DEPARTMENT OF THE ARMY
U.S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

Mr. Kistner/clf/AUTOVON
584-3554

REPLY TO
ATTENTION OF

HSHB-EW-M/WP 27 OCT 1982

SUBJECT: Water Quality Information Paper No. 4

RECYCLE/REUSE OF WASTEWATER

1. PURPOSE. The purpose of this information paper is to provide an overview on the health aspects of wastewater reclamation, recycle, and reuse. (In addition, a comprehensive list of literature cited herein is provided as Inclosure 1 to supplement specific details regarding recycle/reuse of wastewaters.)

2. REFERENCES.

a. Public Law (PL) 92-500, Federal Water Pollution Control Act Amendements of 1972, 18 October 1972.

b. PL 95-217, Clean Water Act of 1977, 27 December 1977.

3. REGULATORY BACKGROUND.

a. Early Federal legislation for water pollution control in the United States had no provisions to encourage reuse or recycling of wastewater as a conservation practice. In fact, the Federal Water Pollution Control Act of 1956 instituted a grants program containing prohibitions and omissions that discouraged development and use of many recycling or reuse alternatives. The Federal Water Pollution Control Act Amendments of 1972 were the first Federal legislation to contain provisions that encouraged recycle and reuse. A Congressional review of progress in 1977 revealed that the first 5 years of the Federal funding program had not achieved the shift to recycle technology anticipated with the passage of the 1972 Act. Congress took this into account in its passage of the Clean Water Act of 1977. In an attempt to stimulate greater use of reuse and recycle technologies, the 1977 Act provided financial incentives for innovative and alternative (I/A) approaches to waste management and specifically designated many water reuse and nutrient recycle approaches as I/A technology.[23a]

b. The specific verbage regarding recycle/reuse methodology is contained in Section 60 of PL 95-217, which officially amends Section 313 of PL 92-500. As applied to Federal facilities, it requires consideration of wastewater reuse as one option when new wastewater treatment facilities are planned for construction. The law states: "Construction shall not be initiated for facilities for treatment of wastewater at any Federal property or facility after 30 September 1979, if alternative methods for wastewater treatment at such property or facility utilizing innovative treatment processes and techniques, including but not limited to methods utilizing recycle and reuse techniques and land treatment are not utilized, unless the life cycle cost of the alternative treatment works exceeds the life cycle cost of the most cost effective alternative by more than 15 per centum." Water reuse technologies which have been designated as eligible for such financial incentives include land treatment, agricultural reuse, direct reuse (nonpotable), and aquifer recharge.[23a 34]

4. EVALUATION OF WASTEWATER REUSE POTENTIAL AT ARMY INSTALLATIONS. A recent study performed by SCS Engineers was initiated in order to provide a tool that could be used by the Army in assessing the potential for water reuse at fixed installations. The resulting 1979 report[36] furnished a comprehensive questionnaire that allows a concise overall evaluation of reuse potential at an installation in a short amount of time (see Inclosure 2). The major criteria focused upon in this preliminary analysis are water supply, wastewater generation, installation activities, institutional aspects, and climate. Following completion and evaluation in this survey at a number of installations, the results could be used as a screening technique; installations identified as having good reuse potential could then be investigated further. Of prime consideration is the reduction in size or elimination of wastewater treatment facilities which can be anticipated if a reuse scheme is implemented.

5. A SUMMARY OF HEALTH ASPECTS OF WASTEWATER REUSE. Inclosure 3 presents a comprehensive evaluation of the health aspects associated with wastewater reuse.

a. Rivers and lakes often serve both as sources for potable water for public supply and as a medium for the disposal of wastewater. It is not surprising that the raw water extracted by many water supply authorities contains a proportion of wastewater discharged by previous users. The indirect reuse of wastewater also occurs widely as a result of the use of such waters in agriculture, for recreation, and for industrial water sources. Drainage from septic tanks, ponds, and treatment lagoons into underground waters also leads to indirect reuse when this water is subsequently extracted.

b. It may be prudent to review the public health aspects of production of potable water from indirect sources. When rivers or ground water contain a high proportion of effluent, the production of water from them should be regarded as analogous to the direct recovery of water from a sewage or industrial effluent, and safeguards appropriate to this situation should be imposed.

c. It should be kept in mind, however, that the water quality parameters of the 1962 US Public Health Service Drinking Water Standards (the forerunner of the Safe Drinking Water Act) were never intended to be applied to waters derived either directly or indirectly from wastewaters. It is assumed that the source would be properly protected, as revealed by a sanitary survey. As previously stated, the operative statement in those standards was that "the water supply should be obtained from the most desirable source which is feasible, and efforts should be made to prevent and control pollution of the source." Most of the chemical contaminants and viruses of concern today are not even mentioned in Safe Drinking Water Act.[25 27] Thus, if indirect and, even more importantly, direct reuse of wastewater are being considered, it is imperative that the standards implemented to protect the health and welfare of the general public take such things as microbiological health risks and chemical contaminants into consideration.

d. The reuse of wastewater effluents and polluted river water for domestic purposes, including drinking, presents potential health risks from the microbiological point of view, since there is ample epidemiological evidence that the ingestion of even a small number of certain pathogens can cause disease in nonimmune subjects. Limited studies have shown that ingestion of one tissue culture infective dose of poliovirus can cause infection in man. It appears that, even if only low levels of enteric viruses pass through a water treatment plant, persons can become infected. It must be pointed out, however, that the potential microbiological risks involved in direct effluent reuse may not be appreciably different from those faced by many cities currently using surface sources heavily contaminated with wastewater from upstream locations. Some rivers carry such a high proportion of treated and untreated wastewater that their use as a water source can be considered as essentially wastewater reuse.[44]

e. Conventional water treatment technology is currently capable of removing or inactivating substantially all pathogenic bacteria, although waterborne viruses may be more difficult to control. There is evidence that enteric viruses have, on occasion, passed through such treatment plants that draw water from heavily contaminated rivers, although such conditions could normally be detected by adequate bacteriological monitoring. Only if water has been treated to such a degree that essentially all ammonia and nearly all residual organic matter have been removed, is it possible to achieve the free chlorine residual of 0.5 mg/L for 1 hour recommended by the World Health Organization (WHO) for effective inactivation of enteric viruses.[44] Such a situation is ironic in that, today, many suppliers of water add ammonia to water sources in order to obtain combined forms of chlorine which are less likely to form trihalomethanes. Furthermore, a 0.5 mg/L free chlorine residual is less likely to be achieved by poorly operated or understaffed conventional water treatment plants which are treating river water heavily contaminated with sewage. Activated carbon treatment, by removing organic materials, enhances the efficiency of the disinfection process. In direct wastewater reuse schemes, advanced procedures involving highly alkaline chemical treatment, filtration, membrane processes, and/or activated carbon treatment prior to disinfection appear to yield very high levels of virus removal that may well provide adequate protection to consumers. The development of rapid, sensitive monitoring methods to detect low levels of enteric viruses in large volumes of water would be valuable in evaluating the safety of the treatment procedure. In addition, strict microbiological standards for viruses and coliform organisms should also be applied in the case of direct wastewater reuse.[44 32a]

f. The unbridled increase in the use of hundreds of new and often structurally complex synthetic compounds in industry and agriculture has resulted in the appearance of many of these potentially toxic materials in municipal and industrial wastewater streams. Many of these chemicals which appear in wastewater are known not only for their acute toxic effects, but for their chronic effects which can be detected only after long periods of exposure. Materials having carcinogenic, mutagenic, and/or teratogenic effects have been isolated in wastewater, polluted surface water, and drinking water from surface sources. Trace metals that may at times reach toxic concentrations have also been found on many occasions in wastewater streams, particularly those carrying a high percentage of industrial wastes.[37]

g. The WHO[44] has recommended that the question of refractory organics be given the highest research priority in studies essential to evaluate the health effects of consuming renovated wastewater. Furthermore, WHO emphasized that there is continued value in applying the use of a general test for total organics in water such as total organic carbon (TOC). It pointed out that good quality drinking water should usually contain no more than a few milligrams per liter of TOC. As a tentative goal, TOC levels under 5 mg/L should be strived for in the case of either direct or indirect water reuse. In any event, it is generally recognized that organic contaminants pose a difficult problem in the area of wastewater reuse, and that some type of surrogate parameter(s) for organic compounds of health concern would be beneficial in assessing the extent of such problems.[32d]

h. There have been many advances and breakthroughs in the field of wastewater reclamation in recent years. It is generally accepted that treatment technology is not a limiting factor in the design of potable reuse facilities.[32a] With the development of many new membrane techniques, advances in ion exchange and carbon absorption, and a greater understanding of the disinfection process, water free from microbiological and chemical contaminants can be produced. Suggested degrees of treatment for various types of reuse were presented in 1973[44] and are reproduced in the following Table. While some 10 years later these treatment schemes still provide sound information, rapidly developing techniques such as reverse osmosis and ultrafiltration provide additional assurances for adequate treatment. What has to be kept in mind, however, are the economics of such sophisticated treatment trains and the operation and maintenance capabilities of staff personnel at an actual water treatment plant. Training, operator certification programs, and preparation of operation and maintenance manuals are critical.

TABLE. SUGGESTED TREATMENT PROCESSES TO MEET THE GIVEN HEALTH CRITERIA FOR WASTEWATER REUSE*

	Irrigation			Recreation			Municipal Reuse	
Health Criteria†	Crops not for direct human consumption (A + F)	Crops eaten cooked; fish culture (B + F or D + F)	Crops eaten raw (D + F)	No contact (B)	Contact (D + G)	Industrial reuse (C or D)	Non-potable (C)	Potable (E)
Primary treatment	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Secondary treatment		xxx	xxx	xxx	xxx	xxx	xxx	xxx
Sand filtration or equivalent polishing methods		x	x		xxx	x	xxx	xx
Nitrification						x		xxx
Denitrification								xx
Chemical clarification						x		xx
Carbon absorption								xx
Ion exchange or other means of removing ions						x		xx
Disinfection		x	xxx	x	xxx	x	xxx	xxx‡

* Extracted from World Health Organization from Reuse of Effluents: Methods of Wastewater Treatment and Health Safeguards. WHO Technical Report Series No. 517. Geneva, 1973.

† Health criteria: A, Freedom from gross solids; significant removal of parasite eggs. B, as A, plus significant removal of bacteria. C, as A, plus more effective removal of bacteria, plus some removal of viruses. D, Not more than 100 coliform organisms per 100 mL in 80% of samples. E, No fecal coliform organisms in 100 mL, plus no virus particles in 1000 mL, plus no toxic effects on man, and other drinking-water criteria. F, No chemicals that lead to undesirable residues in crops or fish. G, No chemicals that lead to irritation of mucous membranes and skin. In order to meet the given health criteria, processes marked xxx will be essential. In addition, one or more processes marked xx will also be essential, and further processes marked x may sometimes be required.

‡ Free chlorine after 1 hr.

i. There is considerable pressure (and with good reason) to employ nonpotable reuse in lieu of potable reuse to the greatest extent possible in an effort to avoid many of the health-related problems associated with drinking reclaimed water. In addition, nonpotable reuse helps to preserve and extend the life of protected sources of potable water. While some public health problems have been identified with nonpotable reuse, such as aerosolization of pathogenic organisms, contamination resulting from the eating of crops consumed raw following treatment with reclaimed water or, most importantly, the danger of cross-connections between potable and nonpotable distribution systems, such difficulties can be overcome.

j. Finally, it may be a combination of economics and need for water which will ultimately dictate the decision to implement a wastewater reuse program - either potable reuse or nonpotable reuse. If the water is truly needed, the health risks associated with such a project must eventually be balanced against a properly engineered and managed system. Continuing research on the various aspects of wastewater reclamation and reuse, translation of these viable research efforts into a practical, "sailor proof" reality, and most importantly, comprehensive standards and criteria for the various categories of reuse activities must be developed as discussed in paragraph 2b of Inclosure 3.

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3 Incl
as

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ARMY WASTEWATER REUSE POTENTIAL EVALUATION[36]

General

Base Name: ______________________________

Location: ______________________________

Date: ______________________________

Name and Organization of Evaluator: ______________________________

Key Contacts at Base:

Name	Phone	Autovon

Instructions:

Answer each question as accurately as possible, using engineering estimates if actual data is not available. Circle the correct answer, total the points, and check your total score against the reuse potential ranges at the end.

Note the column for "Key Question." If that column has an asterisk, then that question is particularly important. If answered positively, the post may have good potential for reuse even if its total score does not indicate such.

Category	Points 0	1	2	3	4	5	6	7	8	9	Key Question
I. WATER SUPPLY											
1. Is the base water supply available from a reliable source for the next 20 years?	YES				NO						
2. Is there possible significant depletion of the water supply within the next 10 years?	NO						YES				

Incl 2

Category	Points 0	1	2	3	4	5	6	7	8	9	Key Question
I. (continued)											
3. Is there an anticipated problem with the water supply within 5 years?	NO									YES	*
4. What is the present cost of water procurement and treatment per 1,000 gallons?	$ <0.10		$ 0.10 0.20		$ 0.20 0.30		$ 0.30 0.40		$ >0.40		
5. Is there a foreseeable event that could markedly increase water costs in the next 10 years?	NO					YES					
6. Is expansion or upgrading of the water supply/treatment system planned in the next 10 years?	NO			YES							*
7. What volume of water is used on the average in MGD?	<1		1-2		>2						
8. What is the TDS (mg/ℓ) of the base water supply?	>800	500-800	200-500		<200						

Comments: Subtotal Points

WATER SUPPLY: ____________

Category	Points 0	1	2	3	4	5	6	7	8	9	Key Question
II. WASTEWATER											
9. Does the base treat wastewater for direct discharge to surface water or land?	NO							YES			
Answer questions 10-13 for Base STP only											
10. Does the treatment plant presently meet discharge requirements?	YES						NO				*

Category	0	1	2	3	4	5	6	7	8	9	Question
	Points										
II. (continued)											
11. Will additional treatment facilities be required within the next 5 years?	NO				YES						*
12. What quality is the plant effluent in terms of BOD (mg/ℓ)?	>30		20-30		10-20		<10				
13. What percentage of design capacity is in use?	<50	50-75	75-100	>100							
Answer questions 14-16 for Base IWTP only											
14. Does the treatment plant presently meet discharge requirements?	YES						NO				*
15. What quality is the plant effluent in terms of COD (mg/ℓ)?	>200		100-200		50-100		<50				
16. Are discharge limits set for specific contaminants (i.e., heavy metals, CN, nutrients)?	NO			YES							
17. What total quantity of wastewater (treated and untreated) is discharged from the base in MGD?	>.5	.5-1.0	1-2	>2							
18. If the base discharges to a municipal or regional sewer system, what is the discharge fee per MG?	$ <100	$ 100-200		$ 200-300		$ 300-400		$ >400			
19. Are future changes likely that would markedly increase the discharge fee?	NO				YES						

Comments:

Subtotal Points

WASTEWATER DISCHARGE: ______________

Category	Points										Key Question
	0	1	2	3	4	5	6	7	8	9	
III. ACTIVITIES											
20. Does the base have a golf course?	NO				YES						
21. Is the golf course irrigated?	NO			YES							
22. How many acres of landscape and athletic fields could be irrigated if reclaimed water were available?	0	0-20	20-40	40-80	>80						
23. How many large industrial cooling towers does the base have? (1)	0	1-5	5-15	>15							
24. If the base has a plating shop, how much wastewater does it discharge in 1,000 gal/day? (1)		<10	10-50	50-100	>100						
25. Does the base have air pollution wet scrubbers?	NO	YES									
26. Does the base have a vehicle wash rack(s)? (1)	NO		YES								
27. Does the base have a paint shop with a water wall? (1)	NO	YES									
28. Does the base perform wet sand-blasting?	NO	YES									
29. Does the base have an industrial laundry? (1)	NO		YES								
30. Does the base have a photo lab?	NO	YES									
31. Does the base contain any type of artificially filled recreational lakes?	NO			YES							

Category	Points										Question
	0	1	2	3	4	5	6	7	8	9	
III. (continued)											
32. Does the base have steam cleaning facilities?	NO	YES									
33. Does the base generate its own electrical power?	NO			YES							
34. Does the base have a central energy facility for generation of steam for heating and cooling?	NO		YES								
35. Does the base have a large pesticide management program?	NO	YES									
36. Does the base have any other activities using more than 25,000 gpd that we have not included? (Point assessment is left to evaluator.)											

(1) If the base has this activity, please refer to the activity descriptions in the main report. This activity has been highlighted as having potential for internal recycle as either a water conservation or pollution control measure. Details of treatment/recycle schemes are provided in the main report.

Comments:

Subtotal Points -

ACTIVITIES: ______________

Category	Points										Key Question
	0	1	2	3	4	5	6	7	8	9	
IV. INSTITUTIONAL ASPECTS											
37. Is the base free of any long-term water purchase agreements that would prohibit the base from cutting back on water usage?	NO				YES						

Category	Points 0	1	2	3	4	5	6	7	8	9	Key Question
IV. (continued)											
38. Is the base free of any water laws (i.e., Doctrine of Prior Appropriation) or commitments to regional wastewater systems that would prohibit a reduction in volume of effluent discharged?	NO				YES						
39. Is wastewater reuse occurring now or being planned in surrounding communities?	NO					YES					
40. What percentage of the total wastewater generated on base is currently being reused?	0		0-10		10-50		>50				
41. Is there a potentially large civilian user near the base (i.e., golf course, power plant, agriculture)?	NO				YES						
42. Are key base personnel interested in using reclaimed water?	NO		SLIGHTLY			MODERATELY				HIGHLY	

Comments:

Subtotal Points

INSTITUTIONAL: ______________

Category	Points 0	1	2	3	4	5	6	7	8	9	Key Question
V. CLIMATE											
43. What is the average yearly rainfall on the base in inches/year?	>40		30-40		20-30			10-20		<10	

Category	Points 0	1	2	3	4	5	6	7	8	9	Question
V. (continued)											
44. What is the average yearly pan evaporation on the base in inches/year?	20-30		30-40		40-60		60-80			>80	

Comments:

Subtotal Points

CLIMATE: ____________

TOTAL POINTS: ____________

SCORE INTERPRETATION

The final point total reflects the following wastewater reuse potential for the base:

1. 0 to 54 points: The base has little or no potential for reusing wastewater on a system-wide scale, and no further reuse evaluation is necessary at this point.

2. 55 to 74 points: The base has marginal potential for reuse on a system-wide scale. The decision as to whether with an in-depth evaluation will depend on 1) whether the score was high or low in the category; and 2) the judgement of the evaluator. Although they don't score highly overall, some bases may have a compelling reason for pursuing reuse alternatives, i.e., one or more "Key Questions" may have been answered positively. For example, a base with a critical water supply crisis may opt for a deeper look at reuse even though its score in other categories was not exceptional.

3. 75 to 100 points: The base has good reuse potential on a system-wide basis.

4. >100 points: The base has excellent reuse potential on a system-wide basis.

HEALTH ASPECTS OF WASTEWATER REUSE

1. DIRECT REUSE VERSUS INDIRECT REUSE.

a. Direct reuse has been defined as the planned and deliberate use of treated wastewater for some beneficial purpose such as irrigation, recreation, industry, or potable reuse. Indirect reuse of wastewater occurs when water used for domestic or industrial puroses is discharged into fresh surface or underground waters and is used again in its diluted form.[39a] Shuval[39b] has stated that today, in almost all heavily populated and industrialized areas, there occurs massive indirect reuse of wastewater as a result of the withdrawal of water supplies for urban, industrial, and agricultural purposes from heavily polluted rivers. The downstream sections of the world's major rivers carry significant loads of wastewater, much of it only partially treated. During periods of minimal base flow, many large river systems may carry anywhere between 20 to 50 percent domestic and industrial wastewater.[39b] Water withdrawn from such sources is without doubt one of the most common forms of wastewater reuse. It has been estimated that some 100 million people throughout the world are being supplied with drinking water by this form of indirect wastewater reuse.

b. Shuval[39b] goes on to say that there is increasing evidence that conventional water treatment plants are not fully capable of removing the hundreds of potentially harmful organic and inorganic pollutants that appear in such water sources. Nor can there be any assurance that all harmful microorganisms of sewage origin will be removed. Viruses have been shown to be particularly resistant to conventional treatment methods of heavily polluted water with high concentrations of organic matter. Advanced wastewater treatment technology now being developed is needed even more urgently to meet the problems arising from indirect reuse than for any future plans that may eventually develop for direct reuse of wastewaters.

c. On the other hand, it is well established that people have been drinking reclaimed sewage for years along the Ohio and Mississippi Rivers system. For the past 100 years or more, the water discharged upstream after dilution in the river has been used by the cities downstream, and there is little, if any, epidemiological evidence to indicate a significant health hazard has resulted from this indirect reuse of wastewater effluent.[23]

d. However, in the treatment of polluted rivers, the methods presently employed are based on those developed over the years for the treatment of relatively unpolluted rivers. It may be that sufficient note has not been taken of the increasing proportion of wastes in many rivers. While there is no "hard" evidence of proof, the inadequacy of such traditional methods may have caused outbreaks of infectious hepatitis in New Delhi in 1955, 1956, and 1958. The waterworks in question were of modern design and, though there may have been some faults in operation, were the sort that may occur at any such facility. However, at the time of the outbreaks, drought conditions prevailed, and the water taken from the river was estimated to contain about 50-percent sewage.[44]

e. It appears that the consensus of opinion in the scientific community is that the public health aspects of the production of potable water from polluted rivers should be scrutinized. When rivers contain a high proportion of effluent, the production of water from them should be regarded as analogous to the direct recovery of water from a sewage or industrial effluent, and safeguards appropriate to this situation should be imposed.[44]

2. POTABLE REUSE VERSUS NONPOTABLE REUSE.

a. If there is one argument central to the debate over wastewater renovation and reclamation, potable reuse is at the heart of the issue.

b. The supplementing of potable supplies with renovated wastewater has been successfully implemented at several locations in the United States and throughout the world.[31 32 44] In general, however, drinking water should preferably come from a clean supply, and communities should make every effort to conserve water so that there are always sufficient quantities for potable purposes.[44] If potable water is to be routinely prepared from wastewater, a long-range plan setting out clearly defined research goals, as well as demonstration projects, will be required to provide additional assurances of safety. Such programs may take several years before they become a practical reality. A formal attempt at potable reuse planning and goal setting took place in the form of a meeting, "EPA Protocol Development: Criteria and Standards for Potable Reuse and Feasible Alternative," July 29-31, 1980, Airlie House, Warrenton, Virginia. At this meeting of experts in the field of wastewater reclamation and reuse, six working groups were established to address prepared issue papers in the subject areas of chemistry, toxicology, microbiology, engineering, ground-water recharge, and nonpotable options. Based on their discussions, many questions were raised and specific findings and recommendations were enumerated.[32a b c d] A summary of the "Statement of Concerns" resulting fom this workshop includes:[32a]

> *In management of the water resource various philosophical, economic and social factors will enter the decision-making process:*
>
> *1. Nonpotable options should be considered as a first choice before potable reuse.*
>
> *2. For many polluted streams, the indirect reuse may be equivalent to direct reuse, so a single set of standards may be indicated.*

3. The economic need for potable reuse may be decisive as against nonpotable options: for example where the potable need is nearby the wastewater source but the nonpotable need is farther away, at higher elevations (such as inland irrigation across the mountains from Los Angeles).

4. Institutional and legal blocks may deter any form of reuse. For example, an irrigator might be unwilling to give up an established water right in exchange for a promise of reuse water or a utility might not be willing to give up a claim to fresh water in exchange for reuse water.

5. Public acceptance of reuse water for drinking has been the subject of several studies and will require careful attention in any specific plan for potable reuse which may be attempted.

Additionally, the key recommendations resulting from this meeting include:

1. Development of comprehensive standards and criteria to define potable water regardless of source.

2. Undertaking a detailed characterization of potential sources of reclaimed water covering variability, frequency and concentration ranges for the various contaminants.

3. Undertaking a major effort to examine unknown or inadequately known organic chemical components.

4. Conduct of toxicology concentrate studies as a key element in a decision-making protocol involving many factors.

5. Stringent microbiology requirements.

In corollary areas key recommendations were also made with respect to:

1. Serious consideration of ground-water recharge options for potable reuse.

2. Serious consideration of nonpotable reuse options for extending available public water supply.

It is estimated that actual protocols and reuse criteria resulting from the Airlie House meeting will probably not be available until at least late 1982 or even into 1983(46).

c. The favoring of potable reuse is well summarized by Dryden[10] when he says that the concern for unidentifiable organics in planned potable reuse projects is no different than in unplanned potable reuse where wastewaters are discharged to streams and lakes used for domestic water services. The difference is that the problem is recognized and confronted in the well monitored and controlled planned reuse, and often ignored in the more extensive but less controlled world of unplanned reuse. The control of pathogens is technically and economically achievable for all forms of reuse. Inorganic pollutants can be managed or removed to meet required limits. Organic pollutants pose a health concern of unknown magnitude which will impair our ability to proceed with any reuse scheme that might result in long-term ingestion of some fraction of reclaimed waters. This situation applies to planned ground-water recharge, potable reuse, and irrigation projects, as well as all domestic water supplies derived from contaminated surface and ground waters.

d. Dryden[10] continues, saying that water reuse programs generally do entail a health risk. The risk is not significantly different than that associated with the use of water supplies containing trace organics from whatever source they are derived. In the future, ground waters can no longer be considered so pure that no treatment need be provided, even though the path by which pollutants reach ground waters is not determined. All domestic water supplies should be monitored for some indicator of possible organic contamination. If required, it is possible to design and operate treatment systems to produce an acceptable supply from any source. The implementation of water reuse projects should and will be related to the need for water. If the water is needed, the health risks discernible will not be sufficient to prevent a properly engineered and managed system from being accepted. If the water is neither needed nor economically justifiable, the health risk will support the argument against implementing such a system. The health consequences and inconvenience of insufficient water should be the determining factors in proceeding with those projects which meet a need, are economically feasible, and have a competent and stable management program.

e. Okun[25 26 27] feels that the type of rationale expressed above has several serious shortcomings. The premise that pathogen control is simply assumed is not appropriate. The operative statement upon which the 1962 US Public Health Service Drinking Water Standards are based, was that "the water supply should be obtained from the most desirable source which is feasible, and efforts should be made to prevent and control pollution of the source." In addition, the sanitary survey was also emphasized as a means to identify sources of pollution, rather than monitoring and analysis of water. However, these same strictures are not stressed at all in the Safe Drinking Water Act, nor do they appear to be an essential element of EPA or regulatory concern.

Major attention is given to maximum contaminant limits, monitoring, and even treatment, but very little attention is given to protection of the source, selection of the purest source, or the institutional measures that would provide the assurance of continuous protection. For example, 95 percent of the more than 60,000 community water-supply systems in the US serve fewer than 10,000 people. There is no question that the personnel, equipment, and operating procedures afforded by such systems cannot be depended upon to provide continuous protection.

f. So, despite the principle that the wisest course of action is to use the purest water, many communities have developed polluted sources and called upon water treatment technology to render the water safe. In particular, because chlorination permitted a chlorine residual which could be maintained and easily monitored, water purveyors assume that with an adequate chlorine residual at a certain temperature and pH, and after sufficient detention, the water is free from infectious disease organisms.[27]

g. Today, a substantial portion of the population that is served from public water-supply systems depends upon sources that comprise wastewaters that have previously been discharged to municipal and industrial sewers upstream. Because the drinking water regulations still emphasize bacterial safety (there is still no mention of viruses), water taken from such polluted sources can readily meet the standards, or at least that portion of the standards concerned with maximum levels of bacteria. Such water does not satisfy the requirement for utilization of the purest source.[27]

h. Regarding trace organics, some 63,000 chemicals are already used in commerce, and others are coming into use at the rate of 1,000 a year.[27] Many of these chemicals are formulated to be long lasting and, therefore, are not readily degraded. They find their way into the aquatic environment and into drinking water supplies through many routes: agriculture, industry, urban runoff, and the home. Those wastewaters that are sewered and treated are the most manageable. Those wastes that are characterized as being present in "nonpoint" sources, reaching water courses through overland runoff from farms and construction sites, from industrial sites, from roadways and urban streets, and from landfills and toxic chemical dumps are less manageable. The sulfur and nitrogen oxides discharged from industrial and power plant stacks and from vehicles result in acid rain, which has had a serious impact on many eastern lakes; also, because it increases the leaching ability of rainfall and stormwater runoff, greater concentrations of pollution chemicals are carried into water courses.[27]

i. It may very well be that, just as with radiation and asbestos, many decades will pass before the full impact of these organic chemicals in the aquatic environment is understood.[27] Is it necessary to wait for convincing scientific proof, or is it prudent for those responsible for providing safe water to assume that polluted sources are inherently more hazardous than protected sources?

j. To summarize, Okun[25] outlines the threats posed by using polluted waters for public supplies:

> *1. A breakdown in water-treatment facilities may serve to carry contaminated water to users in great numbers. If raw waters are polluted, treatment facilities must be adequate in capacity, properly designed, and properly operated, with highly qualified chemists and bacteriologists in close supervision, to ensure that breakdowns in the treatment barrier do not occur.*
>
> *2. Even where conventional treatment is provided, the fate of viruses, particularly those of infectious hepatitis, is uncertain. Only a few virus particles need be ingested for infection to result. Most who are infected may not become visibly ill, but subclinical infections cannot be considered innocuous; their effects may be delayed or camouflaged among other illnesses, or the disease may be passed on to other members of the population.*
>
> *3. Hundreds of new chemical compounds are being introduced into our environment daily. The liklihood of ingesting them increases greatly when contaminated waters are used as sources for municipal supply, because conventional water treatment is ineffective in removing them. Some of the chemicals, either alone or with others, have been shown to cause cancer, genetic damage, or birth malformations. Because the effects of such chemicals ingested in low concentrations over long periods are insidious and are likely to be similar to those manifested by aging, their significance is hard to establish. In the case of environmental pollution, the situation may well become unmanageable if the accumulation of convincing epidemiological evidence is made a prerequisite of social action. In other words, we have to learn to live with these chemicals while protecting ourselves from them.*

k. If the indirect use of polluted sources is hazardous, the direct reuse of wastewaters for drinking is even more dangerous. The benefits and protection afforded by time in transit between the point of discharge of the wastewaters and the point of recovery from the stream for water supply, the dilution afforded by fresh water in the stream, and the disinfection by sunlight, sedimentation, and natural biochemical degradation that takes place in natural watercourses are not available where direct reuse of wastewater is practiced.[25] Such a position is reinforced by an American Water Works Association policy statement on "Use of Reclaimed Waste Waters as a Public Water Supply Source" adopted by the Board of Directors on June 18, 1971, and revised on June 25, 1978.[1] This statement reads as follows:

> *Recognizing that properly treated wastewater constitutes an increasingly important element of total available water resources, the American Water Works Association urges the federal government to support a sustained multidisciplinary research effort to provide the scientific knowledge and technology necessary to the future use of reclaimed wastewater as a public water supply source with full protection of public health.*
>
> *In the development of such an effort these factors are important:*
>
> *1. Ever increasing amounts of treated wastewater are being discharged to the waters of the nation and constitute an increasing proportion of many existing drinking water supplies.*
>
> *2. A growing number of proposals are being made to introduce reclaimed wastewater directly into various elements of domestic water supply systems.*
>
> *3. The sound management of the total available water resources may include consideration of the potential use of properly treated wastewater as part of drinking water supplies.*
>
> *4. Insufficient information exists concerning acute and long-term effects on human health of such wastewater uses.*
>
> *5. Cost-effective and fail-safe technology to assure the removal of all harmful substances from wastewater is not available.*
>
> *6. Any advocacy of the direct use of reclaimed wastewater as a public water supply source must await the development of the necessary scientific knowledge and treatment technology.*

l. Thus, the ultimate question arises, "In these times of increasingly diminished protected sources of potable water, what options remain to address current and projected water shortages that already do and will continue to exist?" One feasible alternative to potable reuse, where water supply is short or supplies are of poor quality, is nonpotable reuse or source substitution. Nonpotable reuse satisfies a conservation ethic with much less threat to the public health. In addition to providing an opportunity for protecting the public from the long-term ingestion of waters containing synthetic organic chemicals, nonpotable water reuse has other benefits:[27]

1. *conservation of water - saving the higher quality sources for those services that require it*

2. *recycling of nutrients - which would otherwise have to be removed before discharge to receiving waters; and that are beneficial when the water is used for urban and agricultural irrigation*

3. *cost and energy savings that result from community water recycling*

4. *reduction in the discharge of pollutants to water courses*

5. *realization of other priorities, such as the preservation of open space and the development of recreational area*

m. The fundamental technique for implementing nonpotable reuse is the dual distribution system. In the past, two main objections - cross-connections and cost - have been cited when dual systems have been proposed. Conventional dual water-supply systems, in which one system delivers potable water and the other generally furnishes untreated water for emergency use only, has led to very serious outbreaks of waterborne disease throughout the world. However, in the dual water-supply system proposed in this instance, the nonpotable supply would be adequately disinfected and could be of a quality that many communities are now providing for their potable systems. Occasional inadvertent ingestion should create no problem, even if not discovered for extended periods of time. The health hazard that results from continuous ingestion of potentially toxic substances over a period of years would not be present. However, proper supervision of construction and management of the systems would preclude this danger.[25]

n. The technology for such dual systems now exists. Because the potable-water system would not be used for fire protection, it would not need to withstand the high pressures that are otherwise required; plastic pipes would be entirely appropriate. Water quality surveillance would be far simpler where water planned for potable purposes is drawn from unpolluted sources.[25]

o. Perhaps the best recourse for the future is to plan the management of polluted waters and wastewaters so that they would not be required as a source of drinking-water supplies; rather, they would serve the wide variety of other beneficial uses to which water is put.[25]

3. AGRICULTURAL REUSE.

a. The advantages of the use of treated wastewater for irrigation are a low-cost source of water, an economical way to dispose of wastewater to prevent pollution and sanitary problems, an effective use of plant nutrients contained in wastewaters, and a means of providing additional treatment before being recharged to the ground-water reservoir.[39c] These advantages are known to those interested in promoting or regulating wastewater reclamation, but they may not be well-known to the public. The public is often not aware of the secondary benefits of reduced rate increases for water and sewer fees resulting from a viable reclamation project. As a result, such projects may be viewed as solely benefiting the supplier or user and may be labeled as an agricultural subsidy when, in fact, it is agriculture working together with the local water district to develop a mutually advantageous program. However, reclamation programs which use wastewater for irrigation have a number of possible disadvantages. These include:[39c]

1. The supply of wastewater is continuous throughout the year, while irrigation is seasonal and dependent on crop demand.

2. Treated wastewater may plug nozzles in irrigation systems and clog capillary pores of heavy soils.

3. Some of the soluble constituents in wastewater may be present in concentrations toxic to plants.

4. Health regulations restrict the application of wastewater to edible crops.

5. When wastewater is not properly treated, it may be a nuisance to the environment.

b. While the coordination of wastewater supply with utilization, the clogging of soils and irrigation systems, and the aesthetic nuisance considerations can be addressed with engineering solutions and best management practices, the problems associated with toxic constituents in the wastewater and health restrictions may warrent further explanation.

c. Treated domestic effluent, and certainly industrial wastes, may contain soluble constituents at concentrations toxic to plants. Domestic effluents pick up between 50 and 100 mg/liter each of chloride and sodium ions. These may concentrate in the root zone and harm sensitive crops. The concentration of sodium may increase in particular where water softeners are in use. The negative effect of sodium on the soil is the deflocculation of clay particles which causes an unfavorable soil structure. This then decreases water and air permeability. Boron concentration increases in effluents mainly due to the use of washing powders that contain perborates. A concentration as low as 1 ppm boron in sewage effluent may harm sensitive crops. Some industrial wastes may add heavy metals at concentrations toxic to plants or animals feeding on plant material. The common heavy metals include zinc, manganese, chromium, cadmium, nickel, lead, and mercury. Due to their chemical properties, the larger proportions of these elements are found in sewage sludge, and their concentration in the effluent is small. However, their buildup in the soil or in ground water may reach hazardous concentrations. In light soils their hazard may be greater because, in heavy soil, heavy metal fixation to insoluble forms renders them unavailable to plants. Other wastes may contain organic compounds, such as organic acids and phenols, that may restrict biological activity in the root zone.[39c]

d. Wastewater may contain pathogenic bacteria, parasite eggs, cysts, and viruses which are carried by human excreta. If wastewater is to be used for the irrigation of agricultural crops, including fruits and vegetables usually consumed uncooked, a high degree of disinfection is necessary to inactivate the pathogens.[39b] Besides the cost, the formation of potentially toxic organohalide compounds by high doses of chlorine may limit such a disinfection technique.[39b]

e. Another aspect of agricultural reuse which has received limited attention is the potential health risks to workers in wastewater irrigation projects or to the public who may live in adjacent residential areas. Early findings of Katzenelson[15] and Sorber[40] relate to the possible inhalation of aerosolized sewage containing pathogens from spray irrigation. Estimates indicate that somewhere between 0.1 to 1 percent of the sewage sprayed into the air forms aerosols which are capable of being carried considerable distances by the wind. The rate of dieaway and reduction in concentration of pathogens incorporated into the aerosols is a function of wind speed, temperature, relative humidity, ultraviolet (UV) radiation, and local topographic features. As a result of such studies, various buffer zones have been recommended to prevent infections in adjacent residential areas. Although there is as yet no sound scientific basis for establishing such buffer zones, there are already sufficient data to indicate that an area of some 500 meters from spray irrigation with sewage can carry infectious bacteria in the air. Shuval[39b] recommends that the limits of the buffer zone including some safety factor should surely be beyond this range. In practice, however, the widths of buffer zones range from zero for remote systems to 60 meters or more for systems using sprinklers near populated areas.[33]

4. INDUSTRIAL REUSE.

a. In the past, most water reusers were primarily motivated by either the lack of adequate water sources or by higher pollution standards.[21] As wastewater treatment requirements have become more stringent and the costs of meeting these requirements have increased, the management of water resources has become more critical, and the reuse of wastewater has become more attractive. At the present time, the reuse practice is not limited to any particular industry; but major water users, such as power, steel, petroleum, chemical, and pulp and paper industries, have been more actively involved in wastewater reuse for purposes such as cooling, processing, boiler feed, washing, and others.[21]

b. If reclaimed wastewater is to be used as process water in industry, special consideration must be given to the possible public health implications. While it is true that one of the most effective and economical ways of using wastewater in industry is in the intraplant reuse of treated and recycled industrial effluents, caution is still warranted. In general, public health problems involved in recycling industrial effluents are less severe than those resulting from the use of municipal sewage. However, great care must be taken to prevent cross-connections with the general community water system which supplies industrial plants reusing wastewater. The arrangement of a total physical disconnection between the community supply by an appropriate air gap is the safest.[39b] In addition, the careful color coding of pipes would be helpful in reducing the risk of cross-connections, with such coding being applied to buried as well as exposed piping.[44]

c. The obvious benefits to industry of a closed-cycle, water-use system are that the rules cannot change very much and the costs of pollution control can be predicted for a long time in the future.[21] Water users would, at the same time, have the maximum practical protection of water quality. The practice of recirculation reduces the overall water volume and the amount of water subjected to pollution, thus reducing the size and the cost of facilities needed to handle and treat the water.[21]

5. RECREATIONAL REUSE.

a. Although many rivers and lakes made up of varying degrees of raw or treated wastewater have been used for recreational purposes including body-contact sports, planned, direct reuse for such purposes is relatively recent. Several projects, all located in California, successfully developed treatment processes that produced renovated wastewater for recreational impoundments meeting the most rigorous microbiological criteria.[2 31] After initial periods of careful monitoring for pathogens, body-contact sports were tentatively approved under carefully supervised conditions with no deleterious health effects being detected. Public reaction at these desert locations suffering from a shortage of water-sport recreational facilities has been favorable.[39b]

b. The evaluation of the health risks associated with bathing in polluted water has been a controversial subject for years, particularly since clear-cut epidemiological evidence associating contaminated bathing water with overt enteric disease transmission has been sparse. While the Medical Research Council (English) concluded " . . . the risk to health of bathing in sewage contaminated seawater can for all practical purposes be ignored," many public health authorities have not accepted such a conclusion.[39b]

c. The State Health Department of California is apparently one of the few authorities to establish specific standards for reclaimed wastewater.[39f] It requires that the reclaimed water used as a source of supply in an unrestricted recreational impoundment shall be at all times an adequately disinfected and filtered wastewater. Its regulations imply that an effective system of coagulation and filtration following secondary biological treatment precedes the disinfection which should produce an effluent with a median coliform MPN which does not exceed 2.2 per 100 mL. For restricted recreational uses, not involving body-contact sports, the same bacteria standard is required, but the requirement for additional filtration after biological treatment is dropped. In Shuval's[39b] words:

> *These requirements are indeed more stringent than those that may be required of naturally polluted recreational areas, but are justified for both hygienic reasons and in light of the fact that the legal and moral responsibility in cases of direct wastewater reuse is a heavy one indeed - and one that falls directly on the shoulders of those operating or supervising such a project. Maximum feasible precautions should therefore be required.*

6. MUNICIPAL REUSE.

a. Municipalities can use well-treated effluents for many nonpotable purposes. Typical examples include firefighting; irrigation of parks, gardens, and golf courses; street cleaning; fish farming; toilet flushing; and laundry water. It should be assumed that, even for limited municipal use, wastewater should be treated and disinfected to such an extent that it would be safe from a microbiological point of view, although it might not meet all the chemical standards usually desirable for drinking water. The specifications for treatment and disinfection should be rather strict because the danger of cross-connections or the possibility of accidental use of treated water for drinking purposes is quite considerable.[39b] Such a policy is also consistent with the argument of Okun[27] who states that "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade."

b. With regard to unrestricted municipal reuse, to include augmenting potable supplies with reclaimed wastewater, those considerations previously presented in paragraph 2 are equally applicable to such a discussion.

7. GROUND-WATER RECHARGE.

a. The use of treated wastewater for ground-water recharge is practiced in a number of areas. In some instances, the sole objective has been to build up a barrier to prevent salt-water intrusion into coastal areas where ground-water withdrawals have been excessive. If the recharge occurs in areas where ground-water pumping takes place, the effect of the effluent on the quality of the ground water withdrawn may be considerable. The main factors that must be considered are the nature of the aquifer, the mean residence time between recharge and withdrawal, withdrawal rates, and finally the degree of dilution obtained with the surrounding ground water.[39b]

b. In uniform sandy aquifers, a high degree of microbial removal can be realized. Studies have shown that within a distance of a few hundred meters from the point of recharge, effective removal of viruses and bacteria can generally be achieved. Long residence times of several hundred days in the aquifer may also prove effective in the removal of viruses and bacteria through dieaway. However, in the case of nonuniform aquifer formations of gravel or karst limestone, there may be little or no microbial removal over extensive distances.[39b]

c. Inorganic and organic chemical removal will be a function of the absorption and ion exchange characteristics of the aquifer which may, under certain circumstances, provide a considerable degree of removal, while, in other cases, such chemicals may travel over great distances with little or no reduction in concentration. Even when studies indicate a degree of chemical removal by filtration through the aquifer, there is the possibility that once the absorptive or ion exchange capacity is exhausted there will be a breakthrough of chemical contaminants which may appear suddenly and possibly in high concentrations at the withdrawal wells. This can present a serious threat to the quality of the reclaimed water.[39b]

d. In areas where ground-water recharge with treated wastewater is planned, a major factor in determining the degree of pretreatment required is the ultimate use of the water withdrawn. If only agricultural or industrial utilization is planned, it will usually be possible to meet health requirements for such use without too much difficulty or, at most, by additional disinfection of the pumped well water. However, if the water is scheduled for municipal use including domestic consumption, all of the limitations discussed in paragraph 2 must be applied, unless very high rates of dilution with pure ground water can be assured. Effective removal of toxic organics and heavy metals must be assured prior to the recharge operation, although some dilution effect and actual removal may be obtained by aquifer filtration.[39b]

e. Ground-water recharge prior to reuse for domestic consumption provides many advantages and a considerable safety factor as a result of the buffering effect of long retention and ground-water dilution, as well as a degree of removal of microbial and chemical pollutants. It also provides for an excellent opportunity to enable complete monitoring of water quality prior to withdrawal, since monitoring wells between recharge areas and withdrawal wells can be used to test water quality months before it is withdrawn from the aquifer. The WHO[44] has pointed out that "groundwater recharge involving extended periods of underground storage can provide a considerable safety factor in wastewater renovation." However, careful planning and control of such recharge programs are essential to insure that the full benefits of such a strategy are obtained.[39b]