model for Child Survival.* Oelgeschlager, Gunn & Hain, Inc. Cambridge, Massachusetts. 190 pp. 1980.

This book offers a mathematical optimization model for comparing and selecting health interventions It suggests that at "low levels of resources" the most effective activities are "health promotion, water and sanitation (public fountains, latrines, and covered sewerage), and well-baby clinics " These programs can be especially effective because "they are not age-group specific and have strong effects on diarrhea in all age groups."

The authors also describe an application of the model developed for five barrios in Cali, Colombia Experiments suggested that the low cost of latrines (one-twentieth the cost of toilets) might compensate for their lower degree of effectiveness (one-third to one-half as effective).

Berg, Lawrence E. and Thomas M. Mowery. "Health Program Evaluation: Impact Study of the Indian Sanitation Facilities Construction Act." Health Program Systems Center, Division of Indian Health, U.S. Public Health Service. Tucson, Arizona. 28pp. 1968.

In order to identify and evaluate the health effects of installing basic sanitation facilities in the homes of American Indians, communities in Minnesota, Montana, Nebraska and South Dakota were studied, including 310 households and 1,943 people. Nine hundred fifty-two people in homes that received sanitary water and waste disposal facilities were matched with 991 people in homes not equipped with such facilities. Five hundred eighty-three (61 percent) of those in the "equipped" group had running water and a pit privy, the minimal acceptable facility. None of the non-equipped group had running water Eight hundred fifty-one (86 percent) had pit privies. Eighty-one (8 percent) had no excreta disposal facility For 59 people (6 percent), the means of excreta disposal was unknown.

Data on the use of out-patient medical care and/or morbidity were analyzed for each group for the two years after provision of sanitary facilities. For six years, the clinical records of members of the households in each group were abstracted for thirteen specific diseases (three skin diseases and ten enteric diseases). Also, the total number of times a person came to an out-patient medical care clinic was recorded These were among the findings:

1. Ninety percent of the outpatient visits were caused by the three skin diseases (impetigo, pyoderma and furunculosis), diarrhea, gastroenteritis, and colitis
2. The rates of use of medical care out-patient clinics were remarkably alike for both groups For each the After rates increased moderately: for the Equipped 389 to 427, for the Non-Equipped 379 to 422.
3. For the Selected Diseases, there were similar increases for both groups from Before to After. The increase for the Non-equipped was larger, from 256 to 371. For the Equipped, the rise was from 282 to 315
4. For the Enteric Diseases (including diarrhea, dysentery, shigellosis, salmonellosis, gastroenteritis and gastritis) there was a decrease in the After rates for the Equipped group, from 159 to 136 That group's rate During Construction rose to 175, higher than the rates for any of three periods for the Non-equipped group (Before 140, During 140, After 154).
5. The authors applied t-tests to adjusted rates for all combined diseases, skin and enteric, for the During and After periods and found a significant difference, t = 13 62. For adjusted rates for enteric diseases for the same period, there was a significant difference between the two groups, t = 3 30

The authors conclude.

1. Analysis showed that morbidity rates of members of equipped homes were significantly lower than the morbidity rates of members of non-equipped homes for a combined period of time during-after the installation of sanitation facilities
2. The construction of sanitary water and waste disposal facilities had no apparent impact on medical care outpatient clinic use
3. Questions arise about the adequacy of the "minimal acceptable" facility (one water tap and a sanitary pit privy), the effect of health education efforts, and the follow-up operation and maintenance of facilities.
4. The installations may have done more for containment than prevention.

The wide geographical area and the use of file data did not allow the collection of information on water use or excreta disposal facility use, or on facility maintenance. The study spread across wide climatic variations, which may influence water use, privy use, and flush toilet maintenance Differences would be missed by treating all as a whole.

Nevertheless, the changes in the enteric disease rates of the two groups of homes are not striking Because of climate and of the cultural differences of and among American Indians, these experiences may not provide patterns for tropical regions.

Bruch, Hans A., Werner Ascoll, Nevin S. Scrimshaw, and John E. Gordon. "Studies of Diarrheal Disease in Central America: Environmental Factors in the Origin and Transmission of Actue Diarrheal Disease in Four Guatemalan Villages." *American Journal of Tropical Medicine and Hygiene,* 12:567-579. 1963.

This study is one of a series on diarrheal diseases by the Institution for Nutrition of Central America and Panama (INCAP), Guatemala City. Its objective was to examine environmental factors in the occurrence of diarrheal diseases in selected Guatemalan villages, 1956-1959

Comprehensive survey methods were used to assess environmental conditions and family life Diarrheal diseases were followed by household visits every two weeks by local field workers. The study made these observations:

1. Feces disposal. No indoor sanitary facilities existed in any of the villages Privies existed in from 60 to 85 percent of the dwellings. About 20 percent had a lined pit and concrete slab Others were improvised and makeshift. About one-half were in an adequate state of cleanliness and repair. Only 2 percent of privy owners admitted failure to use the facility, but feces on the ground and around the privies belied that figure. Families having privies had 16 8 diarrhea attacks per year among all members. For families having no privies, the rate was 22.4. For children 1 to 5 years, the attack rates were 80.3 for those without privies and 60.3 for those with privies. The difference has a significance at the 5 percent level.

2. Water supply The population with the lower rates of diarrheal disease had an abundant supply of water from a mountain spring one kilometer away. Water was piped to 16 public faucets which served 90 percent of the 580 families Ten percent had water piped to their homes Water use from the public standposts was 3 to 4 gallons per person per day Handling of carrying jars and pipeline breaks resulted in contamination and *E coli* were found in samples of water at the standposts on several occasions. Children 0 to 5 years of age on water piped to the house had an attack rate of 32.4, not statistically different from those on public standpost water (38.0)

The other study population shared unequally a spring water source of another town. Whenever the yield was low, the study population had to go to other sources: a river 2 kilometers away, and stored rainwater Twenty-five percent of the 194 families had water piped to their houses. Even among these, the annual attack rate in ages 0 to 5 was 128.6. Among those on public faucets, the rate was 134 8

3. Solid wastes: Few food wastes were found to support fly breeding. Any food not used by people went to domestic animals, pigs, chickens, and dogs

4 Food: Refrigeration existed only in a few stores for beer and soft drinks. Corn and beans were the staples. Both were cooked, eaten, reheated or eaten cold over periods of 2 or 3 days. Other foods were very limited

5. Housing: A classification by structural materials produced the observation that diarrheal disease was no more frequent among residents of the poorer type houses than those with the best type of housing. Rats and mice were judged to be only a minor health hazard, as Salmonella infections were few in all of the villages and no more frequent in those with more rats. Flies were most numerous in the rainy season, May to October. Occurrence of diarrhea was highest at the end of the dry season and less in the rainy months

The authors drew these conclusions about factors contributing to the seasonal rise of diarrheal diseases in the Guatemalan highlands·

1. Migration from the coastal plantations where diarrheal diseases are more frequent introduces fresh sources of infection.

2. The pattern of waterborne outbreaks with a sharp rise in cases and prompt decline occurred rarely. The dominant pattern was a slow buildup to peaks 14 months later and a tailing off in 32 months Water could contribute to this by low-grade, intermittent or accidental contamination.

3 Food-borne outbreaks did not occur with any frequency but food handling in the home and diarrhea in infants at weaning suggest that food is an important source of infectious agents.

4. Secondary peaks of diarrhea occur in September and October. Flies may contribute to these slight peaks.

5 Seventy-one percent of the index cases of diarrhea were among pre-school children Infections occur among susceptible children. In survivors, immunity follows Malnutrition is an important consideration. The case rates for acute diarrheal disease per 100 persons at risk per year in four rural Guatemalan villages in 1956-1959 were under 1 year, 75.0, 1-5 years, 64 1; 6-4 years, 9 7, 15 and over, 5.1. The overall rate was 17.7.

6. Contact spread was believed to be the main mechanism although other modes of transmission contribute The contribution to total cases because of contamination of water in the home, which would be variable and individual, may be appreciable.

The authors were not singularly impressed by their data on the water supply and diarrheal disease rates. They considered long-term epidemiological patterns to be predominant and classical waterborne outbreak patterns rare. However, they failed to offer further comment on the difference in diarrheal disease incidence in the village with a superior and ample water supply and the one that had often had to resort to river, stream and rain water. Even in endemic situations, water can be a major factor in sickness and in health

Butz, William, Julie DeVanzo and Jean Pierre Habicht. "Family, Community and Program Influences on the Mortality of Malaysian Infants." Working Draft No. 992-1-AID (Grant Nos. AID/otr-1744 and AID/otr-1822). RAND Corporation. Santa Monica. 46 pp. 1981.

This examination of determinants of infant mortality variations in Peninsular Malaysia uses retrospective data from a subject-reported questionnaire in the Malaysian Family Life Survey: 1262 households from 52 sampling areas with 5584 live singleton births of whom 270 (4.8 percent) died in infancy It also uses household and community characteristics. A linear probability model, estimated by ordinary least squares, was used to analyze the attributable risk of each factor in infant mortality

Environmental factors analyzed include community water source and sanitation, and household sanitation (excreta disposal). Infants in houses with access to non-flush or flush toilet systems had significantly lower mortality than infants in houses without access to sanitation systems. Also "piped" water was significantly related to lower infant mortality. (Whether "piped" water represents household connections, community standposts, or some combination is not specified) Other water categories were "river," "canal," "well," and "other public." Although toilets and piped water were found to be significant, their proportionate impact was still small relative to birth weight

This examination of the effects of water supply and sanitation practices relative to breastfeeding practices for infants found that communities with well water, piped water, and public non-piped water along with flush sanitation tended to produce significantly lower mortality among non-nursing infants.

Center for Disease Control. "Acute Water Shortage and Health Problems in Haiti." EPI-77-51-2. U.S. Public Health Service, Atlanta. Unpublished document. 9 pp. June 29, 1978.

This is a study of the impact of water quantity on disease in two areas of the Haitian capital city of Port-au-Prince, each with population around 200,000 One area received drinking water constantly from gravity-fed springs. The other was supplied with electrically-pumped well water.

During early 1977, a drought resulted in a ten-week loss of hydroelectric power in the area supplied by wells Mechanical breakdowns of supplementary diesel generators forced severe rationing of electricity, with widespread effects on water availability A retrospective study, using questionnaires, of 400 households in each of the two populations "was devised to estimate per capita water use and the effects on health of restricted water availability " Six disease categories were considered. diarrhea, scabies, external otitis, conjunctivitis, any febrile illness, and malnutrition

It should be noted that Port-au-Prince, with a population of approximately one million, has only 30,000 water service connections The majority of the population obtains its water from municipal standpipes (public hydrants). The following table shows one observation of the study, numbers given are for children under six years of age in large families:

	Water Use Per Person Per Day		
	Less than one can	*One can or more*	*Total*
Illness	258 (51 6%)	115 (33.0%)	373
No illness	242 (48 4%)	234 (67 0%)	476
Totals	500	349	849

Cvjetanovic, B. "Banki Block (Barabanki) Programme of Rural Water Supply in the State of Uttar Pradesh, India." Annex 1 (10 pp.) in Cvjetanovic, Branko. "Effect of Water Supply and Sanitation on Health in Rural Communities in Developing Countries." Unpublished report. Zagreb, Yugoslavia. 42 pp. + 2 annexes. June 1980.

This is an independent confirmation of the project reported by Misra (1971) and reviewed more fully elsewhere in this annex. Cvjetanovic, a physician-epidemiologist, was Chief of Bacterial Diseases for WHO/Geneva at the time he visited Barabanki He reports health impact data for the water-supply project. i e., a fivefold decrease in diarrhea in children and virtual elimination of typhoid, trachoma, and scabies.

The sizes of the villages varied from 500 to 900 people. Their economy was essentially subsistence. Prior to the water supply intervention, four percent of the population were using hand pumps while 96 percent used unprotected open wells.

Part of the water and wastewater was used for kitchen gardens, bringing additional food and income to the village Women grew various vegetables and grapes in yard gardens and used their time for "hand looming." Post-project water use was about 45 liters per day per capita

One table from this study shows long-term cumulative benefits for children under five years of age As shown below, the incidence of diarrhea in that age group dropped dramatically after introduction of water supply.

Year	*Water Supply*	*Incidence in Percent*
1965	Year of introduction	24 0
1966	One year after introduction	14 4
1967	Two years after introduction	11 3
1968	Three years after introduction	5 0

Evenson, Robert E., Mark R. Rosenzweig and Kenneth I. Wolpin. "Economic Determinants of Fertility and Child Health in Philippine and Indian Rural Households." Project AID/otr-G-1723. "Project Summary," 16 pp., and "Technical Report," 31 pp. + appendices. Yale University, New Haven. Undated but circa 1981.

Also: Rosenzweig, Mark R., and Kenneth I. Wolpin. "Governmental Intervention and Household Behavior in a Developing Country." Project AID/otr-G-1723. Yale University, New Haven. 26 pp. Undated but circa 1981.

Both of these reports offer an econometric model of health and family planning programs and their effects on family behavior in relation to contraception and investment in child health The Indian model incorporated data on the primary source of village water supply ("tap," "pumps and wells," "river" and "tank") from the 1971 Indian Census.

However, water supply was of secondary interest to the authors of these papers. They do say that the (assumed) quality of the water supply source "appeared to be influencing child mortality."

Feachem, Richard, Elizabeth Burns, Sandy Cairncross, Aron Cronin, Piers Cross, Donald Curtis, M. Khalid Khan, Douglas Lands, and Hilary South Hall. *Water, Health and Development.* Tri-Med Books Ltd., London. 267 pp. 1978.

This eighteen-month study of village water supplies in Lesotho was commissioned by the British Ministry of Overseas Development, OXFAM, and the government of Lesotho, using staff from the London School of Hygiene and Tropical Medicine and the University of Birmingham. Chapter 9, "Water Supplies and Disease" (pp 139-179) is of particular interest.

The study covers eighteen months (from early 1975) in the Mokhotlong and Mafeteng Districts of Lesotho, Africa It included a population of about 4,000, in 567 households: 125 in mountains (Mokhotlong) and 442 in lowlands (Mafeteng). Its objective was to decide whether water supply improvements were cost-beneficial.

Comparisons were made between villages with water supplies in four categories, ranging from unimproved to improved and reliable. Health data were taken from records of reported diarrhea, skin disease, and eye disease at two hospitals and a clinic. Mortality data were taken from the central medical statistics unit for all hospitals in Lesotho. Morbidity data were taken from St Joseph's Hospital, where diagnoses were made by physicians, laboratory tests were used and reliable records were kept. There was also extensive inspection of water supplies and bacteriological sampling and analysis Economic, political, and social characteristics of the villages were observed and analyzed.

The authors found that chi-square tests of ratios of the three disease groups to other reported diseases did not differ significantly with quality of water supply service. They therefore postulated that "diarrheas and typhoid are not primarily water-borne in Lesotho," and that "improving water quality does not alter the incidence of reported infectious skin and eye diseases."

Furthermore, the study found disease ratios showing that "there was actually more diarrheal disease in villages with improved water supplies" than in villages without. The authors therefore suggest that quantity of water provided is a more important variable than quality as an influence on transmission of water-related diseases

The study does not conclude that water-supply improvements have no public health benefits. But it does indicate that such improvements alone cannot yield large benefits when there are still serious deficiencies in excreta disposal, personal and home hygiene, food sanitation, and fly control.

Fenwick, K.W.H. "The Short Term Effects of a Pilot Environmental Health Project in Rural Africa: The Zaina Scheme Reassessed After Four Years." Kenya Ministry of Health. Nyeri, Central Province. Unpublished report. 1966.

Also the following:

Strudwick, W.H. "The Zaina Environmental Sanitation Project." ***East African Medical Journal.*** **39: 311-331. 1962.**

Strudwick, R.H., and D. Hollinson. ***The Zaina Environmental Sanitation Scheme: A Pilot Project in Rural Africa.*** **Unpublished World Health Organization Document WHO/Env. San./135. 42 pp. 1962.**

This was a study carried out by the Provincial Medical Officer of changes in health status from 1961 to 1965 following provision of a gravity flow piped water supply serving four villages (multiple water points) and 588 farms in the Zaina section on the slopes of Mt Kenya. The purpose of the study was to observe changes in health status and other collateral benefits of the water supply project. A control area, Thegene, was also studied. No changes in environmental sanitation were made in Thegene

By 1965, all Zaina residents had water at their doorsteps or within 100 yards of their houses All water was from the chlorinated piped supply. Water consumption rose from 1.65 gallons per capita per day (gpcpd) in 1961 to 14.7 gpcpd in 1965. The water supply was treated and clean Thegene water was not treated and less than half of it was rated "clean." Consumption in Thegene increased slightly from 1.3 gpcpd in 1961 to 2 gpcpd in 1965. In Zaina, all houses had water located less than one-quarter mile away. Sixty percent of the houses in Thegene were over one-quarter mile from the nearest drinking water. The total days of illness per person, and by age group, as measured during two seven-month periods in 1961 and 1965, showed remarkable differences, primarily for children, between Zaina and Thegene

Age Groups	*Zaina* 1961	1965	*Change*	*Thegene* 1961	1965	*Change*
Under 1	16.1	4 3	−11 8	9 1	8 1	−1.0
1-2	13 0	7 5	− 5 5	7 2	10 1	+2.9
3-6	11 1	5.1	− 6 0	10 0	9 5	−0 5
7-12	5.4	3.1	− 2 3	2 5	5 0	+2 5
Adults	3 3	3.7	+ 0 4	2 7	3 2	+0 5

Fenwick concluded from his study. "As the two areas are similar in every respect except that Zaina has now a plentiful water supply, it is suggested that it is this water supply together with the rest of the environmental health programme which has improved the health of the Zaina people and surmise that as time goes by, the differences between the two areas will become even more marked"

Goodwin, Melvin H., Jr., Gory J. Love, Don C. Mackel, and Rudolf G. Wanner. "Observations of Familial Occurrence of Diarrhea and Enteric Pathogens." ***American Journal of Epidemiology,*** **81 (2): 268-281. 1966.**

The Phoenix, Arizona, field station of the Communicable Disease Center, USPHS, ran this study to determine the need for more specific control measures for diarrheal diseases, beyond the association with environmental conditions

Forty-one families, totalling 328 persons, in the Phoenix area provided fecal specimens each week for twelve weeks or more, for a total of 2,610 person-weeks of observations (PWO). All of the families were of low socioeconomic status. All of the homes had piped water, water heaters, water-carried sewage systems, and refrigerators The houses were in sound condition, but often not well maintained.

During the observation period, the study recorded 246 discrete episodes of diarrhea. Some episodes persisted. fifty-two into a second week, seven into a third, five into a fourth, two into a fifth, and one each into the seventh and ninth weeks Four major pathogenic organisms were isolated during the study. Differences in rates of occurrence allowed the researchers to divide "high rate" from "low rate" families. (Only one family failed to report diarrhea at all) Family size, family crowding, and (to some degree) socioeconomic level differed among the families However, none of those three factors was significant in determining the occurrence of enteric organisms. No objective means was available to evaluate "mother efficiency" or "the ability to cope with a situation." The potential benefit of "sanitational" facilities was not developed. No information was given on diet and nutrition, nor was any statement made on that factor.

Hygiene was a more important factor All families had the physical facilities necessary for adequate personal hygiene, but the facilities were misused among the high-rate families. Examples were: removing valve handles to prevent water wastage by children; storing made-up baby formula in open, unscreened vessels; using washing machines without soap; leaving nursing bottles distributed abut the house for use by a toddler along with the flies, a household pet and other children

In their summary the authors state: "The desirability of providing sanitational facilities to the extent that resources will permit is unquestioned, but it is apparent that realization of their full potential for control of diarrheal diseases depends upon proper use." The sequence is evident. Good design must be followed by good operation and maintenance. Conviction of the benefits of proper use is necessary. In many situations, conviction comes from education

Grosse, Robert N. "Interrelation Between Health and Population: Observations Derived from Field Experience." ***Social Science and Medicine,*** **14C:99-120. 1980.**

This article includes simple and multiple correlation analyses of factors that may be associated with life expectancy: sanitation, health expenditures, health personnel and facilities, economic indicators, and social indicators

"Dominant categories" were santitation (percentage of urban population with water taps), economic factors (percentage of labor force in agriculture), and social factors (literacy). Literacy "explained" 78% of the variation in life expectancy. "Addition of the sanitation factor increased the variation explained to 88% while the addition of the economic factor added only an additional 2%." Water data were from 65 developing countries for 1962 (r = 0 728).

Heller, Peter S. "Interactions of Childhood Mortality and Fertility in W. Malaysia: 1947-1970." Discussion Paper No. 57, Center for Research on Economic Development. University of Michigan, Ann Arbor. 33 pp. 1976.

This paper provides an econometric model of "fertility and infant and toddler mortality," based on census data, and viewed "within the framework of a general model of household decision-making . . . subject to some socioeconomic constraints."

Most of the paper focuses on fertility, which was assumed to be subject to parental control and was shown to have considerable impact on child mortality. Results on the impact of medical-care usage were weak, contradictory, and sometimes "perverse," i.e., contributing to mortality. The rise in the female literacy rate "from 20% in 1947 to 50% by 1970 may have contributed to a 10 to 18 point fall in the infant mortality rate."

Water supply and water disposal rates also had significant effects Water supply and water disposal data were for 1970, expressed as "percentage of living quarters with piped water into home" and "percentage of living quarters with bucket waste disposal " The author suggests "that jeopardy to a child's health from an unsanitary environment principally occurs after the first year, probably at the time of weaning."

Henry, Fitzroy J., "Environmental Sanitation, Infection, and Nutritional Status of Infants in Rural St. Lucia, West Indies." *Transactions Royal Society Tropical Medicine and Hygiene,* 75(4):507-513. 1981.

This study shows clear correlations between water supply/sanitation and infant health in the areas observed Health and growth of some 229 infants were followed for two years in three valleys Socioeconomic conditions and feeding patterns (including breastfeeding) were similar in each valley, but they had different levels of water supply and sanitation

Valley (Intervention)	*Water Supply*	*Daily Water Use per Household (liters)*	*Excreta Disposal*
Cul-de-Sac (None)	Public standpipes "widely dispersed," one per 350 population	64	Latrines of "low quality"
Desruisseau (New water supply)	Individual household water supply	120	Latrines of "low quality"
Ti Rocher (New water supply, new latrines)	Individual household water supply	124	Water seal latrines

Ascaris and *Trichuris* infections dropped 30 and 50% respectively after water supplies and latrines were installed in two of the three valleys Prevalence of diarrhea was substantially less for children in areas with improved sanitation, some 70 percent less for one-year-olds. During the study, 34.7 percent of children from the "non-intervention" area (Cul-de-Sac) were treated for diarrhea and vomiting, compared to 27.8 percent in the area with a new water supply (Desruisseau), and 18 5 percent in the area with both a new water supply and new latrines (Ti Rocher). Treatment for skin diseases showed a similar pattern, reaching 20 8 percent in Cul-de-Sac, 4 9 percent in Desruisseau, and 3.7 percent in Ti Rocher.

The growth of the children was substantially better in the improved areas. Before the installation of the new water supplies and latrines, growth curves of children were similar in all three areas. Following the installations, markedly better growth (weight and height for age) was measured in the improved areas, especially from three months to about eighteen months of age, times corresponding to breast supplementation and weaning. The author concludes that the "better growth that was observed after upgrading the environmental situation suggests that here, malnutrition is more likely to be the consequence than the cause of illness "

Hicks, Norman L., "Sector Priorities in Meeting Needs: Some Statistical Evidence." World Bank, Washington. 22 pp. 1979.

This paper uses statistical analysis of data from 86 countries (69 for water data) to estimate the effect on life expectancy of seven inputs in health care, nutrition, education, and accessibility to clean water. Other variables include income, income distribution, female school enrollment, urbanization, and size of the public sector. Four statistical methodologies were used

Using simple correlation, adult literacy had the highest correlation coefficient (r = 0.906). Per capita calories consumption, population per doctor, percent of urban population, and percent of population with access to clean water had correlation coefficients ranging from 0 703 to 0.714, with water 0.706. Multiple linear correlation yielded similar results for literacy and for water supply When beta coefficients were used to normalize the regression coefficient, literacy ranked first, water supply second, in correlation. When two other methods for "analysis of deviations" were used, water supply had much lower rankings.

Hoffman, Allen H., Theodore C. Crusberg, and Brian J. Savilonis. "Viral Hepatitis and Hydraulic Parameters: An Alternative Hypothesis." *Archives Environmental Health,* 34:87-91. 1979.

The authors of this study did statistical analyses of public health records for Worcester, Massachusetts (population 160,000) for reported cases of hepatitis A viral infections during a five-year period (1968-1972) The results showed strong correlations with certain parameters of the water supply and sewerage systems

Although water quality records showed that samples generally met bacteriological standards, residual free chlorine levels were consistently below 0 1 mg/l in 60 percent of the samples. Some data suggest that some drinking water may have been more contaminated than might have been suspected on the basis of coliform levels alone. Temporary pressure drops were known to occur in these systems.

The highest incidences of hepatitis were associated with census tracts served by old and possibly deteriorated water and sewer pipes and by combined or overflowing sewers

Social and economic parameters (income) were also strongly correlated with the hydraulic parameters. Low-income areas were primarily served with old pipes and low-pressure systems

Leaking or overflowing sewers, combined with low pressure, even negative (suction) pressures in leaking water pipes as hypothesized for Worcester, allow contamination of water supplies; unfortunately, such conditions are commonplace in many urban areas of the developing world.

Hollister, A.C., Dorothy Beck, Alan M. Gilletson, and E.C. Hempill. "Influence of Water Availability on Shigella Prevalence in Children of Farm Labor Families." *American Journal of Public Health,* 45 (3) March 1955.

The U.S. Public Health Service sponsored this study of farm migrant labor camps in Fresno County, California, from October 1952 through April 1953. The population covered was 6,111 children under ten years old in 123 of the 350 farm migrant labor camps in Fresno County These children were among 2,707 "families" (meaning all persons living in one household). The objective of the study was to define the relationship between Shigella prevalence and the availability of water for personal hygiene, including laundry, bathing, and especially hand washing

Rectal swabs were secured from all available children under ten years old in the selected camps at intervals of at least one month. The camps were divided into three types, according to their sanitary facilities 1) Cabins with private water faucets, private showers or tubs, or private toilet or both. 2.) Cabins with only water faucets inside, having access to communal facilities outside. 3) Cabins with no plumbing, dependent on communal facilities for water use and excreta disposal The quality of water met minimum standards in all camps

The following table gives the percent of Shigella culture positives among children under ten years and the percent of households with positive children:

Plumbing Facilities Inside Cabin	*Percent Positive Cultures*	*Percent Positive Households*
Faucet and Shower and/or Toilet	1 6	2 5
Faucet Only	3 0	6 2
Nothing	5 8	11 0

The study showed that Shigella prevalence was associated with the availability of water for personal hygiene This implies that the control of Shigella infections may be significantly improved by providing easily accessible water for personal hygiene. This observation had already been made in 1950, in an unpublished report by James Watt to the California Director of Public Health, and in the published paper by Watt, Hollister and others (summarized elsewhere in this annex.) Water quantity is emphasized because in these studies water quality met minimum standards The paper is a meaningful addition to understanding the usefulness of water in controlling at least one diarrheal disease.

Hughes, James M., John M. Boyce, Richard J. Levine, Moslemuddin Khan, and George T. Curlin. "Water and the Transmission of El Tor Cholera in Rural Bangladesh." Working Paper No. 2. Cholera Research Laboratory. Dacca. 24 pp. 1977.

Also: Hughes, James M., et al., "Epidemiology of El Tor Cholera in Rural Bangladesh: Importance of Surface Water Transmission." *Bulletin World Health Organization.* In press.

These authors describe an epidemiological study in Matlab Thana, Bangladesh. Fifteen cholera index cases were selected at random from the patients at the Cholera Hospital at Matlab Bazaar because 1) they were residents of the Matlab Vaccine Trial Study Area, and 2.) they had a rectal swab culture positive for *V cholerae* on the day of initiation of each study Control index cases were also from the study area, but their swab cultures were negative for *V cholerae*. Each case's and each control index patient's neighborhood was identified and water samples were taken from neighborhood sources of water (tubewells, ditches, tanks, canals, and rivers) for drinking, cooking, bathing, and washing Samples were analyzed and reported as positive or negative for *V cholerae* biotype El Tor.

Extensive contamination of water sources was found in neighborhoods where individuals infected with *V. cholerae* resided. Forty-three percent of all water sources in infected neighborhoods were positive for *V. cholerae*, versus two percent in control neighboorhoods. Families using a culture-positive water source for drinking, bathing, or washing were significantly more likely to be infected with cholera than other families. Families using the same water source as the index family for either drinking or bathing were more likely to be infected. The authors conclude· "The data support the hypothesis that contaminated water is important in the transmission of cholera . in areas where *V cholerae,* biotype El Tor, is endemic "

Hughes, James M. "Potential Impacts of Improved Water Supply and Excreta Disposal on Diarrhoeal Disease Morbidity: An Assessment Based on a Review of Published Studies." Consultation Report, World Health Organization Diarrhoeal Disease Control Programme, Geneva. 10 pp. + 7 pp. Bibliography + Tables. Draft, July 6, 1981.

This paper constitutes a review of forty-three studies that have quantified indicators of diarrhoeal disease populations with different levels of water supply and/or excreta disposal facilities

Among other points, Hughes concludes that earlier pessimism about the problems of documenting health benefits associated with water and excreta disposal projects may be unjustified, since "morbidity reductions of 20 percent or more are usually statistically significant and have been observed" frequently.

He also says that data indicate that "available water near the house may yield health benefits," although not as much as tap water inside. The data suggest, he says, that "volumes in the range of 20-30 lpcd may be a minimum required to yield reductions in diarrhoeal disease morbidity."

Khan, Moslemuddin. "Role of Water Supply and Sanitation in the Incidence of Cholera in Refugee Camps." Scientific Report No. 45. International Centre for Diarrhoeal Disease Research, Bangladesh. Dacca. 14 pp. 1981.

This study compares hospitalized confirmed cholera cases for three major refugee camps, a few miles apart, in Dacca during the cholera epidemics of 1974 and 1975. The results show a clear correlation between water supply/sanitation and cholera incidence

One camp, A, had piped water and latrines connected with sewers. The other two camps, B and C, had tubewells with hand pumps, ponds, and "fenced surface latrines." Comparative facilities and rates of cholera incidence for each camp are summarized below.

Refugee Camp (population)	*Persons Per Water Source*	*Persons Per Latrine*	*Cholera Cases Per 1000*
A Geneva Camp (49,675)	662	130	1.16
B Kamalapur Railway Camp (11,375)	1,896	325	3 95
C Kataban/ Bapupara Camp (12,112)	2,018	404	4 29

Camp A, with piped water and sewered latrines, had 62 percent less cholera than Camps B and C, with inferior water and sanitation facilities.

Koopman, J.S. "Eliminacion de Aguas Negras, Suministro de Agua y Diarrea Endemica en un Barrio Urbano Pobre de Cali, Colombia." *Boletin Oficina Sanitaria Panamericana.* 88(5):402-412. 1980.

This paper describes a study of the incidence of diarrhea, as seen by 19 health centers in Cali, Colombia, from 1973 to 1976 A number of possible contributing factors appear.

A survey of the population and of the sanitary services available showed that incidence of diarrhea was much greater in children under fifteen years old The study also showed that the number of diarrhea cases dealt with in the Melendez center had increased 500 percent. Possible factors were suggested by the fact that Melendez had an "invading" population, poor, unemployed and badly housed.

There was also positive relation with a poor sewage disposal system, but not with the potability of water. Houses with a latrine were found in this study to have 36 percent more cases of diarrhea than those which had a sewer connection. Those with no provision for the removal of excreta had 60 percent more cases of diarrhea than those with a latrine, and 127 percent more than those with a sewer.

Koopman, James S. "Food, Sanitation, and the Socioeconomic Determinants of Child Growth in Colombia." *American Journal of Public Health,* 71 (1):31-37. 1981.

This article is a statistical study of the influence of food availability, neighborhood socioeconomic conditions, and family socioeconomic conditions on a stratified random sample of families of Cali, Colombia

The article concludes that neighborhood factors, including hygiene, had a strong relationship to child growth The findings "certainly suggest a need to expand the attack on malnutrition with programs intended to control the transmission of enteric agents at a neighborhood level "

Kourany, Miguel, and Manual A. Vasquez. "Housing and Certain Socioenvironmental Factors and Prevalence of Enteropathogenic Bacteria among Infants with Diarrheal Disease in Panama." *American Journal of Tropical Medicine and Hygiene,* 18(6):939-941. 1969.

The authors report an attempt to evaluate the role of certain socioenvironmental conditions on a group of infants with identified diarrheal disease and to determine whether the type of housing influences the prevalence of specific pathogens

The study observed 1819 infants in Panama City, Panama. A scheme of housing classification was devised, using observations made during home visits and data on sanitary facilities taken from the National Census of 1960. Information on diarrheal infections was available from an early study (*American Journal of Tropical Medicine and Hygiene,* 18: 930-935).

Forty-five percent of the infant cases came from Type 2 dwellings: i.e , tenements dating to the early 1900s, with communal water and toilets on each floor Twenty-two percent came from Type 3 dwellings· squatter shanties of the poorest sort, with common pit privies Nine percent came from Type 6 dwellings housing for very poor families in a rural area, with few if any toilet facilities The authors state that only the Type 1 dwellings of the middle to high group show a statistically significant difference among the six dwelling types. They state that "The difference in rates among the various substandard dwelling types were not significant at 0.05 level when tested by the chi-square test "

The results for Type 1 dwellings suggest the benefits of piped water to each family and of flush disposal of human excreta to water-carried sewerage The multiplicity of factors influencing diarrheal diseases is recognized in the authors' closing statement: "Planned programs for adequate housing, provision for a safe water supply within each dwelling, if possible, safe removal of human excrement, and improvement of the general standard of living will undoubtedly be accompanied by a significant decrease in the frequency and severity of diarrheal diseases due to enteric infections."

Marshall, Carter L. "The Relationship Between Trachoma and Piped Water in a Developing Area." *Archives Environmental Health,* 17:215-220. 1968.

Also: Marshall, Carter L. "Some Exercises in Social Ecology: Health, Disease, and Modernization in the Ryukyu Islands." In Farvar, Taghi M., and John B. Milton, Editors. *The Careless Technology, Ecology and International Development.* Natural History Press. New York. 1972. Pp. 5-18.

The author reports part of a trachoma control program undertaken during the 1960s in the densely populated Ryukyu Islands of the Western Pacific Surveys of trachoma in school children were undertaken in the capital city of Naha, on the island of Okinawa, in the city of Ishikawi, and in five rural villages. The Ryukyus were and are densely populated (1,142 per square mile in 1965) coral islands with, in 1965, few paved roads Fine dust is common during dry periods, but rainfall averages 83 inches annually. About 40 percent of the population in 1965 was provided with filtered, chlorinated water, piped into individual households Per-capita water use was not stated in the study

Naha (population 260,000), a rapidly growing city with many rural newcomers entering the school system each year, has a modern, piped water system Ishikawi (population 16,000) has no central water supply system Of the five rural villages surveyed, four have piped water to individual households. The fifth, Tonahi, does not have a piped water supply, its residents take their water from shallow wells.

The differences in trachoma prevalence between communities with piped and unpiped household connections were found to be statistically "highly significant" ($P < 0.001$) The trachoma prevalence rate in Naha and in the four villages with piped water was approximately 4 percent, whereas the prevalence for trachoma in Ishikawi (partially provided with house connections) was 24 percent and in Tonahi (no piped water supply) was 42 percent. No explicit data were presented on water quality, per-capita water use, or average distance to nonpiped household sources of water

Marshall suggests that the reasons that a piped water supply may decrease trachoma prevalence "are probably more closely related to the different patterns of water utilization in water-scarce and water-rich areas than to purity of water per se."

Misra, K.K. "Save Water in Rural Areas: An Experiment in Promoting Community Participation in India." *International Journal of Health Education.* 18: 53-59. 1971.

This article describes an experimental water supply project undertaken in 1963 in a rural area of Uttar Pradesh by the Planning, Research and Action Institute of Lucknow, with WHO/UNICEF assistance (WHO/India 84) Seven villages, in Barbanki District, with a population in 1964 of 4,420 were involved

A list of all the families with children below age five was prepared and every fortnight, on a fixed day, they were questioned by a health worker as to whether the child(ren) had had loose stools on that particular day The survey was conducted over 2½ years

The initial survey showed 1) high incidence of diarrhea among children less than five years of age and 2.) lower incidence in children living in housing with tap water or standpost water supplies Following introduction of a piped water supply, diarrhea among children fell from 24.4 percent to 5 0 percent three years later (The project included a health education component.).

In addition to diarrhea and dysentery, 100 randomly selected persons from randomly selected families were examined for typhoid, scabies, conjunctivitis, and trachoma. Again, the introduction of tap water correlated with a drop in disease. The following table shows reduction in morbidity per thousands of population.

	Diseases	Years 1965	1966	1967	1968
Diseases directly related to unclean water	Diarrhea	83 8	36 0	27 1	19 0
	Dysentery	12 2	5 3	3 6	3 1
	Typhoid	3 3	0 0	0 3	0 0
Diseases caused by lack of clean water	Scabies	25.4	16 9	0 0	0 6
	Conjunctivitis	8 5	2 6	3 9	1 9
	Trachoma	3 3	0 9	0 0	0 3

Ultimately 350 of 836 families took private house connections at their own expense The remaining families were served from 42 public standposts Source, storage, distribution, and standpost costs were paid for by the state, the panchayat, and UNICEF

Moore, Helen A., Enrique de la Cruz, and Oscar Vargas-Mendez. "Diarrheal Disease Studies in Costa Rica. IV. The Influence of Sanitation upon the Prevalence of Intestinal Infection and Diarrheal Disease." *American Journal of Epidemiology,* 82(2): 162-184. 1965.

This study, sponsored by the Ministry of Public Health of Costa Rica, the U.S. Agency for International Development, and the Servicio Cooperativo Interamericano de Salubridad Publica, was part of an extensive epidemiological investigation from 1959 to 1961. Part IV covered household sanitary facilities in six districts in a rural canton of Costa Rica. The survey covered all of the 1,202 homes in the Canton de Barba, recording 6,548 consumers on the communal water systems. The objective of study IV was to secure comprehensive data on the sanitation facilities and sanitary conditions, for correlation with diarrhea morbidity and other information on intestinal infections and parasitism

The method used was a house-by-house recording of water source and location, excreta disposal, drains, flies, domestic animals with access to the house, material of the house floor, house ownership, screening, and plumbing facilities. The five communal piped water systems were observed and extensive bacteriological sampling was done of water and of the milk and meat supplied to the communities Four experienced sanitarians and two advanced trainees did the survey work (The overall plan and methods of the whole investigation are reported by the same authors in "Diarrheal Disease Studies in Costa Rica. I." *American Journal of Public Health,* 56(2) 276-285 1966, with the authors as above for part IV.)

The following relationships were observed:

1. The six districts were ranked on an areawide basis from best to poorest for household sanitation Recovery rates of enteropathogenic bacteria from diarrhea cases were lower in the three districts with the best sanitation than for the three with the poorest sanitation. The same characteristic held for the prevalence of *Ascaris* and *Trichuris* among survey subjects. However, diarrhea case rates did not correlate with the sanitation rankings

2 Rental value of houses proved to be a satisfactory means for grouping houses according to their sanitary characteristics. Diarrhea cases increased among 0-4 year-olds as the rental value decreased The number of cases and rates for all ages followed the same pattern.

3. Among all houses, the increased water use as indicated by the number of water-using appliances was compared to case rates per 100 for *Trichuris, Ascaris,* diarrhea and *Shigella*. Houses with only a water spigot or a spigot and sink had the highest rates. Among houses with two water-using facilities there was a reduction in each of the four rates, and further reductions appeared among houses with three or more water-using facilities.

4. Seventy-two houses of the 1,202 in Canton Barba were not on piped water. Differences in enteric diseases in this group were noted Ten of 27 cultures (37 percent) from diarrhea cases in houses without piped water were positive for some enteropathogenic organisms, versus 7 percent for all diarrhea cases cultured. For *Shigella* cultures of diarrhea patients from houses without piped water, 18.5 percent were positive, as opposed to 9.5 percent for those from homes with piped water.

5. The available excreta disposal facility also corresponded to rates for the four enteric diseases *Ascaris* infections dropped from houses with no facility to those with a septic tank *Trichuris* rose slightly from "None" to "Privy," then dropped for homes with septic tanks. Diarrhea was lowest for homes with no facility. *Shigella* was essentially the same for "None" and "Privies," and zero for homes with septic tanks

6. Occupant density was plotted against the four enteric disease rates. All four dropped with lower occupancy rates.

7. Hookworm infections were most frequent in adults (males 21 8 percent, females 19.9 percent). The prevalence was the same with or without a privy The areas where earth floors were most common in homes had hookworm prevalence rates three times as high as other areas. The risk to coffee plantation workers for whom defecation on the ground was without an alternative was also considerable. Shoe use also seemed to reduce hookworm rates.

8 Animal entry to homes showed no evidence that the enteropathogenic organisms recovered from the animals were related to concurrent human infection or disease.

9. Water quality as indicated by coliform MPM values showed some relationship to disease indices. Except for the Santa Lucia district, Wet Season values were higher than Dry Season. Santa Lucia had the lowest values at all times. Despite that indication of water quality, Santa Lucia had the highest diarrhea morbidity rate for the 0-4 ages, and the third highest rate for diarrhea in all ages and *Shigella* positives. Aside from Santa Lucia, the two systems with the high percentages of MPM values had the highest diarrhea morbidity rates and the highest percentage of *Giardia lamblia* positives There was no consistent pattern for the percentage of positives for *Shigella*

10. Santa Lucia's data were further confounding as it had the highest percentage of *E histolytica* positives in the parasitism survey. The authors strongly suspected the dissemination of *E histolytica* through the water system. There was no variation in prevalence of *E histolytica* by socio-economic level or by age A similar interpretation was suggested for the *Giardia lamblia* positive percentages in areas served by the San Roque and Buena Vista systems, both untreated, unprotected surface sources. A classification of the "Worst Water" and "Better Water" relating the high MPM values and the months of high-rainfall to diarrhea morbidity rates was made. There is consistency between the diarrhea rates and the water quality classification The rates are higher for both the 0-4 years and the All Ages during "Worst Water" periods. The differences are not dramatic, however

11. Examinations of meat and milk were unproductive. The few isolations of enteropathogens in meat did not relate to the diarrheal diseases observed. The families that were patrons of four "fluid milk" vendors had few children, and the milk was boiled and taken with coffee. Among those families only 13 diarrhea cases were observed.

The authors reached the following conclusions

1 Piped water was important in reducing the amount of infection with enteropathogenic bacteria Diarrhea morbidity per se and parasitism were not greatly affected. It is suggested that a portion of the diarrhea cases were not of bacterial etiology

2. Increased use of water was associated with decreases in all of the index rates of morbidity and intestinal infections. When water use extended to a bathing facility, usually a simple outdoor shower, the indices for morbidity and parasitism decreased

3 The lack of any excreta disposal facility was associated with extremely high *Ascaris* prevalence. *Entamoeba histolytica* and *Giardia lamblia* infections were judged to be primarily from water.

4. The quality of water piped through the five systems was below any acceptable drinking water standards for MPM values No positive and unequivocal relationship could be established between variations in bacteriological quality and variations in diarrhea morbidity. There was evidence of water transmission of *Entamoeba histolytica* in one system, and *Giardia lamblia* in another There was one period of seasonal coincidence of high morbidity and very high coliform counts.

5. Variations in fly counts and the bacteriological quality of meat and milk did not appear to be related to the variations in diarrhea morbidity. Domestic animals harboring enteropathogenic bacteria were not demonstrated to be related to disease episodes in their owners

6. The incidence of diarrhea was reduced and the prevalence of *Shigella* infections was least where a good level of sanitation was found in homes

This study amasses an impressive volume of data on enteric disease indices and on environmental sanitation conditions. There is a substantial amount of information which supports our hypotheses on sanitation and intestinal disease. However, troublesome variations appeared These result from the lack of any control group in the communities and populations in the study The availability of a control water source that consistently provided water of drinking standard quality at the sources and through distribution might have limited the variations and the lack of consistent patterns of water quality and disease

The extent of privies in these communities indicates a high level of sanitary consciousness. All privies are described as pit privies and in several instances as sanitary pit privies. "Sanitary" implies a complete isolation of the excreta, off the ground surface, away from water sources, and inaccessible to insects, poultry and mammals That all 919 homes with privies should meet such criteria is improbable. The uncertainties of excreta disposal by toddlers under two years of age was another problem recognized by the authors. In the mild semi-tropical climate, young ones are seldom toilet-trained and are free to behave as "door-yard" children

The diarrhea morbidity rates were not a sufficiently sensitive index of the effects of water use and water quality, which was poor at best, to produce conclusive evidence on the water-intestinal infections relationships Matters of diet and nutrition were not noted in Part IV of the study

Despite the inconsistencies and shortcomings, the reported data and the content of the Discussion and Summary support the benefits of piped water, ample facilities for water in the home, and excreta disposal facilities to limit intestinal infections

National Academy of Sciences. *Drinking Water and Health.* Washington. 939 pp. 1977.

This is a follow-up to the Safe Drinking Water Act of 1974, intended as the scientific basis for revision of drinking water regulations by the U.S. Environmental Protection Agency The majority of the report is directed at water quality problems of an industrial society. trace metals, asbestos, synthetic organic chemicals, pesticides, carcinogens, and so on.

Chapter III, "Microbiology of Drinking Water" (pp 63-134), has useful information on infective doses for man of bacterial protozoa and helminths, giardiasis, and radioactivity. It also discusses effectiveness of water treatment and disinfection processes. The study contains over 25,000 references.

Patel, Mahesh. "Effects of the Health Service and Environmental Factors on Infant Mortality: The Case of Sri Lanka." *Journal of Epidemiology and Community Health,* 34:76-82. 1980.

This study traces the relation between infant mortality rates and public health services in Sri Lanka Although the infant mortality rate for Sri Lanka (approximately 50 per 1000 live births) is low for a developing country, regional variations are large, from 26 per 1000 to 91 per 1000. These differences are more strongly associated with regional variations in environmental determinants of mortality than with regional variations in public health expenditure. The most significant environmental factor associated with interregional infant mortality rates was the nature of the water supply ($r = 0\ 82$ significant at the 99 percent level) Regional government expenditures on health had only a weak association with infant mortality rates ($r = 0\ 08$). No relationship was found between supervision of births by the health system and infant mortality rates ($r = -0\ 15$)

There was a weak positive association ($r = 0\ 49$) between availability of latrines and infant mortality This assumed the correct sign and became significant ($r = 0\ 79$) when the tea estate sector was eliminated In the tea estate sector, "latrines are provided but shared by many households, are poorly maintained, and are frequently out of use. . . there are still many pit latrines in use, some of which empty into streams or irrigation canals " Cement floors in houses had a mild association ($r = 0\ 52$)

Peterson, Norman J., and Virginia Hines, "The Relation of Summertime Gastrointestinal Illness to the Sanitary Quality of the Water Supplies in Six Rocky Mountain Communities." *American Journal of Hygiene,* 71: 314-320. 1960.

This project of the Communicable Disease Center of the Public Health Service in 1957 was designed to determine whether a correlation existed between the sanitary quality of the water in six Rocky Mountain communities and their incidence of unreported summertime gastrointestinal illness in June, July and August, 1957

The sanitary quality of the water was determined from the records of the State Health Department. Histories of diarrhea during June, July and August, 1957, were obtained by house-to-house survey of about 100 families in each commuity. Three communities (identified as A, B, and C) were found to differ significantly from the other three in terms of the sanitary quality of the water.

The authors state· "A simple chi-square test indicated that the overall attack rate of 13 9 percent in communities A, B, and C was significantly higher than the rate of 8.8 percent in the communities D, E, and F ($p<0.01$). This correlation between water quality and attack rate was found consistently displayed when computed separately for each community "

The article presents data on the case distribution by months through June, July and August of 1957. It observes that people living in the areas for less than two years had higher attack rates than those living in the locale for more than two years. Clinical symptoms in attacks in communities D, E, and F were shorter and milder No pattern was evident of any common source or single exposure to infection. In communities with consistently contaminated water, the attack rate was 14 percent during June, July and August 1957. For the communities with high quality water, the rate was 9 percent. In the former group, illnesses were more severe and dramatic than in the latter.

The authors conclude:. . . "it is reasonable to believe that the sanitary quality of water supplies in these communities significantly affected the incidence of illness. It is evident, however, that the effect of water supplies on the health of the total population was not great."

They say further, ". . . the overall contribution of water to the attack rate in the population was (a reduction of) about 5 percent. However the effect on the segment of population that had lived in communities with contaminated water for less than 2 years was a much more significant 12 percent."

The authors recognize that the survey was small in size and that etiologic agents were not defined, but the study met its objective. It confirms the value of community water of sanitary quality in reducing gastrointestinal illness. Furthermore, it shows that water supplies of the character and quality of communities A, B, and C are an open door to severe and serious community-wide waterborne disease outbreaks All that are needed are the infectious organism and large infective doses.

Pontes, De Lima, Luiz Augusto, Minervina Ramos, and Carlos Roberto. "Estudo Preliminar do Beneficio-Custo de Investimento em Saneamento Urbano." Secretaria dos Servicios e Obras Publicas do Estado de Sao Paulo. Sao Paulo. 30 pp. 1971.

This study analyzes the relation between infant mortality rates and public water supply for four subdistricts of Sao Paulo, Brazil for the years 1943 through 1967. Two of the subdistricts, Bras and Cambuci, were served by public water supplies over the entire period while in two other subdistricts, Nossa Senhora do O. and Vila Maria, public water supplies were installed during 1953-1957 and in full use thereafter. The first two subdistricts were "controls" and the latter two "experimental" subdistricts

The authors' data show a rapid and dramatic decline in infant mortality in the two subdistricts where public water supplies were introduced. The data show that the annual infant mortality rates in the subdistricts with public water supply interventions, i e., Nossa Senhora and Vila Maria, fell 68 to 80 percent during the five years following the intervention period compared to the five years preceding the intervention Total infant mortality rates of over 130 per 1000 dropped to rates of 28 to 43 per 1000, approximately the rates of the older central subdistricts Undoubtedly other factors were important, but the rapidity and magnitude of the decline in infant mortality rates—contemporaneously with the installation of public water supplies—are striking

Using regression analysis of infant mortality rates over time, the authors developed estimates of the monetary benefits of increased working lifetime attributable to the installation of public water supplies From these estimates and the investment costs of the new water supplies, they derived benefit/cost ratios of 4 4 to 1 for Vila Maria and 5 6 to 1 for Nossa Senhora do 0

Puffer, Ruth Rice, and Carlos V. Serrano. "Environmental Conditions," Chapter XVI (pp. 309-324) in *Patterns of Mortality in Childhood.* Scientific Publication No. 262. Pan American Health Organization, Washington. 470 pp. 1973.

Also: Burke, Mary, Marjorie York, and Innis Sande. *Mortality in Childhood.* Scientific Publication No. 386. Pan American Health Organization, Washington. 145 pp. 1979.

Both of these papers report a collaborative ex-post-facto study of 35,000 deaths of infants and children (one to four years of age) in fifteen areas of ten countries of the Americas (1968-1973). The study was coordinated by PAHO and funded by AID.

Statistical treatments of aggregate data by Puffer and Serrano showed strong inverse correlations between postneonatal mortality and percentage of houses with piped water. i e , mortality decreased as the percentage of houses with piped water increased Correlation coefficients ranged from 0 688 to 0 834 for various data sets The investigators concluded. "The provision of water supplies and sanitary facilities to much higher proportions of families in many urban and rural areas is essential for bringing about major reductions in postneonatal mortality "

The study by Burke *et al.* of the same communities, based on some 30,000 household interviews, "confirmed the relationship" of the inverse "association between availability of piped water service and high mortality, particularly of young children "

Rajasekaran, P., P.R. Dutt, and K.A. Pisharoti. "Impact of Water Supply on the Incidence of Diarrhoea and Shigellosis Among Children in Rural Communities in Madurai." *Indian Journal of Medical Research,* 66: 189-199. 1977.

This article reports on a study made by the staff of Gandhigram Institute of Rural Health and Family Planning, Madurai District, Tamil Nadu, India, during January-December 1972 The objective of the study was to determine whether public water supplies have controlled waterborne diseases in rural areas, using the incidence of diarrhea (shigellosis) as index in children under five years of age

For the study, three villages with open dug wells, 215 households and 388 children under five were the unimproved group Two villages had improved water supply with treated water from a reservoir In one there was a mixture of distribution by street taps and by taps within households. The second improved system provided taps within households for all households with children under five

All children, 1,130 at the start, were visited twice a week for the entire year of 1972 to detect the occurrence of diarrhea (1,041 children completed the year, as 85 moved and four died) Water samples from wells and taps were examined for coliforms each month for eleven months (166 samples) Additionally, 140 samples were collected twice per month from domestic storage containers

Bacteriological quality at the source was found to be best for taps within houses, and poorest at wells It deteriorated badly in home storage for all these sources. Households using street taps produced the largest numbers of diarrhea cases, Shigella positives, and high MPNs in water samples from households with diarrhea attacks. The lowest values were for households with taps within the home.

The authors summarize their findings as follows:

1. The annual diarrhea incidence per 150 children on the stated water sources was: Wells 21.5, Street Taps 32, Taps Within Households 23.5.

2 The annual Shigellosis incidence per 150 children was· Wells 8 8; ST12 5, TWH 4.7

3. Surveys of bacteriological quality found the wells all grossly polluted; 16 to 25 percent of street taps and home taps were polluted, all but 12 to 14 percent of water in home storage was heavily contaminated.

4. "Street taps were not effective in reducing infective diarrhea "

5 "Water stored in the homes is invariably found contaminated, irrespective of the source including even treated and chlorinated water."

6. They conclude that not only a protected, adequate and continuous water supply, but also public education concerning good sanitation practices and personal hygiene, would be necessary to prevent waterborne infections.

Richardson, N.J., and V. Bokkenheuser. "Salmonellae and Shigellae in a Group of Rural South African Bantu School Children." *Journal of Hygiene* (Cambridge), 58:100-117. 1960.

Also the following:

Richardson, N.J., and V. Bokkenheuser. "Salmonellae and Shigellae in a Group of Periurban South African Bantu School Children." *Journal of Hygiene* (Cambridge), 61:257-263. 1963.

Richardson, N.J., and H.J. Koornhof. "Salmonellae and Shigellae in a Group of Bantu School Children in the Eastern Transvaal Lowveld." *South African Medical Journal,* 39:367-370. 1965.

Richardson, N.J., H.J. Koornhof, and S. Hayden Smith. "Salmonellae and Shigellae in a Group of Urban South African Bantu School Children." *Journal of Hygiene* (Cambridge), 64:245-253. 1966.

Richardson, N.J., S. Hayden Smith, V. Bokkenheuser, and H.J. Koornhof. "Salmonellae and Shigellae in Bantu Children Consuming Drinking Water of Improved Quality." *South African Medical Journal,* 42:46-49. 1968.

Richardson, N.J., Gillian M. Durnett, and H.J. Koornhof. "Bacteriological Assessment of Meat, Offal and Other Possible Sources of Human Enteric Infections in a Bantu Township." *Journal of Hygiene* (Cambridge), 66:365-375. 1968.

This series of five studies on salmonella and shigella infections in Bantu school children, 1959 through 1968, identified water supply as one variable The studies were made by members of the Department of Bacteriology, South African Institute of Medical Research, Johannesburg. Four areas were studied: Tlaseng, a rural area near Rustenberg, which was studied in 1959 and again in 1968, 5 years after its water supply had been improved; Witkoppen, a periurban area in the Soweto complex 15 miles from Johannesburg, Komatipoort, a rural Railway Administration settlement, and Dube Township in urban Johannesburg. The objective of these studies was to determine the incidence of salmonella and shigella infections in apparently healthy Bantu school children and to seek factors influencing the incidence.

Fecal samples were taken from school children aged six to seventeen, in nearly even numbers of males and females. Sampling frequency varied from four to seven times per year Intestinal parasite examinations were made in some samples. Water samples were taken concurrently and examined for total bacterial counts. *E. coli* and fecal *E. coli.* General information was given on nutrition (Diet was marginally adequate but usually low in protein.)

The last of the studies concentrated on foods of animal origin, rather than water quality, as possible contributors to the high incidence of salmonellosis and shigellosis in the group of children. In this study, offal prepared and sold for human consumption in Johannesburg and Soweto was tested for salmonella and other organisms.

The authors of the first five studies make the following statements in their summaries or conclusions:

1. Tlaseng near Rustenberg, 1959 "Water was probably implicated in the conveyance of the infections."
2. Witkoppen, 1962: "The drinking water was of poor quality and may well be implicated in the transmission of the infections "
3. Komatipoort, 1965: "Piped water from the town reservoir which was bacteriologically satisfactory and heavily contaminated river water, both used for drinking water purposes, were examined Using the Moore pad technique, 8 different types of salmonella were recovered from the 2 rivers bordering the area "
4. Dube Township, Johannesburg, 1965. "Water supplied to each house by Johannesburg municipality was of good quality, yet did not affect the incidence of salmonellosis and shigellosis "
5. Tlaseng near Rustenberg, 1968· "In the environment of Bantu children, the provision of high quality community water as the only sanitary measure was without effect on the prevalence of intestinal salmonella and shigella infections."

As the studies proceeded, the authors made brief comments on environmental matters other than the water quality. The report on Dube children says, "From this study and its comparison with the previous surveys, it is apparent that there is a need for more efficient food control and for the education of the Bantu as to the importance of personal hygiene habits Furthermore, as the socioeconomic position of the Bantu improves, more judicious spending of money on food of higher nutritional value may have a bearing on their susceptibility to diarrhoeal diseases " The study of offal in Soweto Township found salmonella in amounts of the offal sampled ranging from 14 to 48 percent The authors concluded, "although there is a definite need for improved treatment of the offal before distribution to the consumer the resulting increase in cost must not be such as to deprive the population of this important source of proteins."

The first five studies were almost wholly limited to the occurrence of the presence of salmonella and shigella organisms in the stools of apparently healthy Bantu school children, ages six to sixteen, and to the bacteriological quality of water in the school and communities Limited information was given on water sources, water use, water handling and storage, or water treatment. The studies were not directed toward the susceptible age group of 0 to five years. Very little information was provided on excreta disposal, handwashing or food handling.

Present epidemiological views of the role of water as a mode of transmission of salmonellosis relegate it to a much less important position than contaminated foods. The findings of the sixth study confirm that view.

Rubenstein, A., J. Boyle, C.L. Odoruff and S.J. Kunitz. "Effect of Improved Sanitary Facilities on Infant Diarrhea in a Hopi Village." *Public Health Reports,* 84(11): 1093-1097. 1969.

This study traces the effects of improving sanitation on the incidence of infant diarrheal diseases. Moenkopi, a Hopi Indian village in Arizona, was divided into two parts an upper area in which indoor plumbing was installed and a lower area which was left unchanged. Children from Moenkopi were classified according to residence in the upper or lower village to compare their rates of hospital use for diarrheal complaints. An examination of the health of infants was made from hospital records both before and after the plumbing installation.

The results showed that the average number of visits to the hospital per child in his first year of life declined in the upper village from 2.0 visits before indoor plumbing to 0 85 after indoor plumbing. At the same time, the rate in the lower village was declining from 3.1 to 2 6 the decline in the upper village was significant at the 0.05 level. The decline in the lower village was not Subsequent age groups tended to have indistinguishable patterns of hospital use. The mother's education apparently did not influence overall hospital use by infants in lower Moenkopi

The study notes several problems that could influence results. There seemed to be basic political and social differences between the two parts of the village which might influence the illness of infants, there was no control for breast feeding, refrigerators in homes were not noted; and there was no measurement of willingness to use the hospital and other modern facilities The authors conclude that the refusal of the villagers of the traditional lower Moenkopi to install water indoors was a political decision and not hostility to good health practices, as they had installed their own outdoor water taps without government help long before residents of the "progressive" upper village got their facilities by cooperating with the Public Health Service

Schleissmann, D.J., F.O. Atchley, M.J. Welcomb, and S.F. Welch. "Relation of Environmental Factors to the Occurrence of Enteric Diseases in Areas of Eastern Kentucky." Public Health Monograph No. 54, 1958. Issued as Public Health Services Publication No. 591. Also published in *Public Health Reports,* Vol. 73(11). November 1958.

This study, conducted by the Public Health Service's Communicable Disease Center in mining camps of Eastern Kentucky, took place from September 1954 through December 1956. The Cumberland Field Station of the CDC was established at Prestonsburg, Kentucky, to study a population of nearly 4000 in eleven communities ranging from 1295 to 100 (most between 100 and 300). The objectives were to investigate the associations between specific environmental conditions and the occurrence of diarrheal disease, and to estimate the levels of control attainable by selective environmental changes.

The communities were selected for their sanitary facilities. Group A, a single community of 1,295 people, had complete facilities of flush toilets, hot and cold water in the house. Group A dwellings also were the only ones with solid-waste collection service with covered cans in general use. Group B,15 communities totaling 1,624 people, was incompletely served by public sanitary facilities· 80 percent of the dwelling units had privies; 39 percent had only cold water in the house, 29 percent depended on outside water not under pressure. Group C, 1,009 people in five rural hamlets, had only nominal sanitary facilities. Ninety-three percent of the dwelling units had privies; 77 percent depended on outside water not under pressure

Diarrheal disease was measured by monthly visits to households with children under fifteen. The prevalence of Shigella and Salmonella infections was determined in preschool children at monthly intervals by rectal swabs. Intestinal parasite prevalence was determined from stool specimens from individuals of all ages in various communities. Fly abundance was measured by monthly counts during fly season by the scudder grill method Water samples were taken from public, semi-public and private water supplies to determine coliform counts

The diarrheal disease morbidity rate for all ages during the entire study period in Group C people was 2 6 times, and in Group B people 1.94 times, that among Group A For the 0 to 4 year-olds from September 1955 through August 1956, Group C children had morbidity rates for diarrheal diseases 5 1 times those of Group A children

The percentage of positive rectal swabs for Shigella increased as the extent of sanitation facilities decreased from Groups A to B to C. A similar pattern was found for the helminthic infestations

The ascaris positives in the ages two through twelve were 11 7 percent in Group A, 42 6 in Group B and 60 2 percent in Group C Consistently smaller fly populations were observed around dwellings in Group A than in B and C.

Overall, the coliform test results conformed to the condition and construction of the water supply, with frequent and high coliform counts from the poorly protected sources and those piped without treatment.

Data were also assembled on home crowding, housewives' years of formal education, and sanitary facilities in the home, they were then correlated with reported diarrheal disease, pre-school child Shigella prevalence and ascaris prevalence in all ages These analyses resulted in the following findings:

1. Shigella and ascaris rates were two or more times as high for those in dwellings having 1.5 or more persons per room than those living under less crowded conditions
2. In "well sanitated" areas, there was a higher diarrheal disease rate in less crowded homes (under 1.5 persons per room) than in more crowded ones However, this pattern did not hold for Shigella in pre-school children and ascaris in all ages. Rates were higher by a factor of 2 and 4 respectively in the dwellings with 1 5 or more persons per room.
3. One-third of people reporting enteric disease had flush toilets and water inside their houses, had a minimum of crowding and had higher levels of education than those having water outside the house Persons in higher educational levels tended to report more diarrhea than those in lower educational levels.
4. The combination of increased crowding, large families, and low educational levels tends to increase the prevalence of diarrheal disease However, the combined effects of these factors are not as significant as the effects of inadequate sanitary facilities
5. The incidence of enteric disease was primarily affected by the availability of water and sanitary facilities

The study did not undertake to isolate water supply alone as a beneficial factor in reducing diarrheal disease. No data were reported on the quantities of water used in the home This study did offer strong support for the value of a sanitary water supply and water-carried excreta disposal in reducing intestinal infections and infestations. It also showed that such sanitation items were related to the socioeconomic level of the communities

Shuval, Hillel I., Robert L. Tilden, Barbara H. Perry, and Robert N. Grosse. "Effect of Investments in Water Supply and Sanitation on Health Status: A Threshold-Saturation Theory." *Bulletin World Health Organization,* 59(2):243-248. 1981.

This article hypothesizes a "general theory" for "planning water supply and sanitation investments in the developing countries" that will "explain some of the reported anomalies as regards the health benefits associated with community water supply and other sanitation projects." The "model" attempts to fit a flattened S-shaped, logistic curve to data from 65 developing countries for 1.) national life expectancy at birth as a function of 2.) national adult literacy and 3.) "low" or "high" water supply coverage for the urban population in 1962 Some 38 countries with an average coverage of 79 percent of urban population (with either house connections or public standpipes, excreta disposal unspecified) are termed the "high sanitation" group, 27 countries with an average urban coverage of 41 percent are termed the "low sanitation" group.

The form of the two curves (for high and low groups) was chosen to fit the assumptions of "threshold" and "saturation" phenomena at the beginning and end of the curves. That is, marginal improvement in health status is assumed as nil at lowest levels and at highest levels of sanitation Use of the logistic curve form tends to force such a fit inasmuch as its theoretical form is asymptotic to this origin and to any pre-set maximum (in this study, 70 years life expectancy). Tests for fit of the two curves yielded correlation coefficients of 0.70 and 0.75 respectively for "low" and "high" sanitation. However, visual inspection of the data suggests that many other curvilinear or perhaps even linear forms would fit the data as well as does the logistic curve.

The data used are problematical, differing in space and time, using surrogate measures of socioeconomic conditions and health status. Water-supply data lump house connections and public standposts together and ignore the rural areas where most of the population lives Sanitary excreta disposal, actual use of facilities, and health education are also ignored Literacy data are not differentiated by sex, although strong evidence is available that the literacy of mothers (often much lower than for males) is a critical factor in infant and child mortality. The "theory" tells nothing about relative cost-effectiveness of alternative interventions, levels of service, or technologies or mixes of the same As presented, it assumes homogeneity within countries. The authors do recognize many of these issues and quite properly include numerous caveats and precautionary notes.

The simplicity of a "general theory" has inherent appeal Nevertheless, each water supply and sanitation intervention will continue to require location- and situation-specific engineering, and economic, financial, environmental, social and health effectiveness analyses.

Skoda, John B., J. Bertrand Mendis, and Michael Chia. *A Survey in Rural Bangledesh of Diarrheal Morbidity, Water Usage and Related Factors.* UNICEF/WHO. Dacca. 47 pp. June 1977.

This survey considers the relation between water usage and diarrheal disease. It is a cross-sectional survey of 68,155 rural villagers distributed throughout the country (121 villages in 21 districts in four divisions)

The cost of a tubewell with hand pump averaged less than U.S. $1 per person served. Tubewell use was primarily for drinking water Use for bathing and washing (clothes, utensils, *et al.*) fell off rapidly with increasing distance. Use for drinking water also declined with distance, but more slowly, only about thirty percent used tubewells if the distance to the nearest one exceeded 1000 feet Surface sources, e g , "tanks" (water-filled borrow pits), are readily available in much of Bangladesh

Of the 65 tubewells tested, the bacterial quality was found to be "satisfactory" in 70 percent. All open wells and surface waters tested were grossly polluted. In the households using tubewells, 17.3 percent reported more than one case and 4.2 percent had reported more than two cases of diarrhea and/or dysentery in the week preceding the interview. Households using surface water sources had 29.1 percent reporting over one case, 9.8 percent over two.

The total incidence of diarrhea/dysentery in villages with tubewells equipped with hand pumps was 41 percent lower than in villages using unimproved surface water sources Thus the study concludes that such tubewells can provide bacteriologically safe water under the conditions found in Bangladesh

Spira, W.M., M.U. Kahn, Y.A. Saeed, and M.A. Sattar. "Epidemiological Surveillance of Intra-Neighbourhood El Tor Cholera Transmission in Rural Bangladesh." *Bulletin World Health Organization,* 58(5): 731-740. 1980.

This study of cholera transmission was conducted during the 1976 post-monsoon cholera season (October-January) in the Cholera Research Laboratory (CRL) rural study area in Matlab Thana, Bangladesh Index cases were randomly selected from patients admitted to the CRL Hospital with cholera-like diarrhea and from whom *V. cholerae* had been isolated from rectal swabs. All families who shared any water source for any purpose with an index case family were questioned about their water use habits, water sources, and presence of diarrhea A rectal swab taken from each interviewee was cultured for *V. cholerae* Water samples were collected from all water jars in the study households. Water samples were taken at all surface water points used by persons in the neighborhoods of index cases for bathing, dish washing, playing, or obtaining water for drinking and cooking. Tubewells, tanks and ponds, canals, rivers, and ditches were sampled. Also sampled were leftover foods, and rinsings from the left hands of persons engaged in food preparation or water handling in each household Surfaces of cutting and food preparation boards were also checked

Tubewell water was used only for drinking. Because of the relativity high iron content in local ground water pumped by hand from tubewells, all families interviewed used surface water for cooking, rinsing, dishes, and washing hands and feet Drinking jars containing water from tubewells were refilled daily because the water had a tendency "to form a brown sediment upon standing overnight " (Ferric oxide?) Tubewells were used by 62 percent of families in neighborhoods classified "cholera-negative" compared with 38 percent in "cholera-positive" neighborhoods. Overall, 57 percent of surface water sources were contaminated, but tubewell water was consistently free of detectable *V. cholerae.* Food, hands, and utensils were also virtually free of contamination.

The results showed that cholera transmission was via contaminated surface water, particularly water taken into households for cooking or drinking. Infections resulted from a daily dose not exceeding ten to the fifth power of organisms and the frequency of exposure appeared to be a major determinant of the infection rate. Further, "vehicles other than water played virtually no role in transmitting *V. cholerae* in these outbreaks "

The authors also suggest that "a significant improvement can be obtained if communities establish a safe source of water just for household use. . . Alternatively, it may be feasible to disinfect water in jars prior to using it in the household. It may be possible in some cases to provide tubewell water that is acceptable in quality and availability for household use in this part of Bangladesh "

Stewart, W.H., L.J. McCabe, E.C. Hemphill and T. De Capito. "IV. Diarrheal Disease Control Studies—The Relationship of Certain Environmental Factors to the Prevalence of Shigella Infection." ***American Journal of Tropical Medicine and Hygiene,*** **4. July 1955.**

The U.S. Public Health Service sponsored this study to determine whether the observed differences in Shigella prevalence rates in children were related to environmental differences among blocks of towns in southwest Georgia. The period of study was from April 1949 to April 1952.

The data on about 28,000 rectal swab cultures were the result of the Diarrheal Disease Control Studies; the examination of the data in view of environmental conditions was Part IV of the series. Areas of the towns observed were divided into four groups (Poor, Fair, Good and Very Good) by city blocks according to: 1.) Location and type of water source; 2) Type of excreta disposal; 3.) Fly densities and potential for fly breeding, 4) Esthetic quality of the house and surroundings; 5) Structural quality of the house.

The conclusion was that a few general environmental factors can be used to characterize areas with varying levels of Shigella infection rates Further analysis showed that monthly or seasonal changes in prevalence followed the sanitation classifications. The highest prevalence months (for data from April 1949 through March 1952) were in the Poor Sanitation group.

Further subdivision of the Fair and Poor blocks showed the same correlation, as parts of blocks classed as Poor had higher rates than the parts of blocks classed as Fair. Combining the subdivided Poors showed a rate three times that of the combined subdivided Fair classifications The Shigella infection rates followed the sanitation classes when applied within blocks. Furthermore, infection rates appeared to be correlated with the proportion of Poor sanitation premises in an area. Where many infections occurred, even the families with better sanitation were affected. Organized community efforts, rather than individual improvements of premises, appeared to be needed to reduce diarrheal diseases

The influence of accessibility of water on Shigella infection prevalence was examined by grouping the poorest sanitation situations in the study area by location and type of water source. The conclusion was that infection rates from Shigella were highest where water was least accessible.

The sanitation indices in this study were descriptive and not quantitative. Data on the bacteriological quality of water were not given other than the comment that town water supplies occasionally failed to meet drinking standards. No data were provided on water consumption by households either "close to" or "far from" any type of source, town-supplied or dug wells The assumption was made that consumption and accessibility follow one another Such an assumption is generally accepted. The sanitation classifications of houses, including the element of esthetics, must closely follow the socioeconomic status of the houses. The specific environmental assets must be accompanied by a life-style pattern that favors the prevention of diarrheal disease. Nevertheless, this study supports the value of water supplied in purity and abundance to reduce Shigella infections in children.

Tompkins, A.M., B.S. Drasar, A.K. Bradley, and W.A. Williamson. "Water Supply and Nutritional Status in Rural Northern Nigeria." ***Transactions of the Royal Society of Tropical Medicine and Hygiene,*** **72 (3): 239-243. 1972.**

This study examines the relation between water supply and malnutrition. From September 1976 through May 1977, interviews were conducted with 9,850 people, the entire population of the rural Gamzago village area The village area comprises hamlets scattered over 35 square miles, fifteen miles from Malumfashi in northern Nigeria

Methods used were the classification of water supplies, bacteriological sampling of water, and accepted anthropometric observations on a random sample of pre-school children.

Three characteristics of the children—Weight/Age, Height/Age, and Weight/Height—were observed for relation to water source· Protected Water (deep wells) and Unprotected Water (shallow wells, ponds, or pools) The results show that more children in areas of "unprotected water" are malnourished and "wasted " "Stunting," the result of chronic malnutrition, was essentially the same for both groups

Coliform counts in the "unprotected sources" of water were about 10,000 per ml, in the "protected sources" above 100 per ml, and in stored or heated water about 1 per ml. Pap, a guineacorn porridge, was at the level of U.K. piped water, about 1 per 100 ml. Foods classed as "solids" such as beans and bean cakes ranged from 200 to over 100,000 per 100 ml.

The authors conclude that while the relation of "wasting" to inadequate water supply seems clear, it remains to be determined whether "water purity alone" or "a more complex relationship of unhygienic practice from food and food vessels" is the most important factor.

The study, reported in 1972, was part of an ongoing project, evident shortcomings may be eliminated in future work. There is no mention of excreta disposal With water supply very rudimentary, even for the "protected sources," it is unlikely that excreta disposal met sanitary norms, particularly for the target group, children from three months to 47 months. No information was provided on specific intestinal bacterial or viral infection or helminthic infestations, and the authors do not seem to recognize the function of coliform organisms as an index of pathogenic microorganisms in water. No information was provided on the quantities of water used by those on either "protected" or "unprotected" sources With the implied concern for the coliform content of foods, it is surprising that there is no information on food intake quantities and little on diet These may be fully reported in other articles from the project

This study does not provide substantial data supporting the health benefits of sanitary water supplies. Sanitary engineering consultation would have been beneficial.

Trivedi, B.K., H.S. Gandhi and N.K. Shukla. "Bacteriological Water Quality and Increase of Water Borne Diseases in a Rural Population." *Indian Journal of Medical Science,* 25(11):795-801. 1971.

The objective of this study was to get reliable information on the incidence of waterborne diseases and the bacteriological quality of rural water in India.

Forty-eight wells serving three villages were inspected for location, drainage condition, water table, sources of pollution, construction, disinfection, supervision and laboratory control Bacteriological samples were taken for colony counts and MPN coliform indices every two weeks for two months, January and February 1968. Samples for chemical analysis were taken from seven randomly selected wells. From March to July 15, chlorination was applied to 36 of the wells These were divided into four groups of nine, which received different doses of chlorine weekly Twelve wells of the Kheva village were a control group to which no chlorine was applied.

None of the 48 wells met the norms for a sanitary well. The majority of wells showed high colony counts and MPN values during the pre-chlorination sampling period Throughout the study the control group of wells had high MPNs However, the chlorinated wells showed a decline in MPN values in accord with the residual chlorine level. The highest residual chlorine dose produced the lowest MPN values

The incidence of waterborne diseases was also recorded, using records of the Rural Field Training Centre, the Primary Health Centre of the area, and weekly "domiciliary enquiries." Data were collected on gastroenteritis, dysentery, typhoid fever, and infectious hepatitis Waterborne diseases were rather uniformly epidemic during 1965-1967, highest in May, June, and July of each year. Control and treatment areas had similar incidence rates during January and February 1968, the pre-treatment period. But during the four and one-half months of chlorination of wells, the treated area had an incidence rate one-tenth that of the untreated control area Sub-group I of the experimental group, which had the lowest level of chlorination, did have two infectious hepatitis cases, in June and July 1968. The authors conjecture that the chlorination of the well in sub-group I was not sufficient to destroy the virus of infectious hepatitis. Overall, however, they conclude· "The Chi-square test indicated that chlorination of water resulted in a decrease of bacteriological load of the water with corresponding decrease in the incidence of water-borne diseases."

The data justify the authors' conclusion. "There was a substantial decrease in the incidence of water-borne diseases in the area of experimental wells during the period of chlorination, when compared to the same for the corresponding period in the previous years." The results are particularly striking as chlorination was a weekly treatment, not continuous

Van Zijl, W.J. "Studies in Diarrheal Diseases in Seven Countries by the Diarrheal Diseases Advisory Team." World Health Organization Document. WHO/ENT 66.8. 1966.

This series of studies was to obtain information on the causes of and the factors contributing to diarrheal diseases The availability of water received particular attention. The series was sponsored by WHO and collaborating countries, and took place over a five-year period, 1960-1965. It was conducted by advisory teams made up from a pool of nine epidemiologists, ten bacteriologists, four parasitologists, four pediatricians, five sanitary engineers, and two statisticians. Not all disciplines were represented on each of the teams. The teams were supported and supplemented by country participants. The countries and times involved were: Mauritius, 1960, four months, Sudan, 1961, four months, United Arab Republic (Egypt), 1961, four months; Sri Lanka (Ceylon), 1962, ten months; Iran, 1963, ten months, Bangladesh (East Pakistan), 1964, five months, Venezuela, 1964-1965, twelve months with follow-up 1965-1966, twelve months. (The follow-up data are in WHO/ENT 66 11, reviewed in the next entry.)

The work concentrated on pre-school children in selected villages or towns. Details of procedures varied from country to country. Different situations were selected in respect to water supply, excreta disposal, fly populations, solid waste handling, and quality of housing. Data on diarrhea were from health center records, from case examination, from family interviews, and from fecal sampling by rectal swabs or stools. The bacteriological and parasitological examinations of fecal samples varied depending on facilities and needs

Findings in three of the countries—Sudan, UAR, and Iran—are of special interest They dealt with paired communities, with protected water supply and without water supply. Within each country the water-supply communities were similar to the non-water-supply communities in such matters as religion, race, socioeconomic standards and personal habits. The great difference was in the level of sanitation. That level was higher in water-supply areas, but not high enough to control the incidence of diarrhea.

In Sudan, the water-supply village (Banat) had houses with water to the yards but not inside One-half of the houses had showers, and all had privies. None had kitchen facilities or water-carried excreta disposal In Feitahab, the non-water-supplied area, there was no piped water supply. Other conditions were similar but at a much lower level In Banat, all drinking water was transferred to earthen jars for cooling. The contents of these jars were fecally contaminated. Thus there was little apparent effect of water availability on diarrhea, which occurred in the under-7-year-olds at a rate of 21.8 percent, versus 26 6 percent in Feitahab. Shigella rate was more favorable for Banat, 6.4 percent versus 14 percent in Feitahab

The United Arab Republic data showed more marked differences between water-supply and non-water-supply areas. The diarrhea incidence among the under-6-year-old population was 10 percent in the water-supply areas and 38 percent in the non-water supply areas. The Shigella isolations were 3.4 percent and 9 4 percent respectively for the month of the survey. The water-supply area, the town of Embaba, was described as having complete sanitation with brick houses connected to a central water supply, bathrooms, flush toilets, kitchen facilities, water-carried sewage and solid wastes disposal. The non-water-supply areas had communal sources from standpipes or Abyssinian pumps. Water was drunk from the tap in Embaba, not stored in jars

In Iran, the water supply community was Robat Kareem (population 2,310). The non-water-supply area was four poor rural villages (total population 1,922) Among the under-7-year-olds, the Robat Kareem rate for diarrhea was 36 percent and the Shigella rate was 4.7 percent The rural villages without water service, depending on dug wells or ghanats, had rates of 48.7 percent and 7 5 percent respectively. The sanitation level of Robat Kareem was described as improved, with a central water supply providing house taps in the courtyards with handwashing facilities Drinking water was from earthen cooling jars found to be fecally contaminated Excreta disposal was by pit latrines The sanitation of the four villages was described as primitive Excreta disposal was by pit latrines for some and nothing at all for others Flies were described as abundant in both Robat Kareem and the four villages

In all three countries, Sudan, United Arab Republic (Egypt) and Iran, the water-supply areas all had diarrhea rates among pre-school children that were lower than the non-water-supply areas. The same pattern held for the detection rates for Shigella. The report states: "We may conclude that availability of water reduces the rate of diarrhea as well as the detection rate for Shigella, but the availability of water alone, without further sanitary improvements, is probably not able to reduce diarrhea drastically enough to solve the problem."

The study of Mauritius gathered data on the location of water sources and rates of diarrhea and Shigella infection. Accessibility of water was clearly shown to be a factor in the occurrence of diarrhea and Shigella infections.

All these studies recognized that several factors contribute to the prevalence of diarrhea. Sanitary facilities, nutrition, and domestic and personal hygiene are important to prevent diarrhea Another separate WHO document reviewed later in this work—"Summary Report on Diarrheal Disease Studies in Seven Developing Countries over a Five Year Period (1960-1965)"—presents an age distribution for the Iran study. It makes it clear that the very young are the most vulnerable

The disease conditions under study have a mix of multiple causes Safe and accessible water supply is a helpful protective factor, but does not in itself produce large reductions

Van Zijl, W.J., R. Travieso, and M.A. Matute. "Studies on Diarrhoeal Diseases in Venezuela. Followup Report of the Work Started by the Diarrhoeal Diseases Advisory Team in Cooperation with the Ministry of Health, 14 June 1965 - 14 June 1966." WHO Document ENT/66.11.

This study, sponsored by WHO and the Venezuelan Ministry of Health, continues the preceding one offering further observations on the occurrence and causes of diarrheal diseases in Pampanito and Monay, Venezuela Observations were made of fly counts, rainfall, and temperatures to determine effects on the occurrence of diarrhea The bacteriological quality of water in the new Pampanito system, supplied from a drilled well, was monitored. The characteristics of the distribution system were examined. Chlorination at the well was begun in June 1965 and continued throughout the year of the study The incidence of diarrhea was reported for children under 7 years old.

Pampanito and Monay provided four combinations of water and sanitation. The rural community of Pampanito, new with modern houses, had central water piped into the houses from a drilled well, good sanitary equipment and good wastewater disposal to cesspools The area was designated as new Pampanito. In old Pampanito, water was supplied from a creek The level of sanitation was low, house construction inferior with poor sanitary equipment. Two-thirds of the houses had water inside the house, and forty percent were connected to a sewerage system Most of the remainder discharged waste on the surface

Monay's living conditions, in both old and new areas, were less advanced than Pampanito's In old Monay a dilapidated water system served only a few houses. Water was provided by a public tank truck Sanitary equipment was almost completely lacking, and wastewater disposal was on the ground's surface. Excreta went to pits or the surface New Monay benefitted from well-constructed houses, but water service was by public tank truck as in old Monay. Wastewater disposal was still to the ground surface. Excreta disposal was into pits or on the ground.

The data on climatic conditions, diarrhea, and fly populations revealed no clear patterns The study says that the incidence of flies and of diarrhea both seem related to the climate, but not necessarily dependent on each other. The authors conclude that "man-to-man" contacts are more important than flies in spreading diarrhea The quantity and availability of water, along with good solid waste and wastewater disposal systems, are described as the most useful solutions to the problem.

The authors comment that "improved housing alone does not mean very much. Providing a water supply to the population shows a reduction of the diarrhoea incidence, but a more effective reduction of the diarrhoea rates occurs when the availability of water is concurrent with good sanitation " The data support these conclusions, showing the advantage of water-supplied communities over non-water-supplied: Pampanito (new) over Monay (new), and Pampanito (old) over Monay (old) The advantages, measured as percentage reductions in annual averages of percent of cases of diarrhea in children under seven years, were fifty percent for the first pairing and forty percent for the second pairing Pampanito (new), which had a better water supply in source and distribution than Pampanito (old), showed a thirty-four percent lower rate of diarrheal cases in children under seven years

The report supports the usefulness of piped water into dwellings in reducing diarrheal diseases among the preschool ages It supports the value of an ample water supply to dwellings with complete sanitary facilities for personal and home hygiene

Watt, James, A.C. Hollister, M.D. Beck, and E.C. Hemphill. "Diarrheal Disease in Fresno County, California." *American Journal of Public Health,* 43 (6). June 1953.

The U.S Public Health Service sponsored this study in Fresno, California, July through December 1950 Its objective was to determine the factors contributing to the high prevalence of diarrheal diseases in the Central Valley of California, with particular attention to Shigella infections.

Three types of communities in Fresno County were selected migrant farm labor camps, town fringe areas, and housing projects. The children under ten years old were examined for intestinal infections by rectal swabs. For families visited repeatedly, at intervals of four to six weeks, illnesses were recorded

The water supply and excreta disposal facilities varied in the migrant labor camps from minimum to adequate All had "pure" water, but not all had it piped into the dwelling. Some units had complete baths and kitchens In poor camps, excreta disposal was by privies

Town fringe areas had city water into homes or at public taps. No sewers existed Houses were usually owner-occupied, but of poor construction

The housing projects were publicly owned, well-built with good plumbing Housing-project families had a history of relatively few severe diarrheal diseases.

The resulting data pointed to water use as a single environmental factor which may significantly lower the Shigella prevalence when the risk of acquiring that infection is great. This study aroused concern for the accessibility and quality of water as important water and sanitation assets for the control of shigellosis

White, Gilbert F., David J. Bradley, and Anne U. White. *Drawers of Water/Domestic Water Use in East Africa.* University of Chicago Press. Chicago. 306 pp. 1972.

This is a fascinating account of water use and practices in Kenya, Tanzania, and Uganda during the latter 1960s, particularly in rural areas Chapters Six and Seven, "Costs and Benefits of Water: Health" and "Total Social Costs," together with other works by Bradley, have greatly influenced water and health concepts, as well as the classification of diseases related to water.

With the exception of one report on diarrhea in households with and without piped water, this was not a field study of the health impact of water supplies However, that report found a large difference in the rate of reported cases. 3.4 percent of houses with piped water reported cases of diarrhea during the week preceding the interview, compared to 19 percent of houses with unpiped water.

Based on East African experience, estimated morbidity and mortality of water-related disease in the area, and evidence of the effectiveness of water supply interventions, the authors prepared tables, excerpted below, for the proportionate reduction of each disease which might be expected in East Africa from improved water supplies:

Diagnosis	*Percent Reduction Expected if Water Supply Were Excellent*
Guinea Worm	100%
Typhoid	80
Urinary Schistosomiasis	80
Leptospirosis	80
Trypanosomiasis, Gambiense	80
Scabies	80
Yaws	70
Inflammatory Eye Disease	70
Schistosomiasis, unspecified	60
Trachoma	60
Bacillary Dysentery	50
Amebiasis	50
Dysentery, unspecified	50
Tinea	50
Gastroenteritis, 4 wk. to 2 yr	50
Gastroenteritis, over 2 yr	50
Skin and Subcutaneous Infections	50
Diarrhea of the newborn	50
Paratyphoid and other Salmonella	40
Louseborne Typhus	40
Intestinal Schistosomiasis	40
Ascariasis	40
Louseborne relapsing fever	40
Otitis Externa	40
Classic Skin (leg) Ulcer	40
Trypanosomiasis, unspecified	10
Dental Caries	10
Overall reduction expected	52%

World Health Organization Diarrhoeal Diseases Advisory Team. "Summary Report on Diarrhoeal Diseases Study in

Seven Developing Countries over a Five-Year Period (1960-1965)." WHO Document ENT/66.9.

This WHO report covers the same studies as the WHO report by Van Zijl, which has been reviewed above. The work done in Venezuela in 1964-1965 was recounted in greater detail in this report. Only that part of this document which deals with Venezuela, pages 24 through 31, is reviewed under this heading.

Five communities were selected with differing sanitary conditions. Pampanito had an old section (population of 2,114) with a central water supply, and a new section (population 833) in a modern housing project with piped-in water. Monay similarly had an old section with a population of 1,833 and a new section with 497 people in a modern housing project, but neither had water supplied Houses strung along a highway were designated as Kilometro villages (total population 2,781) These were to provide baseline data against the time when water should be supplied to the Kilometros.

The plan to compare the old section of Pampanito with the modern housing was ruined by the discovery that old section houses were connected to the housing project's water mains and that many inter-connections and cross-connections had been made. Therefore, the data were examined by dividing all of the houses in all of Pampanito into two groups—those houses that had water inside and had washing facilities and those houses that did not have either one. The diarrhea incidence was 35% in the group with water and 43% in the group without water. However, factors in the lower incidence included not only inside water but all of the modern housing project with its full complement of sanitary facilities.

Monay did not have public supplied water either in its old section or in its housing project A division was made among Monay houses using washing facilities or having at least one tap, and those having no such facilities. The diarrhea rate was 33.5% in the first group and 47 5% in the second group The stated conclusion for the Monay diarrhea data was "The difference is statistically significant and is considered to be due to the availability of water, since there were no big differences in other sanitary facilities "

The situations, which initially were believed to offer comparisons between water-supplied and non-water supplied communities, were not readily divisible The Pampanito areas had interconnected supplies. The Monay housing project had plumbing facilities in the units, but the public water supply had not yet been installed However, the results are indicative of the usefulness of water in reducing the incidence of diarrhea.

Other sanitation factors were also observed. Continuous fly counts were examined for relation to level of sanitation and incidence of diarrhea The authors reported that "in the zone with the high fly counts, the highest rate of diarrhoea occurred within the group living under the worst sanitary conditions " This points out the multiple factors influencing diarrhea.

Zaheer, Mohd, B.G. Parsad, K.K. Ctovil, and T. Bhadury. "A Note on Urban Water Supply in Uttar Pradesh." *Journal Indian Medical Association,* 38 (4): 177-182, 1962.

This study reports on the progress of water supplies, water purification, and water quality in 73 towns with piped public water service in Uttar Pradesh (total population four million, one-sixteenth of the total for Uttar Pradesh) It presents the changes in death rates from cholera, typhoid fever, dysenteries and diarrheas in fourteen towns for periods five years before and five years after the establishment of purification systems

The water-supply data apply to conditions in the late 1950s and early 1960s, in 73 cities and towns with piped water in whole or in part. The epidemiological data on waterborne diseases are for fourteen towns for two periods, five years prior to and five years after the establishment of water purification systems. The years of establishment of water purification systems extended from 1943 to 1954

Information was assembled on 73 piped public water supplies and on the death rates for waterborne diseases in fourteen of the towns. Bacteriological analyses were made weekly at the Provincial Hygiene Institute. In 1959, this covered 70 of the supplies, with three services maintaining their own laboratory. Samples for chemical analysis were collected every three months. No detailed data are provided

The study gives the average specific death rate for four waterborne diseases for five years prior to and five years after the installation of a water purification system in fourteen towns in Uttar Pradesh. A substantial reduction in the death rates is recorded. The percentage reduction for the entire group was: cholera 74 percent, typhoid 64 percent; dysenteries 23 percent, and diarrheas 43 percent. There were three exceptions in which there were increases. In Sandika, where there are a substantial number of open wells, "a poor conservancy system" (solid waste handling), and no sewerage, cholera increased. In Deoria, where disinfection was by the manual addition of bleaching powder and without testing for free residual chlorine, dysentery and diarrheas increased somewhat In Vrindaban, which had the oldest system drawing from a shallow tube well since 1943, only 33 percent of the people were served with piped water. Disinfection was handled as at Deoria. Vrindaban showed increases in typhoid fever and dysenteries. It also had the highest death rates from diarrheas for both the before and after periods.

The authors note that the reported diseases can be food- or fly-borne, but conclude that "since there has been no appreciable change in the standard of environmental sanitation in the above mentioned towns of Uttar Pradesh during the period of study, except the improvement in water supply, the differences observed can be safely attributed to the provision of protected water supply "

The data strongly support the value of piped water supply to reduce waterborne diseases, even when the supplies do not fully meet all standards for bacteriological quality, continuity of service and disinfection practice A favorable characteristic of the supplies studied is the high proportion of deep tube wells: i.e , 53 of the 73 supplies serving 37 percent of the total population on piped water Such sources have an advantage over surface sources for inherent protection against biological contamination.

This evidence for water supply to reduce waterborne disease is strong. In fact, it is too strong to be accepted without question. The study did not provide any control towns with piped water supply. It also did not supply information on changes in preventive and curative medical services, despite the long period covered. However, the data is a positive addition to the public health value of sanitary water supply.

Zebec, M., A. Bujevic and B. Cvjetanovic. "Mraclin, 50 years of Rural Drinking Water and Sanitation Programme In Croatia." Annex 2 (22 pp.) in Cvjetanovic, Branko. "Effect of Water Supply and Sanitation on Health in Rural Communities in Developing Countries." Unpublished Report. Zagreb. 42 pp. + Annexes. June 1980.

This reports a program during the late 1920s for improvement of sanitation for the village of Mraclin (pop. approx. 1000), near Zagreb, Yugoslavia. The program resulted in the installation of sanitary wells, latrines, manure pits, sanitary drains, a health center, a public bath, and a public hall. One sanitary well was provided for approximately each thirteen households. Seventy percent of the population were provided with sanitary latrines. The villages paid one-third of the total costs, the authorities two-thirds.

The following table, taken from Cvjetanovic, shows the findings·

Age in Years	*Before Program 1921-1926* *Annual Death Rates per 1000 Population*	*During and After Program 1927-1932* *Annual Death Rates per 1000 Population*
0-0 9	185	143
1-4 9	46	26
5-9 9	6	5
10-19 9	6	6
20-39 9	10	9
40-59 9	13	13
60-79 9	84	66
80	267	314
All Ages	27	19

These results show that most of the reduction in mortality occurred in children under five years of age. Infant mortality was reduced about forty per thousand per year Annual mortality for children for ages one through four was reduced by 45 percent. Overall annual mortality was reduced by 30 percent. The results confirm the health value of a sanitation program, particularly for the very young

The views expressed in this document are the responsibility of National Demonstration Water Project and do not in any way represent the policy of the U.S Agency for International Development Information on this and other "Water for the World" materials may be obtained from the Development Information Center, Agency for International Development, Washington, D.C , 20523, U S A

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