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HEALTH CONSEQUENCES OF WASTEWATER REUSE

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INTRODUCTION AND OVERVIEW

Wastewater reuse is one element of the water resources management of an area. Reuse involves considerations of public health and may also involve considerations of water conservation, water pollution control, and water utility management. Among sanitary engineers this has been a subject of growing interest for at least three generations. Reuse is only one alternative in planning to meet the water resource needs of an area. Water recycling, water conservation, and new project development are other alternatives. Whether reuse will be appropriate depends upon economic considerations, potential uses for the reclaimed water, the degree of severity of waste discharge requirements, and public policy wherein the desire to conserve rather than develop available water resources may override economic and public health considerations.

Domestic wastewater was first reused in the nineteenth century with the development of sewerage systems. Farms using raw sewage were established in England, Australia, Germany, France, and Italy after 1870. By 1900 sewer farms were numerous in the old and the new world; for example, ten California communities had sewer farms. These "farms" were primarily disposal operations and incidental use was made of the water for crop production. It is reported that by 1910, 35 California communities were using sewage for irrigation—11 without previous treatment, 24 after septic tank treatment (1).

Gradually, landmark "uses" were initiated. In 1926, at Grand Canyon National Park, treated wastewater was first used in a dual water system for

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toilet flushing, lawn sprinkling, cooling water, and boiler feed water (2). In 1929, the city of Pomona, California initiated a project utilizing reclaimed wastewater for domestic irrigation of lawns and gardens (3). In 1930, a pilot plant was put into operation in Los Angeles that was intended to produce potable water from sewage effluent (4). In 1931, San Diego Teachers College (California) initiated a lawn and shrubbery irrigation project (3). In 1932, the Golden Gate Park (San Francisco, California) reuse project was initiated for lawn watering and supplying ornamental recreational lakes (5). In 1942, use of chlorinated sewage effluent from the city of Baltimore, Maryland was begun at the Sparrows Point plant of the Bethlehem Steel Company (6). The Kaiser steel mill in Southern California has reclaimed plant wastewater for industrial purposes at the mill since the mid-1940s. In 1960, a dual water system was begun at Colorado Springs, Colorado, which now supplies reused wastewater principally for landscape irrigation at golf courses, parks, cemeteries, and freeways. Beginning in 1962, a major groundwater recharge project by surface spreading was initiated at Whittier Narrows (California), the first major deliberate recycling of wastewater into sources of domestic water supply (7). In 1965, the Santee (California) recreational lakes, supplied with reused wastewater, were opened for swimming (7). Potable reuse has been practiced intermittently since 1969 at Windhoek, Namibia, where reclaimed water has been 10–20% of the water supply. In 1975, groundwater recharge by direct injection of reused wastewater into groundwater aquifers was started by the Orange County Water District (California) (7). In 1977, the Irvine Ranch Water District (California) initiated a major residential landscape irrigation project with a dual water system delivering reused wastewater (7). Also in 1977, another major nonpotable urban reuse system was initiated, in St. Petersburg, Florida (8).

Some of these projects have been developed as a matter of necessity to meet water needs, but many were developed to take advantage of the wastewater as a resource or as a means of waste disposal. In the US, as waste discharge requirements have become increasingly strict, the federal water pollution control agency (EPA) has viewed reuse as an attractive alternative to take advantage of the higher quality effluents being produced.

Through the years the trend generally has been to increasingly "higher" uses, with attendant greater health risks, which in turn require higher levels of treatment and higher standards requiring better quality end-product waters. With respect to these higher uses, questions have been raised about (*a*) viruses with which intimate human contact was likely or possible, (*b*) disease transmission through aerosols, and (*c*) "stable organics" where the reused water is likely to become a part of the community water supply. With the prospect that truck crops would be irrigated with reused wastewater, public health authorities again raised questions about the possibilities of infectious disease transmission through the food crops and about appropriate water quality standards. Research efforts are underway to attempt to define and refine scientific information in order to set policies and establish standards for these various practices.

Regarding major projects for groundwater recharge to augment domestic water supply sources, there is considerable controversy over whether public health authorities should withhold approval pending development of definitive water quality standards or whether such projects should be approved forthwith. Advocates of recharge projects urge approval as a measure to conserve water since the recharge would substitute for new water development projects or protect depleting basins. The central issue is one of "necessity," both as to the need for reuse projects and the degree of treatment required by public health authorities.

Increasing use will be made of treated wastewater, particularly for agriculture and industry, for groundwater recharge if problems from organic compounds can be resolved, and perhaps for nonpotable urban dual water systems. Projects adjusted to local conditions will be developed that take into consideration the quality of community wastewater, the market for possible uses, public health standards, energy and dollar costs, availability of alternative water supplies, and matters of public policy relating to resource development and acceptability of risk.

With respect to direct potable reuse, advocates hold that safe water can be produced and that direct potable reuse should proceed as appropriate. Others hold that the practice is unnecessary, carries with it unreasonable levels of risk, and that it is not possible with current scientific knowledge to promulgate comprehensive standards. The issue of direct potable reuse is receiving attention far beyond what is appropriate, considering the small potential for this ultimate degree of reuse.

WASTEWATER REUSE AS A WATER RESOURCE

Some communities are, or soon will be, reaching the limits of their available water supplies. By instituting conventional conservation measures, communities may be able to defer the need to develop additional water resources, but urban growth and development will press inexorably on existing supplies. Additional water resources will be needed eventually.

But not all communities have ready access to additional sources of water. Developing additional supplies generally requires going further, or shifting from groundwater to surface waters, or using lower quality or polluted sources—all of which entail greater costs for both transmission and treatment.

Tapping of polluted sources has potential effects that go beyond the increased cost of additional treatment. This sort of "indirect reuse" of polluted water may expose people to health risks not associated with protected sources. The chemical revolution of the last decades has created vast numbers of long-lasting synthetic organic chemicals that pose a health threat. Some of these chemicals are carcinogenic, even in trace concentrations, when ingested over long periods of time. The health concerns associated with drawing upon polluted sources apply even more forcefully to wastewaters reused for potable purposes.

By replacing with reclaimed water the potable water used for nonpotable purposes, an increased population can be served from an existing source. The concept of source substitution is endorsed by the United Nations Economic and Social Council in its policy for planned water reuse: "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade" (9).

Another factor favors water reuse: the technological advances made in wastewater treatment. Stringent water-pollution control requirements have resulted in the construction of wastewater treatment plants that turn out effluents of high quality. Many of these plants incorporate costly nutrient-removal processes—processes that are generally not necessary if the effluent is to be reused. For irrigation, for example, the nutrients are beneficial and should not be removed.

Reuse might be promoted because it satisfies the conservation ethic, but it will only be widely adopted, and successful, if it is economical. To determine the economics of wastewater reuse, a survey must be employed that determines the kind of uses and the quantity of reused water for which there is a market, depending upon the cost of the reused water delivered to the prospective users. This cost includes the cost charged to treatment and that for delivery. Cost of treatment for each category of use is contingent upon the establishment of and compliance with public health (and other) standards of treatment and quality. Higher standards require more treatment which increases cost of waters.

The cost of treatment is the incremental cost for the additional treatment necessary to meet the quality requirements for reuse, above and beyond the regulatory requirements for wastewater disposed in the environment. The cost of treatment presents little or no problem for "lower" class uses, such as irrigation of fodder and fiber crops. However, for "higher" class uses, such as truck crop irrigation, spray irrigation of parks and playgrounds, groundwater recharge for potable reuse, and—in the extreme—direct potable reuse, cost of treatment may be much higher. Further, standards either have not been promulgated (groundwater recharge and direct potable reuse) or are controversial (spray irrigation of parks) because they are said to be too stringent. From the point of view of the public health regulatory group, where standards do not exist or costs of meeting standards are too high, other uses should be considered. If insufficient market exists for the permissible uses, then other water resource alternatives should be selected. The reality of reuse proposals, however, as opposed to theory, is that if the wastewater available for reuse cannot be marketed for uses in which standards are well established, the proponents of reuse vigorously press the public health regulatory authorities for relaxation of controversial standards or for hasty promulgation of previously undeveloped standards—standards to be met, or perhaps only approximated.

Health authorities are often charged with being obstructionist and too conservative, thereby preventing large-scale reuse of water. In order to form a sound policy, the following question should be considered: (*a*) is a reuse operation necessary as a water resource alternative; (*b*) what level of risk control is attained by a standard; (*c*) how valid is the judgment of that level of risk or, conversely, the acceptability of a given degree of risk?

Risk analysis as applied to reused wastewater entails the same difficulties as that for other health hazards in the environment. Basically, the problem lies in quantifying the risks involved and agreeing upon what level of risk to accept. W. W. Lowrance (67) points out that expressions of risk are compound measures describing both the probability of harm and the severity. They may describe the risk to individuals, to particular groups, or to society as a whole. They are usually broad statistical measures that take into account the chance of exposure as well as the chance of adverse effect from that exposure.

Handler's comments regarding risk are pertinent to wastewater reuse (68):

> It has become a function of government to determine whether a given technological benefit is worth the attendant risk where such exists; it also assesses whether the cost of mitigating or eliminating such risks are justified by the latter's nature and magnitude. A sensible guide would surely be to reduce exposure to hazard wherever possible, to accept substantial hazard only for great benefit, minor hazard for modest benefit, and no hazard at all when the benefit seems relatively trivial.

There are of course alternatives to meeting water resource needs other than wastewater reuse. These include water conservation and new water resource development. A third alternative is wastewater "recycling." This term means an internal reuse of wastewater by the original user prior to any ultimate "disposal." Principally this applies to the internal reuse of wastewater within an industry. The importance of recycling in contrast to reuse is shown in Table 1. As of 1975, water recycling has contributed 200 times as much as water reuse to water resource needs. The projection for the year 2000 is that the ratio of recycled to reused water will be only slightly less.

Rarely is there need to compromise public health standards seriously for wastewater reuse. Alternatives usually are available. The ultimate prospects for wastewater reuse will be enhanced by development of projects that protect the health of the community and are sound economically (3).

> If the public is aware that reclamation is taking place, the developers of a project must create public confidence. Such confidence is merited and may be commanded only when reclamation projects are developed along sound engineering lines. Projects must be conceived and planned by competent engineers having adequate knowledge of, and experience with, the engineering principles involved. In some kinds of reclamation the scientific principles are well established and projects may be successfully carried on with no doubts about the quality of the reclaimed waters. In other cases, the scientific principles and their application are not fully established, and development must come more slowly. There is an element of pioneering in reclamation projects, and the responsibility rests with those who would carry them out.

USES OF RECLAIMED WASTEWATER

Reclaimed wastewater may be used for virtually all purposes for which water is utilized. An overriding consideration is that the quality of the water be appropriate for its use. Most important, the degree of public health hazard is different for each use; for each kind of use a different quality standard is necessary to provide health protection.

The variety of wastewater reuse applications in the US is illustrated in Table 2. Number of projects and quantity of use in the US and California, shown in Tables 3 and 4, respectively, are taken from surveys completed in 1978 and 1979. On the basis of 1975 data, wastewater reuse is 0.2% of fresh water withdrawals in the US (10). In California, the state with the greatest activity, wastewater reuse was about 0.58% of withdrawal in 1978 (11).

Table 1 US wastewater recycle and reuse[a]

	Quantity in billion gal/day	
	Existing (1975)	Projected (2000)
Water withdrawal	362.7	330.9
Wastewater recycle[b]	139.0	865.5
Wastewater reuse	0.68	4.75

[a] Source: Ref. (10).
[b] Estimates for industrial and steam-electric plants.

INDIRECT POTABLE USE OF WASTEWATER

The promotion of direct potable reuse brings up the issue of "indirect" potable reuse, a widespread practice. "Indirect reuse" refers to water already used one or more times for domestic or industrial purposes that is "disposed" by discharge into surface or underground waters and subsequently used again.

Indirect reuse has occurred since the beginning of water carriage of sewage with discharge into the nearest stream and downstream withdrawal for domestic water supply. Although this is far from a universal practice, it is widespread and in some streams wastewater at times represents a significant portion of the total flow.

A recent study determined how much wastewater and wastewater-derived materials from discharges are to be found in the surface water supplies of US cities of over 25,000 population (12). The study identified 1246 municipal water supply utilities using surface water from 194 basins serving 525 cities with populations greater than 25,000. The results ranged from 142 utilities with no dischargers identified to many utilities where the wastewater constituted a major portion of the water supply. Several utilities were using water from a source whose low flow was less than the combined upstream discharge flows. Water supplies serving cities near the bottom of large river basins were found to contain wastewater from several thousand dischargers. However, those utilities with the highest percentage of

Table 2 Applications for reused wastewater

Groundwater recharge	Nonpotable urban
Water-table management	Fire protection
Salt-water intrusion control	Air-conditioning
Subsidence control	Toilet-flushing
	Landscape irrigation
Recreational/environmental	Park
Lakes and ponds	Golf course
Marsh enhancement	Freeway median
Streamflow enhancement	Cemetery
Fisheries	Greenbelt
Snowmaking	Residential
	Industrial
Agricultural	Cooling
Crop irrigation	Boiler-feed
Commercial nurseries	Process water
Commercial aquaculture	Heavy construction

Table 3 Reuse in the United States in 1979[a]

Type of reuse	Number of projects	Reuse in thousand acre-feet/year
Agricultural/landscape irrigation	470	471
Industry	29	240
Groundwater recharge	11	38
Fish propogation, recreation and other	26	11
Total	536	760

[a] Source: Ref. (10).

wastewater relative to supply flow were generally from small to medium-sized creeks and rivers. Twenty cities with a total population of over seven million had surface water supplies containing from 3.5 to 16% wastewater during average flow conditions and from 8 to 350% wastewater during low flow conditions.

The majority of the US water supplies are obtained from protected sources: from upland streams, lakes, or stream impoundment; or from unpolluted groundwater sources. In the US, engineers have always sought and used, when available, protected, unpolluted sources for community supply. The Federal Drinking Water Standards have always been based on the premise that the best available sources of supply would be utilized.

In the development of the 1962 Drinking Water Standards, the presence of organic substances in water supply was considered for the first time and a recommended standard for carbon chloroform extract (CCE) was adopted, emphasizing control of taste and odors, but recognizing that organic substances have a potential for health hazards. At that time discussions began about the possibility that at some time in the future, granular activated carbon might be used universally for water supplies withdrawn from polluted waters as a matter of providing protection against potential health hazards. With the enactment of the Federal Safe Drinking Water Act of 1974 (13), and adoption of the related 1975 Interim Primary Drinking Water Regulations, consideration was given to adopting a mandatory standard for CCE. Ultimately, the decision was made not to do this.

EPA later proposed two new drinking water regulations—one for total trihalomethanes (TTHM) and one for synthetic organics (14). EPA proposed a maximum contaminant level of 0.10 mg/l for TTHM. For synthetic organics, a treatment technique was proposed as a substitute for establishing a maximum contaminant level. The TTHM regulations were adopted on November 29, 1975 (15). The proposal for synthetic organics has since been withdrawn and future action is uncertain.

Table 4 Reuse projects in California[a, b]

	Use areas	Percentage	1,000 acre-feet year	Percentage
Crop irrigation				
Fodder, fiber, seed	190	52	104	57
Landscape irrigation, golf courses, etc.	77	21	21	12
Parks and playgrounds	27	7	2.7	2
Orchards, vineyards	21	6	8	4
Construction and dust control	12	3	0.2	<1
Industrial	8	2	8	5
Food crop irrigation	8	2	5	3
Landscape impoundments	6	2	2	1
Groundwater recharge	5	1	26	14
Recreational impoundments	1	<1	2.5	1
Wildlife habitat enhancement	1	<1	0.6	<1
Aquaculture	1	<1	<0.1	<1

[a]Source: Ref. (11).
[b]Note: Total use approximately 184,000 acre-feet/year; 220 places; 363 use areas.

TREATMENT TECHNOLOGY

Technology is available for municipal wastewater treatment to virtually any level, within limits of existing analytical methods, as may be deemed appropriate for subsequent uses of the effluent, whether direct or indirect (16). However, challenging issues vital to successful application of wastewater reuse and protection of the public health remain unresolved. Control of trace organics and viruses, and the reliability of reclamation systems, are of particular importance in reuse applications resulting in either direct or indirect use for public water supply or public contact. Such applications include groundwater recharge by percolation (17) or injection (18), discharge to municipal water supply (19), and landscape irrigation in public and private areas (20, 21).

The removal of specific trace organic compounds through full-scale advanced wastewater treatment (AWT) processes including chemical clarification, filtration, air stripping, granular activated carbon adsorption, and reverse osmosis (22–24), has been demonstrated. These studies show that the ability to control most synthetic organic compounds (SOC) to current limits of detectability is good. It is recognized, however, that the majority of organic compounds in AWT effluents are unidentified and of generally unknown significance. The presence of high molecular weight compounds, including humic substances, contribute to the formation of trihalomethanes

(THM) and other organic halogens (TOX) of potential public health significance (25, 26). Ozonation of AWT effluent has also been found to increase mutagenic activity (27). The widely observed mutagenic activity of AWT effluents (28–30) is of unknown public health significance and a matter of continuing research interest. Improved techniques for analysis of currently undefined treated wastewater organics and achievement of lower limits of detection should contribute to improved understanding of the relationship between treated wastewater organic content and mutagenicity.

Control of viruses in reclaimed water is of substantial concern even though such product water may meet microbiological standards set for potable water, e.g. one coliform per 100 ml (31). One reason for concern is that reclaimed water is derived exclusively and directly from sewage in which virus concentrations are far higher than even heavily polluted natural waters. Treatment systems for control of viruses in secondary effluents were compared in a recent study at Pomona (32). Systems compared included the following:

1. Chemical coagulation, sedimentation, filtration, and disinfection to maintain coliforms < 2.2 per 100 ml.
2. Direct filtration with combined residual chlorination at 10 mg/l with 2 hours contact.
3. First stage carbon adsorption, disinfection (combined residual or ozone), second stage carbon adsorption.
4. Direct filtration, free residual chlorine disinfection.

Results indicate that virus removal in the third system was as effective as the first (considered as the basis for comparison) and that the second system (direct filtration, combined residual disinfection) produced virus levels comparable to the baseline system but at lower cost.

The reliability of reclamation system performance may be of critical importance to public health, depending on ultimate uses. A recent General Accounting Office report (33) described poor operating results of US wastewater treatment plants. This is not news to regulatory agencies. Surveys of wastewater reclamation facilities in California producing water principally for agricultural uses have also shown a generally poor record of performance compared to discharge requirements (34). However, studies of individual treatment facilities at Lake Tahoe (35) and Orange County (36) indicate that highly reliable performance is possible from reclamation plants. A key aspect of overall plant performance is the design and operating philosophy. Plants designed as wastewater treatment plants, with normal wastewater variations imposed on the operation, exhibit performance levels and variability characteristic of wastewater treatment facilities.

Plants designed as water production facilities with the ability to reject poor quality influent, to retreat or dispose of poor quality effluent, and to operate at a constant optimum flow rate can produce a consistently high quality product. The limiting or control of input of industrial waste discharge of materials such as organics, typically produced in widely varying concentrations and difficult to monitor and treat, has also been shown to assist in maintaining reliable treatment performance (37).

HEALTH ISSUES

General

The prime water-quality objective in any reuse scheme is to prevent the spread of waterborne diseases that could occur through the use of reclaimed water. User water quality requirements must also be satisfied in developing a successful reuse program, but the starting point remains the safe delivery and use of adequately treated, reclaimed water.

The risk of human exposure to reclaimed water—through inhalation, ingestion, or skin contact—can arise from accidental drinking of reclaimed water; drinking of water that has been contaminated by reclaimed water; inadvertent ingestion at a recreation area using reclaimed water; frequent or long-term exposure to aerosols near spray-irrigation or cooling-tower sites; working with reclaimed water; or eating of raw food crops that have been irrigated with reclaimed water.

In the early (sewer farm) uses of reclaimed water, the health hazards were from the possibility of infectious disease transmission. In recent times, with the advent of potable reuse at Windhoek, the recharge of groundwater basins for potable reuse and the growing promotion of projects for direct or indirect potable reuse, serious concerns have been raised about the possible health effects of long-term exposure to residual organic contaminants in the reused water.

A major advantage of nonpotable reuse lies in the fact that chemical contaminants in the reclaimed water do not have much opportunity for effects on health. Heavy metals in wastewaters are removed from the liquid stream efficiently in conventional secondary treatment. Recent studies on long-term land application of wastewater have shown no tendency of heavy metals or trace organics to accumulate in soils or plants grown on the site (37a).

The need still exists, however, for control of infectious bacteria and viruses to which the public might be exposed. Control of bacteria and their reduction in reclaimed water to low levels are processes well understood. Much less is known about treatment for removal of viruses. It is not known what concentrations of viruses are acceptable, even in potable waters.

Identification and enumeration of viruses in water and wastewater have been hampered by the limitations of sampling techniques, problems of concentration of samples, the complexity and high cost of laboratory procedures, and the limited number of facilities having the personnel and equipment necessary to perform the analysis.

Viruses are generally more resistant than bacteria to the usual disinfection practices (38–40). This, coupled with the many problems of virus monitoring, makes assurance of virus destruction or removal a difficult matter in wastewater treatment.

It has been estimated that the concentration of viruses in raw water is 7000/liter with a secondary effluent containing 10 to 50% of that amount. Since viruses clump together and form resistant aggregates, they are more difficult to inactivate during disinfection than are bacteria. Despite the information gained from current studies, a background of data of viruses in reclaimed water is still lacking. This lack, coupled with the facts that the sources of reclaimed water contain many more viruses at higher concentrations than do the sources of potable waters, that safe levels of exposure are not certain, and that exposure to viruses through aerosols is not well understood (41), compels an increasingly conservative approach to treatment for reclamation as the degree of public exposure increases. Another safety consideration involves the possibility of cross-connections of a nonpotable water distribution system with a potable system.

Organics in Renovated Wastewater

Synthetic organic compounds (SOC) in water used ultimately for public water supply are of public health concern (42). The presence of SOC in municipal wastewaters is widely documented (43); The presence of residual SOC in treated wastewater effluents is similarly well established (44), with the type and concentration of individual SOCs dependent on treatment processes and operating conditions employed (19, 22, 45). Numerous studies and applications conducted in recent years have established the technological feasibility of controlling SOC concentrations in treated wastewater (16). Nevertheless, major issues related to the control of SOC in wastewater treated for reclamation remain unresolved.

Limitations to the application of state-of-the-art technology for control of SOC exist in areas of monitoring, reliability and cost. Only a fraction (approximately 20%) of organics in treated wastewater effluent has been identified or is identifiable (25, 31, 46). This is partly because of the low concentrations present and the limits of detection of existing analytical methods [gas chromotograph/mass spectrometer (GC/MS)], and partly because of insufficient reference data to identify chemical compounds. The high cost of analysis, $800 to $1500 per sample, limits development of data on SOC composition of effluents; it also limits the effluent monitoring required for process control to assure product reliability. Data have been collected in some studies (36) that indicate the nature of variability in effluent concentrations that may be expected from advanced wastewater treatment processes.

Less is known about the behavior and fate of organics discharged from reclamation treatment facilities into either surface or subsurface water reuse systems. Currently the EPA is conducting studies to find out what happens to selected organics in the environment, including in surface waters (47). Knowledge of the behavior of SOC in groundwater is limited to that gained from investigation of contamination incidents (48, 49) and to recent studies on groundwater recharge projects (50, 51). Groundwater contamination incidents demonstrate graphically that some classes of SOC are mobile in soils and may be transported along with percolating recharge flow to the groundwater table and then transported in aquifers by natural groundwater movement. One study (16), investigating SOC behavior in an injection application, suggests that biodegradation, in addition to adsorption and dilution processes, may continue to reduce SOC concentrations in the receiving aquifer. Schmidt & Clements concluded that there are insufficient data to define the movement of pollutants through the groundwater as a function of soil characteristics, groundwater hydraulics, and groundwater characteristics. Thus, water quality requirements to ensure successful recharge over a long period cannot be defined quantitatively (52).

The significance of SOC as a constituent of water used ultimately for public water supply is not well defined, and is troublesome because of potential health effects on consumers. Acute and chronic toxicities along with known or suspected carcinogenic, mutagenic, and teratogenic properties have been used by the National Academy of Sciences (NAS) to identify specific compounds of health significance in water (42). The NAS used this information in part to develop "suggested no adverse response levels" (SNARLs) as guidelines for drinking water quality. While the levels of individual SOCs achievable in treated wastewater effluents is generally significantly below concentrations estimated to be of health significance at the 1 in 10^6 risk level, very little is known about potentially adverse effects of mixtures of organics typical of treated effluents. Similarly, little is known or understood about the effects on human health resulting from long-term low-level exposure to such mixtures. Considerable research is currently devoted to in vitro short-term bioassays of wastewater extracts in an effort to identify potential adverse health effects. Techniques range from bacterial mutagen assays (Ames test) to assays using mammalian organ cell cultures (53, 54) and cell transformation tests. Such tests are being applied to assess the potential health significance of reclaimed wastewaters (27, 55). Some studies have shown a general reduction in mutagenic activity (Ames test) with increasing levels of treatment; others have indicated the inability of advanced waste treatment (AWT) processes to eliminate mutagenic activity (28, 56). Activated carbon adsorption of highly treated AWT effluent has been reported to be effective in reducing mutagenic activity (29). Epidemiological studies have also been conducted in an effort to identify health effects associated with consumption of drinking water containing SOC. A recent review of such studies by the NAS (57) concluded that slight evidence exists between the incidence of some types of cancer and consumption of water with higher concentrations of organics—in particular, trihalomethanes. However, specific study conditions and confounding factors have uniformly led to ambiguous conclusions. Clearly, environmental epidemiology is a blunt tool for studying the impact of organics in reused wastewater.

Wastewater Aerosols

The possibility of disease transmission by aerosols from spray sites and from cooling towers is receiving increasing consideration where the source is reused wastewater. Hickey & Reist (58) summarized results of investigations prior to 1975. Sixteen field studies reported dealt only with bacteria. The authors concluded that the emission and spread of viable bacterial aerosols has been demonstrated and that these aerosols are within the human respirable size range. Several recent studies have been performed on aerosols generated from spray irrigation of wastewater. Sorber et al (59) concluded that spraying of wastewater may be a public health hazard through aerosolized pathogenic organisms, particularly viruses. Katzenelson & Teltsch (60) detected aerosolized coliform organisms at 350 meters downwind of spray irrigation lines using raw wastewater. Johnson et al (61), reporting on a study at Pleasanton, California, states:

> The aerosol studies indicate that use of the traditional indicator organisms to predict human population exposure results in extreme underestimation of pathogen levels. The pathogens studied survived the wastewater aerosolization process much better than did the indicator organisms. Fecal streptococci may be an appropriate indicator due to ease of assay, levels routinely seen in wastewater, and the similarity of their hardiness upon impact and viability decay rate to those of the pathogenic organisms of interest. . . . The overall conclusion is that microbiological wastewater aerosols are generated by spray irrigation, do survive aerosolization, and can be transported to nearby populations. The most reliable means of reducing a potential health hazard from pathogenic aerosols is by disinfecting the wastewater before spraying. Until the necessary dose-response relationships are developed, neither the level of aerosolized microorganisms that constitute a hazard nor the degree of required disinfection can be specified.

A study by Teltsch et al (62) found that, in air samples tested downstream from sprinklers, the ratio of enteroviruses to coliform and the ratio of salmonella to coliform increased with distance from sprinklers, an indication that coliform bacteria experience a faster die-off than the reference organisms. Sorber & Sagik (63) suggest that fecal streptococcus closely satisfies the criteria for an indicator organism. A symposium on aerosols and diseases was held by the US EPA Office of Research and Development in 1979. The proceedings of this symposium (64) present a number of epidemological studies of the incidence of illness at or near wastewater treatment plants. No positive correlations have been found, but these studies cannot be considered to be conclusive.

A study at Castroville, California (65) that monitored aerosols produced under typical spray conditions found that only low levels of pathogens were present in areas adjacent to active sprinklers. A calculated probability of inhaling a single pathogen in an eight-hour exposure is reported to be approximately 1:85,000. Complete characterization of virus transport accumulation and survival is complicated by lack of an established standard procedure for field sampling of viruses.

Okun (31) concluded that while virus data need to be obtained from cooling towers using reclaimed water, if the reclaimed water is treated to not exceed 1 coliform per 100 ml (implying a virus concentration of 1 PFU per 10 gallons), there should be no health hazard to population in the vicinity. However, this assurance derives entirely from maintaining high quality reclaimed water fed to the cooling towers.

Agricultural Application

The great advantage of irrigation of feed and fiber crops is that wastewater needs a minimum of treatment—often less than that required to meet discharge requirements. Further, the crops will receive some benefit from the fertilizer value of the wastewater. Cost of delivery of wastewater may be low in rural sections of the county, but it usually is large, perhaps prohibitive, for metropolitan areas. A limitation is that seasonal storage or alternate uses or disposal may be required during the rainy season.[1]

The history of food crops irrigated with wastewater demonstrates convincingly that disease is transmitted through the food, if raw sewage is applied to crops that may be eaten without cooking. Beyond this, there is a paucity of information about what degree of treatment, or what water quality standards are necessary for assured safety. Because of this uncertainty, two approaches have been used: (*a*) the reused water has been applied only to fiber and fodder crops; (*b*) a very high degree of treatment —including filtration and disinfection—has been required for irrigation of truck crops. As a consequence of this latter requirement, very little

[1]In California, most rainfall occurs between November and April.

wastewater is used on these critical crops. Perhaps this is just as well, but the requirements are limiting and are occasionally challenged.

If a diversity of crops is grown in an area to receive reused wastewater, a management problem may result. Two alternatives are available: either the wastewater is treated to the degree needed to meet standards for the most critical crops being grown, or some provision must be made for effective monitoring to assure that the wastewater is used in accordance with health requirements—only on those crops appropriate to the quality of the reused wastewater.

In the Monterey (California) Wastewater Reclamation Study For Agriculture, experimental agricultural plots will be irrigated with reused wastewater receiving three types of treatment. Soils, plant tissues, and waters in the experimental plots will be sampled and analyzed for chemical, physical, and biological characteristics. Tests will determine if there are significant differences between the characteristics of soils and plants receiving different water types. This pilot project is unique in using reclaimed water on crops that will be eaten raw. In addition, the intensive monitoring and documentation of effects of water reuse on plants and soils make this project unique. The intent of the study is to develop data required to determine the technical and public health feasibility and public acceptability of irrigation with reused wastewater (65, 66).

PUBLIC POLICY

Public Acceptance

An important element in considering development of reuse projects is that of public acceptance. Most reuse projects involve some degree of health hazard to the public, either the public at large or segments of the working population, such as industrial workers or agricultural workers where reused water may be applied. Public acceptance may also be contingent upon esthetic considerations and upon purely emotional factors.

During the last decade, six major survey studies have assessed attitudes toward uses of reclaimed wastewater. Bruvold (69) conducted an interview study that involved approximately 100 respondents from each of ten California communities. Some details from this study are shown in Table 5. Gallup (70) performed a telephone poll that represented a probability sample of the United States for the American Water Works Association, sampling some 3000 respondents. Stone and Kahle (71) made a telephone survey of 100 respondents in each of ten Southern California communities. Carley (72) interviewed 500 respondents in Denver, Colorado. Kasperson et al (73) interviewed about 80 respondents in each of nine United States cities. Results from these five studies were remarkably consistent: somewhat

Table 5 Percentage of respondents opposed to 25 uses of reclaimed water[a]

Use	Percentage[b]	Use	Percentage[b]
1. Drinking water	56.4	14. Orchard irrigation	10.1
2. Food preparation in restaurants	56.0	15. Hay and alfalfa irrigation	7.5
3. Cooking in the home	54.5	16. Pleasure boating	7.3
4. Preparation of canned vegetables	54.1	17. Commercial air-conditioning	6.5
5. Bathing in the home	38.7	18. Electronic plant process water	4.9
6. Swimming	23.7	19. Home toilet flushing	3.8
7. Pumping down special wells	23.2	20. Golf course hazard lakes	3.1
8. Home laundry	22.8	21. Residential lawn irrigation	2.7
9. Commercial laundry	21.9	22. Irrigation of recreation parks	2.6
10. Irrigation of dairy pasture	14.1	23. Golf course irrigation	1.6
11. Irrigation of vegetable crops	14.0	24. Irrigation of freeway greenbelts	1.2
12. Spreading on sandy areas	13.3	25. Road construction	0.8
13. Vineyard irrigation	12.9		

[a]Source: Ref. (69).
[b]Note: Number of respondents = 972.

over 50% of each sample opposed the use of reclaimed water for the highest contact purposes.

In essence, the five studies dealt with the acceptability of a risk—without consideration of possible benefits. The sixth study, by Bruvold & Crook (74), attempted to deal with both the benefit and the risk elements. This study assessed how residents within each of ten selected cities would rank and evaluate real life, site-specific (different for each of ten cities) proposed options for reuse of reclaimed water, considering type of treatment and health, environmental, and economic impacts. Overall, the results showed that respondents favored options that protected public health, enhanced the environment, and conserved scarce water resources.

Statutes, Regulations, and Standards

Three federal statutes deal in small part, but significantly, with wastewater reuse. These are PL 92-500 (1972) and PL 95-217 (1977), the most recent revisions to the Federal Water Pollution Control Act, and PL 93-523 (1974), the Safe Drinking Water Act.

Public Law 92-500 and PL 95-217 recognize the potentially large benefit to be realized if wastewaters can be renovated for reuse applications. Sections 201 (b), 201(d), and 201 (g) (2) (B) require the following: (*a*) that

EPA provide for the application of best practicable waste treatment technology, including reclaiming and recycling of water; (*b*) that construction of revenue-producing facilities providing for reclaiming and recycling be encouraged; (*c*) that works proposed for grant assistance allow for the application in the future of technology that will provide for reclaiming and recycling of water. Section 105 (a) (2) authorizes EPA to make grants for demonstrating advanced waste treatment and water purification methods, and Section 105 (d) (2) requires that the Administrator conduct on a priority basis an accelerated effort to develop, refine, and achieve practical application of advanced waste treatment methods for reclaiming and recycling water and confining pollutants. Section 201 (g) (5) prohibits the EPA Administrator from making any grants for treatment after fiscal year 1978 unless the applicant has demonstrated that treatment processes and techniques, providing for the reclaiming and reuse of water, have been fully studied and evaluated.

The Safe Drinking Water Act of 1974 (Section 1444) also contains mandates of importance with regard to renovation and recycling of wastewaters. Section 1444 authorizes a development and demonstration program (*a*) to demonstrate new or improved technology for providing safe water supply to the public and (*b*) to investigate and demonstrate health implications involved in the reclamation, recycling, and reuse of wastewaters for the preparation of safe and acceptable drinking water.

California has the most highly developed program of wastewater reuse and the most comprehensive regulations pertaining to public health aspects of reuse. In 1949, the State Legislature enacted legislation assigning to the State Department of Water Resources responsibility for conducting surveys and investigations relating to reclamation of water from wastes for beneficial purposes and for reporting annually to the Legislature upon this matter. In 1965, the Legislature adopted the "Water Reclamation Law" (75), which declares that the people of the state have a primary interest in the development of facilities to reclaim water containing waste to supplement existing surface and underground waste supplies and to assist in meeting the future water requirements of the state. It further declares that the Legislature intends that the state undertake all possible steps to encourage development of water reclamation facilities so that reclaimed water may be made available to help meet the growing water requirements of the state.

This Act also provides that "The Department of Health shall establish statewide reclamation criteria for each varying type of use of reclaimed water where such use involves the protection of public health."

In 1977, the California Legislature adopted a statute prohibiting use by public agencies of water of quality suitable for potable domestic use for the irrigation of greenbelt areas, such as cemeteries, golf courses, and parks, where reclaimed water is available for such use.

Also in 1977, California established an Office of Water Recycling to promote recycling and reclamation of wastewaters in California, and to achieve a goal of construction of facilities to make available an additional 400,000 acre-feet of reclaimed water by 1982 (tripling current reuse).

California wastewater reuse regulations have been developed progressively over the past 60 years (76). Table 6 summarizes the current regulations pertaining to irrigation and impoundments. The first regulations were promulgated in 1918, pertaining to irrigation of crops with sewage effluents. These regulations prohibited the use of raw sewage, septic or Imhoff tank effluents, or water polluted by such sewage for the irrigation of tomatoes, celery, lettuce, berries, and other garden truck eaten raw by human beings. Truck crops of the type that are cooked before being eaten could

Table 6 Summary of California standards for use of reclaimed wastewater for irrigation and recreational impoundments[a]

Use of reclaimed wastewater	Description of minimum required wastewater characteristics			
	Primary[b]	Secondary and disinfected	Secondary coagulated, filtered[c] and disinfected	Coliform MPN/100 ml median (daily sampling)
Irrigation				
Fodder crops	X			No requirement
Fiber	X			No requirement
Seed crops	X			No requirement
Produce eaten raw, surface irrigated		X		2.2
Produce eaten raw, spray irrigated			X	2.2
Processed produce, surface irrigated	X			No requirement
Processed produce, spray irrigated		X		23
Landscapes: golf course, cemeteries, freeways		X		23
Landscapes: parks, playgrounds, schoolyards			X	2.2
Recreational impoundments				
No public contact		X		23
Boating & fishing only		X		2.2
Body-contact (bathing)			X	2.2

[a]Wastewater Reclamation Criteria, Calif. Adm. Code, Title 22, Div. 4, Environmental Health, 1978.
[b]Effluent not containing more than 0.5 ml/liter/hr settleable solids.
[c]Effluent not containing more than 2 Turbidity Units.

be irrigated if the application of effluent was not made within thirty days of harvest.

The regulations were revised in 1933 to exempt restriction of effluents for the irrigation of garden truck crops eaten raw if the effluents were well oxidized, nonputrescible, and reliably disinfected or filtered.

In 1968 more comprehensive regulations were enacted, entitled "Statewide Standards for the Safe Direct Use of Reclaimed Waste Water for Irrigation and Recreational Impoundments." These regulations were mainly directed at the control of disease agents and prescribed levels of wastewater constituents intended to assure that the practice of directly using reclaimed wastewater for recreational impoundments and the practice of spray irrigation of crops and golf courses did not impose undue risks to the public health.

In 1975 the regulations were revised, requiring treatment reliability features to minimize public health risks. The reliability features include items such as alarm systems, emergency power, duplicate treatment units, standby units, standby replacement equipment, emergency storage facilities, and flexibility in piping systems to permit most effective use of alternative treatment units.

In 1978, two additional modifications were made to the California regulations. The standard for irrigation of the city parks and other urban landscape irrigation was strengthened to require coagulation, clarification, and filtration in addition to the previous requirement for oxidation and disinfection. The second modification deals with groundwater recharge and states that where reclaimed water is used for recharge of domestic water supply aquifers, the quality of water shall "fully protect public health." These regulations state further that health department recommendations for proposed groundwater recharge projects and for expansion of existing projects will be made on an individual basis. These recommendations will be based on all relevant aspects of each project, including: "treatment provided, effluent quality and quantity, spreading area operations, soil characteristics, hydrogeology, residence time, and distance to withdrawal."

Because of issues raised concerning the 1978 revision to the regulations, a Health Effects Advisory Panel was created in 1981 by the Department of Health Services.

Commentary on Standards

It has been claimed that public health authorities seek zero or near-zero risk for wastewater reuse projects (77). Actually, there never will be a zero-risk world and none of the standards for wastewater reuse provides a risk-free level of health protection. In situations where hazards are severe and the consequences of failure are disastrous, public health objectives for reuse should be to develop standards that reduce risk to a low level.

Another issue that has arisen relates to the so-called "single standard" —meaning that all domestic water sources (natural and reused water) should be subject to the same set of standards. The implication in the use of this term regarding wastewater reuse is that more stringent requirements may be applied to reused wastewater for potable use than for surface water and groundwater sources now in use.

Clearly, whatever the source of a given array of chemical contaminants, the same health effects will occur and be of equal health consequences. There is, however, an important difference in the circumstances. With existing water sources, chemical contaminants should be identified and their harmful effects understood and mitigated as promptly as resources and public policy will allow. On the other hand, proposals to develop projects for potable reuse of wastewater that thereby deliberately introduce residues of organic substances into community water supplies should be delayed until better knowledge is available. Meanwhile, another issue remains: Are the present drinking water standards adequate to deal with organics in existing water supply sources? This question is currently under intensive review.

A question also may be raised about a "single" microbiological standard. One of the provisions of the Safe Drinking Water Act was to commission the National Academy of Sciences (NAS) to conduct a study on the human health effects of exposure to contaminants in drinking water. The NAS study findings on biological indicators of pollution include the following statements relative to the reuse of wastewater (78):

> Current coliform standards are not satisfactory for water reclaimed directly from wastewater. Meeting current coliform standards for water reclaimed directly from wastewater, or for water containing several percent of fresh sewage effluent, is insufficient to protect public health. For such raw water supplies, new microbiological standards should be developed and applied as supplementary to coliform standards.

Conservationists advocating potable reuse have pointed to "advanced waste treatment" plant performance, where effluents "meet the drinking water standards," as demonstrating that such effluents are suitable for potable reuse and, further, that there is no technological obstacle to proceeding with direct potable reuse projects. A commentary on this appears in a recent EPA document, "Drinking Water Research Strategy for the 1980–1984 Period" (79).

> Standards for drinking water explicitly address contamination that might be predicted to arise from the treatment and transport of natural waters to the consumer. For ease of administration of the regulations the number of compounds specified is limited on the assumption that source water is protected from gross contamination. The proposed use of wastewater as a source of potable water seriously strains this concept for providing

safe drinking water. Simple application of drinking water standards to such a situation in the absence of an ability to completely define the nature of chemicals present is potentially very dangerous. Consequently, to suggest that potable water is completely defined by the current drinking water standards is inappropriate.

SUMMARY

The wastewater of a community constitutes a potential resource, the value of which depends on the availability of other water resources in the area. With planned reuse, except for groundwater recharge projects, this wastewater is not generally commingled with the other water resources but is delivered directly for selective uses. Reused wastewater, to a degree depending upon the extent of treatment, contains biological and chemical contaminants potentially harmful to the population exposed. Human exposure may be by contact, by inhalation, or by ingestion. The ingestion may be the result of "indirect," unintentional potable reuse or, in rare instances, the result of deliberate "direct" potable reuse. Ingestion may also include the intake of contaminants through food crops irrigated with reused wastewater. For all uses except direct or indirect potable uses, the hazard to health originates solely from biological organisms that may infect the users. Treatment of the reused wastewater to levels appropriate to the extent of exposure will provide suitable health protection for these uses. Potable (direct or indirect) reuse carries the risk of ingestion of chemical contaminants present in the water, in addition to microorganisms. Residual stable organic substances, largely synthesized compounds, present the greatest problem.

Although direct potable reuse has been developed for a very few communities around the world, there is a great interest on the part of some groups to promote and develop substantial potable reuse for the future, both direct and through groundwater recharge. Thus, there is pressure to develop standards of water quality for potable reuse. Research is underway to study aspects of this problem, including identification of the compounds present, toxicology of the individual compounds, toxicology of mixtures of organic chemicals in wastewater, and rapid means such as bioassay for determining toxicity. The bioassay of greatest use at the present time is the Ames test, an assay for mutagenicity using salmonella bacteria combined with mammalian tissue homogenate. Existing animal tests and human epidemiology alone are inadequate for determining toxicity of substances because of the time and expense involved, as well as the difficulty of dealing with complex mixtures.

Even though the present direct potable reuse of wastewater is exceedingly small and the prospect of significant increased direct potable reuse is un-

likely, research on synthetic organic substances is valuable and necessary because of the large degree of unplanned indirect potable reuse that occurs where wastewaters reach surface and groundwater sources of domestic water supply. Substantial research is being conducted on various aspects of wastewater reuse and should provide valuable information to enable more certain planning for future activities. Data about the toxicology of organic substances in reused water will probably be the slowest in development. The future is never certain—perhaps new problems will be discovered, though this seems unlikely.

Although reuse of wastewaters is only a minor element in water resource development in most areas, needs in semiarid and arid areas make necessary the fullest possible exploitation of this resource consistent with the imperatives of public health protection.

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