EXPANDING NON-AGRICULTURAL USES OF IRRIGATION FOR THE DISADVANTAGED: HEALTH ASPECTS

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and

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TERMS OF REFERENCE

The terms of reference for which this sub-project report was prepared were given by A/D/C (letter of 4·3·81) as:

"Purpose: To prepare a comprehensive review of the scientific and technical literature and recent research in the project files of the University of California at Davis and USAID in Washington, D.C. The review will be part of an ongoing project to prepare for the seminar on 'Expanding Non-Agricultural Uses of Irrigation for the Disadvantaged.'"

"Objectives: The objectives are the following:

- to identify what [adverse] health aspects are associated with irrigation systems. How can they be prevented or minimized by providing domestic water supplies at the same time as irrigation water?
- to identify the opportunities and constraints on pesticides--must water avoid contact with all pesticides? Can it be treated to eliminate harmful effects of certain pesticides?"

The author has rephrased the above objectives, to more accurately reflect the purpose of the seminar and the USAID contract with A/D/C, in the following manner:

- to identify what adverse health effects on humans are associated with agricultural irrigation systems.
- to discuss how such adverse health effects can be prevented or minimized while providing domestic water supplies at the same time and from the same sources as agricultural irrigation systems.
- to identify the constraints that contamination of agricultural irrigation water with pesticides may place on the use of such water for domestic purposes, and the opportunities for reducing such constraints (water treatment, control of non-point source pollution).

METHODOLOGY FOR THE REVIEW

A literature survey and interviews were conducted to gain recent information on the health effects of pesticides in drinking water and surface waters. The references found in "Residue Reviews" and "Pesticide Abstracts" were examined. Dr. M-Y Li, Environmental Toxicologist and Documentations Specialist of the Environmental Toxicology Library, Department of Environmental Toxicology, University of California at Davis, gave the author complete access to the library's up-to-date reprint collection, journals and monographs on pesticides in water and the health effects of pesticides. In addition, use was made of materials in the Health Sciences Library and Physical Sciences Library, University of California at Davis (UC Davis).

Over 25 interviews were conducted, in person and by telephone, with authorities at UC Davis, California State Department of Food and Agriculture (Sacramento), Pan American Health Organization (Washington, D.C.), USAID (Washington, D.C.), Volunteers in Technical Assistance (Maryland), the World Bank (Washington, D.C.), and the Water and Sanitation for Health Project (Virginia).

INTRODUCTION

Background:

The U.S. Agency for International Development (USAID) has been concerned for at least a decade with some of the adverse health effects on humans which may arise from the development and expansion of irrigation systems - man-made canals and lakes. Most attention has focused upon the creation or expansion of aquatic habitats for disease vectors or animal hosts for such diseases as schistosomiasis, onchocerciasis (river blindness), malaria, African trypanosomiasis (sleeping sickness) and insect-transmitted viral encephalitidies.

Recently USAID has become interested in the health effects - both acute and chronic - of pesticides contaminating drinking water and irrigation water. This interest is a result of several separate stimuli: (1) increased concern about the acute and chronic human health risks from pesticide exposure (in general) among the American public; (2) increased concern by some scientists, politicians and other people in LDCs about the environmental and health problems of pesticide exposure in general; and (3) in conjunction with the U.N. Water Supply and Sanitation Decade (Wolman et al. 1979), and recent research on diarrheal disease control (Dworkin and Dworkin 1980), a desire by USAID to expand the <u>quantity</u> of water available to dispersed rural communities in less-developed countries (LDCs). Research by Dworkin and Dworkin (1980) and White et al. (1972) indicates that increases in water quantity alone, relatively regardless of water quality, result in improved health in rural communities (e.g. a reduction in diarrheal disease incidence). Irrigation water systems could provide increased quantities of domestic water, with resultant health benefits (e.g. decreased infant and child mortality and morbidity).

Irrigation Systems-Past and Present Usage:

Historically, traditional irrigation systems have been used to provide water for domestic purposes (including drinking) in such places as Sri Lanka, South India, Syria and Assyria, Greece, Rome, the Nile River Valley, Meso-America and the highland Andes (Wittfogel 1981:30-31). Today, irrigation systems are used to provide drinking water in Nepal, Pakistan, Jordan, Mexico, Guatemala and California, among other areas. Other non-agricultural uses of irrigation water systems, variously practiced, are for bathing of people or livestock, swimming, washing clothes, washing and cooking foods, watering household gardens, production of energy for milling and electricity, transportation, canal-side tree watering, and socio-religious rituals (White et al. 1972; Yoder 1981). The traditional engineering view of irrigation systems is limited to the provision of water for the watering of crops, pastureland, livestock, and desalinization of soil (NAS 1974).

Thus, an agricultural irrigation system includes all phases of the impoundment of water for the purpose of crop irrigation or domestic animal watering: planning, construction, use and maintenance of such human-made structures as dams, barrages, and canals; the physical results of water control: creation of lakes, reservoirs and other bodies of controlled water; and the intentional and unintentional/unplanned/auxiliary uses of such controlled bodies of water.

As a Ministry-planned function, it is apparently rare for water resources development projects in LDCs to be used to provide water for domestic usage. Whether planned or not, today in LDCs it is common for people adjacent to such systems to use such irrigation (or multi-purpose) water for domestic needs. The author has observed such behavior in 1978 in rural Mexico: "campesinos" (landless peasants) in squatters' settlements were seen drawing water from an irrigation channel for domestic use.

USAID Irrigation Projects:

USAID irrigation projects were the subject of a recent analysis by Practical Concepts Inc. (PCI, 1979). Of 109 irrigation projects reviewed, 44% of all "irrigation projects" (many of which were subprojects of integrated rural development projects) had major outputs (i.e. goals) not directly related to agriculture. Yet only one of these irrigation projects (India, project 386-0233) had a purpose of providing domestic water, solely for emergencies. Only seven other rural development projects had health components, such as village water wells and rural sanitation (Indonesia, Philippines, Thailand, Bolivia, Haiti, Peru), run in <u>parallel</u> with the irrigation sub-project.

More recently, USAID projects in Guatemala, Nepal, and Sri Lanka made use of irrigation water (derived from groundwater or protected springs) for drinking (Yoder, 1981). USAID/Jordan has a parallel irrigation/domestic water project under way to provide water in Amman and surrounding areas.

<u>USAID Policy on Domestic Water Supplies, Irrigation, Pesticides and Health</u>:

The Draft Domestic Water Supply and Sanitation Policy Paper of USAID (5 December 1980), in its discussion of intersectoral linkages between water, sanitation and natural resources (pp. 36-37) notes that: "The exploitation of natural resources may unintentionally diminish the availability and quality of water for domestic use (e.g. dam and irrigation projects that divert water supplies), and A.I.D. must pay particular attention to such possible consequences, especially in the context of the initial environmental examination."

"National plans, which may include watershed protection or water conservation activities, should be adopted by developing countries in order to ensure that water of adequate quality in sufficient quantities is available for domestic use. In arid and semi-arid regions water is often the major constraint to continued development; programs and projects should be designed to conserve this scarce resource."

"Environmental pollution should be controlled to avoid contamination of domestic water supplies, especially contamination from municipal sewerage, agricultural chemicals and industrial wastes. The availability and quality of water can be compromised by other development activities, such as irrigation schemes, pesticide spraying and disease control programs. The possibility that other programs may have a harmful effect on water supplies should be studied before hand and avoided."

With regard to the intersectoral links between water supply, sanitation and agriculture the draft policy paper notes (p. 41): "Irrigation activities themselves may make greater quantities of water available for domestic use, although, irrigation programs often have the single goal of increasing agricultural productivity by bringing water closer to the farmer's cropland -- and fields may not be very close to the home. Health objectives are generally not addressed: water is made more convenient in greater quantity, but it is not necessarily made safer."

"Irrigation programs can also have a direct detrimental effect on the water available for domestic use: there are many examples of large-scale irrigation programs that resulted in contamination of domestic water supplies and in the spread of parasitic diseases. Thus careful regional planning, with particular attention to possible environmental degradation and land tenure issues, should be carried out."

"--*The quality or availability of domestic water supply* must not be diminised by A.I.D.-financed rural development activities.

--A.I.D.-supported rural development programs, particularly irrigation programs, will consider the advantages of marginal investment in domestic water supply and sanitation. In some instances it may be most *cost beneficial to address objectives of agricultural development and domestic water supply and sanitation simultaneously* rather than implementing entirely separate programs."

Yet, it is interesting to note that two recent USAID policy papers give minimal attention to the policy issue of health risks and health benefits associated with surface (irrigation) water systems which might be or are used for domestic purposes in LDCs. USAID's *Policy Directions for Rural Water Supply in Developing Countries* (Burton 1979) notes only that: "In most countries urgent action is necessary to ... take measures to protect supply sources from pollution (p. 3); and that heavy use of water supplies in crowded areas is likely to lead to fecal and hence bacterial contamination of the source (p. 13). The paper does stress the importance of public health education with regard to rural water supplies (p. 34).

USAID's Agricultural Development Policy Paper (USAID 1978) notes only that agricultural inputs such as pesticides and fertilizers should be used without having a deleterious impact on health and that their use must entail a consideration of environmental protection problems (p. 51).

ORGANIC COMPOUNDS IN WATER

Introduction:

Organic chemicals are found in surface waters, including irrigation water systems.

Organic, or carbon-hydrogen-oxygen (C:H:O), chemicals can have their origin in water from inorganic systems such as minerals from the earth's crust (Meinschein 1971), as well as from artificial or human-made contamination (Hunter 1971; Dayhoff 1971).

No large concentrations of organic compounds are found in a stable equilibrium in water (Dayhoff 1971); organics in water are thus usually found in a dynamic, limited equilibrium. This fact has favorable implications from the viewpoint of treatment or control of polluted water: any organic compound, under the influence of correct environmental conditions and a suitable catalyst, breaks down into carbon dioxide, methane water, and hydrogen and oxygen gas; and, when nitrogen is included in the organic, free nitrogen, HNO_3 or ammonia (Dayhoff 1971).

Thus, in general terms, the control of organic pollutants can be seen on the chemical level as the search for a suitable catalyst and proper conditions for catalytic activity to occur. Various methods for the treatment or management of toxic organics found in water will be discussed in the recommendations.

What are the various classes of organics which can be found in water? The American Public Health Association (APHA), in its 14th Edition of Standard Methods for the Examination of Water and Wastewater, lists the following (APHA, 1976):

1) grease and oil
2) methane
3) organic acids and volatile acids (e.g. acetic acid, formic acid, pyruvic acid)
4) organic pesticides
5) phenols
6) anionic surfactants (from synthetic detergents)
7) tannin and lignin (from wood pulp waste, plant decay, or tanning industry waste)

Canale (1977) lists five general sources of organics in natural waters:

1) decay of plant and animal life (e.g. humic and fulvic acids)
2) products of metabolic activities and excretions of organisms
3) industrial wastes
4) domestic wastes (feces, urine)
5) nonpoint sources:
    a) agricultural - pesticides
    b) urban - oils, solvents, fuels
    c) landfills - PCBs
    d) atmospheric - pesticides

It may be noted that there is some overlap of organics found in Canale's categories of industrial wastes and nonpoint sources, and that the APHA list also has overlapping categories (e.g., some organic pesticides are phenols, such as nitrophenols--Matsumura 1975:50).

Organic Compounds Other Than Pesticides Found in Surface Water in LDCs:

Conceivably, any and all of the materials in the two lists above could be found in irrigation water in LDCs, depending in some cases on the closeness of the irrigation system to urban and industrial sources of pollution.

If located near roadways or railroads, or if used by motorboats, or used to wash motorscooters or automobiles, irrigation systems may well contain grease, solvents and oil. Methane (swamp gas) and certain organic and volatile acids are natural products of the decomposition of plant matter or other organic waste (e.g., manure) in water, and can be found polluting rural surface waters, especially old lakes.

The organic acids commonly found in industrial wastewater are listed by Hunter (1971:80); he also lists common organic constituents of human urine and feces, urban sewage, urban domestic waste water, and industrial waste water (Hunter 1971). In the context of rural water supplies in LDCs, contamination fo such water supplies with industrial wastewater will be of rare concern, except (1) where rural communities may draw upstream water from an urban-polluted river (or lake) for both irrigation and domestic usage (e.g., Nile delta dwellers below Cairo), or (2) where such rural communities have local rural industries (e.g., tanning factories) polluting such water supplies.

On the other hand, contamination of rural (and urban) surface or goundwater supplies with agricultural pesticides and fertilizers constitutes a serious and widespread public health problem in many LDCs.

HEALTH PROBLEMS AND PESTICIDES IN WATER

Pesticide Contamination of Water in LDCs:

In the cotton-growing regions of Central America, a 1977 study prepared by the Central America Institute of Investigation and Industrial Toxicology (ICAITI) noted that farmworkers become contaminated with the highly toxic pesticide parathion, on the skin and by inhalation, while laboring in the cotton fields. They try to wash the pesticide off the skin by bathing in irrigation drainage ditches in the fields, but may only inflict greater damage; the ditches contain parathion-laden runoff water from the fields (Weir and Schapiro 1981:13).

The federal hospital in Culiacán, México treats another farmworker every 2-3 weeks for aplastic anemia, a blood disease linked to organochlorine pesticides used in the area; about half the victims die (Beckland and Taylor, cited and quoted in Weir and Schapiro 1981:12). These farmworkers live along small patches of earth between the crops and the irrigation canals that receive pesticide runoff. Babies, dishes and clothes are washed in the canals and discarded insecticide containers are filled with canal water to drink.

In Egypt, farmers and farmworkers are known to bathe and wash their clothing in irrigation canals which serve as a source of drinking water for these people and their animals (Kilgore 1972). Residues of the highly toxic pesticide methyl parathion have been found in irrigation and drainage water from cotton fields, in amounts ranging from 68-440 ppm (parts of pesticide per million parts of water) (Kilgore 1972). Residues of the highly toxic insecticide toxaphene have been found at concentrations of 680 ppm in irrigation water and 454-1,972 ppm in drainage waters from fields in Egypt; DDT residues of 214-445 ppm and 315-434 ppm in irrigation and drainage waters have been recorded from the same fields (Kilgore 1972). These very waters were being used for drinking and bathing, and for watering domestic animals (Kilgore 1972). These residues levels in water exceed the Suggested No-Adverse-ResponseLevel (SNARL) in drinking water, established by the Safe Drinking Water Committee (SDWC) of the U.S. National Academy of Sciences (SDWC 1977), as follows:

pesticide	SNARL in drinking water	range of residue recorded in Egypt	factor of excess over SNARL
parathion	0.03 mg/liter (=0.03ppm)	68-440ppm	2,267-14,667
toxaphene	0.0086 mg/liter (=0.0086ppm)	454-1,972ppm	52,791-229,302

There is no SNARL level for DDT in drinking water, because DDT (and DDE) are known animal carcinogens, and the SDWC essentially decided that the only SNARL acceptable was zero (SDWC 1977).

A series of studies by Greichus and co-authors (1977, 1978ab) detected pesticide residues in the waters of two lakes in South Africa, and in Kenya and Zimbabwe; these pesticides (dieldrin, DDT, DDE, DDD) were never found in concentrations greater than 0.001 ppm and were felt to represent no significant hazard to humans consuming the lake water.

An environmental analysis (E.A.) of a recent USAID irrigation project in Bali (USAID n.d.) included data on pesticide residues in Bali river waters. Aldrin, DDT, endrin, lindane, BHC and DDE were each found to exceed U.S. Environmental Protection Agency (EPA) quality criteria for water (EPA 1976), in at least one sample. As a result of this and other data, the E.A. recommended that canal water use be limited to bathing and recreation, and that pesticides used in the project area be limited to the relatively biodegradable and safe insecticides such as diazinon and carbaryl (Sevin).

Concern was expressed by ACRES International (1979), in their environmental analysis of the USAID/Sri Lanka Maduru Oya River Basin Project Feasibility Study, that the waterweed herbicide, Dalapon, employed in canals, is a skin irritant and could harm people bathing in canal or tank water contaminated with it. As well, they noted the herbicide, sodium arsenite, is extremely toxic to rice and other plants and animals, and should never be applied where it can contaminate water used for domestic purposes including bathing. Also, herbicides could leak into groundwater which would be used for domestic purposes, and chemical contaminants of water may have adverse acute and chronic (e.g. carcinogenic) effects on human health. The E.A. annexed to the Maduru Oya-System B Design and Supervision Project (No. 383-0056) recommended that downstream waters be monitored for pesticide residues and fertilizer nutrient contamination and that return flow or other irrigation supply water should be strictly avoided as domestic water supply sources, because of pesticide and nitrate (from fertilizers) contamination (USAID 1979).

The Accelerated Mahaweli Development Program of Sri Lanka, of which the Maduru Oya project is one component, should monitor potable water supplies annually for the presence of organochlorine pesticides (e.g. DDT), nitrates and toxic metals, according to the TAMS Final E.A. (TAMS 1980).

Groundwater and drinking water wells in Nicaragua have been contaminated by pesticides used in cotton production (David Donaldson (PAHO), Carroll Collier (USAID), personal communication 1981).

Pesticide residues in water in the Blue Nile River Valley of Sudan and the onchocerciasis zone of West Africa are being monitored, as part of WHO's Blue Nile Health Project and West African Onchocerciasis Control Program (OCP), both co-funded by USAID (Carroll Collier (USAID), personal communication 1981). In the Blue Nile Health project, insecticides, herbicides and molluscicides are applied to irrigation canals to control mosquito vectors and schistosomiasis host snails, and West African rivers in the OCP are sprayed with the insecticide Dimilin, which kills the larvae of the black fly vectors of onchocerciasis (river blindness). Both watersheds have people drinking their water, directly from the surface or indirectly from goundwater; risks to human health are unknown. Drs. Al Buck and Fred Whittemore of USAID suspect there may be an adverse synergistic effect on health occurring in humans exposed to high quantities of pesticides who are also receiving drug treatment for schistosomiasis; a joint project to investigate this in the Gezira area of the Blue Nile is being proposed by DS/AGR and DS/HEA (Carroll Collier and Fred Whittemore (USAID), personal communication 1981).

Pesticide Use in LDCs: Present Extent, Types and Relative Amounts, Health Effects, Target Crops

The term pesticide includes materials, both naturally and artificially produced, such as insecticides, herbicides, miticides or acaricides, molluscicides, nematocides, fungicides and rodenticides, which are used by people to kill insects, weeds, plant-damaging mites, snails, plant-damaging nematodes, plant-pathogenic fungi, and rodent pests, respectively.

As of 1976, there were no official U.S. or international statistics or other reliable published reports on the amounts of pesticides imported into, produced or used in LDCs (NAS 1976a). A NAS Public Health Study Team believed the combined total of pesticides consumed (in an economic, not gastronomic, sense) in LDCs represented 15-20% of the world total (NAS 1976a). Pesticide usage in LDCs, as measured by cost of purchases, shows Asia purchasing 18% of the world's total, Latin America purchasing 10%, and "all other [LDC] regions" (i.e. Africa, Oceania) only 6% (NAS 1976a:211). Per hectare of cropland sprayed, though, Latin America spends the most on pesticides of any LDC region (NAS 1976a:112), which may indicate pesticide applications/hectare are greatest in that region. Data on total values of U.S. exports of pesticides to LDCs supports this hypothesis (see NAS 1976a:213); the U.S. is the major exporter of pesticides to LDCs (Weir and Schapiro 1981). Geographically disaggregating this data further, we see within Asia, Far East Asia purchases most of U.S. pesticide exports, followed by Near-Central-South Asia (NAS 1976a:213-214). In the Americas, Central America purchases more pesticides than South America; Egypt and Kenya purchase the most among the African LDCs (NAS 1976a:213-215). *Such data are important in informing USAID which LDC regions and countries are likely to have the greatest pesticide pollution* of water; it appears Far East Asia and Central America are the regions at highest risk, assuming the amount of water pollution by pesticides is directly proportional to U.S. export sales of pesticides to LDCs.

Further data was given by USAID in 1979 in a *Report to Congress on Environmental and Natural Resource Management in Developing Countries* (USAID 1979).

For Africa, the Report emphasizes (pp. 41-42) that (1) pressure to use agricultural chemicals is increasing for various reasons; that (2) most of the pesticides used in

Africa (e.g. DDT and dieldrin) have had their EPA safety registrations cancelled for use in the U.S. (or else their use is severely restricted in the U.S.): (3) that these materials remain readily available for purchase and use in Africa; (4) that data on kinds and amounts of pesticides used is virtually non-existent; and (5) that with Africa's typical flash rains, substantial pesticide runoff can be expected.

For Asia, the Report notes (p. 77) that (1) pesticide (and fertilizer) usage is expanding (e.g. a five-fold increase in India from 1960-1975), (2) that data on kinds and amounts of pesticides used are generally not available, and (3) that the health consequences of such usage are generally unstudied.

The Report notes (pp. 104-105), for Latin America, (1) that hazardous levels of pesticide residues have accumulated in streams, lakes and groundwater from runoff, and (2) are found at dangerous or high levels in fish, shrimp, beef cattle and human breast milk (see also Weir and Schapiro 1981); (3) that most of these countries do not prohibit or control the sale of excessively toxic pesticides; (4) that widespread resistance of agricultural pests and some malaria vectors is common in these agroecosystems, and (5) that hundreds of cases of acute human pesticide intoxications (poisonings) are reported from Central America each year.

For the Near East, the Report (pp. 135-136) notes: (1) there is a general trend toward overuse and misapplication of agricultural chemicals; (2) some water supplies have been polluted by them; (3) pesticide residues are found in high levels in some aquatic fishes used for human consumption; and (4) deaths of livestock and humans have resulted from massive use of some pesticides (e.g. leptophos in Egypt).

Table 6 presents one classification system (SDWC 1977) for pesticides, and includes most all pesticides found or likely to be found in drinking water in the U.S. Though the classification system is applicable to pesticides used in LDCs, the types of pesticides found or likely to be found in LDCs are much greater in number since most LDCs are much less strict than the U.S. in what types of pesticides are allowed for use.

For example, Weir and Schapiro (1981:77-78) give two lists of imports of selected pesticides used in Costa Rica (1978) and Columbia (1979), obtained from Ministry of Agriculture statistics: (+ = imported; - = not imported)

Pesticide		Costa Rica	Colombia
Aldrin	insecticides	+	+
Dieldrin		+	+
Endrin		+	+
Chlordane		+	+
Heptachlor		+	+
DDT		+	+
BHC		+	+
Lindane		+	+

Pesticide		Costa Rica	Colombia
Toxaphene	insecticides	+	+
Malathion		+	+
Parathion		+	+
DBCP (a nematocide)		+	-
2,4-D	herbicides	+	+
2,4,5-T		+	-
Silvex		+	-
Paraquat		+	-
EPN (an organophosphate insecticide)		-	+
Phosvel (Leptophos, an organophosphate)		+	-

All of these pesticides, with the exception of DBCP, EPN and Phosvel, occur in the Safe Drinking Water Committee's (SDWC 1977) list of organic compounds of public health concern.

DBCP, a nematocide, was banned for most all uses in 1977 by the U.S. Environmental Protection Agency (EPA) because it was found to be carcinogenic and mutagenic (CEQ 1980; Raski et al. 1981) and caused male sterility among chemical plant workers in California (Weir and Schapiro 1981:19-22). Also, DBCP was found in drinking water wells in California two years after it had been banned (CEQ 1980); the concentration of DBCP in the wells averaged 5 parts per billion (ppb). At a level of only one ppb, one case of cancer is expected for every 2,500 persons who use the wells (CEQ 1980). DBCP has a tendency to be absorbed into groundwater, unlike some other pesticides (CEQ 1980).

Phosvel, an organophosphate nerve toxin insecticide, was found by the U.S. Occupational Health and Safety Administration (OSHA) to cause severe central nervous system (CNS) disorders in chemical plant workers in Bayport, Texas in 1976; thus OSHA/FDA/EPA never allowed its use in the USA (Weir and Schapiro 1981:23). In 1971, Phosvel usage was associated with the deaths of over 1,000 water buffalo and an unknown number of people in rural Egypt (Weir and Schapiro 1981:23). The manufacturer of Phosvel, Vesicol Corporation, began manufacturing EPN, another organophosphate insecticide, to replace its U.S.-banned Phosvel. EPN is now under EPA review; it may be twice as neurotoxic as Phosvel and thus may have its registration revoked in the U.S. (Weir and Schapiro 1981:24-25).

All the other pesticides listed above as imports into Colombia and Costa Rica have moderate to severe restrictions on their use in the U.S. Safe No-Adverse-Effect Levels have been listed by the SDWC (1977) for these pesticides in drinking water, but there is no apparent data on their concentrations in Colombian or Costa Rican drinking water.

Data from 1971 U.S. pesticide export sales worldwide indicate that the organophosphate (OP) insecticides "outsell" the organochlorine (OC, = chlorinated hydrocarbons); the chlorophenoxy herbicides predominate among the herbicide sales, as do the dithiocarbamates among the fungicides

(NAS 1976a:217-218). Presumably sales of these materials in LDCs are directly proportional to sales worldwide, and thus we should probably be most concerned with these particular types of pesticides and their potential to contaminate drinking water and damage health in LDCs.

Of all the crops grown in LDCs (and the U.S.), cotton is generally recognized to receive the greatest amount of pesticides (NAS 1975). In LDCs, the pesticides toxaphene, methyl parathion and DDT usually comprise the majority of pesticides used on cotton (NAS 1976a), though this pattern varies greatly.

In El Salvador, for example, cotton production absorbs one-fifth of all parathion used in the world, while 2400 pounds of insecticides are used each year on every square mile of cotton fields in the country (Weir and Schapiro 1981:33). Various organophosphate (OP) insecticides are used on cotton in El Salvador (and elsewhere in Central America): ethyl parathion, methyl parathion, malathion and trichlorophon--at almost weekly intervals about six months of the year (Breeland et al. 1970).

High levels of pesticide residues have been found in estuarine and marine fish and invertebrates in cotton-growing areas of Guatemala, and several thousands of people have been poisoned each year by cotton pesticides in Guatemala and Nicaragua (NAS 1976a), some of which may be the result of ingestion of contaminated drinking water.

With regard to pesticide contamination of water, we are perhaps most concerned with irrigated crops, simply because irrigation often implies the close proximity of irrigation or drainage canals which might receive pesticide-laden seepage or runoff water from a sprayed field; such water may be used domestically, to the detriment of the public health. Besides cotton, other crops often irrigated in LDCs are rice, sugarcane, various hard grains (maize, barley, teff, wheat, sorghum, etc.) and vegetable crops. Tree crops (dates, carob, etc.) may also be irrigated; indeed, almost any crop is potentially irrigatable, in one manner or another. Irrigation water is also the route of purposeful direct application of some pesticides.

Even if not irrigated, any pesticide-sprayed crop or field may act as a source of pesticides leaching into groundwater, or "running off" the field into adjacent surface waters, as a result of a rainstorm or sprinkler irrigation.

Pesticide Use in LDCs: Future Trends and Problems

Exports of herbicides to LDCs are on the increase, in line with the rapidly expanding worldwide use of herbicides (NAS 1976a:216). If the present push for "no-till" agriculture in the U.S. (a type of agricultural practice calling for massive use of herbicides), spills over into LDCs, herbicide use may increase exponentially; water pollution by herbicides can be expected to follow suit.

"The LDCs are likely to experience increasing water pollution by pesticides, especially chlorinated hyrocarbon insecticides used in irrigated rice culture and export crop production. The Food and Agriculture Organization expects that pesticide usage in the LDCs will grow at 10 percent per year for at least the near future. Should this trend continue until 2000, the volume of pesticides used in the LDCs will have increased more than sevenfold. Presently, about half the pesticides used in the LDCs are organochlorines, a trend that may continue because organochlorines are substantially less expensive than the more specific, less destructive and less persistent alternatives."

"A sevenfold increase in the use of persistent pesticides in Asia would virtually eliminate the culturing of fish in irrigation canals, rice paddies, and ponds fed by irrigation water. Organochlorine insecticides continue to collect in aquatic systems years after they have been applied and affect waters many miles downstream. At moderately high concentrations, they kill fish. Already, many Asian farmers are reluctant to buy fry for their paddies or ponds for fear that pesticide pollution will kill the stock. The amount of protein forfeited could be substantial. Per hectare yields of fish from well-tended ponds can be as high as the per hectare yields of rice, i.e., 2,500 kg/ha animal protein vs. 2,500 kg/ha carbohydrate. Cage culture yields are extraordinarily high and show great commercial promise in several developing countries, as long as waters are not poisoned by pesticices. Projected pesticide increase seriously threatens both freshwater and brackish water aquaculture in much of Asia. If pesticide trends continue, aquaculture in Latin America and Africa will eventually face the same threat."

"The protein that fish culture could provide is badly needed, especially in the humid tropics where aquaculture can thrive. Moreover, while alternative forms of producing animal protein tend to increase the pressures on already stressed soil systems, fish culture places no strain on terrestrial systems and is complementary to the careful water management schemes required for sustained agricultural production in many parts of the humid tropics. The FAO estimates that culture of fresh water and marine organisms could reach 20-30 million metric tons by 2000--between one-third and one-half of the present marine catch. Further pesticide pollution will sharply diminish this promising prospect (CEQ 1980:342)."

Health Risks from Pesticides in Water: Direct Effects

Pesticides are meant for use in killing or controlling pest population (e.g. insects, weeds, snails, rodents, fish), but most pesticides are truly "biocides," implying the potential to kill or injure other forms of life (humans, food animals or crops, beneficial wildlife, etc.). The latter organisms (i.e. all non-pests) are termed "non-target species" by ecologists. Humans are one of many non-target species affected by pesticides; such effects, usally adverse, may be direct or indirect.

Direct effects of pesticides on humans are toxic effects, ranging from acute poisoning to cancer, birth defects or other diseases (see Appendix 1 for details). The author has found no references in the scientific literature which discuss acute poisoning of people who have ingested pesticide-contaminated water, though doubtless the U.S. Center for Disease Control has such data. WHO estimates there are about 500,000 cases of acute pesticide poisoning occurring in the world each year (most of them unreported), with a mortality rate of >1% (WHO, cited in NAS 1976a). Of these poisonings and deaths, some presumably come from ingesting contaminated drinking water, though the majority result from contaminated food; some cases are suicide attempts. Acute poisonings from contaminated water in LDCs may often result from using empty, discarded pesticide containers as vessels for the transport or storage of drinking water.

One of the tests for determining the acute toxicity of a pesticide (before it can be registered for use in the U.S.) is to place different quantities of the material in laboratory animal drinking water and recording any adverse health effects. Such data are used in setting EPA's Quality Criteria for domestic, marine and freshwater (EPA 1976; SDWC 1977), and water for livestock and poultry (NAS 1974). Livestock and poultry acute deaths in the U.S. and in LDCs have occurred as a result of pesticide contamination of their drinking water (NAS 1974).

Chronic toxicity in humans resulting from pesticides can take several forms. The most common chronic risk discussed in the scientific literature for drinking water is carcinogenesis. Schneiderman and others (1978; SDWC 1980b) critically reviewed ten studies which highly correlate the presence of organic chemical contaminants (including pesticides) with cancer cases and cancer deaths in parts of the U.S. Nine of the ten studies indicate statistically significant associations between water quality and measures of cancer frequency, incidence or mortality (Schneiderman et al. 1978).

In Arizona, an Arizona Farm Workers (AFW) Union member has reported: "Before AFW we lived under trees. We drank and bathed in contaminated water." Undocumented workers in Arizona ranches for years took water from irrigation canals to drink, cook with and bathe in. Farmers often flooded fields that the workers worked and slept in with the same irrigation water ... the workers learned recently that the water contained DBCP, a toxic pesticide that can cause cancer and male sterility. AFW requested federal health officials to bring the workers back to the U.S. for medical exams. Up to now the government has not done this (Sandhu 1981).

The pesticide DBCP is applied to crops in irrigation water. DBCP, found in drinking water wells in California's Central Valley in 1977, is also a known animal carcinogen, and more than one out of every 2,500 persons who use or have used the wells are expected to develop cancer from it (CEQ 1980a). DBCP shows a prediliction for absorbtion into groundwater (CEQ 1980a). More than half of the U.S. states reporting water pollution mentioned pesticides as pollutants; the south-central states report pesticides as their primary toxic water problem (e.g. Texas, Louisiana) (CEQ 1980b).

The pesticide, Kepone, was found in the James River in Virginia in the 1970s (CEQ 1980b). Kepone is known to have caused acute toxicity in humans, and is a known animal carcinogen (SDWC 1977); in 1974-75 U.S. corporations exported 99.2% of their Kepone production to Latin America, Africa and Europe (SDWC 1977). Kepone sales are supposedly discontinued at present (Weir and Schapiro 1981:81).

In North America, the following pesticides have been found in natural and potable water, as of 1966: aldrin, dieldrin, endrin, DDT, DDD, DDE, BHC, heptachlor, toxaphene

(OCs); 2,4-D, 2,4,5-T (herbicides); parathion (an OP) (Faust and Suffett 1966). No specific adverse health effects in U.S. citizens resulting from this contamination have occurred to the author's knowledge. Nevertheless, aldrin, dieldrin, endrin, DDT, BHC, heptachlor, and commercial 2,4-D and 2,4,5-T are all known or suspected animal mutagens, carcinogens or teratogens (SDWC 1977; Hollyer 1977; van Strum 1979, Hay 1981).

The Safe Drinking Water Committee of the U.S. National Research Council (SDWC 1977) has reviewed the national and international standards set for certain organic chemicals in drinking water, and made their own recommendations.

SDWC (1977) noted 309 volatile organic compounds have been found in drinking water and published a research review of 129 of these toxic organic compounds which are potential or known contaminants of drinking water. Of these 129 compounds, 55 are pesticides and 74 non-pesticides. More specifically, the compounds selected for study met one or more of the following criteria (SDWC 1977:789-790):

1) experimental evidence of toxicity in humans or animals including carcinogenicity, mutogenicity, and teratogenicity
2) identified in drinking water at relatively high concentrations
3) molecular structure closely related to that of another compound of known toxicity

4) pesticide in heavy use that could result in contamination of drinking water supplies
5) listed in the Safe Drinking Water Act (PL 93-523) of 1974, or National Interim Primary Drinking Water Regulations of 1976.

A list of these organics, as classified by SDWC (1977), appears on Table 6.

Sufficient data were available such that only 3/4 of the organic pesticides investigated permitted judgment as to either the carcinogenicity of the compound or the establishment of an Acceptable Daily Intake (ADI) value (NAS 1977:780). The ADI values do not consider interactions (e.g. additive toxicity, synergism, antagonism) among the many possible contaminants, nor do the ADI values represent a safe level in drinking water because they do not take into account what fraction of the intake may come from water (NAS 1977:790).

The Committee also gave "suggested no-adverse-response level" (SNARL) in drinking water, based on two different assumptions: (1) 20% of total intake of a material is from water and 80% from other sources, or alternatively (2) only 1% of total intake is from water and 99% from other sources (NAS 1977:790); see Table 2.

Table 3 shows those organic pesticides and other organic contaminants found in drinking water, with insufficient data on chronic toxicity to calculate an ADI (NAS 1977:798).

Table 4 is a list of organic contaminants found in drinking water with no available information on chronic toxicity (NAS 1977:799).

Table 5 is a list of categories of known or suspected organic chemical carcinogens found in drinking water (NAS 1977:794).

These tables represent the most complete summary of data on toxicity and safety values for many of the pesticides which may be found in aquatic systems in LDCs. These pesticides represent most of the pesticides for which potential or present domestic water supplies in LDCs should, ideally, be periodically monitored, especially prior to the conversion or addition of a domestic water supply system into a rural agricultural irrigation water system.

As new information becomes available, such tables must be modified, new information added, e.g. from the U.S. National Cancer Institute, U.S. National Academy of Sciences, U.S. Environmental Protection Agency publications.

Health Risks from Pesticides in Water: Indirect Effects

Pesticides in water may cause adverse health effects in several different indirect manners: (1) food crops or food animals irrigated or watered with pesticide-contaminated water may thus become contaminated, and when consumed cause human toxicity; (2) pesticides may act synergistically with other foreign substances in the body (drugs), resulting in even greater injury to health; (3) pesticides in irrigation water may give rise to mosquitoes resistant to the very insecticides meant to control them; (4) people who consume organisms living in polluted aquatic habitats (fresh or saltwater) - such as fish, crayfish, clams, water chestnut, rice, bamboo - may become ill; and (5) pesticides in the aquatic environment may cause a general decline in environmental quality or food sources, which in turn may give rise to malnutrition and disease.

Contamination of grains and other plants, livestock and poultry, with pesticide-laden irrigation water may be responsible for part of the 500,000 cases of pesticide poisonings WHO estimates to occur each year, or for the pesticide residues (e.g. DDT) found in human breast milk, fatty tissue or blood (NAS, 1974, 1976a). Some pesticides, such as the nematocide DBCP (which causes human male sterility and cancer in lab animals), are applied directly into irrigation water instead of being aerially sprayed onto a crop (see below).

USAID officials believe the use of large amounts of pesticides in the Gezira area of Sudan may react synergistically (and adversely) with drugs used to treat schistosomiasis victims in the same area (see below).

The work of Breeland, Georghiou and others on the resistance of the malaria vector, Anopheles albimanus, to OP insecticides in cotton-growing regions of Central America clearly associates the spraying of cotton with OP insecticides to the resistance to OPs seen in these mosquitoes (see review in Ault 1981:144-169). It is probable, though unclear at this time, that the selection pressure for OP resistance placed on A. albimanus occurs in the aquatic stages (larvae, pupae) of the mosquito (as versus the non-aquatic adult stage), as a result of runoff of OP insecticides into the irrigation water in which the mosquito breeds. This has occurred in Aedes aegypti larvae exposed to malathion in Puerto Rico (Fox 1980). In both cases, the stability or increase in the number of cases of malaria (or yellow fever, in the case of A. aegypti) has been partly attributed to pesticides in water, as more pesticide-resistant vector mosquitoes arise.

Pesticide residues in aquatic non-target plants and animals are undesirable from both a health and economic standpoint. In the U.S. in the 1970s, the pesticide Kepone contaminated the James River in Virginia and resulted in sport and commercial fishing losses of about $20 million between 1976-1980 (CEQ 1980b). The EPA sets quality criteria for pesticide residues not only for drinking water but for fresh and saltwater aquatic life; if such criteria are exceeded the aquatic food products are not allowed for human consumption due to inherent health risks (EPA 1976).

General declines in the quality of aquatic ecosystems occur as a result of pesticide residues in surface waters, though recovery may occur once contamination ceases (Pimentel 1971; Sethunathan 1977; Ware 1980; Mulla and Main 1981). Any such declines could indirectly lower the health or nutritional status of people in LDCs dependent upon aquaculture, fishing, etc. for their food or income by reducing the availability of such aquatic life (CEQ 1980a).

THE WATER-RELATED INFECTIOUS DISEASES, IRRIGATION SYSTEMS, AND HEALTH IMPROVEMENT

Introduction:

Feachem (1977) has usefully classified water-related infectious diseases of the tropics as: (1) fecal-orally transmitted; (2) water-washed; (3) water-borne; and (4) water-related insect-transmitted. To varying extents, examples from all four of these categories of disease can be found in association with irrigation systems in LDCs.

Within each category, the types of diseases, and the relative frequency of association of these diseases with irrigation systems varies from pathogen to pathogen and environment to environment--a case-by-case approach is necessary. Bradley (1977) gives a useful list of the frequency of association of several diseases with water supplies, and an estimated percent reduction possible from unnamed "water improvements": cholera, typhoid leptospirosis, scabies, guinea worm and the West African (Gambian) form of sleeping sickness are each estimated to be reducible in frequency by 80% or more, while the water-related viral diseases such as infective hepatitis, some enteroviruses and yellow fever virus are estimated by Bradley (1977) to be able to be reducible by only 10% via water improvements. Given these estimates are relatively valid, such information is useful in water supply and sanitation planning, particularly if a cost-effective approach must be followed.

Pathogenic Fungi and Drinking Water:

Of the few pathogenic fungi found in water, the Tinea or "ringworm" group is probably the most common, widespread and important in LDCs, though other pathogenic fungi have been isolated from water (APHA 1976; Bradley 1977; Feachem 1977). All such fungi are water-washed diseases of human skin, and are not known to cause disease when ingested in water (APHA 1976). Using irrigation water for bathing (or other activities where the skin contacts water) could result in infection with these fungi; transmission results when fungi from one person enter the water source, and get washed onto the skin of another person. Other fungi found in water may only result in the water having a bad taste or odor.

Provision of irrigation water for domestic uses would lessen exposure to such pathogenic fungi, if the irrigation water source was portected from contamination by fungal-infected people.

Fecal-Orally Transmitted Diseases and Water:

The major fecal-orally transmitted diseases in LDCs which can use water as a vehicle of transmission are: shigellosis, cholera, typhoid fever (*Salmonella typhi*), enterotoxic *Escherichia coli* (ETEC), tularemia, leptospirosis; amoebiasis, balantidiasis, giardiasis, some coccidioses; various viruses (e.g. infectious hepatitis, polio, diarrheal viruses such as rotaviruses); and worm diseases (ascariasis, trichuriasis, ancylostomiasis and strongyloidiasis; dwarf tapeworm). Though each of these diseases has its own particular life cycle, each can result from the ingestion of water contaminated with animal or human feces.

Anywhere from one virus particle to several hundred, thousand or million *S. typhi* are needed to establish infection in people upon ingestion of contaminated water. Of these diseases, tularemia, polio, coccidioses, and the worm diseases are normally transmitted by _other routes_, while _cholera and typhoid fever are usually transmitted in drinking water_.

These disease agents may all be found in surface irrigation water systems, including canals, reservoirs, streams or rivers; groundwater rarely if ever is contaminated by these agents. Of all these diseases, cholera transmission has arisen from irrigation canals (India, Egypt), and hookworm transmission is known to occur by the side of irrigation canals and reservoirs in many areas. The provision of _untreated_, _piped_ irrigation water for drinking would likely result in very little transmission of the worm diseases, but the same cannot be said for the bacterial, protozoan or viral diseases. Depending on how the irrigation water is protected from fecal contamination or treated for disease agents, the water may or may not be safe for drinking.

Washing the body (except for contamination of body mucosal orifices) with irrigation water polluted by these bacteria, viruses or protozoa will usually not result in infection (tularemia is the exception; it can enter cuts and abrasions). The skin-penetrating worms (trichuriasis, ancylostomiasis, strongyloidiasis) can penetrate skin if present in bathing water, piped or not; the same is true for schistosomiasis (considered a "water-based" disease by Bradley (1977) and Feachem (1977)). Livestock bathed in such water is at the same risk.

Contaminated irrigation water used for washing dishes or clothing poses a risk to the dish- or clothes-washer, in the case of the skin-penetrating worms and tularemia, and perhaps for polio and leptospirosis, unless this water is properly treated first.

Watering household gardens with contaminated irrigation-water poses a risk of infection with any of the bacteria, protozoa or viruses, if the garden crop is eaten raw soon after being watered (i.e. while still wet). Ascaris eggs and the protozoan cysts, being resistant to drying, can pose a health risk to the consumer for several days after the garden crop has dried off.

In water, the cysts of Giardia, Entamoeba and Bolantidium can survive for several weeks, as can certain pathogenic bacteria and viruses (SDWC 1977).

Irrigation water contaminated with antibiotic-resistant bacteria or plasmids could be responsible for the transmission of such bacteria/plasmids to humans, whose internal bacteria (e.g. ETEC) might then "inherit" the antibiotic resistance (Dr. Hirsch (UC Davis), personal communication 1981). This transferable drug resistance is already a problem in livestock in some LDCs (Harold 1972).

Only proper protection of irrigation water sources, or proper treatment before use, will prevent irrigation water from being a vehicle for transmission of these fecal-orally transmitted diseases.

Water-Based Diseases:

The major water-based human diseases in LDCs are schistosomiasis; dracunculiasis; certain intestinal, liver or lung fluke diseases (fasciolopsiasis, heterophyiasis, metagonimiasis, echinostomiases, gastrodiscoidiasis; clonorchiasis, opisthorchiasis, fascioliasis; paragonimiasis); diphyllobothriasis; and primary amoebic meningoencephalitis (PAM). Of these diseases, schistosomiasis is by far the most important in public health, the most widespread, and the most closely associated with surface irrigation systems in LDCs.

All studies of human/water contact patterns to date indicate that schistosomiasis transmission occurs primarily along small irrigation canals or the shores of man-made lakes (Farooq and Mallah 1966; Amin 1977; WHO/TDR/SER-HWC/79.3). For example, in the Gezira irrigation scheme in Sudan, irrigation water distribution occurs via three types of canals (main, major and minor) and the field channels; of these, the minor canals are the most important foci of schistosomiasis transmission, "since snail populations there are large and man-water contact is high (Amin 1977)." The water contact studies reviewed in the WHO document (above) indicates that most schistosomiasis transmission occurs not as a result of drinking water ingestion, but as a result of the penetration of the skin when people are bathing, playing, or washing clothes or animals in infested canals or lakes or are gathering drinking water at canal- or lakeside, or wading across a canal. Schistosome infective cercarial *can* penetrate the mouth, throat or esophagous when infested water is drunk, but this route of transmission is considered minor, if not rare, in relation to the *normal route of skin penetration*.

Schistosomiasis is recognized by WHO as *one of the most debilitating diseases of LDCs*, with some 180 million people infected worldwide, and takes a toll on many LDC economies and communities, in terms of lost labor productivity and resources spent to control the disease (World Bank 1980). Yet infested irrigation water, pumped straight from a canal or lake, *protected* from further human contact, and *held* for 48 hours before any domestic use was made of it (48 hours is enough time for the infective cercariae to die), and then *piped* to households or community water pumps, would presumably be (schistosomiasis) *safe* for all domestic uses. If available in *sufficient quantities* for bathing, laundry, washing, etc. and *in a consistent manner*, and if otherwise *socially acceptable*, such a water supply could meet most domestic needs, *reduce the contact* with snail-infested canals or lakes, and thus perhaps *reduce the incidence* of schistosomiasis.

Dracunculiasis (guinea worm disease) results from the ingestion of water containing guinea worm-infected "water fleas" (the crustacean *Cyclops*). Irrigation water systems can harbor infected *Cyclops*, and people can obtain the infection if such water is drunk without being boiled or filtered to remove Cyclops. Guinea worm causes serious and lengthy physical debilitation in Africa and elsewhere (Belcher et al. 1975) but WHO believes it is the most likely disease to be reduced during the efforts of U.N. Safe Drinking Water Supply and Sanitation Decade (CDC 1981; Hopkins and Foege 1981). Irrigation water sources, if free of or protected from contamination by infected humans (or animals) bathing in it, or if treated as above before consumption, would be safe to drink. Such infested irrigation water could safely be used for boiling foods, bathing people or animals (if water isn't swallowed), doing laundry, or watering the home garden.

The human flukes and tapeworm parasites mentioned above all infect people when they ingest infested drinking or (more usually) ingest the aquatic intermediate animal hosts or aquatic plants. These fluke and tapeworm diseases are most common in irrigated areas, especially southeast Asian rice paddies, canals, and aquaculture ponds. If people and animals don't contaminate such waters with body exudates (feces, spittle) or if water is boiled before being drunk, or aquatic plants and animals are well-cooked before consumption, then such contaminated irrigation or pond water won't present such health hazards.

The amoebae causing PAM are rare, but present a more difficult control problem and are usually fatal. These soil-water amoebae prefer the warm, still waters of lakes, ponds and bays worldwide (Faust et al. 1970), and can probably be found in warm, slow-moving waters of irrigation canals. They actively penetrate the nasal sinuses of bathers, enter the brain, and cause rapid death. Drinking such infested (irrigation) water could conceivably cause infection, since the mouth-throat and nasal sinuses are connected. Since the amoebae are ubiquitous soil and water dwellers, their control in the environment is very difficult, thus prevention of PAM is the best option: boiling or purifying drinking and bathing water derived from irrigation systems or other surface waters.

Water-Washed Diseases:

The water-washed diseases of LDCs are listed by Feachem (1977) as: conjunctivitis, leprosy, scabies, skin sepsis and ulcers, tinea, trachoma, yaws, arthropod-transmitted typhus, and louse-borne relapsing fever. Leprosy, yaws, scabies, typhus and relapsing fever are normally transmitted by close personal contact and/or encounters with an arthropod vector; they are very rarely water-washed.

Conjunctivitis and trachoma may be commonly water-washed, with tinea, scabies and skin sepsis/ulcers less so. If transmitted in water, such transmission would normally take place in a common wash basin or ablution basin, perhaps in a small pond, but very rarely in an irrigation system. Irrigation water at the source (canal, lake, stream) would rarely be contaminated with enough to give an infectious dose, the author hypothesizes. Thus irrigation water "in site" or piped to a community, if properly protected or treated would rarely act as a source of transmission of water-washed diseases. Indeed, the provision of adequate quantities of such uninfected water, if not shared in common with other people (i.e. in a water basin or ablution urn), could actually reduce the prevalence, incidence or significance of these diseases - particularly (bacterial) skin sepsis and ulcers, as the water cleanses the dirty abrasion or bite sites where these arise.

Water-Related Insect-Trasnmitted Diseases:

Diseases found in LDCs in or near aquatic-habitats and transmitted by insect vectors are: African trypanosomiasis (sleeping sickness); many mosquito-borne diseases (malaria; sylvatic yellow fever, dengue, other mosquito-borne viruses; filariases); loiasis (African eye worm); tularemia; and onchocerciasis (river blindness).

The tse-tse fly transmitters of sleeping sickness often occur and bite near man-made bodies of water (lakes, canals) and natural waterways (Ault 1981:116-119). Provision of piped irrigation water to communities located away from the canal, river or lake could reduce the exposure of people to infected tse-tse fly bites (especially the riverine Glossina palpalis fly group of West Africa), assuming such water were provided in sufficient quantities consistantly, and the main water source had no other uses requiring close physical contact with the source (thus people would be generally out of the biting range of the riverine flies). Uncovered irrigation canals, especially earthen canals showing water seepage at their edges are good habitats for tsetse adults and pupae.

Many mosquitoes breed in irrigation systems (canals, reservoirs) and mate, lay eggs or bite near them. Surtees (1975) gives a table listing mosquitoes (and the diseases they transmit) favored by dam construction and irrigation, while NAS (1976) gives two tables listing rice-field breeding

Anopheles mosquitoes known to transmit malaria and filariases. Some malarial mosquitoes and the periodomestic Aedes mosquito vectors of sylvatic yellow fever breed in irrigation systems but may fly several kilometers away from such systems to bite (and hence transmit disease).

Horse flies and deer flies (which can transmit loiasis and tularemia), black flies, and some biting gnats (which can transmit 3 types of human viral encephalitis) often breed in or near any freshwater source and, like the mosquitoes, can fly some distance away from their water source to bite and transmit disease (Harwood and James 1979).

A covered or piped system to bring irrigation water to a community located away from the irrigation water source may reduce the exposure of people to the bites of such infected mosquitoes and flies, with the same provisos as those for tse-tse fly areas (above): adequate water quantity, consistent availability, social use and acceptability. Such a system, if uncovered and brought into a community may only aggrevate such disease problems.

INORGANIC COMPOUNDS IN WATER: HEALTH EFFECTS

The Safe Drinking Water Committee of the U.S. National Academy of Sciences (SWDC 1977) lists certain trace metals and other inorganic "solutes" as being of potential public health importance, and their recommended maximum safe concentrations for drinking water are found in Table 1.

WHO's International Standards for Drinking Water, 3rd edition (WHO 1971) recommends monitoring of the following inorganic compounds, as a minimum, in drinking water: arsenic, cadmium, cyanide, lead, mercury, selenium, flourides and nitrates.

The adverse health effects on humans of these inorganic chemicals in drinking water (and other systems) are reviewed and discussed in detail in SDWC (1977:205-477). The author will discuss in detail only two classes of such compounds: flourides and nitrates. These two are chosen as examples because the toxicity of one (flourides) is affected by daily air temperature variations and is thus a more serious concern in the tropics, while the other (nitrates) represents a class of inorganic compounds whose chemistry can change in water to possibly produce carcinogenic-precursor nitrogenous compounds.

Small amounts of fluoride in drinking water (1 mg/liter) in temperate areas of the world are generally considered to have a beneficial effect on prevention of dental caries, especially among children (SDWC 1977:433-434). Yet two forms of chronic toxic effects are generally seen as being caused by excessive longterm fluoride intake: mottling of the tooth enamel (dental fluorosis) and skeletal damage in children and adults (skeletal fluorosis) (SDWC 1977). In cold temperate climates, where the annual average of maximum daily air temperature (in °C) is 10-12°C, the WHO recommended lower and upper limits for fluorides in drinking water is 0.9 and 1.7 mg/liter, respectively (WHO 1971). In areas of the world (e.g. the warm, humid tropics) where such temperatures are 26.3-32.6°C those same limits are set at 0.6 and 0.8 mg/liter, respectively (WHO 1971). Dental fluorosis increases with the mean daily air temperature, at concentrations of only 0.8-1.6 mg/liter of fluorides (SDWC 1977:434).

All sources of combined nitrogen (e.g. municipal and industrial wastewater, refuse dumps, animal feed lots, septic tanks, manured or fertilized agricultural lands, urban drainages, and natural biochemical nitrogen fixation by aquatic freshwater plants such as *Azolla*) must be regarded as potential sources of nitrate, since natural waters have a tendency to convert all such nitrogenous materials to nitrate (after SDWC 1977:436). Nitrate is common in food and is secreted in human saliva, as well (SDWC 1977:437). Nitrates (and nitrites) pose two separate health hazards to humans: (1) an acute toxicity resulting in a form of anemia in infants (only), called methmeglobinemia, in areas where water contains more than 10 mg/liter nitrate; and (2) action as a carcinogen precursor where nitrates in water are reduced to nitrite, the latter reacting with secondary amines or amides in water (or food) to form the carcinogenic N-nitroso compounds (SDWC 1977:438). This latter step apparently occurs only in acidic waters or in a low pH (very acidic) stomach, pH 3.5 or less (SDWC 1977:438). Environmental conditions in the tropics (high temperature and humidity, microbiological contamination) are seen to favor formation of N-nitroso compounds (Preussman, in Smith and Babaunmi 1980).

An unusually high incidence of stomach cancer in certain mountainous areas of Colombia is associated with high concentration of nitrate in drinking water (SDWC 1977:438). Berwick (1979) discussed the problem of nitrate levels in groundwater from the Fleuve, Senegal, while Strathouse et al. (1980) discuss similar problems in California. Caro and Lever (1981) discuss the possible association between low level nitrate intake and cardiovascular disease in humans.

In agricultural irrigation systems, there occur certain inorganic compounds used as pesticides and fertilizers which may be of concern if some water is to be used in the domestic context.

Copper sulfate is a pesticide (specifically, a molluscicide) recently widely used to control the snail intermediate hosts of *Schistosoma* spp., the genus of flood flukes causing schistosomiasis. The material has a prolonged lethal effect on fish and other aquatic animals, and is toxic (though slightly) to humans and domestic livestock (Davey and Wilson, 1971). Copper sulfate, like the newer organic compound molluscicides which have mostly replaced it (niclosamide [Bayluscide], sodium pentachlorophenate ([NaPCP], and N-tritylmorpholine [Frescon]) (Davey and Wilson, 1971), is applied directly into irrigation water and other bodies of water, and thus contaminates that water source.

Various inorganic fertilizers are applied to soils scarce (or excessive) in certain plant nutrients. Examples are sulfur, lime (CaO base), nitrogen (inorganic forms), phosphorus, potassium, magnesium, manganese, calcium, sodium, molybdenum, boron, cobalt, copper, iron, zinc, and chloride (Tisdale and Nelson 1975). Note that several of these inorganic compounds also are listed in Table 1, together with the drinking water standards for them. They usually enter irrigation water as post-application runoff from fertilized soils or plants, and are often tied up with particulate matter in the soil or water, and/or with organic compounds containing the inorganic compound (e.g., urea, $CO(NH_2)_2$; dolomite, $CaMg(CO_3)_2$)

Sulfur is an example of an inorganic compound used both as a pesticide (specifically, an acaricide or miticide; and also as a fungicide) and as a fertilizer; as such, multiple opportunities exist for it to enter irrigation water in soil or agricultural runoff water. Sulfur usually appears in water as sulfate (SO_4), where, in the presence of magnesium or sodium, it can cause gastronintestinal irritation (WHO 1971);

thus WHO (1971) has set the "highest desirable level" of sulfate in drinking water at 200 mg/liter. Fortunately substances such as sulfate, iron, copper, chloride and magnesium can impart a distasteful flavor to drinking water (WHO 1971) at certain concentrations of the compounds, thus reducing the risk of excessive consumption of same in certain cases.

SOLID PARTICULATES IN SUSPENSION AND RADIONUCLIDES IN WATER: HEALTH EFFECTS

Particles of asbestos and other fibrous minerals and radionuclides can be found in surface and drinking water, depending upon the natural geophysiography of a region or the amount of man-made industrial pollution of water.

Contamination of drinking water with asbestos in Duluth, Minnesota has not revealed any increase in deaths to date from asbestos-induced cancer, but since the contamination began only 20 years ago, and since many cancers have long latent periods (30+ years), we may yet see such an increase among Duluth residents (SDWC 1977:189).

Clay, organic, and biological particulates in water can act as substrates to which toxic pesticides, metals, etc. can adhere and thus be ingested - for instance, viral-clay particulates are infectious to animal hosts (SDWC 1977:190).

Turbidity of water, as produced by particulates, can give only a gross indication of water pollution and thus potential adverse health effects of turbid waters; further water analyses are always needed (SDWC 1977:190).

Radionuclides of various types, especially natural ones, are unavoidable contaminants of all Earth's surface waters- they form a small part of the Earth's background or natural radiation effect on people. Potassium-40 is the major natural radionuclide found in drinking water, followed by certain bone-seeking radionuclides (SDWC 1977). Of the latter group, only radium caould pose a higher risk of bone cancer in some local areas of the world (SDWC 1977). Natural exposures are unavoidable, but radio-geologic studies may help find zones of high natural radium contamination in rural areas of LDCs.

Rural water supplies in LDCs, including irrigation water, will contain both particulates and radionuclides. They normally pose insignificant health risks if such water is used domestically. An exception would be in LDCs where large amounts of man-made pollution of waters used for irrigation occurs from factories, or from nuclear power plants (e.g. India, Brazil, Philippines, Pakistan, Egypt).

RECOMMENDATIONS

Introduction:

Based upon material presented above, as well as references and judgements given below, the author makes the following series of recommendations to USAID to mitigate or avoid adverse health effects which might arise when irrigation water is used for various domestic purposes in rural and agricultural areas of LDCs.

These recommendations focus primarily on ways to avoid or reduce the contamination of irrigation water with pesticides (and fertilizers), or the treatment of such water to remove pesticides. Limited attention is given to the other health issues involved in the domestic use of irrigation water: infectious diseases, other organic and inorganic contaminants of water, particulates in solution and radionuclides. This is a conscious decision based upon five factors: (1) relatively little is known about the health problems and risks presented to people who use pesticide-contaminated water; with a paucity of such knowledge, the most ethical public health position is a conservative one (expect the worst and emphasize prevention); (2) pesticide (and fertilizer) use is on the rise in LDCs, thus present problems can be expected to increase; (3) the same may be said for deforestation and soil erosion problems, which contribute to pesticide and fertilizer runoff into surface waters; (4) much more information is available in the literature on methods to control or treat water-related infectious diseases than on health problems caused by pesticides in the environment, especially water; so this paper emphasizes the pesticide issue; (5) except in some local regions, the potential health problems to arise from the presence of other organic and inorganic chemicals, particulates and radionuclides in rural water sources in LDCs are probably slight.

Design Alternatives for Dual Irrigation/Domestic Water Systems:

In order to maximize the protection of public health, dual purpose (agricultural irrigation/domestic water provision) irrigation systems should be designed as follows:

- Groundwater based sources should be preferred over surface water based sources for such dual systems, as contamination problems should be less for groundwater. Infiltration galleries are one example of a groundwater based system which can be used in such a dual manner.
- If surface water is used it should be piped or otherwise covered to protect it from runoff contamination during conveyance to the community.
- The domestic water part of a dual irrigation system, including the conveyance system, must provide water in adequate quantity (e.g. via large pipes, good pumps) and in a consistent manner through time, in order to reduce opportunities for people to pollute the irrigation water source or become infected at the source (e.g. with schistosomiasis, sleeping sickness, river blindness, hookworm).
- Any dual irrigation system design chosen must be socially and politically acceptable to the community (cf. Freeman and Lowdermilk 1981; Levine and Hart 1981; Taylor and Wickham 1979; Coward 1977; Coward and Ahmed 1979).
- Any design chosen must be financially maintainable, in the majority, by consumer/community funds, to ensure long-term system operation (World Bank 1976; Saunders and Warford 1976).

Siting of Dual-Use Irrigation Systems:

-The careful choice of site for a dual purpose water system is the best way to mitigate or avoid the problem of pesticide contamination of drinking/irrigation water, according to Pan American Health Organization officials (David Donaldson, Harold Hubbard of PAHO, personal communication 1981).

-Such dual irrigation systems should not be sited in cotton agroecosystems or in watersheds/command areas containing cotton fields, because of the high incidence of heavy pesticide use on cotton and attendant health problems (e.g. in Central America, Sudan, Egypt, California).

-All possible sites for such systems should be thoroughly assessed geochemically and biologically for the presence of pesticide residues, infectious disease agents, etc. prior to the final choice of site. Sites with severe problems of residues or disease should not be chosen if possible.

-A preferred site when a (ground or) surface water source is used would be a watershed exposed to minimal pesticide use.

-The site chosen should result in minimal or no trade-off with agricultural production, with regard to the domestic water demand component of the dual system; excessive domestic water demand over agricultural irrigation water demand could result in a decline in agricultural productivity, with concurrent decline in nutritional status. Since the amount of irrigation water used for domestic purposes would be slight compared to that used to irrigate crops, this should not normally be a problem physically.

Irrigation/Domestic Water Treatment:

-There is no satisfactory treatment system available to economically remove pesticide residues from irrigation or drinking water in rural areas of LDCs, other than the natural treatment provided irrigation water derived from deep groundwater (ie. percolation) or infiltration galleries.

-The high costs, inavailability and complexity of chemical treatments of water to remove pesticide residues make such techniques inappropriate and uneconomic for use in rural areas of LDCs.

-The storage and settlement of water prior to use will not significantly reduce pesticide residues. Water storage of 48 hours will allow the natural death of the infective stage of schistosomiasis (the cercariae), and usually reduce most pathogenic bacterial populations (e.g. ETEC)(Mann and Williamson 1976).

-Flocculation (coagulation) of water contaminants, using certain chemicals, is an inappropriate (expensive, complex) method for use in LDCs (Mann and Williamson 1976).

-Water filtration (e.g. slow sand filtration) through sand, diatomaceous earth, carbon (charcoal) or other local media (cotton, clay, coconut husks, burnt rice) can be used to filter out/absorb some microorganisms (parasites, bacteria, viruses) and, less satisfactorily, for pesticide residues (Malina 1977; Richford 1977; WHO 1979; SDWC 1980a).

-Aeration of water (e.g. by trickling filters) can assist in the breakdown of some pesticide residues and microorganisms, reduce the iron and manganese content of water, and improve the taste and odor of water (Pickford 1977; Dayhoff 1977).

-Sterilization of water by rapid boiling for 30 minutes will destroy most microorganisms and break down some pesticides, but is useful only at the household level (ie. very small quantities of water - a potful); it carries with it a high cost in fuelwood/charcoal use, time and labor expended to collect the fuel, and perhaps deforestation and soil erosion (Fleuret and Fleuret 1978).

-Chlorination of water in an appropriate manner can disinfect water of many bacteria, cercariae and some viruses (SDWC 1977, 1981a), as can other chemical treatments. Some protozoan cysts are resistant to such treatments, and chlorination of drinking water has been associated with increased cancer in some human populations (SDWC 1977, 1980a). Chlorination still represents our bestmethod for the chemical disinfection of irrigation/drinking water, with regard to microorganisms, in LDCs (Orihuela et al. 1979).

-Solarization of drinking water by sunlight, a new experimental to kill pathogenic bacteria in water (Acra et al. 1980), is probably useful only for very small quantities of water at a time (e.g. one liter) as used in the household; its use to disinfect an entire community's irrigation/domestic water system is remote at present.

Environmental Management and Water Supply Protection:

-Because of the complex series of interactions between pesticides, the environment and human health (e.g. a 30 year lag time between initial environmental contamination and evidence of increased cases of cancer), and the difficulty in obtaining good health risk estimates (SDWC 1980b), it is best to take a preventive approach to pesticide residue management.

-An environmental management program to protect irrigation water from environmental pollutants (runoff, aerial pesticide drift) should consist of the following components: a pollutant detection system, a pollutant identification system, a continual (through time) sampling/monitoring/survey system (CRME 1981; NAS 1977), and various control programs (e.g. water quality, integrated pest management (IPM), disease control, soil conservation and erosion control, afforestation, livestock and wildlife management).

-In rural areas of LDCs, any chemical pollutant detection and identification system should focus on what potential water pollutants (pesticides, fertilizers) are being applied to cropland or forests or surface water itself. Under rural conditions, this information is easier to obtain than the actual sampling and analysis of pollutants in waters, and is probably a more cost-effective approach. Usually, such information is obtainable simply by asking local farmers, agricultural officials, and other residents what chemicals are used locally.

-The probability of these pollutants reaching surface waters, and in what concentrations, can then best be estimated by using various pesticide runoff models (e.g. Steenhuis and Walter 1980; Haith 1980; Wauchope and Leonard 1980; Overcash and Davidson 1980).

- Pesticide persistence or breakdown in water is a complex question (Sharom et al. 1980ab), but a new simple technology for pesticide residue analysis in water (Hammock and Mumma 1980; Hammock et al. 1980) may enable us to cheaply and rapidly determine the presence or absence of a given pesticide residue or its breakdown products; this development should be carefully followed by USAID.
- Since, of all the pesticides, wettable powder herbicides, leaf-applied OC insecticides, paraquat, and the arsenical herbicides are most prone to run off into water (Wauchope 1978; Overcash and Davidson 1980), their use should be limited in areas where irrigation water may be used domestically; most of these pesticides are both acutely and chronically toxic (compare Wauchope's list with the health data in SDWC 1977).
- Because of its tendency to readily enter groundwater (CEQ 1980a), the pesticide DBCP makes groundwater-derived irrigation water in DBCP-use areas a great risk to human health (DBCP is a human sterilant and causes cancer at low doses); the use of such contaminated water for drinking should be completely avoided.
- Sampling/monitoring/surveillance systems (CWCPPECE 1975; NAS 1977,1981; Hakanson 1980; Kohn 1980) should be created and maintained for both local water quality and water-related diseases in any dual water system project.
- If the monitoring system shows water quality is poor (or water-related diseases are prevalent), the following control strategies or programs should be initiated locally, depending

upon the nature of the problem:

(1) Integrated Pest Management (IPM) and Plant Protection: to reduce pesticide use on crops (NAS 1969, 1975; Metcalf and Luckman 1978).

(2) Reforestation and Soil Conservation (Colman 1953): to reduce soil erosion by wind and rain which may spread pesticide residues, and minimize habitat disruption which might increase disease vector populations.

(3) Multiple-Crop Permanent Agricultural Systems (ASA 1976; Mollison 1979): to help stabilize the agroecosystem (Vandermeer 1981), which may in turn allow for reduced pest and disease problems and thus less dependence on pesticides to control them.

(4) Reduced Use of Pesticides Along Waterways: herbicides and insecticides applied along canal banks or in the canal (NAS 1976b; CEQ 1981; Gangstad 1978, 1980) - such an actions may have trade-offs with other public health problems (e.g. schistosomiasis control) and should be carefully examined first before implemented as a strategy.

Human Management and Water Quality and Health Protection:

-USAID should continue to stress with host country officials and project beneficiaries the importance of IPM as a strategy to reduce pesticide resiudes in the rural environment, including water supplies, and to protect their health. The costs of poor pesticide management far outweigh the gains perceived by farmers (NAS 1976), both financially and in terms of public health. USAID should continue to finance IPM programs in LDCs.

-Environmental and health education for project beneficiaries and host country officials should be a major part of every rural development or irrigation project; such education should stress the acute and long-term adverse effects of improper pesticide use and the importance of proper, careful use of pesticides (cost savings, health benefits, etc.).

-In the domestic arena, USAID should continue to stress the need for and importance of a strong hazardous substances export policy for U.S. pesticide manufacturers and marketeers (CEQ 1981; Weir and Schapiro 1981), to discourage such businesses from exporting pesticides banned or restricted for use in the U.S. (e.g. DBCP in Colombia) - "dumping."

-In the host country arena, USAID should encourage host country officials to develop and enforce hazardous substances import policies, laws and regulations.

-Host country officials should be encouraged by USAID to emphasize among their multinational and national pesticide businesses to act ethically and in the interests of public health, as well as with an eye to sustained agricultural production.

-USAID and host country officials should continue to emphasize and <u>sensitize agriculturalists and rural development project engineers</u> to the direct and indirect adverse health and environmental impacts their practices may incur, and the short and long-term benefits (better health and agricultural productivity sustained) to be gained by good environmental design of projects and agricultural practices (USAID 1980).

APPENDIX 1: TOXICOLOGY

Toxicology is the qualitative and quantitative study of the injurious effects of chemical and physical agents, as observed in alterations of structure and response (behavior) in living systems (after Hayes 1975). Toxicity, strictly defined, refers simply to the toxic (poisonous) dosage of any particular compound for a given species or organism (Hayes 1975:64). In lay terms, such toxicity is thought of as <u>acute toxicity</u> (i.e., what dosage brings about immediate or short-term illness).

Translated into quantitative terms, acute toxicity is most often measured in terms of the LD_{50} (lethal dose, 50% of population) value, i.e., in a given animal species and population, the LD_{50} is the dosage of chemical (or physical) agent which will kill 50% of that population immediately or in the short term (a few hours or days). Chemicals are usually classified for <u>acute toxicity</u> according to their LD_{50} values (Matsumura 1975); the convention is as follows:

Toxicity Category	LD_{50} Value
extremely toxic	< 1 mg/kg
highly toxic	1-50 mg/kg
moderately toxic	50-500 mg/kg
slightly toxic	0.5-5 g/kg
practically nontoxic	5-15 g/kg
relatively harmless	> 15 g/kg

The kilogram (kg) value above refers to the body weight of the animal ingesting the toxicant. Other less common expressions of acute toxicity exist (see Hayes 1975).

Toxicity in the broader sense includes chronic toxicity and other usually non-acute phenomena as: (Hayes 1975; Brand and Ames 1979; SDWC 1977:800-804).

1) neurotoxicity - delayed or persistent paralysis
2) teratogenicity - "monster"-causing; any influence during pregnancy that leads to birth defects
3) carcinogenicity - causing cancer (abnormal rapid cell division or growth)
4) mutagenicity - causing inheritable mutations (related to teratogenicity); includes chromosome "scrambling" and "point" mutations within chromosomes)
5) hypersensitivity and allergy
6) interference with cellular metabolism and storage
7) unnatural enzyme induction (stimulation or inhibition of enzyme activity)
8) other alterations in behavior

Each form of toxicity measurement, and most commonly acute toxicity measures, is also classified by the route of exposure. The route of exposure is an important parameter not only in terms of the variability seen in toxic effects, but in terms of measures which could be taken to prevent or reduce personal exposure to pesticides. Those routes are commonly noted as: oral, topical, contact, dermal, inhalation, or interperitoneal exposure (J. Granett, personal communication 1981).

Other factors affecting toxicity are the concentration of the pesticide compound in a water source, duration of the person's exposure; pH and alkalinity of the water source, the person's age, sex, health and nutritional status and genetic background; the degree of acclimatization to the toxicant; the actual dose absorbed by the person's body; and potentiation and antagonism with other toxicants present either in the water source or in the person's body (partly after Hartung 1977).

Exposure safety guidelines for many pesticides and other organic and inorganic substances are usually set for industrial exposure, for adult white males in good health, weighing 160 lbs. and working an 8-hour shift (Freedman 1981), and are usually set for acute toxic effects through inhalation or skin contact. These types of criteria are not particularly useful for considering pesticide residues in domestic water.

As well, any criteria for pesticide exposure, in water (or other media), should and may well vary among different ethnic groups (Smith and Bababunmi 1980) and among infants, and children (Babich and Davis 1981; DiPerna 1981; Freedman 1981), pregnant or lactating women, elderly people, and for acutely or chronically malnourished, underweight or ill people. The problem of multiple exposure routes to such pesticides (food, skin contact, inhalation, ingestion of water) merely increases the health risks and the analysis of such risks (Durham 1967).

Often, epidemiological evidence may be the only tool we have to elucidate causality and define health policy toward pesticides or other pollutants and toxic substances (Lave and Seskin 1979), and we must use it such as it is.

TABLE 1

Inorganic Compound	No-Adverse Effect Maximum Limit of Concentration/Liter of Drinking Water (Authority)*	Natural Occurance in Surface Water/Liter**
Barium	1.0 mg (NAS)	2-340 μg
Beryllium	0.2 μg (USSR)	< 0.22 μg
Cadmium	10 μg (USPHS)	< 1.0 μg
Chromium	0.05 mg (NAS)	0.7-84 μg
Cobalt	1.0 mg (USSR)	< 1.0-99.0 μg
Copper	1.0 mg (NAS)	≤ 860 μg
Lead	≤50 μg (NAS)	1-10 μg
Magnesium	30-150 mg (WHO)	4 mg
Mercury	1 μg (WHO)	≪ 10 μg
Molybdenum	0.5 mg (USSR)	2-1500 μg; median 10 μ
Silver	0.5 mg (Illinois)	0.1-38 μg; median 1.6 μ
Tin	none	0.8-30 μg
Vanadium	0.1 mg (USSR)	2-300 μg
Zinc	5 mg (NAS)	≪ 5 mg
Manganese	none	0.4-1.1 mg
Nickel	none	≤ 100 μg
Arsenic	≤50 μg (NAS)	10-110 μg; median 10 μg
Selenium	0.01 mg (WHO)	≤10-2000 μg
Fluoride	none	0.2-4.4 mg+
Sodium	≤20 mg for hypersensitive persons (NAS)	0.4-1900 mg
Nitrate	~10 mg (NAS)	0-127 mg
Sulfate	500 mg (NAS)	0.1-1000 mg+

*most conservative value used if different authorities give different values; source: SDWC 1977

source: SDWC 1977

*TABLE 2: Organic Pesticides and Other Organic Contaminants in Drinking Water, Concentration, Toxicity, ADI, and Suggested No-Adverse-Effect Levels

Compound	Maximum Observed Concentrations in H_2O, μg/liter	Maximum Dose producing No Adverse Effect mg/kg/day	Uncertainty Factor[a]	ADI[b] mg/kg/day	Suggested No-Adverse-Effect Level from H_2O μg/liter Assumption[r]	
					1	2
2,4-D	0.04	12.5	1,000	0.0125	87.5	4.
2,4,5-T		10.0	100	0.1	700	35.0
TCDD		10^{-5}	100	10^{-7}	7x10^{-4}	3.5x10^{-5}
2,4,5-TP	detected[d]	0.75	1,000	0.00075	5.25	0.26
MCPA		1.25	1,000	0.00125	8.75	0.44
Amibel		250	1,000	0.25	1,750.0	87.5
Dicamba		1.25	1,000	0.00125	8.75	0.44
Alachlor	2.9	100	1,000	0.1	700.0	35.0
Butachlor	0.06	10	1,000	0.01	70.0	3.5
Propachlor		100	1,000	0.1	700.0	35.0
Propanil		20	1,000	0.02	140.0	7.0
Aldicarb		0.1	100	0.001	7	0.35
Bromacil		12.5	1,000	0.0125	87.5	4.4
Paraquat		8.5	1,000	0.0085	59.5	2.98
Trifluralin (also for Nitralin and Benefin)	detected	10	100	0.1	700.0	35.0
Methoxychlor		10	100	0.1	700.0	35.0
Toxaphene		1.25	1,000	0.00125	8.75	0.44
Azinphosmethyl		0.125	10	0.0125	87.5	4.4
Diazinon		0.02	10	0.002	14.0	0.7
Phorate (also for Disulfoton)		0.01	100	0.001	0.7	0.035
Carbaryl		8.2	100	0.082	574	28.7
Ziram (and Ferbam)		12.5	1,000	0.0125	87.5	4.4
Captan		50	1,000	0.05	350	17.5

Table 2, con't.

Folpet		160	1,000	0.16	1,120	56.0
HCB	6.0	1	1,000	0.001	7	0.35
PDB	1.0	13.4	1,000	0.0134	93.8	4.7
Parathion (and Methyl parathion)		0.043	10	0.0043	30	1.5
Malathion		0.2	10	0.02	140	7.0
Maneb (and Zineb)		5.0	1,000	0.005	35	1.75
Thiram		5.0	1,000	0.005	35	1.75
Atrazine	5.1	21.5	1,000	0.0215	150	7.5
Propazine	detected	46.4	1,000	0.0464	325	16.0
Simazine	detected	215.0	1,000	0.215	1,505	75.25
Di-n-butyl phthalate	5.0	110	1,000	0.11	770	38.5
Di(2-ethyl hexyl)	30.0	60	100	0.6	4,200	210.0
Hexachlorophene	0.01	1	1,000	0.001	7	0.35
Methyl methacrylate	1.0	100	1,000	0.1	800	35.0
Pentachlorophenol	1.4	3	1,000	0.003	21	1.05
Styrene	1.0	133	1,000	0.133	931	46.5

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[a] Uncertainty factor--the factor of 10 was used where good chronic human exposure data was available and supported by chronic oral toxicity data in other species, the factor of 100 was used where good chronic oral toxicity data were available in some animal species, and the factor 1,000 was used with limited chronic toxicity data.

[b] Acceptable Daily Intake (ADI) - Maximum dose producing no observed adverse effect divided by the uncertainty factor.

[c] Assumptions: Average weight of human adult = 70 kg. Average daily intake of water for man = 2 liters.

1. 20% of total ADI assignment to water; 80% from other sources
2. 1% of total ADI assigned to water; 99% from other sources

[d] Detected, but not quantified.

*From NAS 1977:796-797
"
SDWC 1977

*TABLE 3: Organic Pesticides and Other Organic Contaminants Found in Drinking Water, with Insufficient Data on Chronic Toxicity to Calculate an ADI

Compound	Highest Concentration in Finished Water, μg/liter
Acetaldehyde	0.1
Acrolein[a]	
Bromobenzene	detected[b]
Bromoform	detected
Carbon disulfide	detected
Chloral	5.0
Chlorobenzene	5.6
Cyanogen chloride	0.1
1,2-Dichloroethane	21.0
2.4-Dichlorophenol	36.0
2,4-Dimethylphenol	detected
e-Caprolactam	detected
Hexachloroethane	4.4
o-Methoxyphenol	detected
Methyl chloride	detected
Methylene chloride	7.0
Phenylacetic acid	4.0
Phthalic anhydride	detected
Propylbenzene	< 5.0
t-Butyl alcohol	0.01
Tetrachloroethane	4.0
Tetrachloroethylene	< 5.0
Toluene	11.0
Trichlorobenzene	1.0
1,1,2-Trichloroethane	detected
Nicotine	3.0
Methomyl[a]	
Cyanazine	detected
Xylene	< 5.0

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[a] Not detected in finished water.

[b] Detected = detected but not quantified.

*from NAS 1977:798

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SDWC 1977

*TABLE 4: Organic Contaminants Found in Drinking Water with No Available Information on Chronic Toxicity

Compound	Highest Concentration in Finished water, µg/liter	Highest Concentration in Raw Water, µg/liter
1,2-*Bis*(chloroethoxy) ethane	0.03	
Bis(2-chloroisopropyl) ether	1.58	
Bromochlorobenzenes	detected	
Bromodichloromethane	116	11
Butyl bromide	detected	
Chloroethyl methyl ether	detected	
Chlorodibromomethane	100	1.4
Chlorohydroxybenzophenone	detected	
Chloromethyl ethyl ether	detected	
Chloropropene	detected	
Crotonaldehyde	5.0	
Dibromobenzene	detected	
Dibromodichloroethane	0.63	
1,3-Dichlorobenzene	< 3.0	
Dichlorodifluoroethane	detected	
Dichloroiodomethane	0.5	
1,1-Dichloro-2-hexano	1.0	
1,2-Dichloropropane	< 1.0	
1,3-Dichloropropene	< 1.0	
1,2-Dimethoxybenzene	detected	
4,6-Dinitro-2-aminophenol	detected	
Dioctyladipate	20.0	
Hexachloro-1,3-butadiene	0.07	
Isodecane	5.0	
Metachloronitrobenzene	detected	
Methylstearate	detected	
Nonane	4.0	
Octyl chloride	detected	
Pentachlorophenyl methyl ether	0.1	
1,1,3,3-Tetrachloroacetone	1.0	1.0
2,4,5-Trichlorophenol	detected	
Trimethylbenzene	6.1	

*from NAS 1977:799
"
SDWC 1977

*TABLE 5: Categories of Known or Suspected Organic Chemical Carcinogens Found in Drinking Water

Compound	Highest Observed Concentrations in Finished Water µg/liter	Upper 95% Confidence Estimate of Lifetime Cancer Risk per µg/liter
Human carcinogen		
Vinyl chloride	10	4.7×10^{-7}
Suspected human carcinogens		
Benzene	10	I.D.
Benzo(*a*) pyrene	D.	I.D.
Animal carcinogens		
Dieldrin	8	2.6×10^{-4}
Kepone	N.D.	4.4×10^{-5}
Heptachlor	D.	4.2×10^{-5}
Chlordane	0.1	1.8×10^{-5}
DDT	D.	1.2×10^{-5}
Lindane (γ-BHC)	0.01	9.3×10^{-6}
β-BHC	D.	4.2×10^{-6}
PCB (Aroclor 1260)	3	3.1×10^{-6}
ETU	N.D.	2.2×10^{-6}
Chloroform	366	1.7×10^{-6}
α-BCH	D.	1.5×10^{-6}
PCNB	N.D.	1.4×10^{-7}
Carbontetrachloride	5	1.1×10^{-7}
Trichloroethylene	0.5	1.1×10^{-7}
Diphenylhydrazine	1	1.1×10^{-7}
Aldrin	D.	I.D.
Suspected animal carcinogens		
Bis (2-chloroethyl) ether	0.42	1.2×10^{-6}
Endrin	0.08	I.D.
Heptachlor epoxide	D.	I.D.

I.D. = insufficient data to permit a statistical extrapolation of risk;
N.D. = Not detected;
D. = Detected but not quantified.

*from NAS 1977:794
"
SDWC 1977

TABLE 6 *

PESTICIDES: HERBICIDES

Chlorophenoxys: 2,4-D
2,4,5-T and TCDD (a dioxin)
2,4,5-TP and MCPA (Silvex)
Benzoics: Amiber (Chloramben)
Dicamba
Amides: Alachlor, Butachlor, Propachlor
Propanil
Triazines: Atrazine, Simezine, Propazine, Cyanazine
Uracil: Bromacil
Bypyridl: Paraquat
Dimitroanile: Trifluralin (Treflan), Nitralin, Benefin
Aldehyde: Acrolein

PESTICIDES: INSECTICIDES

Chlorinated Hydrocarbons: Aldrin, Dieldrin, Endrin, Chlordane, Heptachlor and Heptachlor Epoxide
DDT and DDE
Methoxychlor
Benzene Hexachloride (BHC) and Lindane
Kepone
Toxaphene
Organophosphates: Azinphosmethyl
Diazinon
Phorate and Disulfoton
Malathion
Parathion and Methyl Parathion
Carbamates: Aldicarb and Methomyl
Carbaryl

PESTICIDES: FUNGICIDES

Dithiocarbamates: Ferbam, Maneb, Zineb, Nabam, Thiram, and Ziram (and ETU)
Phthalimides: Captan and Folpet
Other Fungicides: Hexachlorobenzene (HCB)
Pentachloronitrobenzene (PCNB)

PESTICIDES: FUMIGANTS

p-Dichlorobenzene (PDB, Paracide)

OTHER ORGANIC CONSTITUENTS

Acetaldehyde
Benzene
Benzo(a)pyrene
Bromobenzene
Bromoform
tert-Butyl Alcohol
e-Caprolactam
Carbon Disulfide
Carbon Tetrachloride

TABLE 6, con't.

Chloral
Chlorobenzene
bis (2-Chloroethyl) ether
Chloroform
Cyanogen Chloride
Di-n-Butylphthalate
1,2 -Dichloroethane
2,4 -Dichlorophenol
Di (2-ethylhexyl) phthalate (DEHP)
2,4-Dimethylphenol
Diphenylhydrazine
Hexachloroethane (HCE)
Hexachlorophene (HCP)
o-Methoxyphenol
Methyl Chloride
Methylene Chloride (dichloromethane)
Methyl Methacrylate
Nicotine
Pentachlorophenol (PCP)
Penylacetic Acid
Phthalic Anhydride
Polychlorinated Biphenyls (PCBs)
Propylbenzene
Styrene
1,1,1,2-Tetrachloroethane
Tetrachloroethylene
Toluene
Trichlorobenzene
1,1,2-Trichloroethane (vinyl trichloride)
Trichloroethylene (trichloroethene)
Trichlorofluoromethane (Freon 11)
Vinyl Chloride
Xylenes

*prepared from SDWC 1977

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